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Biodiversity in arid fruit crops: A review

P.R. Meghwal and Akath Singh

ICAR-Central Arid Zone Research Institute, Jodhpur-342003, Rajasthan, India

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ABSTRACT

Hot arid regions are confronted with climatic adversities besides lack of sufficient irrigation water availability. However, there are numerous fruit species which have inbuilt mechanism to sustain under inhospitable edaphoclimatic condition with available rainfall. The fruits like ber, *deshi bordi*, *jhar ber*, *khejri*, *ker*, *pilu*, etc. have been grown successfully under natural condition without irrigation. In some pockets (10-12%), where irrigation water is available either by canal system or underground tubewell, cash crops like date palm, pomegranate, fig, aonla, citrus fruits, etc. are some of the successful ventures by the farmers. The available natural biodiversity present in these fruit crops have been successfully employed to develop high yielding improved varieties mostly by selection from seedling population. The development of clonal propagation techniques enabled perpetuation of developed varieties without the loss of original quality. The strengthening of R&D in ICAR institutes and SAUs further helped in the development of location specific agro-techniques, which led to yield enhancement and post-harvest value addition in typical arid fruit crops. This review article highlights the availability of biodiversity and varietal development in arid fruit crops.

Introduction

The hot arid regions of India are suitable for growing many fruit species despite climatic constraints and limited irrigation facilities. These include ber (*Ziziphus mauritiana* L.), *bordi* (*Ziziphus rotundifolia*), *Jhar ber* (*Ziziphus nummularia*), *khejri* (*Prosopis cineraria*), *pilu* (*Salvadora oleoides*), pomegranate (*Punica granatum* L.), aonla (*Emblica officinalis*), date palm (*Phoenix dactylifera*), bael (*Aegle marmelos*), *lasora* (*Cordia myxa*), *karonda* (*Carissa carandas*), *ker* (*Capparis decidua*), etc. These fruit crops are very rich from nutraceuticals

and can provide income security besides contributing to environmental amelioration and ecosystem services. Great deal of variability exists in these fruit crops at both genotypic and phenotypic level as they have been primarily propagated by seeds.

The role of germplasm in the improvement of arid fruit crops has been well recognised. Most of the present-day commercial cultivars are selections from the variability generated by the germplasm collected/introduced in the past. A large number of collections are maintained and evaluated for utilisation at different research stations (Table 1).

Corresponding author

Email: pr.meghwal@icar.gov.in (Dr. P.R. Meghwal)

Table 1. Germplasm and their conservation status and major diversity states of different arid fruit crops

Crop	Conservation centres	Number of accessions	Conservation status	Major states of diversity
<i>Aegle marmelos</i> (Bael)	ICAR-NBPGR, New Delhi	427	Cryo-bank (265) and field gene bank (162)	Jharkhand, U.P., Orissa, West Bengal, Rajasthan, Gujarat, Bihar, Chhattisgarh, H.P., A.P., M.P., Maharashtra, Kerala
	ANDUA&T, Ayodhya	12	Field gene bank	
	ICAR-CISH, Lucknow	36	Field gene bank	
	ICAR-CIAH, Bikaner	21	Field gene bank	
	ICAR-CAZRI, Jodhpur	08	Field gene bank	
<i>Capparis decidua</i> (Ker)	ICAR-NBPGR, New Delhi	35	Cryobank (265)	Rajasthan, Gujarat
	ICAR-CIAH, Bikaner	09	Field gene bank	
<i>Cordia myxa</i> (Lasora)	ICAR-NBPGR, New Delhi	231	Cryobank (12) & field gene bank	Rajasthan, Haryana, H.P., Gujarat, Maharashtra, U.P., M.P., Jharkhand, Chhattisgarh
	ICAR-CIAH, Bikaner	67	Field gene bank	
	ICAR-CAZRI, Jodhpur	17	Field gene bank	
<i>Emblica officinalis</i> (Aonla)	ICAR-NBPGR, New Delhi	51	Field gene bank	U.P., Gujarat, Rajasthan, M.P., Bihar, Tamil Nadu, Jharkhand
	ANDUA&T, Ayodhya	22	Field gene bank	Chhattisgarh
	ICAR-CAZRI, Jodhpur	08	Field gene bank	
<i>Phoenix dactylifera</i> (Date palm)	ICAR-CIAH, Bikaner	64	Field gene bank	Gujarat, Rajasthan, Punjab
	SKRAU, Bikaner	35	Field gene bank	
	PAU Research Station, Abohar	31	Field gene bank	
	GAU Research Station, Mundra	24	Field gene bank	
	ICAR-CAZRI, Jodhpur	23	Field gene bank	
<i>Carissa carandas</i> (Karonda)	ICAR-NBPGR, New Delhi	29	Field gene bank	Bihar, West Bengal, Chhattisgarh, Orissa, U.P., M.P., Jharkhand, Rajasthan, Gujarat, Maharashtra, Kerala, Karnataka, Haryana
	ICAR-CIAH, Bikaner	05	Field gene bank	
	ICAR-CAZRI, Jodhpur	05	Field gene bank	
<i>Punica granatum</i> (Pomegranate)	ICAR-NBPGR, New Delhi	360	Field gene bank	Maharashtra, Gujarat, Karnataka, Rajasthan, Tamil Nadu, H.P., U.P., J&K
	ICAR-NRCP, Sholapur	375	Field gene bank	
	ICAR-IIHR, Bengaluru	203	Field gene bank	
	ICAR-CIAH, Bikaner	144	Field gene bank	
	ICAR-CAZRI, Jodhpur	28	Field gene bank	
<i>Ziziphus mauritiana</i> (Indian jujube, ber)	ICAR-NBPGR, New Delhi	285	Field gene bank	Rajasthan, U.P., Haryana, Gujarat, M.P., A.P., Karnataka, Tamil Nadu, Maharashtra
	ICAR-CIAH, Bikaner	372	Field gene bank	
	ICAR-CAZRI, Jodhpur	40	Field gene bank	

Several promising varieties of different arid fruits have been developed by utilizing the existing germplasm. The important varieties developed through selection from diverse germplasm are given below.

Table 2. Germplasm utilized for selection of promising varieties

Crops	Varieties
Ber	Gola, CAZRI Gola, Seb, Mundia, Umran, Kaithali, Banarasi Kadaka, Illaichi, Chhuhara, Thar Bhubraj, Thar Sevi-ka, Goma Keerti, etc.
Pomegranate	Ganesh, Bassein Seedless, Jalor Seedless, Muskat, Jodhpuri Red, G-137, Alandi, Dholka, Kandhari, Bhagwa, Super Bhagwa, CAZRI Vishal, CAZRI Shresth, P23, P26, Jyoti etc.

Aonla	NA 7, NA-6, NA-10, Kanchan, Krishna, Balwant, Laxmi-52
Date palm	Medjool, Khadrawy, Halawi, ADP-1, Shamran, Zahidi and Khunaizi, etc.
Karonda	Pant Suvarna, Pant Manohar, Pant Sudarshan, Maru Gaurav, CAZRI Sadabahar
Lasora	Maru Samridhi, Karan Lasoda, Thar Bold, CZCM-2011, CZCM-2012, CZCM-2062, CZCM-2021
Bael	NB-5, NB 9, Pant Aparna, Pant Sujata, Pant Shivani, CISH Bael-1, CISH Bael-2, Goma Yashi
Fig	Poona Fig, Dianna, Dinkar, Black Ischia

Biodiversity in some selected fruits plants of hot arid region is described below:

Aonla (*Emblica officinalis*, Gaertn.)

Aonla or Indian goose berry is ancient fruit of Indian origin. Its fruit is valued in indigenous Ayurvedic medicine for curative properties. The genetic variability is widespread particularly in Uttar Pradesh (Pratap Garh), Gujarat, Rajasthan and Maharashtra. Banarasi, Francis, Banshi Red, Chakaiya, and Deshi are well known old cultivars. NA6, NA7, NA10, Krishna, Kanchan, Anand-2, etc. are the recent cultivars. Evaluation of aonla cultivars in arid areas of Rajasthan revealed variation in growth attributes and physico-chemical parameters of fruits in different varieties (Meghwal and Azam, 2004).

Ber (*Ziziphus* spp.)

The ber or Indian jujube is the most important arid fruit belonging to family Rhamnaceae with more than 600 species world wide of which 18-20 are native to India (Watt, 1883). Singh and Arora (1978) listed eight species having edible fruits found in different parts of India. The *Ziziphus mauritiana* is commercially important which has more than 300 varieties. The *jhar ber* (*Z. nummularia*) is endemic to arid region and grows naturally in crop field under rain fed condition. The third species, *Z. rotundifolia* also bears edible fruits but of smaller size which is used as rootstock for *Z. mauritiana*. Huge variability available in *Z. rotundifolia* may be exploited for selection of elite types having desirable fruit characteristics and further maintained by vegetative propagation techniques which is already well standardized. The presence of enormous diversity may be attributed to sexual propagation, heterozygosity, cross pollination and natural polyploidy. The most of so-called improved varieties have been evolved as a result of natural and man-made selection. Khoshoo and Singh (1963) reported that segmental allopolyploidy also plays an important role in creation of variability.

Pomegranate (*Punica granatum* L.)

Pomegranate belongs to family Punicaceae and is one of the favourite table fruits in tropical and subtropical

regions. Pomegranate has very narrow genetic variability. The genus *Punica* consists of two species i.e. *granatum* and *protopunica*, with two sub species (*chlorocarpa* and *prophyrocarpa*) in *granatum*. The major variability is found in Maharashtra, Karnataka, Tamil Nadu, Gujarat and Rajasthan. The germplasm collection at various research centers in India includes several cultivars, including exotic introductions from the temperate zone. The germplasm is being maintained at Rahuri, Abohar Bengaluru, Ayodhya, Hisar, Jodhpur, Bikaner, Junagarh, Ludhiana, Solan, and Udaipur.

At ICAR-CIAH, Bikaner, about 106 germplasm of pomegranate have been collected and maintained in field gene bank (Anonymous, 2023). Muskat, Bassein Seedless, Dholka, Jalore Seedless and Jodhpuri Red are the traditional cultivars. Selections P-23 and P-26 from Muskat, Ganesh from Alandi, G-137 from Ganesh, and IIHR selection from Basein Seedless, and Yercaud-1 (Sayed *et al.*, 1985) have been made. A new cultivar Mridula has been developed at Rahuri, from the open pollinated progeny raised from the F_1 population, derived from Ganesh x Gul-E-Shahi Red (Anonymous, 1994). It has red arils with very soft seeds.

At Hisar, Shirin Anar and Russian seedlings were found resistant to bacterial leaf (Singh and Rana, 1993). Evaluation of nine pomegranate cultivars under arid conditions of Jodhpur showed significant variation in plant growth, fruit yield and physico chemical properties of fruits (Prasad and Banker, 2000). The pomegranate orchard in Jalore and Jodhpur district in western Rajasthan have spread through seed propagation with lot of variability (Vashistha *et al.*, 2003).

At ICAR-CAZRI, Jodhpur, a new variety CAZRI Vishal has been developed recently (Singh and Meghwal, 2020). This is a selection from F_1 population of a cross between Ganesh x Khog. The seeds are soft with pink arils. Its fruits mature early (120-130 days after anthesis). The TSS is 17.5-18.6 % with low acidic juice (0.48-0.52%) along with high recovery of arils (60%) and juice (>40%). Maru Shresth (CAZRI/JSM-17) is another variety released from CAZRI (Anonymous, 2023). It is medium maturing (140-150 days after anthesis) variety. Fruits are medium in size (270-300 g) with attractive bright red colour rind. The seeds are soft with dark red and bold arils. The average TSS is 17.8°B with high juice content (43.1%). The fruit yield is about 20-25 kg/ plant after five years of planting following ideal management practices. The developed variety Maru Shresth may offer alternative to predominant variety i.e. Bhagwa for sustainable cultivation of pomegranate in India.

Jamun (*Syzygium cumini*)

Syzygium cumini (Linn.) Skeels syn. *Eugenia jambolana* Linn. has long been in cultivation in Malayan Archipelago and India and said to be originated in India, Burma and Ceylon. The genus *Syzygium* has many species yielding edible fruits and some of these are of ornamental value. *Syzygium jambos* (rose apple or gulab jamun) found in India is a popular fruit. Its fruits are yellow and the tree is ornamental. *S. zeylanica* a small tree with edible fruits is found in the Western Ghats. *S. malaccensis* (Malay rose apple) and *S. uniflora* (Surinam cherry or Pitanga cherry) are also found in south India. *S. javanica* (water apple) is distributed over south India and Bengal. A wild species, *S. fruticosum*, with small edible, dark purple fruit is grown as wind break and *S. densiflora* used as rootstock is found to be resistant to termites.

A number of seedling strains with variation in fruit shape, size, pulp colour and content, TSS, acidity and earliness are found particularly in U.P., Gujarat and Maharashtra, providing good scope for selection of better types. However, no standard variety exists, but the common type grown in north India is purple red jamun having bigger size, oblong fruits which ripen in June-July. Another type is late ripening (August) and bears round blackish, small fruit. Singh *et al.* (1999) evaluated eight genotypes under Ayodhya conditions and reported that oblong types had more weight and relatively small seeded.

Date palm (*Phoenix dactylifera* L.)

