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Development and Application of Sea Buckthorn Harvesting Machinery

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Abstract. As the country with the richest sea buckthorn resources in the world, China has played an important role in sea buckthorn planting and industrial development in recent years. With the expansion of sea buckthorn cultivation area, the harvesting efficiency and quality of this economic crop have attracted the attention of growers and researchers. This paper reviews the current development and application of sea buckthorn harvesting machinery, analyzing the technological advancements both domestically and internationally that enhance harvesting efficiency and reduce labor intensity. Given China's complex terrain and the diversity of sea buckthorn, this paper proposes a double-ended adjustable-angle harvesting tool module, which can flexibly adapt to different types of sea buckthorn and operational environments, featuring a simple structure and ease of operation. This design provides a new perspective and technical support for the mechanized harvesting of sea buckthorn and other hard-stemmed crops, promoting the development of the sea buckthorn industry towards efficiency and intelligence.

Keywords: sea buckthorn resources; harvesting machinery; double-ended adjustable-angle tool module

Introduction

Sea buckthorn, a plant of the genus Hippophae in the Elaeagnaceae family [1], is characterized by rapid growth, cold resistance, drought tolerance, and salt-alkali resistance [2]. It can quickly establish forests even in “non-suitable forest areas,” such as the soil erosion-prone regions of the Loess Plateau. Sea buckthorn is an excellent species for rapidly restoring vegetation, preventing wind erosion, stabilizing sand, improving soil quality, and enhancing ecological conditions in arid and semi-arid areas [3]. Its nutritional value is also notable, as it contains high levels of vitamin C, which can boost immune function [4]. According to surveys and statistics organized by the Secretariat of the International Sea Buckthorn Association, as of the end of December 2022, sea buckthorn is distributed in about 55 countries worldwide, covering an area of approximately 37.8 million mu [5]. It is widely found in temperate regions, including China, Russia, and Europe [6].

a) b)

a) unripe sea buckthorn fruit; b) ripe sea buckthorn fruit

Fig. 1. - Sea buckthorn fruit

In September 2021, the Sea Buckthorn Committee of the China National Sand Control and Desert Industry Society released the National Sea Buckthorn Resource Survey Report, which showed that the total area of sea buckthorn forests in China amounts to 19.1044 million mu [7]. Sea buckthorn plays an important role not only in economic development and improving livelihoods but also in ecological restoration, particularly in soil conservation and land reclamation. The sea buckthorn fruit is small with thin skin, closely clustered on thorny branches, and firmly attached, which makes manual harvesting a significant challenge. As the planting area of sea buckthorn continues to expand, traditional harvesting methods are no longer sufficient for large-scale production, making mechanized harvesting a critical factor for scaling up the sea buckthorn industry.

Against this backdrop, researchers have begun to explore mechanized methods for harvesting sea buckthorn fruit. Mechanized harvesting not only improves harvesting efficiency and reduces labor costs but also has the potential to address labor shortages and the limited harvest season, thus supporting the sustainable development of the sea buckthorn industry. However, the research and application of mechanized harvesting technology still face numerous challenges, including the effective design and manufacturing of harvesting equipment, accurate identification and collection of fruit, and the need to balance harvesting efficiency with fruit preservation. This paper aims to review the development and application of sea buckthorn harvesting machinery both domestically and internationally, analyze the advantages and disadvantages of different machines, and propose a dual-end adjustable-angle cutting tool module design adapted to complex operating conditions, thereby providing reference and technical support for the mechanized harvesting of sea buckthorn.

2. Manual Harvesting of Sea Buckthorn

In the sea buckthorn industry, harvesting is a critical and time-intensive task that directly affects the quality and profitability of the fruit. As one of the most traditional harvesting methods, manual harvesting plays an essential role in the industry's development. Its simplicity and ability to preserve fruit integrity mean that it remains widely used in many regions. A comparison of manual harvesting methods in China and abroad is summarized as follows.

2.1 Manual Harvesting

1) Fruit Picking Method: This simple and direct method relies on manually picking sea buckthorn berries, usually during the ripening period. Workers pluck the fruit from the branches by hand and place it into containers. While easy to operate and suitable for small-scale, sparsely distributed fruit, this method is low in efficiency and can damage both fruit and branches, making it unsuitable for large-scale production. The advantages of this method are its simplicity, but it also presents challenges due to high labor intensity, low efficiency, and reliance on labor resources.

