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# Prospects of Mechanization in Direct Seeded Rice: A Comprehensive Review

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## Abstract

The traditional method of transplanting rice seedlings is labor-intensive, prompting a shift towards direct seeding of rice as an alternative crop establishment method. Direct seeding offers several advantages, including reduced labor requirements, timely sowing, and water conservation. Innovations in machinery have significantly enhanced the efficiency of direct-seeded rice cultivation, spanning advancements from land preparation to harvest. Techniques such as no-till methods and laser leveling promote efficient resource utilization and water conservation while minimizing soil disturbance. Specialized seeders and precision seed meters ensure accurate seed placement and uniform germination. Power-operated seeders and hand-held rotary dibblers further improve sowing efficiency. Modern irrigation systems, including drip irrigation, alternate wetting and drying, and automated soil moisture sensing, optimize water productivity. Weed management has advanced with mechanical, solar-powered, and autonomous weeding technologies. Additionally, crop mapping, variable rate technology, and unmanned aerial vehicles enable precise and site-specific weed control. Overall, modern machinery has transformed direct-seeded rice cultivation, resulting in increased input use efficiency, reduced labor demands, higher crop yields, and improved sustainability. Continued innovation offers significant potential for optimizing plant establishment, minimizing post-harvest losses, enhancing profitability, and conserving natural resources. This review article examines these advancements and their implications for the future of direct-seeded rice cultivation.

**Keywords:** Dibbler, Direct Seeded Rice (DSR), Drum Seeder, Mechanization

## Bibliometric analysis

A bibliometric analysis of the provided references reveals a comprehensive and diverse range of research topics related to agricultural technologies, particularly focusing on rice cultivation, spanning from 2007 to 2024. This period shows a continued interest in modern and traditional farming techniques, including irrigation, water management, precision agriculture, laser land leveling, direct seeding, and transplanting methods. It also highlights strategies for weed management using UAVs and AI, alongside a focus on agricultural mechanization and environmental sustainability. The majority of studies are concentrated in Asia, specifically in countries like Nepal, India, Bangladesh, China, and Malaysia, emphasizing the regional significance of rice cultivation. In addition,



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contributions from Africa and Europe indicate a global interest in these technologies. The research is disseminated through various reputable journals and conferences, including "Journal of Agriculture and Natural Resources," "Advances in Agricultural and Food Research Journal," "Agronomy," "Agriculture," "Indian Journal of Ecology," "Irrigation Science," and presentations at IOP Conference Series and IEEE Global Humanitarian Technology Conference. Technological advancements highlighted in the references include the development and evaluation of agricultural machines like paddy seeder, drum seeder, power weeder, transplanter, precision farming tools such as laser-guided and drone-based technologies, and data-driven models for forecasting and improving agricultural outcomes. This analysis underscores the rapid evolution and diversification of agricultural practices aimed at enhancing efficiency, sustainability, and productivity in rice cultivation, reflecting the dynamic nature of research and innovation in this critical sector.

## Introduction

Rice is a vital staple food for over half of the world's population, particularly in South and Southeast Asia and Latin America (De Nardi, Carnevale, Raccagni, & Sangiorgi, 2024). Rice cultivation is crucial in ensuring food security and sustainable agriculture (Rao, Johnson, Sivaprasad, Ladha, & Mortimer, 2007). It is cultivated in approximately 60 million hectares of land in South Asia, with India alone accounting for about 43.5 million hectares (Kemparaju, 2023). The traditional method of establishing rice crops is through transplanting seedlings from a nursery, which can be labor-intensive and time-consuming. However, in recent years, direct seeding of rice has gained popularity as an alternative method of crop establishment (Liu *et al*., 2014). Direct seeding of rice refers to the practice of sowing rice seeds directly in the field, eliminating the need for nursery preparation and transplanting. There are several advantages associated with direct seeding of rice. Firstly, direct seeding of rice saves labor as it eliminates the need for nursery preparation and the subsequent transplanting of seedlings (Kumar & Ladha, 2011). This is particularly beneficial in countries like India, where increased economic growth has led to reduced availability of labor for agriculture. Secondly, direct seeding of rice allows for faster and easier planting, enabling farmers to sow their crops on time. This is especially important in regions with unpredictable weather patterns (Farooq *et al*., 2011). Additionally, direct seeding of rice requires less water compared to the traditional method of transplanting. This is crucial in areas where water resources are being depleted and more water is required for urbanization (McDonald *et al*., 2014).

