

CURRENT STATUS AND FUTURE PERSPECTIVES OF MECHANIZED HARVESTING TECHNOLOGIES FOR SEA BUCKTHORN (*HIPPOPHAE RHAMNOIDES*) BERRIES

沙棘果机械化收获技术研究现状与发展展望

Jia ZHANG¹⁾, Tianlun WU¹⁾, Yong HUANG¹⁾, Libo ZHOU²⁾, Caigang CHANG²⁾, Weisong ZHAO^{4*)}

¹⁾ School of Mechanical and Electrical Engineering, Xinjiang Institute of Engineering, Urumqi, Xinjiang/China

²⁾ Xinjiang Xinke Technology Development Co., Ltd., Urumqi, Xinjiang/China

³⁾ Western Agricultural Research Center, Chinese Academy of Agricultural Sciences, Changji, Xinjiang/China

⁴⁾ Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing/China

Tel: +8613579297197; E-mail: zj34@xjje.edu.cn

Corresponding author: Weisong Zhao

DOI: <https://doi.org/10.35633/inmateh-78-122>

Keywords: sea buckthorn, mechanized harvesting, vibration harvesting, branch-cutting harvesting, fruit detachment and cleaning, development prospect

ABSTRACT

Sea buckthorn (*Hippophae rhamnoides*) is an important tree species for ecological restoration and the specialty forest-fruit industry in northern China. Its fruits possess high nutritional and economic value; however, harvesting operations still rely predominantly on manual labor because of the small fruit size, short pedicels, dense fruit clustering, thorny branches, and thin skin that is highly susceptible to mechanical damage. These limitations result in low harvesting efficiency and constitute a major bottleneck restricting large-scale industrial development. To systematically clarify these challenges and support the development of effective mechanized solutions, this review summarizes the physical and mechanical properties of sea buckthorn fruits and the agronomic requirements associated with mechanized harvesting. Furthermore, from the perspective of technological evolution, the study analyses the operating principles, research progress, and applicability of the main harvesting methods, including vibration-based harvesting, pneumatic harvesting, pruning-based harvesting, and whole branch-fruit harvesting systems, together with subsequent fruit detachment, cleaning, and sorting operations. The reviewed studies indicate that international research has primarily focused on cultivars suitable for mechanized harvesting, leading to technological approaches centered either on direct field harvesting or on post-harvest processing after whole branch-fruit collection. In China, significant progress has been achieved in optimizing vibration parameters for fruit detachment, developing low-damage cutting and conveying mechanisms, and improving freezing-assisted fruit detachment, cleaning, and sorting technologies. Nevertheless, several major challenges remain, including the limited availability of cultivars and planting systems suitable for mechanization, insufficient integration between agronomic practices and machinery design, and the relatively low level of intelligence and automation of harvesting equipment. Future research should therefore focus on the breeding of mechanization-oriented cultivars, the establishment of standardized cultivation systems, the development of low-damage and high-efficiency harvesting components, and the advancement of integrated intelligent harvesting equipment, thereby supporting technological innovation and the industrial application of mechanized sea buckthorn harvesting in China.

摘要

沙棘是我国北方生态修复与特色林果产业的关键树种，果实营养与经济价值高，但受果粒小、果柄短、簇生紧密、多刺、果皮薄易破损等制约，采收长期依赖人工，效率低下，已成为产业规模化发展的主要瓶颈。为系统梳理并推动解决该问题，本文归纳了沙棘果实的物理力学特性及其对机械化采收的农艺要求；进而从技术演进角度综述了国内外振动式、气吸式、剪枝式及枝果统收与脱果清选协同作业模式的工作机理、研究进展与适用性。研究表明，国外技术主要面向宜机化品种，形成了以田间直接采收和枝果统收后处理为主的技术体系；国内在振动脱果参数优化、低损伤切割输送、冷冻脱果清选等方面取得进展，但仍面临品种与种植模式宜机化基础薄弱；农机农艺融合不足及装备智能化水平偏低等问题。未来应重点围绕宜机化品种选育与标准化种植、低损伤高效采收部件、成套装备研发等方向开展研究，以期为我国沙棘机械化收获技术创新与产业化应用提供参考。

Jia Zhang, Prof.; Yong Huang, Assoc. Prof.; Tianlun Wu, Lecturer; Libo Zhou, Engineer; Caigang Chang, Engineer; Weisong Zhao, Assoc. Prof

INTRODUCTION

Sea buckthorn is a pioneer tree species for soil and water conservation and desertification control in the Three-North region of China, with substantial ecological and economic value (Hu et al., 2019). Its berries are rich in vitamins, flavonoids, polyphenols, unsaturated fatty acids, and other bioactive compounds, making them promising raw materials for functional foods, nutraceuticals, and other value-added products (Mei et al., 2023; Wang et al., 2022; Wang et al., 2022). As ecological-priority and green-development strategies continue to advance, the sea buckthorn industry is shifting from a predominantly ecological role towards coordinated ecological and economic development (Lu, 2023; Zhang et al., 2026). However, inefficient and costly harvesting remains a major constraint on resource utilization and industrial scale-up.

Compared with woody fruit crops such as apple and walnut, sea buckthorn berries exhibit distinctive harvesting challenges because they are small, short-stalked, densely clustered on thorny branches, and covered by a thin, fragile, juice-rich skin (Ciesarová et al., 2020). Mature fruits are therefore highly susceptible to mechanical damage, and even minor impacts can cause rupture and juice leakage, leading to quality loss (Tiitinen et al., 2005). A survey in the Altay region reported that manual harvesting yields only 6–8 kg per worker per day, highlighting the extremely low efficiency of current harvesting practices and the limited suitability of existing mechanized methods for local production systems (Yang et al., 2017).

Mechanized harvesting of sea buckthorn is inherently a complex engineering problem shaped by the interaction among fruit material properties, branch mechanical characteristics, and agronomic planting patterns. Consequently, relevant technological development is highly specialized and strongly system-oriented. A fundamental basis for mechanized harvesting is a clear understanding of the physical and mechanical properties of the fruit and their compatibility with different harvesting strategies (Liu et al., 2010; Feng et al., 2017). To date, research has mainly followed two technical routes. One route adapts experience from major fruit crops to develop direct in-field fruit-detachment methods, including vibration-based and pneumatic harvesting. The other is specifically designed for sea buckthorn and involves whole branch–fruit harvesting followed by post-harvest separation, in which fruit-bearing branches are cut and collected before berries are recovered through freezing, fruit detachment, and cleaning processes (Liu et al., 2010). Over the past two decades, substantial progress has been achieved in China in vibration-harvesting dynamics, low-damage branch cutting, vibration-assisted fruit detachment from cut branches, and the optimization of detachment and cleaning equipment (Song et al., 2025), with some technologies approaching practical engineering application.

Against this background, systematically reviewing the technological evolution of mechanized sea buckthorn harvesting, identifying the major unresolved challenges, and proposing development strategies suited to China's resource conditions and industrial demands are important for advancing innovation and accelerating equipment industrialization. This review therefore summarizes the biological characteristics of sea buckthorn berries, examines the current status of the major technical routes developed in China and abroad, distills the common key challenges, and discusses future research directions.

BIOLOGICAL CHARACTERISTICS OF SEA BUCKTHORN FRUIT AND REQUIREMENTS FOR MECHANIZED HARVESTING

Morphological characteristics of fruits and branches

Major sea buckthorn cultivars grown in China include 'ShenqiuHong', 'ZhuangyuanHuang', 'Suiji No.1', and 'Zhongji No.3' (Feng et al., 2017; Yan et al., 2026; Zhao et al., 2024). Sea buckthorn fruit are berries that are spherical or ellipsoidal in shape and turn orange-yellow or orange-red upon ripening. The fruits are small (6–10 mm in diameter), borne on short pedicels (<3 mm), and usually densely clustered on two- to three-year-old branches. These branches are densely covered with thorns, which greatly increases the difficulty of bringing mechanical end effectors into close contact with fruit clusters. In addition, the fruit skin is extremely thin (approximately 0.1–0.2 mm), with a fragile cell-wall structure and high turgor pressure at maturity, making the berries highly susceptible to rupture under external loading (Ma et al., 2025).

From the perspective of material mechanics, sea buckthorn branches exhibit a high degree of lignification. Studies have shown that xylem accounts for 70%–75% of the branch cross-sectional area, with average bending strength and shear strength of 76.3 MPa and 32.6 MPa (Ren, 2023). This implies that, whether using vibration-based fruit detachment or cutting-based whole branch–fruit harvesting, equipment design must fully account for branch mechanical strength as well as the increased operational resistance and energy dissipation caused by thorny branch structures.