2) Frozen Fruit Shaking Method: This efficient harvesting method requires temperatures below -20°C, but it may lead to frozen cracking or overripe fruit. By tapping the branches with sticks or other tools, the fruit falls to the ground or into containers. This method is suitable for dense, abundant fruit and is relatively simple and efficient. However, to prevent contamination or damage to the fruit, plastic sheets or other materials must be laid out before the fruit matures.

2.2 Manual Tool-Assisted Harvesting

This method uses various hand tools for harvesting, such as handwheel harvesters and branch-cutting harvesters. In the branch-cutting method, branches are manually cut after the sea buckthorn ripens, then frozen and shaken to obtain the fruit. Although this approach is flexible, it remains inefficient. September is typically a busy agricultural season, leading to a labor shortage, so manual harvesting with tools remains less efficient and adaptable than mechanized methods.

A survey of community harvesting efficiency is shown in Table 1[8].

Table 1. Production efficiency of sea buckthorn fruit in mass harvesting belt

Total fruit harvest (kg)	Number of fruit pickers (person)	Fruit picking days (days)	Fruit picking efficiency	
			[kg/(h • person)]	[kg/(d • person)]
5300	120	4	5.1	33.2

3. Development of Mechanized Sea Buckthorn Harvesting

With the expansion of sea buckthorn cultivation and increasing demand, traditional manual harvesting can no longer meet efficiency and cost requirements. Sea buckthorn is known for its small fruits, short stems, and growth characteristics of clinging to thorny branches. When ripe, the fruit is very fragile and can easily break with slight contact, creating significant challenges for harvesting and hindering the industry's transition to large-scale industrialization [9-10]. To address these issues, it is necessary to design and optimize harvesting devices based on sea buckthorn's harvesting needs, crop characteristics, and agronomic requirements to achieve mechanized harvesting. This approach can reduce harvesting costs, free up labor, improve efficiency, and meet raw material demands for enterprises. Additionally, it prevents random pruning of trees that can lead to reduced yields and resource waste in subsequent years [11].

Researchers are therefore dedicated to developing various mechanized harvesting technologies to increase production efficiency and reduce labor costs. Both domestic and international efforts have led to the development of diverse harvesting equipment for sea buckthorn, ranging from simple spring vibration devices to complex pneumatic suction harvesters, as well as integrated machines capable of simultaneous branch cutting and vibration. Countries such as Russia, Canada, and Germany were early pioneers in the research and development of sea buckthorn harvesting machinery. Russia began developing such equipment in the 1950s and has continued to refine it over the decades[12]. These machines not only enhance harvesting efficiency but also reduce labor intensity, making a significant contribution to the development of the sea buckthorn industry. Meanwhile, China has also been actively exploring this field, introducing, assimilating, and adapting advanced foreign technologies while strengthening research and innovation to gradually establish a comprehensive mechanized harvesting system for sea buckthorn. The development and application of these machines provide strong support for the sustainable growth of the sea buckthorn industry and lay the groundwork for future improvements and innovations in sea buckthorn harvesting technology.

3.1 International Research Progress

Canadian researchers Danny D. Mann and Donald S. Petkau developed a clamping and vibration-based sea buckthorn harvesting device (as shown in Figure 2), which consists of a telescopic pole, clamping mechanism, springs, rotating platform, and telescopic cylinder. By clamping the sea buckthorn tree and shaking a part of the plant, the applied force on the trunk, branches, or leaves causes the fruit to detach from the stem. Although this vibrating harvester is highly efficient, it has a low harvest rate and can cause some damage to the sea buckthorn tree [13].

