Review Article

A Review of the Current Status, Challenges, and Strategies for Precision Soybean Seed Metering Devices in China

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Abstract

Soybeans serve as a crucial grain, oil, and cash crop in China, yet the nation currently suffers from alarmingly low self-sufficiency rates. The sowing process, being the most critical phase of soybean production, directly determines crop yield and quality. Notably, the suboptimal performance of precision seed meters remains the primary bottleneck limiting yield enhancement due to issues with seeding accuracy. This study aims to analyse the current state of soybean production, highlight technological advancements in seed metering devices, and propose improvement strategies to enhance sowing quality and reduce import dependence, thereby providing a theoretical foundation. This paper systematically retrieves literature from databases such as CNKI, Web of Science, Elsevier, and IEEE Xplore, integrating journal articles, patent documents, and industry reports published between 2000 and 2024. It conducts a comparative analysis of the types, working principles, and research progress of soybean seed metering devices in China and abroad. Results showed that domestic seed metering devices are primarily mechanical, suffering from issues such as excessive seed damage and missed seeding rates, whereas foreign pneumatic seed metering devices offer high precision but are costly and lack adaptability.

Keywords: Research status, Seed planter, Seed quality, Solution, Soybeans

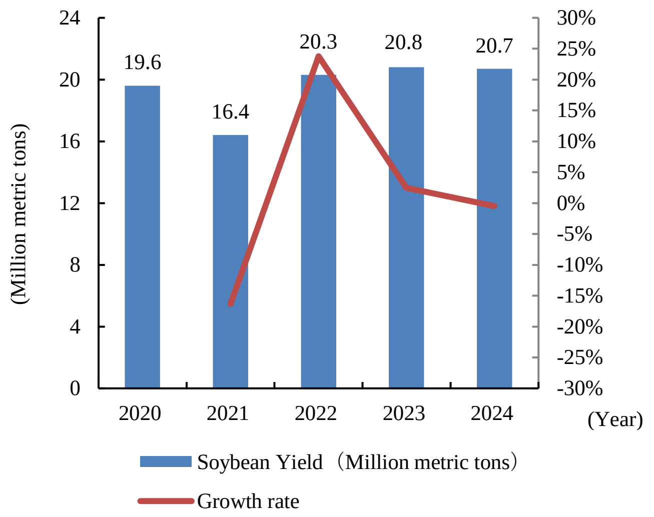
Introduction

Soybeans, renowned for their high protein content, unsaturated fatty acids, and dietary fibre, serve as a strategically vital crop in China—functioning simultaneously as a staple food, oilseed, and cash crop (Ding *et al.*, 2024a; Dong *et al.*, 2024; He & Wu, 2022; Sharma *et al.*, 2014). Furthermore, soybean byproducts such as stalks provide high-quality forage for dairy and beef cattle, making soybean cultivation integral to China's food security, livestock industry sustainability, and broader socioeconomic stability (Colletti *et al.*, 2020; Huai *et al.*, 2022; Jing *et al.*, 2019; Moroșan *et al.*, 2023; Yu *et al.*, 2023).

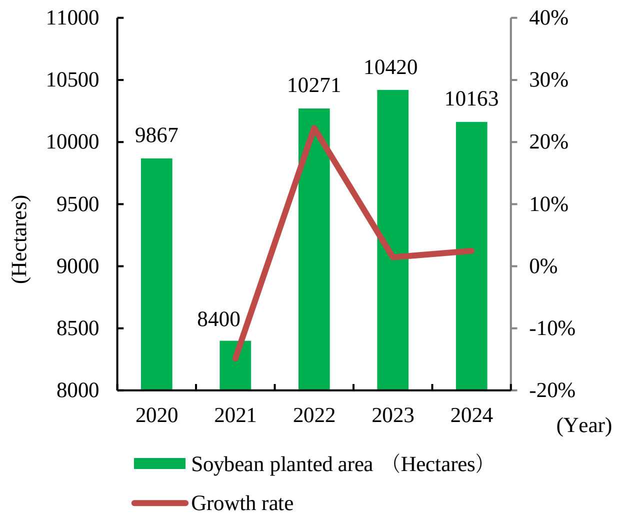
China's current domestic soybean production remains severely insufficient to meet demand (Dong *et al.*, 2021; Jia *et al.*, 2018; Jin *et al.*, 2024). To ensure a stable supply of meat and protein for domestic consumption, the country still relies heavily on soybean imports annually (Wei *et al.*, 2023; Wu *et al.*, 2023; Zeng, 2017). Extensive practical evidence demonstrates that seeding quality is a decisive factor in soybean yield (Zuo *et al.*, 2023). Traditional crop production followed the principle of "30% dependent on seeding, 70% on field management," whereas modern agricultural practices have shifted to "70% dependent on seeding, 30% on management" (Li *et al.*, 2024a). As a pivotal stage in soybean cultivation, improving seeding precision has become one of the most effective strategies to enhance yield per unit area, as it directly determines final production output (Li *et al.*, 2022a; Qu *et al.*, 2023; Zhao, 2023). With the rapid expansion of land transfer policies and the increasing scale of field operations, conventional seeders can no longer meet the demands of high-speed, high-precision, large-scale planting. This technological limitation has become a major bottleneck restricting the development of China's soybean industry. Since the performance of seed metering devices fundamentally dictates seeding quality, enhancing their precision is a critical step toward advancing domestic soybean production (Chen *et al.*, 2020; Liao *et al.*, 2023). Therefore, developing high-speed precision seed metering technology and designing optimised soybean seed meters, featuring simple structure, high operational speed, superior seeding consistency, and reliable stability, holds significant importance for increasing China's soybean yield.

