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REVIEW ARTICLE

A review on way towards mechanized castor cultivation

Gowsalya R[1], Natarajan SK[2]*, Ragavan T[1], Venkatachalam SR[3] & Thambidurai S[4]

[1]Department of Agronomy, Agricultural College and Research Institute, Madurai 625 104, Tamil Nadu, India
[2]Department of Agronomy, Tapioca and Castor Research Station, Yethapur, Salem 636 119, Tamil Nadu, India
[3]Department of Genetics and plant Breeding, Tapioca and Castor Research Station, YethapurSalem 636 119, Tamil Nadu, India
[4]Department of Farm Machinery and Power Engineering, Agricultural Engineering College and Research Institute, Coimbatore 641 003, Tamil Nadu, India

*Email: natarajan.s.k.@tnau.ac.in

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Abstract

Castor (*Ricinus communis* L.) is an important non-edible oil seed crop which is known for its oil content (48–60%) and it accounts for 0.15% of the global production of vegetable oil. In recent years, farmers have preferred castor cultivation due to its suitability for both rainfed and irrigated conditions. But the farmers face many challenges, which include labour scarcity, pest incidence, high input and labour costs, inadequate market information, etc. Due to a significant labour shortage, the area under this crop is gradually decreasing. The high reliance on human labour leads to the incompletion of various agronomic operations on time. In these circumstances, the cultivation of castor by adopting various mechanization techniques for critical operations such as field preparation, sowing, fertilizer application, weeding, irrigation, crop protection measures and harvesting will be the solution for getting higher productivity and profitability by spending minimum expenses. Adapting mechanization through rotavator for field preparation, tractor with seed drill for sowing, power weeder for weeding, irrigation and nutrient application through drip fertigation, chemical spraying using drone for crop protection measures, combine harvester for harvesting etc. are crucial for achieving sustainable development goals by enhancing production through timely farm operations, minimizing losses and reducing operational costs through efficient management of expensive inputs.

Keywords

Castor; drip; harvest; labour; mechanization; seed drill

Introduction

Castor (*Ricinus communis L.*) is one of the commercially important non-edible oil seed crops in the Euphorbiaceae family (1). Because of its very high oil content (48–60%), high potential oil production levels (500–1000 L acre^{-1}) and special ability to produce oils with exceptionally high levels of ricinoleic acid (80–90%), castor is considered to be an ideal candidate for the production of high value industrial oil feedstocks (2). Ethiopian-East African region is considered to be the most likely place of origin (3). Growth is suitable for both rainfed and irrigated conditions along with a hot and humid climate (4). According to FAO statistics, the average global output, cultivation area and yield of castor seeds in 2021 are estimated to be 1861700 tons, 1296895 ha and 1435.5 kg ha^{-1} respectively (5). Major castor-growing countries are India, China, Brazil, Paraguay and Thailand, which account for 82.58% of the world's total area. India alone contributes around 70% of total castor area on a world-wide scale (6). With an average productivity of 1902 kg ha^{-1}, India produces 15.68 lakh tons of castor annually from an 8.24 lakh hectare growing area (7). India is generating export revenue of 10692 crore rupees from the annual export of 10.92 million tons, with China, Japan, South Korea, France, the USA and the European Union, being the primary importers of Indian castor (8). The majority of these crops are cultivated in Gujarat, Rajasthan, Andhra Pradesh and Karnataka. However, the land under this crop is gradually diminishing in all regions and labour shortages are becoming significant (9). The area dedicated to castor crops has varied annually and is not showing an increasing trend (Fig. 1) (10). Agricultural labours accounted for around 16.3% of total power availability in 1960–61, but this figure is expected to fall to 2.3% by 2032–33 (11). Farm mechanization has been shown to give a number of economic and social benefits to farmers. It saves 15–20% on inputs such as seeds and fertilizers, as well as 20–30% on labour and operating time. Thus, critical operations such as sowing, inter-cultivation, plant protection, harvest and shelling are mechanized to reduce the cost and labour involved in castor cultivation, while also increasing castor yields and making the farmers self-sufficient in agricultural activities (12). By adopting mechanization, the need for manual labour is reduced significantly, which leads to marked decrease in labour costs and overall production costs. And also, the mechanization ensures the timely completion of critical farming tasks simultaneously enhancing the overall productivity of the crop. This also improves the standard of farmer's community and increases the self-sufficiency of the farmers. In the long run, such advancements in technology and mechanized operations facilitate sustainable farming practices, enabling farmers to meet growing demand while managing environmental and resource-related challenges. The integration of mechanization into castor farming, therefore, represents a significant step toward modernization, improving both the economic viability and long-term sustainability of agricultural activities. Therefore, this review investigates the techniques used in machine-based castor cultivation.

