

# **Agronomic techniques and mechanized harvesting techniques for yams Status and countermeasures**

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## **ABSTRACT**

Yams are increasingly recognized for their good health benefits as people increasingly focus on healthy eating and wholesome eating. However, the high cost of yam cultivation and harvesting, as well as the limited level of mechanization, severely restricted the development of the industry. For this deep rhizomatous, brittle, and breakable yam crop, mechanized harvesting is prone to breakage, skin breakage, and low damage rates to the intact crop. In this paper, we have analyzed the characteristics of yam, the current situation of the yam economy in China, the development of mechanized techniques for yam harvesting at home and abroad, and the constraints. In addition, the development of casing yam cultivation techniques and mechanization of harvest is also promising. It mainly introduced plowshare furrow openers, disc furrow openers, spiral furrow openers and chain furrow openers, double-row chain yam planting and harvesting machines, spiral yam harvesting and planting machines, fully hydraulically suspended single-row yam harvesters and vibrating yam harvesters.

*Keywords: Yam, characteristics, agronomy, mechanized harvesting, casing cultivation*

## **1. INTRODUCTION**

Yam was one of the first plants consumed by humans. As early as in the Tang Dynasty, the poet Du Fu had the famous line of "filling the intestines with yams". Yam tubers contain amylase, polyphenol oxidase and other beneficial substances, which promote the body to secrete interferon and enhance immunity, and are known as "underground ginseng". Yams and their processed products, which are rich in various vitamins and have both food and medicinal uses, have become popular in recent years as people's living standards have continued to rise [1]. Worldwide, yams are mainly found in South Korea, Japan, and China. Yam has a long history of cultivation in China and is grown in a wide range and large area.

However, in major growing regions of China, the peculiar characteristics of yam tubers and the non-uniform planting depth and row spacing have resulted in mechanized planting still not being the norm, and most planting methods are manual. Yam harvesting is based on manual digging or excavator-side trenching to assist manual harvesting. These two harvesting methods have problems such as high labor intensity, low efficiency, high cost and low harvesting integrity, which significantly reduce the economic benefits of yam cultivation and seriously affect farmers' planting enthusiasm and severely restrict the development of yam industry [2-3].

## 2. STUDY OF YAM CHARACTERISTICS

Yam tubers are deeply buried in the soil, and the roots are widely distributed around the tubers, resulting in a complex bond between the tubers and the soil. This bonding relationship is an important reason for the difficulty in harvesting yams. To solve the problem of tuber-soil separation during yam harvesting, it is necessary to understand the physical properties of yam tubers themselves, soil properties and the bonding relationship between yam tubers and soil, and then harvest yam tubers through a reasonable soil-root separation method [4]. With improved computer performance and the development of numerical simulation theory and software, there has been a growing number of studies analyzing soil-root interactions using numerical simulation software. An automated spinach harvester was developed by Naoto Takayama. A harvesting concept with a cutting blade that propagates automatically through the soil is used to plan the path in advance and reduce variations in blade motion in the vertical direction. Automated harvesting can be done without gripping or clamping during crop harvesting. However, this method is not suitable for harvesting deep-rooted crops. Gao et al. [5] modeled the root-soil complex of greenhouse vegetables, but they modeled the root as a rigid body with no bond between the root and the soil. Yuan Jin et al. [6] developed a discrete element simulation model of spinach root-soil composites and calibrated the binding parameters between the root systems but did not consider the influence of the root systems on spinach. Li Jinguang et al. [7] used the discrete element method to model asparagus and citrus fruit stalks, demonstrating the feasibility of using DEM to model rootstocks. Long Sifang et al. [2] established a yam-sand loam discrete element simulation model and conducted a simulation experiment to analyze the operational parameters during yam harvesting. The vibrational frequencies and amplitudes were obtained for the

lowest yam break rate and the highest sandy loam break rate.

