Research progress on the key technologies and equipment for mechanized potato harvesting

Zhiqiang Song[1], Zheng Ma[1,2*], Shuai Wang[1]

(1. *School of Agricultural Engineering, Jiangsu University, Zhenjiang 212013, China*;
2. *Key Laboratory for Theory and Technology of Intelligent Agricultural Machinery and Equipment, Jiangsu University, Zhenjiang 212013, China*)

Abstract: Potatoes are a staple food in many countries due to their rich nutritional content, including vitamins and carbohydrates, leading to their widespread cultivation globally. As China ranks first in the world in potato cultivation area and yield, making the crop vital to national food security, mechanized harvesting has become an indispensable solution for the sustainable development of the potato industry. This paper analyzes key technologies in potato mechanized harvesting, including efficient vine removal, low-loss and obstruction-reduced digging, high-efficiency cleaning and separation, and intelligent harvesting, based on an overview of China's potato cultivation modes, mechanized harvesting methods and equipment. Furthermore, the study identifies gaps between Chinese potato harvesting equipment and that of European and American countries in terms of harvesting performance, intelligence level, and adaptability. Key challenges are also highlighted, such as significant regional variability, the lack of high-efficiency and low-loss separation devices, and difficulties in overcoming critical "chokepoint" technologies. Finally, the paper proposes future development directions for China's potato harvesting equipment, emphasizing 1) synergistic multi-mode development, 2) research on flexible and low-loss separation devices, and 3) the integration of intelligent technologies. This study aims to provide references for key technologies and optimized design solutions, supporting the advancement of mechanized potato harvesting and promoting sustainable and efficient practices in the potato industry.

Keywords: potato mechanized harvesting, vine removal, low-loss and obstruction-reduced digging, potato-soil separation, potato cultivation modes

DOI: 10.25165/j.ijabe.20251805.9976

Citation: Song Z Q, Ma Z, Wang S. Research progress on the key technologies and equipment for mechanized potato harvesting. Int J Agric & Biol Eng, 2025; 18(5): 1–14.

1 Introduction

Potato is an annual herbaceous plant of the Solanaceae family and Solanum genus, rich in various nutrients such as dietary fiber, starch, protein, minerals, and vitamins. Potato has been a staple food for more than 70 countries including China, India, Ukraine, Russia, and the United States, because it can be processed into Mantou, noodles, and other staple foods, and it plays an important role in industrial material and animal feed[1,2]. Therefore, potatoes are widely cultivated around the world. According to the China Statistical Yearbook, in 2022, the potato cultivation area in China was 7.185 million hm^2, while its total production was 29.774 million tons[3]. The proportion of potato production in China to global production remained between 21% and 25% from 2011 to 2022, as shown in Figure 1 and Figure 2.

According to statistics from the Food and Agriculture Organization (FAO), the consumption of potatoes of the top ten countries in 2018 is listed in Table 1. According to relevant statistics, the per capita annual consumption of potatoes in European countries has stabilized at 50-60 kg, and that in Russia has reached more than 170 kg[4]. China's per capita consumption is among the first in the world. China's potato industry has always maintained a leading position in the world, with its cultivation area and production consistently ranking first on a yearly basis. Additionally, potatoes in China have become the fourth main staple crop after maize, wheat, and rice, which is of great significance in ensuring national food security and consolidating the achievements of poverty alleviation[5,6].

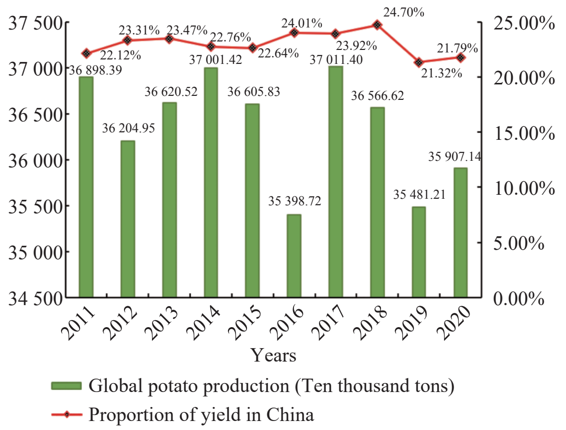


Figure 1 Global potato production and China's production share

The potato production process roughly includes variety selection, cultivation, field management, and harvesting. Among them, the harvesting process is the most time-consuming and the most labor-intensive. At the same time, manual harvesting of potatoes has the problems of low efficiency and high cost, and the

Received date: 2025-06-21 **Accepted date:** 2025-08-12

Biographies: Zhiqiang Song, PhD, Assistant Researcher, research interest: optimization design and intelligent control of agricultural harvesting equipment; Email: zqsong@ujs.edu.cn; **Shuai Wang**, PhD, Lecturer, research interest: intelligent agricultural equipment and non-destructive detection technology, Email: swang@ujs.edu.cn

***Corresponding author: Zheng Ma**, Professor, research interest: status assessment and fault diagnosis of agricultural machinery systems; School of Agricultural Engineering, Jiangsu University, No.301 Xuefu Road, Jingkou District, Zhenjiang 212013, China. Email: mazheng123@ujs.edu.cn.

harvesting phase is short. Therefore, the mechanized harvesting of potatoes is the primary goal of potato mechanization production.

According to the Statistical Bulletin on the Development of Agricultural Mechanization in China and the China Agricultural Mechanization Yearbook[7], the mechanization rates of potatoes cultivation, cultivation, harvesting, and comprehensive mechanization in China in 2022 were 78%, 31%, 32%, and 50%, respectively, which are lower than the full mechanization rates of wheat, maize, and rice production operations. Although there are various types of potato harvesters available on the market, in some regions of China potatoes are still harvested manually or semi-mechanically for different terrains and soil types.

The purpose of this study is to provide a comprehensive reference for the research and development of potato harvester, as well as to provide suggestions for improving the quality of potato harvesting and the sustainable development of potato harvesting mechanization. To achieve this purpose, this study analyzes the cultivation modes of potato in different regions of China, and focuses on the key technologies of the vines killing, tubers digging, conveying, and separating. Furthermore, this study provides the current development status of potato harvesters on a national and international scale, and compares the types of existing potato harvesting mechanisms, along with their advantages and disadvantages. Finally, the problems and challenges of potato mechanized harvesting are identified, and an outlook is provided on the development of the potato harvesters for the sustainable development of agricultural mechanization.

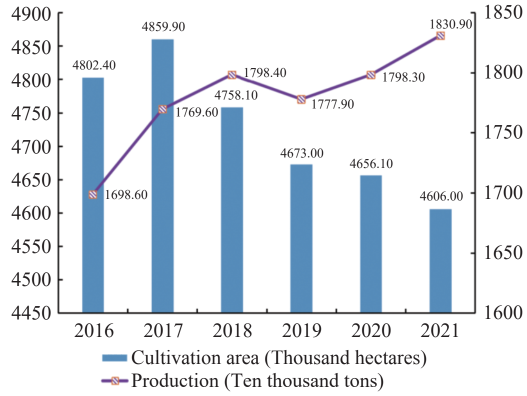


Figure 2 Potato cultivation area and yield in China from 2016 to 2021

Table 1 Consumption of potato-producing countries in 2018 Unit: 10000 t

Country	China	India	Russia	Ukraine	USA	Germany	Bangladesh	France	Netherlands	Poland
Consumption	9910	4364	3042	2200	2000	980	954	630	680	780

2 Characteristics of potato cultivation and harvesting in China

2.1 Regional characteristics of potato cultivation in China

Potatoes are cultivated in all regions of China throughout the year due to potatoes have the advantages of being tolerant to cold, drought, and barrenness although the natural conditions such as terrain, climate, and soil in different regions of China are significant different. The potato cultivation regions in China can be categorized into the first cultivation region of northern China, the second cultivation region of central plains, the mixed cultivation region of southwestern China, and the winter cultivation region of southern China.

The first cultivation region of northern China is mainly composed of plains, with a dry climate and little rainfall. The potato cultivation area accounts for about 50% of the total potato cultivation area in China. The potato cultivation area in the second cultivation region of central plains accounts for about 7% of the total potato cultivation area in China, with small plots mostly on the edges. The terrain of the southwestern mixed cultivation region is mainly hilly and mountainous, with small fields and heavy soil, accounting for about 38% of the potato cultivation area in China. The winter cultivation region in the south of China is mainly hilly and mountainous, the plots are small, the soil is sticky, and the cultivation mode is mainly based on ridges. Its potato cultivation area accounts for about 5% of the total potato cultivation area.

2.2 The cultivation modes of potato in China

The cultivation mode of potato in various regions of China is tailored to local conditions such as terrain, climate, and soil. The terrain of the first cultivation region of northern China and the second cultivation region of central plains is relatively flat, the categories of cultivation modes include a large ridge and double rows, a single ridge and single row, and the typical row spacing is 60-85 cm. The comprehensive mechanization rate of cultivation potato in these regions is about 60%[5]. The southwestern China mixed cultivation region and the winter cultivation region in south China mainly rely on traditional manual cultivation, with diverse cultivation modes, and the mechanized harvesting rate is less than 5%, due to the hilly and mountainous terrain and sticky soil. The purpose of studying these cultivation modes of potato is to achieve efficiently mechanized harvesting with low losses.