Soybean yield analysis

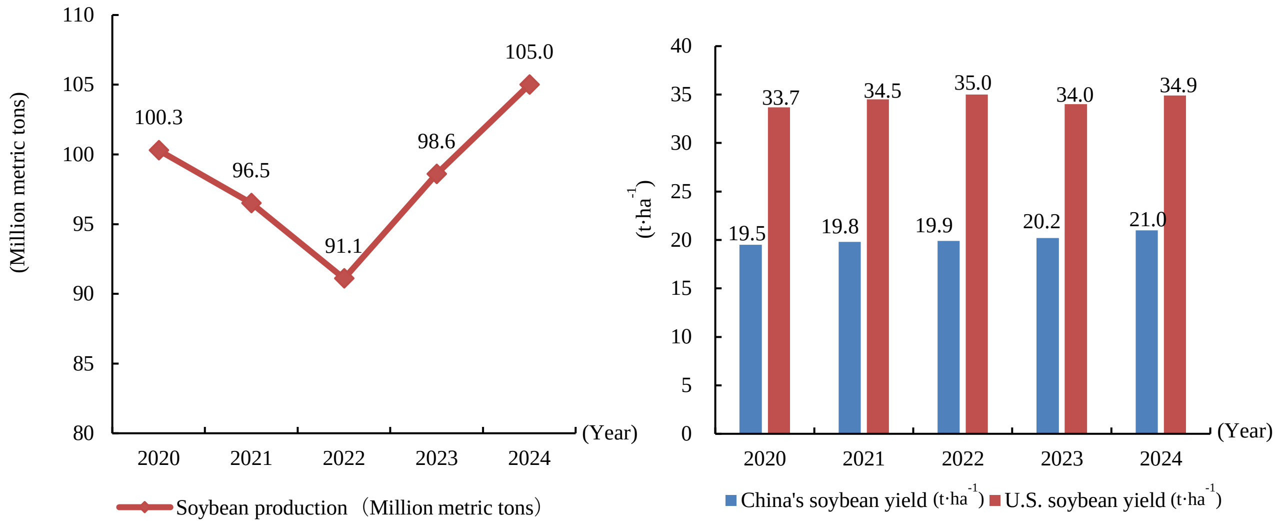
China's annual soybean demand currently stands at approximately 120 million metric tons, with domestic production meeting only 20 million tons, while imports account for 100 million tons. This represents a significant supply gap, with imports constituting over 80% of total consumption. The domestic soybean cultivation area spans about 15 million hectares (225 million mu), with limited potential for further expansion due to land constraints. As illustrated in Figures 1a and 1b, both production output and cultivation area have demonstrated steady growth over the past five years, with the exception of 2021 when favourable corn prices led some farmers to shift planting preferences, resulting in temporary reductions. Figure 1c reveals China's substantial import volumes, which consistently exceed domestic production by 4-6 times annually. A critical productivity gap is evident in Figure 1d, which compares yield per unit area between China and the United States. This significant yield disparity represents a fundamental challenge contributing to China's heavy import reliance. Enhancing domestic yield performance emerges as a crucial strategy for improving China's soybean supply security.



(a) Soybean production in China from 2020 to 2024



(b) Soybean planting area in China from 2020 to 2024



(c) China's soybean import volume from 2019 to 2023

（d）Comparison of Soybean Yields Between China and the United States from 2020 to 2024

Fig. 1. Status of the soybean industry

Types and working principles of seeders

The seed metering device serves as the core component of precision seeders, functioning through four critical operational stages: seed pickup, seed clearing, seed transport, and seed release, which collectively transform disordered seed populations into organised single-seed flows (Kang *et al.*, 2023; Li *et al.*, 2024b; Yang *et al.*, 2016; Zhu *et al.*, 2023). Based on their working principles, these devices are primarily classified into two fundamental categories: pneumatic and mechanical systems (Gai *et al.*, 2023; Li *et al.*, 2024c). Pneumatic seed meters are further subdivided into vacuum-type, air-blow type, and positive-pressure type configurations, while mechanical variants encompass diverse structural designs, including spoon-wheel, finger-pick, fluted-roller, disc-type (horizontal, vertical, and inclined orientations), cell-wheel, and brush-type mechanisms. This systematic classification reflects the technological diversity developed to address various agronomic requirements and operational conditions in precision planting systems (Li *et al.*, 2024d; Liu *et al.*, 2017; Shang *et al.*, 2023).

As illustrated in Figure 2a, the vacuum-type precision seed metering device operates through negative pressure seeding: the seed pickup mechanism initially attracts multiple seeds, followed by a precision clearing system that removes excess seeds to ensure single-seed retention (Han *et al.*, 2023; Li & Gao, 2023). The selected seeds remain securely adhered to the suction holes under sustained vacuum pressure during transportation, with precise seed release achieved through controlled airflow interruption at the designated drop zone. Figure 2b demonstrates the positive-pressure type seed meter, which utilises compressed air for seed pickup. This configuration exhibits superior seeding performance under high-speed operating conditions, particularly in terms of seed pickup and release accuracy (Wang *et al.*, 2015). However, its operational efficiency is heavily dependent on a sophisticated air supply system capable of maintaining consistent pressure levels. The air-blow type seed meter (Figure 2c) employs a unique combination of airflow differential and mechanical orifices for seed acquisition (Han *et al.*, 2017; He *et al.*, 2015). While this design provides excellent seed protection during transport, its clearing mechanism relying solely on fan-generated airflow, presents significant limitations. The inherent difficulty in regulating airflow intensity results in suboptimal seed clearing performance, representing a critical technical constraint for this configuration.

(a) Vacuum-Aspirated Precision Seed Metering Device (b) Positive-Pressure Seed Metering Apparatus (c) Air-Blast Precision Seed Metering Device

Fig. 2. Schematic of pneumatic precision seed metering devices

Pneumatic precision seed meters are less sensitive to seed size and shape, ensuring minimal seed damage during operation. They also demonstrate superior seeding performance under high-speed working conditions. However, their complex structure and requirement for precise air pressure control result in higher costs. In contrast, mechanical precision seed meters feature simpler structures, lower manufacturing costs, and better operational practicality. These advantages have led to their widespread adoption in China's agricultural production (Ding *et al.*, 2024b; Zhang *et al.*, 2022).

