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REVIEW ARTICLE

Turmeric planting methods and mechanization strategies: A review towards the development of a fully automatic planter

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Abstract

Turmeric (*Curcuma longa*), a major crop in India accounting for 80 % of global production, faces challenges such as pest infestations, diseases, climate change and economic volatility, necessitating precision agriculture strategies to enhance sustainability. Planting is a critical determinant of crop yield and quality; however, conventional manual methods remain labor-intensive and inefficient, underscoring the need for mechanization. Mechanical turmeric planters have been shown to decrease the cost and time associated with planting by 59.52% and 96.57 %, respectively. This review examines key turmeric planting methods, including flat-bed, ridge-and-furrow and raised-bed systems, while analyzing the engineering properties of turmeric rhizomes relevant to planter design. It has been found that ridge planting has produced 86.78 q ha^{-1} of yield compared to flat-bed planting of 67.26 q ha^{-1} and raised bed planting significantly reduced disease incidence, with only 9.6 % leaf spot and no rhizome rot observed, compared to 22.5 % leaf spot using the flat bed method. The evolution of planting technology from manual to semi-automatic and fully automatic systems is discussed, along with a critical assessment of metering mechanisms such as vertical rotating discs, multistage rotating cups and auger conveyors. The influence of furrow opener design and operational parameters, including planting speed and accuracy, on field performance was also reviewed. By identifying research gaps related to the impact of rhizome properties on planter efficiency, this study concludes that optimized automatic planters tailored to turmeric's specific agronomic requirements can enhance planting precision, improve productivity and contribute to sustainable cultivation practices.

Keywords

automatic turmeric planter; engineering properties; metering mechanisms; raised-bed planting; single-bud transplantation

Introduction

Turmeric (*Curcuma longa*), which is widely recognized for its distinctive color and medicinal properties, has an extensive history of cultivation in India. Globally, turmeric is cultivated in various countries in Asia, Africa and America. However, India dominates both the production and export markets, contributing approximately 80 % of the global supply (1). India is the largest producer, consumer and exporter of turmeric, cultivating it on 324000 hectares and producing 1.161 million tons (2). Productivity has increased from 2224 kg ha^{-1} in 2018-19 to 3349 kg ha^{-1} in 2022-23 (3). The state-wise production of turmeric has been reported (4), as illustrated in Fig. 1.

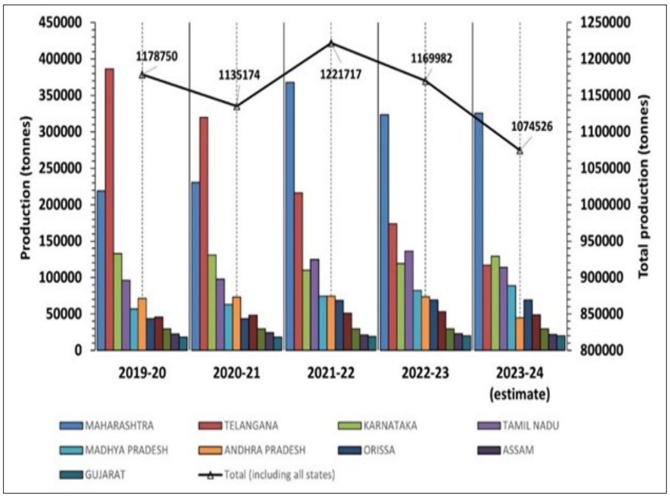


Fig. 1 State-wise production of turmeric in India, (DASD, 2023).

Despite its prominence, the turmeric industry faces significant challenges that jeopardize its sustainability and profitability. Agricultural obstacles, such as susceptibility to diseases, such as leaf blotch and rhizome rot, along with pests, such as shoot borers (5), pose ongoing risks to crop health. Furthermore, climate change exacerbates these issues, leading to irregular rainfall patterns and temperature fluctuations that adversely affect crop yield (6). Economically, turmeric farmers often contend with volatile market prices and a lack of formalized markets, resulting in exploitation by intermediaries and reduced profitability, particularly for small -scale producers (7). Due to challenges, the area dedicated to turmeric cultivation in India is projected to decline in the coming years (4), as illustrated (Fig. 2). This trend underscores the urgent need for precision agriculture to address the evolving demand for turmeric farming.

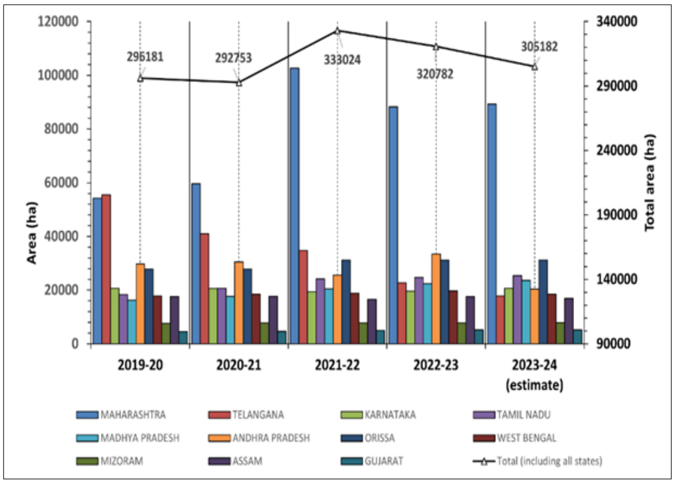


Fig. 2 Trends in the sowing area of turmeric in India, (DASD, 2023).

