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Mechanization in Grape Production and Current Requirements in Indian Context: A Review

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ABSTRACT

Grape production farming system in India is different than other countries. Grape production mechanization scenario is studied with focus on machinery and tools used in Indian grape orchards. India is 7th largest producer of grape in the world, however the mechanization in Indian grape farming remains at a preliminary stage compared to other developed countries. Major constraint for low level of grape mechanization is trellising system of growing grapes. The grapes are planted in a row of 1.5 to 2 m and plants climb on trellising system that bounds the grape growers to perform the task manually or with small orchards tractor. It came out from study that potential areas for mechanization in grape production is shoot thinning, de-leafing and harvesting of grape. Proper hand tools with ergonomic designs needs to be developed for shoot thinning and de-leafing. The major attention is required in developing multipurpose machinery that can be utilized round the year to harness maximum economic benefits. This paper presents the study of various tools and equipment used in Indian grape production system and also reveals the need of improved tools and machinery for different unit farm operation in grape production system.

Key words: Grape harvesting, Grape, Horticulture, Orchard, Trellising.

India is a major producer of horticultural crops. The overall horticulture production in India was 314.7 million metric tonnes with the productivity of 13.4 tonnes ha^{-1}. The horticultural production in the country surpassed food grain production by 8.4% (Anonymous, 2022a). The major horticultural crops cultivated are potato, tomato, onion, brinjal, cabbage, pomegranate, papaya, turmeric, okra and papaya. India is also an exporter of various fruit crops that include grape, mango, banana, orange and pomegranates. India exported fresh fruit and vegetables worth Rs.13185.3 crore, of which grapes accounted for Rs.2,675 crore (Anonymous, 2022).

Grape (*Vitis sp*.) is a commercially important fruit crop grown around the world (Kiran *et al*., 2020; Sun *et al.,* 2022). Grape cultivation is believed to have originated in Armenia near the Caspian Sea in Russia, from where it spread westward to Europe and eastward to Iran and Afghanistan. It was introduced in India in 1300 AD by Moghul invaders from Iran and Afghanistan (Krithika and Naik, 2015). It is primarily cultivated for its edible qualities as fresh table fruit, as well as in production of wines and raisins (Adsule, 2013). China is the lead producer of grape with 14.19 million metric tonnes grapes produced from 0.74 million hectares (18.5% of total world grape production, Anon. 2022a). Italy is the second largest producer of grape with 7.9 million metric tonnes production from 0.69 million hectare area forming 10.24% of total grape production of the world. India stands 7th in grape production with 3.35 million metric tonnes from 0.155 million hectare area forming 3.94% of total world grape production (Anonymous, 2021). Grapes are the temperate fruit crop which is adopted in sub-tropical region of peninsular India. The state wise production of grape in India is shown in Fig 1.

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Despite the sizable production of grapes in India, lack of timeliness in its farming operations degrade the productivity of the produce (Kumari, 2023). Primarily, most of the grape production operations are performed manually. The lack of labour in prime season of grapes production season degrades the quality of produce (Jobbagy *et al.,* 2021). Various farming practices to cultivate grapes are land preparation, nursery development, vine establishment, canopy management, trellising, pruning, training, spraying and harvesting (Adsule *et al.,* 2013). The farming practices are performed in trellises which are above the shoulder height of the labour (Li *et al.,* 2019). In order to perform the task, farmers may adopt various odd postures (Reimer *et al.,* 2016). Various farm implements for grape production were developed in various countries like autonomous electric robot implement for intra-row weeding in vineyards, semi-

automatic vineyard sprayer, sucker detector, automatic harvester (Reiser *et al.,* 2019; Adamides *et al.,* 2017; Kang *et al.,* 2012; Quaglia *et al.,* 2022). Although in Indian context these machineries are not favourable to use (Khandetod *et al.,* 2019; Shinde *et al.,* 2023). The judicious application of mechanization in grape production will increase efficiency, consistent quality, reduce dependency on manual labour and will provide ease in managing larger vineyards more efficiently (Khadatkar, 2024). Therefore, there is a pressing need to study the farming practice of grape production, the tools and implement being used. Hence, the study on the farming practices and machinery used in grape production were reviewed from 2023 to 2024.