The spoon-wheel precision seed meter, as illustrated in Figure 3a, operates through a unique scooping mechanism. Seeds are captured by the spoons and transported to the cleaning zone, where excess seeds are removed under the combined action of gravity and centrifugal force (Li *et al.*, 2018; Yuan *et al.*, 2017; Zhang *et al.*, 2023a). Upon reaching the seeding zone, seeds are discharged with the assistance of a guide wheel to complete the planting process. This type of seed meter offers advantages such as a simple structure, low manufacturing cost, and reliable performance at low operating speeds. However, it is prone to significant seed skipping at high speeds, leading to seedling gaps and yield reduction. Consequently, its operational speed is typically limited to below 7 km h^{-1}.

The finger-type precision seed metering device (Figure 3b) employs a unique clamping mechanism for seed feeding. During operation, seed grippers securely hold individual seeds as the metering disk rotates to the cleaning zone. Here, a vibration-based clearing mechanism removes excess seeds, retaining only the most securely held single grain (Zhang *et al.*, 2023b). Upon reaching the discharge position, the grippers release the seed into the seed tube, completing the planting cycle (Wang *et al.*, 2021). The finger-type seed metering device demonstrates exceptional operational reliability owing to its positive clamping mechanism for seed pickup and transport, which effectively minimises seed skipping caused by mechanical vibrations (Wang *et al.*, 2019; He *et al.*, 2020). However, this design presents several inherent limitations: (1) a relatively complex mechanical structure, (2) stringent requirements for seed dimensional uniformity, and (3) potential seed damage during the clamping process.

As shown in Figure 3c, the fluted-roller precision seed meter employs a groove-filling mechanism with gravity-assisted seed discharge, featuring simple construction and strong adaptability (Ge *et al.*, 2023). However, it tends to produce pulsation effects that adversely affect seeding accuracy. Figure 3d illustrates the cell-wheel precision seed meter, which utilises gravity-based seed filling and discharge. This cost-effective design allows for adjustment of cell size and number to accommodate different crops, but is prone to significant seed skipping and seed damage at high operating speeds, making it primarily suitable for small-to-medium-sized planters (Du *et al.*, 2022; Lai *et al.*, 2020; Jia *et al.*, 2018).

Precision disc-type seed metering devices are primarily categorised into three configurations: horizontal, vertical, and inclined disc seed meters, all operating on the fundamental principle of cell-filling seed acquisition, scraper-based seed cleaning, and gravity-assisted seed discharge. As depicted in Figure 3e, the horizontal disc configuration demonstrates structural simplicity and achieves superior seeding accuracy at low operational speeds, yet its elevated seed release height often induces seed bouncing within the furrow, rendering it unsuitable for high-speed applications. The vertical disc variant shown in Figure 3f offers cost-effectiveness and reduced seed drop height, though its constrained filling area leads to pronounced seed skipping during high-speed operation. Figure 3g illustrates the inclined disc design, which combines an expanded filling zone with minimal seed release height, but requires a more sophisticated transmission system to maintain operational efficiency.

The brush-type precision seed metering device (Figure 3h) employs a sophisticated mechanism combining cell-filling seed acquisition, flexible brush-based seed cleaning and transport, and gravity-assisted seed discharge to achieve precision seeding (Li *et al.*, 2024a). This innovative design features exceptional seed protection through its gentle brushing system, effectively preventing seed damage while maintaining high seeding accuracy at low operating speeds. Particularly suitable for legume crops, the device demonstrates excellent performance in various bean seeding applications. However, its operational limitations become apparent during high-speed operation, where significant seed skipping occurs, making it challenging to maintain precision seeding quality at elevated working speeds.

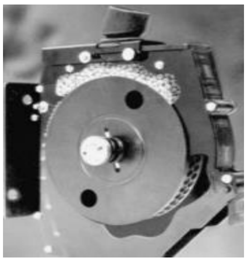

(a) Spoon-Wheel Seed Metering Device


(b) Finger-Pickup Seed Metering Device


(c) Fluted-Roller Seed Metering Device


(d) Cell-Wheel Seed Metering Device


(e) Horizontal Disk Seed Metering Device


(f) Vertical Disk Seed Metering Device


(g) Inclined Disk Seed Metering Device


(h) Brush-Type Seed Metering Device

Fig. 3. Schematic of a mechanical precision seed metering devices

Mechanical precision seed meters offer distinct advantages, including simple construction, low cost, and reliable performance at low operating speeds—characteristics that align well with China's prevailing soybean cultivation practices predominantly conducted on small-scale plots (Li *et al.*, 2023; Lei *et al.*, 2021). These merits ensure mechanical seed meters maintain significant market applicability, currently representing the mainstream solution for precision soybean planting in China. However, their operational limitations become pronounced during high-speed operation, where severe seed skipping leads to dramatic deterioration in seeding quality. Consequently, most mechanical seed meter applications are currently restricted to low-speed operations (Li *et al.*, 2022b; Li *et al.*, 2021a).

Research status of soybean seeders at home and abroad

Research status of soybean seed metering technologies in Europe and North America

In developed countries such as those in North America and Europe, where soybean cultivation is predominantly conducted on large-scale farms, pneumatic precision seed metering systems have gained widespread adoption due to their ability to maintain superior seeding quality even under high-speed operations. In contrast, mechanical precision seed metering technology has seen relatively limited application in these markets, primarily because of its incompatibility with high-speed planting requirements.