The planting process is a critical component of successful turmeric cultivation and significantly influences the health, yield and quality of crops. The conventional method of planting turmeric is labor intensive, time-consuming and economically demanding. Among various costs involved in turmeric cultivation, seed and labour costs account for 34.22 % and 29.42 % of the total cost of cultivation (8). Due to improved industrial and urban livelihood opportunities, labour availability has decreased to a great extent in agriculture sector. The compound growth rate of agricultural labors from 1994-2018 reveals a shift from moderate positive growth (1994-2005) to a consistent decline (2005-2018) (9). Hence, the key in reducing the cost of cultivation of turmeric is by reducing the dependence of human power which can be achieved by increased mechanization. Despite the lower number of man-days required for planting turmeric rhizomes compared to other turmeric cultivation activities (10), as illustrated in Fig. 3, mechanized planters would significantly reduce labor intensity and improve productivity as the cultivation area increases. This is because planting is more critical for determining yield than harvesting or weeding is.

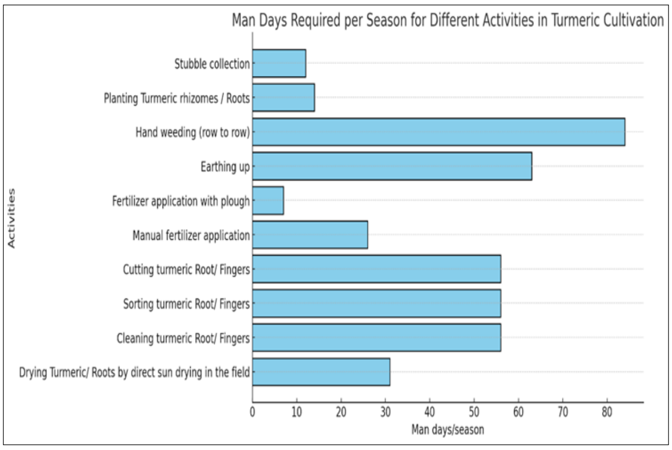


Fig. 3 Labor requirements for turmeric cultivation (10).

Precision planting enhances crop yield through optimal seed placement, spacing optimization and efficient resource utilization. Techniques such as variable-rate applications and site-specific management have improved productivity and reduced the environmental impact of crops such as potatoes, cotton and rice (11, 12). Advanced systems also contribute to yield stabilization over time, increased nutrient efficiency and waste reduction (13, 14). Mechanical turmeric planters have been shown to decrease the cost and time associated with planting by 59.52 % and 96.57 %, respectively (15). Automatic planters provide precise control over seed depth and spacing, thereby facilitating uniform crop development. This uniformity is crucial for streamlining harvesting operations and ensuring high-quality turmeric production (16). Additionally, these machines are designed to handle seeds with minimal damage to rhizomes during planting, thus reducing plant stress and susceptibility to diseases, which in turn enhances the overall growth and yield (17). Although existing turmeric planters are available, they are not optimized for the specific conditions required for turmeric cultivation. This gap underscores the necessity of developing a specialized automatic turmeric planter that specifically addresses these unique requirements, thereby improving planting efficiency and productivity. In this review, an analysis was conducted of the planting methods and mechanization aspects of turmeric planting for the development of automatic turmeric planters.

Turmeric planting methods

Turmeric cultivation uses diverse planting methodologies that significantly influence plant growth, yield, pest incidence and disease management. Each method creates distinct environmental conditions surrounding the rhizomes, thereby affecting the growth patterns and susceptibility to diseases and pests. The various turmeric planting methods are illustrated in Fig. 4 and the recommended plant spacing is

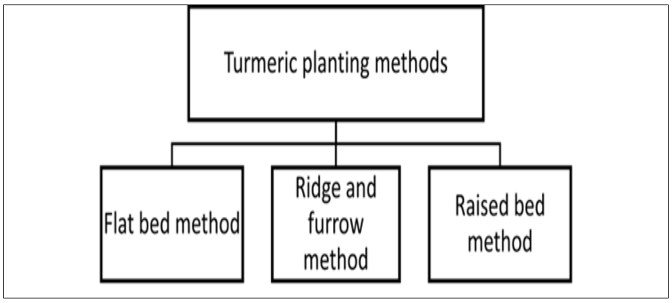


Fig. 4 Turmeric planting methods.

shown in Fig. 5. Despite increased yields, the risk of pest and disease problems also increases with flat-bed planting (18). Enhanced drainage and soil aeration can be achieved through ridge-and-furrow practices, thereby improving rhizome health and yield. Ginger rhizome health and yield enhancement has been demonstrated through improved drainage and aeration (17). In addition to increasing yield, ridge planting has demonstrated efficacy in terms of plant height, leaf number, leaf breadth and number of clumps per plant (19). Raised beds enhance growth parameters and yield compared with traditional flat planting when implemented with optimal plant density (16, 20). Furthermore, this method significantly reduced disease incidence, with only 9.6% leaf spot and no rhizome rot observed, compared to 22.5 % leaf spot and 30.8 % rhizome rot observed using the flat-bed method (21). A summary of the advantages and limitations of different planting methods is presented in Table 1.

