Mechanized Technology Research and Equipment Application of Banana Post-Harvesting: A Review

Jie Guo 1, Jieli Duan 1, Jun Li 1 and Zhou Yang 1,2,*

1 College of Engineering, South China Agricultural University, Guangzhou 510642, China; 20191009002@stu.scau.edu.cn (J.G.); duanjieli@scau.edu.cn (J.D.); autojunli@scau.edu.cn (J.L.)
2 Guangdong Provincial Key Laboratory of Conservation and Precision Utilization of Characteristic Agricultural Resources in Mountainous Areas, Jiaying University, Meizhou 514015, China
* Correspondence: yangzhou@scau.edu.cn

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Abstract: In all operations of banana post-harvesting, picking and transportation are the operations with the highest labor intensity and the highest production costs. The operation of banana de-handing is still in the traditional stage by manual cutting, which seriously impedes the development of the banana industry towards mechanization, automation and intelligence. This review summarizes and analyzes the mechanized technology research status and equipment application of the banana picking, transportation and de-handing operations in banana orchards around the world and proposes basic ideas and constructive suggestions for quickening the mechanized development of banana post-harvesting.

Keywords: banana; post-harvest science; banana picking; banana transportation; banana de-handing; agricultural machinery

1. Introduction

The banana (Musa spp.), is the fruit with the largest trade volume and the fourth food crop following rice, wheat and corn in the world. It is mainly planted in tropical and subtropical areas between north 30° and south 30° latitudes in the eastern and western hemispheres [1–3], whose planting areas and yields have continued to increase in recent years [4]. With the development of society and the construction of urbanization, more and more young laborers leave the countryside and flock to the cities. Especially in hilly banana orchards, human resources for banana production decrease drastically, the population is aging, and the labor costs are rising. Therefore, the banana industry urgently needs to transform from the backward traditional mode to the advanced modern mode. In all operations of banana post-harvesting, banana picking and transportation are labor-intensive and require a lot of laborers. However, because banana fruits are susceptible to mechanical damages and because of the geographical environment of banana orchards, etc., it is very difficult to achieve automation and intelligence in banana picking and transportation [5].

At present, the operations of banana picking, transportation and de-handing in banana orchards around the world generally rely on humans to work with simple tools. In most developing countries where large bananas are growing, such as China, Brazil, India, Ecuador, the Philippines, etc., some banana orchards are equipped with semi-mechanized banana picking and transportation devices. While in some developed regions, such as Europe and Australia, more and more scientific researchers apply new technologies to agricultural engineering fields, such as banana picking and transportation, the level of mechanization for banana post-harvesting has a great influence on banana storage, fresh-keeping, selling price and market competitiveness. Strengthening the scientific researchers to research and develop the banana post-harvesting technologies, and actively manufacturing practical
devices for banana picking, transportation and de-handing are effective ways to vigorously promote
the banana industry towards mechanization and intelligence, which is also an inevitable developing
trend in the future of banana picking, transportation and de-handing. Therefore, we analyze and
discuss the current mechanized research status and future developing tendency of banana picking,
transportation and de-handing operations and hope to provide references for the development of
high-tech and mechanized devices in the banana industry.

2. Materials and Methods

2.1. Banana Picking

Banana picking is the first operation in banana post-harvesting. The banana picking mode is
different from that of other fruits and vegetables. Banana bunches are heavy, banana hands are easily
susceptible to external mechanical damages, and the terrains of the banana orchards are complicated.
Therefore, the traditional banana picking operations require the cooperation of two workers, one using
a machete to cut the banana bunch stalk and separating it from the pseudostem of the banana mother
plant, the other putting a flexible pad on the shoulder to hold the cut banana bunch, as shown in
Figure 1. The entire banana picking procedure is only manual, which not only requires high physical
ability of the workers, causing higher labor costs, but also increasing the risk of mechanical damages of
banana hands during the picking procedure, which affects the fruit quality of bananas.