As illustrated in Figure 4, the pneumatic soybean seed meter developed by German Horsch Company incorporates multiple innovative technologies to ensure precision seeding performance. The system features an air-cushion sealing mechanism that maintains stable negative pressure in the vacuum chamber. In the seed-filling zone, a specially designed seed-pushing wheel actively clears blocked soybeans, significantly improving filling efficiency while preventing seed accumulation. The cleaning zone utilises a dual-sided seed-clearing system that guarantees single-seed retention per vacuum hole. Additionally, an integrated high-speed air-flow seed delivery system enhances planting accuracy, particularly during high-speed operations. This comprehensive design addresses critical challenges in precision planting through its coordinated subsystems working in unison. The seed meter achieves reliable seed singulation via negative pressure, enabling a seeding speed of up to 12 km h^{-1}, while optimal seed embedding ensures maximum crop yield potential.

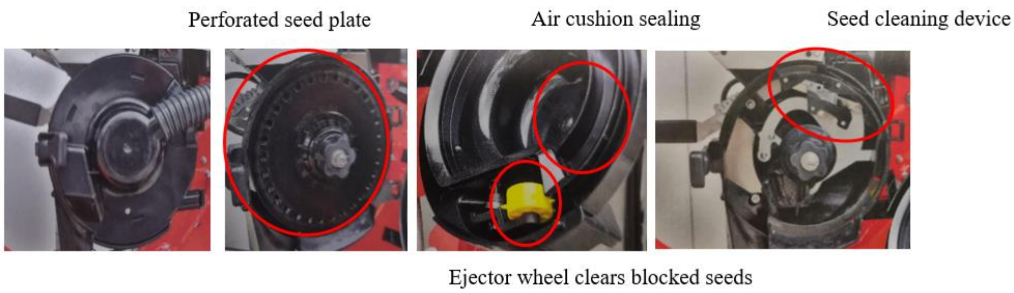


Fig. 4. Horsch vacuum-aspirated precision seed metering device

As shown in Figure 5, the pneumatic precision seed meter developed by Precision Planting (USA) features an optimised design for superior soybean seeding performance. The seeding system adopts a negative-pressure adsorption perforated seed disc, equipped with a sealed rubber air duct to effectively maintain vacuum pressure for consistent seed pickup. It enables high-speed precision seeding at 15 km h^{-1} with a qualified seeding rate exceeding 98%. Key functional components include: an active seed-pushing wheel in the filling zone to prevent clogging, a dual-side seed cleaning mechanism that eliminates double pickup and ensures single-seed retention per hole, and an air-block seed discharge system in the drop zone for precise placement. The interchangeable multi-crop seed disc design enhances versatility, allowing adaptation to various crop types with quick configuration changes.

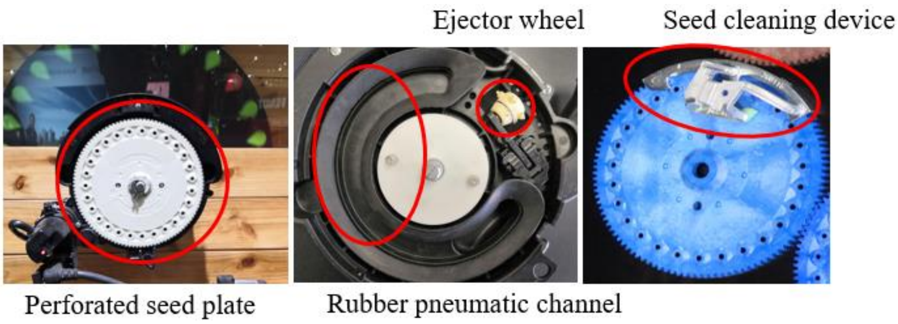


Fig. 5. Precision planting vacuum-aspirated precision seed metering device

As presented in Figure 6, the pneumatic precision seed meter developed by German Amazone Corporation utilises a unique positive-pressure working principle for high-performance soybean planting. The system incorporates several innovative features: a rubber wheel air-block mechanism

that precisely interrupts airflow at the seed release position for accurate seed placement, and an active seed-pushing wheel that effectively clears debris to ensure consistent seed delivery. This advanced design demonstrates exceptional field performance, maintaining superior seeding accuracy even at elevated operating speeds of up to 12 km h^{-1}, with field tests showing 98.5% single-seed precision and less than 0.5% seed damage rate.

Fig. 6. Amazone positive-pressure seed metering apparatus

The pneumatic seed meter from Swedish Vaderstad, as shown in Figure 7, features a perforated seed disc with positive-pressure seed engagement. By replacing different seed discs, it can accommodate various seed types. The system employs rubber wheels for air-blocking seed release and is equipped with knock-out wheels to clear blocked holes. High-speed airflow transports seeds through circular seed tubes from the disc apertures to the seed furrow, complemented by press wheels for precise seed placement. This enables high-speed precision seeding at 18-22 km h^{-1} with a qualified seeding rate exceeding 98%.

The system replaces traditional mechanical drives with a direct electric motor drive for the seed disc, achieving stepless speed regulation and instant response. Integrated with the energy control system, it automatically adjusts seeding speed in real-time to match ground speed, ensuring uniform seed distribution even at high operating speeds.

Fig. 7. Vaderstad positive-pressure seed metering apparatus

As shown in Figure 8, the precision seeding system developed by John Deere (USA) features an intelligent combination of pneumatic seed metering and electric drive technologies. The system's optimised inclined configuration significantly improves seed pickup efficiency during high-speed operation. It incorporates a dual-stage seed cleaning mechanism consisting of an adjustable-pressure brush cleaning device and a knock-out wheel, working in conjunction with an innovative brush-belt seed delivery system to minimise seed damage while maintaining over 98% seeding accuracy at high operating speeds of 15 km h^{-1}.

Fig. 8. John Deere pneumatic precision seeding system

In summary, while developed countries in Europe and America have achieved sophisticated pneumatic precision seeding technologies featuring pneumatic seed meters with electric drive controls that can operate at speeds exceeding 15 km h^{-1} with over 98% seeding accuracy, these systems face significant adaptation challenges in the context of China's soybean cultivation. The fundamental disparity between large-scale field operations predominant in foreign soybean production and China's characteristic small-plot farming systems renders existing pneumatic seeding equipment unsuitable for domestic conditions. Furthermore, the inherent complexities of pneumatic seed meters—including their intricate mechanical structures, high manufacturing costs, and demanding maintenance requirements—present substantial obstacles to the development and widespread adoption of pneumatic seed metering technology for soybean production in China.