Mechanization in grape production

Major unit operations in grape cultivation and implements used are shown in Fig 2. Various tools and equipment used for field preparation in grapes are cultivator, plough, rotavator and trencher. Nursery preparation is done with small spade, cultivator, bed former, various kinds of hoes, diggers and shovels. Auger diggers are extensively used but manual digging is also preferred for planting or vine establishment operation. The trellising and training operation in grape is performed to provide the support to the grapevines. It is usually supported by bamboo or wooden structure. These structures restrict the farmers to use advance machineries. Other farming operations such as pruning, canopy management, fertilizer application, harvesting and de-suckering is performed manually with traditional hand tools. The spraying operation is done by knapsack sprayers 3 ha day^{-1} spraying and with small tractor operated sprayer it takes 1 hours to cover 1 ha area Gatot and Anang (2018).

Nursery preparation

Rootstock grafting and bag filling

Grapes are not typically grown from seeds for commercial production. Prior to it the rootstocks are grafted, which is currently done manually by using a grafting knife. Vegetable grafting machine was developed in IIHR to mechanize the grafting operation. The capacity of machine to graft vegetable is 150-180 gratfs h^{-1}. Althoug these machines are made to cut the vegetable rootstock which are softer than the grape rootstock (Fig 3a). This highlights the need for innovation in grapevine grafting technology. Nursery bag filling prior to the cultivation of grape is arduous and time consuming operation. The automatic nursery bag filling (Fig 3b) machine was developed in ICAR-Indian Institute of Horticulture Research (IIHR), Bangalore. The bag filling machine sieves, mixes and fills the growing media into the nursery poly bags. It's filling capacity is 1000 bags/h. For inserting the seedlings automatic dibbler cum seeder was developed by IIHR, Bangalore (Fig 3c). The dibbling capacity is 150 protrays h^{-1}. Although the grapes are propagated by rootstock some modifications are suggested for propagating the rootstock in nursery bags. These advancements in grafting and bed preparation tools have the potential to streamline nursery operations and increase productivity.

Field preparation and plantation

Field preparation

The field preparation prior to planting the rootstock is done by various tillage implements such as mould board plough, disc plough, cultivator, rotavator and disc harrow. It facilitates effective field establishment by ensuring optimal soil structure and texture as required for grape rootstocks. This is done to provide proper water infiltration, easy root penetration and aeration for setting up of the grapes rootstocks. Furthermore, it improves nutrient uptake by the grape rootstock which will enhance the yield in grape orchard. Subsequent to the field preparation, trench opening is done prior to the planting of the grape rootstocks. It is done to apply farm yard manure (FYM) near to the grape plant as shown in Fig 4. It is an important operation in grape cultivation that requires precision. To accomplish this tractor operated trencher for grape orchards was developed at ICAR- Central Institute of Agricultural Engineering, Bhopal (Anonymous, 2020a). It was developed to dig a trench of 300 mm depth and 1-1.6 m width as per the

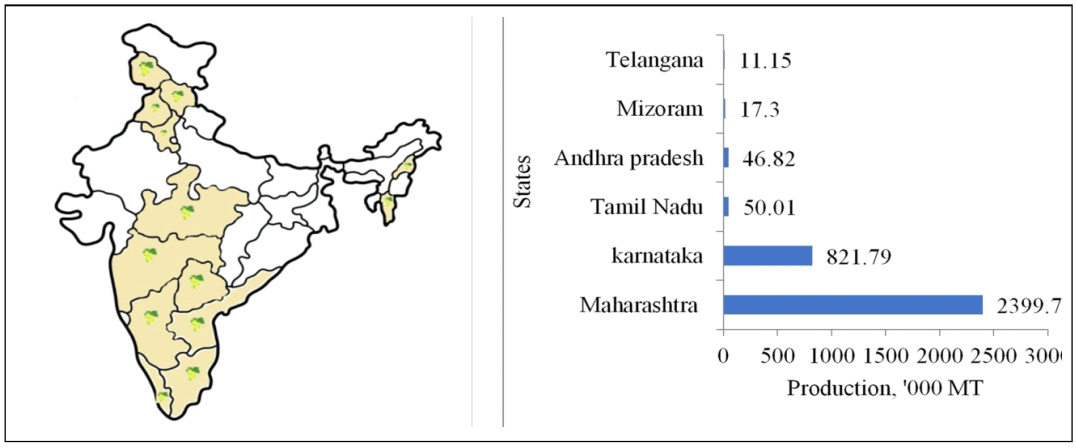


Fig 1: State wise production of grape in India (Anonymous, 2021).

plant geometry. Furthermore, the trencher offers significant efficiency gains with a field capacity of 0.28 ha h^{-1} and a field efficiency of 85%. This translates to faster and more cost-effective field preparation compared to traditional manual trenching methods.