![Figure 1. Workers are picking a banana bunch.](image)

In order to ensure the appearance quality and economic value of banana, nondestructive picking
technology has been the research direction of improving the quality of bananas and economic benefits.
In Queensland, Australia, workers using an equipment named “banana bender” to assist with picking
bananas. It is an eight-foot stick with steel drawbars on the top end; a high hook with the steel pull
rod facing downward is used to pull down the cut pseudo-stem, and the low hook with the steel
pull rod facing upward is used to support the curved pseudo-stem, which makes it possible to pick
banana bunches at a height of 1.35 m. The Massachusetts Institute of Technology [6] has developed
an assist equipment for picking bananas, and the optimized design of the light tripod is equipped
with a gripper on the top where a one-way lock cam with a spring is installed. When picking bananas,
the worker uses the gripper to cover the banana bunch stalk firstly, and the cam mechanism clamps
the bunch stalk after cutting it. When the worker picks up the banana bunch, the one-way lock cam
is released and the banana bunch is released from the gripper. Jason [7] developed a banana picker,
which is mainly composed of a tripod support, double-blade cutters, hydraulic cylinder, pulley, etc.
The double-blade cutter is mounted on the top of the support frame and is driven by a hydraulic
cylinder. The picked banana bunches can slide into the bag directly, thus achieving the purpose of
taking the place of humans to pick bananas. Wang [8] in Guangxi University, China, have manufactured
a simple banana mechanical picking device, as shown in Figure 2, which is based on the banana
planting patterns and growth characteristics. The brackets support the banana bunches when picking
bananas, and a worm gear mechanism and a vertical rod are installed on the frame. The vertical rod is divided into two sections, which are connected by hinges. The lower section is placed in a guide sleeve which is fixed on the frame, and a rack is installed to mesh the worm gear. The upper section has a support plate and a guardrail which are connected with an adjustable sleeve. When picking bananas, the bunches can be protected without damaging the banana plants, which can effectively reduce mechanical damages and decrease the labor intensity of workers. In order to support the banana bunches better during the picking procedure and avoid mechanical damages, aiming at the fixation of banana bunch stalk, Yang [9] designed a banana bunch gripper that simulates the artificial pinching action, analyzed the working principle, structure and main parameters of each part of the device, and realized the flexible gripping of the gripper and the adaptable adjustment of clamping force by using the force feedback system. Wang [10,11] designed a mechanical picking gripper, analyzed the relationship between the load and the deformation, obtained the influence of key parameters on the clamping stiffness and strength of banana bunch stalk, and finally optimized the design of the clamping mechanism. Wang [12–15] and Tang [16] designed the end-effector of the banana picking robot, according to the behavior characteristics of the workers when picking bananas, and did the simulation analysis. The experimental results show that the design of the grasping mechanism is reasonable and the scheme is feasible.

![Figure 2. Banana assist picking equipment.](image)

A document in the *Australian Agricultural Journal* mentioned that [17] “the Western Australian Department of Agriculture designs and manufactures a banana picking machine”, and this machine is specially designed for picking bananas. The entire machine is mounted on a trailer towed by a miniature agricultural tractor. It mainly consists of a hydraulic driven manipulator, a cutting mechanism and a bucket container mounted at the end of the manipulator. When picking bananas, the manipulator moves the bucket container and cutter to an appropriate position and then cuts the banana bunch stalk. After grabbing banana bunches into the bucket container, the manipulator shrinks and puts the banana bunches on a trailer. This banana picker greatly reduces the labor intensity of workers. As shown in Figure 3, Tom Johnston [18] modified the crawler excavator and equipped it with a telescopic arm, a grabber and a hydraulic operating mechanism and completed the mechanical banana picking operation.
In order to improve the efficiency of banana picking, reduce the labor intensity of workers, decrease the picking cost and reduce the incidence of injury and disability accidents, Wang [19] from South China Agricultural University, China, developed a banana picking machine, based on banana planting patterns and the characteristics of biology and agronomy. It uses a wheeled trolley as walking device, and an electric hydraulic pump provides power to the hydraulic cylinder. The clamping mechanism of the end-effector is driven by a motor to rotate the screw, driving the clamping gripper on the manipulator opening and closing to clamp the banana bunch stalk and then the cutters to cut the bunch stalk, so that it completes the banana picking work, as shown in Figure 4. Zhu [20] manufactured a rail-guided banana picking machine, which realized the mechanized picking of banana bunches, and the picking efficiency was increased by 90% compared with the traditional manual picking modes. Li [21] designed an electric banana picker that can achieve multi-degree of freedom rotation, and the results of kinematic analysis show that the machine can achieve a predetermined motion trajectory and meet the actual work requirements. Li [22] made an all-in-one machine for hydraulic driven clamping and cutting, which is driven by a mini tractor and tows a specially designed banana bunch trailer. The picking machine has a clamping mechanism that can clamp the banana bunch stalk and a cutting mechanism driven by a hydraulic motor, which improves the efficiency of banana picking.