Date palm is considered to be the oldest cultivated fruit tree. It is believed to be originated from countries around Persian Gulf. There are three major species of date palm grown in India viz., *Phoenix dactylifera* L., *P. sylvestris* L. Roxb. and *P. canariensis* Chabaud. *Phoenix dactylifera* is very common and grown commercially because of its superior quality edible fruits. Several Phoenix species grow wild in different parts of the country. *P. sylvestris* grows naturally with small sized fruits with less pulp content. In India, date groves are found in coastal belts of Kachchh from Anjar to Mandvi and other regions of Gujarat.

At present, 35 date palm varieties are conserved at Date palm Research Station, Bikaner, 19 cultivars at ICAR-Central Arid Zone Research Institute, Jodhpur but only 5-6 varieties are recommended for commercial cultivation. The evaluation of 19 cultivars at ICAR-CAZRI, Jodhpur indicated variation in flowering time and fruit characteristics (Anonymous, 1994-95). The date of initiation of spathe emergence varied from 15 January (Medni) to 18 February (Nagar Hilali). The initiation of Doka stage was earliest in cv. Abdul Rehmana and Medni (June, 2) followed by Muscat-2 (June, 10) and last in cv. Sayer (June, 30). The peak daoka stage was also earliest

in Medni and Abdul Rehman and last in Barhee. The colour of berry at doka stage was yellow in all the cultivars except Khadrawy (yellowish green), Umshok (Red), and Muscat-2 (Reddish purple).

Fig (*Ficus carica* Linn.)

The edible common fig is thought to be a native of southern parts of Arabian Peninsula, Italy, the Balkan Peninsula and the USSR. The genus *Ficus* has over 1000 species, and the species found wild in India are *F. semicordata* syn. *F. pumila* syn. *F. cordifolia* (pakar, gagjaira), *F. glomerata* (gular, domoor), *F. hispida* (kathumabar, konea-dunmbar), *F. auriculata* syn. *F. roxburghii*, *F. macrophylla* (timla, tirmal) pamtai forsk.

Singh (1969) suggested that since the fig varieties grown in India have faintly lobed leave, these are probably hybrids between the common fig and Indian wild species. The available fig varieties are; Poona fig, Dinkar, Daultabad, Excel, Conadria, Black Ischia and Dianna.

Bael (*Eagle marmelos* Correa)

Bael is an indigenous fruit crop well known for its nutritional and therapeutic properties. It is in great demand for native system of medicine such as *ayurvedic*. The marmelosin content of fruit is known as the panacea of the stomach ailments. Plenty of seedling trees of bael are spread all over the country with great deal of variability. Wide ranging variation in physico-chemical characteristics of fruits were observed by Lal (2002) in a trial on seven strains of bael in Rajasthan.

Gonda (*Cordia myxa* L.)

Gonda also known as lasoda or lehsua is a drought tolerant fruit crop, which is found growing as stray plantation in semi-arid and arid regions of Rajasthan, Haryana, Gujarat and Madhya Pradesh. This drupaceous fruit has mucilaginous pulp, which constitutes about 70 per cent of the fruit. An important member of family Boraginaceae and genus *Cordia* to which large number of species belongs of which *Cordia gharaf* is another popularly known species. The genus is distributed throughout the country especially in western region. A great variation exists in size of fruits and their pulp content. Accordingly, large fruited type in Gujarat is recognized as "Paras". At Bawal in Haryana, 27 germplasm of gonda have been collected.

An exploration survey of gonda germplasm in Haryana indicated range of diversity in morphological and qualitative characters of fruits (Kaushik and Dwivedi, 2004). At ICAR-CAZRI Jodhpur, nine gonda accessions collected from different parts of Rajasthan and adjoining areas were

evaluated for growth and fruiting behaviour and fruit characteristics (Anonymous, 2007). Long term evaluation of germplasm resulted in identification of five high yielding genotypes i.e. CZCM-2011, CZCM-2012, CZCM-2021, CZCM-2025 and CZCM-2062. The accession CZCM-2025 has been released as Maru Samridhi from CAZRI with fruit yield of more than 100 kg per plant.

The variety Karan Lasoda has been identified as improved selection from SKNAU, Jobner, while Thar Bold from CIAH Bikaner. The budded plants of these varieties are in great demand. The development of new varieties and standardization of agro-techniques have resulted in popularization of this species as commercial sole orchard rather than boundary plantation practiced earlier.

Karonda (*Carissa carandas* L.)

Karonda is evergreen, densely branched, spiny shrub and an excellent for bio fencing species belonging to family Apocynaceae. There are about 20 species of which five are of Indian origin including *C. carandas*. At Rahuri in Maharashtra, some promising types No. 13, 16, 12 and 3 have been identified (Karale *et al.*, 1989). At ICAR-Central Arid Zone Research Institute, Jodhpur, 27 collections were made from karonda growing tracts in Rajasthan and Maharashtra. Phenotypic variability was observed in plant growth, fruit size, shape and colour of fruit, (Bankar and Prasad, 1992; Bankar *et al.*, 1992). Diversity in *Carissa* have also been observed in northwestern India, particularly in Mount Abu and Khandala in Maharashtra (Mehra and Arora, 1982). Six accessions and a variety (Pant Manohar) of karonda were evaluated at ICAR-CAZRI, Jodhpur (Anonymous, 2008). They could be grouped into two broad categories based on fruit colour. Good diversity in canopy volume, plant height, growth habit, precocity, morpho-physico-chemical characteristics of leaves, fruits and fruit yield were recorded (Meghwal *et al.*, 2012). Based on the performance of the germplasm over a period of eight years for fruit yield and other desirable attributes, the accession number CZCC-2011, CZCC-2022 and CZCC-2031 could be found suitable for hot arid zone on account of their higher yield and bold fruit size (Meghwal, 2018).

Subsequently one of the accessions (CZCC-2011) was released as Maru Gaurav an improved high yielding variety from ICAR-CAZRI, Jodhpur (Meghwal *et al.*, 2019). Another accession CZCC-2001 has been found to flower and fruit three times in a year. The first flowering occurs during March-April with fruit maturity in June-July, while second flowering take place in the month of July-August with fruiting in October-November. The third flowering occur during late October to early November with fruit maturity during December-January. This genotype has recently been released from ICAR-CAZRI, Jodhpur as CAZRI Sadabahar

(Anonymous, 2020). Thar Kamal has been released recently from ICAR-CIAH, Bikaner (Singh *et al.*, 2015) while Pant Manohar, Pant Suverna and Pant Sudarshan were released earlier from GBPUA&T, Pantnagar

Ker (*Capparis decidua* Forsk. Edgew)

Ker a much branched, straggling, glabrous small tree or shrubs belongs to family Capparidaceae. The species is valued for its fruits which are used as vegetables and made into pickle. Exploration survey of *Capparis decidua* undertaken in different parts of Rajasthan and Haryana indicated wide variability in morphological and fruit related traits (Singh *et al.*, 2007). Significant variations were recorded in traits like growth habit, presence of spines, plant spreads and compactness of canopy, time of flowering and fruiting, etc. The plant height ranged from 120 cm to 750 cm while plant spread from north to south direction varied from 90 cm to 660 cm. Marked variation in the size of spines was also observed with 60.6% plant having spines of 3-5 mm, 27.3% had small sized spines (<3 mm) while 3% plant had large spines (>5 mm), the remaining 9.1% plants were without spines. The fruit shape was globular with slight variation. Diversity with respect to plant types, canopy, flowering and fruiting were also observed during survey of natural population in Jaisalmer district of Rajasthan (Mahla and Singh, 2013).

Khejri (*Prosopis cineraria*)

Khejri is lifeline of desert dwellers due to its multiple utility and its ability to tolerate odds of climatic conditions. Each part of *khejri* is useful in some or the other way (Saroj *et al.*, 2001). *Prosopis cineraria* (Linn) belongs to Leguminosae, sub-family Mimosoideae; is one of the 44 species of leguminous trees and shrubs in the genus *Prosopis*. Indian arid region is considered as home of *Prosopis cineraria* and even today, it is principal species in arid ecosystem. The natural propagation of *khejri* is by seeds; hence, variability in the natural population is evident.

Survey of *Prosopis cineraria* in western Rajasthan revealed wide phenotypic variation with respect to vegetative growth, yield and attributes of pods. In general, there are two distinct ecotypes, one having erect branching, narrow angle, and bigger leaf size, more thorn with more open canopy and another drooping branches, wide angle, smaller leaf size, less thorn with compact canopy. The colour of pod was found as an important indicator. Based on ripe pod colour, there are two types: one is green pod colour which is common and another pink pod colour which is rare (Saroj *et al.*, 2001).

The pods also vary in shape, size, seed content and taste. The variability in vegetative vigour of *khejri* trees has also been mentioned by Mann (1980), Muthana (1980) and Kaul *et al.* (1991). Recent survey of *khejri* germplasm for desirable pod

types for culinary purpose resulted in identification of two superior types of plants having longer pods and thorn less (Anonymous, 2008). Thar Shobha is selection from naturally occurring trees from Bikaner.

Phalsa (*Grewia subinaequalis* D.C.)

Phalsa is one of the oldest known fruits, which finds mention in Vedic literature as having certain medicinal qualities. It is one of the most drought tolerant crops, suitable for cultivation in wasteland and salt affected soils, as it can be grown in saline soils up to 12 dSm⁻¹ and in sodic soils up to 40 ESP. Its small-scale cultivation is confined near big cities in the states of Haryana, Punjab, Gujarat, Rajasthan, U.P. and Maharashtra.

A member of family Tiliaceae having 18 genera and 40 species which are mostly distributed in tropical and subtropical region of the world (Gauri Shankar, 1985). The genus *Grewia* has 140 species, out of which 40 occur in India. However, *G. subinaequalis* D.C. is only of commercial importance. Thar Pragati is the first improved variety released from ICAR-CIAH Regional Station, Godhara (Singh *et al.*, 2018).

Pilu (*Salvadora oleoides* Decne.)

Pilu is a very common tree found growing luxuriously in Thar desert especially in Rajasthan and Gujarat areas. The tree gives good fodder for camels during summer when other vegetations are scarce. Fruits are rich in non-edible oil (40-50%) which has many industrial uses. It is an excellent plant for shelterbelts and wind breaks. *Salvadora oleoides* grown naturally in arid areas showed great deal of variability in different growth and quality attributes (Jindal *et al.*, 2006).

Khirni (*Manilkara hexandra*)

Khirni is found wild in the forests of South India, North-central India, parts of Gujarat and Rajasthan. ICAR-NBPGR, New Delhi collected 47 accessions and recorded wide variability in eight physico- chemical characteristics (Malik *et al.*, 2010). GK-1, GK-10 and Thar Rituraj are improved varieties (Singh *et al.*, 2018).

Conclusion

The hot arid regions of India are reservoirs of agrobiodiversity despite adverse edapho-climatic conditions and limited rainfall. The crop improvement methods like selection and introduction have led to improvement in the fruit species suitable for arid regions. The development of clonal propagation techniques and availability of irrigation facilities

have further played key roles in the utilization of these fruit crops. The collection and conservation of fruit germplasm at different research institutes in field gene bank is necessary for future research requirement including the development of varieties resistant to biotic and abiotic stresses. Although, the efforts made so far has helped in commercialization of many arid fruit crops like ber, pomegranate, aonla, date palm, etc., however, lot more needs to be done to fully exploit some underutilized fruit species like *ker*, *pilu*, *jhar ber*, *lasora* and phalsa, etc. to their full potential.

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Conflict of Interest

The authors have no conflict of interest.

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Propagation strategies for conservation and commercial development of root medicinal crops: A review

Swarajya Laxmi Nayak, Parmeshwar Lal Saran and Manish Das

ICAR-Directorate of Medicinal and Aromatic Plants Research, Boriavi, Anand, 387310, India

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ABSTRACT

India is one of the mega diversity regions endowed with a rich array of medicinal plants. However, the surging demand for herbal medicines has triggered destructive harvesting methods, jeopardizing the natural populations of these plants. Medicinal crops such as *ashwagandha*, *mulethi*, and *shatavari* are globally sought-after due to their therapeutic potential, addressing stress relief, immune function, and hormonal balance. Despite their historical use as natural remedies, the escalating demand is primarily met by wild populations, endangering the survival of these crop species. The alarming rate of over-exploitation necessitates the development of efficient propagation protocols. This ensures planting material for commercial cultivation and contributes to conservation efforts. Moreover, the cultivation of high-value medicinal plants is creating a new dimension in the field of agriculture, propelling the Indian herbal industry into a flourishing stage. However, the intricate nature of medicinal plant cultivation poses challenges, particularly due to limited knowledge of seed biology. This review concentrates on *ashwagandha*, *mulethi*, and *shatavari* cultivation practices, compiling existing literature to serve as a guide for future research in this crucial field.

Introduction

Medicinal plants have been providing a tremendous source of natural medicines since time immemorial. *Ashwagandha* (*Withania somnifera* (L.) Dunal), *mulethi* (*Glycyrrhiza glabra* L.) and *shatavari* (*Asparagus racemosus* Willd.) are popular medicinal root crops used in traditional Ayurvedic medicine (Niraj and Varsha, 2020). These have been used for centuries for their various health benefits and therapeutic properties (Das and Pandey, 2023). They can be used individually or in combination with other herbs in Ayurvedic formulations to address specific health concerns and promote overall well-being. *Ashwagandha* also known as Indian Ginseng/winter

cherry provides benefits to the nervous system, rejuvenates the body, prevents aging, improves muscle and joint function, and aids in sleep (Saran *et al.*, 2025; Singh *et al.*, 2021). While *mulethi* or licorice has sweet-tasting roots, is commonly used for respiratory health, digestive support, anti-inflammatory, antioxidant properties, immune-modulatory effects, and more (Ahemed *et al.*, 2021). Similarly, *Shatavari* is believed to enhance fertility and is associated with various health benefits, particularly for the female reproductive system (Alok *et al.*, 2013).