Planting of orchard/ grape rootstock

Grape cultivation starts with establishment of rootstocks. Grapes are typically propagated through dormant cuttings or by grafting onto rootstocks. Pits of the size 300×300×300 mm are dug and filled with FYM for planting the rootstock of grapevine. Primarily, the digging of pits is done manually by spades. Manual digging is a strenuous and arduous task that requires a significant amount of human energy with 47.6 kJ/min of energy expenditure rate (Mehta, 2022). Auger diggers of different diameters with helical blades, operated by tractor, engines or electric motors are improved implements for digging pits in the prepared seedbed (Kumar *et al.,* 2020). The design of auger blade enables it to cut into the soil and remove excavated material as it drills deeper into the ground (Pandey *et al.,* 2018). This method provides an efficient and precise way to prepare

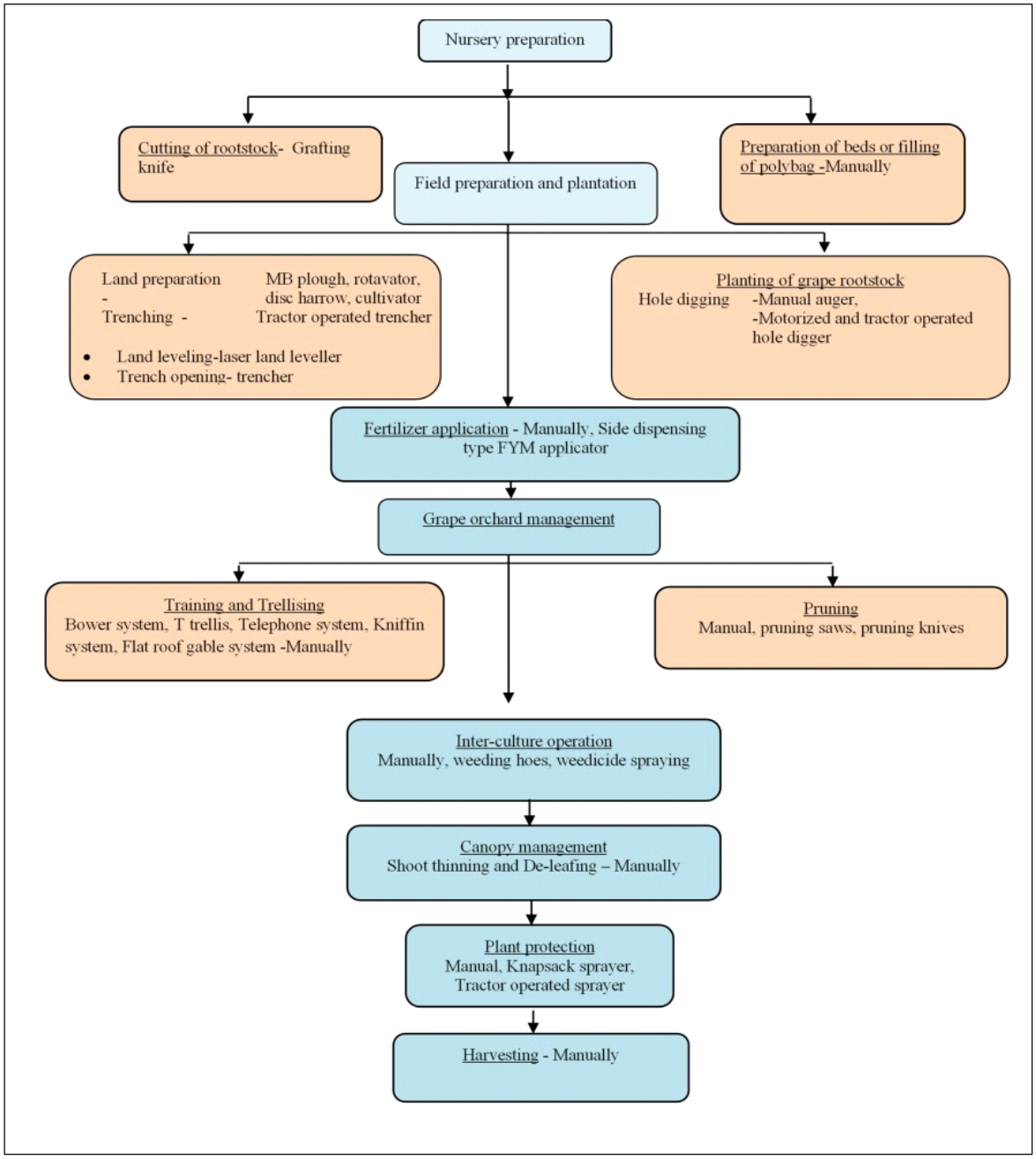
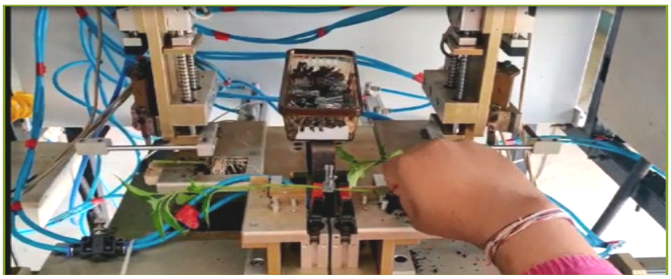