The appropriate picking time of bananas has a great relationship with banana varieties, planting dates, and the climate environment of banana orchards, etc. In order to guide the workers to test the maturity of bananas accurately and plan the banana picking time properly, Gardner [23] of the University of Warwick, UK, used tin oxide gas sensor arrays and FuzzyArt map neural network system to form an electronic nose. The accuracy rate of banana maturity detected is 92%, which promotes the development of informatization of banana picking. Zou [24] developed a virtual design and simulation...
A system for fruit picking manipulators with the help of virtual simulation technologies. Fu [25] studied the detection of banana bunches in natural light based on SVM and Adaboost classification algorithms. The method of combining single-scale detection and multi-scale detection was used to achieve accurate positioning of banana bunches in banana orchards and laid a good foundation for further development of a vision system of the banana-picking robot. At present, many intelligent high-tech are being used in the field of agricultural engineering to improve the crop productivity and build automatic monitoring systems [26]. The banana-picking operation is developing towards mechanization, standardization, specialization and intensification [27].

2.2. Banana Transportation

When banana bunches are picked from the banana plants, they first need to be transported to the fixed collecting stations in the orchards and then transported uniformly and in batches to the post-harvest commercial processing workshops. A study in Jamaica [28] shows that vibrations during transportation can cause mechanical damages to bananas. Mechanical damages can severely shorten the storage and transportation time of bananas and reduce the economic value of bananas. Avoiding mechanical damages is a problem that must be paid attention to in the procedure of banana transportation. In the procedure of banana transportation, apart from improving the transportation efficiency and reducing the labor intensity, the probability of mechanical damages to the bananas should be minimized as much as possible [29–32]. The most primitive method of transportation was to pick banana bunches by human shoulders, which is convenient and flexible to operate but requires high physical ability of workers. The labor is expensive and inefficient, so it is only suitable for small-scale and scattered banana orchards. Aiming at the shortcomings of the above methods, Zhao [33] designed and manufactured a banana frame that can be used on a human’s back. It can effectively reduce the mechanical damages to bananas when the workers are carrying them, and now it has been applied in some mountainous banana orchards of Yunnan Province, China.

At present, the most common semimechanized banana transportation methods in the world are car transportation and ropeway transportation. Car transportation includes modified flatbeds, motorcycles, tractors, etc. [34]. Flexible protective pads are laid on flatbeds and motorcycles, and banana bunches are placed horizontally and transported to the post-harvest commercial processing workshops [35]. Tractor transportation consists of hanging the picked banana bunches on the tractor and taking them to the post-harvest processing workshops. The car transportation methods of banana are comparatively common in Hainan Province, China. Researchers from South China Agricultural University designed a banana transport car with an L-shaped frame. Banana bunches are kept upright during transportation, and the bunch stalk bears its own weight. The experiments show good results of the transport effects [36]. Cai [37] and Li [38] studied the morphological and mechanical characteristics of banana hands and fruits. The range of pressure that different parts of the banana hand can withstand was determined by experiments. After that, they designed and developed a banana transport vehicle, by which they solved the key technical problems including the stability of the vehicle, etc. Zhu [39,40] designed a wheeled electric banana transport vehicle, which transmits power through a chain drive mechanism and can control the real-time walking speed of the vehicle. It has feedback systems on the driving functions such as starting, speed regulation, forward walking, backward walking, emergency stopping, etc., which can satisfy the transportation demands of small-scale banana orchards.