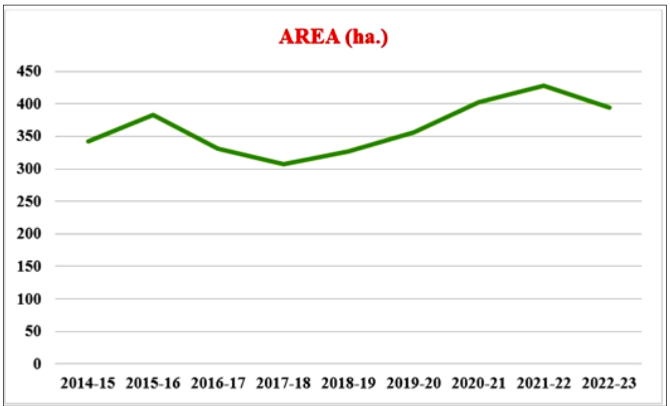

Fig. 1. Area under the castor crop in Tamil Nadu state.

Importance of castor

Castor is commercially grown for their seeds, which produce a thick, pale yellow, non-volatile, non-drying castor oil (13). It is vital for the chemical industry as it is the sole commercial source of ricinoleic acid, constituting about 84.5% of the oil (14) (Fig. 2), making it a natural polyol that has been extensively employed in the manufacture of polyurethanes. In ancient times, oil served as a source of fuel for lamps and today it finds its utility in more than 700 different applications (15) which include oil-based lubricant and grease formulations, oleochemicals, reactive components for paints, coatings, functional fluids and process oils, emulsifiers, vinyl compound stabilizers, textile finishing agents, wetting agents, inks, polymers and foams (16). Moreover, the leaf or seed extracts (1–10%) in water or chemical solvents, as well as crude oil (3–5%) derived from seed, have been shown to be useful as sprays against foliage insect pests such as *Epilachna varivestis, Epilachna septima, Helicoverpa armigera, Monolepta signata* and *Spilosoma obliqua* (17). Oil cake is regarded as a rich source of concentrated organic manure, since it contains 6.6% N, 2.6% P_2O_5 and 1.2% K_2O from decorticated seeds, and 4.5% N, 0.7% P_2O_5 and 1.9% K_2O from undecorticated seeds, and it can be applied to the fields (18).

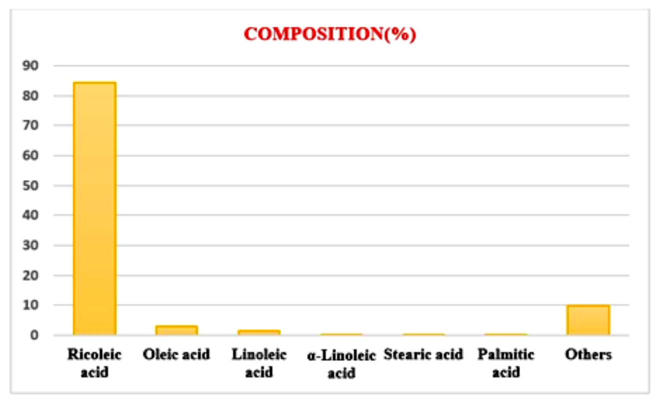

Fig. 2. Castor oil composition.

Challenges in castor cultivation

The farmers have recently switched from other rainfed crops (groundnut, pigeonpea and millets) to castor crops due to the high market prices of castor. Despite expanding crop acreage, yields are modest and staggered at the base (19). These consequences are due to various challenges faced by the castor farming community. Pest incidences, labour scarcity, lack of monsoon rains, inadequate market information, high input and labour costs have all been recognized as major restrictions. The difficulties in reliance on human labour include inability to complete various agronomic operations on time, loss of energy and productivity, poor production per unit time, body discomfort, fatigue and health disorders (20). Moreover, the productivity of agricultural labour is four and six times lower than that of the industry and service sectors, respectively (21). The key hurdles for castor cultivation include the development of high-yielding types that are non-shattering, dwarf, resistant or tolerant to disease and insect pests and low ricin (toxic protein), ricinin (toxic alkaloid) and RCA (*Ricinus communis* Agglutinin) (toxic lectin) content (22). Ricin is a highly toxic protein that can cause severe damage to the cells and tissues of the body when ingested, inhaled or injected (23). Ricinin is a lesser-known compound present in castor seeds. It is a toxic alkaloid that has been shown to have inhibitory effects on the growth of cells (24). *Ricinus communis* Agglutinin (RCA) is a lectin, a type of protein that binds to carbohydrates and can agglutinate (clump together) red blood cells (25). The limited understanding of genetic factors influencing modest and erratic crop yields, as well as vulnerability to diseases and pests, pose significant problems in effectively breeding castor plants (26). When both indeterminate growth and seed cracking occur at the same time, the barriers to oilseed crop adaptation increase (27). Among small-scale farmers, the most challenging and time-intensive tasks in castor production involve harvesting the crop and removing the seeds from the capsules (28). And also, the major problem of oilseed marketing is the lack of transports facilities. Therefore, toxic seed compounds (ricin), harvesting problems, high N requirements, marketing difficulties are considered to be the major shortcomings of castor cultivation. Due to these issues, farmers are sometimes forced to sell their produce at the farm gate and at the local market for a low price (29). Additional challenges restricting the utilization of castor include the presence of the highly poisonous ricin compound in its seeds, a plant structure and growth pattern that complicates mechanized harvesting and its vulnerability to various types of environmental and biological stress factors (30).