2.3 Harvesting mode of potato in China

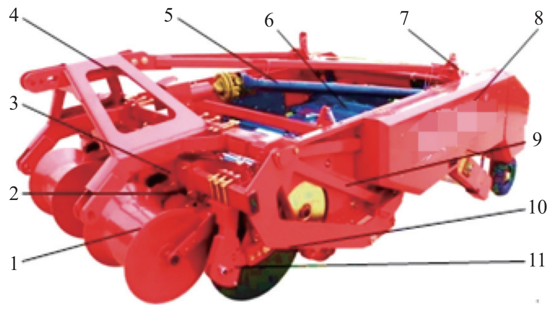
At present, there are two main mechanized harvesting modes of potatoes: segmented harvesting and combined harvesting. Segmented harvesting mode is more suitable for small- and medium-sized potato cultivation areas compared to combined harvesting, and relatively common in China.

2.3.1 Segmented mechanized harvesting modes of potatoes

Segmented harvesting potatoes includes two stages. In the first stage, potato tubers are dug up by using a digging mechanism after removing the potato vines, which are preliminarily separated through a conveying and separation mechanism, and then the tubers are laid on the ridges in strips. In the second stage, the potato tubers laying on the ridges are picked up and sorted for collection according to their size or quality by manual work[8]. The workflow is shown in Figure 3. Segmented harvesting mode is more suitable in hilly and mountainous areas and small-size plots, as it requires smaller machines, lower power demands, and lower initial investment costs. However, it is labor-intensive.

A digging, conveying, and separation mechanism serves as the core component in segmented potato harvesting systems. It is designed with a compact structure and minimal dimensions, as shown in Figure 4, and it is implemented by tractor-towing for field harvesting operations. The device typically incorporates two conveying and separation rod chains with distinct vibrating operational parameters. The primary rod chain operates with larger amplitude to enhance potato-soil separation efficiency, while the secondary rod chain employs reduced amplitude to minimize tuber damage. Following this separation process, potatoes are deposited onto the soil ridge.

Figure 3 Segmented harvesting process of potatoes[9,10]



Note: 1. Imitation monopoly-shaped depth-limiting wheel; 2. self-cleaning device for depth-limiting wheel; 3. digging shovel; 4. rear suspension; 5. power transmission shaft; 6. grid type conveying separation screen; 7. collection barrier for potato; 8. transmission mechanism; 9. body frame; 10. vines and grass cutting disc; 11. self-cleaning device for cutting disk.

Figure 4 Diagram of segmented potato harvester[11]

2.3.2 Combined mechanized potato harvesting

Combined mechanized potato harvesting refers to an integrated process that simultaneously performs: potato tuber digging, soil and impurity separation, potato transportation and grading, and bulk packaging. The optimal operational time for combined harvesting occurs 4-11 days post vine removal. To achieve the combined harvesting function of potatoes, a combined potato harvester is equipped with the key components including vine removal equipment, digging equipment, conveying and separation mechanism, sorting and collection mechanisms, a power transmission system, a hydraulic control device, a walking mechanism, and other parts. Figure 5 shows the process of combined potato harvesting mode.

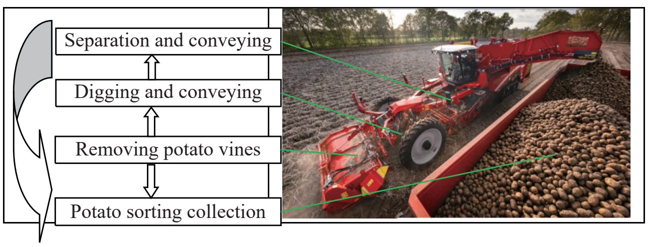


Figure 5 Diagram of combined potato harvesting operation[12]

3 Key technologies and equipment of combined mechanized potato harvesting

Combined mechanized potato harvesting requires the integration of multiple core technologies and specialized equipment to achieve efficient, high-quality, and low-loss operations. The geometric design and operational parameters of the digging shovel directly influence the harvester's tuber collection efficiency and loss rate. Similarly, the configuration of separation and conveying systems significantly impacts three key performance metrics: 1) mechanical damage rate, 2) periderm breaking rate, and 3) residual impurity content. To optimize harvesting quality, these critical technical aspects of potato vines removal, digging up, row aligning and depth limiting, separation, packing potatoes into ton bags, and intelligent control should be the focus of research and development[13].

3.1 Potato vines removal technologies and equipment

3.1.1 Advantages of potato vines removal before harvesting

Potato vines removal prior to digging up potatoes offers several benefits: eliminating vines prevents harvesters from becoming entangled with weeds and potato stems, ensuring smoother and more efficient operations. In addition, once vines are removed, nutrients no longer flow to the tubers, accelerating periderm aging and promoting lignification. This helps potato tubers naturally detach from creeping stems and develop a tougher periderm, reducing damage from collisions and friction during harvesting. Crushed vines left in the field decompose and return organic matter to the soil, increasing carbon sequestration, improving soil structure, and enhancing fertility.

3.1.2 Potato vine removal technology

Potato vine removal methods include mechanical, frost-induced, and chemical approaches. Among these, mechanical vine removal is the most widely adopted due to its high efficiency and minimal environmental impact. Mechanical vine removal can be further classified into segmented removal and combined removal. During the process of mechanical vine removal, some technical requirements should meet the following criteria: minimal soil disturbance to avoid displacing tubers; uniform stubble height for consistent field conditions; controlled vine fragment length to facilitate decomposition.

3.1.3 Key components of the vine removal device

To achieve these goals, a vine removal device should be equipped with rotary cutting blades, a main shaft, a depth-limiting wheel, upper jaw plates, one-way clutches, and other components. The rotary cutting system comprises three blade configurations: ridge-top, ridge-side, and ridge-bottom cutters[14]. These blades are symmetrically arranged on the primary drive shaft, with their geometric alignment precisely matching the ridge contour profile (Figure 6). This configuration ensures complete vine coverage while maintaining cutting consistency across the entire ridge surface.

The depth-limiting wheel regulates stubble height during operation, while the upper jaw plate guides and ejects crushed vines smoothly. A one-way clutch mechanism prevents power transmission backflow, safeguarding the drive system. For optimal performance, the rotary blades require a cutting speed ≥1300 r/min to: 1) ensure efficient vine pulverization, and 2) generate sufficient aerodynamic lift for vine transportation into the crushing chamber. Blade quantity and spatial configuration should be adaptively designed according to specific cultivation patterns[16,17].

Figure 6 General assembly of potato vines removal cutter[15]

3.1.4 Potato vine removal equipment

Table 2 presents several representative models of potato vine removal equipment from China, which come from Zhongji Meinuo, Shandong Xisen Tiancheng, and Qingdao Hongzhu Agricultural Machinery Co., Ltd.

Compared to leading international models such as Netherlands APH 6LKB-550, GRIMME (Germany) HT-400, and KS3600 series, the Belgium AVR Rafale series features automatic depth adjustment technology, three distinct technological advantages emerging in international equipment, advanced cutting systems for real-time cutting pressure adjustment, precision performance control systems, and strong adaptability to cross diverse field conditions. The comparison reveals several areas where Chinese manufacturers need further development to reach international standards, such as automation capabilities, adaptability to varying soil conditions, long-term durability, and reliability.

Table 2 Representative technical parameters and characteristics of potato vine cutters at home and abroad

Brand/Model	Photos	Technical characteristics
MENOBLE/1804	 [18]	Rear-mounted suspension type, supporting power of 66.2-88.3 kW, tractor output speed of 760 $r\cdot min^{-1}$, suitable for large ridge single-row cultivation mode, row spacing of 80/90 cm, 4 rows per operation, double-sided belt transmission form, work efficiency of 1-1.5 $hm^2\cdot h^{-1}$[18].
Xisen/4JM-360B	 [17]	Rear-mounted suspension type, supporting power of 73.6-132.4 kW, tractor output speed of 760 $r\cdot min^{-1}$, suitable for large ridge single-row cultivation mode, row spacing of 90 cm, 4 rows per operation, double-sided belt transmission, work efficiency of 1.4-2.5 $hm^2\cdot h^{-1}$[17].
Hongzhu/1JH-110	 [19]	Rear-mounted suspension type, supporting power of 18.4-33.1 kW, working width of 1000 mm, blade roller working speed of 2000 $r\cdot min^{-1}$, suitable for large ridge double- row cultivation mode, one ridge and two rows per operation, single-sided belt transmission form, working efficiency of 0.26-0.33 $hm^2\cdot h^{-1}$[9].

3.2 Potato digging technology and equipment

3.2.1 Key technologies of potato digging

Potato digging equipment is designed to dig tubers from ridges with minimal soil adhesion and ensure smooth transfer to the cleaning and separation mechanism. The digging equipment must meet the following core requirements: The digging shovel should avoid mechanical injury to potato tubers, and has the optimized performance of low digging resistance, high soil fragmentation efficiency, superior wear, and fatigue resistance[19,20].

To meet the agronomic requirements of potato digging, the structural composition of the potato digging equipment includes: a digging shovel, press wheel, soil-cutting disc, anti-clogging device, depth-limiting mechanism, automatic row-following system, and conveying chain, as shown in Figure 4 in Section 2.3.1.

3.2.2 Digging shovel

The digging shovel is a critical soil-contact part in potato digging equipment, the structural shape and performance of which directly affect digging efficiency, potato damage rate, and energy consumption of the digging equipment. The general requirement for digging shovel is to minimize resistance, wear resistance, and automatic soil cleaning. To optimize the performance of the digging shovel, the manufacturing materials for digging shovels are usually 65Mn and alloyed boron steel, and various structural forms of digging shovels are researched and developed.