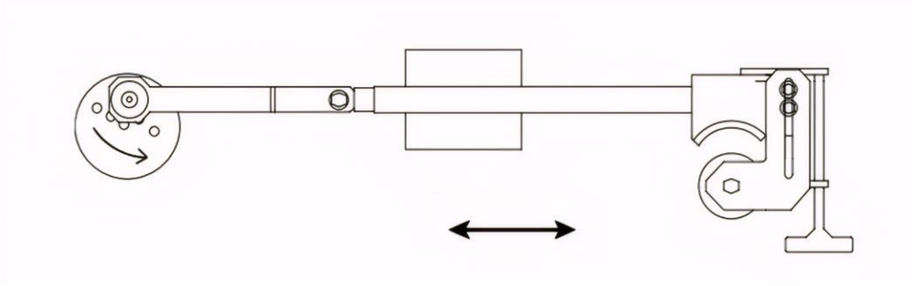


Fig. 1. - Holding device of Russian sea buckthorn harvester

The German company Kranemann GmbH developed a sea buckthorn cutting harvester [14] (as shown in Figure 3) equipped with adjustable deflectors, a circular saw, a reel, an elevator, and a container. The popular harvesting method in Germany involves cutting branches, freezing them, and then shaking off the frozen berries. During harvesting, the machine moves along rows of sea buckthorn, with the deflectors adjusting to the growth habits of the shrubs. The deflectors can travel under drooping branches, lifting the mower deck via the reel. The reel, installed with a curved profile, aligns the branches and guides them to the set position for cutting, where a circular saw trims the berry-laden branches, which are then transported to a container. This method is efficient and adaptable to various sea buckthorn varieties. However, it requires leaving some branches with leaves intact post-harvest, as sea buckthorn branches need 2-3 months to regrow and adapt. Without sufficient leaves, many sea buckthorn plants could die over winter, leading to a substantial decrease in the following year's yield. Additionally, this harvester requires a row spacing of at least 3 meters, making it suitable only for commercial plantations with one-year harvest intervals.

Fig. 3. - Structure of sea buckthorn fruit cutting machine

The MII70-6 air-sucking sea-buckness-picking machine developed by the Moscow Academy of Agricultural Science Machinery (as shown in Figure 4), with a supporting power of 36.6kW or more tractors, is mainly composed of universal transmission shaft, pulley assembly, vacuum pump, harvesting container tank, fruit box, vacuum tube and picking and other parts. At work, the tractor power through the drive shaft to drive the vacuum pump to produce enough negative pressure, so that the special picking head to form an suction flow, pick the sea buckthorn fruit, after being sucked into the harvest container, through the separator to separate the fruit, branches and leaves, and finally into the fruit box to complete the harvest. The machine is usually equipped with 6 picking heads, which can work for 6 people at the same time, and the daily picking efficiency is about 1000kg, which is suitable for harvesting large-fruit sea buckthorn [15].

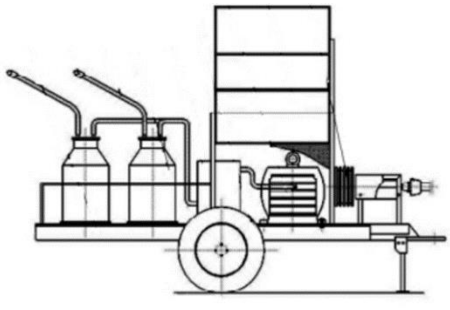


Fig.4. - Structure diagram of air-suction sea buckthorn fruit harvester

3.2 Domestic research progress

Since 1997, the Inner Mongolia Academy of Forestry has focused on research into sea buckthorn harvesting technology and associated machinery. Building on Russian sea buckthorn harvesting technology, and taking into account the distribution, terrain, and cultivation conditions of sea buckthorn in China, the academy developed two proprietary sea buckthorn harvesting machines, as shown in Figure 5. The first is a spring vibration and variable-frequency vibration suction combination harvester powered by a small gasoline engine, suitable for large-scale artificial sea buckthorn forests on gentle slopes. The second is an electric, spring-vibration, and variable-frequency vibration backpack harvester designed for natural sea buckthorn forests and capable of harvesting on sloped terrain. Through patent development and technological improvements, two prototype harvesters based on different principles were developed, integrating suction devices with mechanical spring and variable-frequency vibration mechanisms. These machines are adaptable for harvesting various types of small forest fruits, including sea buckthorn, goji berries, and nanking cherries. These innovations provide efficient and flexible solutions for harvesting sea buckthorn and other small forest fruits [16].