However, the conservation of these plants is among the most pressing issues. To satisfy the need for medicinal plants, natural resources are being depleted at an exponential

Corresponding author:

Email: swarajyalaxminayak@gmail.com (Dr. S.L. Nayak)

pace (Sen *et al.*, 2011). The medicinal crops are not grown systematically; people generally collect them from the forest. In this context, it is important to promote their cultivation scientifically to prevent genetic erosion and maximize profits. To achieve the full health benefits of these medicinal crops, proper GAP (Good Agricultural Practices) protocols are needed during planting (Saha *et al.*, 2018). Planting root crops such as *ashwagandha*, *mulethi* and *shatavari* can be done through a few different methods, depending on the specific requirements of each plant as outlined in Fig. 1. These plants are commonly propagated through their seeds or root divisions/cuttings. However, the rapidly changing climate has resulted in changes in the key components of certain Medicinal and Aromatic Plants (MAPs) (Manish *et*

al., 2016). Hence, it is essential to explore alternative ways of growing Medicinal and Aromatic Plants (MAPs). Currently, micropropagation, hydroponics, and aeroponics are gaining popularity in this regard. However, micropropagation has started for certain medicinal plants, the adoption of hydroponics and aeroponics in the production of Medicinal and Aromatic Plants (MAPs) is still at an early stage. These techniques offer a sustainable alternative, providing high-quality roots that are devoid of pesticides and soil-borne diseases (Mehdizadeh and Moghaddam, 2023). The conservation and sustainable use of medicinal plants require a long-term approach, so this review focuses primarily on their propagation methods. Here is a general guide to planting these root crops:

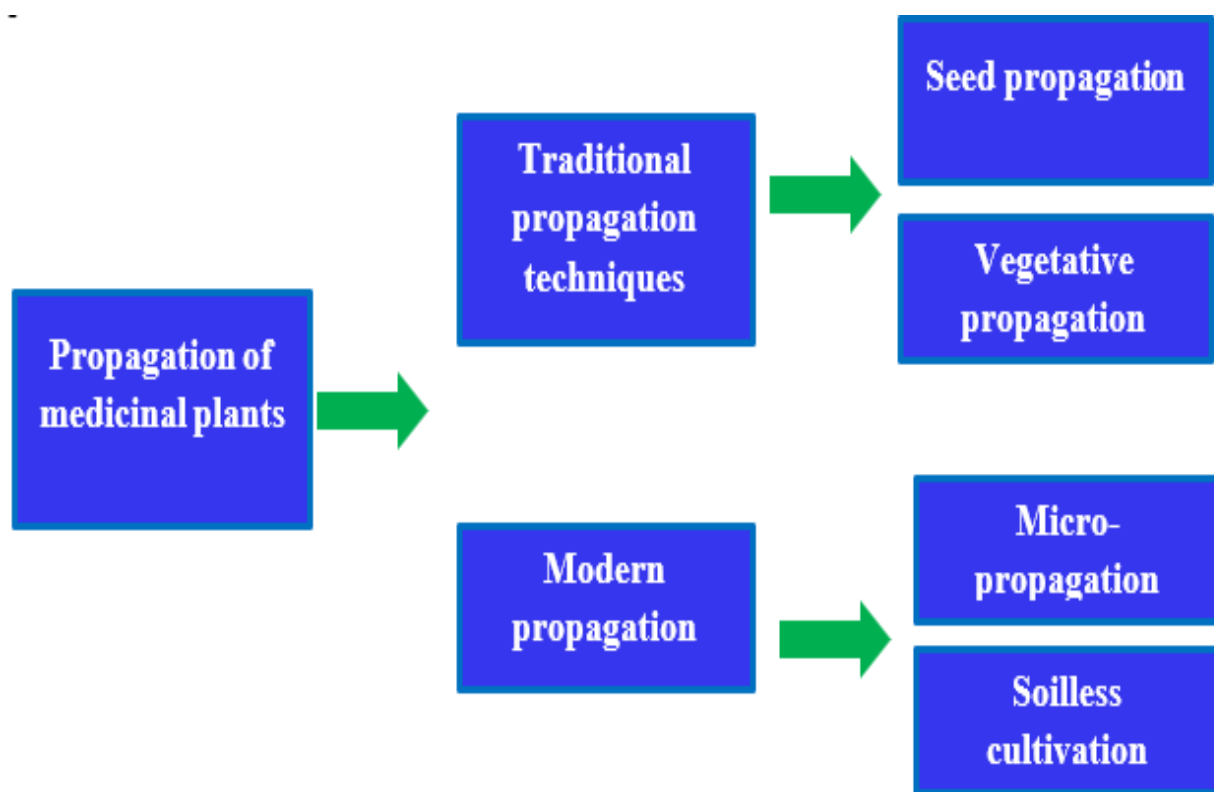


Fig. 1. Different propagation methods of medicinal plants

Planting methods of different medicinal root crops

The planting method is almost similar for *ashwagandha*, *mulethi* and *shatavari*. However, specific climatic and soil conditions may affect their growth.

Site selection

Selecting an ideal location for cultivating medicinal root crops is essential for a successful harvest. Medicinal root

crops such as *ashwagandha*, *mulethi* and *shatavari* thrive well when they receive a minimum of 6-8 hours of direct sunlight daily. Sunlight is vital for photosynthesis, enabling plants to produce energy for robust root growth. Root crops prefer loose, fertile, and well-drained soil that allows their roots to penetrate easily. Well-drained soil prevents water logging and the risk of root diseases. Ensuring there are no hard layers beneath the soil further aids good root penetration (Gupta, 2017).

Soil and climate

Ashwagandha, *mulethi* and *shatavari* are medicinal herbs

that thrive in warm climates and have specific soil and environmental preferences conducive to their growth. These herbs can adapt to various soil types but perform exceptionally well in specific conditions. For instance, *ashwagandha* does best in sandy or loamy soil within a pH range of 7.5 to 8.0 (Kumar *et al.*, 2023), while *mulethi* prefers a pH range of 5.5 to 8.2 (Cui *et al.*, 2023), and *shatavari* thrives in soil with a pH range of 6.0 to 8.0 (Chaudhary *et al.*, 2023). These pH ranges reflect their soil acidity or alkalinity requirements for optimal nutrient absorption. However, it is equally important to provide good air circulation in the planting area. Adequate air circulation prevents the development of fungal diseases and promotes overall plant health by reducing humidity levels.

Land preparation

Preparing the soil for the cultivation of *ashwagandha*, *mulethi*, and *shatavari* is a crucial step in ensuring their successful growth. To create optimal growing conditions, it is essential to thoroughly pulverize the field. This process typically involves ploughing and harrowing, which break up compact soil and enhance its structure. For root crops, loose soil with good aeration is essential as it allows their roots to penetrate easily and promotes healthy growth. Therefore, it is advisable to loosen the soil to a depth of about 12 inches (30 cm) to provide ample space for root development (Gupta, 2017). In regions with heavy or clayey soil, additional measures are necessary. Two to three rounds of ploughing before the rainy season can help break down the soil structure further. Moreover, incorporating well-decomposed farmyard manure (FMY) or organic matter into the soil can significantly improve its texture and fertility.

Propagation of *Ashwagandha* (*Withania somnifera* (L.) Dunal)

Propagating *ashwagandha*, an important medicinal plant, can be achieved through two primary methods: direct sowing and propagule raising in a nursery. The choice of method depends on factors such as the availability of seeds or seedlings, the local climate, and the specific needs of the cultivation process. However, the best way to propagate *ashwagandha* is through seed. Choose disease-free and high-quality seeds from well-recognized fibrous varieties, like Jawahar Asgand-134, Jawahar Asgand-20, Raj Vijay Ashwagandha-100, Gujarat Anand Ashwagandha-1, Vallabh Ashwagandha-1 (Khabiya *et al.*, 2023). The second group of *ashwagandha* varieties is rich in starch (low crude fiber) having long, stout, and thick root quality of produce obtained (Saran, 2023, Saran and Das, 2023). The starchy type high-yielding varieties/landrace/germplasm are Vallabh Shahi

Ashwagandha-1 (DTWr-1), DNA-4, Nagori, CIM Pratap and CIM Chetak are rich in starch and low crude fiber content (Saran *et al.*, 2025).

Ashwagandha cultivation can involve either using seeds directly or purchasing seedlings from a nursery. When directly planting seedlings in the field, dig a hole slightly larger than the root ball of the plant, carefully place the seedling in the hole, fill it with soil, and gently firm the soil around the plant. As a precautionary measure, treat the seeds with Captan at a rate of 5 g/kg seed before sowing to protect emerging seedlings from potential seed-borne diseases (Kumar *et al.*, 2023).

Direct sowing

The process of sowing seeds for *ashwagandha* typically involves the broadcasting method, where the seeds are evenly scattered across the main field. Sowing of the seeds generally occurs in the second week of July to August. During this period, the soil is adequately moistened by the rains, creating ideal conditions for germination. However, it is worth noting that the timing of sowing can be somewhat flexible depending on local weather conditions. In cases where there is ample rainfall and soil moisture, the sowing can be extended up to September. The field is divided into convenient-sized plots or rows to facilitate organized and efficient planting. The recommended seed rate is typically 10-12 kg of seeds per hectare, ensuring sufficient plant density for a successful crop (Mathew *et al.*, 2005). Matured seedlings, whether raised through sowing or broadcasting, should be manually thinned approximately 25 to 30 days after seed sowing. This thinning process aims to achieve a plant population ranging from about 30 to 60 plants per square meter (Moharana *et al.*, 2020).

Nursery raising

In a nursery bed, compost and sand are thoroughly mixed and then raised from ground level. Fresh seeds are sown in well-prepared nursery beds in rows, spaced at 5 cm and sown at a depth of 1-3 cm (Chaurasiya *et al.*, 2019). The spacing between plants and rows can be adjusted based on soil fertility and the variety being cultivated. In less fertile soil, closer spacing is recommended, while in more fertile soil, greater distances are advisable, taking into account factors such as resource competition, root development, water management, and pest control to facilitate robust growth and maximize yield. Maintaining a gap of 20 to 25 cm between rows and 8 to 10 cm between individual plants is generally recommended (Moharana *et al.*, 2020). Approximately 5-10 kg of seeds are required for planting in one hectare of the primary field (Namdeo and Ingawale, 2021). Sowing takes

place right before the beginning of the monsoon and is lightly covered with sand. Germination typically occurs within 5 to 7 days. Once the seedlings reach approximately 35 days of age, they are transplanted into the well-prepared main field during July-August (Farooqi and Sreeramu, 2004). Adequate moisture, facilitated by a light shower after sowing,

is essential for good germination. It is crucial to maintain consistently moist soil until the seedlings emerge. Although transplanting *ashwagandha* seedlings is a common practice, it has been observed that transplanted seedlings exhibit bifurcated roots, hence, direct sowing is recommended (Fig. 2).

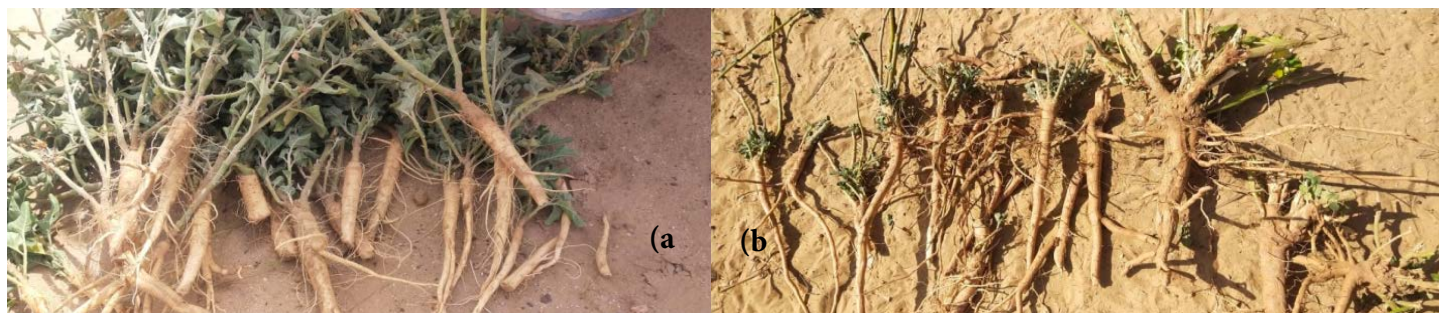


Fig. 2. Nagori ashwagandha root (a) direct sowing (b) transplanting

Transplanting

For the cultivation of *ashwagandha*, the selected field should be thoroughly pulverized through ploughing or harrowing, followed by leveling. While the *ashwagandha* crop does not demand heavy doses of manure, it is advisable to apply 10 to 20 tons of Farm Yard Manure (FYM). Ridges are prepared at a spacing of 60 cm, and healthy seedlings are planted at intervals of 30 cm. In certain locations, spacing of 60 cm x 60 cm or 45 cm x 30 cm is also adopted (Farooqi and Sreeramu, 2004). However, the preferred spacing is 60 cm x 30 cm, ensuring an optimal seedling population of approximately 55,000 per hectare (Namdeo and Ingawale, 2021). Notably, there is a noticeable variation in profitability due to different sowing methods. Regarding sowing techniques, the highest net return was observed with the raised bed method, followed by the ridge and furrow method, and then the flat-bed method (Ratre et al., 2018).