Path towards castor mechanization

In the context with the challenges discussed above, the mechanized agriculture systems have the ability to maximize output and quality while reducing losses and their negative effects on the environment (31). The benefits include reduction in labour expenses (cost savings for sowing, irrigation cum fertigation, weeding, chemical application, harvesting and threshing are recorded to be 45%, 86.2%, 45%, 44.4%, 78.56% and 77.7% respectively) (Fig. 3) (32), decreased labour-intensive tasks, convenience, faster and more timely operations, better risk management related to weather and less grain loss during harvest and also countries employed with advanced technological progress can significantly lower agricultural carbon emissions by enhancing agricultural mechanization. Technological advancements play a positive regulatory role in achieving this outcome (33). Farm mechanization lowered the amount of time required for farm operations while substituting animal power by 50% to 100%. As productivity in Indian agriculture improves, there's been a significant rise in the adoption of upgraded implements and machinery powered by electro-mechanical sources. This increase has effectively lowered the costs and labour intensity associated with castor cultivation, while also enhancing castor yields. From 2014–15 to 2022–23, India allocated Rs. 5490.82 crores for agricultural mechanization. This investment led to the distribution of 1388314 subsidized machines and equipment to farmers by December 2022 (34). The use of mechanized castor cultivation resulted in timely and precise completion of all field operations, as well as significant labour and time savings (58 man days ha^{-1}) for various agronomic tasks (12). Farm mechanization has been shown to give a number of economic and social benefits to farmers. In addition, it saves inputs like seeds and fertilizers up to 15–20%, as well as labour and operating time by 20–30% (35). The overall goal is to enable farmers to become self-sufficient in their agricultural operations.

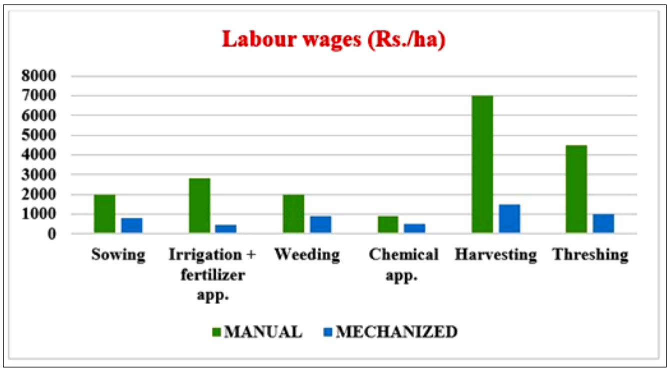

Fig. 3. Comparing Labour wages for critical operations in castor cultivation.

Pre-requisites favouring mechanization

From sowing to processing, the entire castor production process is manual, involving little to no fertilization and soil ploughing (29). Mechanizing the production process is essential to increase castor yields and the only existing method to enable the mechanization of the crop cycle is through breeding programs to create an appropriate plant architecture (16). The ideal morpho-agronomic characteristics for castor breeding programs aimed at mechanized farming (Fig. 4) involve compact plant stature, tall primary raceme positioning, slender to moderately thick stems, plentiful commercial racemes, increased seed weight, elongated racemes and higher seed oil content (36). Castor plants optimized for mechanical harvesting exhibit fewer branches and overall racemes per plant. The abundance of branches and the indeterminate growth pattern of castor plants leads to labour intensive and challenging harvesting processes (37). Dwarf hybrid variety with ideal type suitable for mechanical harvesting has dwarf internode, none or less branching, erect stem and long primary raceme. Breeding programs targeting dwarf castor varieties suitable for mechanical harvesting prioritize accessions with compact stature (less than 1.5 m), primary raceme length exceeding 40 cm, over 60 capsules per raceme, a harvest-