In recent years, there have been several advancements in machinery for direct sown rice cultivation, from land preparation to harvesting (Kumar, Dogra, Narang, Singh, & Mehan, 2021). These advancements have greatly improved the efficiency and productivity of rice cultivation, making it more cost-effective and sustainable. One of the significant advancements in direct seeded rice cultivation machinery is the development of specialized equipment for land preparation (Pitoyo & Idkham, 2021). This includes the use of no-till approaches, plows, and disks. These advancements have allowed for more efficient soil preparation, reducing the need for manual labor and increasing the accuracy and uniformity of seedbed preparation (Kumar *et al*., 2021).

Another significant advancement in direct seeded rice cultivation machinery is the development of equipment for crop establishment. This includes the use of direct sowing machines, which allows for the precise placement of seeds in the field (Rajamanickam, Uvaraja, Selvamuthukumaran, & Surya, 2021). These advancements have streamlined the entire process, from land preparation to yield, resulting in increased efficiency, higher yields, and reduced labor requirements (Yu, Zhang, & You, 2021). Overall, the advancements in machinery for direct sown rice cultivation have transformed the industry and contributed to its success (Muazu, Yahya, Ishak, & Khairunniza-Bejo, 2014). They have allowed for more precise and efficient land preparation, resulting in improved soil health and reduced soil compaction. Additionally, direct seeding of rice offers savings in the cost of nursery raising and leads to significant labor and time savings. The use of machines in sowing also eases intercultivation practices, which enhances aeration to the roots, promoting better plant health and growth.

**Innovation Techniques in Land Preparation for Rice Cultivation**

Innovative land preparation techniques have been developed to achieve optimal productivity in rice cultivation (Rao & Naidu, 2019). These techniques aim to make the most efficient use of resources, decrease labor requirements, and encourage water conservation. One innovative approach is the implementation of no-till or conservation tillage practices. These methods involve minimizing soil disturbance by avoiding intensive plowing or using disks (Pittelkow *et al*., 2015). This helps to retain moisture, reduce soil erosion, and maintain the natural structure of the soil. Additionally, no-till practices also promote the retention of crop residue on the soil surface, which helps to improve soil fertility and organic matter content. Furthermore, innovative machinery has revolutionized land preparation for rice cultivation. The innovation in land preparation for rice cultivation is essential for sustainable and efficient rice cultivation. These innovations not only improve productivity but also contribute to the conservation of natural resources and reduction of labor requirements, ultimately benefiting farmers and the environment. Innovation in land preparation for paddy cultivation, including techniques such as no-till methods and the use of mechanized rice transplanters, is revolutionizing the way rice is cultivated (Regalado & Cruz, 2010). According to a recent study by Hassan *et al*. (2021), the use of mechanization and precision agriculture technologies plays a vital role in achieving this goal. Sustainable and efficient rice production is of utmost importance in today's rapidly changing world, as highlighted by Zhang *et al*. (2013).

Power tillers and tractors offer greater versatility in terms of their attachments and applications (Hassan *et al*., 2021). They can be used for plowing, harrowing, leveling, and even transplanting or seeding. This versatility allows farmers to adapt to different soil conditions and cultivation techniques, further enhancing efficiency. Moreover, power tillers and tractors enable farmers to cover larger areas of land in a shorter period of time. This helps to ensure proper seed placement, spacing, and depth, resulting in uniform crop emergence and higher yields (Miah & Haque, 2015). It is important to note that the choice of tillage practices should be based on various factors, such as soil type, climate, and crop variety (Quayum & Ali, 2012). In comparison to manual labor and traditional tillage methods, the use of power tillers and tractors in rice cultivation has been found to significantly improve efficiency, productivity, and cost-effectiveness (Paman, Wahyudy, & Bahri, 2019).