Research status of soybean seeders in China

China has independently developed multiple types of precision soybean seed metering devices, with pneumatic seed meters currently in the development phase, while mechanical seed meters have entered the promotion stage and have become the mainstream technology in practical applications (Chen *et al.*, 2018). Huang *et al.* (2022) addressed the critical challenge of declining seeding quality in mechanical soybean seed meters during high-speed operation, primarily caused by inefficient seed filling. Their innovative solution involved developing a side-guided precision seed meter featuring a laterally positioned cell structure, which achieved both orderly seed pickup and stable seed delivery. This design provides valuable insights for improving the performance of mechanical seed meters at elevated operating speeds. However, the study identified persistent limitations: when the seed disc rotates at excessive speeds, seed pile-up phenomena still lead to compromised filling quality, indicating that a robust engineering solution for this particular high-speed challenge remains elusive.

Hou *et al.* (2020) developed a flexible mechanical precision seed meter for soybeans (Figure 9) to address the common issue of pneumatic seed meters ingesting debris during no-till operations, which compromises performance. The design utilises flexible cleaning brushes that effectively protect seeds from damage while improving operational performance. However, the system still cannot reliably remove excess seeds, making true single-seed precision planting difficult to achieve.

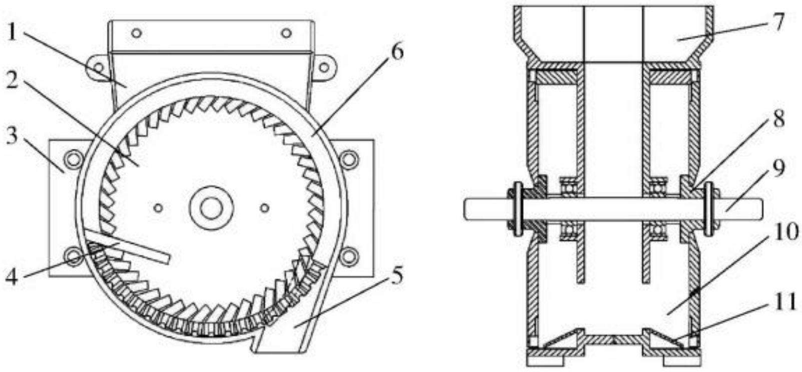


Fig. 9. Schematic of flexible mechanical seeder: 1. Split housing, 2. Seed tray, 3. Installation seat, 4. Cleaning brush, 5. Seed feeding port, 6. Seed protection brush, 7. Seed inlet, 8. flange, 9. Seed shaft, 10. Seed filling chamber, and 11. Seed filling inclined surface

Li (2021b) developed an internally-fed precision seed meter for soybean monocrop planting (Figure 10), employing an innovative inner-filling mechanism that significantly reduces seed damage and prevents quality seed waste. While this design demonstrates improved seed protection during the filling phase, the study identified a persistent challenge: seeds tend to dislodge from the cell openings during transport, leading to increased miss-seeding rates that compromise precision planting performance.

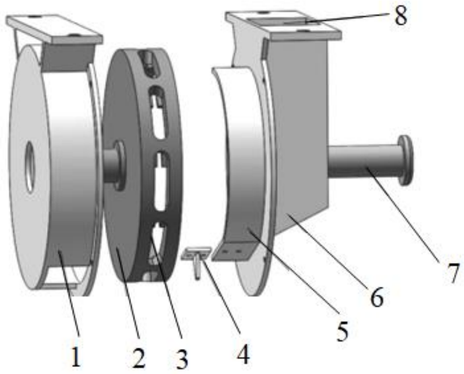


Fig. 10. Schematic of internal filling seed metering device: 1. Shell, 2. Seed tray, 3. Type hole, 4. Scraping plate, 5. Seed protection plate, 6. Seed storage chamber, 7. Shaft sleeve, and 8. Seed inlet

To address the strip intercropping requirements for soybeans in the Huang-Huai-

Hai region, Chen *et al.* (2022) developed an innovative skip-row planting pattern and designed a compatible no-till precision planter specifically for this cultivation method, as illustrated in Figure 11. The research employed comparative trials to demonstrate the yield-enhancing effects of this skip-row pattern over conventional planting methods, while field experiments verified the planter's operational suitability for the skip-row system. However, the design exhibited inconsistent seed placement that increased the coefficient of variation for plant spacing, resulting in poor sowing uniformity. This irregularity led to uneven distribution of water, nutrients, and sunlight among plants, ultimately significantly compromising soybean yield potential.

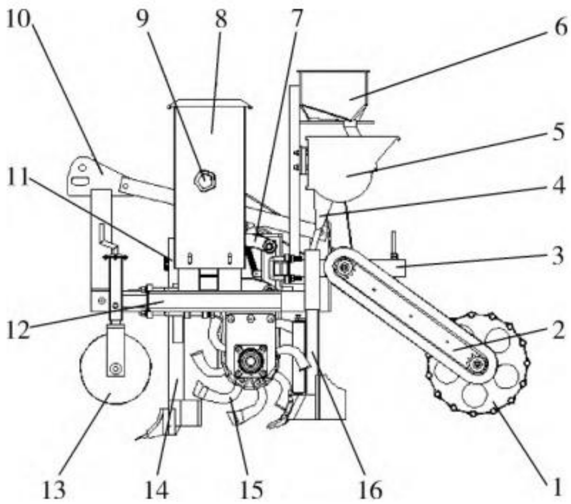


Fig. 11. Cross-seedling belt soybean precision seeder: 1. Cage-type soil compaction wheel, 2. Transmission mechanism, 3. Planting unit frame, 4. Seed splitter, 5. Staggered seedling belt seeder, 6. Seed box, 7. Copying mechanism, 8. Fertiliser box, 9. Fertiliser amount adjustment device, 10. Suspension device, 11. Transmission box, 12. Rack, 13. Depth-limiting wheel, 14. Fertilisation trenching device, 15. Seedling belt cleaning and preparation device, and 16. Seeding trenching device