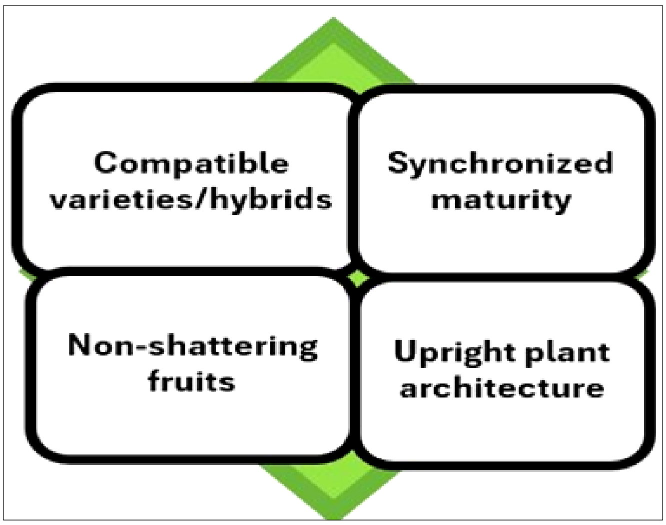

Fig. 4. Agronomic prerequisites for mechanized castor farming.

ing period of less than 150 days, upright plant architecture and non-shattering fruits (38). Choosing a specific type of castor hybrid is important which lead to increased production as a result of trimming side branches. Non-shattering varieties are ready for harvest when their capsules are fully dry. Conversely, shattering types should be harvested when their capsules change colour from green to yellow (22). The creation of a new dwarf type plant variety that is appropriate for mechanical harvesting may boost seed yield productivity and improve the range of cultivars available to farmers and industries (39).

Mechanization of critical operations

Field preparation

Tillage is an important activity in agricultural production because it optimizes soil bed conditions for seed germination, seedling establishment and crop growth. Tillage practices involving a disc plough for deep tillage, followed by two cultivator ploughings and one planking to incorporate residues, yielded the best results compared to minimum tillage in a castor-based legume intercropping system (40). For primary tillage, the majority of progressive farmers utilize mould board ploughs and disc ploughs; for secondary tillage, they employ rotary tillers or rotavators and disc harrows. Rotovation-based tillage produced considerably more dry matter, more capsules per plant, longer primary spikes, more 100-seed weight and shelling percentage than non-rotovation tillage techniques (41). Deep ploughing operations, using a tractor-drawn mould board plough at 30 cm depth, yielded superior results compared to shallow ploughing (at 20 cm depth). The roto till drill and strip till drill have greater operational costs due to their higher initial cost when compared to the rotary plough with seed drill and till planter (42). With the implementation of the combined plough, there's a reduction of 14.65% in labour costs and a decrease of 18.3% in operating costs compared to the conventional method (43). For primary tillage, the majority of progressive farmers utilize mould board ploughs and disc ploughs; for secondary tillage, they employ rotary tillers or rotavators and disc harrows (44). During pre-monsoon showers, mechanized tillage procedures involving a tractor-drawn cultivator followed by one disc ploughing to a depth of 10–12 cm maintained greater sustainable yield indices than minimum tillage (45). Deep ploughing operations, using a tractor-drawn mould board plough at 30 cm depth, yielded superior results compared to shallow ploughing (at 20 cm depth). This method also led to notably higher root depth penetration in castor plants (46). The best outcome was attained through a sequence of agricultural practices: summer ploughing at a 30 cm depth, harrowing with a disc harrow at a 12 cm depth during autumn, and two rounds of seedbed preparation using a seedbed cultivator at a 10 cm depth just before spring sowing (47). The mouldboard low, with a speed of 3.8 km/h, outperformed other methods in reducing soil bulk density, increasing porosity, and decreasing specific soil resistance (48). Repetitive use of cultivators not only leads to the formation of hardpan but also negatively impacts root development and penetration (49). Hence the effective tillage practices, particularly those involving deep tillage and advanced machinery, significantly improve crop growth and yield in castor cultivation, while also offering notable reductions in labor and operational costs compared to conventional methods.