Overview of established planting practices for turmeric

Turmeric exhibits diverse responses to varying planting methodologies, with each significantly affecting the plant yield, growth rate and disease susceptibility. Ongoing research efforts are aimed at optimizing these aspects and elucidating numerous effective strategies. For instance, studies have demonstrated that both planting time and plant density are critical factors influencing the severity of leaf blotch and overall yield. Specifically, denser and earlier planting has been shown to substantially reduce disease impacts while simultaneously enhancing yield (22). Furthermore, innovative advancements, such as the single-bud transplanting technique, have not only reduced production costs but have also expedited the growth phases of turmeric, facilitating earlier maturity and harvest (23). This method utilizes smaller disease-free seed rhizomes, indicating a shift towards more economically viable cultivation practices. Additionally, employing various land configurations and incorporating soil conditioners, such as bio-compost, has been found to significantly enhance growth and yield, particularly when utilizing raised bed configurations as opposed to conventional methods (24). Moreover, mother rhizomes produce greater yields than secondary rhizomes when combined with raised bed planting (25). Furthermore, mother rhizomes of size 45-50 g were determined to be optimal for maximum yield (26). The optimum planting density for turmeric is 166667-222222 plants per hectare (27) and for organic cultivation, it is approximately 33300-37000

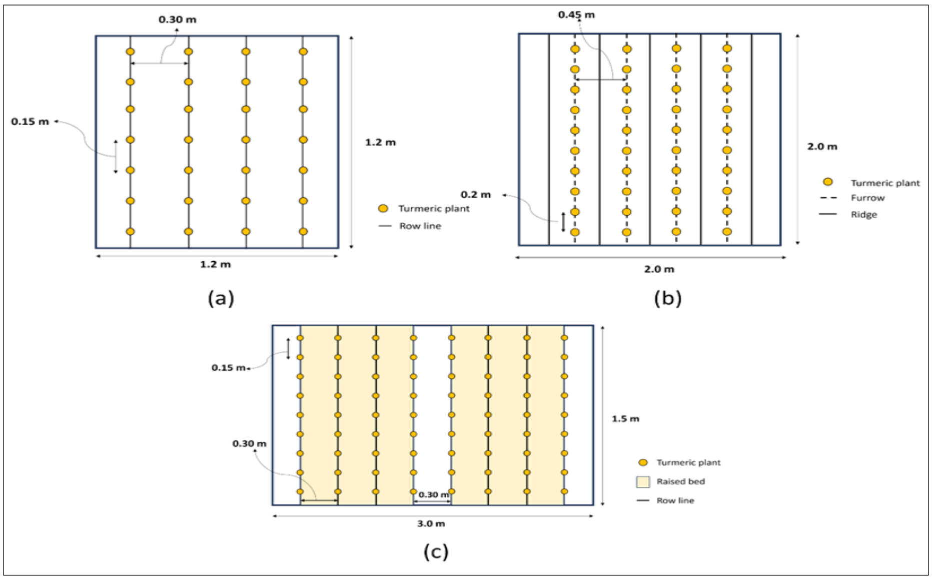


Fig. 5. Recommended spacings for (a) flat-bed planting, (b) ridge and furrow planting and (c) raised bed planting.

Table 1. Comparative analysis of different planting methods of turmeric

Aspect	Flat Bed Planting	Ridge Planting	Raised Bed Planting
Planting Method	Turmeric is planted on a levelled field without raised structures.	Turmeric is planted on ridges with furrows in between.	Turmeric is planted on wide, raised beds with furrows.
Plant spacing			
Efficiency (Yield & Growth)	Moderate yield; growth may be affected by poor drainage.	Higher yield due to better root aeration and drainage. A 26 % increase in yield was achieved compared with flatbed	High yield; optimal root development and aeration. The yield was 17.14 % higher than flatbed method
Cost (Labor & Inputs)	Lower cost; minimal labor and materials required.	Moderate cost; requires additional labor for ridge formation.	Higher cost; requires more labor and input for bed preparation.
Soil Suitability	Suitable for well-drained loamy soils; not ideal for heavy clay.	Best for clayey and heavy soils where drainage is a concern.	Well-suited for sandy, loamy and even clayey soils.
Water Management	Poor drainage can cause waterlogging in high-rainfall areas.	Good drainage; excess water flows into furrows.	Excellent drainage; prevents water stagnation. It can save upto 16.5 to 36.8 % of water compared to flatbed planting.
Weed & Pest Control	Higher weed growth; pests may be more prevalent.	Moderate weed control; some pests may persist.	Lower weed and pest infestation due to structured layout.

plants per hectare (28).