Fruit detachment characteristics and low-temperature mechanical properties

Fruit detachment characteristics

The connection characteristics between the fruit and pedicel, and between the pedicel and branch, are important determinants of the appropriate mechanical harvesting method. Previous research has shown (Lin, 2023; Tang, 2023) that the fruit–pedicel separation force is more concentrated in distribution and significantly lower than the pedicel–branch separation force. Therefore, the preferred detachment position during mechanical harvesting should be located at the fruit–pedicel interface. The same study further reported that, at the mature stage, the fruit–pedicel separation force of sea buckthorn is generally concentrated within the range of 0.5–2.0 N (Lin, 2023). Zhang Qianglin et al., (2024), in a further study of frozen fruit-bearing branches, found that fracture occurs more readily at the pedicel–branch junction and that the normal bonding force at this junction is greater than the tangential bonding force. These findings provide a theoretical basis for achieving fruit–branch separation through vibration, impact, or drum-rubbing mechanisms.

Low-temperature mechanical properties of sea buckthorn

Low-temperature freezing markedly alters the mechanical properties of sea buckthorn fruit by increasing fruit firmness and resistance to damage, thereby reducing the risk of fruit injury during mechanical detachment and cleaning. Studies have shown (Lin et al., 2023; Zhang et al., 2024) that fruit detachment force, fruit mass, and peel firmness differ significantly under different frozen-storage temperatures, and that storage at –10 to –20 °C is more favorable for controlling fruit damage during vibration-based detachment. Such low-temperature conditions not only form the basis of manual knock-harvesting practices, but also directly support the feasibility of vibration-based harvesting and cut-branch fruit-detachment approaches.

Agronomic requirements and evaluation indicators for mechanized harvesting

Mechanized harvesting of sea buckthorn must achieve not only fruit detachment, but also compatibility with fruit quality requirements, downstream processing demands, and the sustainable productivity of the tree (Wang, 2021). Based on existing studies, the agronomic requirements for mechanized sea buckthorn harvesting can be summarized as follows (Lin, 2023; Zhang, 2024; Zhu et al., 2011).

First, fruit damage rate is the primary evaluation criterion, and fruit injury must be minimized to ensure raw-material quality and subsequent processing value.

Second, harvest efficiency, particularly fruit removal or recovery rate, is the core indicator of operational performance. Because sea buckthorn has a concentrated harvest window and is subject to losses from natural fruit drop and bird damage, harvesting must be both timely and efficient.

Third, the effect on yield in the following year is an important sustainability indicator. In direct vibration harvesting, excessive excitation forces that may damage branches should be avoided; in pruning-based harvesting, scientifically designed pruning regimes are required to prevent excessive branch removal.

Fourth, impurity content is a key quality indicator because it directly affects the cost and efficiency of subsequent cleaning and sorting operations.

Therefore, the evaluation of mechanized sea buckthorn harvesting should not be limited to whether fruit can be harvested at all. Instead, a comprehensive and multidimensional evaluation system should be established, encompassing harvest rate, fruit damage rate, impurity rate, operational efficiency, and tree damage, with the ultimate objective of ensuring that harvested raw materials meet the quality requirements of different processing applications.

DEVELOPMENT OF MECHANIZED SEA BUCKTHORN HARVESTING TECHNOLOGIES ABROAD

Research on mechanized harvesting of sea buckthorn began relatively early outside China. Since the 1950s, the former Soviet Union, Russia, Germany, Canada, and several Eastern European countries have continuously carried out equipment development and process exploration for mechanical harvesting of sea buckthorn berries, gradually forming a relatively clear trajectory of technological evolution (Schroeder et al., 2014; Zhai et al., 2024).

Early exploration and the stage of direct in-field harvesting

From the 1950s to the 1970s, two major technological prototypes were established abroad, namely vibration-based harvesting and pneumatic harvesting. Russia began research on vibration harvesting as early as the 1950s. A machine reported in 1989 was suitable for orchards with tree heights above 1 m and row spacings of 4–5 m, but its harvesting rate was only about 50% (Wang et al., 2023). This exposed the limitations of early vibration-harvesting systems, particularly their low energy-transfer efficiency and poor adaptability to complex tree architectures. During the same period, pneumatic harvesting technology also began to be explored. In 1990, Varlamov et al. established a mathematical model for pneumatic fruit separation, and the prototype achieved a fruit recovery rate of over 90%. However, this technology showed strong dependence on pedicel length and fruit attachment force.

Parallel development of multiple technological routes

From the 1990s onward, research increasingly focused on a deeper understanding of harvesting mechanisms and on the optimization of different technical routes. In the field of vibration harvesting, *Mann et al.*, (2001), designed a slider–crank branch shaker and found that fruit detachment rate was linearly and positively correlated with vibration amplitude. *Olander et al.*, (1995), further pointed out that vibration energy attenuates severely in long, slender, and flexible branches, making fruit at the distal ends difficult to detach. This finding clearly revealed the conditions under which vibration harvesting is most applicable, namely cultivars with regular canopy architecture, short and relatively thick fruiting branches, and low fruit attachment force.

Concurrently, to circumvent the challenges of direct fruit detachment in the field, the concept of cut-branch integrated harvesting began to emerge and move toward practice. In 2009, the cutting-type sea buckthorn harvester developed by the German company Kranemann employed a circular saw to cut fruit-laden branches, which were then collected using a reel and elevator (*Kranemann, 2009*), achieving a harvesting rate of over 80% and a damage rate below 5%. This marked the transition of the integrated branch–fruit harvesting approach from concept to engineered prototype. *Fu et al.*, (2014), considered this cutting-type harvester to be the only commercially viable technical route at the time, and emphasized that cultivar breeding and agronomic innovation are key prerequisites for improving the efficiency of mechanized harvesting.

Maturation and systematization of post-harvest separation processes

Since the beginning of the twenty-first century, with advances in cold-chain technology and automation equipment, the focus of overseas research has shifted from single-stage in-field harvesting to the system-level integration of the entire chain, including harvesting, freezing, fruit detachment, and cleaning. A representative feature of this transition is the engineering maturity of the whole branch–fruit harvesting plus post-harvest separation route. Research attention has increasingly turned to the efficiency and quality of post-processing operations. For example, *Aare Aan et al.* (2015) established a kinematic model of frozen fruit in a drum-type fruit-detachment device and analyzed the effects of equipment parameters on fruit damage rate. *Milea et al.*, (2019), systematically summarized the separation and processing technologies for frozen fruit-bearing branches and pointed out that post-processing equipment has become an indispensable component of large-scale harvesting technology systems.

The international evolution of mechanized sea buckthorn harvesting demonstrates that its success has been built on two major foundations: first, mechanization-suitable cultivars characterized by large fruits, fewer thorns, and a greater tendency to form an abscission layer; and second, standardized orchards characterized by wide row spacing and regular canopy architecture. These experiences provide an important lesson for China: breakthroughs in mechanized harvesting cannot rely solely on the development of individual machines, but must be coordinated with cultivar breeding and innovation in planting systems.

CURRENT STATUS OF MECHANIZED SEA BUCKTHORN HARVESTING RESEARCH IN CHINA

China's sea buckthorn resources are dominated by *Hippophae rhamnoides* subsp. *sinensis*, whose characteristics—small fruit, short pedicels, strong fruit attachment, and densely thorny branches—make the direct transfer of foreign harvesting technologies difficult (*Qin et al.*, 2019). Since the late 1980s, sustained research efforts have been devoted in China to addressing the challenges of sea buckthorn harvesting. According to differences in working principles and operational modes, domestic sea buckthorn harvesting technologies have gradually evolved into a diversified pattern comprising manual and hand-held assisted harvesting, pneumatic harvesting, vibration-based harvesting, and whole branch–fruit harvesting combined with fruit detachment and cleaning.

Manual and hand-held assisted harvesting

Manual harvesting remains the primary harvesting method in the major sea buckthorn-producing regions of China, and mainly includes two approaches: cutting branches bearing fresh fruit and knocking frozen fruit from branches (*Liang et al.*, 2008; *Yang et al.*, 2019). Harvesting by cutting fresh fruit-bearing branches generally ensures better fruit quality; however, improper pruning may negatively affect yield in the following year. Frozen-fruit knocking is carried out when the ambient temperature is below $-10\text{ }^{\circ}\text{C}$, taking advantage of the increased firmness and easier detachment of frozen fruit, and thus offers relatively higher operational efficiency. Nevertheless, prolonged freezing may adversely affect fruit flavor to some extent. Overall, manual harvesting is labor-intensive and inefficient, and has become a key bottleneck restricting industrial development (*Hu et al.*, 2017).