Sowing

The choice of sowing equipment might be crucial to the establishment of a suitable crop by maintaining the proper sowing depth (50). Optimizing the plant population represents a cost-effective strategy with the potential to markedly enhance the yield of castor seeds. Directly sowing castor seeds resulted in notably higher seed yield (3230 kg ha^{-1}) and stalk yield (5361 kg ha^{-1}) compared to other planting methods (51). In the uniform row planting system, the sole castor recorded a significantly higher seed yield of 43.4 q ha^{-1} compared to paired row planting at 80/160 cm (52). The recommended spacing is 90 cm × 60 cm, however we selected 120 cm × 45 cm to facilitate mechanized operations in the inter-row space without impacting plant population (20). About 45 kg of seeds are needed for manual planting, while about 15 kg and 26 kg are needed for mechanical planting using a planter and a seed drill respectively (53). Tractor-drawn seed cum fertilizer drills, which execute both sowing and basal fertilizer delivery, have gained favour in numerous crops. When evaluating the performance of manual seeder for direct sown castor, it was found that it attained a field efficiency of 88.6% and had an operational cost of Rs. 445 ha^{-1} and this cost is lower in comparison to manual sowing (54). When employing the ridger seeder, pneumatic planter and cultivator seeder for sowing cotton, significant cost savings (44%, 42.85% and 41.64%, respectively) and time savings (96.4%, 96.3% and 96.2%, respectively) were observed compared to manual sowing (55). Castor planter recorded the field capacity of 1.1 ha h^{-1} and sowing cost of Rs.600 ha^{-1}, while the method behind country plough recorded a field capacity of 0.15 ha h^{-1} and sowing cost of Rs. 2000 ha^{-1}, respectively (56). The choice of sowing equipment and planting methods significantly influence both the efficiency and cost-effectiveness of castor cultivation, with mechanized sowing offering substantial savings in time and labor costs while improving yields.

Fertilizer application

Castor's productivity is determined by the source and quantity of nutrient input under which it is grown (57). The recommended fertilizer application includes N:P:K in proportions of 60:40:40 kg ha^{-1}. The full dose of P and K is applied initially, while N is split into three equal parts: applied initially, then at 35–40 days after sowing (DAS) and finally at 65–70 DAS. Mechanized sowing cum fertilizer applicator resulted in a 24% reduction in seed input and a 30% reduction in fertilizer usage compared to traditional farmer practices (58). The combined machine, a raised bed seed cum fertilizer drill, demonstrated superior and trouble-free performance compared to other conventional methods (59). The seed-cum-fertilizer drill allows for line sowing and precise application of seed and fertilizer with 10–15% reduction in inputs and 30% saving in fertilizer usage (60). The rotary weeder cum fertilizer drill was designed to provide timely weed management and precise fertilizer delivery while taking into account unique soil conditions and crop requirements (61). The field efficiency of rotary weeder cum fertilizer drill with adjustable fertilizer drop was found to be 81.79% with the forward speed of 3.0 to 3.9 km h^{-1} during first weeding (62). The CRIDA (Central Research Institute for Dryland Agriculture) Six Row Tractor Drawn Planter has a spring auger type fertilizer metering mechanism that allows for an effective and appropriate dose of fertilizer application (70–200 kg DAP ha^{-1}) (63). Optimizing nutrient management and adopting mechanized fertilizer application techniques significantly enhance castor productivity by reducing input costs, improving efficiency and ensuring precise fertilizer application tailored to specific crop needs and soil conditions.

Irrigation

Castor is a drought-tolerant crop (64) with a low water demand (500 mm) (65). Compared to an IW:CPE (Irrigation Water and Cumulative Pan Evaporation) ratio of 0.4, the IW:CPE ratio of 0.8 showed 13.9 and 15.6% higher seed and stalk yields, respectively (66). The number of racemes per plant exhibited the highest plasticity to water availability among yield components, followed by the number of seeds per raceme and seed weight. Meeting irrigation demands in the diminished delta is a serious task and consequently, maximizing the efficient use of canal water becomes vital. The CUE (Consumptive Use Efficiency) can be improved by implementing technology such as micro irrigation, which is an effective irrigation strategy (67). The water productivity of crops irrigated by micro irrigation systems (MIs), both in terms of physical output and economic returns, greatly surpassed that of crops irrigated using traditional methods. The best outcome is achieved with drip irrigation at 0.4 Epan (pan evaporation) until flowering and then at 0.8 Epan thereafter (68). Farmers are increasingly adopting drip irrigation to enhance irrigation application efficiency, water productivity and seed yields (69). Drip irrigation saves 25% of irrigation water as compared to surface irrigation (70). For achieving profitable yields from semi-rabi castor, irrigate at 1.0 ADFPE (Alternate Day with calculating the Fraction Pan Evaporation) using drip irrigation in conjunction with fertigation of nitrogen at 60 kg ha^{-1} through urea in four equal splits at 30, 60, 90 and 120 DAS, respectively (71). Water stress must be applied to drip-irrigated paired row-planted castor plants after 50% emergence of the main spikes in order to achieve increased crop yield and conserve irrigation water more effectively (72). Irrigating the castor crop at 80% cumulative pan evaporation through drip irrigation, combined with 100% RDF using water-soluble fertilizer, enhances growth and yield attributes and also increases the castor equivalent yield in a castor-plus-onion intercrop (73). Drip irrigation at 0.4 PEF (Pan Evaporation Fraction) in paired row-planted castor yielded almost the same seed yield (2.3 t ha^{-1}) as surface irrigation control under conventional planting (2.5 t ha^{-1}), achieving a substantial 39% reduction in water usage (74). Drip irrigation at a lateral pipe of 15 mm (diameter) demonstrated superiority in water use efficiency (5.74 kg ha^{-1} mm^{-1}), net returns (Rs. 43821 ha^{-1}) and the B:C ratio (2.86) compared to other drip irrigation levels (10 mm and 20 mm) in castor (75). When evaluating various irrigation techniques, check basin irrigation, sprinkler irrigation and drip irrigation resulted in seed yields of 1516 kg ha^{-1}, 1399 kg ha^{-1} and 2005 kg ha^{-1} respectively (18). Surface irrigation faced significant challenges primarily due to drainage inadequacies, whereas sprinkler irrigation encountered obstacles like gravelly soil texture, drainage deficiencies and the presence of calcium carbonate. The overall efficiency of surface, sprinkler and drip irrigation was found to be 30–35%, 50–60% and 80–90% respectively and also the surface moisture evaporation was found to be 30–40%, 30–40% and 20–25% respectively (76). Henceforth, drip irrigation emerged as the most effective among all the irrigation methods.