**Efficiency of Laser Land Leveler in Preparing Fields for Direct Seeded Rice Cultivation**

The laser land leveler is a modern technology that has gained popularity in preparing fields for direct seeded rice cultivation. It offers several advantages compared to traditional methods such as plows or disks (Yaligar *et al*., 2017). Firstly, the laser land leveler provides a higher level of precision and accuracy in leveling the field. This ensures an even distribution of water across the field, which is crucial for optimal rice growth and yield. Additionally, the laser land leveler is highly efficient, allowing for faster field preparation compared to manual labor or conventional machinery. Furthermore, the laser land leveler helps to reduce soil compaction and improve soil health. This is achieved through its ability to precisely control the depth and intensity of field leveling, minimizing unnecessary soil disturbance

(Hoque & Hannan, 2014). The reduced labor requirements not only save on costs but also address the challenges of labor availability during peak farming seasons. Moreover, the use of laser land levelers contributes to environmental sustainability by minimizing the environmental impact of traditional land preparation methods (Maqsood & Khalil, 2013). The precision and accuracy of the laser leveler result in minimal soil erosion and disturbance, maintaining the ecological balance of the farmland. The adoption of laser land levelers in direct seeded rice cultivation not only enhances overall agricultural productivity but also aligns with sustainable farming practices, making it an important technological advancement for modern farming operations (Kumar, Karaliya, & Chaudhary, 2017). Thus, the laser land leveler is an efficient tool for preparing fields for direct seeded rice cultivation. Its precision and ability to optimize seed placement, reduce labor and water requirements, and minimize soil disturbance make it an asset for farmers (Manandhar, Zhu, Ozkan, & Shah, 2020). Hu *et al.* (2020) conducted a leveling verification test on a 0.36 ha paddy field, and field flatness was measured using a mesh method before and after the operation. It showed that the standard deviation of the relative elevations of the field decreased from 5.97 to 1.59 cm and work efficiency was 8.7 mu $h^{-1}$ (1 mu = 0.67 ha.), which means that the proposed leveler worked effectively and more efficiently than the rotary leveler.

In Direct Seeded Rice (DSR) experiment conducted during Kharif (June to october) 2014-15 and 2015-16 at the Agricultural Research Station, Karnataka, India. The total irrigation water applied showed a significant reduction of 23.2% for laser-leveled lands and 18.1% for traditionally leveled lands compared to the control treatment. The net returns and benefit-cost ratio were highest in the DSR treatment on laser-leveled land, amounting to ₹80,972 $ha^{-1}$ and 3.11, respectively. Conversely, the lowest net returns and benefit-cost ratio were observed in the pre-transplanted rice (PTR) treatment on traditional-leveled land, with ₹62,618 $ha^{-1}$ of net returns and a benefit-cost ratio of 2.4 (Rajkumar *et al.*, 2017). The variable cost per acre demonstrated a decrease in laser land-leveled farms in comparison to non-adopter farms. Furthermore, owing to enhanced productivity, adopter farms yielded higher gross returns, amounting to ₹43,518, compared to ₹40,739 in non-adopter farms. The returns over variable costs were also notably higher in laser land-leveled fields, reaching ₹32,966 per acre, while non-adopter farms only witnessed returns of ₹30,034 per acre. Consequently, the utilization of laser land leveling technology resulted in an increase in profit, reaching ₹2,932 per acre in rice crop (Sandhu, Singh, Kaur, & Singh, 2019).

**Enhancements in Sowing Equipment for Direct Seeded Rice**

Direct seeded rice cultivation, also known as dry sowing or direct drilling, is an innovative method that involves sowing rice seeds directly into the fields without the need for transplanting seedlings (Zeng *et al.*, 2011). This method not only saves labor and time, but also reduces the risk of transplanting shock and allows for better utilization of resources such as water and fertilizers. To improve the efficiency and effectiveness of direct seeded rice cultivation, there have been several advancements in sowing equipment. These advancements aim to address the challenges and limitations associated with traditional broadcasting methods, such as uneven seed distribution, poor seed-to-soil contact, and increased susceptibility to weed competition. Some of the enhancements in sowing equipment for direct seeded rice cultivation include:

**(i) Improved seed drills**

Modern seed drills have been designed to ensure accurate and consistent seed placement, allowing for better seed-to-soil contact and optimal germination rates (Ningthoujam, Haribhushan, Langpoklakpam, & Bhattacharjya, 2020).

**(ii) Seed rate adjustment mechanisms**

Some sowing equipment is now available with built-in mechanisms that allow farmers to easily adjust the seed rate according to their specific requirements, thus optimizing seed usage and reducing wastage.

**(iii) Automatic depth control**

Advanced sowing equipment now includes automatic depth control mechanisms that ensure consistent and precise seed placement at the desired depth, promoting uniform germination and plant growth (Kumar *et al.*, 2021).