In-vitro propagation

The substantial disparity between the demand and supply of *ashwagandha* cannot be addressed effectively through traditional propagation methods due to its low seed germination rate and seedling viability (Ameen et al., 2023). *In-vitro* propagation emerges as the most suitable approach to overcome the constraints of conventional propagation and meet the commercial demands for *ashwagandha*. Numerous biotechnological interventions, including callus and suspension culture, hairy root culture, and others, have been developed to enhance the propagation process, as highlighted in Table 1.

Table 1. *In vitro* regeneration of *ashwagandha*

Mode of propagation	Explant used	Reference
Direct regeneration	Nodal explant	Tawade et al. (2023)
Multiple shoot differentiation	Nodal explant	Kaur et al. (2021)
Callus induction	Shoot explants (shoot tips, cotyledonary leaf, matured leaves, node, internode)	Sharada (2004)
Multiple shoots differentiation	Nodal explant	Govindaraju et al. (2003)
Multiple shoots differentiation	Nodal explant	Mir et al. (2014)
Direct regeneration	Nodal explant	Autade et al. (2016)

In contrast to callus culture, cell suspension culture offers the advantage of containing homogeneous cell populations and can be readily scaled up for large-scale cultivation (Ahuja et al., 2021). In addition, it is noteworthy that somatic embryogenesis stands out as the swiftest method for generating a substantial quantity of clonal plants, given that somatic embryos encompass both shoot and root ends. Nevertheless, the utilization of synthetic seeds, including encapsulated somatic embryos or vegetative propagules such as nodes, axillary buds, and shoot apices, serves as a valuable strategy for preserving germplasm in elite medicinal plants (Verma et al., 2010). Moreover, Singh et al. (2006) documented their successful production of synthetic seeds

in *ashwagandha*. This was accomplished by encapsulating shoot tips from 4-week-old in vitro-cultured shoots using a mixture of sodium alginate (3.0%) and calcium chloride (75 mM). Similarly, Fatima *et al.* (2013) employed axenic nodal segments to create synthetic seeds in *ashwagandha*. These nodal segments were enveloped in a matrix consisting of 3% sodium alginate and 100 mM calcium chloride, then cultured on a Murashige and Skoog (MS) medium supplemented with BAP (6-benzylaminopurine) and NAA (naphthaleneacetic acid), aiming to facilitate the optimal transformation of encapsulated nodal segments into plantlets.

Propagation of Mulethi (*Glycyrrhiza glabra* L.)

Mulethi propagation can be accomplished through two methods: using seeds or employing root/stolon cuttings (Dastagir and Rizvi, 2016). However, the latter, involving 10-15 cm root/stolon cuttings, is more commonly chosen due to the relatively low seed set and germination rates (Bakhane *et al.*, 2014; Sharma *et al.*, 2010). The recommended variety for cultivation is 'Haryana Mulhatti-1,' released by Chaudhary Charan Singh Haryana Agricultural University, Hissar (Bhardwaj *et al.*, 2020). Planting is typically carried out in January and February in areas with irrigation facilities and during July and August in regions dependent on rain for sufficient soil moisture.

Propagation through seed

Variations in the germination capacity of *mulethi* were observed among seeds at different stages of maturation (Rao 1993). It is difficult to germinate seeds at the milky way ripe stages but seeds collected in July have the highest germination rates. It is advisable to plant the seeds at a depth of around 1/4 inch in soil. Furthermore, it is advisable to space the seeds at least 6 to 12 inches apart when planting to ensure that there is adequate room for the plants to grow (Öztürk *et al.*, 2018).

Propagation through crown root

For optimal results, it is essential to plough and harrows the field thoroughly, ensuring a fine tilth and weed-free soil. During field preparation, it is recommended to apply Farm Yard Manure (FYM) at a rate of 10 tons per hectare to promote good underground root development (Tewari and Singh, 2019). Planting cuttings of the underground stolon, measuring 10-15 cm in length and possessing 2-3 eye buds, at a depth of six to eight cm and spaced at intervals of 60 x 45 cm or 90 x 45 cm is advisable (Akhtar and Anjum,

2022). Additionally, raising the rows 45-60 cm can facilitate irrigation. The stolon typically begins sprouting within 15-20 days after planting. Notably, *mulethi* propagation can also be achieved through a single root node cutting, which conserves planting material and promotes rapid germination (Fig. 3). During the initial phase, it is essential to provide light and frequent irrigation to support the establishment of the cuttings in the field. Once the plants reach a height of 20 to 30 cm, elevating the rows encourages healthy root expansion. To ensure optimal stolon growth and achieve a substantial yield, it is recommended to leave the crop in the field for a period of 3 to 4 years (Dastagir and Rizvi, 2016).



Fig. 3. *Mulethi* germination from single root node

In-vitro propagation

Traditional seed-based propagation faces economic challenges due to issues like poor seed set, low seed viability, and a slow growth rate (Jaiswal *et al.*, 2017). As a result, the primary method for propagating the crop relies on valuable vegetative components such as stolons, rhizomes, or cuttings. However, vegetative propagation is not practical, especially for economic parts like roots that take several years to mature (Gupta *et al.*, 1997). Tissue culture stands out as the viable alternative strategy, providing a large-scale *in vitro* propagation of *mulethi* germplasm. This approach enables the production of pathogen-free and season-independent clonal plants. This can be accomplished by utilizing different components of *mulethi*, including nodal buds, apical meristem, axillary buds, leaf segments, shoot buds or by employing somatic embryogenesis.

It can be achieved by using different parts of *mulethi* namely nodal bud, axillary buds, apical meristem, shoot buds, leaf segment or through somatic embryogenesis (Srivastava *et al.*, 2019). Several biotechnological interventions have been

reported in recent years to develop alternative strategies to meet industrial demands. Some of the *in vitro* study has been mentioned in Table 2.

Table 2. *In vitro* regeneration of *mulethi*

Mode of propagation	Explant used	Reference
Callus induction	Leaves and nodal segments	Rathi (2017)
Callus induction	Hypocotyl	Fu <i>et al.</i> (2010)
Multiple shoots differentiation	Nodal segment	Arya (2009)
Callus induction	Cotyledon	Wawrosch <i>et al.</i> (2009)
Callus induction	Young leaves	Mousa <i>et al.</i> (2007)

Considerable research efforts have been directed towards micro-propagation of *mulethi* using shoot tip and nodal culture techniques. *In vitro* rooting has proven to be most effective on full-strength MS medium enriched with IBA, with optimal levels ranging from 0.5 to 1.0 mg/l (Patel *et al.*, 2007). Yadav and Singh (2012) provided a detailed micro-propagation protocol involving the manipulation of growth regulators, cultural conditions, and external factors influencing *mulethi's in vitro* proliferation. Optimal results were achieved by selecting middle-order nodes, specifically the 3rd to 5th node from the apex, resulting in the highest bud-break rate (86.6%), longest shoot length (8.0 cm), and the greatest number of shoots (3.0). Similarly, Fu *et al.* (2010) conducted a study focused on enhancing the development of embryogenic callus and embryogenesis in *mulethi*. They observed that using hypocotyl explants led to the highest frequency of callus formation, reaching 93.3%, when cultured on MS medium supplemented with 2.0 mg/L 6-benzylaminopurine (6-BA) and 0.5 mg/L 2,4-dichlorophenoxyacetic acid (2,4-D).

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using hypocotyl explants yielded the highest frequency of callus formation, reaching 93.3%, when cultured on Murashige and Skoog (MS) medium supplemented with 2.0 mg/L 6-benzylaminopurine (6-BA) and 0.5 mg/L 2,4-dichlorophenoxyacetic acid (2,4-D).

Propagation of *Shatavari* (*Asparagus racemosus* Willd.)

The National Medicinal Plant Board has identified *shatavari* as one of the 32 medicinal plants designated for conservation based on its extensive use (Thakur *et al.* 2015). Therefore, the preservation of this species is of utmost significance. They can be propagated through two main methods: seeds or divisions of rhizomatous discs (Sachan *et al.*, 2012).

Seed propagation

For sowing purpose seeds are typically harvested from March to May, specifically when they undergo a transition in color from red to black. As part of the pre-sowing treatment, these seeds can be soaked in water for duration of two days or subjected to gibberellic acid treatment for periods of 96 hours, which helps expedite the germination process (Gupta *et al.*, 2002). In the initial week of June, seed sowing takes place in meticulously prepared elevated nursery beds, as illustrated in Fig. 4. The seeds are planted at a depth of 2 cm beneath the soil surface within raised beds measuring 4.5 m x 1.2 m and standing at a height of 20 cm. With a spacing of 5 cm between seeds in rows, they are carefully positioned and lightly covered with fine sand. Regular watering with a rose cane is employed to sustain optimal moisture levels in the beds. Typically, germination occurs within a span of 15 to 20 days. Approximately 7 kg of seeds are required to cultivate enough seedlings for one hectare of the crop (Krishnamurthy *et al.*, 2004).

Transplanting

The soil ought to undergo thorough disc plowing, succeeded by harrowing and leveling processes. To facilitate irrigation management, the field is partitioned into separate plots with an irrigation channel positioned between every two rows of plots. About one month before the transplanting phase, it is advised to incorporate 10 tons of well-decomposed FYM into the soil, ensuring thorough mixing for optimal soil conditioning. August is ideal for transplanting. Seedlings are ready for transplantation about 45 days after sowing. Seedlings of 5 cm height are carefully removed from the beds, ensuring minimal root damage, and transferred to the field. During planting, they are placed into pits measuring 45

x 45 x 45 cm and spaced 1 meter apart (Saran *et al.*, 2020). In addition, seedlings are transplanted on ridges, maintaining a distance of 60 cm between plants, while ridges are 45 cm apart (Yadav *et al.*, 2022). The ridge method of transplanting

is superior in comparison to a flatbed method. The ideal number of seedlings required per hectare is approximately 150,000 plants/ha.



Fig. 4. Nursery raising of Shatavari

Propagation with crown bud

The propagation of the plant can be done by taking the crown bud along with its root. After transplanting sprouting commence after 8-10 days of planting. The yield of the crop is influenced by the number of plants per unit area. The highest yield was achieved with a plant density of 1x0.5 meters spacing, resulting in a dry yield of 12.5 kilograms per 24 square meters in irrigated areas during the final harvest at 19 months. In contrast, a lower plant density of 1x1 meter spacing yielded 9-9.4 kilograms per 24 square meters under similar conditions (Krishnamurthy *et al.*, 2004). The first harvest is usually done after 1.5-2 years of planting, and this can continue for 10-15 years (Saran *et al.*, 2019).

In vitro propagation

Shatavari can be grown from either seeds or other plant parts (like root cuttings) (Sachan *et al.*, 2012). However, since the roots are the valuable part used for medicine, people usually prefer seeds to grow the plant. But multiplication through seed has its drawbacks such as low germination percentage, slow growth and existence of heterozygosity (Singla and Jaitak, 2014; Sharan *et al.*, 2011). Hence, the requirement for consistent and high-quality planting material is of utmost importance. In this context, *in vitro* techniques can prove advantageous. Numerous studies have documented the standardization of micro-propagation protocols for *shatavari*. A compilation of the *in vitro* propagation methods employed in *shatavari* is presented in Table 3.

Table 3. *In vitro* regeneration of *shatavari*

Mode of propagation	Explants used	References
Adventitious shoot bud regeneration	Nodal explant	Sulava <i>et al.</i> (2020)
Somatic embryoids formation through callus culture	Zygotic embryos	Chaudhary and Dantu (2019)
Somatic embryoids formation through callus culture	Nodal explant	Pant and Joshi (2017)
Adventitious shoot bud regeneration	Shoot apex and nodal explant	Sharan <i>et al.</i> (2011)
Indirect organogenesis via callus culture	Shoot explants (node, internode, shoot tips)	Pant and Joshi (2009)
Axillary branching	Nodal explant	Bopana and Saxena (2008)
Adventitious shoot bud regeneration through callus culture	Nodal explant	Kumar and Vijay (2008)

Kar and Sen (1985) pioneered the initial efforts to cultivate *Asparagus racemosus in vitro*. They successfully induced shoot proliferation from callus cultures of *shatavari* using stem discs as explants, with the aid of 2,4-D and kinetin.

Bopana and Saxena (2008) later devised a more effective protocol for axillary branching using nodal explants. Normally, *in vitro* rooting in *A. racemosus* is tedious and hormones are not enough to induce roots. However, this study successfully induced roots by employing phloroglucinol. The researchers utilized an MS medium supplemented with 3.69 μ M 2-isopentyl adenine and 3% sucrose, leading to a multiplication rate of 3.5.

Post-planting care of tuberous medicinal plants

Caring for tuberous medicinal plants after planting is crucial to ensure their growth, health, and maximum medicinal yield. Here are some important post-planting care steps to follow:

Manure and fertilizer

Root crops generally do not demand heavy fertilization; however, applying a balanced fertilizer or compost during the growing season proves beneficial in providing essential nutrients. Organic manures like FYM, vermicompost, and green manure can be utilized based on the specific requirements of the species (Gupta *et al.*, 2011).