The study of the rootstock properties of yams is essential for mechanized seeding and harvesting to reduce damage during harvesting. The study of its own bending resistance, compressive resistance, and other mechanical properties plays a key role in the mechanical excavation and harvesting process. Cao Shaobo [9] et al. used the HY-0580 microcomputer electronic universal mechanical testing machine produced by Shanghai Hengyi Precision Instruments Co. The tensile strength, flexural strength and compressive strength of hemp yam rhizomes in tension have been studied using traditional methods for testing engineered materials. Tests have shown that hemp-yam rhizomes have relatively poor tensile strength, are most susceptible to compressive crushing, and have high bending strength and durability. Therefore, during mechanical acceptance, the tensile and compressive forces on the hemp rhizome should be minimized to reduce the breakage rate. However, the test did not take into account the effect of the moisture content of the yam, the size of the diameter and other factors. Liu Guohua [10] et al. used the ETM series B small desktop microcomputer-controlled electronic universal testing machine from Shenzhen Wanxiao Testing Equipment Co. The effects of three factors, namely, the diameter of the yam, the moisture content, and the loading speed, on the tensile, crushing, and fracture forces to which they are subjected, were investigated by means of single-factor and orthogonal tests, respectively, and the significance of the influencing factors was analyzed. Tests have shown that yams have the strongest flexural strength, the second strongest compressive strength and the weakest tensile strength. Therefore, when designing a yam collector, it should minimize the effect of the axial tensile force it receives to reduce yam breakage.

### 3. AGRONOMIC ANALYSIS OF YAM

Yam sowing and harvesting is a diverse and complex planting pattern and sowing process compared to dwarf root crops. Yam rhizomes are long and brittle, prone to injury and breaking when harvested, and these factors determine the difficulty of mechanized sowing and harvesting of yams. It is therefore important to start paving the way for mechanized harvesting from cultivation.

There are various varieties of cultivated yams in China. This is based on the fact that yam is a deep underground root crop, combined with the time-consuming and labor-intensive nature of the yam planting and digging process. The invention of Wang Yaoqin et al. [11-12] discloses an agronomic-agricultural-mechanical combination of a minimalist cultivation method. By mechanical drilling, fill is added to the hole to prevent soil collapse. This method expands the expansion space of the yam tubers and reduces the area of contact between the tubers and the soil. It separates the mature tubers from the soil so that they can be separated quickly without breaking during mechanical harvesting. The cultivation model was subjected to a series of field trials on yam cultivation density, perforation depth, irrigation volume, and fertilization methods. Tests have shown that rice husks have some ability to absorb and retain water. It provides water to the root system at the same time, is more suitable as a filler, and saves cost and efficiency. However, this cultivation method is still not fully mechanized and highly simplified, and further research is needed.

Yam cultivation is more efficient, but the labor input in sowing and harvesting yams is enormous, and the yams are crooked, forked, and poorly commercialized. This is the main reason why it is difficult to expand the area under yam cultivation. The use of casing for cultivation of yam has been reported more frequently [13-15]. Casing allows the yam tubers to grow and develop in a certain location, producing thick, straight yams that are easy to harvest and do not

damage the yam. This has contributed to the change of yam cultivation technology to be more economical, labor-saving and modern [16]. However, mechanized cultivation techniques for sowing yams have not been reported. As a result, the implementation of mechanized yam cultivation and harvesting has become an inevitable trend.

### 4. DOMESTIC AND INTERNATIONAL RESEARCH, DEVELOPMENT AND TECHNOLOGY

#### 4.1 Exotic yam harvesting techniques and status of research

The main countries and regions in the world where yam cultivation is practiced are China, Korea, Japan, etc. Countries in Europe and the Americas began early to develop harvesting machines for root crops, and mechanized harvesting of a wide variety of root crops has been achieved. Such as potatoes, sugar beets, garlic, ginseng and other cash crops mechanized harvesting [17]. Among them, the mechanized ginseng harvesting in Korea represents the highest level in the world and has been mechanized from sowing to transplanting, irrigation, and harvesting [18]. Ginseng harvesting machines have also been improved according to the characteristics of the yam, and the whole process of yam harvesting has been largely mechanized. Foreign short rootstock harvesting machines mainly use the clamping process, the principle of vibration separation, to clamp the crop from the ground for shearing. These harvesters are affected by the plant spacing row spacing, and the clamping device is not effective when the soil is hard, and it is easy to break the crop and affect the harvesting rate [19]. In West Africa, Bosrotsi et al [20] used the finite element method to simulate and optimize the blades of yam harvesters, but failed to solve the problem of high damage rate of hemp yam during harvesting. A successful small root crop harvester was developed in Japan in the 1860s - the dig-and-pull cassava harvester. Developed according to the