In summary, mechanical precision seed meters are predominantly used for soybean planting in China. Researchers have essentially mastered the working principles of mechanical precision seed meters for soybeans and have developed new structural designs to address practical issues encountered during sowing, thereby advancing the development of mechanical precision seed metering technology in China. However, mechanical seed meters still face the following challenges during high-speed operation:

(1) Seed filling process: During high-speed operation, the excessive rotational speed of the seed disc drastically reduces the seed filling time, making it difficult for seeds to be captured by the cell openings on the disc. This often leads to missed filling in the cells, resulting in deteriorated filling quality that severely affects the seeding accuracy and ultimately causes crop gaps and yield reduction.

(2) Seed cleaning process: Current mechanical seed meters lack a stable and reliable seed cleaning device, leading to excessively high reseeding indices. Moreover, the cleaning devices in some mechanical seed meters tend to over-clean properly filled seeds in the cells, significantly reducing the qualified seeding index and hindering the development of precision seed metering technology in China.

(3) Seed transport process: After seeds are transported to the carrying area, they are prone to detach from the cell openings due to centrifugal force generated by the rotating seed disc. This increases the miss-seeding index and is detrimental to achieving precision seeding.

(4) Seed release process: After seeds are transported to the release area, it is difficult to ensure consistent release points, resulting in significant variations in spacing between adjacent seeds. This uneven distribution adversely affects the allocation of water, nutrients, and sunlight among plants, ultimately impacting crop growth and yield.

Solutions

To address the performance limitations of mechanical seed meters during high-speed operation, the following technical recommendations are proposed:

(1) Installation of a Seed Agitation and Filling Enhancement Device

Seed filling represents the initial operational stage of the seed meter, where filling quality critically determines overall seeding performance. During this process, seed accumulation leads to reduced soybean mobility, consequently diminishing the capturing capability of the seed disc's cell openings and impairing filling effectiveness. Under conditions of fixed soybean planting spacing and constant numbers of cell openings on the seed disc, high-speed operation necessarily increases the rotational speed of the seed disc. This acceleration dramatically shortens the time window for seeds to be captured by the cell openings, further deteriorating filling performance and resulting in missed-filling phenomena. Figure 12 illustrates the seed-missing phenomenon in brush-type seed metering devices. To address the poor seed filling performance of mechanical seed meters during high-speed operation caused by seed accumulation and short filling time, a seed agitation and filling enhancement device should be installed. This device improves seed population mobility, accelerates seed movement speed in the filling area, reduces the time required for seeds to reach the cell openings, and prevents seed accumulation and shortened filling time from causing filling quality degradation, thereby improving the qualified seeding index of the seed meter.

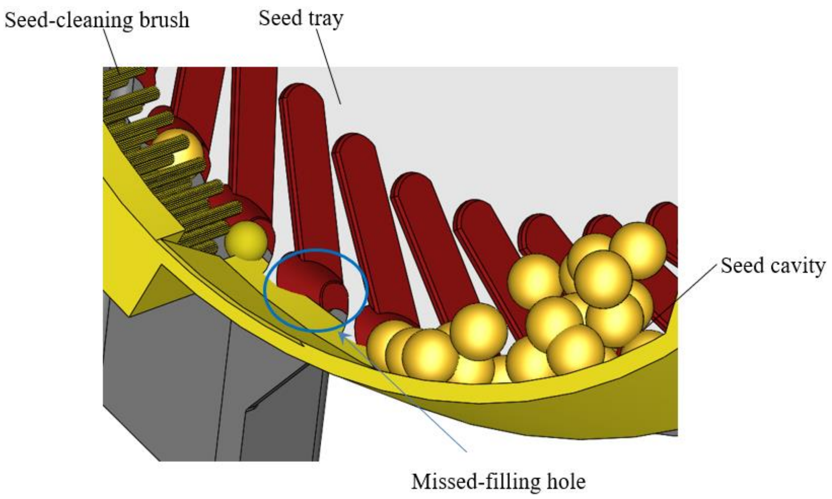


Fig. 12. Schematic of seed filling failure in soybean

(2) Optimisation of Seed Cleaning Mechanism

Seed cleaning refers to the process of removing excess seeds from the cell openings back to the filling area, ensuring single-seed retention per cell for precision monocrop planting. However, current mechanical seed meters still exhibit significant deficiencies in both under-cleaning and over-cleaning (Figure 13). Under-cleaning results in increased miss-seeding index, while over-cleaning leads to elevated multiple-seeding index, both of which adversely affect the qualified seeding index of the seed meter. To address these cleaning challenges during high-speed operation, the cleaning mechanism requires substantial improvements through the implementation of a flexible cleaning approach. Firstly, excessive cleaning force must be avoided to prevent seed damage. Secondly, a comprehensive force analysis should be conducted on seeds during the cleaning process, coupled with an optimised design of the cleaning mechanism's profile. This dual approach ensures that properly captured single seeds remain undisturbed in the cell openings while effectively removing excess seeds, thereby achieving reliable precision seeding performance.