Fig 2: Flow chart of major unit operations in grape cultivation.

the soil for grape cultivation. Fig 5 shows different kind of augers diggers used in making pits for planting grape rootstocks.

Fertilizer application

Application of fertilizers increases the supply of nutrients for optimal growth. In grapevines, fertilizers are typically placed around the vine at a depth of 10-15 cm within a shallow circular ring with a radius of 600-750 mm. An effective fertilizer management strategy encompasses selecting suitable nutrient sources and doses, utilizing split applications, timing applications, choosing the best method of application and ensuring proper placement. In small-scale grape orchards, fertilization is done manually that has low work efficiency. Tractor operated side dispensing type farmyard manure applicator (Fig 6a) was developed at Indian Council of Agricultural Research-Central Institute of Agricultural Engineering, Bhopal, for applying fertilizer in grape orchards (Khadatkar *et al.,* 2024). This equipment is capable of consistently dispensing farmyard manure alongside the plant roots on both sides. It can deliver farmyard manure at a rate of 7.8 kg min^{-1} from each outlet at the tractor engine speed of 1000 rpm, in accordance with the recommended dose. The actual field capacity is 0.44 ha h^{-1} with field efficiency of 80%. A site-specific grape orchard fertilizer applicator was developed (Jyoti *et al.,* 2022) that places the right amount of fertilizer and also reduces the risk of chemicals to human health and environment. A tractor operated organic manure spreader has been developed at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra that spreads the FYM uniformly in between the two rows of plants (Anonymous, 2019).



(a) Grafting machine



b) Automatic bag filling machine



c) Bag filler machine for nursery

Fig 3: Machineries for nursery preparation.



Fig 4: Tractor operated trencher for grape orchard.

This machine uses a spreader turbine that agitates and mixes the organic manure, ensuring proper distribution (Fig 6b) with effective field capacity of 0.18 ha h^{-1} and field efficiency of 81%. These machines are still in less use by the grape growers due to lack of awareness. The cost of fertilizer applicators and the associated operation and maintenance expenses are the barriers for small grape growers.

Training and trellising

Grape plants are climbers that can grow and climb on trellises or other support structures. The grapevines can be allowed to climb up an existing fence to get support. Training of grapevine is done to ensure proper vine growth, canopy management and fruit production. This includes training the vines to grow along a trellis or support system



(a) Manual auger for hole digging (b) Engine operated for hole digging (c)Tractor-operated post-hole digger

Fig 5: Auger digger used in making pits for planting grape rootstocks.



Fig 6a: Tractor operated side dispensing FYM applicator.



Fig 6b: Tractor operated manure spreader.

and directing the growth of the vine in a way that maximizes sunlight exposure and air circulation. Trellising system supports the foliage and bunch of grapes as stem of grapevines are soft. Trellising of grape orchard is also important for disease and pest management in the crop, as it allows for better inspection and control measures. In India, different types of trellising system are as following.

Bower system

This is most widely used in the commercial cultivation of grapes and particularly for vigorous varieties with a high degree of apical dominance as shown in Fig 7(a). As the shoots start growing from the newly planted rootstocks in the main field, only the best shoot growing vertically is allowed to grow along the stake provided up to the bower height.

T-trellis

In this training system the foliage wire is made to support the canopy. The cordons are placed below the foliage wires in T shape as indicated in Fig 7(b).

Telephone System/ overhead trellis system

It is a mini discontinuous bower with shoots hanging downwards with three topped wires and T-shaped support, the trellis looks like a telephone pole and wires as indicated in Fig 7(c). The vines are supported to vertical stakes of eucalyptus or bamboo poles of 1.50 m length. These supports are fixed very close to the vine 300 mm deep in the soil leaving 1.20 m above the ground.