1) Structural forms of potato digging shovel

Digging shovels are divided into integral blade shovel and multi-blade combined shovel. The combination digging shovel is composed of multiple independent shovel body modules, which can be combined with shovel blades of different lengths, widths, and shapes according to actual needs to adapt to different cultivation spacing, soil types, or terrains. In addition, these modules also include adjustable components for adjusting digging parameters such as shovel depth and shovel surface tilt angle to achieve optimal harvesting results. By replacing or adding specific functional modules, the combined digging shovel can also adapt to the digging and harvesting of other root and stem crops, such as sugar beets, carrots, etc., improving the utilization rate and economic benefits of the equipment.

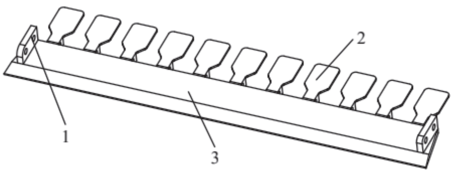
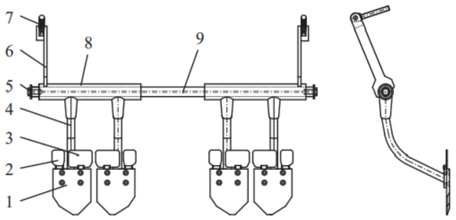
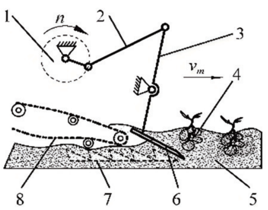
As shown in Table 3, it can be seen that the flat digging shovel has the advantages of simple structure, easy operation, and less damage to soil. However, its adaptability is poor and it is not suitable for hard soil or soil with a lot of stones. While the vibrating digging shovel has the advantage of strong adaptability and can be applied to various types of soil, its complex structure and high destructive power to soil may not be conducive to soil and water conservation. Therefore, when designing a digging shovel, the appropriate digging shovel type should be selected based on soil type, crop planting method, and root depth, especially in hard or rocky soil, where a digging shovel with high strength and good wear resistance should be chosen.

2) Structural shape of potato digging shovel

Various structural shapes of digging shovel are researched and developed for potato digging, such as triangular flat shovels, strip flat shovels, concave curved shovels, groove shovels, and biomimetic digging shovels. Usually, flat shovels are used commonly, and their structure should include a front end processed into a sharp angular slanting edge, which can reduce the resistance to digging and prevent the entanglement of weeds and congestion. The angle of the flat-type digging shovel is generally between 20 degrees and 35 degrees, as shown in Figure 7.

To reduce the resistance of digging potato tubers with a digging shovel and minimize the mechanical damage to potatoes, many scholars have designed biomimetic digging shovels based on physiological structural characteristics of certain animals and plants in nature, such as claws, beaks, and scales, with low soil adhesion. These digging shovels possess unique performance capabilities, adapting well to specific soil conditions and demonstrating advantages of low energy consumption and high efficiency during the digging process. However, they suffer from significant drawbacks such as complex structures and high design and maintenance costs[23,24]. Table 4 shows typical examples of biomimetic shovels and their characteristics.

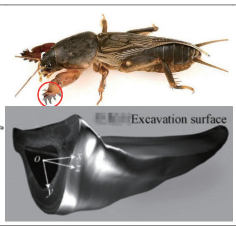
Table 3 Structural form, characteristics, and application performance of potato digging devices

Structural forms	Structural diagram	Characteristics	Application
Integrated flat shovel[21]	 1. Frame fixing point, 2. Stone screening grid, 3. Digging shovel.	The characteristics of this shovel are simple structure low manufacturing cost, and easy installation. The width of the shovel surface is generally less than 200 mm. A stone sieve grille is installed in the transition gap between the rear end of the digging shovel and the separation device to prevent hard objects such as stones from blocking the separation device.	It is commonly used in small potato harvesters in China, such as Hongzhu 4U-90, 4U-130, Xisen Tiancheng 4UX-120, etc.
Split flat combination shovel[21]	 a. Front view b. Side view 1. Flat shovel, 2-3. Stone screening grid, 4. Cantilever bracket, 5. Shaft end limit screw, 6. Angle adjusting lever, 7. Angle adjusting screw rod, 8. Main beam of shovel frame, 9. Articulated shaft.	The split flat combination shovel is independently installed on a cantilever bracket, and the front end of the shovel is processed into a sharp-edged blade, which has good sliding cutting performance and low digging resistance. The burial angle can be adjusted between 30° and 42° to accommodate different types of soil.	This type of digging shovel is commonly used in large potato combine harvesters produced by Germany GRIMME company, and Belgium AVR company.
Vibratory digging shovel[22].	 1. Eccentric wheel, 2. Connecting rod, 3. Reciprocating shovel frame, 4. Potatoes, 5. Landridge, 6. Digging shovel, 7. Digging shovel movement trajectory, 8. Conveyor lifting chain.	Vibration digging shovel carries out horizontal and vertical vibration by using a combination of a four-bar mechanism and concentric wheels. It increases the cutting effect on soil blocks, and the soil blocks break smoothly, which helps to transport potatoes to the separation component and facilitates potato soil separation. The vibration of the digging shovel reduces the digging resistance, but does not decrease the total power required.	Vibratory digging shovel is mainly used to solve the problems of high digging resistance and high energy consumption. For example, Chen Kai, Lv Jinqing, Liu Xiao, et al. designed a vibrating shovel potato harvester, respectively.

a. Triangle two-piece shovel b. Triangle combination shovel c. Triangle one-piece shovel d. Stone fence combination shovel

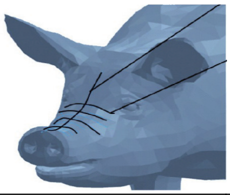
Figure 7 Common flat digging shovels

Table 4 Typical examples of biomimetic shovels and their characteristics

Bionic shovels	Structural diagram	Biomimetic prototype	Performance characteristics
Biomimetic curved shovel			The forelimbs of Gryllotalpa orientalis Burmeister are highly adapted for soil digging. Their forefoot toes exhibit an upward-facing shovel-like morphology, with a curved lateral profile of specific curvature. The claw tips feature a square-wedge structure, characterized by wedge angles of approximately 30° on both the frontal and lateral aspects. Through evolutionary optimization, the configuration of these claws and toes minimizes resistance during soil penetration, enhancing burrowing efficiency[25,26].

(To be continued on the next page)

Table 4 (*Continued*)

Bionic shovels	Structural diagram	Biomimetic prototype	Performance characteristics
Biomimetic ripple shovel			The structure of earthworms and scallops has good soil flowability. By constructing relevant biomimetic digging shovels and conducting relevant experiments, the results show that the digging resistance of the biomimetic ripple shovel and the damage rate are reduced by 14.45% and 0.736%, respectively[27].
Biomimetic wild boar's snout digging shovel			The head and nose of wild boars have unique advantages in turning, arching, and breaking soil, and their digging process is very similar to that of a digging shovel. By collecting point cloud data from the head and nose of wild boars and then conducting reverse engineering modeling, a biomimetic digging shovel can be obtained. Both simulation experiments and soil trench experiments have shown that the average digging resistance of biomimetic digging shovels is lower than that of flat digging shovels, with a drag reduction rate of 24.29%[28,29].

3.2.3 Potato digging depth limiting technology

Potato tubers grow at a certain position in the soil ridge, so when excavating the potato tubers, it is necessary to control the appropriate digging depth. If the digging depth is too short, the digging shovel is prone to damage the potato tubers, increasing the damage rate and reducing the harvest quality. If the digging depth is too long, the amount of soil excavated will increase sharply, while also increasing the load and power consumption of the potato soil separation components.

At present, there are mainly two types of digging-depth-limiting technologies for potato harvesting. One technique is to adjust the height of two guide wheels installed on both sides of the frame. The two guide wheels guide the digging shovel along the potato rows before digging potato tubers, as shown in Figure 8a. Another technique is to adjust the height of an imitation monopoly-shaped depth-limiting roller, which is installed at the front-end of the harvesting devices as shown in Figure 8b.

a. Twoguide wheels

b. Imitation monopoly-shaped depth-limiting roller

Figure 8 Digging-depth-limiting device[13]

Generally, the digging angle α for potato ridge harvesting is set at 20° to 30°. Considering that different cultivation techniques and soil types also affect the friction angle φ between the potato soil mixture and the digging shovel, the digging angle α of the digging shovel needs to be adjusted reasonably according to the actual situation. In addition, under the conditions of slope operation, the digging depth on both sides of the excavator is not consistent, which can easily lead to unnecessary losses. The relative position relationship between the adjustable frame and the harvesting frame can be controlled by hydraulic cylinders on both sides, thereby adjusting the digging angle of the shovel to ensure the quality of the harvest and reduce drag and consumption. Digging-depth-limiting technology is used to adjust the shovel's penetration depth to ensure a reasonable digging depth, avoiding the digging shovel mechanical damage to some potatoes that grow deeper[30].

3.3 Potato separation technology and separation device

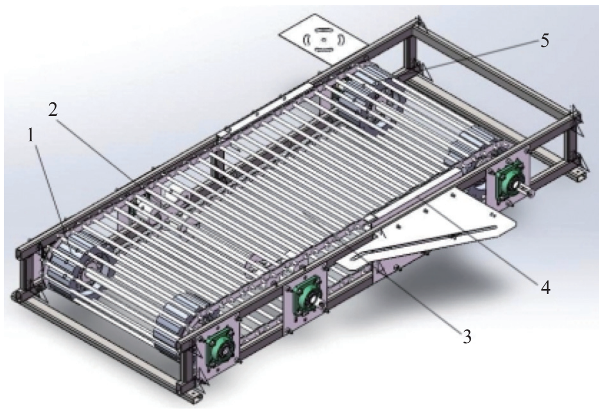
Potato separation device located behind the digging shovel is employed to separate potatoes from the mixture entering the separation device, including potato tubers, fine soil, clods of soil, stones, potato vines, and weeds. It can be divided into segmented harvesting and separation technology, combined harvesting and separation technology, and impurity separation technology according to different mechanized harvesting methods. Research on the conveyor and separation mechanism of potato harvesters aims to improve the separation efficiency of potato-soil while also reducing skin breakage and damage rates during the harvesting process.