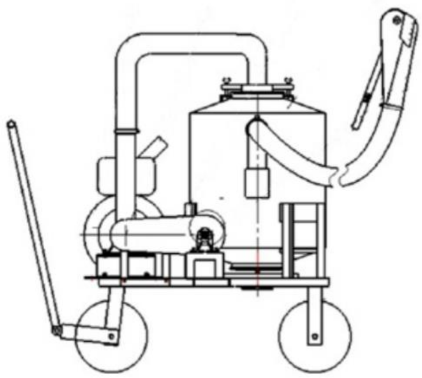


Fig. 5. - Spring Vibration and Suction-Type Sea Buckthorn Fruit Harvester

Wang Min, Cao Silin, and others designed a mechanical vibration-type sea buckthorn harvesting machine in response to the rapid development of the sea buckthorn processing industry, where there are currently no mature tools for fruit picking[17]. The design is intricate, consisting of key components such as a vibrating head, machine body, crank-slider mechanism, flexible shaft, and gasoline engine, as shown in Figure 6. The crank-slider mechanism includes a telescopic shaft, crank, and gear pair, which enables complex motion conversion. Its working principle is quite ingenious: after starting the gasoline engine, power is transmitted through the flexible shaft to the crank-slider mechanism, converting rotational motion into the linear reciprocating motion of the vibrating head. The vibrating head drives the telescopic shaft to shake off the sea buckthorn fruits, facilitating the harvesting process. The shaken fruits are collected by a gathering device, perfectly achieving the automation of sea buckthorn harvesting.

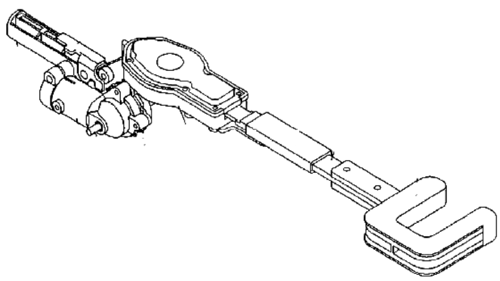


Fig.6. - Schematic Diagram of Mechanical Vibration-Type Sea Buckthorn Harvesting Machine

Zhai Zhiyuan, Lei Jin, and their research team successfully developed the first domestic self-propelled sea buckthorn reciprocating pruning and harvesting machine based on German sea buckthorn cutting and harvesting technology[18]. This machine integrates multiple innovative designs, including a fully functional cabin control system (covering walking, steering, branch displacement, cutting, and lifting), an efficient pruning device (comprising a branch displacement wheel, cutter, and branch gathering system for branch separation, combing, and cutting), a flexible walking chassis (hydraulically driven rear wheels with flexible steering of front wheels, and a ground clearance of 1200 mm), as well as a grading, lifting, and storage system (first-level lifting of branches to a storage box, and second-level lifting to an accompanying vehicle). The harvester optimizes space utilization through a three-segment folding design, making it easier to transport. Its fully hydraulic drive control characteristics are suitable for the complex working conditions of sea buckthorn shrubs, significantly improving operational efficiency and quality, and achieving an automated process from cutting to collection.

Further research based on sea buckthorn planting patterns and growth characteristics involved detailed parameter measurement and data analysis, providing foundational data support for sea buckthorn growth management. However, the machine still has several shortcomings in practical applications, such as non-adjustable position and speed of the branch displacement wheel leading to poor combing effects, mismatches between manual operation and pruning results causing harvesting losses, tool fatigue and chipping issues affecting service life, poor adaptability to plants of different heights, and insufficient stability during slope operations, which require further optimization in subsequent research.

Fig.7. - Self-Propelled Sea Buckthorn Reciprocating Pruning and Harvesting Machine

4. Discussion

A review of the research progress on sea buckthorn harvesting machinery both domestically and internationally reveals that there are different technological paths and adaptations in the development of sea buckthorn harvesting machinery. In countries such as Russia, Canada, and Germany, the development of sea buckthorn harvesting machinery began earlier and is more technologically mature, with significant achievements in mechanical types such as air suction, cutting, and clamping vibration systems. These machines excel in improving harvesting efficiency and reducing labor input and intensity; however, they often have higher requirements regarding planting modes and terrain conditions. In contrast, domestically, advanced foreign technologies have been introduced, digested, and absorbed, leading to independent research and development that gradually forms sea buckthorn harvesting machinery with independent intellectual property rights.