biological and physical characteristics of cassava, it can simultaneously perform excavation, transportation, and separation of tubers, and the digging shovel, gripper, and separator are important components of the cassava harvester [21]. In the early 21st century, Isaac N Itodo et al [22,23] evaluated the performance of a yam harvester mounted on a tractor. The effects of cutting depth, lifting angle, and forward speed on the number of tubers lifted, the number of exposed yams, the number of damaged yams, and the number of yams delivered to the collection unit were investigated using ANOVA to evaluate the harvester. Field experiments have shown that speed and lifting angle affect damage to yam tubers. Harvesters operating at a speed of 3.2 km/h with a depth of 46 cm and lifting angles of 20° and 22.5° caused the least damage to tubers [24-26].

There has also been some research into mechanizing yam harvesting in Japan. In the early 2000s, mechanized harvesting of yams in Japan also began to mature, with the entire process from planting-cultivation-harvesting being mechanized. The yam grown in Japan is different from the Chinese yam. Japanese yams are grown in shallow, relatively coarse-grained locations, and there are some differences between the two, as Japan has mostly volcanic ash soils. Thus a harvester for deep-buried root crops can be used to harvest Japanese yams. In Japanese yam harvesting, two machines work in tandem, with the tractor carrying the harvester forward, which picks up the soil and digs out the yam fruit. Workers sitting on harvesting machines then pull out the yams, place them on a conveyor belt and transfer them to another conveyor for boxing and sorting. The soil delivery device delivers yams and soil to the ground with simple hand-picking and a low damage rate. Japan Agricultural Machinery Co. makes the YCD-60 root and stem versatile harvester, mainly used to harvest garlic and yams. The machine has a low damage rate to yams, low labor intensity, and relatively high operating efficiency. And it can perform both

loosening and hoeing functions, but the cost of this machine is too high and maintenance is difficult [27]. In Japan, there is a method of harvesting yam called "water digging". The method involves watering the area where the yams are grown before harvesting and then pulling the yams out by force. However, this method is only suitable for sandy soils and is not effective for clay loam soils. The "water-digging method" of yam harvesting tends to break yam, has a high damage rate, and wastes water. Thus, the mechanization of yam harvesting in Japan is not suitable for promotion in China.

#### **4.2 Current state of domestic yam harvesting techniques and research**

Because yams have deep rhizomes and are brittle, direct digging is not feasible. It is labor-intensive and yields poor harvests. Trencher machinery is the source of yam harvester design in China [28]. One of the main types of construction machinery, the digger, is a trenching machine used in earthwork construction. It is widely used in agricultural water conservancy construction, communication cable and oil pipeline laying, municipal construction, and military engineering. It was later introduced in Mac for the study of yam harvesting. Currently, most existing yam harvesting machines only have a trenching function. Only very few harvesters are equipped with loosening, lifting and conveying devices, but the operation effect is poor and yam damage is more serious [2]. China's yam harvesting technology is relatively backward, with the automatic mechanization of removing yams from the soil, cleaning and sifting, automatic placement and box storage not yet fully realized.

Domestic research and development of the trencher started late. It has gone through the development process from ploughshare, disc, spiral and chain. In the 1950s, plowshare-type diggers began to appear. The machine has a simple

structure, the trench shape is straight, and the energy cost of excavating a unit of soil is small. But the traction resistance, the need for high-power tractor supporting operations, so the scope of application is limited, only suitable for opening the depth of less than 1 m ditch [29]. In the 1950s, plowshare-type diggers began to appear. The machine has a simple structure, the trench shape is straight, and the energy cost of excavating a unit of soil is small. But the traction resistance, the need for high-power tractor supporting operations, so the scope of application is limited, only suitable for opening the depth of less than 1 m ditch [29]. In the 1990s, vertical spiral furrow cutters and chain furrow cutters began to appear. It allows cutting, lifting and spreading in the trenching process to be completed in one go, and its trenching depth can also meet the yam harvesting depth, compensating for the limitations of disc-type trenching. Meanwhile, the development of domestic high horsepower tractors has gradually improved to be able to match the trenchers, and the mechanized planting and harvesting of yams has also developed significantly [31-32].