Weeding

The most popular approach for controlling weeds in castor crops has been mechanical control, which is carried out with animal traction equipment or with tractors, mostly on small holdings. It has been reported that in castor, the critical period of weed competition occurs 30 to 60 DAS because of its unusual wide crop geometry, 90–120 cm between rows and 40–60 cm within rows, which stay uncovered with leaves due to slow plant growth (77). It's projected that weeding one hectare of castor crop during the initial weed development stage requires the labour of 15 men per day. For inter-row weeding using animal traction, it necessitates two days of work by one man ha^{-1} (78). An effective early-season weed management strategy is to do row cultivation after rotary hoeing in the first few weeks following planting (79). Employing a tractor-drawn blade (covering 2 rows) along with a minitractor-drawn rotavator (covering 1 row) for inter-cultivation not only conserves labour (10 ha^{-1}) and time (35 h ha^{-1}) but also aids in moisture conservation and provides efficient weed control (18). When compared to human weeding, the cost savings of using a bullock drawn junior hoe, self-propelled power weeder and tractor drawn weeding cum earthing-up equipment were 78.7%, 79.8% and 68.7%, respectively (80). In castor crop, the multi-crop power weeder results in labour and time savings of 86.09% compared to hand weeding with less damage to plants (6). The power tiller can remove weeds and harrow the soil to create a suitable seedbed. The tiller is a lightweight, compact machine designed for easy mobility and operator convenience. The bullock-drawn hand hoe increased weeding efficacy by 75% compared to traditional methods, while the tractor-drawn blade harrow improved weeding efficiency by 95% (9). For weed management and intercultural operations, under mechanized condition the time taken and labour requirement was found to be 68.7 h ha^{-1} and 7 men ha^{-1} respectively whereas for the non-mechanized condition it was 261.3 h ha^{-1} and 32.7 men ha^{-1} respectively (12). Therefore, by adopting mechanical weed control methods in castor cultivation not only enhances efficiency by saving labour and time but also significantly reduces costs and improves overall crop management, making it a more sustainable and effective approach compared to traditional hand weeding.

Crop protection measures

Castor yield loss of approximately 40% has been calculated due to insect infestations (81). In terms of disease, vascular wilt during flowering and at later growth stages caused 77.0% and 39.0–63.0% yield loss, respectively (17). Effective management of diseases and pests in castor production (Table 1) is essential for achieving higher yields and producing high-quality oil to meet the demands of industrial and pharmaceutical purposes. Appropriate chemical application for crop protection is crucial since it has a substantial impact on crop output and agricultural production's economic efficiency (82). The power sprayer is designed to make pesticide and herbicide application easier for farmers and gardeners, eliminating the need to carry heavy tanks on their backs and it operates by being pushed forward, similar to a trolley, reducing back pain and strain. A tractor-operated power sprayer is less time-consuming, suitable for both marginal and larger farms which offers more effective spraying and its field efficiency was estimated at 73.20% (83). Drone pesticide application on tall-growing crops such as castor found to be more effective where hand spraying with power sprayers and tractor-mounted sprayers becomes impossible after 60 days (19). The integration of UAVs (Unmanned Aerial Vehicle) and sprayer systems has the potential to create a platform for pest management and vector control. One-nozzle spraying generated higher spraying quality than four-nozzle spraying, yet four-nozzle spraying resulted in a larger effective spraying field capacity (84). The heavy lift UAVs are necessary for large-area spraying and the researcher proposed the Quad copter (QC) technology, which is low-cost and lightweight, also known as the Unmanned Aerial Vehicle (UAV). The drone using flat fan type nozzle has the spraying speed of 47 L ha^{-1} (85) while using centrifugal type nozzle the recorded spraying speed was 0.6–1 L min^{-1} (86). Hence, effective management of pests and diseases, along with the adoption of advanced spraying technologies such as power sprayers and drones, is crucial for improving castor yields, ensuring high-quality oil production and enhancing the economic viability of agricultural practices.