Ropeway transportation method has been used in some countries since 1971 [41]. Ropeway transportation is a relatively advanced semi-mechanized transportation method. It is similar to the aerial ropeway transportation method which is used in forestry production to transport timber, which can effectively avoid mechanical damages such as bumps, crushes and scratches of banana bunches during transportation, as shown in Figure 5. The specific methods are to install several continuous aerial ropeways in banana orchards to the processing points, according to the overall planning and the layout of the banana orchard. The ropeways can be radial or rectangular mesh where pulleys are installed. The banana bunches cut by the worker are tied with ropes and hung on the pulleys’
hooks. The pulley is suspended on a ropeway supported by an arch. The pulleys are connected with each other by a brace rod, which can maintain a safe distance between the banana bunches to avoid collisions. After a certain number of banana bunches are hung on the ropeways, the workers will drag them to the processing points. During the whole transportation procedure, the banana bunches do not touch the ground, which can effectively reduce mechanical damages, improve work efficiency, increase bananas’ commercial value and improve the economic benefits of the banana industry [42]. Kemp [43] designed improved banana ropeways and tested in hilly banana orchards and obtained good results. Ecuador has built a complete set of ropeway transportation devices, by which mechanical damages during banana transportation can be avoided, and the commercial processing capacity is up to 85% [44]. Valdés-Hernández [45] designed a transportation system applied on slopes, which can change the transportation speed and the hanging distance between banana bunches according to actual demands and terrain slopes and reduce the physical impact damages between banana bunches.

Figure 5. Ropeway transportation of banana bunches: (a) transportation in banana orchard; (b) transportation in the fixed collecting stations of the orchard; and (c) transportation in the post-harvest commercial processing workshop.

The common banana transport ropeways are mainly divided into three types: supported transport ropeway, unsupported transport ropeway and cable transport ropeway [46]. The supported transport ropeway adopts galvanized pipe as the supporting rod and welds round steels as the hanging pulleys. It has the characteristics of large transport volume, low manual pulling strength and high transport efficiency. The rails are easy for splicing, and it is easy to form a transport network in banana orchards. This kind of transportation ropeway is mainly used in big orchards in the Philippines. The unsupported transport ropeway directly uses round steel as the hanging pulley, and the transport volume is medium. Auxiliary rails are needed to splice into a transport network in banana orchards. It is mainly used in big orchards in the Americas. The cable transport ropeway is to directly hang the pulley on the steel cable, with small transport volume, high manual pulling strength, low efficiency, and difficult ropeway splicing, which make it difficult to form a banana orchard transport network. It is mainly used in big orchards in Australia. Researchers from South China Agricultural University have manufactured an electric transport system in banana orchards. The towing sheave and the pulley hook set are both set on the guide rail and are connected by a connecting rod. During the transport operation, the pulley hook set is pulled by the towing sheave to complete the nondestructive transportation of banana bunches. This system has been promoted and applied in Zengcheng District of Guangdong Province, China [47]. Another steel cable towing hanging transport system developed by researchers from South China Agricultural University is powered by a hoister. The picked banana bunches are hung on a ropeway and transported by cable. A guiding mechanism is provided at the curve of the ropeway, which has a good running stability and terrain adaptability. It has been promoted and applied in Dongguan, Guangdong Province [48]. The chain circulating transport ropeway system developed by them is driven by electric motors. The horizontal, vertical and combined supporting mechanisms and automatic tensioning mechanisms, etc. are installed to allow it to be laid freely in complicated hilly
banana orchards. It realizes continuous and circular banana bunch transportation, which has been put into use in Longmeng County of Guangdong Province and Anyuan County of Jiangxi Province, and the productivity is up to 6.48 t/h [49,50]. Sun [51] modified the banana nondestructive transport ropeway by establishing an optimized design model. The experiments in Yunnan Province, China, showed that the proposed track change technology of bifurcate road can better solve the problem of cross transportation between tracks. Fan [52] summed up and formulated a set of technical regulations in banana nondestructive transport and commercial processing of post-harvesting, with the designs and work experience of transport ropeways in some countries for reference, which promoted the mechanical development of banana post-harvesting.