A performance comparison of various sea buckthorn harvesting machines is shown in Table 2.

Table 2. Comparison of Sea Buckthorn Harvesting Machines

Type	Country/Developer	Working Principle	Harvesting Efficiency	Fruit Damage Rate	Advantages	Disadvantages
Clamping Vibration Harvester	Canada (Danny D. Mann et al.)	Vibrates the fruit off by clamping the trunk	High	Relatively High	High harvesting efficiency	Low clean rate, destructive to the tree
Cutting Harvester	Germany (Kranemann GmbH)	Cuts branches and shakes off the fruit after freezing	30 kg/h, 80% drop rate	5%	High harvesting rate, suitable for multiple varieties	Some damage to trees, requires 2-3 months to recover
Air Suction Fruit Picker	Russia (Moscow Agricultural Scientific Machinery Institute)	Uses vacuum suction to collect fruits into a container	Approximately 1000 kg/day	Moderate	Suitable for large sea buckthorn, allows for 6 people working simultaneously	Requires high-power tractor, high cost

Contanuation of the table 2

Type	Country/Developer	Working Principle	Harvesting Efficiency	Fruit Damage Rate	Advantages	Disadvantages
Spring Displacement-Air Suction Combined Harvester	China (Inner Mongolia Academy of Forestry)	Vibrates to drop fruits and collects them using air suction	Moderate	Medium-Low	Suitable for large flat areas and various small fruit varieties	Not suitable for complex terrain
Mechanical Vibration Harvester	China (Wang Min, Cao Silin et al.)	Converts rotational motion to linear reciprocating motion of the vibrating head to shake off fruits	Moderate	Moderate	Simple design, suitable for small to medium-scale harvesting	Lower level of automation
Self-Propelled Reciprocating Pruning and Harvesting Machine	China (Zhai Zhiyuan, Lei Jin et al.)	Automatically walks, prunes, and collects, suitable for shrub areas	High	Moderate	High degree of automation, suitable for densely planted shrubs	Component lifespan issues, insufficient stability on slopes

Various types of sea buckthorn harvesting machines each have their advantages in different structural designs and working principles, making them suitable for different harvesting needs and terrain conditions. Clamping vibration harvesters and air suction fruit pickers are characterized by high efficiency, but they face issues such as significant damage to the tree and high equipment costs. In contrast, cutting harvesters are considered commercially viable due to their high harvesting rate and low fruit damage, though they have higher requirements for tree recovery. The domestically developed spring displacement-air suction combined harvester and self-propelled reciprocating pruning and harvesting machine offer flexibility in adapting to different terrains and environments, making them particularly suitable for the complex terrain conditions of sea buckthorn forests in China. However, they still require optimization in terms of component durability and operational stability. Overall, the development direction of sea buckthorn harvesting equipment aims to balance harvesting efficiency, fruit protection, and tree health while further enhancing automation and adaptability to meet the demands for large-scale mechanized harvesting in the sea buckthorn industry.

Specifically, for harvesting deciduous shrubs like sea buckthorn, the design and optimization of cutting devices are crucial for improving harvesting efficiency and quality. Researchers both domestically and internationally have developed various high-efficiency and adaptable cutting devices through innovation, such as reciprocating dual-action knives, sliding-cut and shearing combinations, bionic blades, and finite element analysis, which have significantly improved cutting efficiency and quality. However, research on disk-type cutting mechanisms specifically for sea buckthorn remains insufficient and needs to be strengthened further.

5. Development

Sea buckthorn branches are characterized by high lignification and hardness, categorizing them as hard-stemmed crops[19]. During the harvesting of sea buckthorn, it is necessary to harvest the branches, leaves, and fruits together to improve harvesting efficiency. The mechanical properties of sea buckthorn branches and the cutting methods of the tools are particularly important, as they directly affect the quality of the harvesting process [20].

Currently, research reports on specialized sea buckthorn branch and fruit harvesting machines in China are relatively limited, and there is also a lack of studies on cutting devices for sea buckthorn branches. However, there is a wealth of research on harvesting machinery for other hard-stemmed crops, such as corn and sugarcane. Therefore, this paper analyzes and references harvesting machinery for hard-stemmed crops.