Ashwagandha crops exhibit excellent responsiveness to organic manures. For this crop, approximately 10 to 12 tonnes of well-decomposed FYM or 1 to 1.5 tons of vermicompost per hectare are recommended during plantation. In soils with average fertility, supplementing with 15 kg of nitrogen (N) and 15 kg of phosphorus (P) per hectare is advantageous for achieving higher yields (Tuteja, 2022). In cases of poor fertility soils, it is advisable to increase the application to 40 kg of nitrogen (N) and 40 kg of phosphorus (P) per hectare to optimize root yield. *Mulethi* crops generally do not require heavy fertilization, but the application of a balanced fertilizer or organic compost once or twice during the growing season can enhance growth. Applying compost or FYM at the rate of 12-18 tons per hectare is sufficient to meet the nutrient requirements of the plant. However, due to difficulties in obtaining organic manures in large quantities, a chemical fertilizer dose at the rate of 40:40:20 kg per hectare per year (urea, superphosphate, and chloride of potash) may also be considered. The full basal dose of superphosphate and potash is applied at the time of planting, while nitrogen is applied in three split doses: at planting, six months later, and one year after planting. Since the crop remains in the field for two and a half to three years, every year the same dose has to be applied (Farooqi, 2001). Further, *shatavari* cultivation demands a fertilizer dose of 60 kg nitrogen, 40 kg phosphate, and 40 kg potash per hectare to achieve optimal growth and enhance tuberous root yield (Parida *et al.*, 2018). It is recommended to place one-third of the nitrogen and the entire dose of

phosphate and potash 10–12 cm deep in the rows before the transplanting process. This strategic placement ensures that the essential nutrients are available to support *shatavari* plants during their growth and development.

Irrigation

Tuberous medicinal plants are sensitive to excess water, and it is vital to avoid water-logging in the field. Stagnant water can result in problems like damping-off and root rot. To promote the successful establishment of seedlings in the soil, it is recommended to apply light irrigation at the time of transplanting. For optimal root yield, irrigation should be carried out at intervals of 8 to 10 days (Namdeo and Ingawale, 2021). However, during the dry summer season, the crop may require irrigation at intervals of 30-45 days, and in the winter season, one to two irrigations may be necessary to maintain root health. If there is regular rainfall, additional irrigation may not be needed. *Mulethi* plants, on the other hand, demand consistent moisture, especially during the growing season, typically requiring a total of 7-10 irrigations on average for successful crop cultivation (Zaidi, 2018). In contrast, *shatavari* requires minimal irrigation as it can thrive without frequent watering. An annual rainfall range of 800-1200 mm, distributed evenly, is generally sufficient for *shatavari* plants. During the initial establishment phase, plants may be irrigated weekly, and once they have firmly established themselves, light irrigation can be provided at monthly intervals (Saran *et al.*, 2021).

Mulching

The mulching technique involves spreading a protective layer of organic materials, such as straw, leaves, wood chips, or compost over the soil surface around the base of the plants. It is an effective practice that offers multiple advantages. This practice aids in conserving moisture, regulating soil temperature, enhancing soil health, suppressing weeds, and mitigating erosion (Carrubba and Militello, 2013).

Weeding

Keep the area weed-free, as weed competition can impede their development. During the initial year of planting, it is essential to conduct three to four hoeing cum weeding sessions. In the following years, two hand weeding-cum-hoeing sessions prove adequate to maintain a weed-free field and enhance the overall well-being of the plants. Typically, the first weeding should occur within 21–25 days of sowing, with the second weeding scheduled after an additional 21–25 days following the initial one (Carrubba and Militello, 2013).

Staking

Ashwagandha, *mulethi* and *shatavari* may require support as they grow taller. Staking is crucial to counter potential damage from strong winds or heavy rainfall. *Ashwagandha* plants can grow up to 4 to 5 feet in height, and their branches may need some support. Consider staking or using a trellis to help the plants stay upright (Mathew *et al.*, 2005). Likewise, *mulethi* plants can reach heights of 3 to 5 feet and may need support as they mature (Bakhane *et al.*, 2014). It is worth noting that *shatavari* crops, being climbers, also necessitate support for their optimal growth (Babu *et al.*, 2016). To facilitate this, 4-6 feet long stakes are commonly employed to provide the necessary support for the overall growth of the plants.

Pest and disease control

Major pests and diseases have not been reported in medicinal crops; however, early detection and timely intervention can effectively prevent any potential serious damage. It is advisable to employ natural pest control methods whenever possible. Bio-pesticides, either prepared individually or as a mixture from plant parts such as neem, chitrakmool, dhatura, and cow's urine, can be utilized for this purpose (Gupta *et al.*, 2011). Implementing this proactive strategy helps to ensure the overall health of root crops.

Harvesting

Ashwagandha roots are typically harvested between January and March, approximately 150 to 180 days after sowing, when they reach the desired size. The maturity of the crop is determined by the drying out of leaves and the presence of yellow-red berries (Moharana *et al.*, 2020; Saran *et al.*, 2025). It is recommended to maintain adequate soil moisture during the digging process. Careful extraction of the tap root is essential to preserve the health of even the smaller lateral roots. A yield of 6.5 to 7.0 quintals per hectare can be achieved in fibrous type, with a preference for commercially viable root species with diameters ranging from 6 to 15 mm and lengths of 7 to 10 cm. DTWr-1 has maximum fresh root length (36-39 cm), fresh root girth (2-4 cm), dry root yield (5 t h⁻¹) and starch yield (2.70 t h⁻¹), as compared to all available checks as shown in Fig. 5 (Saran and Das, 2023; Saran *et al.*, 2025). The alkaloid content in the roots varies from 0.13 to 0.31%.

Mulethi crops are ready for harvesting after 2.5-3 years of planting, just before fruiting, typically in November and December, when glycyrrhizin content is at its peak (Ahmed

et al., 2021). The plants are uprooted, and the aerial parts are removed, leaving clean roots. Herbage may be left in the field to recycle minerals and nutrients. The Haryana Mulhatti-1 variety yields 7-8 tons of roots with a 7.5 percent glycyrrhizin content (Zaidi, 2018). *Shatavari* crops mature within 12 to 14 months after planting (Saran *et al.*, 2019) and are expected to yield approximately 4-5 tonnes per hectare, depending on soil and climatic conditions (Fig. 6). The optimal period for harvesting tuberous roots is in November to December, coinciding with the time when the above-ground parts of the plant begin to exhibit a pale-yellow color (Vel, 2017).



Fig. 5. Freshly harvested roots of starchy type *Ashwagandha*

Conclusion

The medicinal tubers are a vital group of medicinal plants. Their commercial value often leads to overexploitation, which threatens their natural populations. To address this issue, we have been exploring various propagation methods, including *in vitro* plant propagation. The review aims to provide a comprehensive overview of existing studies and investigations related to the propagation of medicinal tuber plants. This not only helps consolidate existing knowledge but also identifies research gaps that require further exploration. This approach aligns with a more holistic and forward-looking strategy to ensure the survival of these important medicinal plants for future generations. In this way, farmers will be encouraged to cultivate these medicinal plants for commercial use, which will curb overexploitation in the wild and thus complement the conservation process.



Fig. 6. Harvesting of *Shatavari*

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Author Contribution Statement

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Conflict of Interest

The authors have no conflict of interest.

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Scope and opportunities of precision agriculture on arid horticulture-A review

Ramawatar Choudhary¹, Ramesh Chand Kantwa², Astha¹, Ganesh Ram¹, Hemant Kumar Meena¹ and Sunil Khandoliya¹

¹Department of Horticulture, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, M.P

²Subject Matter Specialist (Fruit Science), KVK-Fazilka, ICAR-CIPHET, Abohar, Punjab

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ABSTRACT

Precision agriculture (PA) is the use of mechatronics to control the fields' temporal and spatial variability. Numerous elements, including appropriate planting, weeding and interculture, irrigation, insect and pest attacks, and harvesting methods, influence the output and quality of horticultural commodities. A proactive strategy that lowers some of the risks associated with these frequent horticultural and agricultural variables is precision agriculture. Producing high-quality, highly productive fruits in the fields requires the development of an exact and accurate autonomous production system, which frequently largely depends on human involvement. In arid regions, where water and arable land are limited, precision agriculture holds significant promise for enhancing the productivity and sustainability of fruit crops. Mechanization, precision farming, and agricultural transformation are three of these important technologies. Among these, precision and mechanical engineering are the foundations of a more all-encompassing system that makes use of automated technology. Accurate farming management is based on recognizing and adjusting to in-field variation. Some of the newest technologies used to assess and analyze agricultural and agricultural output disparities include robotic control systems for real-time weed detection and control, microcontroller-based variable rate herbicide/pesticide application systems, site-specific variable rate irrigation, wireless sensor network (WSN) enabled crop stress monitoring systems, RTK-GPS enabled seed planters or transplanters for geospatial mapping of row-crop plants/transplants, automated harvesting Sensors, satellites, aerial photography, Geographic Information Systems (GIS), and Global Positioning Systems (GPS). In order to manage water resources, choose the ideal harvesting site, balance fertilizer requirements, and forecast crop performance, sensor networks are crucial. In order to satisfy the requirements of certain regions and plants, accurate farming employs a set of extremely precise methods for technology users.

Introduction

The goal of precision farming (PF), a complete knowledge-

based approach in farm management, is to maximize profits, preserve sustainability, and manage local and inter-sectoral variety through identification, analysis, and management.

Corresponding author

Email: ramawatarmoon1999@gmail.com (Ramawatar Choudhary)

It helps to prevent unwanted habits in the plant, regardless of the local soil or environment (Swain and Sharma, 2014). Precision agriculture is the management of temporal and spatial diversity in the context of ICT (information, computers, and technology). Following an analysis of the spatial and temporal changes of field and plant areas, field regions with similar characteristics are called management areas. Improved management that optimizes profitability and reduces environmental impact can result from using the appropriate inputs in management areas. The concept of precision farming first appeared in the US in the 1980s. In order to detect, analyze, and manage the unique and temporary variability of agronomic parameters (soil, disease, water, nutrients, etc.) in a sustainable way with the least amount of adverse environmental impact, this technique improves agricultural management by leveraging satellite-based technologies and information technology (IT).

The Principle

As a matter of fact, orchard performance can be enhanced by modifying precision crop production technologies to provide fruit and fruit production with exact farming methods that minimize negative environmental effects while enhancing yields and quality.

The Need for Accurate Farming

The 1960s “Green Revolution” enabled our nation to meet its food production needs. From little over six million tons of wheat produced in 1947 to over 72 million tons gathered in 1999 by our farmers, the nation now ranks second in the world for wheat output. Grain yields have more than doubled during the last 50 years, and grain production has more than tripled. This is all due to high demand, which has increased the use of HYV, pesticides, fertilizer, irrigation, and agricultural Machinery.

Fatigue of the Green Revolution

Degradation of natural resources

Agricultural strategies that can assist produce more with existing land, water, and resources without causing harm to the environment or society must be implemented in order to turn this green transition into an evergreen one (Swaminathan, 2002). This objective can be accomplished by suggesting that the tailor's management techniques be determined by exact farming.

Basic steps in precision farming

The basic steps in precision farming are (i) Assessing variation, (ii) Managing variation, and (iii) Evaluation. The available technology offers site-specific agricultural recommendations.

Assessing variation: For precise farming, flexibility testing is a crucial first step. Clearly, man cannot control what he does not understand. Crop-specific materials and procedures that govern or affect crop performance change periodically. It is difficult for accurate agriculture to assess the variety of these elements and processes and to determine the precise time and locations of the various combinations that cause temporal and geographical variation in crop yields. Accurate farming makes use of widely accessible and extensively used geographic diversity assessment methodologies.

A significant portion of accurate agriculture lies in exploring biodiversity. Temporary diversity assessment methods are also available but simultaneous reporting of local and temporary variability is not uncommon. We need both local and temporary statistics. We can see the variety of crop yields in the area but we cannot predict the reasons for the variety. Plant development and growth throughout require monitoring, which is useless without transient variability. Therefore, in order to apply precise farming techniques, we require both space and time estimates. However, this is not unique to all crop yield-determining varieties or factors. Current forms of precision management are made easier by the fact that some variables are more frequently produced in space than in time.

Managing variation: Once the diversity has been adequately explored, farmers should use management recommendations to match agronomic measurements with existing conditions. Utilizing precise application control techniques, those are site-specific. Technology is something we can use extremely well. Under site-specific diversity control. The GPS technology will make it easier and more cost-effective to administer the site and disclose its specs. We should be cautious while collecting soil and plant samples because we can use the domain link sample for management purposes. This prevents spoiling and leads to an efficient utilization of inputs, which is what we desire. Their potential and capacity to handle precision increase with the degree of reliance on a regulated geographical area. The degree of difficulty, however, grows as the transient component of local variability increases. The fact that fertilizing with phosphorus and potassium is particularly beneficial in controlling precision because of the minimal transient variations can be supported by applying this theory to soil fertility. In certain situations, it can be more challenging to

precisely manage N because the temporal component of the variance may exceed its partial area.