During the process of conveying and separating potatoes, potatoes often collide and rub with surrounding potatoes and devices, resulting in potato periderm breakage and damage[31,32]. According to relevant national standards, the harvesting quality of the combined harvester is required to have a periderm breakage rate of no more than 3% and a damage rate of no more than 2%[33].

3.3.1 Potato-soil separation technology

1) Potato-soil separation technology in segmented harvest

The link bar conveyor chain is a common working component of potato segmented harvester, which not only fulfills the purpose of transporting potato but also takes on the task of potato–soil separation, as shown in Figure 9. The link bar conveyor chain is configured with parallel metal bars, a rubber conveyor belt, a vibrating mechanism, a driving wheel, several roller wheels, etc. The diameter of metal rods is usually 12 mm, with a spacing of 44-55 mm between adjacent rods. The metal rods are covered with a certain thickness of flexible materials such as rubber or



Note: 1. Passive wheel; 2. Shake mechanism; 3. Conveyor chain; 4. U-shaped bracket; 5. Drive wheel.

Figure 9 Structure of link bar conveying separation device polyurethane to reduce collision damage to potatoes[34].

The vibrating mechanism is a critical part of the separation conveyor chain, as its frequency and amplitude directly influence the potato damage and epidermis breakage rates. Currently, most vibrating systems employ a continuously variable speed drive, allowing stepless adjustment of frequency and amplitude to ensure effective separation while minimizing potato tubers damage. Typical jitter wheels are shown in Table 5.

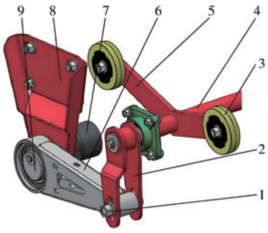
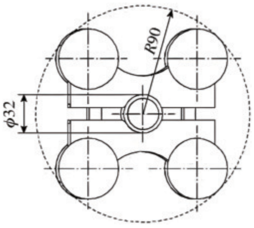
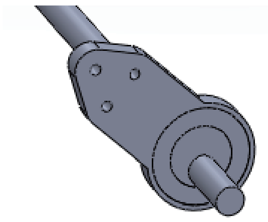
The link bar conveyor chain is widely used in potato segmented harvester in China due to its relatively simple structure and low production cost. The representative models include Xisen Tiancheng 4UX-165 and Qingdao Hongzhu 4U-90. However, the separation of potatoes from soil is poor, and potatoes roll excessively on the conveyor chain, easily causing damage.

To avoid potatoes rolling or bouncing on the rods, the link bar conveyor chain is equipped with the combination of curved and straight rods, enhancing the support capacity of the screening surface and improving the separating efficiency of potato-soil[35].

2) Potato-soil separation technology in combined harvest

To achieve effective separation of potatoes from soil and impurities, three or more stages of conveying and separation mechanisms are usually used in medium or large potato combine harvesters. The first and second stage separation mechanisms are mainly used to separate most of the soil and impurities, while the third and subsequent separation mechanisms are mainly used to complete the transportation and sorting of potato tubers. The conveying and separation system in potato combine harvesters usually uses a combination of various structural forms of conveying and separation mechanisms, including vertical annular conveying and separation devices, grid plate conveying and separation devices, and multiple sets of roller combined conveying and separation mechanisms[38]. Their characteristics are listed in Table 6.

Table 5 Characteristics of different vibration mechanisms

Mechanism	Photograph	Characteristics
Y-shaped swinging mechanism	 [36]	The "Y"-shaped swing frame is driven by a hydraulic motor through a connecting rod, and the rubber wheels at both ends alternately strike the screen surface to vibrate it up and down, causing the soil blocks to break and fall to the ground[36].
Rotating four head vibrating rubber wheel	 [34]	Four rotating rubber wheels alternately strike the screen surface to make it vibrate up and down. The height of the four rubber wheels can be controlled and adjusted by an electro-hydraulic push rod to achieve stepless amplitude adjustment, ultimately achieving the goal of crushing soil and causing it to fall off the screen surface[34].
Eccentric vibration wheel	 [37]	The integrated design of the electric motor and vibration wheel allows the electric motor to directly drive the eccentric block, resulting in a compact structure and high energy transfer efficiency. By adjusting the motor speed (such as frequency converter control), the vibration frequency can be flexibly changed. By changing the eccentricity of the eccentric block, the amplitude can be adjusted to meet different working conditions.

3.3.2 Potato-impurity separation technology and device of combined harvest

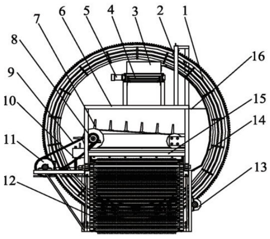
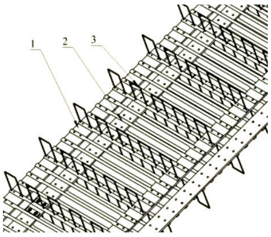
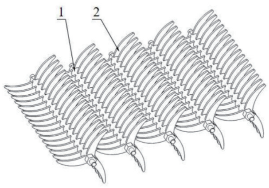
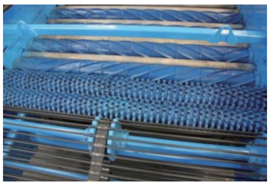
For potato-impurity separation technology, airflow separation, mechanical separation, and vibration screening separation are widely used. Usually, there is a positive correlation between the ability of separation potato from vines and the potato damage rate, that is, the stronger the separation ability, the greater the potato damage rate.

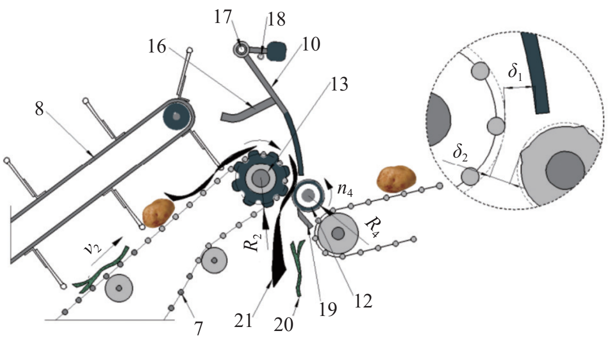
Airflow separation technology utilizes airstream generated by a fan to remove lightweight impurities, such as soil particles and residual leaves. Typically, a blower is installed at the end of the lifting chain or tail conveyor screen. The strong airflow generated by the blower blows away the mixture of falling potatoes and residual seedlings, effectively removing lightweight impurities like leftover seedlings from the machine and reducing overall impurity content[42].

Mechanical separation leverages differences in physical properties (e.g., size, density) between potatoes and impurities for segregation. For instance, a staggered rollers separation mechanism is used for conveying and separation during the combined harvesting process. As the potato-impurity mixture passes through, potatoes move forward unimpeded, while potato seedlings and weeds become entangled in the threaded de-vegetation rollers and are thereby separated. Vibration screening separation uses the differences in inertial forces between potatoes and impurities to separate them. The adjustment of vibration frequency and amplitude is achieved by adjusting the speed of the driving mechanism and the length of the top rod, respectively[37].

The typical impurity removal device illustrated in Figure 10 comprises staggered light rollers and threaded impurity removal rollers. When the potato-impurity mixture passes through, potatoes will pass through unimpeded, while potato vines and weeds are entangled by the threaded rollers and subsequently separated. To minimize potato damage, the threaded rollers are coated with a flexible material.

Table 6 Characteristics of different conveying-separation mechanisms

Mechanism	Photograph	Features
Vertical circular conveying and separating mechanism	 	1. Vertical circular separating screen 2. Positioning guide wheel 3. Inclining baffle 4. Secondary conveying mechanism 5. Hydraulic motor 6. Frame 7. Transverse transfer mechanism 8. Driven sprocket 9. Chain 10. Guide plate of the screen 11. Drive sprocket 12. Belt-type conveying mechanism 13. Fixed wheel set 14. Protective screen 15. Transverse transfer baffle 16. Connecting plate of protective grating strip[39].
	The vertical circular conveying and separating mechanism is installed on a self-propelled potato combine harvester. When potatoes are digged along with soil and impurities, they move backwards via a belt-type conveyor mechanism. Then, potatoes are dipped onto the vertical circular separating screen by rubber fingers on the transverse transfer mechanism. The vertical annular separation sieve is rotated by the engagement drive of gears and ring gears. During the rotational process, potatoes and soil blocks are subjected to the combined effects of their own gravity and centrifugal force, resulting in different rolling characteristics. During the process of circular lifting, potatoes separate from soil through relative motion, and the vertical circular separating screen can prevent potatoes from falling[40].	
Grid plate conveying and separation mechanism	 1. Rubber belt 2. Rod 3. Grid plate[41]	The grid plate conveying and separation mechanism is similar to the bar-rod type conveying separation chain, as both use parallel metal bars arranged in an orderly manner on conveying chain. The difference between these two structures is that some grid plates are installed on the grid plate conveying and separating mechanism, which is beneficial for lifting potatoes. When potatoes fall onto the grid plate conveying and separation mechanism after passing through the conveyor chain, they are lifted to a higher height within a shorter horizontal distance while remaining relatively stationary relative to the grid plate, to prevent damage to the potatoes[41].
Roller pushing-based conveying-separation mechanism	 1. Drive shaft 2. Dial finger[41]	The structure of the roller pushing-based conveying-separation mechanism consists of a series of rotating rollers. The rotation rollers push potatoes to roll on the roller assembly, causing the detached soil to fall through the gaps between the rollers, while the potatoes continue to be conveyed backward achieving the separation of the tubers from the soil. This technology can be found in potato harvesters focusing on the heavy clay soil areas[41].
Staggered rollers separation mechanism	 [41]	The separation mechanism is composed of multiple finger rollers or spiral rollers arranged side by side horizontally or vertically, and is installed after the lifting conveyor chain. It can efficiently separate potatoes from soil by the relative motion. The gap between the rollers can be adjusted to improve the separation efficiency of potato and soil. The damage rates are low because the relative motion between potatoes and the staggered rollers separation mechanism is minimal[41].