2.3. Banana De-Handing

Banana de-handing is a commercial processing operation between banana picking, transportation, cleaning and packaging in post-harvesting. The traditional de-handing mode is to first remove the residual flowers on the banana fingers, and then the banana crown is cut from the bunch stalk by a sharp arc cutter, as shown in Figure 6. At present, some developed countries have formed a set of standardized processes for banana post-harvesting operations [53]. All operations, from banana cleaning, disinfection, air drying to packaging have been fully mechanized [54]. Regardless of this is that in banana orchards or in the post-harvest processing lines, the banana de-handing operation basically relies on manual labor, whose efficiency is low and costs are high. Researchers at the Haikou Experimental Station of the Chinese Academy of Tropical Agricultural Sciences [55] designed a new type of de-handing cutter by using an S-shaped handle and an arc-shaped blade, which increases the operating space between the workers’ hands and the cutter, avoids the friction between human fingers and banana bunch stalk, ensures the stability and safety of the de-handing operation and improves the working efficiency. However, Merino [56] found that, in the procedure of banana de-handing continuously one by one, this mode requires workers to adapt to the position of the bunches, and the repetitious movements of workers limits their mobility and increases health risks to the worker’s spine and hips. Musculoskeletal diseases are the most common and costly diseases in agricultural production. Therefore, the research of mechanized technologies and the development of practical devices for banana de-handing procedures are urgent.

![Figure 6](image_url)

Figure 6. Traditional mode of banana de-handing, (a) in the post-harvest processing line and (b) in the fixed collecting station of the orchard. (c) A simple arc tool of banana de-handing.

The existing banana mechanized de-handing mode is to vertically fix the whole banana bunch on lifting equipment, and the lifting equipment drives the whole banana bunch to move downward slowly. Then, the banana hands are cut one by one from the bottom to top of the bunch stalk, until the banana hands on the bunch stalk are completely de-handed. A complete mechanical de-handing system mainly includes a banana-bunch-stalk clamping device, a banana bunch lifting device and a
banana-hands-cutting device, which is the core of the whole banana mechanized de-handing system. At present, the clamping mode of banana bunch stalk generally uses a sharp part to pierce the bunch stalk, which leads to the failure of the bunch stalk automatically separating from the gripper when the de-handing work is completed, which is negative to the development of mechanization and automation of banana de-handing. Therefore, in order to fix and grip the bunch stalk in the early stage of banana de-handing, Yang [57,58] from South China Agricultural University designed a banana bunch stalk clamping device with a self-locking function. During the banana de-handing operation, the bunch stalk can be locked and firmly fixed in the expected working space. When the de-handing work is completed, the self-locking switch can be opened and the bunch stalk can be removed and prepared for the next banana bunch de-handing. This clamping device with the self-locking function can effectively reduce the probability of banana bunches slipping during the de-handing work, laying a foundation for subsequent operation of banana de-handing. In order to clamp and fix the banana bunch stalk better by the clamping device and to prevent banana bunch slipping from the gripper during the de-handing procedure, Zhu [59] designed a pneumatic clamping device based on curved clamping parts, deeply analyzed the interaction between the clamping parts and the bunch stalk and determined the key factors affecting the equivalent friction between the clamping parts and bunch stalk. Yang [60] designed a kind of clamping gripper for banana bunch stalk. The clamping gripper consists of an air cylinder, a linear movement mechanism and a clamping base. The influence of different types of clamping gripper on the clamping force of banana bunch stalk was analyzed, and the structural parameters of the mechanical gripper were optimized, which provided references for the design of the gripper on the banana bunch stalk in the mechanized banana de-handing operation.

Due to the special morphological structure and physical and chemical properties of banana bunch stalk fiber [61,62], biological analysis must be done on banana bunches in order to realize the mechanized banana de-handing. Zhu [63] and Chen [64] analyzed the structural characteristics and cutting mechanical characteristics of banana crown at different positions on the banana bunch stalk. The principle of bunch stalk clamping, the principle of banana hands de-handing and the principle of banana hands movement were deeply studied, and the relationship between the elastic modulus, peak cutting force, etc. of the banana crown and the position were obtained. The finite element simulation method was used to analyze the force of the cutting blade during the de-handing procedure, which provided the data support for manufacturing the intelligent banana de-handing devices [65]. Yang [66] developed a rotary banana de-handing machine, where a pair of gears are driven by a motor and cutters are fixed on the second gear. The first blade and the second blade of the cutter rotate with the rotation of the gear and to make a circumferential cutting on the banana crown. In the mechanized banana de-handing works, different de-handing methods have different effects on the quality of banana crown cut. The quality of banana crown incision directly determines the fruit grade and the commercial value. In order to obtain a greater quality of banana crown incision in mechanical de-handing works, Yang and Duan proposed an impact cutting mechanism of banana de-handing with the self-adaptive cutter to the banana bunch stalk and manufactured experimental prototypes [67–69]. Yang [70] and Xu [71] designed ring cutters with staggered arrangement of soft and hard blades and optimized key parameters of cutting speed, cutting edge angle, the number of blades of the cutter, etc. and obtained a greater quality of banana crown incision with a relatively low energy consumption.