Harvesting

In order to broaden the cultivation area and enhance the productivity of castor, there is a need to achieve the mechanization of castor harvesting (87). Castor harvesting technology is essential to address mechanization challenges, reduce harvesting costs and promote sustainable development in the castor sector. An area of 66.2 hectares with minimal mechanization is needed to produce 1000 Giga Joule of net energy, compared to 37.5 hectares with highly mechanized agricultural production (88). Under manual harvesting, 5 workers are required, accounting for 32% of the total cost and in mechanical harvesting only one worker is needed, contributing 13% to the total expenses. However, mechanical harvesting experiences considerable losses of up to 50%, indicating the necessity for enhancements (89). There is currently no mechanized equipment available for the harvesting of castor crops. A traditional combine harvester, when outfitted with a sunflower header, may serve as the initial stage in the progression towards achieving a completely mechanized harvesting process. Sunflower and cereal headers resulted in harvesting 92% w/w and 86% w/w of the potential seed yield, respectively (90) and the sunflower head appears to be more optimal for processed seeds, while cereal heads are better suited for unprocessed seeds and also more extensive seed damage was observed under sunflower header (91). The plants need to wither and dry out before harvesting. If this condition is met, minimal adjustments to the standard combine harvester will suffice to ensure efficient threshing of the capsules and minimize seed loss or damage. Applying harvesting aids through spraying is a crucial preliminary step before mechanical harvesting. Harvest aids are employed to expedite processes such as defoliation, dehydration, fruit ripening and the inhibition of regrowth (92). Enhancing harvest or picking efficiency stands out as a key advantage of defoliation(37). It has been observed that parquet, the broad spectrum herbicide which causes effective defoliation without affecting the seed yield. For reducing the residual moisture in dwarf castor plants, glyphosate (6 L ha^{-1} 20 days before harvesting), Spotlight© BASF (6 L ha^{-1} 20 days before harvesting) and diquat (5 L ha^{-1} 10 days before harvesting) can be used, but reduced seed loss from dehiscence was noted when diquat is applied (93). Trinexapac-ethyl, mepiquat chloride and chlormequat chloride were found to be effective at limiting stem elongation in castor plants grown in shade. However, the last two required far higher doses to get the desired effect (94).

Table 1. Major pests and diseases, and chemicals used for mechanical spraying

S.No	Particulars	Species	Chemical for mechanized spraying
1.	Major pests (107)	*Achaea janata* *Spodoptera litura* *Conogethes punctiferalis* *Amsacta albistriga* *Trialeurodes ricini* *Retithrips syriacus*	Monocrotophos (0.05%) or Profenophos (0.05%)
2.	Major diseases (108)	Fusarium wilt (*Fusarium oxysporum*)	Soil borne (Spraying is not effective)
		Leaf blight (*Alternaria ricini*)	0.2% mancozeb
		Grey mould (*Botrytinia ricini*)	2 prophylactic sprays of carbendazim
		Powdery mildew (*Levillula taurica*)	Hexacanazole (0.1%)
		Rust (*Melamspora ricini*)	Propiocanazole (1 L ha^{-1})

Dwarf genotypes are now commercially accessible and have shown promising performance even in challenging conditions (36). In India, disbudding (nipping) is a cultivation technique for the castor-oil plant aimed at shortening maturation time and enhancing grain yield. Nipping the buds in rainfed castor cultivation has shown to significantly increase yields up to 40% (95). Vibration picking, widely used in agroforestry crop harvesting, has shown effectiveness but remains unexplored in Castor harvest because of its indeterminate growth habit and uneven maturity. Studying its characteristics and mechanism in Castor capsule harvesting is crucial for developing a new Castor combined harvester (96). Comb brush harvesting allows fruit-bearing branch penetrates the comb's finger, the impact force between the finger and the fruit causes the fruit to detach from the stem. Brush harvesters have the advantage of causing less damage to crop roots when compared to vibration harvesters (97). The mechanization of castor harvesting is essential for improving productivity, reducing costs and ensuring sustainability in castor cultivation. While advancements such as the adaptation of traditional combine harvesters and further innovations are necessary to minimize losses, enhance efficiency and optimize seed quality.