In 1998, the Beijing Shunyi District Agricultural Equipment Research Institute designed the first two-row chain yam planting and harvesting machine in China. It consists chiefly of a frame, digging apparatus, and transmission apparatus, etc. The digger is a two-row chain drive unit with two sprocket shafts equipped with the main and drive sprockets. The input end of the transmission device can have a universal joint, in use, it will be connected to the output end of the transmission device on the power machine, the universal joint can make its work between the input end of the shaft and the power machine shaft for adaptive displacement [33]. When the yams are planted, the device can be used to dig and turn the soil to the desired depth. During yam harvesting, this device is used to grind the soil off the side of the yam row, which is then picked up by hand digging, greatly reducing labor intensity. However, the soil at the roots of the yam

is still firm and can be easily dug up at harvest time.

In 2011, Wang Maocheng designed a dual-use machine for yam harvesting and planting. It consists of a frame, a power unit and a cropping device. The upper end of the vibrating sleeve is assembled at the back of the furrowed device, and the lower end is secured by a wedge-shaped vibrating box. Ensuring that the yam remains intact during excavation dramatically increases efficiency. The invention also allows the use of a trenching device alone to dig loose soil and improve the efficiency of yam cultivation [34]. This mechanism, with the addition of a vibrating device compared to previous trenching devices, was able to achieve a slight separation of the yam from the soil, but soil resistance was high and access to the soil was difficult.

Ltd. and Shandong Agricultural University jointly developed the Sasaki brand 4USY-1 yam harvester in 2013 [35]. The machinery is single-row operated and can perform trenching, digging, lifting and earth moving in one go. Field tests show that the machine produces good results with deep excavations in place, high operational efficiency and low yam breakage rate. However, the machine is highly demanding for standardised planting, unsuitable for harvesting in wide and narrow row planting patterns, and inconvenient to operate.

In 2014, Wansheng Yu of Hebei University of Technology designed a yam harvester that enables automatic yam emergence and separation from the soil. The mechanism of each section of the yam harvester is designed by removing soil from the sides of the yam rhizome and removing the yam center. It consists, in turn, of six parts: the connecting power mechanism, the rear suspension mechanism, the hydraulic reduction system, the depth-digging mechanism, the connecting transmission mechanism, and the conveyance mechanism. In the power mechanism, the angle between the digger and the ground is adjusted by a lifting cylinder, which changes the depth of the digger. The angle between the

delivery mechanism and the ground is adjusted by the delivery cylinder. The improvement of these two parts facilitates the harvesting of yams of different depths, and improves the versatility of the machine.

2016 Li County First Seeding Machinery Factory, Hebei Institute of Agricultural Mechanization, and Hebei Agricultural University, jointly developed a self-propelled hemp yam harvester [37]. The machine has a bulldozer mechanism, trenching device, earth-turning and backfilling mechanism all in one, and is compact and versatile. During operation, the trenching chain rotates into the soil, and the tilting and vibrating mechanism then enters the soil to loosen the yam in multiple directions at the bottom and sides, so that the yam can be easily pulled out by hand at the back. The backfilling mechanism backfills soil from the trench chain into the trench, enabling automated trench filling and dramatically reducing the intensity of human labor. Field tests showed that the breakage rate of the yams was less than five percent, in line with agronomic requirements.

In 2020, Yang Development et al. [38] designed a fully hydraulic suspended single row yam harvester based on an empirical design approach. In conjunction with the agronomic requirements of yam harvesting, the optimal structural parameters were determined by studying the frequency, amplitude of the reciprocal oscillations, and the associated mechanical structure parameters of the vibrational dredge-up part. The moving structure is designed with chain trenching on the left and right sides, which results in high trenching efficiency and better overall soil breaking effect of the vibrating device. It can isolate soil-bound yams and has a high rate of mechanically intact harvests, essentially meeting farmers' requirements for high harvests and low loss rates.