Kniffin system

In this system two row of wires are stretched at a height of 1.05 and 1.55 m from ground level with iron poles. Second pair of arms is allowed at 0.50 m above the lower layer as shown Fig 7(d).

Flat roof gable system

Combining the advantage of the bower and the extended Y systems and eliminating their disadvantages, an interconnected Y trellis forming a flat roof gable is being adopted as shown in Fig 7(e). This system is particularly followed by vigorous vines (vines grafted on rootstocks). In this system, the grape bunches are protected from direct sunlight and well exposed to the spray of pesticides. The clusters hang within the reach of the worker of an average height. Owing to these advantages, this system is gaining popularity among the growers in Maharashtra Andhra Pradesh and Karnataka (Papademetriou, 2001)

The grape vines are tied to these structures and trained to grow in this pattern. The tying operation is done manually by the grower which is a drudgery prone occupation at the height above shoulders. Hence the prototype has been developed at in ICAR- Central Institute of Agricultural Engineering, Bhopal (Anonymous, 2022b) for tying the vines to the grape orchard structure as shown in Fig 8.

Pruning

Pruning is a major manual operation in vine grape yards for removing extra plant growth and suckers. Pruning is done typically in late winters or early spring. It helps in maintaining the shape of the vine, promotes airflow and regulates crop load. Different pruning techniques, such as spur pruning or cane pruning, can be used depending on the grape variety and trellising system. Presently, pruning is done with hand tools such as hand pruners, scissors and secateurs.Hand pruners are suitable for cutting small to medium-sized grape vines. Leaves on lower branches are pruned by scissors. It requires 35-40 man day to prune 1 ha (Dobrei *et al.,* 2020). The influence of manual and mechanical pruning on grape quantity and quality and the efficiency of vineyards management. Secateurs are used

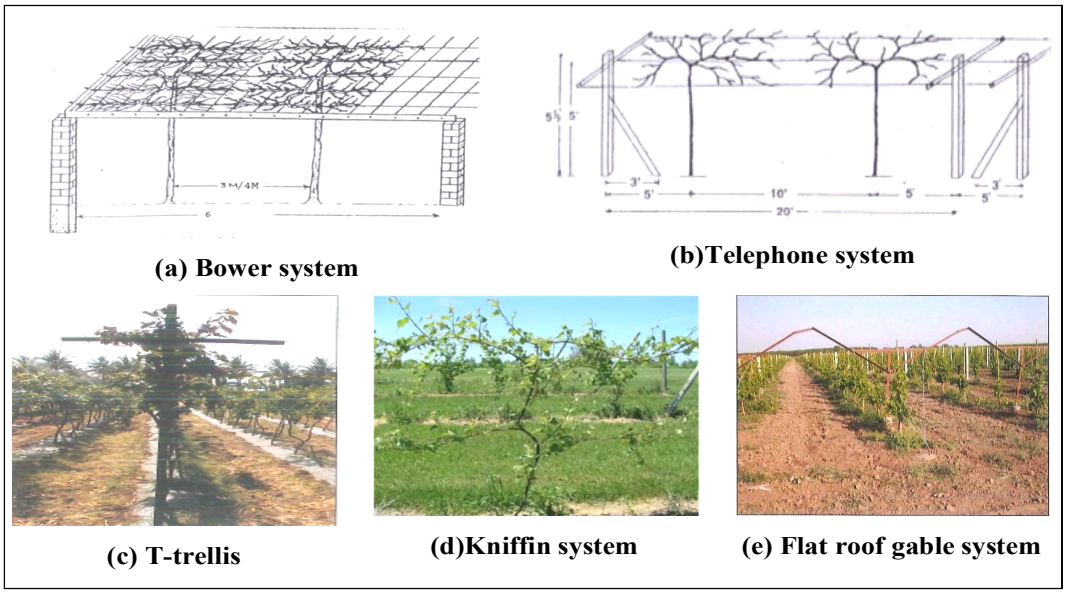


Fig 7: Different types of trellising system (Somkuwar, 2008).