**(iv) Precision seed meters**

These seed meters have been developed to accurately measure and distribute the seeds at a consistent rate, ensuring uniformity in seed spacing and reducing seed wastage.

**Power Operated Direct Seeded Rice Cultivation**

Power-operated direct seeded rice cultivation is a method that aims to mechanize the process of sowing paddy seeds directly into the soil. Several sources highlight the importance of precision in seed distribution to achieve optimum plant population and yield (Yu *et al.*, 2021). Additionally, the use of power-operated machines for direct seeding in rice fields can significantly reduce labor needs and increase efficiency. By analyzing the agronomic requirements of film-covering direct seeding in rice fields and considering the characteristics of operating conditions, a machine has been designed to ensure the efficient and effective distribution of paddy seeds, while also minimizing resistance and maintaining excellent trafficability in rice fields (Pitoyo & Idkham, 2021). This machine, powered by a high-speed rice transplanter, incorporates a suspension structure to enhance its maneuverability across various soil conditions.

**Hand-held rotary Dibbler for Direct Seeded Rice Cultivation**

A major drawback of direct-seeded cultivation of rice is the uneven distribution of pre-germinated seeds on wet puddled soil, leading to lower yields. To overcome this challenge, researchers at South China Agricultural University have developed a precision rice hill-drop drilling technology with synchronous furrowing and ridging. This technology allows for the uniform hill-dropping of pre-germinated seeds in the desired positions on puddled soil (Zeng *et al.*, 2011). This precision seeding method significantly improves crop growth and effectively reduces disease and pest infestations caused by irregular and uneven seed distribution. To further enhance the efficiency and ease of direct seeding cultivation, a hand-held rotary dibbler has been designed. This hand-held rotary dibbler ensures accurate and controlled placement of rice seeds at the correct spacing and depth, resulting in optimum plant population (Pitoyo & Idkham, 2021). The hand-held rotary dibbler is lightweight and easy to use, making it suitable for small-scale farmers. Its adjustable depth and spacing settings offer flexibility to accommodate different seed varieties and spacing requirements. This tool helps farmers achieve uniform seed placement, which is essential for improving crop establishment and maximizing yields. Additionally, the ease of use and affordability of this tool make it a practical solution for smallholder farmers looking to enhance their rice cultivation methods (Nageswar Bandi, Mathew, & Patil, 2020). To evaluate the performance of a hand-held rotary dibbler for direct-seeded paddy cultivation, various parameters were considered. These parameters included the theoretical and effective field capacity, field efficiency, and missing hill percentage (Ratnayake & Balasoriya, 2013). The theoretical field capacity of the hand-held rotary dibbler was observed to be 0.22 ha $h^{-1}$, with an effective field capacity of 0.18 ha $h^{-1}$. The field efficiency was found to be 81%, indicating the effectiveness of the rotary dibbler in terms of its ability to effectively sow rice seeds directly in the field.

**Fig. 1.** Hand-held rotary dibbler

**Performance of Drum Seeder**

The mechanization of direct seeding rice cultivation has been achieved using a manually operated mechanical drum seeder. However, it has its drawbacks, such as uneven distribution of seeds and lower yield (Rao & Naidu, 2019). To address these challenges, a redesigned manually operated mechanical drum seeder was developed. Known as the conical drum seeder, it was evaluated in paddy fields against traditional methods such as manual broadcasting (Ratnayake & Balasoriya, 2013). The conical drum seeder showed higher field capacity, field efficiency, and accuracy in seed placement compared to manual broadcasting. These results indicate that the conical drum seeder technology holds great potential for direct seeded rice cultivation, offering increased productivity and cost savings while maintaining optimal plant population and yield. The use of precision hill seeders, such as the conical drum seeder, in direct seeded rice cultivation offers numerous benefits (Nageswar Bandi *et al.*, 2020). These include improved distribution uniformity, increased yield, seed conservation, labor and time savings, and overall efficiency. Direct sowing using a drum seeder not only diminishes the expenses associated with nursery establishment and transplanting but also elevates yield by 12.7 percent, concurrently abbreviating crop duration and cultivation expenses. The adoption of this method led to a reduction in cultivation costs by 19.5 percent and amplified net returns by 34.3 percent (Kumari & Sudheer, 2015).

