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2026 Volume 4, Issue 1
Lecture Notes in Education, Arts, Management and Social Science
ISSN(Online): 2705-053X

Design and Simulation of Potato Digging and Collecting Machine

Xiao Liu[1], Kailiang Zhang[2], Zihan Liao[1], Xin Niu[1], Zongming Liu[1], Baijin Xu[1]

[1]Gansu Construction Vocational and Technical College, School of Intelligent Manufacturing, Lanzhou 730050, Gansu, China

[2]Tianshui Great Wall Switch Factory Group Co., Ltd., Gansu, Tianshui 741300, Gansu, China

Abstract: To address the challenges of high labor costs and physical strain in small-scale potato harvesting in Gansu's Longzhong hilly regions, and to address the shortage of young and able-bodied agricultural labor, this study proposes a bionic-inspired self-propelled multifunctional potato harvester. The innovative design integrates digging, conveying, separating, and potato collection mechanisms, significantly enhancing mechanization efficiency in potato harvesting.

Keywords: Hilly mountainous area; Potato harvesting; Mechanical design; Simulation study

Online publication: January 26, 2026

1. Introduction

The potato, also known as a tuber, has special effects such as invigorating qi, strengthening the spleen, detoxifying, and reducing swelling. Due to its wide range of uses, short growth cycle, high yield, strong environmental adaptability, great potential for deep processing, and rich content of trace elements, it has become the world's fourth major staple crop [1]. The extremely favorable soil and climate conditions in Gansu Province are very suitable for the development of the potato industry. Dingxi City in Gansu Province is even known as the "Hometown of China Potatoes." By 2023, the potato planting area in Gansu Province was approximately 4.67×10^5 mu, with a total output of 8.75×10^5 tons and a total output value of about 3.45×10^6 yuan. Compared to the previous year, the planting area and total output increased by 5.9% and 2.1%, respectively [2]. With the support of relevant documents such as the "Gansu Provincial Regulations on the Cultivation and Management of Gansu Flavor Agricultural Products Brands" and the "2024 Gansu Province Implementation Plan for the Six Major Characteristic Industries of Cattle, Sheep, Vegetables, Fruits, Potatoes, and Medicinal Plants", the potato industry in Gansu Province has achieved significant development, which greatly promotes the economic development of farmers and rural revitalization in Gansu Province. Potato harvesting accounts for over half of the total workload and remains the weakest link in the mechanization process [3–4]. In Gansu's Longzhong region, the terrain is predominantly hilly and mountainous with narrow, rugged mountain roads and small plots, making it impossible for large machinery to operate underground. This results in manual digging for potato harvesting, which is labor-intensive and inefficient. Existing potato harvesters can only dig potatoes and then collect and spread them, requiring manual follow-up to pick up the harvest. The low level of mechanization has not fully liberated labor. Therefore, designing a harvesting machine that integrates potato

digging and harvesting functions is particularly necessary.

2. Development of the potato harvester

In recent years, international research on potato harvesters has focused on two major developments. Germany's GRIMME, the world's largest potato harvester manufacturer, has developed the SE series of hopper-type and boom-type harvesters. These large-scale combine harvesters integrate intelligent automation with smart auxiliary systems, including intelligent screen speed matching, boom torque control, smart video monitoring, real-time potato unloading positioning, and human-machine interaction. They feature functions such as real-time depth adjustment of digging shovels, intelligent tray driving, multi-stage debris separation, and potato-soil transfer [5–7]. Belgium's AVR company produces the Puma4 self-propelled combine harvester and Spirit9200 tractor-type potato harvester, both of which are large-scale and fully functional, capable of completing multiple operations, including digging, conveying, harvesting, and grading in a single pass. OLT et al. [8–9]. designed a potato harvester that first vibrates and separates soil-potato mixtures, then discharges fine soil through screen gaps, directing potatoes via rubber diverters to separate them into two streams for harvesting. BULGAKOV et al. developed a potato-digging and separation device that achieves simultaneous digging and potato-soil separation, improving the rate of bare potatoes and reducing skin breakage [10]. In recent years, the large-scale application in China has mainly been the potato harvester developed and manufactured by Qingdao Hongzhu Agricultural Machinery Co., Ltd., and in collaboration with the Agricultural Machinery Research Institute of China Tropical Agricultural Sciences Academy, the 4UMZ-1400 type post-collecting cassava combine harvester was developed [11]. Based on this, this paper addresses the current situation of low mechanization level and high manual labor intensity in potato harvesting in the Longzhong region of Gansu Province. Combining the design requirements of potato harvesters, a potato-digging and harvesting integrated machine was designed to provide a new idea and solution for improving the mechanization level of potato harvesting in the Longzhong region of Gansu Province and reducing manual labor intensity.