for cutting the stems of the plants (Fig 9a). The height of grapevines is about 3-4 m therefore for pruning at such height special telescopic hand-held tools are used. Nevertheless the manual pruning is time consuming and labour intensive job. Hence, a tractor front mounted hydraulic pruner was developed in ICAR-Central Institute of Agricultural Engineering, Bhopal (Anonymous, 2021) as shown in Fig 9b. The pruning system comprises of circular saw blades, hydraulic motors, control valves, hose pipes, radiator. The four-bar mechanism rotates the blade in circular motion for tree pruning. Some pruner developed such as box pruner, hedge bar pruner and rotary drum pruner can be modified for Indian condition to use for pruning. Hedger bar pruners, with minimal canopy penetration, are suitable for summer and minimal dormant pruning, requiring low hydraulic flow. The tunnel-type pruner, a self-propelled machine with adjustable brush rollers and the side pruner, a tractor-mounted PTO-operated tool, both efficiently trim excess growth with adjustable settings (Kurtural and Fidelibus, 2021). Box pruning, resembling hand pruning developed by Wessener and Kurtural (2013) trims grapevine spurs to create an adjustable box shape, useful in various pruning stages. Innovative solutions include a tractor-attached grape pruner by Santos *et al*. (2015) featuring cutting discs and obstacle avoidance for small to mid-range vineyards and Botterill *et al.* (2017) developed robotic system, using AI and 3D modeling for precise pruning of grape orchard. These novel technologies can be incorporated to develop pruner for Indian farmers.

Inter culture operation

Weed management is crucial for enhancing soil health and ensuring optimal vine growth in grapevine yards. Failure to control weeds can result in significant yield losses, ranging from 20% to 60% (Khandetod, 2019). Typically, weeding operations are conducted manually using tools like khurpi and wheel hoe, consuming considerable labour, estimated at 1000 man-hours (Choudary *et al.,* 2022). However, small scale farmers have turned to power tillers for weed control and soil preparation (Kumar *et al.,* 2021). Power tillers, equipped with rotating blades or tines, efficiently churn the soil and mix in weeds. Its suitability for weeding in confined spaces, such as grape orchards, makes them preferable over larger machinery, despite the risk of potential damage to grapevines during operations. Researchers have also focused on developing specialized weeders for horticultural crops. Singh *et al.* (2016), introduced a four-wheel weeder tailored for wide-row crops, enabling manual weeding in row spaces as narrow as 20 cm. The weeder provides field capacity of 0.0206 ha h^{-1}, with a weeding efficiency of 95%. Tractor operated Phule hydromechanical controlled weeder (Fig 10) for inter row cum intra row weeding was developed at Mahatma Phule Krishi Vidyapeeth, Rahuri (Anonymous, 2019). Although the weeders are adopted for weeding in grape orchard, the weeding operation in intra row cannot be accomplished by power tillers due to narrow spacing. Also, the weeders for wide row crop were developed for specific

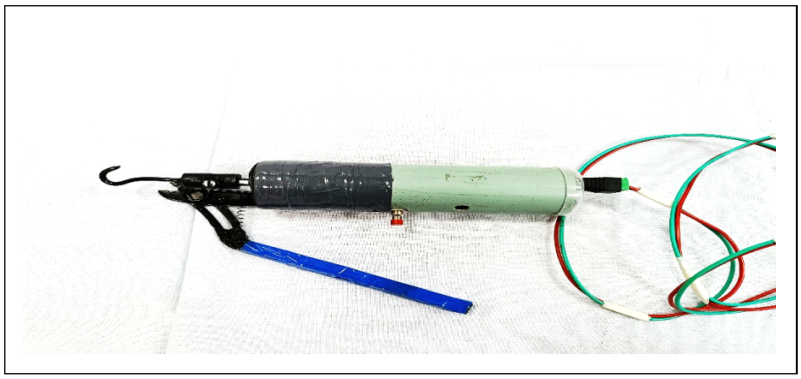


Fig 8: Vine tying equipment (Anon. 2022).



(a) Pruning with hand held tool



(b) Tractor front mounted hydraulic pruner

Fig 9: Pruning tools and machineries.

vegetable crops. However specific to grape orchard no such weeders have been developed. One of the weeder developed by Tamagnone *et al.* (2012) with combined feature of weeding as well as spraying for weed control in grape orchard. This machine has a cutting element that works between the plants coupled with a spraying system that applies the herbicide mixture only in correspondence plants. It will save up to 80% of chemicals with respect to conventional application methods. Hence, machines can be developed with combined advantage to reduce the cost of production and improve the weeding efficiency in grape orchard.