Evaluation: The fact that the value of accurate agricultural profit analysis derives from data utilization rather than technology use is its most important component. The potential to improve environmental quality often justifies accurate farming. Potential environmental benefits are frequently mentioned, including less use of agrochemicals, high nutrient efficiency, improved efficiency of controlled inputs, and higher soil output as a result of deterioration. Agricultural principles and decision-making rules can make it work and increase productivity efficiency or other types of value that can make it more profitable. Technology can enable agricultural precision.

Precision agriculture techniques for arid horticulture applications

Remote sensing: It is the process of gathering data about an object, the earth, or the water without the sensor and the object being physically in contact. An alternative method is to use a recording device that is not physically connected to or close to the object or events being examined in order to measure or collect data on their location. To obtain accurate information from above without making physical touch, one can collect, process, and evaluate data using a remote sensor. Its high-resolution tracking of spatial changes over time offers significant promise for precise farming.

Principle: Depending on their chemical, physical, and other characteristics, different materials either emit or reflect varying amounts of energy at different wavelengths of the electric spectrum. For example, when rays strike red and green apples, they emit radiation in the form of an electromagnetic spectrum that contains some information about the substance. These radiations have highly specific properties and can determine the object's characteristics. The color, shape, and glowing pattern of the fruits in this instance, for example, allow us to distinguish between a red and a green apple. The same principle applies to distant hearing as well: when radiation hits an object, it emits a pattern of radiation that is detected by the senses.

Remote sensor applications

A remote sensor is a group of methods that use the gloss or light that plants and soils release to gather data in their natural habitat without having to come into contact with the thing. The PA employed bright light, either from the sun or artificial light, to determine the plant indices. The normalization difference vegetation index (NDVI), which is found in fruits with low chlorophyll and canopy imaging, is the most widely

used agricultural index. A few more indications can be approximated and used to provide a good agreement with the chemically determined leaf chlorophyll (Richardson *et al.*, 2002). Consequently, there is a substantial correlation between NDVI and crop strength and production, and occasionally quality. The pigment content of the xanthophyll cycle affects the photochemical reflectance index (PRI), a standard differential index that uses two bright bands (531 and 570 nm). For example, picture prevention and water stress in plants, PRI is utilized as an indicator of stress that offers an effective indicator (Weng *et al.*, 2006). Usha and Singh recently analyzed remote sensors that use hyper- and multispectral techniques (2013).

In order to forecast citrus tree yield, Xujun *et al.* (2007) developed mathematical models based on canopy features derived from airborne hyperspectral data captured over three years utilizing nine air missions at the start of each growing season. The models' performance has been good, demonstrating their capacity to forecast orange yield several months ahead of harvest. Furthermore, Liakos *et al.* (2011) discovered a connection between the apple tree crop for two years in a row and the first season of NDVI.

In order to determine plant indication, in an olive orchard, Suarez *et al.* (2008) used an aerial hyperspectral camera and found a correlation between the PRI of similar plants pointing tops and leaf-level steady-state fluorescence. While chlorophyll fluorescence kinetic analysis is still a problem in automated measurements, chlorophyll fluorescence in stable conditions was utilized to assess chlorophyll and water content in order to generate a canopy map (Ac *et al.*, 2015). Using data from a multispectral fluorescence imaging system, Hsiao *et al.* (2010) created a flexible fluorescence index to gauge the water stress levels of cabbage sprouts. In recent years, the use of UAS has also seen a sharp increase (Zhang and Kovacs, 2012), when applications to high value plants begin to appear already being run by companies that provide semi-commercial solutions.

Berni *et al.* (2009) mapped the canopy conductance and crop water stress index (CWSI) on olive trees using high-resolution imagery obtained with a UAS over a two-year period in order to estimate the water condition. Furthermore, for two years in a row, Cohen *et al.* (2012) measured the CWSI in palm trees in three drip-irrigated locations using an air-conditioned thermometer. A water-based mapping variation procedure that may be utilized for irrigation planning has been successfully developed by them. In order to identify water leaks, malfunctions in muskmelon drip irrigation, and inadequate watering rates, Clarke (1997) employed a hot airborne image in plants. These are only three arbitrary instances of how Jones (1992) has been applied and developed. A recent evaluation examined the use of hot photography for plant water quality analysis (Maes and Steppe, 2012).

Ultrasound, image-based image analysis, and light and vibration detection (LiDAR) are other sensors that have the

ability to detect remotely. An ultrasonic or laser scanner can be used to assess a tree's canopy in Florida orchards (Zaman and Salyani, 2004; Zaman *et al.*, 2006). According to Walklate *et al.* (2002) and Mendez *et al.* (2014), this might be considered the first publication of horticultural accuracy and sophisticated commercial applications aimed at open and closed rivers. Consequently, canopy fluctuations in terms of spectrophotometric characteristics and shape can be analyzed using a remote sensor; nevertheless, precise measurements are required to gather data on product quality. Geographic Information System (GIS)

It is a concept of precision farming. It is a computer database management system used to calculate, store, analyze and display location data in the form of a map. GIS is the key to extracting value from a variety of information. It is aptly named the brain for precision farming.

It facilitates the organization and compilation of simulation models and GIS data (crop, soil, climate, field history, etc.). The engineering component of creating GPS-enabled gadgets offers extra support. In order to facilitate the integration, storing, retrieval, and analysis of feature and location data for the purpose of creating maps, this application integrates computer hardware, software, and procedures. GIS connects data to a specific location so that it may be extracted when needed. Computer-based GIS maps, as opposed to traditional maps, use a wide range of data sources, such as yield, rainfall, vegetation, soil nutrient levels, insects, and soil mapping. Although GIS is a sort of computer-generated map, its true function is character and location analysis using local statistics and techniques.

Field topography, soil types, water and groundwater flow, soil tests, irrigation, rates of chemical use, and crop yields can all be found in the GIS farming database. After analysis, this data is used to comprehend how the different elements influencing a plant at a given location relate to one another. GIS can be used for more than just storing and displaying data; it can also be used to analyze management circumstances by integrating and altering data layers.

Global Positioning System (GPS)

Real-time data collection and accurate position data generation are made feasible by GPS. GPS is essential for determining the exact location in a field, measuring location volatility, and directing site utilization in inputs. With an accuracy of 100 to 0.01 meters, GPS is a satellite-based navigation system that assists users in recording location data (latitude, longitude, and altitude).

Field data, such as water holes, boundaries, barriers, insect activity, and soil type, can be precisely located by farmers using GPS. An antenna, receiver, and light or audio control panel (DGPS) make up an automatic control system. GPS satellites provide signals that enable location determination

by GPS receivers. Depending on prior operation techniques and application applications, farmers can utilize the system to examine field areas and apply inputs (seeds, fertilizers, pesticides, herbicides, and irrigation water) to each field.

RTK-GPS based vegetable transplanter

The development and successful use of a real-time Kinematic-Global Positioning System (RTK-GPS) installed on a tractor allows for the mapping of the geographic location of planting activities that take place on the tractor-drawn transplanter. The tractor and transplanter's mechanical hitch interface is instrumented via orientation sensors. Transplanter odometry data, planting events, GPS location, and sensor monitoring have all been recorded using a ruggedized, real-time, embedded control system. For upcoming centimeter-scale precision plant care chores, the technology can generate extremely accurate maps of agricultural plant locations.

Variable Rate Irrigation (VRI)

One crucial element of precision irrigation is thought to be site-specific or variable rate irrigation. The majority of researchers anticipate that water use will decrease on at least some fields, if not the total amount of water used on all fields (Sadler *et al.*, 2005). It has been demonstrated that variable rate irrigation (VRI) uses 10–15% less water than conventional irrigation techniques (Yule *et al.*, 2008). Hedley and Yule (2009) showed that spatially diversified irrigation applications can increase application efficiency and result in water savings of about 25%. The initial results from a study by Osroosh *et al.* (2016) reported that the utilization of wireless sensor networks, decision support and monitoring software, and weather and plant-based algorithms for autonomous irrigation management of drip-irrigated orchard trees were all supported by the comparison of irrigation automation algorithms for scheduling irrigation in apple trees. A network of scattered, small sensing devices known as sensor nodes or motes that collaborate to process and share data about physical phenomena via wireless channels is known as a wireless sensor network (WSN). WSN-based irrigation control systems that use real-time soil moisture data and remote access to in-field soil water conditions could be a way to optimize water management by managing irrigation systems on a site-specific basis (Kim and Evans, 2009; Hedley *et al.*, 2011).

To operate individual sprinklers on a precision irrigation system, the system must seamlessly integrate real-time soil moisture data via an ADSL or 3G cellular network. Peters and Evett (2007) assessed the extent of crop leaf warming, a symptom of water stress, on a fully automated

center-pivot irrigation system using infrared thermocouple thermometers mounted on the pivot's trusses. Although this canopy temperature method is a good way to see when water stress is starting, it can't tell you when a plant is getting close to moisture stress. If we are trying to eradicate the impact of water stress on yield reduction, it may be too late to irrigate when the plant is experiencing stress.

Precision mechanical weeder

Real-time weed control can also be achieved with robotic control systems. By cutting the stem of the weed and applying the chemical to the cut surface, the direct chemical application end effector applies the chemical directly through the vascular tissue of the plant. Two micro-pumps, a specially made circular saw with a DC motor, an applicator, a chemical tank, a flow controller, and a tiny reservoir make up the robotic system. Machines for inter-row weeding are widely available, while there are still relatively few for intra-row weeding. Both intra-row and inter-row weeds have an impact on crop quality and yield. Blades mounted on a pivoting arm comprised the intra-row weed control technology developed by Radis Mechanization (FR). For plant detection, a light sensor was employed. The weeding system's arm blade was managed by an air pressure cylinder. In order to cultivate and eradicate intra-row weeds, the pivoting arm was moved into the intra-row area when no plants were found.

According to Bakker (2003), weeds are eliminated up to 20 mm from the plant when the system is operated at a speed of 5 km/ hr. The maximum speed of 3.0 km/ hr is appropriate for weeding operations because the intra-row hoe's mechanical transition causes more plant damage (Bleeker, 2005). The system may operate with a minimum intra-row spacing of 220 mm and is intended for vegetables that are widely spaced (Bakker, 2009). Additionally, it was noted that stray foliage presents challenges because distance is determined by measuring the time it takes for an ultrasonic signal to reach and reflect back from the target; as a result, the reflected signal may come back from a weed instead of the crop.

Site Specific Nutrient Management (SSNM)

Site Specific Nutrient Management (SSNM) uses a variety of SSNM methods, including crop monitoring, GPS, GIS systems, remote sensing, and VRT, to supply plants with the nutrients they require to meet their immediate and local nutritional demands. Poor fertilization can reduce the output of horticulture plants, while over fertilizer might have negative environmental effects. Applying a fertilizer prescribed by a physician has made it feasible to control soil nutrient variations across the field since the introduction of SSNM. Another area in which SSNM might assist Indian farmers

is pressure control.

In India, the majority of the cultivated soil is acidic, and the pH varies greatly from place to place. Certain field applications of fertilizers and soil amendments can benefit from the use of remote sensing and GIS data integration to identify nutrient stress. By doing this, the fertilizer's effectiveness will rise and nutrient loss will decrease. Although SSNM in India is still in its infancy. It is particularly effective for valuable plants. Therefore, the adoption of innovative tactics to attain productive success depends on efficient communication between farmers, public and private enterprises. SSNM is a versatile composting idea that has been adjusted to the need for crop protection and the soil's capacity to satisfy different needs.

Volatile Biomarker Discovery: This makes it possible to identify plant diseases quickly. When detecting citrus illness, this approach has special advantages that can be quite beneficial. The ability of a few near- and far-range sensing techniques to detect citrus huanglongbing has been shown in numerous studies. Similarly, sensors from handheld or close-by devices have been tested with aerial photography on a few forums. A number of signs of chlorosis between leaves at different growth stages, varying degrees of infection, and resemblance to other illnesses (deficiency, chemical damage, etc.) present difficulties in diagnosing huanglongbing. Diagnostic accuracy was typically significantly higher when hand-held or under-controlled sensors were used than when aerial applications were used.

Drones in farm monitoring

Drones have revolutionized farming by increasing efficiency, generating extra revenue, and reducing costs. Drones may monitor plant health, increase spray accuracy, make a map of the area, and more. Large areas are swiftly explored using drones.

Potential of drones

Drones equipped with thermal, multispectral, or hyperspectral sensors can identify areas of the field that want improvement or are dry. Drones make it possible to calculate the crop index, which reveals the temperature signature and the quantity of heat-producing plants, after the crop has grown.

Drone types used in horticulture Possibilities for further drone use in the area. Purchasing drones entails accessing hazardous regions. With a crew of two operators and ten drones, they can effectively plant 400,000 plants every day.

Spraying drones: Comparable to planting robots that employ computer-camera-equipped smart sprayers to identify weeds used in targeted herbicides.

Picking drones: The purpose of one of the Agri Bots is to harvest strawberries. Agri Bot cuts fruit other than calyx and utilizes machine learning technologies to measure and

identify fruit maturity. In this manner, there is little chance of injury or scratches because the reaper never touches the fruit.

Drone pollination: Drone cooling technique is one of the most popular drone polishing technologies. Researchers in Japan and the Netherlands are developing tiny drones that can silence plants.

Harvesting drones: Another innovation is soft harvesting, in which fruit is protected during harvest by machines equipped with pressed grabbers or soft suction cups. The first vaccine harvest was constructed in 2016 by Abundant Robotics' developers. This counts the number of apples every second by using a computer idea to recognize them before sucking them through a soft tube.