Engineering properties of turmeric rhizome for development of a planter

The various engineering properties of turmeric, such as its physical, mechanical and frictional properties, are essential for developing the components of a turmeric planter, particularly in metering and seed delivery systems. The common engineering properties of the agricultural materials are shown in Fig. 6. The average length, breadth and thickness of turmeric rhizomes range from 30.38 to 50.60 mm, 9.77 to 10.64 mm, and 5.18 to 6.44 mm, respectively. The geometric mean diameter varied between 12.77 and 13.76 mm, sphericity between 0.27 and 0.42 and the aspect ratio from 0.20 to 0.35 (29). The average length, width and thickness of fresh turmeric rhizomes are 67.66 mm, 22.24 mm and 16.78 mm, respectively (30). When examining the geometric properties of turmeric rhizomes, the arithmetic mean diameter, square mean diameter and equivalent diameter increased as rhizome size increased. Conversely, sphericity and aspect ratio decrease with larger dimensions, indicating that larger rhizomes tend to exhibit a more elongated morphology (31). The bulk density is found to be348±6.30 kg m^{-3}, the true density is found to be 1354±7.89 kg m^{-3} and the porosity is around 74.53±0.64 % (29). For the PTS 10 variety of turmeric, the average true density was 785.13 kg m^{-3} and the bulk density was 468.417 kg m^{-3} (32). Differences in bulk density were observed between mother rhizomes (570.38 kg m^{-3}) and finger rhizomes (492.11 kg m^{-3}), which also influence the design of equipment for the handling of turmeric. The coefficient of friction of turmeric rhizome varied with the surface material, 0.81±0.07 on an aluminum sheet, 0.94±0.05 on a mild steel sheet and 0.86±0.08 on a plywood sheet (33). The angle of repose of turmeric rhizomes is around 37.57±0.61° and 38.90°, indicating the behavior of rhizomes when accumulated (29). The coefficient of static friction on a mild steel was observed to be 0.81±0.04, with an angle of repose of 36.80°, which is an essential property for the design of conveyors and other handling equipment (34). The true density of turmeric rhizomes was 1002 kg m^{3}, with a bulk density of 0.512 kg m^{-3}. The measured shear forces of 0.0408 kN for the mother rhizomes and 0.0159 kN for the finger rhizomes indicate that finger rhizomes are more susceptible to mechanical damage (35).

Evolution of turmeric planters

The evolution of turmeric planting technology has progressed from manual methods to fully automatic systems, as evidenced by various studies. This progression has addressed key challenges in turmeric cultivation, particularly in terms of efficiency, labor requirements and yield optimization. Manual planting (Fig. 7), the traditional method, is labor-intensive and time-consuming. This often results in inconsistent plant spacing and reduced productivity (34, 36). These limitations prompted the development of more efficient planting methods. Animal drawn planters have been found to reduce drudgery while achieving a field capacity of 0.3 ha h^{-1} (37), which is significantly higher than manual planting. Semi-automatic planters (Fig. 8) have also been introduced to overcome the drawbacks of manual planting. Research has shown that these mechanized systems improve rhizome spacing and overall yield compared with manual methods (38). Further advancements in semi-automatic planters have focused on optimizing the metering mechanisms to ensure accurate seed placement. The latest development in turmeric planting technology is a fully automatic, tractor-drawn planter. Research have shown that the performance of a fully automatic tractor-drawn turmeric planter (Fig. 9) is effective in improving planting precision and reducing labor intensity (39).

Fig. 7. Manual planting of turmeric rhizomes (34).

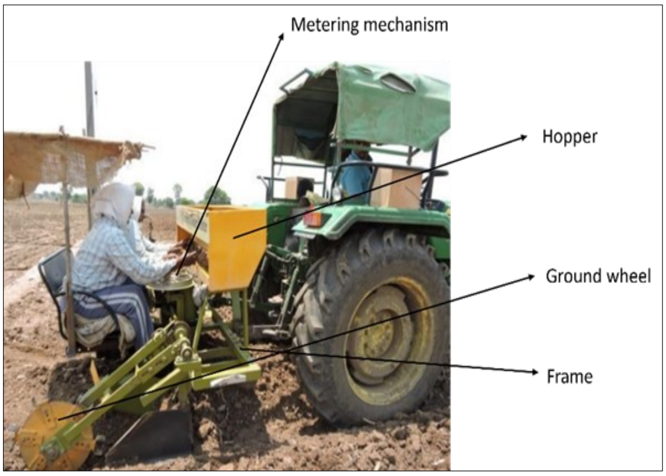


Fig. 8. Semi-automatic turmeric planter (38).

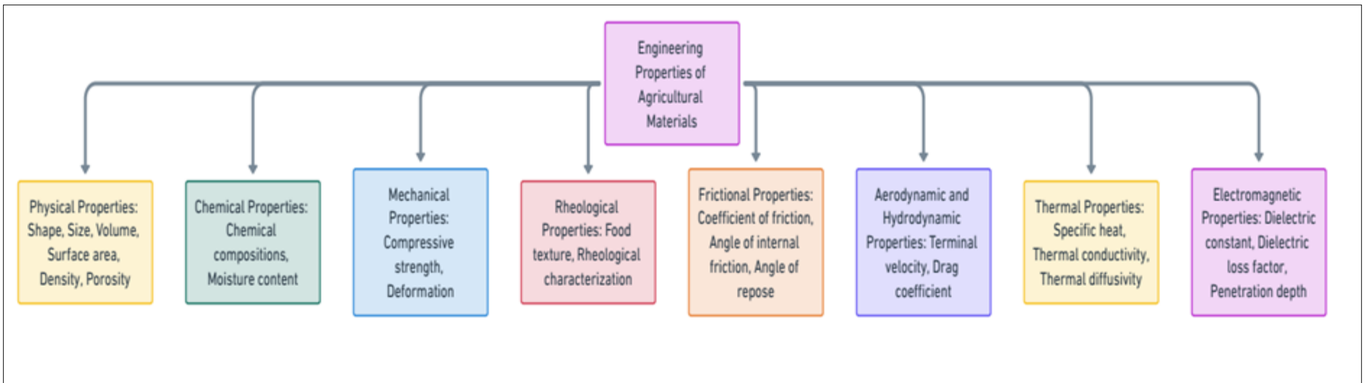


Fig. 6 Classification of engineering properties of agricultural materials.