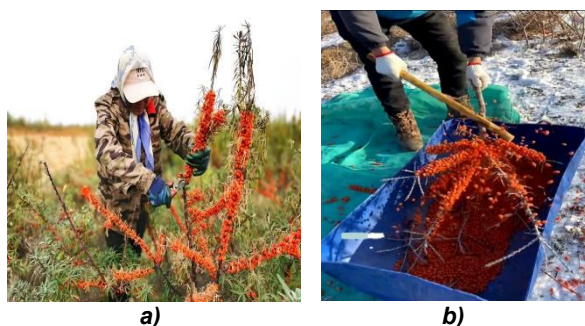


Fig. 1 – Manual harvesting of sea buckthorn
a) Fresh-fruit branch cutting; b) Frozen-fruit knocking

To alleviate the burden of manual harvesting, a series of hand-held assisted harvesting tools were developed in China during the early stages of research. Among vibration-based tools, the 1ZGQ-2B harvester developed by the Inner Mongolia Academy of Forestry used a hand-held vibrator to induce branch vibration for fruit detachment, with a fan-assisted collection system (Cao *et al.*, 2012). The Xinjiang Academy of Agricultural and Reclamation Sciences designed a hand-held vibrating head that enabled fruit collection through reciprocating motion (Cai *et al.*, 2016). Gansu Normal University for Nationalities developed an adjustable rotary-disc picker, in which fruit harvesting was achieved through contact between a rotating disc and the branches; this device was characterized by a simple structure and convenient operation (Gao *et al.*, 2022). Among combing or brushing tools, Yan, (2017), designed a roller-brush harvester for small berries, which used two counter-rotating roller brushes to apply vibration to sea buckthorn branches and thereby remove and collect the fruit. In addition, Wang *et al.*, (2013), focusing on the cut-branch harvesting mode, proposed a set of technical requirements covering harvesting methods, grading standards for fruit-bearing branches, and storage and transportation specifications, thereby providing a reference for the standardization of manual cut-branch harvesting.

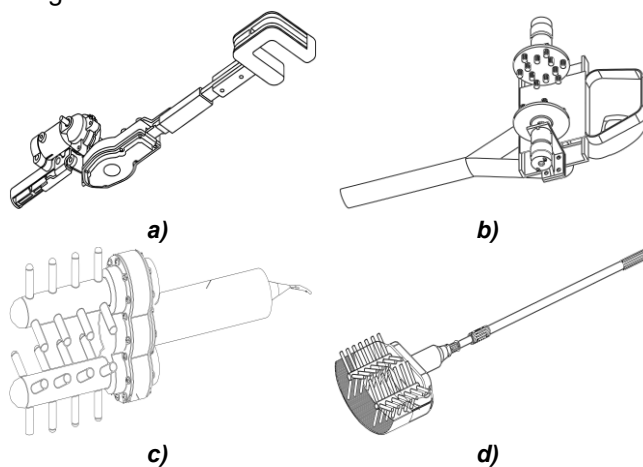


Fig. 2 – Handheld sea buckthorn harvesting tools
a) Vibration-type picker; b) Rotary-disc picker; c) Roller-brush picker; d) Integrated brushing and collecting picker

Although these hand-held tools have made some progress in structural simplification and operational convenience, they still generally suffer from limited gains in harvesting efficiency, difficulties in high-position operation, and poor suitability for prolonged use. As a result, they have not been widely adopted in commercial production. This indicates that simple auxiliary tools alone are insufficient to fundamentally resolve the technical bottlenecks of sea buckthorn harvesting, and that further breakthroughs towards mechanization and automation are urgently needed.

Pneumatic harvesting technology

Pneumatic harvesting technology has attracted considerable attention in China because of its non-contact mode of operation and its theoretically low risk of fruit damage (Zhang, 2016). Based on the introduced Russian МП70-6 model, the Inner Mongolia Academy of Forestry developed an improved pneumatic harvester, designated 1ZSQ-80 (Lin *et al.*, 2021; Ni *et al.*, 2015). Fu Longsheng *et al.*, (2014), designed a pneumatic harvesting device incorporating fruit–leaf separation, while Liu Zhihui *et al.* (2022) optimized key parameters, including conveying-pipe diameter and airflow rate, through FLUENT-based simulation analysis.

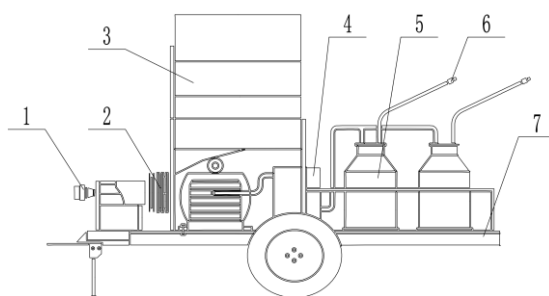


Fig. 3 – Pneumatic sea buckthorn harvester

1. universal joint; 2. pulley assembly; 3. fruit box; 4. vacuum pump; 5. fruit collection cylinder; 6. picking head; 7. frame

However, experimental studies have shown that the applicability of pneumatic harvesting is highly dependent on cultivar characteristics. This technology performs well for large-fruited Russian sea buckthorn cultivars with relatively long pedicels and fewer thorns, with daily harvesting capacity reaching up to 1000 kg. In contrast, its performance is much less satisfactory for *Hippophae rhamnoides* subsp. *sinensis*, which is characterized by inconspicuous pedicels, dense thorns, and strong fruit attachment (Yang *et al.*, 2017). This limitation fundamentally restricts the broad applicability of pneumatic harvesting technology in China. At present, it remains mainly at the stage of experimental investigation under specific operating conditions.

3.3 Vibration-Based Harvesting Technology

Vibration-based harvesting is one of the longest-researched technology directions in China, with the most substantial accumulated knowledge (Peng *et al.*, 2017; Kou *et al.*, 2025). Its fundamental principle involves applying forced vibration to the trunk or branches via an excitation device; when the inertial force on the fruit–pedicel system exceeds the bonding strength, the fruit detaches from the pedicel. The advantage of this method lies in its theoretical preservation of tree integrity and its compatibility with integrated fruit collection and receiving devices.

Regarding whole-plant or trunk vibration, Wang *et al.*, (2013), developed a mechanical vibration-type sea buckthorn harvester that uses a vibrating head clamped onto the trunk to apply excitation and achieve fruit detachment. Subsequent research has continuously improved the vibrating head structure and fruit collection system, resulting in enhanced harvesting rates. Experimental studies indicate that for effectively clampable branches, vibration harvesting efficiency is approximately 15 times higher than manual harvesting. However, due to limited adjustability of the clamping mechanism's angle, adaptability to branches with oblique growth angles or those located deep within the canopy remains poor, and the technology is still at the research and experimental stage.

Theoretical research has progressed in parallel. Peng *et al.*, (2017), through dynamic analysis of whole sea buckthorn trees, revealed the influence of tree modal characteristics on vibration parameter selection, noting that vibrating branches is more conducive to energy transfer to fruit-bearing parts than vibrating the trunk. Rahimov *et al.*, (2023), determined the first 12 natural frequencies of sea buckthorn trees, ranging from 11.204 to 79.895 Hz, providing a theoretical basis for optimizing vibration frequencies.

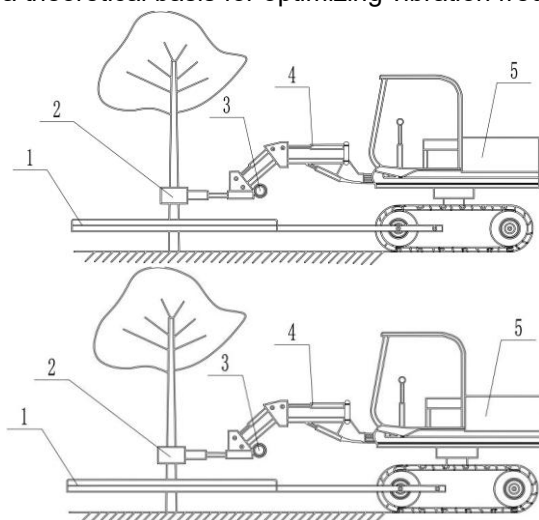


Fig. 4 – Trunk vibration – type sea buckthorn harvester

1. collecting device; 2. clamping device; 3. hydraulic motor; 4. height-control hydraulic cylinder; 5. tractor

In branch-vibration harvesting, research has focused more specifically on the precise excitation of individual branches or local branch sections. *Liu et al.*, (2026), found through finite element simulation and vibration experiments that the rupture strength of sea buckthorn berries is 1.577 MPa, and that approximately 80% of fruit detachment occurs when the vibration acceleration exceeds 2.5 g. By optimizing the vibration parameters, a relatively high harvesting rate can be achieved while keeping fruit damage at a moderate level. *Xu et al.*, (2011) designed a high-speed rotary vibration harvester whose picking head can flexibly hook onto branches and detach fruit through high-frequency vibration. Wen Baoqin at Shihezi University designed a self-propelled sea buckthorn harvester integrating fruit collection, picking, and storage functions (*Wen et al.*, 2019). *Chang et al.*, (2025), developed a fully automatic multifunctional harvester for sea buckthorn orchards, in which fruit is detached by high-frequency vibration and then conveyed through transport and impurity-removal systems into a collection box, thereby enabling fully automated harvesting. The Xinjiang Academy of Agricultural and Reclamation Sciences developed a novel vibrating head designed to reduce bark damage. *Wang et al.*, (2021), designed an adjustable clamping vibration device that achieved a relatively low fruit damage rate. Hebei Jilong Agricultural Machinery Co., Ltd. launched a bionic knocking-type integrated harvester employing a high-frequency vibrating rod that simulates manual knocking; its operational efficiency reached 0.33 ha·h⁻¹, although the problem of a relatively high missed-fruit rate has yet to be resolved (*Feng et al.*, 2025).