In 2022, Fan Suxiang [39] et al. disclosed a vibrating yam harvester. The vibrating yam harvester of the present invention consists of a frame attached to a tractor by means of a traction frame,

which in turn is connected to a vibrating apparatus. The frame is provided with a lifting mechanism for raising the helical slack mechanism. A helical loosening mechanism is used to loosen the soil on both sides of the yam belt to a depth greater than a predetermined maximum yam depth. The vibrating apparatus is connected downward with a vibrating frame, which is used to vibrate and loosen the soil in the yam belt. The soil within the yam band is loosened, and the bond between the yam and the soil is broken by the upward and downward vibrations, so that the yam within the band can be easily, completely, and quickly drawn out by hand.

## **5.PROBLEMS AND RESEARCH DIRECTIONS**

### **5.1 Problems**

At present, there are many questions about the actual condition of yam harvesting machinery in China. Based on the introduction of reference to foreign rootstock harvesting machinery, it is also necessary to focus on the characteristics of the domestic yam industry for targeted improvement.

(1) The agronomic planting pattern is not uniform. China's terrain is complex and rugged, with too much mountainous terrain. Yam cultivation is scattered in size, with planting patterns varying from region to region. The plant spacing, row spacing, planting depth, and burial depth of the crop before harvesting are not uniform throughout the planting process, resulting in broken yams, cracked skins, and damage during mechanical harvesting. Therefore, the adaptability of yam harvesting machinery is highly desired.

(2) Complex harvesting environment and high resistance. Yam rhizomes are over 1 m long and have a complex underground growth environment and deep excavation depth. This leads to problems such as easy clogging and sticking during work, poor workmanship, high functional consumption, and severe wear and tear on the machine.

(3) The transmission structure is huge and complicated, and there is a lack

of professional equipment. Yam harvesting machinery consists of several parts, among which are furrowing, vibrating loosening and mulching, and is complex in structure. It causes the machinery to be too big and not pretty enough. In addition, the biological and physical-mechanical properties of the yam rootstock itself have been less studied, and the design of yam harvesting machinery lacks theoretical foundations. Professional machinery and equipment for yam harvesting is still lacking, and there are drawbacks such as low efficiency, high energy consumption and high loss rate.

(4) The harvesting function is single. Current yam-harvesting machinery is only capable of performing these functions when the trenching vibrations are relaxed. It also requires manual assistance in digging and picking, and has yet to implement yam-harvesting machines that automatically clamp soil and automatically place yam rootstock.

(5) Casing yam technology is not yet widely available on a large scale. The study of casing materials, specifications and soil fertility supply in casings adapted for yam growth is still a blank, and a comprehensive and supportive study of this technique should be further enhanced.

## 5.2 Future Research Directions

(1) Cultivation patterns consistent with mechanized harvesting. Exchange research favors mechanized planting, management, and harvesting, making it possible to mechanically harvest yams from planting to harvesting in one go.

(2) Study of yam characteristics. The study of the physical properties of the yam rootstock. Bending strength, flexibility, and tensile strength can provide a theoretical basis for the development of yam harvesters and the setting of key

component parameters to reduce the loss rate.

(3) Intelligent harvesting system. With the rapid development of smart control technology, navigation and positioning technology and yam identification devices can be added to yam harvesters. To achieve accurate harvesting and reduce energy consumption for harvesting.

(4) Casing yam technology design and optimization. Research into the proper tubing for yam growth and the depth and angle of entry into the soil to maximize the yield of packed yams and mechanized planting and harvesting.