Post-harvest techniques

Post harvest operations are the activities that increase the value and condition of agricultural commodities. Shelling and threshing are critical postharvest procedures in pod processing. The conventional method involves manually collecting the flower heads of castor plants, which are then piled up and left to dry in the sun before being threshed (98). Currently, the scarcity of labour for threshing process is a significant issue. Therefore, although threshers were originally developed for wheat crops, they may now be used for a variety of crops by modifying the speed and choosing the appropriate size sieves for cleaning. Mechanical power threshers use either a diesel engine or an electric motor to operate and the horsepower (hp) ranges from 5 to 15 hp (99). These days, standard combine harvesters harvest, thresh and clean crops mechanically. The cutter-bar chops the crop, while the conveying system feeds it into the threshing and cleaning systems. Power and tractor-operated threshers designed for specific crops and with high capacities, such as the semi-axial flow multi-crop thresher, have been developed. These machines incorporate various mechanisms for both threshing and cleaning (100). The groundnut thresher was changed by modifying the main cylinder, concave and sieves for kernel separation and it was tested with castor (Kranthi) varieties and the sieve size of 27 mm × 6 mm produced good results for castor shelling (101). CRIDA (Central Research Institute for Dryland Agriculture) has developed two castor shellers powered by 1 and 2 hp respectively and the smaller unit has a capacity of 1.7 q h^{-1} (102). At 6% moisture content, the castor shelling machine had the maximum shelling efficiency, cleaning efficiency and seed recovery percentages of 81.3%, 58% and 85%, respectively (103) and it saves 90% of labour compared to the traditional method. Shelling capacity and shelling efficiency of the motorized castor decorticating machine was found to be 500 kg h^{-1} and 92.6% respectively (104). The power needed to operate a castor decorticator ranges from 0.55 to 0.87 kilowatts (105). The Groundnut cum Castor Decorticator developed by the Central Institute of Agricultural Engineering in Bhopal saves 98% of labour and operating time compared to manual hand shelling methods (106). Therefore, the adoption of mechanized shelling and threshing methods has greatly enhanced the efficiency of castor processing, minimizing labour requirements and maximizing productivity in post-harvest operations.

Conclusion

Mechanization provides an effective solution to the numerous challenges faced in castor farming. One of the main issues in castor farming is the scarcity of workers, which directly impacts productivity and increases the cost of cultivation. However, by adopting various mechanized technologies farmers can be able to increase their self-sufficiency in farming activities with increased castor yields (Table 2). Despite the mechanical adaptation of diverse processes, harvesting cannot be fully mechanized due to the lack of solely motorized equipment for collecting castor pods. Thus, building a combine harvester for harvesting and adapting various operations mechanically will lead to tremendous change in castor cultivation.

Future directions

At present, the header of sunflower and maize harvesters is slightly modified and used in castor harvesting. Even so farmers face yield losses due to seed damage. Accordingly, these consequences may be overcome with the future

Table 2. Comparison between the conventional and mechanical practices in castor cultivation

S.No.	Cultivation practices	Practicing technique		Capacity		References
		Conventional	Mechanical	Conventional	Mechanical	
1.	Field preparation	Bullock drawn implements	Rotavator	102 h ha^{-1}	18.7 h^{-1}	(12)
2.	Sowing	Manual sowing	Tractor drawn Ananta planter	0.15 ha h^{-1}	6-7 ha h^{-1}	(19)
3.	Fertilizer application and weeding	Broadcasting and hand weeding	Rotary weeder cum fertilizer drill	8 h	5.1 h	(109)
4.	Irrigation technique (WUE)	Check basin	drip	2 kg ha^{-1} mm^{-1}	2.68 kg ha^{-1} mm^{-1}	(18)
5.	Crop protection measures	Knapsack sprayer	drone	4 ha h^{-1}	1.57ha h^{-1}	(110)
6.	Harvest	Manual harvesting	Mechanical harvesting	60 hrs ha^{-1}	50hrs ha^{-1}	(111)
7.	Post harvest	Manual decortications	Rotary-mode decorticators	2 kg h^{-1}	40-60 kg h^{-1}	(112)

designing of vibration picking of castor bean under combined harvesting.

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Authors' contributions

RG and SKN conceived the idea for this manuscript. RG conducted the literature review and drafted the initial manuscript. TR, SRV and ST provided critical feedback and revisions to the manuscript. RG and SKN prepared the final version of the manuscript. All authors read and approved the final manuscript for submission.

Compliance with ethical standards

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