Wang Bingpeng and colleagues analyzed the optimal cutting parameter combinations for sea buckthorn branches by designing a cutting test platform using blades from other stem crops [21]. This test platform utilized a reciprocating dual-action knife structure and conducted experiments on factors affecting the cutting of sea buckthorn branches, as well as multi-factor response surface cutting tests. Ultimately, the study revealed the variation laws of the main factors affecting sea buckthorn cutting and determined the optimal cutting parameter combinations. The cutting experiments for sea buckthorn branches provide significant reference value for this research; however, the experimental methods differ from the operational conditions of harvesting machines in complex field environments.

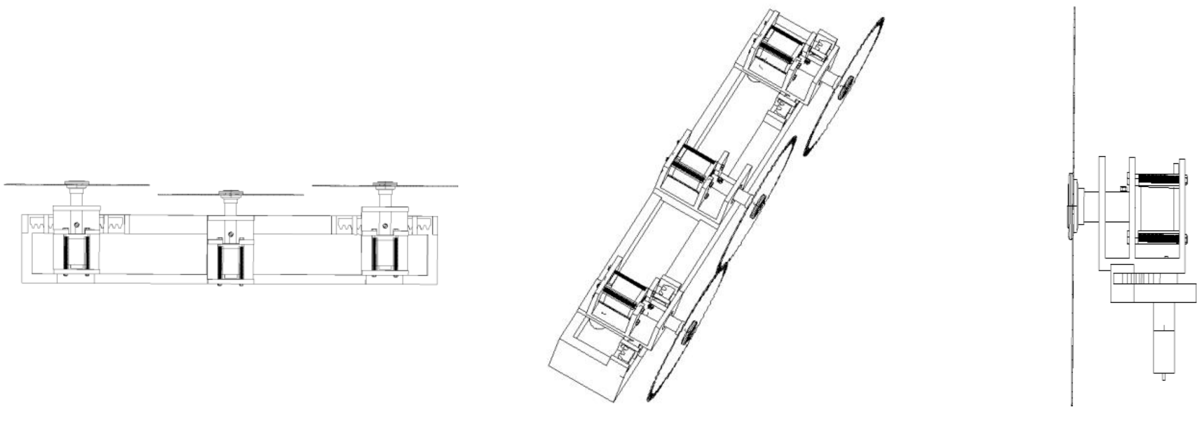
Ni Chang'an and colleagues explored the performance and power consumption of several types of disk cutters during the cutting of corn stalks [22]. The experiment selected three types of cutters: straight knife, serrated knife, and star-toothed knife, analyzing how their structures and operating parameters affect cutting results. The results indicated that the straight knife cutter performed best in terms of power consumption and is suitable for cutting smaller diameter corn stalks, while the star-toothed knife consumed the most energy under the same conditions. Additionally, cutting power consumption is related to the speed of the cutting tool and the forward speed of the machine. The research also pointed out that the idle power consumption of disk cutters is relatively high; thus, practical designs should focus on simplifying the transmission structure and ensuring reliability to reduce energy consumption and improve operational efficiency.

Qing Shangle and colleagues mainly studied the kinematic characteristics of a single disk cutter during the sugarcane harvesting process [23]. By establishing motion equations and models, they analyzed how the structural parameters of the cutter and the geometric parameters of the sugarcane affect the cutting results, determining the conditions for avoiding missed cuts and ensuring that the cutting disk does not contact the sugarcane. The results showed that the maximum speed ratio for avoiding missed cuts is related to the structural parameters of the cutter and not the motion parameters, and that the speed ratio decreases as the disk angle increases and increases as the blade angle increases; the disk angle should not exceed 20°. The maximum speed ratio for avoiding contact is related to the diameter, tilt angle, and cutting position of the sugarcane, where a tilt angle exceeding 40° is detrimental to harvesting.