Rao, Patil, Rao, & Reddy (2014) evaluated the performance of a manually operated paddy drum seeder inAndhra Pradesh, India, over three years. Complete mechanization in paddy (drum seeder, cono weeder, and paddy thresher) ($T_1$), with Reclamation of soil by Dhaincha + complete mechanization in paddy (drum seeder, cono weeder, and paddy thresher) ($T_2$), which resulted in a 10% and 14% increase, respectively, in the average grain yield compared to conventional farming practices. In treatment $T_2$, where a green manure crop (Dhaincha) was cultivated and incorporated into the soil using traditional plowing methods before sowing the seeds in paddy, the average cost of cultivation decreased by 25%. Additionally, the adoption of mechanized cultivation techniques led to the crop reaching maturity eight to ten days earlier than with traditional farming methods. This study demonstrated the potential for improving the socio-economic status of farmers by transitioning towards mechanized and organic paddy cultivation strategies.

On comparison of drum seeding with transplanting of rice, it was revealed that direct seeding using a drum seeder was identified as the most economically viable option, yielding higher grain output and resulting in a shorter crop duration and consuming less water, leading to increased water-use efficiency compared to the transplanting approach (Kumar, Singh, Sagar, & Maurya, 2018).

Sangeetha, Balakrishnan, Sathya Priya, and Maheswari (2009) evaluated the influence of seeding methods and weed management practices on direct seeded rice at Tamil Nadu Agricultural University, Coimbatore, India. The results revealed that the drum seeding combined with green manure technique led to a significant increase in leaf area index (LAI), higher number of tillers per square meter, enhanced dry matter production (measured in kg per hectare), and superior grain yield, outperforming the broadcasting method.

Komatineni *et al.* (2023) reported that Bluetooth based remote controlled battery powered drum seeder exhibited a field capacity of 0.023 ha $h^{-1}$ and a field efficiency of 82%, whereas the manual drum seeder had a field capacity of 0.017 ha $h^{-1}$ and a field efficiency of 62%. Compared to the manual drum seeder, the developed seeder reduced the physical strain by 64%, as evidenced by the operator's heart rate and energy expenditure rate; the operational cost of the developed seeder was reduced by ₹230 per hectare compared to the manual drum seeder.

Mir *et al.* (2023) opined that four times of mechanized cono-weeding operation was found promising for improving productivity and efficient weed control in direct drum-seeded rice in temperate conditions of Kashmir, India.

Kumar and Chinnamuthu (2022) evaluate the effect of time and method of sowing of wet direct seeded rice at Tamil Nadu Agricultural University, Coimbatore, India during the first fortnight of July using the Paddy + Dhaincha drum seeder method and recorded a higher grain yield of 5707 kg $ha^{-1}$ which resulted in 33 percent higher yield than that achieved with thebroadcasting method. Table 1 presents the sowing equipment along with their corresponding field capacities.

**Fig. 2.** Drum seeder

**Table 1-** Sowing equipment and field capacity

| Sowing Equipment | Field Capacity (ha $h^{-1}$) | Reference |
|---|---|---|
| Drum Seeder | 0.12 – 0.18 | Pradhan, Nayak, Mohanty, and Behera (2014) |
| Power-Operated Direct Seeder | 0.168 – 0.114 | Dhruw and Verma (2018) |
| Hand-held Rotary Dibbler | 0.02 – 0.04 | Sahoo, Sahu, and Rout (2012) |

**Enhancements in irrigation technologies for Direct Seeded Rice**

Water Productivity (WP) and Water Use Efficiency (WUE) are crucial for sustainable agricultural water management, ensuring the conservation of resources (Luo *et al*., 2022). Drip irrigation, though not widely adopted in rice farming, is advocated for its potential to enhance productivity while minimizing water usage (Kilemo, 2022). Recent advancements in automated irrigation systems, utilizing soil moisture sensing through Internet of Things (IoT) technology, offer significant water and labor-saving benefits (Arouna, Dzomeku, Shaibu, & Nurudeen, 2023). Integration of smart irrigation systems across various cropping scenarios, with decreasing costs, shows promise for more efficient and sustainable water management practices in agriculture, potentially reducing global water consumption and alleviating labor burdens associated with frequent irrigation (Conesa, Conejero, Vera, & Ruiz-Sánchez, 2021).