3. Overall structure and working principle

3.1. Overall structure

The potato-digging and harvesting integrated machine comprises a digging shovel, soil-cutting disc, three-point suspension traction frame, frame, support shaft, soil-shaking frame, rubber wheels, traction holes, potato-harvesting frame, push-pull plate, support wheels, depth-limiting wheels, driven shaft, closed soil-sifting chain, gearbox, and spline shaft [12]. Its overall structure is shown in **Figure 1**, with key technical parameters detailed in **Table 1**.

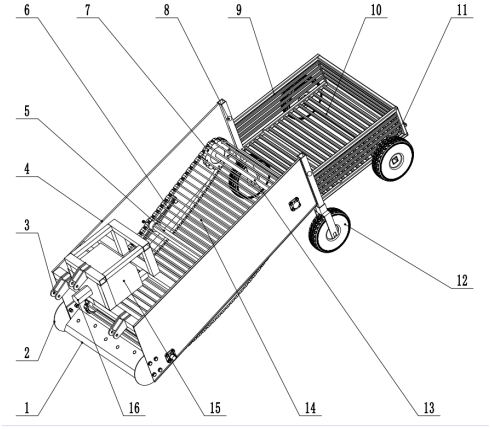

Figure 1. Schematic diagram of the overall structure. Note: 1. Excavation shovel; 2. Cutting disc; 3. Three-point suspension drawbar; 4. Frame; 5. Support shaft; 6. Soil shaking frame; 7. Rubber wheel; 8. Traction hole; 9. Potato collection frame; 10. Lower push-pull plate; 11. Support wheel; 12. Depth-limiting wheel; 13. Driven shaft; 14. Closed soil screening chain; 15. Gearbox; 16. spline shaft

Table 1. Main technical parameters of potato digging and harvesting integrated machine

Project name	Parameter values
Rack dimensions (length × width)/mm	2500×1000
Potato frame dimensions (length×width×height)/mm	1000×1000×400
Job width/mm	900
Excavating depth/mm	250
Number of rows/row	1

3.2. Working principle

During operation, the machine is suspended from the tractor's rear via a three-point suspension system. The tractor provides traction to drive the digging blade for potato tuber extraction and the side-cutting disc for soil slicing. Meanwhile, the tractor's rear output shaft transmits power to the spline shaft through a coupling. The spline shaft then reduces speed, increases torque, and changes direction via a gearbox before transmitting power to the drive shaft through a transmission chain. The drive shaft drives the driven shaft to perform closed rotary motion via a closed soil screening chain, enabling backward potato tuber conveyance and tuber-soil separation. The excavated potatoes then fall into a collection frame due to inertia. When the frame is full, the tractor stops, and the push plate is retracted to allow the potatoes to fall into a collection pile for manual picking or loader loading [13].

4. Design of key components

4.1. Optimization design of excavator structure

The digging shovel, positioned at the front of the potato harvester, is designed to excavate the soil-mud mixture and convey it to the closed screening chain, primarily responsible for withstanding soil resistance [14]. Its structural design is determined by factors such as dimensions, soil characteristics, machine speed, and potato planting patterns. Current types of digging shovels include flat, curved, and forked tooth designs. As shown in **Table 2**, the characteristics of these different types are summarized below.