7. Rod–chain separation screen; 8. scraper auxiliary lifting device; 10. counterweight blocking rod; 12. flexible impurity removal roller; 13. rod–chain separation screen driving shaft; 16. comb film teeth; 17. hinged rod; 18. limit rod; 19. film-clearing knife; 20. separated stem and vine; 21. separated plastic film.

Figure 10 Schematic diagram of film and vine separation structure[43]

4 Current situation of potato harvester

4.1 Segmented potato harvesting equipment

Table 7 shows some typical segmented potato-harvesting equipment in China and abroad and their models, equipment photos, and technical characteristics.

4.2 Structure and characteristics of combined potato harvesting equipment

To save costs and improve harvesting efficiency, combined potato harvesting equipment is designed to complete multiple potato-harvesting processes at the same time, such as potato digging, transportation, clear selection separation, and packing potatoes into boxes. Potato combine harvesters are classified into two main types: small-scale and large-scale harvesters. Small-scale potato harvesters feature a lightweight structural design, offering superior maneuverability and the ability to adapt to varying terrain conditions for optimal harvesting performance.

4.2.1 Small-sized combined potato harvester

Common small-sized potato harvesting equipment is shown in Table 8. Large-scale potato harvesting equipment is mostly used on plains, large plots, and other areas, as it has a high harvesting efficiency. The main types of small-sized potato harvesters are listed in Table 8.

As detailed in Table 8, the lightweight potato excavator employs a simplified mechanical design with two-stage separation sieve that deliberately omits electromechanical-hydraulic or intelligent control systems. While this minimalist approach restricts functionality to fundamental digging operations[47], it provides two significant agronomic advantages: substantially reduced tuber

Table 7 Typical segmented potato-harvesting equipment and technical characteristics

Model	Equipment photos	Basic structure and technical features
Hongzhu 4U 160D	 [10]	The equipment is rear-suspended with three-point, and powered by a 58.8-88.2 kW tractor. The overall dimensions are 5200 mm (L)×2030 mm (W)×1550 mm (H) and a working width of 1600 mm for double-row potato harvesting. The device employs a stepped shovel and a two-stage lifting chain mechanism for digging, conveying, and separating potatoes[10].
Hongzhu 4U-170B	 [11]	The equipment is rear-suspended with three-point and grid screen conveyor chain, and powered by a more than 66.2 kW tractor. The overall dimensions are 3810 mm (L)×2020 mm (W)×1200 mm (H). The working width is 1700 mm for double-row potato harvesting, and the digging depth is 150-350 mm[11].
Hand-held self-propelled potato harvester	 [44]	This equipment is towed by a walk-behind tractor and powered by a 19 kW engine. It features an overall width of 800 mm and a working width of 600 mm, enabling it to efficiently harvest potatoes in either single or double rows. Its operational capabilities include key tasks such as digging, potato-soil separation, and windrowing (forming crop rows). The compact design of this machine makes it particularly well-adapted for small-scale farming operations in mountainous and hilly regions[44].
GRIMME WH200S	 [45]	This equipment is rear-suspended with three-point and is powered by a 50 kW tractor. With overall dimensions of 3800 mm (L)×1900 mm (W)×1400 mm (H) and working width of 900 mm, it is designed for double-row potato harvesting. The machine combines two specialized techniques to accommodate both tender and tough potato epidermis characteristics during harvest[45].

Table 8 Small-sized potato harvesters

Model	Photos	Basic structure and technical features
4UFD-1400 potato combine harvester	 [46]	The structure of this potato combine harvester is a rear suspension type, with dimensions of 4700×2000×2050 mm, a working width of 1400 mm, and an adjustable excavation depth within the range of 0-300 mm. It needs to match a driving power of 44.0-58.8 kW and has functions of excavation, conveying separation, classification, and bagging[46].
4UZ-110 crawler self-propelled potato combine harvester	 [21]	The structural form of this potato combine harvester is a tracked chassis self-propelled harvester, which consists of a chassis walking system, excavation and conveying mechanism, depth limiting ground wheels, multi-stage conveying and separation device, potato collection box, etc. The matched engine power is 55 kW. The working width is 1000 mm and can adapt to ridge spacing of 800 mm to 1000 mm. The harvesting speed can reach 1.0 m·s^{-1}[21].

impact damage and lower periderm breakage rates attributable to shortened conveyance pathways. These performance characteristics make the equipment particularly suitable for fresh market potato production, where it serves as the primary digging unit in a two-stage harvesting system-mechanical digging followed by manual collection and bagging operations.

4.2.2 Large-sized combined potato harvester

Large-sized combined potato harvesters are primarily deployed in plain regions, extensive fields, and other flat or expansive areas, given their large machine dimensions. However, the breakage rate of potato periderms is higher than that in small potato harvesters, as the lengthy transportation process heightens the risk of potato compression, collision, and dropping.

Table 9 lists the models, structures, and characteristics of potato combine harvesters manufactured in China, while Table 10 lists the models, structures, and technical characteristics of potato combine harvesters manufactured in other countries.

According to Tables 9 and 10, it can be seen that the majority of potato harvesters produced and manufactured in China have pure mechanical structures. Compared with potato harvesters produced and manufactured in other countries, they have simple structures, lack intelligent control systems, and the technical parameters of key components cannot be automatically adjusted. The technical level is not high, resulting in poor adaptability of potato harvesters if operating in different regions and soil environments. The potato harvesting equipment produced and manufactured in developed countries has multifunctional, information-based, and intelligent technological features, which can monitor the working status of

Table 9 The models, structures, and characteristics of potato combine harvesters manufactured in China

Model	Country	Harvester photos	Basic structure and technical characteristics
4ULZ -170 Xisen Tiancheng	China		This is a rear-suspended traction device requiring a matching power output of ≥88.2 kW. The key specifications are as follows: Dimensions (L×W×H): 9795×3300×3360 mm; Machine Mass: 5960 kg; Working Width: 1700 mm; Ridge Width Adaptability: ≥700 mm; Digging Depth: 150-300 mm; PTO Input Speed: 540 r·min^{-1}. It is equipped with a multi-stage star-roller soil-clearing and debris-removal system, ensuring efficient separation of soil and debris from harvested potatoes[48].
DEVO 4UML-180	China		This is a rear-suspended traction device requiring a matching power output of ≥110 kW. The key specifications are as follows: Dimensions (L×W×H): 8800×3400×3500 mm; Machine Mass: 8380 kg; Working Width: 1600-1800 mm; Ridge width adaptability: 800-900 mm; Digging depth: 150-350 mm; Double ridge digging harvesting; Operating speed: 2-5 km·h^{-1}; Operating efficiency: 0.1-0.2 hm^2·h^{-1}. Five-level belt conveyor system reduces potato skin breakage rate, and three-level potato-vines separation system reduces impurity content[49].
MENOBLE 1710B	China		This is a rear-suspended traction device requiring a matching power output of ≥73.55 kW. The key specifications are as follows: Dimensions (L×W×H): 5000×3300×3400 mm; Machine mass: 4000 kg; Working width: 1600-1800 mm; Ridge width adaptability: 800-900 mm; Digging depth: 0-300 mm; Double ridge digging harvesting; Operating speed: 2-5 km·h^{-1}. Floating disc knife effectively cuts through weeds and reduces digging resistance. The conveyor belt and lifting device behind the vibrating screen directly transport the harvested potatoes to the transport vehicle[50].