Due to the different diameters of the banana bunch stalk with the different banana hands on the whole banana bunch, how to achieve the profiling cut of the banana bunch stalk by the cutter during the mechanical de-handing procedure and improve the self-adaptive performance of the cutter to the bunch stalk with irregular geometry characteristic is one of the difficulties in the current mechanized banana de-handing operation. In order to achieve the purpose of self-adaptively changing the diameter of the de-handing cutter to the banana bunch stalk, Yang designed impact insert-type de-handing cutters [72] and rotary de-handing cutters [73] with radially movable cutting blades. In the procedure of the whole banana bunch de-handing, in order to avoid the phenomenon of cutting the banana hand separated and cutting off the banana fingers, which can affect the appearance quality and incision
quality of banana hands, the cutter needs to fit the banana bunch stalk to cut the banana crown. The clamping force of the annular ring cutter increases with the increase of bunch stalk diameter, which is not conducive to the subsequent banana hands de-handing operation. In order to ensure the clamping force of the ring cutter on the bunch stalk to keep constant during the banana de-handing procedure, improve the self-adaptive performance of the ring cutter to the bunch stalk and make the procedure of the whole banana bunch de-handing smoothly, Yang [74] designed a self-adaptive banana de-handing device to the banana bunch stalk based on a constant force mechanism, as shown in Figure 7. The device equips a constant force mechanism and a mounting plate that can release two rotational degrees of freedom, which improves the self-adaptability of the cutter to banana bunch stalk.

![Figure 7. A self-adaptive banana de-handing device based on constant force mechanism: (a) overall diagram of the device; (b) banana de-handing procedure; and (c) the constant force mechanism of the device.](image)

In order to enhance the enveloping performance of the profiling cutter on banana bunch stalk, Yang [75] designed a variable diameter arc mechanism, which can fit the banana bunch stalk well and realize the profiling envelope to the bunch stalk with different diameters. Xu [76] established the multi-constrained coupling conditions of the banana mechanical de-handing workspace by measuring the basic physical characteristics and geometrical characteristics of banana hands, banana crown and the crown fiber of the main banana varieties in Guangdong Province. The cutting mechanism of banana crown fiber during de-handing procedure was obtained, and the combined method of discrete element and finite element was used to numerically simulate the cutting procedure of banana crown fibers. After that, a profiling de-handing method based on the vibrated cutting mechanism was proposed, and a banana vibrated de-handing device based on the deployable mechanism was manufactured [77], as shown in Figure 8. The coupling movement formed by three flat sliders in the device can realize the arc mechanism deploying. The flexible de-handing cutter is driven by the arc mechanism to perform circumferential reciprocating motion, cutting the banana crown gradually and finally completing the banana de-handing work.
In the banana mechanized de-handing operation, apart from the impact insert-type de-handing mechanism, the rotary cutting-type de-handing mechanism and the vibrated cutting-type de-handing mechanism, Yang [78] tried to use a wire cutting method which is industrially mature in banana de-handing operation and designed a kind of wire-cutting device. The device has a simple structure, wide adaptability, easy controllability, high reliability and good profiling effects, which can be effectively applied to banana de-handing operation with profiling cutting along the circumferential direction. In the transportation operation of the banana hands after banana de-handing, the current methods are pushed by the water and held with pallets by workers, and both have low efficiency and high labor intensity. In order to improve the efficiency of collecting banana hands and reduce the labor costs, Yang [79] proposed a planar two-direction staggered synchronous transport device, which has a simple structure, easy operation, low labor intensity and higher collecting efficiency of banana hands. When using the device to transport banana hands, the speed is fast and the efficiency is high, which can improve the post-harvesting efficiency and shorten the banana post-harvesting time. Aiming at the recycling problem of banana bunch stalks after banana de-handing, Zhang [80–82] and Xu [83] designed a banana bunch stalk fiber extractor by using the dehydration technology of bunch stalk. Banana fiber is often used to make composite materials because of its good mechanical properties [84–87]. It not only solves the entanglement problem that banana stalks are easily attached to the roller surface but also lays a foundation for the promotion and application of the technology of returning banana bunch stalk to the field in tropical regions of southern China.