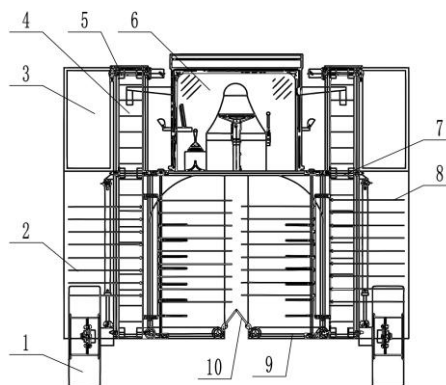


Fig. 5 – Branch vibration – type sea buckthorn harvester

1. crawler track; 2. left vibrating brush; 3. collection box; 4. conveyor belt; 5. drive wheel; 6. cab; 7. drive motor; 8. right vibrating brush

These studies indicate that vibration-based harvesting in China is evolving from prototype development towards parameter optimization based on dynamic mechanisms. Overall, however, because sea buckthorn typically exhibits a disordered basal branch structure rather than a single dominant trunk, vibration-based harvesting tends to suffer from a relatively high missed-fruit rate. In addition, inherent limitations such as vibration-energy attenuation and difficulty in parameter matching remain unresolved. Consequently, this technology is still mainly at the prototype testing stage. Its engineering adaptability, especially for *Hippophae rhamnoides subsp. sinensis*, which is characterized by highly flexible branches and strong fruit attachment, still requires further verification.

Whole branch–fruit harvesting with post-harvest fruit detachment and cleaning

This technological route divides the harvesting process into two relatively independent stages: in-field cutting and collection of fruit-bearing branches, and post-harvest separation of fruit from branches. It is intended to avoid the major difficulties associated with direct in-field fruit detachment, particularly interference from thorns and the high susceptibility of fruit to mechanical damage. At present, it represents one of the most practically relevant and fastest-developing technological directions for sea buckthorn harvesting in China.

Pruning-based harvesting technology

Pruning-based harvesting, also known as whole branch–fruit harvesting, constitutes the in-field operational stage of this technological route. Its core objective is to achieve efficient and low-damage cutting and collection of fruit-bearing branches. In studies on cutting mechanisms, *Wang et al.*, (2023), conducted double-acting blade cutting experiments and optimized the operating parameters using response surface methodology. The optimal parameter combination was an average cutting speed of 0.45 m·s⁻¹, a branch feeding speed of 0.64 m·s⁻¹, and a blade sliding-cut angle of 9.4°, under which the peak cutting force per unit diameter was reduced to 53.33 N·mm⁻¹ and the cutting energy consumption per unit area to 69.87 kJ·m⁻¹. *Ren*, (2023), further carried out simulation-based design and analysis of the cutting device using virtual simulation methods.

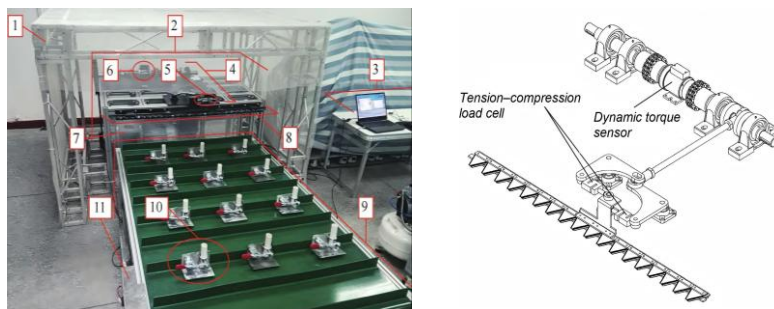


Fig. 6 – Double – acting cutter cutting test
a) Cutting test bench; b) Double-acting blade structure

In terms of equipment development, *Qin Xinyan et al. (2022)* designed a zoned pruning-type sea buckthorn harvester capable of meeting the cutting requirements of branches at different heights while also providing pruning and canopy-shaping functions. On this basis, the same team further proposed a self-propelled pruning harvester with secondary sectioning capability (*Dai et al., 2026*), in which long branches are cut into shorter segments to facilitate subsequent freezing-assisted fruit detachment. *Zhai Zhiyuan et al., (2024)*, developed an integrated cutting–branch-guiding–conveying device. Field experiments showed that when the machine operated at a forward speed of $0.6 \text{ m}\cdot\text{s}^{-1}$, a cutting speed of $1.2 \text{ m}\cdot\text{s}^{-1}$, and a conveying speed of $0.8 \text{ m}\cdot\text{s}^{-1}$, the missed-cut rate, fruit damage rate, and conveying failure rate were 6.72%, 4.06%, and 7.79%, respectively.

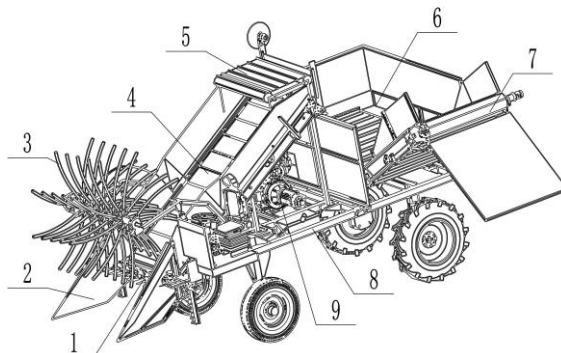


Fig. 7 – Cutting – type sea buckthorn harvester
1. cutting blade; 2. guide plate; 3. pressing and feeding roller; 4. conveyor belt; 5. sectioning device; 6. storage bin;
7. elevating storage conveyor; 8. machine body; 9. engine

These studies indicate that, in China, whole branch–fruit harvesting technology has progressed from research on individual cutting components to integrated machine-level development involving coordinated cutting, conveying, and collection. The main advantage of this route lies in its high in-field operating efficiency and its compatibility with subsequent cold-chain, fruit-detachment, and cleaning processes. Its limitation, however, is that its effectiveness depends strongly on tree training and pruning regimes; in the absence of supporting agronomic standards, it may adversely affect yield in the following year. Overall, this technology remains at the stage of pilot-scale validation and demonstration.

Fruit detachment and cleaning technology

Fruit detachment and cleaning constitute the post-harvest processing stage of this technological route, the core objective of which is to achieve efficient separation of fruit from quick-frozen fruit-bearing branches and the recovery of clean berries. At present, this field is evolving from the design of individual devices towards system-level integration and optimization.

In terms of fruit-detachment equipment, *Dai et al. (2026)* and *Yang. et al., (2022)*, developed a multistage drum-type fruit detacher and a fruit detachment–impurity removal machine, respectively, both of which achieve fruit detachment and preliminary screening through the coordinated action of beating rods and rotating screens. *Feng. et al., (2016)*, designed a beating-rod drum-type fruit-detachment screen and introduced a pre-crushing and loosening stage to improve the feeding performance of long fruit-bearing branches. *Wu et al., (2018)*, developed a loosening device to address the tendency of quick-frozen branches to agglomerate, while *Ma et al., (2018)*, used orthogonal experiments to determine the effects of the rotational speeds of the loosening device, drum screen, and beating unit on fruit detachment rate and fruit damage rate.

Lin. *et al.*, (2023), adopted a vibration-based fruit-detachment principle and, through parameter optimization, found that the best combined performance in terms of missed-fruit rate and fruit damage rate was obtained at -18°C , a vibration frequency of 21.1 Hz, an amplitude of 18 mm, and a vibration duration of 2 s. Jin *et al.*, (2025), developed a threshing device for sea buckthorn fruit-bearing branches that sequentially separates large branches, leaves, dust, and small twigs through the combined action of a drum mechanism and a screening mechanism, thereby achieving relatively thorough recovery of clean fruit.

With respect to cleaning equipment, Zhang. *et al.*, (2024), designed a low-damage sea buckthorn fruit detachment and cleaning machine to address problems such as high fruit damage rate, high impurity rate, and screen clogging. By adding a flow-reducing plate, the rate of incompletely detached fruit was reduced by 43%. After response surface optimization, the fruit damage rate in the detachment stage was reduced to 4.07%, and the incompletely detached fruit rate to 1.07%. In the cleaning stage, a three-layer screen structure was adopted and optimized using EDEM simulation. When the vibration frequency was 17.52 Hz, the vibration direction angle was 44.7° , and the screen inclination angle was 1.56° , the cleaning rate reached 99.62%. Hu *et al.*, (2021), also optimized the rotational speed and inclination angle of the drum screen through EDEM simulation.