## 6. CONCLUSION

Demand from farmers has been on the rise as the area under yam cultivation continues to expand. There is an urgent need to develop mechanized yam harvesting machines that integrate the entire process of planting, trenching, soil excavation, picking, sifting and delivery in a single combined harvester. On the one hand, there is a need to standardize planting patterns, unify planting specifications and determine row spacing. Mechanized planting is used to reduce bias in the yam rootstock and improve straightness. To avoid increasing the difficulty of mechanical manipulation during harvesting, the breakup rate is reduced and the yield is increased. On the other hand, we must also strengthen the research and development of narrow wheel bases suitable for yam harvesting, as well as the power of small tractors to achieve smart harvesting with low energy consumption and high yield. At the same time, we must also increase the research and development of casing yam technology to achieve technological breakthroughs and fully mechanize and intelligent yam cultivation and harvesting as soon as possible.

## REFERENCES

1. Niu Shaobin. Research on water and fertilizer integration technology and spatial and temporal water and fertilizer transport

distribution characteristics in yam production[D]. Hebei Agricultural University, 2020.

2. Long S. F., Liu Y. G., Mas, et al. Mechanized harvesting technology of yam

- and its development[J]. *Agricultural Machinery Use and Maintenance*,2020(03):4-7.
3. Feng Xiaojing, Yang Xin, Liu Hongjie, et al. Current status and countermeasures of hemp yam harvest mechanization technology[J]. *Chinese Journal of Agricultural Chemistry*,2017,38(4):113-116.
  4. Liu Y, Zhao J, Yin B, et al. Discrete element modelling of the yam root-soil complex and its verification[J]. *Biosystems Engineering*, 2022, 220: 55-72.
  5. Gao G., Xie H. F., Wang T. P.. EDEM simulation and experiments on the mechanical properties of pulling of facility vegetable harvesters[J]. *Journal of Agricultural Engineering*, 2017, 33(23): 24-31.
  6. Yuan Jin, Li Jinguang, Zou Liangliang, Liu Xuemei. Optimal design and experiment of root cutting shovel for spinach harvester based on discrete elements[J]. *Journal of Agricultural Machinery*,2020,51(S2):85-98.
  7. Li J, Liu X, Zou L, et al. Analysis of the interaction between end-effectors, soil and asparagus during a harvesting process based on discrete element method[J]. *Biosystems Engineering*, 2020, 196: 127-144.
  8. Wang Y, Zhang Y, Yang Y, et al. Discrete element modelling of citrus fruit stalks and its verification[J]. *Biosystems Engineering*, 2020, 200: 400-414.
  9. Cao Shaobo, Li Xin, Yang Xin, Feng Xiaojing. Research on mechanical properties testing of hemp yam rootstocks[J]. *Agricultural mechanization research*,2018,40(04):200-205.
  10. Liu Guohua. Design development and simulation study of deep buried root crop yam harvester[D]. *Qingdao University of Technology*,2019.000035.
  11. Wang Yaoqin, Liu Jianping, Nan Huailin, Gao Yufeng, Ren Haixin, Wang Xiaobing. Research on a combination of agronomic and agro-mechanical minimalist cultivation technology for Jin yam[J]. *Agricultural Science and Technology Communication*,2016(03):82-85.
  12. WANG Yaoqin, LIU Jianping, NAN Huailin, REN Guoxiang, ZHANG Jie, TIAN Hongling, GUO Shuhong, HAO Yaopeng, GAO Yufeng, REN Haixin. An agronomic-agricultural-mechanical combination for simple cultivation of yam [P]. Shanxi Province: CN103947436B,2016-05-11.
  13. Su Chengjun. High-yielding and efficient cultivation technology of yam in plastic casing[J]. *Chinese squash*, 2010,23(03):55-56.
  14. Song YW. Efficient cultivation technology of yam [J]. *Modern Agricultural Science and Technology*,2008,(21):55-57.
  15. Song Yuanlin. Cultivation technology of yam without trenching[J]. *Practical Technology*,2013,(2):41.
  16. Zhao Bing. New technology of yam cultivation [M]. Beijing: Golden Shield Publishing House, 2001.
  17. Wang Dongwei, Shang Shuqi, Han Kun. Design and test of 4HJL-2 harvester for peanut picking-up and fruit-picking[J]. *Chinese Society of Agricultural Engineering*,2013,6:27-36.
  18. WANG Xinyang, ZHANG Liang, LI Jian, YANG Yuehua, LIU Feng, FU Jiaqing. Research on mechanized ginseng harvesting equipment[J]. *Southern Agricultural Machinery*,2016,47(12):27-28.
  19. Liu JJ, Song JN, Lu JW, et al. Analysis and discussion of garlic harvesting process[J]. *Agricultural Mechanization Research*, 2008,1:24-25.
  20. Bosrotsi, C., Addo, A., Dzisi, K., & Agodzo, S. (2017). Development of a yam harvester using finite element method. *International Journal of Modern Studies in Mechanical Engineering (IJMSME)*, 3(1),35e44.
  21. Liao Yulan, Sun Youpan, Liu Shihao. Development and prototype trial of digging-pulling style cassava harvester[J]. *Chinese Society of Agricultural Engineering*,2012,10:29-35.
  22. Isaac N Itodo & Joakim O Daudu. Performance Evaluation of a Tractor Mounted Yam [*Dioscorea spp.*] Harvester fitted with a Collection Unit[C]. ASABE Annual International Meeting. 2013, July 21-July 24.