The efficacy of Alternate Wetting and Drying (AWD) in conserving water and enhancing productivity exhibits remarkable superiority within the Direct Dry Seeded Rice (DDSR) system when contrasted with AWD in the Transplanting Rice (TPR) system (Ishfaq, Akbar, Anjum, & Anwar-Ijl-Haq, 2020). Additionally, drip irrigation combined with direct seeded rice managed at 20% Cumulative Pan Evaporation (CPE) with 1-day intervals, showcased superior performance in growth parameters, as well as grain and straw yields, achieving statistically higher grain yield (8076 kg $ha^{-1}$) and straw yield (8651 kg $ha^{-1}$) compared to conventional transplanted rice. Furthermore, when scrutinizing water use efficiency between direct-seeded rice and puddled transplanted rice, the former demonstrates greater efficiency without compromising growth, yield, and other yield characteristics (Kumawat, Sepat, Kumar, Jinger, & Kaur, 2017).

**Enhancements in Weed Management Technologies for Direct Seeded Rice**

Weeds, as unwanted plants, threaten crop yields by competing for vital resources such as water, nutrients, light, and space, highlighting the necessity for effective weed management in agriculture to meet future food demands. Mechanical weeding, recognized for its eco-friendly and sustainable attributes, has gained traction in recent years due to its cost reduction, labor efficiency, and suitability for organic farming, particularly in rice cultivation. A solar-powered sprayer was engineered for herbicide application, harnessing solar energy as its primary power source. Weighing in at 15 kg, the sprayer operates at a speed of 2.5 km $h^{-1}$. Upon evaluation, the theoretical field capacity, effective field capacity, and field efficiency of the developed solar-operated sprayer were determined to be 0.6 ha $h^{-1}$, 0.5 ha $h^{-1}$, and 83.33 percent, respectively. This innovation not only diminishes laborious tasks but also proves to be economically viable and environmentally friendly, utilizing readily available solar energy, which is accessible to farmers at an affordable cost (Basavaraj, Ajaykumar, & Swathi, 2020). Ongoing research focuses on enhancing mechanical weed control methods (Barbaś, Sawicka, Marczak, & Pszczółkowski, 2020). Crop and weed mapping aids in site-specific herbicide applications and optimizing management strategies, while precision agriculture, employing technologies like Variable Rate Technology (VRT) and remote sensing, enables precise and efficient weed management. Advancements in autonomous driving technology have led to the development of intelligent paddy weeding machines, incorporating satellite navigation and automatic control systems for precise intra-row and inter-row weeding (Daponte *et al*., 2019). Additionally, Unmanned Aerial Vehicles (UAVs) are increasingly utilized for their ability to swiftly monitor and manage weed patches, particularly in navigating between crop rows, thus contributing to effective weed control in agriculture (Radoglou-Grammatikis, Sarigiannidis, Lagkas, & Moscholios, 2020).

Ragesh, Jogdand, and Victor (2018) reported that the modified Paddy power weeder stands out as the superior choice for weed management compared to the Ambika paddy weeder, boasting higher weeding efficiency at 20 and 45 days after sowing (DAS). While both the Paddy power weeder and Ambika paddy weeder exhibit comparable field efficiency, a notable distinction arises in operational cost, where thePaddy power weeder proves to be significantly more feasible than its Ambika counterpart.

Utilizing drones for the application of pretilachlor followed by bispyribac sodium herbicide proves to be a highly effective strategy for weed management in direct seeded rice. This approach not only demonstrates superior efficacy but also offers advantages in terms of energy utilization and profitability (Paul, Arthanari, Pazhanivelan, Kavitha, & Djanaguiraman, 2023).

Unmanned aerial vehicles (UAVs) are predominantly employed for tasks such as nutrient application and pesticide spraying, especially among smallholder farmers and in various industries. The incorporation of artificial intelligence (AI), which encompasses UAVs along with a range of sensors including hyperspectral, multispectral, and RGB cameras, as well as thermal and odor sensors, for early weed detection methods holds promise for more effective weed management outcomes. And the use of UAVs and AI technologies for the detection and control of weeds in rice crops (Ahmad *et al*., 2023).

Kishore Kumar (2018) studied the effect of different wet seeding methods and weed management practices on grain yield of unpuddled rice in Tamirabarani command area of Tamil Nadu, India and the results revealed that rice established through drum seeder along with the pre emergence application of pyrazosulfuron ethyl at 20 g a.i $ha^{-1}$ on 8 DAS followed by post emergence (POE) bispyribac sodium at 25 g a.i $ha^{-1}$ at 30 DAS not only significantly reduced density and dry weight of weeds but also increased the grain yield of rice and benefit-cost ratio.