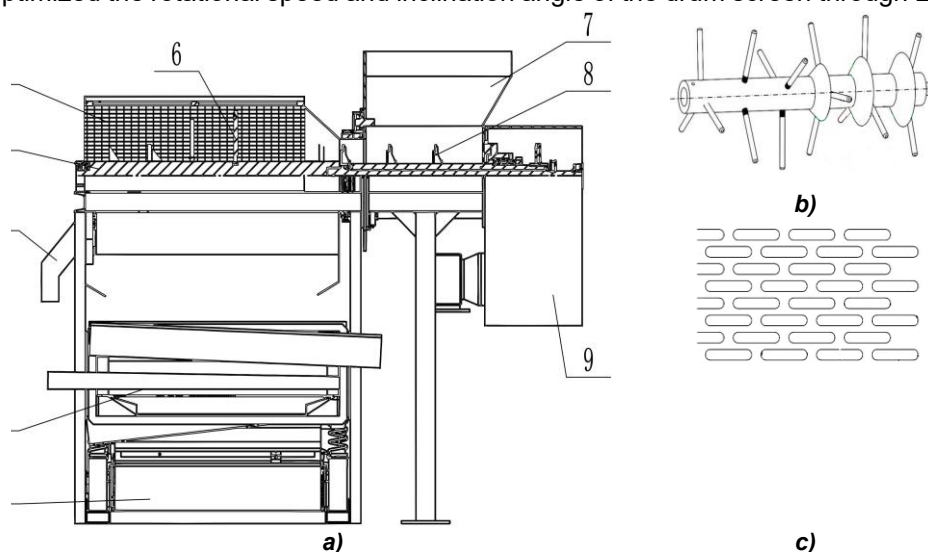


Fig. 8 – Schematic diagram of the fruit-detachment device structure

1. fan; 2. cleaning screen; 3. branch outlet; 4. main shaft; 5. flow-reducing plate; 6. drum screen; 7. feed inlet; 8. screw conveyor; 9. controller

At present, fruit detachment and cleaning technology has preliminarily formed two operating modes: a production-line mode and an integrated-machine mode. The former provides a complete processing workflow but requires relatively high investment, whereas the latter features a compact structure but remains highly dependent on manual assistance (Yang. *et al.*, 2022). Overall, this technology is developing towards the goals of low damage, high cleanliness, and continuous operation. However, its stable performance still depends heavily on the quality of upstream branch cutting, the stability of the quick-freezing process, and the precision of system matching. As a whole, it remains at the stage of research refinement and pilot-scale validation.

MAIN CHALLENGES IN MECHANIZED SEA BUCKTHORN HARVESTING

Although substantial progress has been made in China, several core challenges remain when current research is assessed against the industrial demands for large-scale, high-efficiency, and intelligent production.

1) **Weak mechanization-oriented foundations in cultivars and planting systems**

The dominant cultivated taxon in China, *Hippophae rhamnoides* subsp. *sinensis*, differs markedly from introduced large-fruited sea buckthorn cultivars in key traits such as pedicel length, thorn density, and fruit attachment force, making it difficult for existing equipment to simultaneously achieve broad applicability and satisfactory operating performance (Wen *et al.*, 2026; Wu *et al.*, 2025). At the same time, traditional planting systems generally lack standardized specifications for row spacing, plant spacing, and canopy architecture, and orchard infrastructure is often inadequate, which severely restricts the access and efficient operation of large-scale or specialized machinery (Zhu *et al.*, 2011). The weak mechanization-oriented foundation of both cultivars and planting systems has therefore become the primary obstacle to the adoption of mechanized harvesting technologies.

2) Insufficient integration of agricultural machinery and agronomy

Current research has focused predominantly on technical advances in harvesting equipment itself, whereas insufficient attention has been paid to the study and dissemination of supporting agronomic measures, such as mechanization-suitable canopy training, precise pruning regimes, and harvest-time management (Shang, 2023; Xie *et al.*, 2025). As a result, a disconnect between machinery development and agronomic requirements is widely observed. Even prototypes with good technical performance often fail to achieve stable and reliable operation under the complex and variable conditions of commercial orchards. Deep integration between agricultural machinery and agronomy has not yet been developed into a systematic solution.

3) Difficulty in the coordinated optimization of low fruit damage, high harvest efficiency, and high cleanliness

Adjusting the operating parameters of harvesting equipment can improve harvest rate to some extent, but this is often accompanied by an increase in fruit damage rate (Liang *et al.*, 2023). Existing studies have generally identified relatively optimal parameter combinations only for specific machine types, cultivars, and operating conditions. However, the robustness of these parameter sets remains limited, making it difficult to maintain stable performance across different cultivars, maturity stages, and temperature conditions. A systematic understanding of the trade-off mechanisms among harvest rate, fruit damage rate, and cleanliness is still lacking, which in turn restricts the cross-scenario adaptability of harvesting equipment.

4) Unclear coordination mechanisms between harvesting and processing quality

Sea buckthorn fruit has diverse end uses, including juice production, oil extraction, and flavonoid recovery, and each application imposes different requirements on fruit maturity, integrity, and bioactive component content. Studies have shown (Shang *et al.*, 2023) that harvest date significantly affects vibration-detachment characteristics, fruit color, chemical composition, and antioxidant activity. However, harvesting decisions in current production are still largely based on empirical judgement, and quantitative models linking processing targets, maturity indicators, harvesting parameters, and quality prediction are still lacking. Consequently, harvested raw materials are often poorly matched to downstream processing requirements, making it difficult to achieve quality-oriented utilization.

5) Low levels of equipment integration, intelligence, and standardization

Most existing achievements remain either single-function prototypes or individual machines at the pilot-testing stage, and their overall reliability, environmental adaptability, and continuous operating capacity still require further improvement (Zhai, 2024; Zhang *et al.*, 2024). Integrated equipment solutions covering the entire chain—from branch cutting, collection, and transport to quick-freezing, fruit detachment, and cleaning—are still lacking, and effective matching and coordination among different operational stages have not yet formed a closed-loop system. Meanwhile, there is a serious shortage of industry standards, testing-method standards, and operation-quality evaluation specifications specifically for sea buckthorn harvesting equipment. Research on intelligent sensing and adaptive control technologies is still at an early stage (Chen *et al.*, 2026), and the translation of research outcomes into large-scale application lacks adequate support from both technical standards and policy guidance.

FUTURE TRENDS AND RECOMMENDATIONS

In response to the five core challenges outlined above, future development of mechanized sea buckthorn harvesting in China should follow a coordinated strategy centered on agronomic guidance, equipment innovation, system integration, intelligent empowerment, and standards-based leadership. Progress should be advanced systematically in the following six directions.

1) Promoting the breeding of mechanization-suitable cultivars and the establishment of standardized planting systems

The development of mechanized sea buckthorn harvesting cannot be separated from the foundations provided by cultivars and agronomic practices. Future efforts should adopt a region-specific, cultivar-specific, and end-use-oriented strategy. In regions suitable for fresh-fruit processing and large-scale harvesting, priority should be given to cultivars with fewer thorns, larger fruit, clearly developed pedicels, and favorable abscission characteristics at maturity. In areas where ecological restoration and shelterbelt functions remain dominant, ecological adaptability should be balanced with the need for limited mechanized assistance (Wen, 2026). On this basis, standardized planting systems compatible with mechanized harvesting should be established by defining key technical parameters such as row and plant spacing, canopy training, pruning regimes, branch renewal practices, and machinery access lanes, thereby creating stable and controllable operating conditions for vibration-based, pruning-based, and semi-automatic harvesting equipment.

2) Deepening the integration of agricultural machinery and agronomy through innovation in cultivation systems

Resolving the mismatch between machinery and agronomy requires coordinated development of cultivation systems and harvesting equipment from the outset. On the one hand, mechanization-suitable canopy architectures, such as trunk-type and hedgerow-type systems, together with fruiting-branch renewal regimes and harvest-time regulation techniques, should be systematically studied in response to the requirements of different harvesting routes, so as to establish agronomic specifications tailored to mechanized harvesting (Song. *et al.*, 2025). On the other hand, equipment development should fully account for the biological characteristics and cultivation patterns of sea buckthorn, replacing simple technology transfer with adaptive design. In this way, agricultural machinery and agronomy can be deeply integrated at the levels of design concept, operating parameters, and operational timing.

3) Strengthening the development of key components for low-damage and high-efficiency harvesting

To address the central challenge of simultaneously achieving low fruit damage, high harvest rate, and high cleanliness, research should focus on several key components and technologies. These include variable-parameter excitation mechanisms adaptable to different branch structures and fruit maturity stages, flexible clamping components that balance gripping stability with low-damage requirements, low-power cutting devices suitable for highly lignified branches, and efficient fruit-detachment and multistage cleaning technologies under frozen-fruit conditions. Existing studies have already provided a relatively clear parameter basis for these directions. The next step should therefore be cross-scenario validation under different cultivars, branch ages, and temperature conditions, in order to improve the robustness and general applicability of equipment parameters.

4) Advancing integrated equipment for coordinated harvesting and processing quality

Sea buckthorn fruit serves diverse processing purposes, and different end uses impose different requirements on raw-material quality (Kyriakopoulou *et al.*, 2013). Quantitative models linking processing targets, maturity indicators, harvesting parameters, and quality prediction should therefore be established to enable quality-oriented harvesting decisions based on final use, thereby promoting value coordination between harvesting and processing. At the equipment level, multiple technical routes should be developed in parallel according to the characteristics of different production regions. In major production areas dominated by large-fruited cultivars, priority should be given to integrated technical systems combining whole branch–fruit harvesting, cold-chain pretreatment, mechanical fruit detachment, and high-efficiency cleaning. In orchards with favorable mechanization conditions, field vibration-based harvesting or semi-automatic assisted harvesting equipment should be further improved. The development goal of integrated equipment should shift from improving the performance of individual machines to achieving continuous, low-damage, and high-efficiency coordination across the entire process chain.