Table 10 The models, structures, and technical characteristics of potato combine harvesters manufactured in other countries

Model	Country	Harvesters photos	Basic structure and technical features
GRIMME VARITRON 470	Germany		This is a self-propelled harvester with an engine power of 338.33 kW, and the chassis is driven by a static hydraulic system. There are two types of harvesters, suitable for harvesting ridges with a spacing of 750 mm and 900 mm, separately. It can harvest 4 rows at the same time, so the total length is 12 740/15 615 mm, the width is 3490mm/3855 mm, and the height is 4000 mm. It has a circular lifting belt with a tarpaulin groove, which reduces damage to potato chunks caused by collisions. The advanced and comfortable driver's cabin is equipped with a video surveillance system that enables all-round blind spot monitoring at the rear of the machine. Real-time images are transmitted through WIFI, and a 12-inch touch screen display is available[51,52].
AVR - Puma 3	Belgium		This is a wheeled self-propelled harvester equipped with a 345 kW engine. Four wheels are driven by static hydraulic pressure system. The machine size (L×W×H) is 14 500×3480×4000 mm, adapting to ridge spacing of 750 mm or 900 mm, harvesting 4 rows at each time, supporting an 8t storage capacity. The working parameters of each component can be adjusted through the driving terminal, and can be monitored by imaging and sensor. It has the function of automatic control and assisted driving. The unloading device has functions such as adaptive adjustment of height and unloading speed[53].
Dewulf Kwatro	Belgium		This harvester adopts a self-propelled wheeled and crawler chassis system with four-wheel drive and needs to be equipped with 367.75 kW. The machine size (L×W×H) is 15 090×4100×4000 mm. It can operate four rows. The whole machine adopts full hydraulic drive, which can realize the stepless regulation of several operating parameters, and the potato collection section uses adaptive height adjustment technology, so potato chunks have less damage[21].
Double L 7340	America		This is a traction harvester pulled by a forward extending lifting arm, with a 338.33 kW engine. The machine size (L×W×H) is 11 480×6530×3710 mm, harvesting 4 rows at each time. Its transmission adopts a combination of mechanical and hydraulic systems. The working status of key components of the machinery is monitored in real time through sensors, and the working data and fault information can be transmitted to the visual monitoring terminal in the cab and external computer through Bluetooth controls[21].

potatoes in real time during the harvesting process and adaptively adjust the working parameters, having low potato damage rate and low periderm breaking rate harvesting performance.

5 Challenges and development prospects of potato harvesters in China

5.1 Challenges facing potato harvesters in China

5.1.1 Lower mechanized harvesting rate of potatoes

China's vast potato cultivation areas span diverse terrains, including plains, mountains, and terraces, resulting in significant regional variations in mechanized harvesting rates. The southwestern mixed-cropping and southern winter-cropping regions, accounting for approximately 43% of China's total potato cultivation area, are predominantly hilly and mountainous. Meanwhile, the mechanized potato harvesting rate is less than 5% in these areas due to moist, sticky soil conditions. In hilly and mountainous regions of China, the application rate of potato harvesting equipment remains comparatively lower than that in plain areas.

Faced with diverse terrain conditions in hilly and mountainous areas, the working parameters of potato harvesting machinery requires frequent manual adjustment to accommodate varying field conditions. But parameter adjustment limitations lead to high potato loss rate, high skin damage rate, and high impurity rate[54].

Consequently, the low mechanization harvesting rate of potatoes in hilly and mountainous regions remains a critical bottleneck in China's potato harvesting sector, demanding urgent technological and equipment improvements.

5.1.2 Limitations in manufacturing precision of potato harvesters

There are still many practical bottleneck technologies in practical applications due to limitations in manufacturing capabilities and key components. The primary reason is that agricultural machinery manufacturers lack the financial capacity to invest in high-precision processing equipment and specialized high-performance materials, which entail prohibitively high costs[55]. Many Chinese agricultural machinery manufacturing enterprises suffer from outdated processing techniques, low production accuracy, sub-optimal material selection, and reliance on empirical design rather than data-driven optimization. As a result, key components often fail to meet expected performance standards, deviating significantly from theoretical models. Common operational issues include: 1) Poor wear resistance of digging shovels, leading to frequent replacements; 2) Excessive vibration in transmission systems, causing high failure rates; 3) Inefficient soil removal, increasing post-harvest cleaning efforts; 4) High mechanical impact during lifting, resulting in potato damage (e.g., skin breakage, bruising) due to collisions, free-fall drops, and rolling friction within the harvesting mechanism.

5.1.3 Lack of intelligent control systems

Current Chinese potato harvesters primarily employ fixed mechanical configurations with limited intelligent capabilities. These existing harvesters notably lack several advanced systems that are critical for modern agricultural operations, such as electro-hydraulic integrated control systems, environmental recognition systems, real-time parameter monitoring systems, and fault identification and diagnostic systems. These technological deficiencies result in significant functional limitations, such as: 1) The absence of environment recognition systems makes it impossible to identify the work environment in different regions and soil conditions[56]; 2) Without real-time parameter monitoring, operators cannot track the performance status of critical components during operation[57,58]; 3) Missing electro-hydraulic integrated control systems hinders smart decision-making and adaptive parameter adjustment of critical components[59]; 4) Missing fault recognition and diagnosis systems delays fault detection, reducing operational efficiency and increasing downtime. These limitations collectively result in poor machine adaptability to different field conditions, failure to meet versatile operational requirements for harvesting other root crops (e.g., sugar beets, onions), and low equipment utilization rates.

The fixed parameter design severely restricts the machines' functionality, making them unsuitable for diversified agricultural operations. This technological gap highlights the urgent need for more intelligent, adaptive harvesting systems in China's agricultural sector.

5.2 Development prospects of potato harvesters in China

5.2.1 Collaborate to develop multi-mode potato harvester

To bridge the gap of uneven development of potato harvesting mechanization in different regions, domestic agricultural machinery enterprises, research institutes, and universities should draw upon advanced technologies from developed countries[60]. In Europe and the USA, fully mechanized potato harvesting has been achieved across large fields and small plots. Meanwhile, countries like Japan and South Korea—where hilly and mountainous landscapes dominate—have excelled in developing and deploying small-to-medium-sized harvesting equipment, achieving high mechanization rates and advanced intelligent technologies[61]. To improve the balance of China's potato-harvesting mechanization, the following strategies are recommended: optimized harvesting technology should be introduced to hilly and mountainous regions, modifying potato-harvesting equipment to suit local terrain characteristics, ensuring operational efficiency and adaptability, and promote equitable mechanization rates across regions by tailoring solutions to varying topographic needs. By integrating global innovations with localized adaptations, China can achieve balanced and efficient potato harvesting mechanization nationwide.

5.2.2 Strengthen the manufacturing technology of agricultural machinery

To develop high-performance potato harvesting equipment characterized by low damage rates, minimal epidermis breakage, low impurity content, and high reliability, it is essential to optimize structural design, material selection, and manufacturing processes[62]. Key focus areas include: a) Conduct stress analysis to refine structural design and improve equipment durability, and enhance manufacturing precision of transmission mechanisms to minimize operational failures; b) Adopt advanced materials to increase structural strength and longevity; c) Investigate the formation mechanisms of potato collision damage during conveying and separation processes, and develop innovative buffer structures to mitigate impact and reduce potato damage rates; d) Study the separation dynamics of potatoes from soil and vines to identify optimal operational parameters, and optimize separation devices to maximize efficiency and minimize impurity retention[63]. By addressing these critical aspects, the development of next-generation potato harvesting equipment can achieve superior performance and operational reliability.

5.2.3 Enhancing potato harvester adaptability

Advancements in sensing technology, machine vision, AI models, information control systems, and new energy power drives present opportunities to integrate intelligent technologies into potato harvesters, addressing bottlenecks[64]. In terms of intelligent system, real-time monitoring & sensing, adaptive control decision-making, and eco-friendly power & mobility should be integrated into potato harvesters[65,66].

Many kinds of sensors including soil sensors, crop sensors, position sensors, speed sensors, and machine vision should be installed to monitor the work status, and machine vision should be used to identify impurity rate and damage rate of the mixture of potatoes, soil, and vines during potato harvesting[67-69]. To optimize the harvester performance, digging depth, conveying speed, and separation parameters should be dynamically adjusted based on real-time soil and crop conditions, and an automatic alignment system for precision digging should be applied, minimizing missed or incorrect digs when the harvester makes a U-turn at the end of the field[70,71]. Hybrid (diesel+electric) or pure electric drives should be supported to reduce emissions and develop eco-friendly agriculture[72,73]. Each wheel of the walking chassis should be driven by static hydraulic to achieve stepless speed regulation, and walk unobstructed in muddy fields[74]. In uneven environments, it also has the function of automatically adjusting the body posture[75,76].

5.2.4 Government departments should innovate mechanisms and establish special funds to overcome weak technologies

Under policies aimed at overcoming agricultural machinery shortcomings and promoting mechanization in hilly and mountainous regions, relevant government agencies should implement stronger supportive measures[77]. These supportive measures should increase research and development (R&D) funding to encourage collaboration among research institutions, enterprises, and producers to integrate industrial, academic, research, and practical applications[78,79]. Additionally, it is necessary to establish special funding projects, for example, research on mechanisms of reducing soil adhesion during potato digging, potato-soil-vines separation, and flexible conveying structure design in sticky, heavy soils[80,81]. Special funding should be allocated for improving potato variety to enhance the lignification of potato epidermis during harvest period. Special funding should also be allocated for leading agricultural machinery enterprises to design potato harvesters suited to hilly and mountainous terrain. Additionally, local agricultural extension services should intensify the promotion and training of mechanized potato cultivation and harvesting technologies, progressively refining the agricultural machinery and agrotechnical social service system.

6 Conclusions

Against the backdrop of rapid technological advancement and strong national support for sustainable agricultural mechanization, the market demand for potato harvesters continues to rise, along with increasingly stringent requirements for their operational performance.

This article systematically summarized the operational modes of mechanized potato harvesting, with a particular focus on reviewing the current research status in China regarding vines removal, potato digging, and transport-separation technologies and mechanisms in potato harvesters. It summarizes the functional characteristics of different harvesting methods and analyzes relevant foreign reference technologies and structural designs.

The key stages of mechanized potato harvesting—vines removal, digging, and transport-separation—play a critical role in overall efficiency. To address the prevalent issues of high breakage and damage rates in existing harvesters, this study conducts a comparative analysis of segmented harvesting technology and combined harvesting technology, evaluating the advantages and disadvantages of their respective mechanisms. Based on this analysis, the primary strategy proposed involves the ongoing development of higher-performance potato harvesters. This approach aims to reduce damage and skin breakage rates, enhance harvesting quality, and further advance the sustainable development of agricultural mechanization.