Table 2. Comparative performance metrics of different methods of turmeric planting

Planting Method	No. of rows planted	Field Efficiency (%)	Labor Requirement (man-h ha^{-1})	Field Capacity (ha h^{-1})	Source
Animal-Drawn Planter	2	~65-75 %	80-100	~0.05-0.1	(37)
Semi-Automatic Planter	2	79.3 %	40-50 (depends on number of rows planted)	~0.12-0.15	(38)
Fully Automatic Planter	3	70.85 %	0	~0.19	(39)

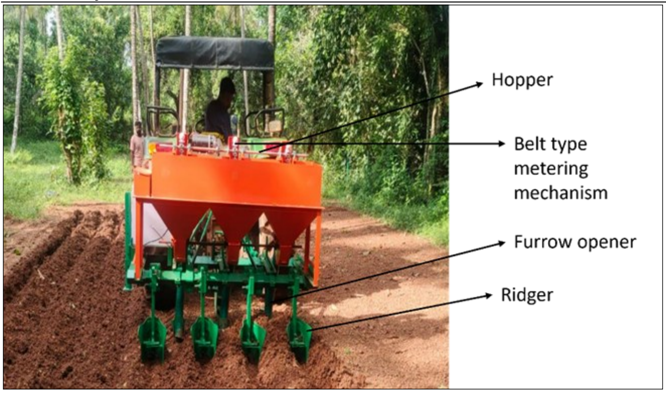
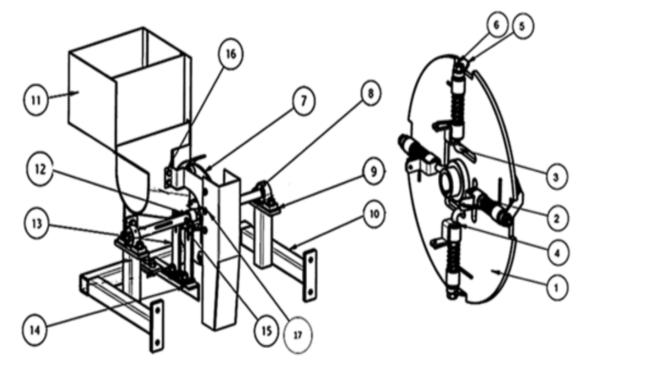


Fig. 9. Fully automatic turmeric planter (39).



1. Metering disc plate 2. Torsion spring 3. Pickup-finger lever 4. Pivoted washer 5. Pickup-finger 6. Hexagonal nut 7. Metering disc assembly 8. Bearing block 9. Nut and bolt 10. Main frame 11. Seed hopper 12. Main shaft 13. Cam assembly 14. Cam support 15. Cam 16. Plastic brush 17. Seed delivery tube

Fig. 10. Automatic ginger metering mechanism (41).

The comparative metrics of different levels of turmeric planting is presented in Table 2.

Metering mechanisms for automatic rhizome planting

Given that rhizomes such as ginger and root crops such as potatoes exhibit bulbaceous characteristics, they share common morphological features such as size and shape, with turmeric to a certain extent and could be utilized in the investigation of appropriate metering mechanisms for automatic turmeric rhizome planting. The metering mechanism in automatic planters ensures that manual labor is not required during the planting process, in contrast to manual and semi-automatic planters. Furthermore, the transition from semi-automatic to automatic planters was observed to reduce the overall labor cost by 60 % (40). Commonly employed metering mechanisms in automatic planters of rhizomes and root crops are categorized as follows:

1. Vertical rotating disc
2. Multistage rotating cup
3. Auger conveyor

A vertically rotating disc (Fig. 10) allows for velocity adjustments that significantly influence seed spacing, resulting in enhanced planting efficiency and crop yield. It is found to achieve a multiple index as low as 0.04 at a forward speed of 0.83 m s^{-1} (41, 42). Additionally, a high emergence ratio of up to 98.9 %, uniform tuber spacing of approximately 88.5 %, and a reduced missing tuber ratio of 0.9 % were achieved with this mechanism (43). The multistage rotating cup mechanism (Fig. 11) comprises multiple stages, wherein seedlings are extracted from a feeding wheel using a rotating cup and subsequently transferred to the planting site. The efficacy of these systems remains high across a range of operational velocities but may diminish as the velocity increases (44). As illustrated in Fig. 12, the auger-type metering device is appropriate for metering seedlings in nursery pots, including rhizome crops cultivated in controlled environments. This mechanism ensures high feeding and transplanting efficiencies up to a certain velocity, rendering it suitable for controlled and precise metering tasks (45). In addition to these three types, various other metering mechanisms have been developed by researchers for the automatic planting of rhizomes and root crops, as discussed in Table 3. Among the various metering mechanisms reviewed, a vertical rotating disc or multistage cup system may be the most promising, as these mechanisms have demonstrated favorable results with similar crops and can be optimized for the specific characteristics of turmeric. The picker wheel type

Fig. 11. Multistage rotating cup metering mechanism (44).