5) Promoting intelligent sensing and adaptive parameter control

With the increasing intelligence level of agricultural equipment, sea buckthorn harvesting machinery should evolve from purely mechanical execution towards intelligent regulation. Technologies such as machine vision, near-infrared sensing, vibration monitoring, and force-feedback systems can be used to achieve real-time perception of fruit maturity, branch structure, and operating status, thereby enabling the establishment of adaptive control models for online adjustment of vibration frequency, amplitude, cutting speed, conveying speed, and cleaning parameters (Li *et al.*, 2022). Liang., (2023), showed, in research on optimizing the vibration-separation trajectory of sea buckthorn fruit, that the introduction of improved strategies such as polynomial interpolation, adaptive inertia weights, and asynchronous learning factors significantly reduced fruit damage rate. This finding indicates that digital modelling and intelligent algorithms have considerable potential for improving harvesting performance. Liang. *et al.*, (2023), combined adaptive inertia weights, asynchronous learning factors, and 3-5-3 polynomial interpolation to propose an improved particle swarm optimization (I-PSO) algorithm for trajectory time optimization of a sea buckthorn fruit vibration separation manipulator. The results demonstrate that this algorithm can improve the mechanized harvesting efficiency and fruit detachment performance of sea buckthorn.

6) Improving standards systems and industrial support policies

It is recommended that operational quality evaluation standards, test-method standards, and safety specifications be established specifically for sea buckthorn harvesting equipment, with clear testing methods for core indicators such as fruit damage rate, harvest rate, impurity rate, cleaning rate, and tree damage. Such standards would provide an essential basis for equipment certification, market access, and technology promotion. At the same time, mechanized harvesting demonstration bases should be established in major

production regions such as Xinjiang, Inner Mongolia, and Shanxi to promote collaborative innovation among research institutes, equipment manufacturers, and processing enterprises. Harvesting equipment that is urgently needed by the industry and has reached a relatively high level of technological maturity should be considered for inclusion in agricultural machinery purchase subsidy programs, thereby lowering adoption thresholds for producers and accelerating the transformation of research achievements into practical productive capacity.

CONCLUSIONS

The biological characteristics of sea buckthorn fruit—small size, short pedicels, dense clustering, thorny branches, and thin, fragile skin—make mechanized harvesting a highly complex systems-engineering challenge that differs fundamentally from the harvesting of conventional fruit crops such as apple and walnut. The low efficiency of harvesting has become a major bottleneck restricting the improvement in quality and efficiency of the sea buckthorn industry in China. International mechanized harvesting technologies have mainly been developed for mechanization-suitable cultivars characterized by large fruit and fewer thorns, giving rise to technical systems represented by direct in-field harvesting and whole branch–fruit harvesting followed by post-harvest processing. In contrast, sea buckthorn resources in China are highly diverse, and *Hippophae rhamnoides subsp. sinensis* is characterized by small fruit, strong fruit attachment, and densely thorny branches, making the direct transfer of foreign technologies difficult.

In recent years, substantial progress has been made in China in areas such as optimization of vibration parameters for fruit detachment, low-damage cutting and conveying, vibration-assisted fruit detachment from pruned branches, and freezing-assisted fruit detachment and cleaning. Key technologies, including vibration-assisted detachment from cut branches, cutting–conveying devices, and low-damage fruit detachment and cleaning, have already established relatively clear parameter foundations. However, when assessed against the demands of large-scale, high-efficiency, and intelligent development, several major challenges remain, including weak mechanization-oriented foundations, insufficient integration of agricultural machinery and agronomy, difficulties in multi-objective coordinated optimization, unclear coordination mechanisms between harvesting and processing quality, and relatively low levels of equipment integration and intelligence.

Future development should therefore follow a coordinated strategy focused on agronomic guidance, equipment innovation, system integration, and intelligent technologies. Continued efforts should prioritize the breeding of cultivars suitable for mechanized harvesting, the establishment of standardized planting systems, the optimization of key harvesting components, the development of integrated harvesting equipment, the advancement of intelligent control technologies, and the establishment of technical standards, thereby gradually building a mechanized sea buckthorn harvesting technology system adapted to the diverse regional conditions, cultivar characteristics, and processing requirements of China.

ACKNOWLEDGEMENT

The authors were funded for this project by the Science and Technology Plan Project of the 12th Division, Xinjiang Production and Construction Corps (Grant NO.SRS2025303).

REFERENCES

- [1] Aan, A., Heinloo, M. (2015). Dynamics of a frozen sea buckthorn berry motion in a separator. *Procedia Engineering*, Vol. 100, No. 4, pp. 689-698, Netherlands.
- [2] Asif, R., Hu, J., Yang, M., Zhang, Q., Xiang, J., Zhang, W. (2023). Design and test of sea buckthorn quick-freezing storage based on CFD. *Xinjiang Agricultural Mechanization*, No. 3, pp. 9-11+20, Xinjiang/China.
- [3] Bai, Q. (2024). Pruning and Stubble Renewal Techniques of Sea Buckthorn (沙棘修剪及平茬更新技术). *Shanxi Forestry*, No. 4, pp. 40-41, Shanxi/China.
- [4] Cai, Y., Liu, J. (2016). A vibrating head for a novel sea buckthorn fruit harvester (一种新型沙棘果实采收机振动头). Patent No. 201620020313.8, China.
- [5] Cao, S., He, Y., Wang, M., Wang, X., Zhu, X., Li, L. (2012). Research Status and Consideration of Mechanized Harvesting Technology for Sea Buckthorn Fruit (沙棘果机械化采收技术的研究现状与思考). *Journal of Agricultural Mechanization Research*, Vol. 34, No. 5, pp. 12-15, Heilongjiang/China.

- [6] Chang, C. (Xinjiang Yuheng Sanshan Heavy Industry Manufacturing Co., Ltd.) (2025). A fully automatic multifunctional harvester for sea buckthorn forests (一种全自动沙棘林果多功能收获机). Patent No. 202311289189.6, China.
- [7] Chen, T., Liu, P., Ren, Y. (2026). Application of Artificial Intelligence in Agricultural Mechanization (人工智能在农业机械化中的应用探析). *Tractor & Farm Transporter*, Vol. 53, No. 2, pp. 62-65, China.
- [8] Ciesarová, Z., Murkovic, M., Cejpek, K., Kreps, F., Tobolková, B., Koplík, R., Belajová, E., Kukurová, K., Daško, L., Panovská, Z., Revenco, D., Burčová, Z. (2020). Why is sea buckthorn (*Hippophae rhamnoides* L.) So exceptional? A review. *Food Research International*, Vol. 109, 109170, Netherlands.
- [9] Cui, Y., Fu, L., Su, H., Li, R. (2014). Harvesting technologies for sea buckthorn fruit. *Engineering in Agriculture, Environment and Food*, Vol. 7, pp. 64-69, Netherlands.
- [10] Dai, Q., Zhang, C., Yang, J. (2026). Design and simulation analysis of multi-stage frozen sea buckthorn fruit detachment and cleaning device (多级式沙棘冻果脱果清选装置设计与仿真分析). *Journal of South China Agricultural University*, pp. 1-23, Guangdong/China. (Online First)
- [11] Feng, C., Bi, Y., Hu, W., Hu, J. (2016). Simulation test of sea buckthorn fruit detachment drum screen based on EDEM numerical simulation (基于 EDEM 数值模拟的沙棘脱果滚筒筛仿真试验). *Forestry Machinery & Woodworking Equipment*, Vol. 44, No. 6, pp. 34-37, Heilongjiang/China.
- [12] Feng, X. (2025). A Walking Blueberry Harvesting Device (一种行走式蓝莓收割装置). Patent No. 202421362254.3, China.
- [13] Feng, Y., Peng, J., Sun, S., Wu, Y., Fu, L. (2017). Determination and analysis of mechanical properties and morphological characteristics of sea buckthorn at harvest stage (收获期沙棘的力学特性与形态特征测定与分析). *Journal of Agricultural Mechanization Research*, Vol. 39, No. 10, pp. 180-184, Heilongjiang/China.
- [14] Fu, L., Li, R., Zhang, C., Wang, B., Yan, F., Guo, J., Su, B. (2014). Air-suction sea buckthorn fruit harvesting device (气吸式沙棘果实采收装置). Patent No. CN203735096U, China.
- [15] Gao, B., Li, X., Liu, Y., Xie, L., Min, Q., Liang, X. (2022). An adjustable rotary-disk sea buckthorn picker (一种可调节的转盘式沙棘采摘器). Patent No. 202122213582.X, China.
- [16] Hu, J. (2019). Construction, development and utilization of sea buckthorn industrial raw material forest in the Three-North region (三北地区沙棘工业原料林资源建设与开发利用). Beijing: China Environment Publishing Group, Beijing/China.
- [17] Hu, T., Hu, J., Bi, Y., Yang, M., Li, M., Yang, J. (2021). Design of sea buckthorn drum screen based on EDEM numerical simulation (基于 EDEM 数值模拟的沙棘滚筒筛设计). *Journal of Chinese Agricultural Mechanization*, Vol. 42, No. 9, pp. 122-129, Jiangsu/China.
- [18] Hu, W., Hu, J., Bi, Y., Zhang, Z., Feng, C. (2017). The Design and Test Research of Spiraling Stretch Shear for Sea-Buckthorn (沙棘螺旋伸缩剪的设计与试验研究). *Journal of Agricultural Mechanization Research*, No. 4, pp. 173-176, Heilongjiang/China.
- [19] Jin, H., Wang, G. (2025). Threshing device for sea buckthorn branch-borne fruit (沙棘枝条果脱粒设备). Patent No. 202511185000.8, China.
- [20] Kou, X., Qu, Z., Wang, D., Li, S., Tang, J., Cao, Y. (2025). Research Progress and Trends of Forest Fruit Vibratory Harvesting Equipment (林果振动式采收装备研究进展与趋势). *Forestry Machinery & Woodworking Equipment*, Vol. 53, No. 5, pp. 9-20, Heilongjiang/China.
- [21] Kranemann, H. H. (2009). Method and apparatus for mechanical harvest of sea buckthorn berries. German Patent No. DE102009040245, Germany.
- [22] Kyriakopoulou, K., Pappa, A., Krokida, M., et al. (2013). Effects of Drying and Extraction Methods on the Quality and Antioxidant Activity of Sea Buckthorn (*Hippophae rhamnoides*) Berries and Leaves. *Drying Technology*, Vol. 31, No. 9, pp. 1063-1076, United States.
- [23] Li, C., Tang, Y., Zou, X., Zhang, P., Lin, J., Lian, G., Pan, Y. (2022). A Novel Agricultural Machinery Intelligent Design System Based on Integrating Image Processing and Knowledge Reasoning. *Applied Sciences*, Vol. 12, 7900, Switzerland.