Arivukodi and Velayutham (2017) evaluated the evolving suitable weed management practices for direct sown drum seeded rice in the Thamirabarani command area of Tamil Nadu, India, and the results revealed that the application of pretilachlor @ 750 g a.i. $ha^{-1}$ on 8 DAS as PE + bispyribac sodium @ 25 g a.i. $ha^{-1}$ on 30 DAS as POE not only significantly reduced density and dry weight of weeds but also increased the grain yield of rice.

**The Impact of Modern Mechanization on Yield and Efficiency**

Modern machinery had a significant impact on rice yield and efficiency in rice production. By utilizing advanced technologies and machinery, farmers can improve various stages of rice production, leading to increased yield and higher efficiency levels (Paman *et al*., 2019). Furthermore, the availability of machine power, such as hand tractors, irrigation pumps, power threshers, and rice milling units, has increased significantly in recent years. This increased availability of machine power has contributed to the overall mechanization of rice production, leading to improved productivity and higher rice yields (Haryono, Hudoyo, & Mayasari, 2021). Furthermore, the intensification approach, which includes the use of good seeds and a mechanization approach, has also played a crucial role in increasing rice production and yield. In summary, modern machinery has revolutionized the paddy rice production system, allowing for more efficient and productive farming practices. Modern machinery has revolutionized rice production, leading to increased yield and efficiency. Overall, the impact of modern machinery on rice yield and efficiency in rice production has been significant (Acharya, Regmi, Gauchan, KC, & KC, 2020). Modern machinery has revolutionized rice production, leading to increased yield and efficiency. By employing modern machinery in rice production, farmers can streamline and optimize various stages of the process, resulting in higher yields and improved efficiency in the field. The use of modern machinery in rice production has greatly increased threshing and winnowing capacity, leading to higher yields in rice farming (Ningthoujam *et al*., 2020). Table 2 and Table 3 present the rice sowing methods along with the grain yields obtained (kg ha$^{-1}$), as well as the sowing and weeding equipment utilized, along with their respective efficiencies (%).

**Table 2-** Type of sowing and yield (kg ha$^{-1}$)

| Types of sowing | Yield (kg ha$^{-1}$) | Reference |
|---|---|---|
| Manual Broadcasting | 5518 | Ratnayake and Balasoriya (2013) |
| Drum seeder | 7553 | Ratnayake and Balasoriya (2013) |
| Transplanter | 5680 | Rao, PB, and Chandrayudu (2020) |

**Table 3-** Sowing and weeding equipment and efficiency

| Equipment | Efficiency (%) | Reference |
|---|---|---|
| Drum Seeder | 65 – 75 | Pradhan *et al*. (2014) |
| Power-operated Direct Seeder | 68 – 78 | Dhruw and Verma (2018) |
| Hand-held Rotary Dibbler | 60 – 70 | Sahoo *et al*. (2012) |
| Power-operated Weeder | 70 – 80 | Kumar and Mohankumar (2019) |

**Future Prospects of Machinery in Direct Seeded Rice Cultivation**

The prospects of machinery in direct seeded rice cultivation hold tremendous potential for improving efficiency, productivity, and sustainability in the agricultural sector. With advancements in technology and the development of specialized machinery, farmers can expect to see significant benefits in various aspects of rice cultivation (Haryono *et al*., 2021). For instance, the availability and utilization of power-intensive machines for land preparation, threshing, and milling have already contributed to increased capacity in rice mechanization in some regions (Paman *et al*., 2012). Furthermore, the implementation of sustainable agricultural mechanization programs has resulted in the distribution of combine harvesters and four-wheel tractors to farmer groups, further enhancing the mechanization of rice farming (Haryono *et al*., 2021). These developments in machinery offer several advantages for direct seeded rice cultivation. Firstly, the use of machinery can greatly reduce manual labor and physical exertion required in various farm operations (Paman *et al*., 2012). This not only alleviates the burden on farmers but also saves time and increases overall efficiency, enabling timely completion of farm operations. Additionally, mechanized farming schemes provide the opportunity to optimize plant establishment methods, such as direct sowing or transplanting, as well as different harvesting techniques. This can lead to improved crop yield, reduced post-harvest losses, and increased profitability for farmers. Overall, the prospects of machinery in direct seeding rice cultivation are promising and hold the potential to revolutionize the agriculture industry.