1. Seedling feeding wheel, 2. Seedling conveyer cum feeding wheel, 3. DC motor, 4. Gearbox, 5. Chain and sprocket power transmission system, 6. Delivery tube, 7. Shovel opener with disc closer attachment, 8. Slotted plate for feeding wheel, 9. Slotted plate for metering wheel, 10. DC speed controller, 11. Linear speed measurement setup, 12. Data acquisition system

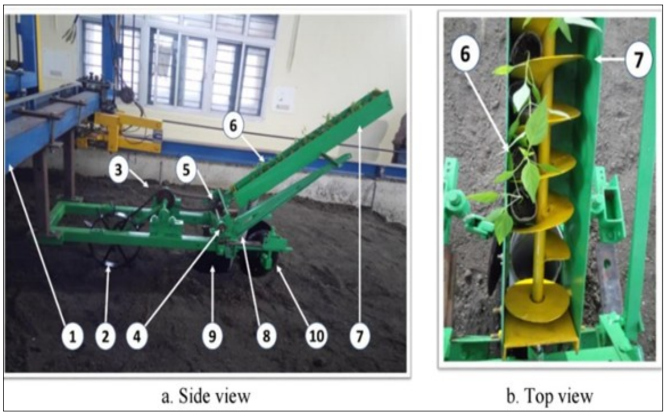


Fig. 12. The Auger-type metering device (45).

Implement trolley, 2. Ground wheel, 3. Power transmission system, 4. Main shaft, 5. Bevel gear holding assembly, 6. Seedling feed side of auger box, 7. Auger conveyer unit, 8. Delivery tube, 9. Furrow opener, 10. Furrow closer

Table 3. Study of performance of metering mechanisms for automatic planting of rhizome and other similar crops

S. No.	Design	Effects on seed spacing uniformity	Author
	Picker wheel type		
1	The mechanism consists of several key components including a circular disc, picker fingers, a hopper, and a delivery pipe. The circular disc, integral to the mechanism's function, rotates to facilitate the sequential picking and placement of bulbs or corms into the soil. Picker fingers attached to the disc pick up the bulbs from the hopper and transport them to the delivery pipe, which guides them into the planting furrows.	It was tested in a linear soil bin at varying forward speeds (1.5 to 3.0 km/h) and nominal spacings (15, 20, and 25 cm). The metering unit performed best at the lowest speed of 1.5 km/h for both types of plants, achieving the highest Quality of Feed Index (QFI) of over 91 %. As the speed increased, the quality of feed index and coefficient of uniformity, decreased, while the missing index and precision values increased, indicating less accuracy and uniformity in planting.	(46)
2	The electric cup-chain potato metering device incorporates tilting seed cups with guard plates on an electrically driven chain to optimize seed placement. This setup is controlled by a differential GPS that adjusts the seeding speed in real time to the speed of the tractor.	The optimized metering device demonstrated a missing-seeding rate of 4.39 % and a double-seeding rate of 8.78 %, which are improvements over traditional systems. These outcomes were achieved under specific operational conditions: a seeding speed of 0.32 m/s, a chain tightening distance of 0.94×10^{-3} m, and a cup tilting angle of 12.5°. Additionally, the implementation of an electric control system replaced the traditional ground wheel-driven chain, allowing for faster seeding and more accurate intra-row seed placement.	(47)
	Belt type		
3	The mechanism consists of a conveyor belt equipped with cups that are specifically sized to hold individual seed potatoes. As the belt transports the potatoes upwards, it turns over an upper sheave where the potatoes are then dropped onto the back of the next cup in line. This system ensures that each potato is metered and dropped at consistent intervals. At the bottom, the belt loops over a roller, creating an opening through which the potato drops into a furrow prepared in the soil.	Increased speeds of the cup-belt led to more uniform planting intervals, suggesting that faster belt speeds can reduce the variability in potato placement. Contrary to initial hypotheses, more regularly shaped potatoes (spherical) did not significantly improve planting accuracy. Instead, irregularly shaped potatoes achieved comparable or better accuracy. It was recommended that significant improvements in planting uniformity might be achieved by reducing the opening time at the bottom of the duct and by revising the cup design and its positioning relative to the duct.	(48)
	Cup type with torsion springs		
4	The mechanism consists of a vertical disc outfitted with cups, holding pins, and torsion springs, all attached at equal angles. Seeds are picked up from the hopper by the cups as the vertical disc rotates. The seeds are then secured by the holding pins until they are positioned over the furrow, at which point the pins are released by a pin-position cam, allowing the seeds to drop into the furrow.	Larger cups tended to produce more uniform seed spacing compared to smaller ones. However, the largest cup size used in the study also showed a higher percentage of doubles, indicating a trade-off between cup size and the risk of double planting. Oblong seeds achieved better uniformity in seed spacing than spherical seeds. Lower angular speeds resulted in more uniform seed spacing. As angular speed increased, the incidence of skips (gaps in planting) also increased, suggesting that slower speeds benefit the precision of the metering mechanism.	(49)
	Pneumatic type		
5	The mechanism includes a seed box where micro-tubers are stored before they are individually picked up by suction tubes connected to a rotating seeding disc, which operates under negative pressure. As the disc rotates, micro-tubers are held by the suction until they are positioned above the seed trench, where they are then released into the ground. This release occurs when the suction holes align outside the negative pressure zone, allowing the seeds to drop by gravity into the planting furrow.	The air-suction seeder achieved a high seed placement accuracy, with a qualified seeding index of over 90% under optimal conditions. Lower vibration frequencies and amplitudes contributed to higher seeding accuracy. The pneumatic design significantly reduced the risk of seed damage and loss.	(50)

can also be utilized if the occurrence of multiples is mitigated through the integration of an appropriate mechatronic system. However, additional empirical studies are required to determine the optimal mechanism.