At present, more and more technologies are applied to the banana industry [88], and remarkable achievements have been made in cultivation of new varieties, healthy seedling production, integrated management of water and fertilizer, and post-harvest storage and fresh-keeping, etc. Su [89] and Zou [90] analyzed the research and application of banana storage and fresh-keeping technologies and pointed out the direction of the mechanized development of the banana industry. The research results have promoted the rapid development of banana industry in China and provided technical reserves for sustainable development in the industry [91].

### 3. Results

At present, banana picking in banana orchards mainly depends on humans. Our research indicates that the large volume of banana bunches and their susceptibility to mechanical damages are urgent problems that need to be solved during the mechanized development of banana picking. In addition, the terrain of banana orchards is complicated. The plantation patterns in flat orchards and hilly mountain orchards are different. Only a few semi-mechanized types of picking equipment can be used.
to pick banana bunches. Therefore, a closer integration of agricultural machinery and agronomy is the
key to mechanized development of banana picking in the future.

The common transportation method in banana transportation operation is ropeway transportation. Compared with the traditional mode of carrying banana manually, rope transportation greatly reduces labor intensity, improves work efficiency and reduces labor costs. In some small-scale banana orchards, the rope transportation is still towed by human or animal power. The remote location and complex terrain of banana orchards are the main reasons for the incomplete construction of power facilities. In addition, most of the rope ways are easily worn, and the cost of constructing rope way transportation network in banana orchards is high. As a result, artificial shoulders are still used to carry and transport banana bunches in some banana orchards.

Compared with other banana post-harvesting operations, the banana de-handing operation started late in mechanization and is still in its infancy. Whether it is in banana orchards or in commercial processing lines of post-harvesting, the banana de-handing operation basically relies on workers with simple arc-shaped cutters. The repeated periodic work brings risks to the health of workers, so it is necessary to increase the mechanized development of the banana de-handing operation. However, the major banana-growing countries in the world are mainly concentrated in developing countries, and the research and development of mechanized technology started late and progressed slowly. In addition, banana hands are susceptible to mechanical damage. Therefore, the fundamental starting points for the research of mechanization of banana de-handing are ensuring the quality of banana hands, and prolonging the transportation time, thereby improving the economic benefits of bananas. Although the existing mechanized de-handing devices are still in the experimental stage, research on the mechanization and automation of banana de-handing technology based on machine vision and image processing have been underway. The banana de-handing devices equipped with automated and intelligent systems will definitely improve the quality and efficiency of banana de-handing in the future.

4. Conclusions

In order to develop towards automation and intelligence for banana post-harvesting operations, high-level mechanized picking, transportation, and de-handing technologies and devices are necessary. Faced with the increasing shortage of human resources and the aging population, they are still goals for agricultural engineering researchers to strengthen related technical research, explore new methods of working and optimized ways of mechanical structures, design automatic, intelligent, and accurate banana picking devices based on machine vision, build stable, reliable and remote-controllable, lightweight and wear-resistant banana transport ropeways, develop banana profiling de-handing devices with low energy consumption, safety and great self-adaptive performance, reduce mechanical damages of banana hands during the whole post-harvesting procedure, reduce the labor intensity of workers and quicken the commercial procedure of banana industry. In the future, the development direction of precise picking, nondestructive transport and high-efficiency de-handing technologies in banana post-harvesting operations is continuous innovation and promoting application of mechanized and intelligent operations, which can not only improve the production efficiency of the banana industry around the world, but also improve the product quality, enhance economic benefits and create favorable conditions for competition and cooperation in the international banana market.

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