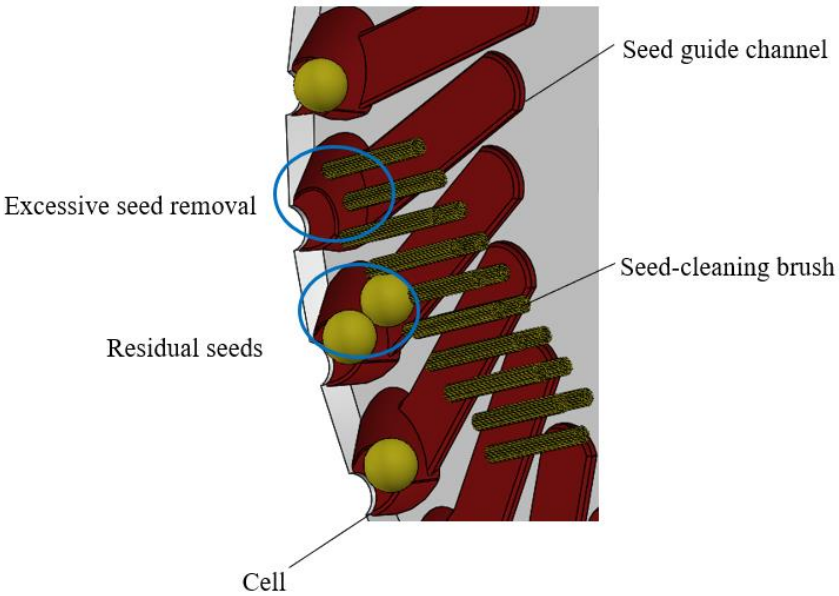


Fig. 13. Schematic of seed cleaning process defects

(3) Optimisation of Seed Transport Mechanism

Seed transport refers to the process by which seeds are stably conveyed from the cleaning zone to the release zone after completing the cleaning process. However, current mechanical seed meters still suffer from seed detachment during transport, leading to increased miss-seeding index, as shown in Figure 14. To prevent seeds from dislodging from the cell openings during transport and consequent rise in miss-seeding index, the seed transport mechanism should be optimised. The improved design should softly confine seeds within an enclosed space formed by the seed meter housing, cell openings, and transport mechanism. This approach prevents seed detachment from cell openings during transport and ensures stable delivery of seeds to the release zone.

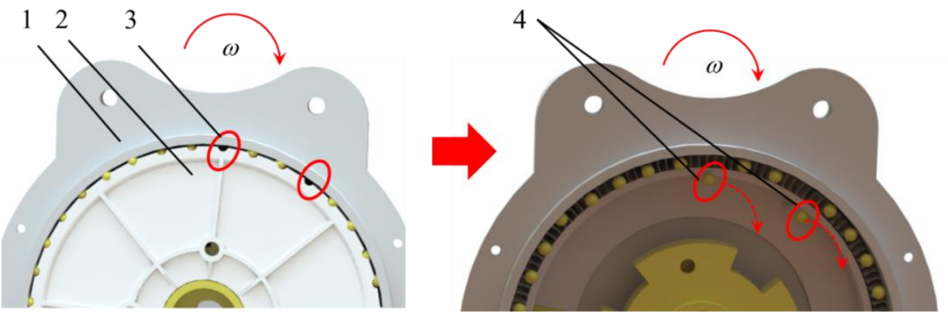
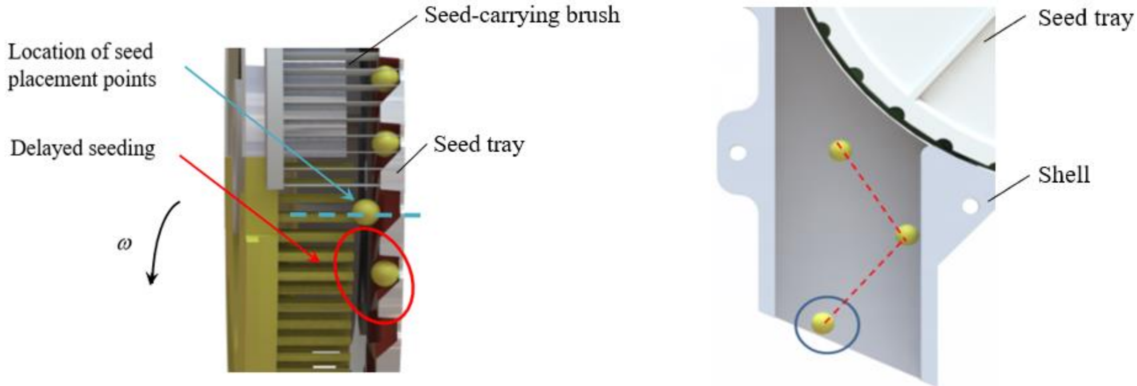


Fig. 14. Schematic of seed drop during seed conveyance: 1. Shell, 2. Seed tray, 3. Hole for dropped bean seeds, and 4. Dropped bean seeds

(4) Addition of Seed Release-Assisting Mechanism

Seed release is the final working process of the seed meter, and the release quality significantly affects the overall seeding performance. Uneven seed release leads to poor sowing uniformity, resulting in uneven distribution of water, nutrients, and sunlight during soybean growth and development, which seriously affects soybean yield. However, current mechanical seed meters still have two main deficiencies in the seed release process (Figure 15): First, during high-speed operation, the high rotational speed of the seed disc causes significant centrifugal force on seeds, making it difficult to ensure seed release at the same point and easily resulting in the "delayed release" phenomenon. Second, when seeds detach from the cell openings, they have an initial velocity tangential to the seed disc with a horizontal component, which tends to cause collisions with the seed tube, thereby altering the original seed trajectory. This leads to increased plant spacing variation coefficient and reduced seeding quality. Therefore, a seed release-assisting mechanism should be added to the release zone of the seed meter. When seeds reach the release point, the force applied by this mechanism can counteract the centrifugal force on the seeds, ensuring seed release at the designated point. Simultaneously, the mechanism can reduce the horizontal initial velocity of seeds to zero, preventing collisions with the seed tube and maintaining the original seed trajectory. This improvement will decrease the plant spacing variation coefficient of the seed meter, ensure sowing uniformity, and increase soybean yield.