Canopy management of grape orchard

Canopy management is the crucial operation in grape cultivation. It is done to delay the sugar accumulation in the berries. Shoot thinning and leaf removal is done to manage the canopy of the grape orchard. Shoots are trained in proper direction to maintain the aeration in grape orchard which prevents fungal growth. Extra leaf removal is also done to reduce the density of leaf on the vines. Primarily, both the operations are done manually with the help of scissors. Hence there is the need of developing shoot thinners for creating balance between fruit and foliage. The pruned material left over the orchard field needs to be removed and managed to avoid insect infestation. Hence, tractor operated shredder was developed at Mahatma Phule Krishi Vidyapeeth, Rahuri (Anonymous, 2020b) to shred the residues after pruning. In grape cultivation some activities like swabbing of the chemical, desuckering and bark removal are carried out manually which are labour intensive job. Hence to reduce the drudgery of the farmers, hand tools such as chemical swabber, desuckering tool and bark remover (Fig 11) was developed at ICAR-Central Institute of Agricultural Engineering, Bhopal (Anonymous, 2022b).

Plant protection

Plant protection activity is the measure to safeguard plants from pest, diseases and weeds. Pesticides, insecticide, weedicides and biological control agent are applied for



Fig 10: Tractor operated Phule hydro-mechanical weeder.



Fig 11: Grape vine swabbing, de-suckering and bark removing tool.

this in the plant. However, to apply these biocides farmers prefer knapsack sprayers. Regarding grape vineyard the specific sprayers are required because it is to be sprayed on canopy (Adsule, 2013). Although some canopy sprayers in India have been developed (Narang *et al.,* 2013; Kumar *et al*., 2020). But it is specific to cotton and pigeon pea crop. Some researchers have developed overhead sprayers for grape orchard (Kotwal *et al.,* 2020) to apply pesticides in a grape farm. It comprises of crane type arrangements for proper locomotion inside the grape orchard. Bhalekar *et al*. (2023) studied ultrasonic sensor-based automatic control volume sprayers for pesticides and growth regulators application in grape orchards. They used two different types of sensors *i.e*. ultrasonic sensor and infrared proximity sensor, which were evaluated to detect the grape cluster and response time. The performance was assessed in terms of droplet size, chemical application, cluster and berry growth characteristics. The results were reported to develop a sensor-based control volume sprayer, with 30% savings in chemical use and 35.5% savings in operational time compared with the conventional dipping method.

Harvesting

Grapes are typically harvested when they reach their desired sugar levels, flavor and color. The sugar content of the juice of ripe grapes varies between 150 to 250 g L^{-1}. In unripe berries, glucose is the predominant sugar. At the ripening stage, glucose and fructose are usually present in equal amounts (1:1 ratio). The timing of harvest varies depending on the grape variety and the intended use such as wine, table grapes, or raisins (Adsule, 2013; Adsule *et al.,* 2013). When compared to early-harvest grapes, the late-harvest grapes contributed a more favourable sensory profile to the wines (Bhanu and Kumar, 2024). Grapes are generally harvested by hand, carefully cutting the clusters from the vine. However, the efficiency of work is poor when harvesting is done manually and it is a highly drudgery prone operation. Hence for the development of grape harvester, the grape fruit cluster detector and estimation robot has been developed by Chauhan and Singh (2022). It is anovel approach employing, an open-source computer vision library and the Random Forest machine learning algorithm for the tasks of counting, detecting and segmenting blue grape bunches. However, some harvesters have been developed in other developed countries can be modified and adjusted according to the Indian farmers such as Jobbagy *et al*. (2021) developed mechanical grape harvesters, effective in row plantations, can be either trailed or self-propelled. Trailed harvesters are economical and safer on slopes but can damage vines and require skilled operation. However, self-propelled harvesters, used extensively in countries like France and Germany, integrated with shaking, collecting and cleaning mechanism to streamline the harvesting process (Novak and Burg, 2013).Innovations such as autonomous robots and adaptable tools for different grape sizes show promise. For instance, Vrochidou *et al*. (2021) developed a robot with aerial, remote control and ground units for multifunctional vineyard tasks, while Quaglia *et al*. (2022) created a tool that adapts to various grape peduncles with a 100% success rate. Hence, new technology can be adopted with similar technologies, incorporating efficient features like conveyor belts, robotics and grape detection system (Pezzi and Caprara, 2009), to enhance productivity and reduce manual labor in grape harvesting.

Future need of mechanization in grape cultivation

Mechanization in grape production is in initial stage in India. The major operation of grape cultivation is done by traditional practices that reduce the efficiency and are full of drudgery. Majorly, the operations are performed manually having low capacities and efficiency. The machineries that are already available need to be modified and adopted for local grape production system. Table 1 illustrates different tools and machinery in grape production system and requirement of improved machinery for that particular operation, its status and need of development, where required.