Furrow openers

Furrow openers are critical components of the efficacy of mechanized planters. Their design significantly influences the soil penetration, soil disturbance, seed placement, germination rate, and operational efficiency. The selection of an appropriate furrow opener for specific soil conditions and planting requirements is crucial for optimizing crop yields and minimizing energy consumption in mechanized agriculture. Table 4 provides a concise overview of the various furrow openers.

Effect of various operational and machine parameters on performance of turmeric planters

An increase in the operational speed enhanced the performance of the turmeric planters. At velocities up to 12 km h^{-1}, the field capacity attained 0.96 ha h^{-1}, achieving optimal efficiency (58). However, elevated operational speeds increased the number of missed seeds. This observation suggests a decrease in seed placement accuracy with increased operational speeds, indicative of a speed-accuracy trade-off (59, 38). The length of the turmeric rhizome does not significantly influence the field capacity of the planter (58). Further studies have explored the relationship between the machine parameters and planting outcomes. Research findings indicate that increasing the peripheral velocity of the seed metering disc from 0.17 to 0.23 m/s led to an increase in rhizome spacing from 17.26 cm to 30.8 cm (60). The relationship between speed and spacing is not limited to rhizome planting. For instance, higher forward speeds enhance tuber deposition uniformity by accelerating the release process, whereas the irregularity of tuber shape has no significant impact on planting accuracy in a potato planter (48). These findings collectively highlight the complex relationship between operational speed and planting efficiency. However,

Table 4. Comparative performance of different furrow openers

Opener Type	Description	Performance Evaluation	Suitability for Planting Turmeric
Hoe-Type	Traditional tools designed to penetrate and disturb the soil, creating a furrow for seed or rhizome placement.	Effective in hard soils; higher draft force; higher soil moisture loss (51, 52).	Suitable for hard soils and provides good soil penetration, but may cause excessive soil moisture loss.
Disc-Type	Rotating discs that cut through the soil, creating a precise and narrow furrow with minimal disturbance.	Less soil disturbance; consistent seed placement; less draft force; poor penetration in hard soils (53, 54).	Not ideal for hard soils but suitable for well-tilled soils; minimal disturbance and accurate seed placement.
Shovel-Type	Characterized by a wide blade, opening a broader furrow compared to hoe-type openers.	Good soil penetration; higher draft forces; better vertical and lateral separation; higher soil moisture loss (55, 56).	Suitable for various soil types; good for turmeric rhizome placement due to wider furrow, but higher draft forces required.
Vibratory	Use mechanical vibrations to break up soil and create furrows, suitable for no-till or minimum tillage systems.	Efficient soil breakup; less power required; good seed placement; minimal soil disturbance (57).	Not ideal for turmeric as it is mainly suitable for no-till systems and may not provide the necessary soil depth and coverage for rhizomes.

despite these operational insights, there remains a notable gap in research on the effects of specific crop parameters such as rhizome size, weight and shape on the performance of turmeric planters. Although the length of the rhizome has been shown to have a minimal influence on field capacity, other crucial parameters may significantly affect planter efficiency and accuracy. The lack of comprehensive studies addressing these variables underscores a critical research gap and emphasizes the need for further investigation to guide the development of more efficient and crop-specific turmeric planters.

Recent advancements in planters

Recent advancements in planter includes mechatronic based control system for seed metering. As the control system is not based on the properties of planting material, it can be universally integrated with any planters irrespective of the size and shape of the crops. Traditional planters are driven by ground wheels and gearboxes, which can lead to poor seeding quality, especially at high speeds. GPS-based control system enhances precision, efficiency and cost-effectiveness in planting operations, particularly for large-scale, high-speed planting systems. GPS could be used as speed sensors with an advantage of neglecting slip in speed calculation. The integration of electric seed metering drive and GPS could be made for enhancing the seed spacing uniformity. Even at higher forward speeds of 10 to 12 km h^{-1}, a GPS based control system (Fig. 13) has achieved exceptional performance, with an average Quality Index (QI) of at least 92.84 %, a Miss Index (MI) not exceeding 5.80 % and a Precision Index (PI) surpassing 18.57 % (61).

In addition to tractor mounted automatic planters, a

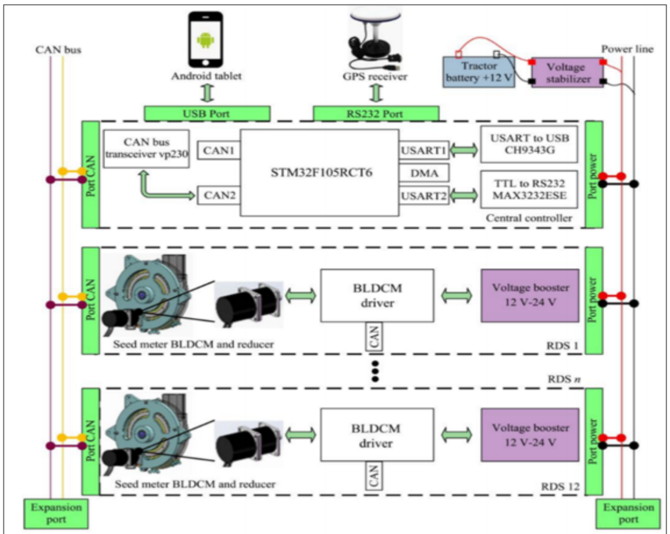


Fig. 13. GPS based Seed metering control system (61).