Table 2. Comparison of excavator shape characteristics

Digger blade	Type	Merit	Shortcoming
Planar plane	Flat shovel, U-shaped shovel, V-shaped shovel, W-shaped shovel	The feeding amount is uniform and the inclination angle of the shovel face has little effect on the variation of the potato quantity.	The crushed soil exhibits average performance and poor adaptability to heavy clay soils; it tends to entangle weeds and demonstrates suboptimal soil cleaning efficacy.
Curved shovel	Convex surface, Concave surface	The crushed soil exhibits excellent properties and good penetration performance.	The manufacturing process is complex and costly; the shovel surface is prone to wear, resulting in high maintenance expenses; the operational efficiency is slightly lower when working on light soils.
Forked shovel	Grating shovel, Wide tooth shovel	Low soil penetration resistance, suitable for deep-layer operations; reduced soil-to-tooth contact area, minimizing grass entanglement and adhesion; excellent soil clearance performance.	Poor strength, Prone to fracture

4.2. Co-design of potato soil separation and potato collection device

The synergistic performance of the potato-soil separation and potato collection device is crucial for enhancing harvester efficiency and reducing manual intervention. Therefore, during the design of the integrated potato digging and collection machine, a two-stage separation structure combining “closed soil screening chain + soil shaking frame” can be introduced to effectively establish a coordinated operational system. Firstly, the closed soil screening chain serves as the core component of the primary separation stage. Its chain segments can be constructed using a rubber material combined with a metal frame, with anti-slip protrusions designed on the rubber surface. This design not only reduces damage from potato block collisions during transportation but also enhances soil scraping efficiency. Specifically, the screen holes can be designed as 25mm×25mm diamond-shaped openings. Compared to circular holes, this configuration enables dynamic screening during transportation. When the chain experiences high-frequency vibrations, it accelerates the breaking and detachment of adhered soil. During this phase, the chain’s operational speed is synchronized by the gearbox and tractor’s power, achieving efficient potato-soil separation.

Secondly, the shaking frame functions as the secondary separation mechanism in the potato digging and harvesting integrated machine. Positioned below the closed soil screening chain, it performs soil separation through shaft-driven transmission. The frame’s vibration direction forms a 30-degree angle with the screening chain’s conveying path, creating a compound motion trajectory. This design effectively dislodges fine soil particles adhering to potato tubers, ensuring optimal separation purity and enhancing the yield of clean potatoes.

Thirdly, the potato collection device employs an inclined frame design with a 12-degree tilt angle. The inner walls are lined with rubber padding (preferably Shore A60) to prevent impact damage during potato drop, while the tilt angle facilitates automated stacking. The structure can be optimized through hydraulic control of the collection frame and lower sliding plate, with the side-opening sliding plate configuration being the optimal design. Hydraulic valves precisely regulate mechanical operation, potentially achieving a 30% improvement in separation efficiency compared to traditional equipment, thereby enhancing potato stacking performance [15].

5. Conclusion

The potato harvesting and collection machine designed for small plots in Gansu’s Longzhong hilly region holds significant value. Featuring four core functions—digging, conveying, separating tubers from soil, and collecting—this equipment effectively addresses the poor compatibility of existing harvesters and the inefficiencies of manual harvesting. Its compact design allows tractor-mounted suspension operation, solving the problem of large machinery being unable to access underground areas and small machines requiring manual retrieval. This innovation not only boosts planting efficiency in local narrow and rugged terrain but also ensures stable crop yields.

Critical Components Design: The equipment’s design aligns with operational requirements, featuring optimized shovel selection and angle configuration to ensure robust soil penetration. Its closed screening chain that efficiently separates tuber soil. The integrated tuber frame and sliding plate structure delivers superior performance, streamlining the harvesting process. This system completes excavation and tuber collection in a single operation, reducing manual labor intensity and significantly improving crop harvesting efficiency.

The all-in-one machine design balances practicality and cost-effectiveness, featuring low manufacturing costs and user-friendly operation. Its multifaceted advantages align with the needs of farmers and small-scale growers in Gansu’s Longzhong region. Future improvements will involve optimizing device performance through adjustable mounting parameters, guided by simulation analysis and field trials. These enhancements aim to significantly reduce tuber breakage rates, improve operational stability, and drive comprehensive upgrades in equipment models, ultimately promoting high-quality development of Gansu’s potato industry.

Funding

1. Gansu Provincial University Teachers' Innovation Fund Project 2026 "Design and Research of 'Gan Flavor' Characteristic Rhizome Crop Harvesters" (Project No.: 2026A-348);
2. Gansu Construction Vocational and Technical College 2025 School-Level Research Project "Design and Research of Potato Digging and Harvesting Integrated Machines Based on Bionics" (Project No.: 2025KY-1).

Disclosure statement

The authors declare no conflict of interest.

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