## Conclusion

The evolution of machinery in direct-seeded rice cultivation marks a transformative shift towards efficiency, sustainability, and productivity in agriculture. From innovative land preparation techniques to precision sowing equipment, irrigation advancements, and weed management technologies, each aspect of modern machinery contributes to streamlined operations and improved outcomes for farmers. These technological advancements not only alleviate labor burdens but also optimize resource utilization, conserve water, enhance soil health, and mitigate environmental impacts. Looking forward, the future of machinery in rice cultivation holds significant promise for further innovations, which are poised to elevate efficiency, productivity, and sustainability in the agricultural landscape, ultimately ensuring a more resilient future for farmers and the global food supply chain.

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## Conflicts of Interest

The authors declare that they have no conflict of interest.

## Data Availability

The article contains the statistical data used to substantiate the findings of the study.

## Authors Contribution

S. Manoj Kumar: Conceptualization, Data collection, Writing the manuscript.

R. Karthikeyan: Supervision, Visualization, Correction.

K. Thirukumaran: Supervision, Visualization, Correction.

A. Senthil: Technical advice

P. Dhananchezhiyan: Visualization, Technical advice

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# چشم‌انداز مکانیزاسیون کشت مستقیم بذر برنج: مروری جامع

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## چکیده

روش سنتی نشاکاری برنج نیاز به نیروی انسانی زیادی دارد و منجر به تغییر به سمت کاشت مستقیم بذر برنج برای کشت برنج شده است. از جمله مزایای کاشت مستقیم بذر می‌توان به کاهش نیاز به نیروی کار، کاشت به‌موقع و صرفه‌جویی در آب اشاره کرد. نوآوری در ماشین‌آلات کشاورزی کارایی کشت مستقیم بذر برنج را به‌طور قابل‌توجهی بهبود بخشیده است و این پیشرفت تمام مراحل از آماده‌سازی زمین تا برداشت را در برمی‌گیرد. تکنیک‌هایی مانند روش‌های بدون خاک‌ورزی و تسطیح لیزری، استفاده کارآمد از منابع و حفظ منابع آب را تضمین می‌کند و در عین حال اختلالات خاک را به حداقل می‌رساند. امکان قرارگیری دقیق بذر و جوانه‌زنی یکنواخت با استفاده از بذرکارهای اختصاصی و دستگاه‌های سنجش دقیق بذر فراهم شده است. استفاده از بذرکارهای پشت‌تراکتوری و کارنده‌های دستی گردان راندمان کاشت را بیشتر افزایش می‌دهند. روش‌های آبیاری مدرن مانند آبیاری قطره‌ای، آبیاری تناوبی، و سنجش خودکار رطوبت خاک، بهره‌وری آب را بهینه می‌کنند. مدیریت علف‌های هرز با فناوری‌های وجین‌کن‌های مکانیکی از طریق انرژی خورشیدی و خودران تکامل یافته است. نقشه‌برداری‌های مختلف زمین و عملکرد محصول، فناوری نرخ متغیر و وسایل نقلیه هوایی بدون سرنشین (پهپاد) امکان کنترل دقیق علف‌های هرز بر اساس مدیریت مکانی خاص را فراهم می‌کنند. به‌طور کلی، ماشین‌آلات مدرن انقلابی در کشت مستقیم بذر برنج ایجاد کرده‌اند که منجر به افزایش عملکرد، کارایی بالاتر در استفاده از نهاده‌ها، کاهش نیاز به نیروی کار، افزایش عملکرد محصول و بهبود پایداری تولید شده است. تداوم نوآوری، چشم‌انداز وسیعی برای بهینه‌سازی استقرار گیاه در خاک، به حداقل رساندن تلفات پس از برداشت و افزایش سودآوری و در عین حال حفظ منابع طبیعی دارد. این مقاله مروری به بررسی این پیشرفت‌ها و پیامدهای آن‌ها برای آینده کشت مستقیم بذر برنج می‌پردازد.

**واژه‌های کلیدی:** بذرکار، بذرکارهای استوانه‌ای، دیبلر، کشت مستقیم برنج، مکانیزاسیون

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