(a) Schematic of the delayed release phenomenon

(b) Schematic of the collision between bean seeds and seed delivery tube

Fig. 15. Schematic of seed release process issues

This optimised solution implements technological innovations across four critical operational stages of the seed meter: seed filling, cleaning, carrying, and delivery. The seed filling stage incorporates an agitation device that significantly improves filling efficiency, while the cleaning mechanism employs a flexible design to effectively reduce duplicate seeding. The optimised seed-carrying structure substantially minimises seed loss, and the innovative seed delivery mechanism markedly enhances sowing uniformity. The upgrade demonstrates significant cost advantages, with complete modification costs amounting to only 25%-30% of purchasing new pneumatic seed meters, while reducing operational costs per unit area by 35%-40%. The investment payback period is approximately 1-1.5 working seasons, demonstrating sound economic feasibility. Furthermore, through modular design, this solution can be adapted to most existing equipment, eliminating the substantial investment required for complete machinery replacement. It maintains the economic benefits of mechanical seed meters while achieving high operational precision, providing a practical and reliable technical solution for improving soybean sowing quality in China.

Conclusion

This paper reviews the current types of soybean seed metering devices and their working principles, summarises the research status of seed metering devices both domestically and internationally, and provides a comprehensive analysis of the existing problems and corresponding improvement measures during the seed filling, seed cleaning, seed carrying, and seed delivery processes. The main research findings are as follows:

(1) This paper provides a comprehensive review of existing precision seed metering devices, focusing on their structural types and operational mechanisms. Pneumatic seed meters demonstrate high seeding accuracy and adaptability to high-speed operations, though their complex structure results in higher manufacturing costs. In contrast, mechanical seed meters feature simpler designs and reliable performance at low speeds, but are prone to significant seed skipping during high-speed operation.

(2) The study further examines the current research status of soybean seed metering devices globally. In foreign countries where large-scale soybean cultivation predominates, pneumatic seed meters have gained widespread adoption due to their seed-friendly operation and superior metering accuracy during high-speed planting. In contrast, China's domestic pneumatic seed meter technology remains predominantly in the R&D phase, with limited field application owing to maintenance challenges. Consequently, mechanical seed meters currently dominate China's soybean planting sector. However, these mechanical systems face significant limitations, including pronounced seed skipping and seed damage during high-speed operation. While demonstrating reliable performance at low speeds, their inherent design constraints render them unsuitable for high-efficiency planting requirements.

(3) To address the operational deficiencies of mechanical seed meters during high-speed sowing operations, this study proposes a comprehensive solution package targeting four critical performance bottlenecks: installing agitation-assisted filling devices to mitigate cell vacancy caused by excessive disk rotation during seed filling; redesigning cleaning mechanisms to prevent over-removal of properly positioned seeds; optimising seed retention structures to minimise seed detachment during transportation; and incorporating active discharge mechanisms to ensure consistent seed placement accuracy. These integrated mechanical improvements—comprising enhanced filling agitation, precision cleaning systems, optimised carrying configurations, and active discharge assistance—collectively elevate the seeding performance of mechanical meters under high-speed conditions, effectively overcoming their current quality limitations in field applications.

Authors Contribution

All authors contributed to the study conception and design. Ideation for the article was performed by [Shibin Yan], [Fanzhan Yang], [Jing Li], and [Xue Wang]. The literature search and data analysis were performed by [Xian Li], [Guangdi Li], and [Anqi Chen]. [Fanzhan Yang] critically revised the work. The first draft of the manuscript was written by [Shibin Yan], and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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مقاله مروری

مروری بر وضعیت فعلی، چالش‌ها و استراتژی‌های دستگاه‌های کاشت دقیق بذر سویا در چین

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چکیده

سویا به‌عنوان یک غله، روغن و محصول اقتصادی حیاتی در چین عمل می‌کند، با این حال این کشور در حال حاضر برای این محصول نرخ خودکفایی نگران‌کننده‌ای دارد. فرآیند کاشت، که بحرانی‌ترین مرحله تولید سویا است، به‌طور مستقیم عملکرد و کیفیت محصول را تعیین می‌کند. نکته قابل‌توجه این است که عملکرد نامطلوب دستگاه‌های کاشت دقیق بذر، به دلیل مشکلات مربوط به دقت کاشت بذر، همچنان گلوگاه اصلی محدودکننده افزایش عملکرد است. هدف این مطالعه، تجزیه و تحلیل وضعیت فعلی تولید سویا، برجسته کردن پیشرفت‌های تکنولوژیکی در دستگاه‌های کاشت بذر و ارائه استراتژی‌های بهبود برای افزایش کیفیت کاشت و کاهش وابستگی به واردات است و در نتیجه یک مبنای نظری ارائه می‌دهد. این مقاله منابع را به‌طور سیستماتیک از پایگاه‌های داده‌ای مانند CNKI، Web of Science، Elsevier و IEEE Xplore که شامل مقالات مجلات معتبر علمی، اسناد ثبت اختراع و گزارش‌های صنعتی منتشرشده هستند بین سال‌های ۲۰۰۰ تا ۲۰۲۴ استخراج نمود. این مقاله تجزیه و تحلیل مقایسه‌ای از انواع، اصول کار و پیشرفت تحقیقات در دستگاه‌های کاشت بذر سویا در چین و دیگر کشورها انجام می‌دهد. نتایج نشان داد که دستگاه‌های کاشت بذر چینی عمدتا مکانیکی هستند و مشکلاتی مانند آسیب بیش از حد به بذر و میزان بالای بذر تلف شده دارند، در حالی‌که ماشین های کاشت بذر در برخی کشورها بصورت پنوماتیک بوده و دقت بالایی دارند اما هزینه آنها بالاست و مشکل قابلیت انطباق دارند.

واژه‌های کلیدی: دانه سویا، دستگاه کاشت بذر، راه‌حل، کیفیت بذر، وضعیت تحقیق

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