Nursery preparation such as grafting, filling bags and planting the root stock are done manually or either by traditional tools. The available tools need to be refined according to the physical properties of the grape rootstock. Soil bag filling machines are away from the reach of the grape cultivators. These machines need to be popularized in the local market. Land preparation and trenching is completely mechanized. Some modifications in tractor operated trenchers focusing the required depth and width for grape can be incorporated. Tractor operated side dispensing type FYM applicator is developed at ICAR-Central Institute of Agricultural Engineering, Bhopal that can be utilized well in grape orchards.

The efforts need to be done for development of small sized machines for spraying with proper locomotion inside the vineyard. New approach needs to be introduced such as computer vision technologies and mechatronics control for target specific application of pesticides, insecticides and plant growth regulators. The major operations such as pruning, shoot thinning, de-leafing and harvesting of grape is done manually by traditional hand tools such as scissors or secateurs. These tools need further refinement according to the morphology of grapevine and anthropometry of the human. The prime focus on telescopic pruning tools of light weight, mechanized pruner needs to be targeted to reduce human drudgery. Proper hand tools with proper ergonomic consideration for shoot thinning and de-leafing needs to be developed. The advancement in grape harvesting can be done by introducing battery operated harvester or grape detection devices for picking of the grape. The prime attention should be given in developing multipurpose machinery that can be utilized year round so that economic benefit can be achieved.

Table 1: Status of mechanization of different farm operations in grape cultivation in India.

Farm operation	Tools/ Implements used	Improved tools/ machinery needs to be introduced	Status
Nursery preparation			
Grafting rootstock	Grafting knife	Grafting machine	Available for vegetables. Needs to be modified for grapes
Preparation of beds and filling of polybags in nursery	Manual tools	Nursery bag filling machine	Available. Needs to be popularized
Establishment of grape orchard			
Land preparation	Mould board plough, disc plough, cultivator, rotavator and disc harrow	Available	Available
Trencher	Tractor operated trencher	Tractor operated trencher cum fertilizer applicator	Fertilizer applicator needs to be integrated with trencher
Planting of rootstock	Manual auger, motorized and tractor operated auger digger	Many types of auger	Available
Fertilizer application	Manually operated implement	Tractor operated side dispensing type FYM applicator	Developed at ICAR - CIAE, Bhopal
Vineyard management			
Training and Trellising	Manual tools	Vine tying tool	Developed at ICAR-CIAE Bhopal
Pruning	Manual, pruning saws, pruning knives	Small tractor operated grape pruners	Available. Needs to be adopted specifically to grape
Inter-culture operation	Manual weeding hoes, knap sack weedicide sprayer	Small tractor operated weeder, sprayer	Available
Canopy management			
Leaf thinning	Manually shoot thinning and de-leafing	Power operated shoot thinners and leaf removers	Developed at ICAR - CIAE, Bhopal
Chemical application	Chemical pruned application on leaves	Chemical swabbing machine	Developed at ICAR - CIAE, Bhopal
Plant protection	Manual, Knapsack sprayer, Tractor operated sprayer	Small tractor operated sprayers	Available. Needs adoption
Harvesting	Manual scissors	Power operated grape harvester	Needs development
Fruit/ other material carrying inside the orchard	Manual	Suitable powered trolley	Needs development

CONCLUSION

This study highlights the critical importance of mechanization in the grape cultivation in India and potential impact on increasing the productivity and profitability on improving the mechanization in grape production orchards. There is a notable expansion in grape cultivation across

the country, but lack of adequate mechanization presents a substantial challenge to further enhance the productivity and efficiency of production. Several factors contribute to this mechanization gap including limited access to modern farming equipment, high initial investment, inadequate technologies and lack of awareness or training among grape farmers regarding the benefits and proper utilization of mechanized technologies. Improved tools and machinery are suggested to focus research efforts in those operations for development of new devices to improve productivity and profitability. Among these are main requirements for grape nursery preparation tools, suitable canopy pruners, powered shoot thinners, grape harvesters in country vineyard conditions, powered trolley for movement of fruit and other material inside the grape orchard. Focusing in these researchable issues will better equip the grape farmers in increasing the productivity and profitability along with reduction in drudgery of operation in grape production in Indian context.

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Conflict of interest

The authors declare that they have no known conflict of interestthat could have appeared to influence the work reported in this paper.

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