Based on an in-depth analysis of previous research, this paper proposes a design for a disk-type sea buckthorn harvesting knife module with dual-end adjustable angles, aiming to optimize the flexibility and efficiency of sea buckthorn harvesting operations. This module consists of a single cutting tool and a main frame, with the control mechanism including a cutting motor and a steering motor. The adjustment mechanism achieves micro-adjustment of the angles of the dual-end tools through cams, gears, and racks on a central support frame. Users can precisely adjust the working angles of the two cutting tools to meet the harvesting needs of different sea buckthorn varieties and complex terrains.

The innovation of this design lies in utilizing high-speed, smooth circular saws to cut sea buckthorn, while using a DC motor and a brushless motor to control steering and cutting, respectively, in order to meet a wider range of harvesting needs. The angle adjustment of the tools can adapt not only to the branch structures of different sea buckthorn varieties but also optimize cutting performance by changing the entry angle, improving the smoothness of the cutting surface and the overall quality of the harvest. Compared to traditional fixed-angle tools, the proposed module offers a simple structure, convenient operation, and strong adaptability, promising a more efficient solution for the harvesting of sea buckthorn and other stem crops.

As shown in Figure 8.



a) b) c)

a) Top view; b) Isometric view; c) Side view of single-point cutting tool

Fig. 8. - A dual-end adjustable-angle saw-type sea-buckthorn harvesting tool module

Conclusion

This review thoroughly explores the transition of sea buckthorn harvesting machinery from traditional manual methods to mechanization, analyzing the developmental process and challenges involved. It also provides an in-depth discussion on the strengths and weaknesses of various domestic and international harvesting technologies, particularly in terms of efficiency, fruit protection, and adaptability.

By conducting a detailed comparison of advanced equipment from countries like Canada, Germany, and Russia (e.g., clamping vibration, cutting, and air-suction harvesting machinery), this article provides a nuanced understanding of the technical benefits and practical contexts in which these machines can enhance harvesting efficiency and reduce labor costs. The effectiveness of these technologies across diverse planting models, terrain conditions, and operational scales has gradually driven the replacement of traditional manual harvesting with mechanized solutions, thus serving as a pivotal force in advancing the sea buckthorn industry.

Considering China's diverse terrain and the variability of sea buckthorn varieties, this review further examines the advancements in domestically developed harvesting machinery, with a focus on innovations from regions such as Inner

Mongolia and Ningxia that address specific local challenges. Building upon foreign technologies, China has gradually developed an independent machinery system tailored to small forest fruits, significantly boosting harvesting efficiency and operational flexibility. The development emphasizes strategic adaptation to local conditions while fostering indigenous innovations.

Based on these developments, a dual-end adjustable-angle harvesting cutter module for sea buckthorn is proposed. This module utilizes an adjustable design with efficient cutting and steering motors that independently control the cutting and entry angles, thereby optimizing performance for different sea buckthorn varieties and working environments. This innovative design aims to address the limitations of traditional fixed-angle cutters, particularly their inability to adapt to varying operational environments. It enhances flexibility, smooth operation, and fruit protection, thereby improving overall harvesting quality. Compared to traditional fixed-angle equipment, this module efficiently handles complex working conditions while featuring a straightforward structure and easy operation. It significantly improves sea buckthorn harvesting efficiency and quality, providing a strategic advancement for the mechanized harvesting of sea buckthorn and other rigid-stemmed crops, offering new insights and practical directions for future technological development. This innovative design is intended to address the limitations of traditional fixed-angle cutting tools, which struggle to adapt to diverse operating environments, thereby improving harvesting flexibility, smoothness, and fruit protection. Compared with conventional fixed-angle equipment, the proposed module not only operates efficiently under complex working conditions but also features a simple structure and ease of operation. It significantly enhances the efficiency and quality of sea buckthorn harvesting, offering a new direction and practical reference for the mechanized harvesting of sea buckthorn and other hard-stemmed crops in the future.

This innovative design is intended to address the limitations of traditional fixed-angle cutting tools, which struggle to adapt to diverse operating environments, thereby improving harvesting flexibility, smoothness, and fruit protection. Compared with conventional fixed-angle equipment, the proposed module not only operates efficiently under complex working conditions but also features a simple structure and ease of operation. It significantly enhances the efficiency and quality of sea buckthorn harvesting, offering a new direction and practical reference for the mechanized harvesting of sea buckthorn and other hard-stemmed crops in the future.

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