Acknowledgements

This project is funded by the 14th Five Year Plan National Key R&D Program Project (Grant No. 2024YFD2300301), the Jiangsu Province Education Science Planning Project (Grant No. B/2023/01/60), and the National Natural Science Foundation of China (Grant No. 32401691).

[References]

[1] Liao M, Qi Y J, Liu S Y, Obadi M, Xu B. Sandwich-type sheeting improved the processing and eating qualities of potato noodles. Journal of Texture Studies, 2020; 52(1): 81–90.
[2] Tunio M H, Gao J M, Shaikh S A, Lakhiar I A, Qureshi W A, Solangi K A, et al. Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security. Chilean Journal of Agricultural Research, 2020; 80(1): 118–132.
[3] Liang Z W, Wada M E. Development of cleaning systems for combine harvesters: A review. Biosystems Engineering, 2023; 236: 79–102.
[4] Ruan S Y, Wang L, Li Y L, Li P Y, Ren Y H, Gao R C, et al. Staple food and health: a comparative study of physiology and gut microbiota of mice fed with potato and traditional staple foods (corn, wheat and rice). Food & Function, 2021; 12(3): 1232–1240.
[5] Tang J Z, Wang J, Wang E L, Yu Q, Yin H, He D, et al. Identifying key meteorological factors to yield variation of potato and the optimal planting date in the agro-pastoral ecotone in North China. Agricultural and Forest Meteorology, 2018; 256: 283–291.
[6] Xu N, Zhang H L, Zhang R H, Xu Y K. Current Situation and Prospect of Potato Planting in China. China Potato Journal, 2021; 35(1): 81–96. (in Chinese).
[7] Zhou G M. China Agricultural Mechanization Yearbook. Beijing: China Agricultural Science and Technology Press. 2023; 340p. (in Chinese)
[8] Xie S S, Wang C G, Deng W G. Model for the prediction of potato impact damage depth. International Journal of Food Properties, 2018; 21(1): 2517–2526.
[9] Qingdao Hongzhu Agricultural Machinery Co., Ltd. Hongzhu 1JH-110 potato seedling killing machine. Available: https://hznyjx.nongji1688.com/sell/itemid-5472221.shtml. Accessed on [2025-05-25]. (in Chinese)
[10] Qingdao Hongzhu Agricultural Machinery Co., Ltd. Hongzhu 4U-160D new dynamic knife potato harvester. Available: https://hznyjx.nongji1688.com/sell/itemid-5472209.shtml. Accessed on [2025-02-25]. (in Chinese)
[11] Qingdao Hongzhu Agricultural Machinery Co., Ltd. Hongzhu 4U-170B potato harvester. Available: https://hznyjx.nongji1688.com/sell/itemid-5436129.shtml. Accessed on [2024-06-15]. (in Chinese)
[12] GRIMME. Product-We are experts in root and stem crop technology. Available: https://www.grimme.com/cn. Accessed on [2025-03-25]. (in Chinese)
[13] Liu C C, Wu F, Gu F W, Cao M Z, Yang H G, Shi L L, et al. Recent research progress on key technologies and equipment for mechanized potato harvesting. Agriculture-Basel, 2025; 15(7): 675.
[14] Sun J B, Li X Q, Wang X Y. Optimization design and analysis of potato seedling cutter. Journal of Agricultural Mechanization Research, 2017; 39(7): 83–88. (in Chinese)
[15] Transce. 4JM-360B. Available: http://www.xs-tc.com/en/html/malingshushayangjixilie/2017/0102/44.html. Accessed on [2025-05-25].
[16] Peng H T, Zuo Z Y, Ma G X, Han L H, Liu ., Mao H P. Design and experiment of a ridge-surface based cutting height active adjustment system for a leafy vegetable harvester. Biosystems Engineering, 2025; 257. doi: 10.1016/j.biosystemseng.2025.104196.
[17] Wang G Q, Li Z Y, Jia W D, Ou M X, Dong X, Zhang Z J. A review on the evolution of air-assisted spraying in orchards and the associated leaf motion during spraying. Agriculture-Basel, 2025; 15(9): 964.
[18] MENOBLE. 1804 potato seedling killing machine. Available: http://www.menoble.com/productinfo/862405.html. Accessed on [2025-05-25]. (in Chinese)
[19] Yan K H, Yao S, Huang Y C, Zhao Zhan. Study on Pulling Dynamic Characteristics of White Radish and the Optimal Design of a Harvesting Device. Agriculture, 2023; 13(5): 942.
[20] Qian P F, He Q, Tang Z, Gu T W. Biomimetic structural design for reducing the adhesion between wet rice leaves and metal surfaces. Agriculture, 2025; 15(9). doi: 10.3390/agriculture15090921.
[21] Wang H C, Zhao W Y, Sun W, Zhang H, Liu X L, Li H. Research progress on the technology and equipment for potato mechanized harvesting. Transactions of the Chinese Society of Agricultural Engineering, 2023; 39(14): 1–22. (in Chinese)
[22] Lv J Q, Tian Z E, Wu J E, Yang Y, Shang Q Q, Wang Y B, et al. Design and experiment on 4U1Z vibrating potato digger. Transactions of the Chinese Society of Agricultural Engineering, 2015; 31(12): 39–47. (in Chinese)
[23] Guan C S, Fu J J, Xu L, Jiang X Z, Wang S L, Cui Z C. Study on the reduction of soil adhesion and tillage force of bionic cutter teeth in secondary soil crushing. Biosystems Engineering, 2022; 213(38): 133–147.
[24] Cao Y L, Yu Y, Tang Z, Zhao Y F, Gu X Y, Liu S F, et al. Multi-tooth cutting method and bionic cutter design for broccoli xylem (Brassica oleracea L var. Italica Plenck). Agriculture-Basel, 2023; 13(6): 1267.
[25] Zhang Y, Qiao C X, Wang T Q, Cao J F, Wang P F, Shi L. Drag reduction mechanism of the 3D geometry of foreleg’s claw toe of the mole cricket (Gryllotalpa orientalis). Transactions of the Chinese Society of Agricultural Engineering, 2021; 37(19): 309–315. (in Chinese)
[26] Lin S B, Sun H Y, Yan G G, Que K X, Xu S J, Tang Z, et al. Structural design and analysis of bionic shovel based on the geometry of mole cricket forefoot. Agriculture-Basel, 2025; 15(8): 854.
[27] Li J W, Li X Y, Hu B, Gu T L, Wang Z J, Wang H L. Analysis of the

resistance reduction mechanism of potato bionic digging shovels in clay and heavy soil conditions. Computers and Electronics in Agriculture, 2023; 214: 108315.

[28] Issa I I M, Zhang Z G, ElKolaly W, Wang F A, Wang Y. Innovated design, simulation and evaluation of potato harvester excavation and separation conveyors. Int J Agric & Biol Eng, 2025; 18(2): 132–145.

[29] Zhang Z G, Xue H T, Wang Y C, Jie K T, Deng Y X. Design and experiment of panax notoginseng bionic excavating shovel based on EDEM. Transactions of the Chinese Society for Agricultural Machinery, 2022; 53(5): 100–111. (in Chinese)

[30] Wei Z C, Li H W, Mao Y J, Sun C Z, Li X Q, Liu W Z, et al. Experiment and analysis of potato-soil separation based on impact recording technology. Int J Agric & Biol Eng, 2019; 12(5): 71–80.

[31] Feng B, Sun W, Shi L R, Sun B G, Zhang T, Wu J M. Determination of restitution coefficient of potato tubers collision in harvest and analysis of its influence factors. Transactions of the Chinese Society of Agricultural Engineering, 2017; 33(13): 50–57. (in Chinese).

[32] Ma Z, Liu C, Zhang J Q, Wang S, Li Y M. Study on blockage monitoring of differential-speed roller potato-soil separation device. Computers and Electronics in Agriculture, 2025; 236: 110424.

[33] Ministry of Agriculture of the People's Republic of China. NY/T 648-2015 Technical specification of quality evaluation for potato harvesters. Beijing: China Agriculture Press, 2015.

[34] Zhang Z G, Wang H Y, Li Y B, Yang X, Issa I, Zhang Z D. Design and experiment of multi-stage separation buffer potato harvester. Transactions of the Chinese Society for Agricultural Machinery, 2021; 52(2): 96–109. (in Chinese).

[35] Lv J Q, Sun H, Dui H, Peng M M, Yu J Y. Design and experiment on conveyor separation device of potato digger under heavy soil condition. Transactions of the Chinese Society for Agricultural Machinery, 2017; 48(11): 146–155. (in Chinese)

[36] Chen M D, Liu X T, Hu P X, Zhai X T, Han Z L, Zhu, W J, et al. Study on rotor vibration potato-soil separation device for potato harvester using DEM-MBD coupling simulation. Computers and Electronics in Agriculture, 2024; 218: 108638.

[37] Ma Z, Zhang Z L, Zhang Z H, Song Z Q, Liu Y B, Li Y M, et al. Durable testing and analysis of a cleaning sieve based on vibration and strain signals. Agriculture-Basel, 2023; 13(12): 2232.

[38] Liang Z W, Huang Y, Li D P, Wada M E. Parameter determination of a viscoelastic–plastic contact model for potatoes during transient collisions. Biosystems Engineering, 2023; 234: 156–171.

[39] Yang R B, Yang H G, Shang S Q, Ni Z W, Liu Z S, Guo D. Design and experiment of vertical circular separating and conveying device for potato combine harvester. Transactions of the Chinese Society of Agricultural Engineering, 2018; 34(3): 10–18.