Automated harvesting system

Since the early 1960s, a variety of techniques have been put

forth, researched, and used for fruit harvesting by machine. In order to liberate the fruits, mechanical harvesting techniques have been employed, including limb shaking, air blasting, canopy shaking, trunk shaking, and the application of an abscission chemical agent (Li *et al.*, 2011).

Mechanical harvesting technologies are unable to preserve the selection of size and quality. A vision control system, on the other hand, may choose the size and maintain quality. An alternative to mechanical harvesting systems is the automated harvesting system for horticultural crops (Schertz and Brown, 1968). Automated harvesting systems use machine vision control systems to recognize the fruits on trees. The vision control system uses a color camera to tell the control system where the fruits are and how far away they are (Li *et al.*, 2011). Due to their large initial investment, limited intelligence, and low efficiency, automated harvesting systems are not yet suitable for the commercialization stage (Zhao *et al.*, 2016). A lot of academics are trying to create effective horticultural crop harvesting robots.

Table 1. Harvesting robots for horticultural produce (Zhao *et al.*, 2016)

Products	Robots	Vision scheme	Success rate (%)	Speed /fruit
Fruits	Apple harvesting	Camera-in-hand and positioning sensor	77	15
	Citrus harvesting robot	A fixed camera and a camera-in-hand	NR	<8
	Melon harvesting robot	A far-vision CCD and a near-vision CCD	>85	>22
	Strawberry harvesting robot	A stereovision system and a central camera	<41.3	11.5
		A stereo camera, a camera and a laser sensor		7.0
			NR	
	Watermelon harvesting robot	A stereo vision sensor and a camera in hand A Stereo Vision sensor	100 66.7	12s NR
Vegetables	Kiwifruit harvesting robot	Eight cameras (four stereo vision systems)	NR	NR
	Grape harvesting robot	A camera-in-hand	NR	NR
	Cherry harvesting robot	A red and infrared laser active sensor	66.7	14
	Tomato harvesting robot	A binocular stereo vision sensor	70.0	3-5
	Cucumber harvesting robot	A fixed camera and a camera-in-hand	80.0	74.4
	Mushroom Harvesting robot	A near-infrared camera and a camera A mono-chrome camera in hand	45 >80	65.2 6.7
	Sweet-pepper harvesting robot	Two cameras, a stereo camera and a camera	79	NR

Canopy Sensors

These sensors are available from many leading manufacturers as additional options. In order to modify the spray volume appropriately, they employ infrared or ultrasonic technology to determine the canopy's existence, length, and density. Infrared sensors seem to be affordable and dependable. If

possible, the sensors should be connected to a tractor cab so that they can be used to apply flexible fertilizer.

Spectroscopy for Identification of Disease in Horticulture Crops

Using fluorescent imaging spectroscopy, Sindhuja *et al.* (2013) created and assessed a computer vision and machine learning method for classifying healthy and diseased leaves.

Normalized graphs were used to segment fluorescence images, and co-occurrence matrices were used to extract texture properties from the segmented images.

The support vector machine classifier uses the retrieved features as an input. Artificial intelligence and machine vision control systems were utilized in Florida to identify citrus diseases, identify early infections, and apply selective fungicides (Pydipati *et al.*, 2006). Plant characteristics are part of the indirect disease detection method. Stress based disease detection imaging techniques like hyper spectral and fluorescence imaging.

Opportunities for precision agriculture in arid horticulture

Increased productivity: By optimizing water, nutrient, and pest management practices, PA can significantly increase the productivity of fruit crops in arid regions. This can result in higher yields and better-quality produce, even under water-scarce conditions.

Sustainability: PA promotes the sustainable use of resources by minimizing waste, reducing chemical inputs, and promoting efficient water management. This can help conserve biodiversity, reduce carbon footprints, and ensure long-term viability of agriculture in arid regions.

Economic viability: With improved resource efficiency, farmers can reduce operational costs while maintaining or increasing output. Precision agriculture tools can also help farmers access better market opportunities by ensuring consistent quality and timely harvests.

Improved crop breeding: The data collected through precision agriculture technologies can support crop breeding programs by providing insights into plant performance under different environmental conditions. This can lead to the development of drought-resistant or salt-tolerant fruit varieties, which are vital in arid areas.

Policy and support programs: Governments and agricultural organizations in arid regions can support the adoption of precision agriculture by providing training, subsidies, or financial incentives. This would enable small-scale farmers to benefit from cutting-edge technology and improve their agricultural practices.

Conclusion

The technology and management of horticulture is a new and difficult area of agriculture. Precision agriculture holds vast potential for transforming fruit farming in arid regions. By leveraging technologies that optimize resource use, improve

crop health, and predict environmental challenges, farmers can enhance productivity, sustainability, and economic viability. While the adoption of PA tools may require initial investment and technical expertise, the long-term benefits make it a compelling option for farmers in arid areas looking to improve their agricultural practices. Although this assessment might stimulate more research on other horticultural plants using the automated yield mapping method, there aren't any standard technologies or processes for evaluating yield in vegetable and orchard production at the moment. Since the majority of fruit plants are perennials, fields must be temporarily stabilized in order to establish permanent blocks or tiny blocks. Further research is still necessary to fully understand the quality pattern's transient stability. Lastly, as horticulture crops is grown on small pieces of land in many parts of the world, it is necessary to develop small-scale technologies and procedures that are practical, affordable, and easy to use for small-scale farmers. The future of arid fruit crops lies in the integration of precision agriculture, where every drop of water and every resource counts toward maximizing yield and ensuring sustainability.

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Conflict of Interest

The authors have no conflict of interest.

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Studies on the role of honey bees pollination in pomegranate (*Punica granatum* L.)

Ashok R. Walunj and Mahesh Chavan

Department of Entomology, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra

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ABSTRACT

This study investigated the foraging activity of honey bees and other pollinators during the flowering period of pomegranate (*Punica granatum*). The highest foraging activity of honey bees was recorded under open conditions during the IV SMW, particularly between 12:00 to 14:00 hrs. Thirteen insect pollinator species were observed, with ants, butterflies, and beetles being the most abundant. Open pollination significantly outperformed other methods, including protected nylon net with bee cages, in promoting higher fruit set (65.60 fruits per plant), fruit length (81.16 mm), fruit diameter (78.09 mm), and fruit weight (280.40 g). Additionally, open pollinated plants showed the highest number of arils (601.40) and total soluble solids (16.92°Brix).

Introduction

Pomegranate (*Punica granatum* L.), a tropical and subtropical fruit from the Punicaceae family, with a long tradition. According to Soriano *et al.* (2011), it likely originated in Iran and northern India. Xhuvli (2012) reports that wild pomegranate plants are sometimes cultivated in gardens for their fruit or aesthetic value. According to reports, pomegranates are produced all over the world between latitudes 41° N and 42° S. India ranks first in area (2,57,000 ha), production (3097.72 MT) and productivity 12.01 MT/ha of pomegranate. Maharashtra state is leading state in country growing first in area 137.85(000) ha, production (1554.25 (000) MT and productivity 11.28 MT/ha (Anonymous, 2023) Maharashtra is major producer of pomegranate fruit. It has emerged as a significant export crop in India during the last decade (Chandra and Jadhav, 2008).

In north India, there are two blossoming seasons, whereas Nalawadi *et al.* (1973) reported three in western India. There are three distinct flowering seasons in subtropical central and western India: ambe bahar (January-February), mrig bahar (June-July), and hast bahar (September-October). Growers like ambe bahar because of its significant results due to abundant blossoming in comparison to other flowering seasons (Prasanna Kumar, 1998). Flowering was seen in Karnataka lasting 80-87 days between June and August (Nalawadi *et al.*, 1973). Only one flowering season occurred in Punjab, from April to June (Josani *et al.*, 1979).

Pollination is the most important factor in increasing crop productivity in which there will be transfer of pollen from male to female reproductive structure for effective fruit setting. Wind, water and animals including insects are involved in pollination of flowering plants. Insects specially honey bees play an important role in cross pollination. Both

Corresponding author

Email: jaigurdeo63@gmail.com (Dr. A.R. Walunj)

self and cross pollination noticed in pomegranate, however cross pollination is favoured for increased fruit yield. Hand pollination yielded a higher proportion of fruit set than pollination under natural circumstances (Josani *et al.*, 1979; Bavale, 1978).

Previous scientific research has shown that self pollination can also result in significant crop yields (Martinez *et al.*, 2009; Patil and Pastagia, 2016), despite some research suggesting that insect pollinators, such as honey bees, are beneficial in improving pomegranate crop yield and fruit quality (Vazifeshenas *et al.*, 2015). This raises concerns about whether pollinators are necessary for pomegranates or if self-pollination is adequate. However, there is currently very limited knowledge on pomegranate cross-pollination and its impact on pomegranate fruit, especially in Phule Bhagwa Super variety. The study hypothesizes that integrating honey bees will increase pomegranate fruit quality and quantity along with studies on different insect pollinators. Hence, the current research was conducted to comprehend the impacts of various pollination modes on pomegranate fruit, especially in the western dry zones.

Material and Methods

The present investigation was carried out during flowering time of pomegranate under All India Co-ordinated Research Project on Arid Zone Fruit at Mahatma Phule Krishi Vidyapeeth, Rahuri. A standard package of practices was followed in the cultivation and management of the crop. The study was conducted on pomegranate cultivar Phule Bhagwa Super comprising three different treatments viz., (T₁) Open pollination to all insect pollinators, (T₂) Protected covered insect cage house without honey bees, and (T₃) Protected covered insect cage house with honey bees (1 hives of *Trigona irridipenis*). The experiment was laid out in randomized block design with seven replications.

The foraging activity of honey bees and other insects were recorded on randomly selected five flowers of pomegranate from 08:00 hrs to 16:00 hrs at two hourly interval for five minutes at weekly interval and expressed as the mean number of foragers per 5 flowers per 5 minute. The data were recorded on diversity of insect pollinators, number of fruit set/ plant, fruit length, fruit diameter, fruit weight, number of arils/ fruit and total soluble solids. The collected data were analyzed statistically.

Results and Discussion

Insect foragers diversity on pomegranate

Thirteen species of insect pollinators were recorded foraging

during the flowering period of pomegranate (*Punica granatum*). The study on the diversity of insect pollinators in pomegranate, honey bees were found to be the most dominant pollinator as documented below in Table 1. The results were in confirmation with the observation recorded by Chavhan *et al.* (2023) who studied on floral visitors of pomegranate recorded in Bhagwa variety revealed 20 species of insects.

Table 1. Insect pollinator diversity on pomegranate flower

Order	Family	Species
Hymenoptera	Apidae	<i>Apis cerana indica</i>
		<i>Apis mellifera</i>
		<i>Apis dorsata</i>
		<i>Apis florea</i>
		<i>Trigona irridipenis</i>
Lepidoptera	Formicidae	<i>Camponotus spp.</i>
	Pieridae	<i>Phoebis sennae</i>
	Lycaenidae	<i>Strymon melinus</i>
	Nymphalidae	<i>Vanessa cardui</i>
	Papilionidae	<i>Papilio demolius</i>
		<i>Pachliopta aristolochiae</i>
Diptera	Muscidae	<i>Musa domestica</i>
Hemiptera	Pentatomidae	<i>Nezara viridula</i>

Foraging activity of honey bees and other pollinator under open condition in pomegranate

Foraging activity of honey bees were observed throughout the flowering period of pomegranate (Table 2) from I to VII SMW i.e. from first week February to fourth week of March, 2023. The mean foraging activity increased from I week to IV week (first week of February to fourth week of February) as availability of flower to honey bee increased for pollen and nectar collection and then decreased from V SMW. Highest mean foraging activity recorded in IV SMW with 2.58 mean number of honey bees / 5 flower / 5 minute as pomegranate tree were in full flowering stage.

The foraging activity of honey bees was recorded at two hour interval in a pomegranate flowers from morning (08:00 hrs) till to evening (16:00 hrs) once in a week till to fruit setting of pomegranate during the year 2023 and mean foraging activity was calculated. Higher bee visitation was observed at 12:00 to 14:00 hrs interval with 1.90 mean numbers of honey bees / 5 flower / 5 minute which was followed by at 10:00 to 12:00 hrs interval with 1.71 mean numbers of honey bees / 5 flower / 5 minute.

The data recorded on foraging activity of other pollinators on pomegranate (Table 3) revealed that the ants were found

large in number (1.29 ants/ 5 flower/ 5 minute) as compared to other pollinators and as compared with different time duration, maximum number of other pollinators visited during 10:12 hrs interval with (1.22 other pollinators/ 5 flower/ 5 minute) and on the other side the lowest number of other pollinators recorded at 14:16 hrs interval (0.20 other pollinators/ 5 flower/ 5 minute).

Foraging activity of honey bees (*Trigona irridipenis*) under caged condition in pomegranate

It is evident from Table 5 that the foraging activities of honey bees under caged conditions in pomegranate were observed from 08:00 hrs to 16:00 hrs at two-hour intervals. These observations were conducted weekly to monitor the bees' activity patterns. The mean foraging activity was observed maximum during IV SMW after 10 percent flowering with 1.92 mean numbers of honey bees/ 5 flower/ 5 minute. Thereafter gradually decreased from 0.50 mean numbers of honey bees/ 5 flower/ 5 minute in V and VI SMW, respectively. Similarly, the (*Trigona irridipenis*) started visiting the pomegranate plot early at 08:00 hrs and it gradually increased and peak activity was observed at 12:00 hrs to 14:00 hrs interval with an average of 1.61 mean numbers of honey bees/ 5 flower/ 5 minute thereafter, decreased gradually from 14:00 hrs.