23. Lou X Y. Study on the Design of Composite Transmission System for Crawler Type Full-Feeding Combine Harvester[J]. Applied Mechanics and Materials, 2014,722:80-83.
24. Silva L E R E, Trindade R C P, Lemos E E P. Rooting cuttings of yam (*Dioscorea* spp.) [J]. *Comunicata Scientiae*,2014,5(4): 486-492.
25. Brunnschweiler J, Luethi D, Handschin S, et al. Isolation, Physicochemical Characterization and Application of Yam (*Dioscorea* spp.) Starch as Thickening and Gelling Agent[J]. *Starch - Stärke*,2010,57(3-4):107-117.
26. E.N.K. Sowley, N.J. Osei, C. Katsekor. Evaluation of neem as a surface protectant of yam (*Dioscorea rotundata* Poir) tubers[J]. *Acta Horticulturae*,2013,1007(1007):179-186.
27. Business Station. Yam Harvester. [DB/OL]. [http://www.007swz.com/jkyang/products/s houhuojixie\\_312389.html](http://www.007swz.com/jkyang/products/s houhuojixie_312389.html).2014,7.
28. WANG Jun-Fa, MA Xu, MA Liu-Xuan, et al. Current status of harvesting equipment and harvesting process of root and stem Chinese herbs[J]. *Agricultural Mechanization Research*,2009,12:12-15.
29. Alvarez M, Grima, P N W, Verhoef. Forecasting rock trencher performance using fuzzy logic[J]. *International Journal of Rock Mechanics and Mining Sciences*.1999,36:413-432
30. Vilde Arvids, Rucins Adolfs. Development of agricultural mechanics[C]. *Engineering for Rural Development*,11th International Scientific Conference.2012.5:67-73
31. Li Z. H., Ke B. K.. *Agricultural Mechanics* [M]. Beijing:China Agricultural Press,1991,3:150-175
32. Zhu Xinmin.1KLZ-27 type spiral trencher[J]. *Agricultural and Food Machinery*,1991,24:38-38
33. Gao S.W.,Liu W.H.,Liu J.F. Yam planting and harvesting machine.CN,98252126.X[P].1999.10.16
34. Wang Maocheng. Yam harvesting and planting machine.CN,102144450.A[P].2011.08.10
35. Diao Huaqing.Field trial study of 4USY-1 yam harvester[J]. *Agricultural Technology and Equipment*,2014,(12):30-31,33.
36. Yu Wansheng. Design and research of yam harvesting machine[D]. Tianjin:Hebei University of Technology,2014.
37. SONG Shuaishuai,YANG Xin,FENG Xiaojing,et al. Research on self-propelled hemp yam harvesting machine[J]. *Agricultural Mechanization Research*,2018,2:80-84.
38. Yang D, Yang YP, Li WH, et al. Design and test of vibratory excavation and soil crushing device for suspended yam harvester[J]. *Journal of Agricultural Machinery*,2020,51(06):104-111.
39. Fan Suxiang, Cai Pei Fang, Sun Rui et al. Vibrating yam harvesting machine and yam harvesting method. CN114097397B [P].2022.11.25