[40] Yang R B, Yang H G, Shang S Q, Xu P X, Cui G P, Liu L H. Design and test of poking roller shoving type potato harvester. Transactions of the Chinese Society for Agricultural Machinery. 2016; 47, 119–126. (in Chinese)

[41] Peng J W, Wang Y M, Peng B L, Xue G Y, Hu L L, Wang G P. Research status and prospects of sweet potato harvesters' conveying and separation mechanisms. Sustainability, 2024; 16(24): 10957.

[42] Wang P R. Analysis and experiment of potato harvester potato-stem separation equipment. Master dissertation. Harbin: Northeast Agricultural University, 2020; 6: 70p.

[43] Wang H C, Zhao W Y, Sun W, Liu X L, Shi R J, Zhang H, et al. The design and experimentation of a wheeled-chassis potato combine harvester with integrated bagging and ton bag-lifting systems. Agriculture-Basel, 2024; 14(9): 1461.

[44] Li Y B. Design and experiment of hand-held self-propelled potato harvester. Master dissertation. Kunming: Kunming University of Scienceand Technology, 2023; 3: 114p. (in Chinese)

[45] GRIMME. Simple harvester WH 200. Available: https://products.grimme.com/cn/p/wh-200. Accessed on [2025-02-25]. (in Chinese)

[46] Wei H A, Zhang J L, Yang X P, Huang X P, Dai L X, Sun G H, et al. Improved design and test of 4UFD-1400 type potato combine harvester. Transactions of the Chinese Society of Agricultural Engineering, 2014; 30(3): 12–17. (in Chinese)

[47] Cui L F, Xue X Y, Le F X, Mao H P, Ding S M. Design and experiment of electro hydraulic active suspension for controlling the rolling motion of spray boom. Int J Agric & Biol Eng, 2019; 12(4): 72–81.

[48] Transce. 4ULZ-170. Available: http://www.xs-tc.com/malingshushouhuoji/xinghao-4ULZ-170_150.html. Accessed on [2025-02-25]. (in Chinese)

[49] DEWO. 4UML-180 potato combine harvester. Available: http://www.dewojituan.com/index/draw_details/type_id/11/id/188.html. Accessed on [2025-02-25]. (in Chinese)

[50] MENOBLE. 1710B potato (beet) combine harvester. Available: http://www.menoble.com/productinfo/862400.html. Accessed on [2025-01-25]. (in Chinese)

[51] Wang H Y. Mountain self-propelled potato combine harvester design and experiment. Master dissertation. Kunming: Kunming University of Science and Technology, 2021. 146p. (in Chinese)

[52] GRIMME. Potato Equipment | Grime GRIMME Products. Available: https://products.grimme.com/cn/o/kartoffeltechnik. Accessed on [2025-05-25]. (in Chinese)

[53] Dou Q Q, Sun Y J, Sun Y T, Shen J X, Li Q L. Current situation and development of potato harvesting machinery at home and abroad. Journal of Chinese Agricultural Mechanization, 2019; 40(9): 206–210. (in Chinese)

[54] Hu Y F, Tang Z, Wang S G, Li B, Guo X H, Chen S R. The influence of the distribution law and uniformity of a threshed mixture with the working parameters of a soybean threshing device. Agronomy, 2024; 14(7): 1581.

[55] Ingallina C, Spano M, Sobolev A P, Esposito C, Santarcangelo C, Baldi A, et al. Characterization of local products for their industrial use: The case of Italian potato cultivars analyzed by untargeted and targeted methodologies. Food, 2020; 9(9): 1216.

[56] Jia W D, Tai K L, Dong X, Ou M X, Wang X W. Design of and experimentation on an intelligent intra-row obstacle avoidance and weeding machine for orchards. Agriculture, 2025; 15(9): 947.

[57] Lu E, Ma Z, Li Y M, Xu L Z, Tang Z. Adaptive backstepping control of tracked robot running trajectory based on real-time slip parameter estimation. Int J Agric & Biol Eng, 2020; 13(4): 178–187.

[58] Li Y, Xu L Z, Lv L Y, Shi Y, Yu X. Study on modeling method of a multi-parameter control system for threshing and cleaning devices in the grain combine harvester. Agriculture, 2022; 12(9): 1483.

[59] Cui L F, Xue X Y, Le F X, Mao H P, Ding S M. Design and experiment of electro hydraulic active suspension for controlling the rolling motion of spray boom. Int J Agric & Biol Eng, 2019; 12(4): 72–81.

[60] Taha M F, Mao H P, Zhang Z, Elmasry G, Awad M A, Abdalla A, et al. Emerging technologies for precision crop management towards agriculture 5. 0: A comprehensive overview. Agricultur, 2025; 15(6): 582.

[61] Wang H J, Gu J A, Wang M N. A review on the application of computer vision and machine learning in the tea industry. Frontiers in Sustainable Food Systems, 2023; 7: 1172543.

[62] Ji K Z, Li Y M, Liang Z W, Liu Y B, Cheng J H, Wang H H, et al. Device and method suitable for matching and adjusting reel speed and forward speed of multi-crop harvesting. Agriculture-Basel, 2022; 12(2): 213.

[63] Zhou M L, Shan Y Y, Xue X L, Yin D Q. Theoretical analysis and development of a mechanism with punching device for transplanting potted vegetable seedlings. Int J Agric & Biol Eng, 2020; 13(4): 85–92.

[64] Zhao J M Y, Fan S X, Zhang B H, Wang A C, Zhang L Y, Zhu Q Z. Research status and development trends of deep reinforcement learning in the intelligent transformation of agricultural machinery. Agriculture, 2025; 15(11): 1223.

[65] Zhu X Y, Chikangaise P, Shi W D, Chen W H, Yuan S Q. Review of intelligent sprinkler irrigation technologies for remote autonomous system. Int J Agric & Biol Eng, 2018; 11(1): 23–30.

[66] Jiang L, Xu B Y, Husnain N, Wang Q. Overview of agricultural machinery automation technology for sustainable agriculture. Agronomy, 2025; 15(6): 1471.

[67] Liu W, Hu J P, Liu J X, Yue R C, Zhang T F, Yao M J, et al. Method for the navigation line recognition of the ridge without crops via machine vision. Int J Agric & Biol Eng, 2024; 17(2): 230–239.

[68] Lin J L, Cai J P, Xiao L P, Liu K, Chen J, Ma J, et al. An angle correction method based on the influence of angle and travel speed on deposition in the air-assisted spray. Crop Protection, 2023; 175: 106444.

[69] Jin M Z, Zhao Z, Chen S R, Chen J Y. Improved piezoelectric grain cleaning loss sensor based on adaptive neuro-fuzzy inference system. Precision Agriculture, 2022; 23(4): 1174–1188.

[70] Yu L M, Gao W L, Shamshiri R R, Tao S, Ren Y Z, Zhang Y J, et al. Review of research progress on soil moisture sensor technology. Int J Agric & Biol Eng, 2021; 14(4): 32–42.

[71] Zheng K, Zhao X G, Han C J, He Y K, Zhai C Y, Zhao C J. Design and experiment of an automatic row-oriented spraying system based on

machine vision for early-stage maize corps. Agriculture-Basel, 2023; 13(3): 691.

[72] Zhu Z H, Chai X Y, Xu L Z, Quan L, Yuan C C, Tian S C. Design and performance of a distributed electric drive system for a series hybrid electric combine harvester. Biosystems Engineering, 2023; 236: 160–174.

[73] Qian Y, Quan L. Cooperative control strategy of multi-component speed of distributed electric drive combine harvester. Applied Engineering in Agriculture, 2025; 41(2): 205–215.

[74] Liu H, Yan S C, Shen Y, Li C H, Zhang Y F, Hussain F. Model predictive control system based on direct yaw moment control for 4WID self-steering agriculture vehicle. Int J Agric & Biol Eng, 2021; 14(2): 175–181.

[75] Luo Y S, Wei L L, Xu L Z, Zhang Q, Liu J Y, Cai Q B, et al. Stereo-vision-based multi-crop harvesting edge detection for precise automatic steering of combine harvester. Biosystems Engineering, 2022; 215: 115–128.

[76] Jiang Y Y, Wang R C, Ding R K, Sun Z Y, Jiang Y, Liu W. Research review of agricultural machinery power chassis in hilly and mountainous areas. Agriculture, 2025; 15(11): 1158.

[77] Li H B, Chen L W, Zhang Z Y. A study on the utilization rate and influencing factors of small agricultural machinery: evidence from 10 hilly and mountainous provinces in China. Agriculture, 2023; 13(1): 51.

[78] Zhang Z G, Li Y B, Wang H Y, Zhang Z D, Liu X C. Research progress on key technology and equipment of potato mechanized harvest. Journal of Yunnan Agricultural University (Natural Science), 2021; 36(6): 1092–1103. (in Chinese)

[79] Song X Q, Yu X J, Zhou C S, Xu B G, Chen L, Yagoub A E A, et al. Conveyor belt catalytic infrared as a novel apparatus for blanching processing applied to sweet potatoes in the industrial scale. Lwt-Food Science And Technology, 2021; 149: 111827.

[80] Fang W Q, Wang X Z, Han D L, Ohiemi I E. Design and testing of film picking-unloading device of tillage residual film recycling machine based on DEM parameter calibration. Agronomy, 2025; 15(4):955.

[81] Qian P F, He Q, Tang Z, Gu T W. Biomimetic structural design for reducing the adhesion between wet rice leaves and metal surfaces. Agriculture, 2025; 15(9): 921.