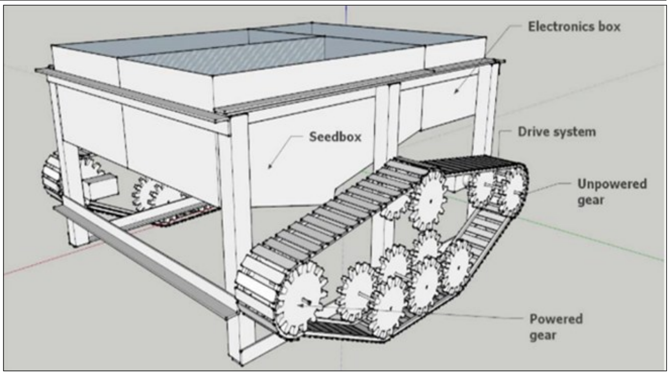


Fig. 14. Autonomous planting robot (62).

fully autonomous planting robot can further reduce the labor shortage and fuel consumption associated with tractor mounted planters. For an instance an autonomous seed planting robot (Fig. 14) was developed with a solenoid actuated seed metering mechanism and magnetometer-based navigation system demonstrating the feasibility of going full autonomous in planting operation (62). But this technology has not reached the field level operation. As a result, there are no adequate field evaluation metrics to compare its performance with the existing technologies.

Although GPS has some navigational advantages, it adds to the initial cost of the machine more than other alternatives. For example, RADAR could achieve the same function with reduced complexities and minimal cost in comparison with GPS. Since it uses doppler effect for forward speed determination, the measured velocity is free from slip of the tractor wheel in case of tractor-mounted planters. Unlike GPS it does not rely on geographical co-ordinates for forward speed determination which reduces the complexity of the seed

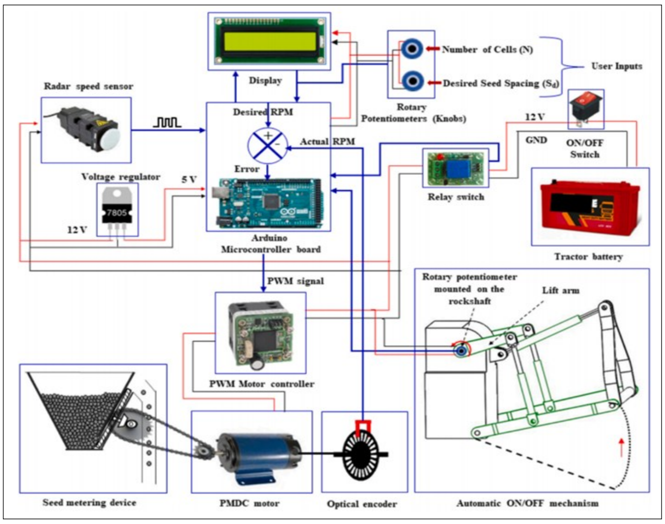


Fig. 15. RADAR based mechatronic seed metering control system (63).

control system. For example, a RADAR based mechatronic seed control system (Fig. 15) developed was able to achieve an increase of 8.12-21.32 % in the quality of feed index across a speed range of 1.6-4.8 km h^{-1} compared to the ground wheel driven mode (63).

Conclusion

The optimization of turmeric cultivation through innovative planting methods and mechanization presents significant opportunities for enhancing productivity and efficiency. The development of an automatic turmeric planter, informed by a review of various mechanical planters and automatic metering mechanisms, such as vertical rotating discs and pickers, promises to address key challenges such as labor intensity, inconsistent seed placement and susceptibility to diseases. The fresh turmeric rhizomes ranged in length from 30.38 to 50.60 mm, breadth from 9.77 to 10.64 mm and thickness from 5.18 to 6.44 mm. The geometric mean diameter of the rhizomes varied between 12.77 mm and 13.76 mm, sphericity ranged from 0.27 to 0.42 and the aspect ratio was between 0.20 and 0.35 (27). These measurements suggest that designing cups and buckets for a metering mechanism within these dimensional ranges would optimize the mechanized planting of turmeric. Turmeric rhizomes were found to have a low coefficient of friction with aluminum (31), suggesting the potential development of planter components designed for the flow of turmeric rhizomes in aluminum. Available turmeric planters are not exclusively tailored to the diverse and specific requirements of the optimal planting conditions. Given the proven influence of factors such as planting density, planting time, land configuration, and seed rhizome size on yield, growth and disease management, future planter designs must account for these parameters. To enhance productivity and efficiency, turmeric planters should incorporate flexibility in planting density, accommodate various rhizome sizes and support advanced techniques, such as single bud transplanting and raised bed configurations. To meet the demands of optimum turmeric planting configurations such as raised beds and triangular planting patterns, there is a need to develop a metering mechanism that can accommodate precise seed placement and spacing. Current planter designs fail to address the flexibility required for triangular planting, which offers optimal space utilization and airflow, thereby enhancing yield. A robust metering system should ensure the accurate positioning of seed rhizomes, maintain an ideal planting density and adapt to varying land configurations, such as raised beds, to fully optimize the potential benefits of these techniques. Shovel-type furrow openers were the most suitable for turmeric planting. In conclusion, mechanized planting strategies are essential for sustainable and profitable turmeric production, offering a path to increased efficiency, higher yields and greater economic viability for farmers.

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Authors' contributions

SV and RK carried out the collection of literature and drafted the manuscript. BS and APM carried out the revisions and discussions. VR and NS participated in the design of manuscript and final draft making. All authors read and approved the final manuscript.

Compliance with ethical standards

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