- [24] Liang, B. (2023). Optimization and experimental study on vibration separation trajectory of sea buckthorn fruit (沙棘果实振动分离轨迹优化与试验研究). Master's thesis, *Gansu Agricultural University*, Gansu/China.
- [25] Liang, B., Lin, X., Liu, G., Lei, J., Wang, W. (2023). Trajectory analysis and optimization of sea buckthorn fruit vibration separation manipulator based on I-PSO algorithm. *Scientific Reports*, Vol. 13, 20124, United Kingdom.
- [26] Liang, J. (2008). Introduction of achievements - sea buckthorn fruit harvesting technology and matching machinery (引智成果 - 沙棘果实采收技术及配套机械). *Inner Mongolia Forestry Science and Technology*, Vol. 34, No. 4, pp. 61-62, Inner Mongolia/China.
- [27] Lin, H., Sun, L., Wang, E. (2021). Development and application status and prospect of fruit tree vibration harvesters in China (我国林果振动采收机发展应用现状与展望). *Jiangsu Agricultural Sciences*, Vol. 49, No. 1, pp. 36-42, Jiangsu/China.
- [28] Lin, X. (2023). Design and research of vibration detachment device for cut branches of sea buckthorn (沙棘剪枝枝条振动脱果装置的设计与研究). Master's thesis, Shihezi University, Xinjiang/China.
- [29] Lin, X., Lei, J., Ren, Z., Zhang, J., Liang, B., Wang, B., Wang, W. (2023). Study on physical parameters and biological characteristics of Xinjiang seabuckthorn fruit after frozen storage (冻藏后沙棘果实的分离力与相关物理特性参数分析). *Xinjiang Agricultural Sciences*, Vol. 60, No. 10, pp. 2479-2485, Xinjiang/China.
- [30] Liu, L., Niu, C., Liu, X., Guo, Z., Zhu, Z. (2010). Development status and analysis of sea buckthorn harvester (沙棘收获机的发展现状及分析). *Xinjiang Agricultural Mechanization*, No. 1, pp. 35-37, Xinjiang/China.
- [31] Liu, M., Hou, J., Ding, H., Li, C., Tang, Q., Li, C., Zhu, Z., Huang, W. (2026). Investigation of Sea Buckthorn Vibration Shedding Damage Based on Experiment and Finite Element Method. *Journal of Food Process Engineering*, Vol. 1, pp. 1-18, United States.
- [32] Liu, Q., Zhang, Z., Liu, S., Lu, F. (2025). Pharmacological activity and medicinal value of different parts of sea buckthorn (沙棘不同部位药理活性与药用价值探究). *Frontiers in Pharmacy*, Vol. 29, No. 5, pp. 802-815, Hubei/China.
- [33] Liu, Z., Wang, P., Xu, B., Xia, Y., Luan, H., Yu, F., Wang, K. (2022). Simulation analysis of air-suction conveying system for sea buckthorn fruit picking device (沙棘果采摘装置气吸输送系统的仿真分析). *Journal of Jilin Institute of Chemical Technology*, Vol. 39, No. 9, pp. 75-79, Jilin/China.
- [34] Lu, S. (2023). International sea buckthorn development report (国际沙棘发展报告). Beijing: International Sea Buckthorn Association, Beijing/China.
- [35] Ma, C., Hu, J., Bi, Y., Li, Q., Shen, W. (2018). Design and test of pre-crushing sea buckthorn fruit detacher (预破碎沙棘脱果机的设计与试验). *Journal of Gansu Agricultural University*, Vol. 53, No. 3, pp. 166-172, Gansu/China.
- [36] Ma, Z., Fang, Y., Li, J., Wang, K., Luo, J., Peng, C., Ma, J., Wang, X. (2025). Comparative experiment on fruit characteristics of 10 sea buckthorn varieties (10 种沙棘品种果实特性比较试验). *Journal of Green Mine*, Vol. 24, pp. 172-174, China.
- [37] Mann, D. D., Petkau, D. S., Crowe, T. G., et al. (2001). Removal of sea buckthorn (*Hippophae rhamnoides* L.) berries by shaking. *Canadian Biosystems Engineering*, Vol. 43, pp. 2.23-2.28, Canada.
- [38] Mei, D., Ma, X., Fu, F., Cao, F. (2023). Research Status and Development Prospects of Sea buckthorn (*Hippophae rhamnoides* L.) Resources in China. *Forests*, Vol. 14, No. 12, 2461, Switzerland.
- [39] Milea, D., Visan, A. L., Bogdanof, C. G. (2019). A study regarding the actual state of art for technologies and equipment's used to separate the sea buckthorn fruits from harvested branches. *Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series*, Vol. 49, No. 2, pp. 379-388, Romania.
- [40] Ni, K. (2015). Design and analysis of fruit vibration harvesting mechanism based on epitrochoid trajectory (基于外旋轮线轨迹的果品振动采收机构设计与分析). Master's thesis, Zhejiang Sci-Tech University, Zhejiang/China.

- [41] Olander, S. (1995). Mechanical harvesting of sea buckthorn[C]. Proceedings of the International Sea Buckthorn Workshop, Germany.
- [42] Peng, J., Sun, S., Fu, L. (2017). Dynamic research on mechanical vibration harvesting of sea buckthorn (机械振动式沙棘采收的动力学研究). *Journal of Agricultural Mechanization Research*, Vol. 39, No. 1, pp. 32-37, Heilongjiang/China.
- [43] Qin, J. (2025). Optimization of Tissue Culture Rapid Propagation System of *Hippophae rhamnoides* L. (沙棘优良品种组培体系优化研究). Master's thesis, Xinjiang Agricultural University, Xinjiang/China.
- [44] Qin, X., Zhai, Z., Lei, J., Zhang, J., Wang, W. (2022). A zone-divided cut-branch sea buckthorn harvester (一种分区域剪枝式沙棘收获机). Patent No. 202111066061.4, China.
- [45] Qin, X., Song, J., Chen, Z., Lang, X., Wei, C., Xiao, Y., Lu, L., Wang, J., Wang, W., Tang, C. (2025). A secondary cut-and-segment self-propelled crescent rotary cut-branch harvester for sea buckthorn (一种二次可裁段式自走沙棘月牙旋转剪枝收获机). Patent No. 202510598249.5, China.
- [46] Ren, Z. (2023). Design and experimental study of cutting device for sea buckthorn harvester (沙棘收获机剪切装置设计与试验研究). Master's thesis, Shihezi University, Xinjiang/China.
- [47] Ren, Z., Lei, J., Peng, X., Qin, X., Wang, W. (2024). Experimental study on mechanical properties of sea buckthorn branches (沙棘枝杆力学特性试验研究). *Journal of Agricultural Mechanization Research*, Vol. 46, No. 7, pp. 146-151, Heilongjiang/China.
- [48] Schroeder, W. R., Soolanayakanahally, R. Y., Naeem, H. A. (2014). Harvest Moon Seabuckthorn. *Canadian Journal of Plant Science*, Vol. 94, No. 7, pp. 1309-1312, Canada.
- [49] Shang, L. (2023). Effects of Pruning with Different Tree Shapes on Seed Yield and Quality of Sea Buckthorn Seed Collection Forest (不同树形的修剪对沙棘采种林种子产量和质量的影响). *Tianjin Agricultural Science and Technology*, No. 6, pp. 22-24+38, Tianjin/China.
- [50] Song, H., Zhao, K., Zhao, X., et al. (2025). Orchard Mechanization Construction and High Light Efficiency Tree Shape Cultivation Techniques for Peach Orchards in Sichuan Province (四川省桃园宜机化建园与高光效树形培养技术). *Sichuan Agricultural Science and Technology*, No. 8, pp. 36-39, Sichuan/China.
- [51] Song, J., Lei, J., Qin, X., Chen, Z., Lang, X., Wang, J., Wang, W., Tang, C. (2025). Design and Experimental Investigation of a Self-Propelled Sea Buckthorn Cutting Harvester with a Reciprocating Cutter. *Agriculture*, Vol. 15, 2428, Switzerland.
- [52] Tang, K. (2023). Comparative on Fruit Separation Ability of 10 Different Subspecies of *Hippophae rhamnoides* Strains at Maturity (十个不同亚种沙棘株系成熟期果实分离力比较). *Heilongjiang Agricultural Sciences*, No. 10, pp. 42-46, Heilongjiang/China.
- [53] Tiitinen, K. M., Hakala, M. A., Kallio, H. P. (2005). Quality components of sea buckthorn (*Hippophae rhamnoides*) varieties. *Journal of Agricultural and Food Chemistry*, Vol. 53, No. 5, pp. 1692-1699, United States.
- [54] Varlamov, G. P., Gabuniya, V. G. (1990). Picking sea buckthorn fruit by suction air stream. *Traktory i Sel'skokhozyaistvennye Mashiny*, No. 1, pp. 29-30, Russia.
- [55] Wang, B., Lei, J., Qin, X., et al. (2023). Analysis and experiment of cutting parameters for sea buckthorn branches using double-acting cutter (双动刀沙棘枝条切割参数分析与试验). *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 39, No. 10, pp. 26-36, Beijing/China.
- [56] Wang, B., Liu, C., Shi, X., Song, Z., Tang, Z. (2025). Establishment and Promotion of an Ecological Intercropping Model of *Hippophae rhamnoides* with Medicinal Herbs (沙棘林药间作生态种植模式构建与推广). *China Wild Plant Resources*, Vol. 44, S1, pp. 89-93, China.
- [57] Wang, K., Xu, Z., Liao, X. (2022). Bioactive compounds, health benefits and functional food products of sea buckthorn: a review. *Critical Reviews in Food Science and Nutrition*, Vol. 62, No. 24, pp. 6761-6782, Beijing/China.
- [58] Wang, M. (2013). Harvesting technology of sea buckthorn branch-borne fruit (沙棘枝条果采收技术). *Friend of Farmers*, No. 6, pp. 86, China.

- [59] Wang, M., Cao, S., He, Y., Wang, X., Ying, Y., Zhu, X., Li, L. (2013). Experimental study on mechanical vibration type sea buckthorn harvester (机械振动式沙棘采收机的试验研究). *Journal of Agricultural Mechanization Research*, Vol. 35, No. 9, pp. 202-204+208, Heilongjiang/China.
- [60] Wang, P., He, T., Wang, C., Ying, J., Yi, W. (2025). Current status of mechanized harvesting technology for characteristic forest fruits in China (我国特色林果机械化采收技术现状). *Journal of Chinese Agricultural Mechanization*, Vol. 46, No. 7, pp. 48-54, China.
- [61] Wang, W., Lin, X. (2021). An adjustable clamping vibration harvesting device for sea buckthorn branch-borne fruit (一种可调式沙棘枝条果夹持振动采收装置). Patent No. 202110768977.8, China.
- [62] Wang, Z. (2021). Harvesting, postharvest treatment and processing of sea buckthorn fruit (沙棘果实采收、采后处理与加工). *Agricultural Engineering Technology*, Vol. 41, No. 17, pp. 42+44, China.
- [63] Wang, Z., Zhao, F., Wei, P., Chai, X., Hou, G., Meng, Q. (2022). Phytochemistry, health benefits, and food applications of sea buckthorn (*Hippophae rhamnoides* L.): A comprehensive review. *Frontiers in Nutrition*, Vol. 9, No. 9, 1036295, Switzerland.
- [64] Wen, B., He, L., Kan, Z., Li, J. (2019). A sea buckthorn harvester (一种沙棘收获机). Patent No. 201710853922.0, China.
- [65] Wen, E. (2026). Systematic elaboration of optimization schemes for variety breeding and efficient cultivation techniques of sea buckthorn in arid and semi-arid regions (干旱半干旱区沙棘品种选育与高效栽培技术的优化方案系统阐述). *Friend of Farmers*, No. 7, pp. 147-149, China.
- [66] Wu, Y., Tang, K., Wang, R., Zhang, L., Fang, L., Li, P., Hou, S., Song, M. (2025). Analysis of Excellent Variety Characteristics of Sea Buckthorn by Heilongjiang Academy of Agricultural Sciences (黑龙江省农业科学院沙棘优良品种特性分析). *Heilongjiang Agricultural Sciences*, No.3, pp.33-38, Heilongjiang/China.
- [67] Wu, R., Hu, J. (2018). A loosening device for sea buckthorn (一种沙棘打散装置). Patent No. 201720423596.5, China.
- [68] Xie, S., Ma, F., Zhang, C. (2025). Effects of different harvesting periods on processing quality of *Hippophae rhamnoides* L., "Shenqihong" in the Ninth Division of Baiyang City (不同采收期对第九师白杨市“深秋红”沙棘加工品质的影响). *Oasis Agriculture Science and Engineering*, Vol. 10, No. 4, pp. 95-106, Xinjiang/China.
- [69] Xu, Z., Wang, J., Yuan, Y. (2011). High-speed rotary vibration type sea buckthorn fruit harvester (高速旋转震动式沙棘果实采收机). Patent No. 201110119461.7, China.
- [70] Yan, D., Yang, N., Wang, Y., Li, Z., Shi, J., Shi, Y., Wang, Y., Chen, Q. (2026). Analysis of differences in quality of sea buckthorn fruits in different regions (不同地区沙棘果实品质差异分析). *Food and Fermentation Industries*, China. (Online First)
- [71] Yan, L. (2017). A roller-brush small berry picker (一种滚刷式小浆果采摘器). Patent No. 201510049164.8, China.
- [72] Yang, D., Niu, C. (2017). Analysis of sea buckthorn harvesting status in Altay region (阿勒泰地区沙棘采收现状浅析). *Xinjiang Agricultural Mechanization*, No. 4, pp. 33-34+47, Xinjiang/China.
- [73] Yang, J., Hu, J., Yang, M., Bi, Y. (2022). Design and simulation analysis of screening device for frozen sea buckthorn fruit (沙棘冻果筛分装置设计与仿真分析). *Agricultural Research in the Arid Areas*, Vol. 40, No. 6, pp. 276-285, Shaanxi/China.
- [74] Zhai, Z. (2024). Design and experiment of cutting-conveying device for sea buckthorn harvester (沙棘收获机切割 - 输送装置的设计与试验). Master's thesis, *Shihezi University*, Xinjiang/China.
- [75] Zhang, D., Zhao, X., Jiang, X., Du, W., Ruan, C., Ge, S. (2024). Comparison of phenolic acids and flavonoids in leaves and berries of different varieties of seabuckthorn. *Non-wood Forest Research*, Vol. 42, No. 4, pp. 247-256, Henan/China.
- [76] Zhang, Q. (2024). Design and research of low-damage sea buckthorn fruit detachment and cleaning machine (低损伤沙棘脱果清选机的设计研究). Master's thesis, *Gansu Agricultural University*, Gansu/China.

- [77] Zhang, X. (2026). Planting Techniques and Industrial Development Suggestions of Sea Buckthorn (沙棘栽植技术与产业发展建议). *Modern Rural Science and Technology*, No. 1, pp. 97-98, Hebei/China.
- [78] Zhang, Y. (2016). Parameter Optimization and Experimental Research of Air Suction Berries Harvester Picking Head (气吸式小浆果收获机采摘头参数优化与试验研究). Master's thesis, *Northeast Agricultural University*, Heilongjiang/China.
- [79] Zhu, X., Li, L. (2011). Problems and suggestions on mechanized harvesting of sea buckthorn in Altay region (阿勒泰地区沙棘采收机械化存在的问题及建议). *Xinjiang Agricultural Mechanization*, No. 1, pp. 49-52, Xinjiang/China.
- [80] Zhu, Z. (2024). Experimental study on vibration harvesting damage of sea buckthorn (沙棘振动收获损伤试验研究). Master's thesis, *Shenyang Agricultural University*, Liaoning/China.