Effect of different mode of pollinations on quantitative and qualitative parameters

Quantitative parameters such as number of fruit set per plant, fruit length, fruit diameter, fruit weight, number of arils per fruit, and total soluble solids (TSS) differed significantly among different modes of pollination in pomegranate (Table 6).

The number of fruit set per plant was found significantly highest (65.60 fruits per plant) in case of open pollination

treatment and found superior to remaining treatment. Whereas, lowest number of fruit set per plant (29.20 fruits per plant) recorded in caged house without honey bees. The present findings are in conformity with the observation of (Chavhan, 2023; Karimi and Mirdehghan, 2015; Wetzstein *et al.*, 2011)

The fruit length was recorded significantly highest in the open pollinated plants (81.16 mm) followed by covered caged house with honey bees pollinated plants (76.02 mm). However, covered caged house without honey bees treatment (65.76 mm) recorded lower fruit length.

The fruit diameter showed significant difference between the treatment. It was comparatively highest in case of open pollinated plants (78.09 mm) which was at par with covered caged house with honey bees pollinated plants (75.88 mm). The least fruit diameter was recorded in covered caged house without honey bees treatment (64.89 mm).

As regards the open pollinated plants recorded significantly highest fruit weight of (280.40 g). On the other side covered caged house plants (170.60 g) which registered the significantly least fruit weight. Significantly higher fruit set and fruits weight of pomegranate was reported in case of bee pollination, when compared to the self-pollinated plants i.e. not observed in closed condition. Therefore, these results are also found in agreement with the findings reported by Derin and Eti 2001 and Tao *et al.* 2010.

Significantly highest number of arils per fruit was recorded in case of open pollinated plants (601.40). However, covered caged house plants without honey bees recorded significantly lower number of arils per fruit (260.20).

The maximum total soluble solid (TSS) content of 16.92°Brix was observed in the open pollination plot. In contrast, plants grown in covered caged houses without honey bees showed a significantly lower number of arils per fruit, recording only 260.20 arils. TSS detects soluble solids in a liquid and impacts taste, making it an important produce quality indicator (Hadiwijaya *et al.*, 2020; Bexiga, 2017). Karkar and Ghetiya (2022) reported that TSS was found to be higher in the fruits of open-pollinated plants.

Table 2. Foraging activity of honey bees under open condition in pomegranate

Time	Number of honey bees/ 5 flower/ 5 minute				Total	Average
	08:10 hr	10:12 hr	12:14 hr	14:16 hr		
Week no. 1	0.66	0.66	0.33	0.00	1.65	0.41
Week no. 2	0.33	0.33	2.00	1.00	3.66	0.92
Week no. 3	0.66	2.33	2.66	3.33	8.98	2.25
Week no. 4	1.00	3.33	3.33	2.66	10.32	2.58
Week no. 5	2.00	3.36	3.33	1.33	10.02	2.51
Week no. 6	1.33	1.66	1.33	1.00	5.32	1.33
Week no. 7	0.00	0.33	0.33	0.00	0.66	0.17
Total	5.98	12.00	13.31	9.32		
Average	0.85	1.71	1.90	1.33		

Table 3. Quantitative and qualitative parameter of pomegranate

Treatment	Number of fruit set/ plant	Fruit length (mm)	Fruit diame- ter (mm)	Fruit weight (g)	Number of arils/ fruit	TSS (°Brix)
Open pollination (T_1)	65.60	81.16	78.09	280.40	601.40	16.92
Caged house without hon- ey bees (T_2)	29.20	65.76	64.89	170.60	260.20	15.38
Caged house with honey bees (T_3)	52.20	76.02	75.88	258.20	560.40	15.82
SEm±	0.99	1.15	0.99	2.08	1.99	0.33
CD at 5%	3.05	3.55	3.07	6.42	6.14	1.02

Table 4. Foraging activity of other pollinators on pomegranate under open condition

Time	Number of other pollinators/ 5 flowers/ 5 minute				Total	Average
	House fly	Beetle	Butterfly	Ants		
08:10 hr	0.52	0.22	0.78	0.66	2.18	0.54
10:12 hr	1.32	0.66	0.58	2.33	4.89	1.22
12:14 hr	0.92	0.52	0.33	1.66	3.43	0.85
14:16 hr	0.30	0.00	0.00	0.52	0.82	0.20
Total	3.06	1.4	1.69	5.17		
Average	0.76	0.35	0.42	1.29		

Table 5. Foraging activity of honey bees (*Trigona irridipenis*) under caged condition in pomegranate

Time	Number of honey bees/ 5 flower/ 5 minute				Total	Average
	08:10 hr	10:12 hr	12:14 hr	14:16 hr		
Week no. 1	0.33	0.33	2.33	1.33	4.32	1.08
Week no. 2	0.33	1.33	2.33	1.66	5.65	1.41
Week no. 3	1.33	2.66	2.00	1.33	7.32	1.83
Week no. 4	2.00	3.33	1.33	1.00	7.66	1.92
Week no. 5	0.33	1.00	0.66	0.00	1.99	0.50
Week no. 6	0.33	1.00	0.66	0.00	1.99	0.50
Total	4.65	9.65	9.31	5.32		
Average	0.78	1.61	1.55	0.89		

Table 6. Quantitative and qualitative parameter of pomegranate

Treatment	Number of fruit set/ plant	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	Number of arils/ fruit	TSS (°Brix)
Open pollination (T_1)	65.60	81.16	78.09	280.40	601.40	16.92
Caged house without honey bees (T_2)	29.20	65.76	64.89	170.60	260.20	15.38
Caged house with honey bees (T_3)	52.20	76.02	75.88	258.20	560.40	15.82
SEm±	0.99	1.15	0.99	2.08	1.99	0.33
CD at 5%	3.05	3.55	3.07	6.42	6.14	1.02



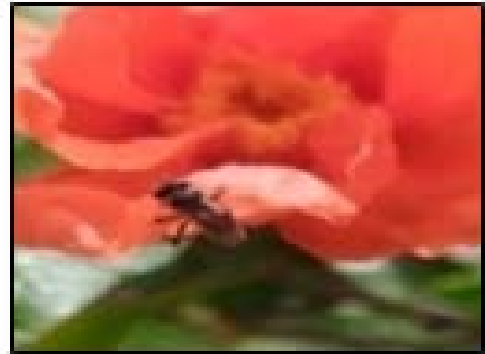
Apis mellifera



Apis dorsata



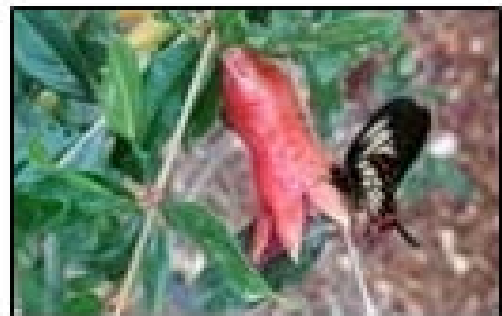
Apis cerana indica



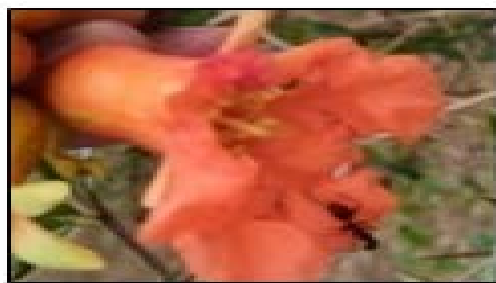
Trigona irridipennis



Apis florea



Pachliopta aristolochiae



Camponotus spp.

Conclusion

In conclusion, a total of 13 species of insect pollinators were observed during the flowering period of pomegranate, with honey bees being the most dominant pollinators. Peak

foraging activity of honey bees occurred during the IV SMW, with the highest foraging activity observed between 12:00 to 14:00 hrs under open conditions and 10:00 to 12:00 hrs in caged conditions. Ants were also found to be significant

in number. Open pollination, followed by protected nylon net with bee cages, proved to be the most effective for maximizing both quantitative and qualitative characteristics of pomegranate, such as fruit set, size, weight, and TSS.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Screening of watermelon genotypes for tolerance against mosaic disease in Western Rajasthan

S. K. Maheshwari, B. R. Choudhary, Hanuman Ram and D. Singh

ICAR-Central Institute for Arid Horticulture, Bikaner- 334 006 (Rajasthan)

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ABSTRACT

Mosaic disease, caused by the cucumber mosaic virus, is a significant threat to watermelon production in the arid and semi-arid regions of India. Screened 13 watermelon genotypes for tolerance to mosaic disease under open field conditions during the summer season of 2021 ICAR-Central Institute for Arid Horticulture, Bikaner. Among the 13 watermelon genotypes, none was found to be immune or highly resistant to mosaic disease. However, seven genotypes-AHW/BR-1, AHW/BR-13, AHW/BR-16, AHW/BR-37, AHW/BR-5, AHW/BR-7, and AHW/BR-11 were classified as moderately resistant, with disease indices (PDI) ranging from 12.36% to 21.38%.

Introduction

Watermelon [*Citrullus lanatus* (Thunb) Mansf.] is one of the most popular desert fruit grown all over world. In India, it is grown, mostly as riverbed side crop, in Uttar Pradesh, Rajasthan, Gujarat, Maharastra, Punjab and Haryana. China is the leading country in production of watermelon followed by Turkey, United States and Iran (Huh *et al.*, 2008). It is an excellent source of vitamin A and C and one cup of watermelon juice contain approximately 48.59 mg of vitamin C and 556.32 IU of vitamin A besides 48 calorie of energy. The fruit contains 92% water, 0.2% protein, 03% minerals and 7.0% carbohydrates (Thamburaj and Singh, 2000). It has sufficient variation in productivity and quality and is able to withstand damage from biotic and abiotic factors and caused great economic losses (Wehner *et al.*, 2001). The low productivity of watermelon is mainly due to many diseases incited by viruses, fungi, bacteria, nematodes and phytoplasma. A large number of viruses have been reported from time to time to infect this crop *viz.*, watermelon mosaic

virus-1, watermelon mosaic virus-2, cucumber mosaic virus, watermelon chlorotic stunt virus, watermelon bud necrosis virus and watermelon curly mottle virus, which induced mild to severe mosaic, yellowing, chlorosis, necrosis, puckering, distortion, mottling, reduction of leaf size, development of vein clearing and stunting of the plants.

Systemic symptoms consist of downward leaf curling or rolling and mosaic. Severely infected plants did not bear flowers and could not produce fruits. In a very few cases, if flowers appeared, very small sized distorted fruits were produced. Mosaic disease caused by cucumber mosaic virus has become potential threat to the cultivation of watermelon. Cucumber mosaic virus (CMV) is the most destructive and economically important plant virus which drastically affects the crop quality and yield of the cucumber plants (Scholthof *et al.*, 2011). The first mosaic disease in cucurbits was caused by cucumber mosaic virus (Doolittle, 1916). Cucumber mosaic virus (CMV) has wider host range of 1200 different plant species and transmitted by 60 different species of aphids (Lecoq and Desbiez, 2012). Field screening is one of

Corresponding author

Email: maheshwariskciah@gmail.com (Dr. S.K. Maheshwari)

the best method of integrated disease management against this disease. The cheapest and economical control of this disease can be achieved by resistant genetic stock. Keeping in view, this important component of integrated disease management, efforts were made to screen watermelon genotypes against mosaic disease and to identify tolerant genotypes in Western Rajasthan.

Material and Methods

Thirteen watermelon genotypes *viz.*, AHW/BR-1, AHW/BR-5, AHW/BR-7, AHW/BR-11, AHW/BR-13, AHW/BR-14, AHW/BR-16, AHW/BR-17, AHW/BR-25, AHW/BR-28, AHW/BR-30, AHW/BR-31 and AHW/BR-37 were tested against mosaic disease at Vegetable Block of ICAR-Central Institute for Arid Horticulture, Bikaner with normal cultivation practices under field conditions. Seeds of 13 genotypes were sown in Randomized Block Design with a spacing of 50 cm x 100 cm in three replications during summer season of 2021. No plant protection measures were sprayed in the present study. Susceptible genotype 'AHW/BR-14' was sown after each five rows of the test genotypes as check. It was also grown around the border of the field to serve as infector rows. Data on disease severity of mosaic symptoms were recorded during growth period of the crop. The reactions for tolerance due to mosaic disease in watermelon were categorized by using 0-4 disease rating scale (Singh *et al.*, 2007): immune (0) = 0% symptoms, resistant (1) = 0.1 to 10.0% leaf area infected, moderately resistant (2) = 10.1 to 25.0% leaf area infected, susceptible (3) = 25.1 to 50.0% and highly susceptible (4) = > 50.0% leaf area infected. The percent disease index (PDI) was calculated a formula suggested by McKinney, 1923.

Results and Discussion

Data presented in Table 1 indicated that variation in percent disease index (PDI) of mosaic disease was found in all the genotypes of watermelon crop. Among 13 genotypes of watermelon, range of average percent disease index (PDI) of mosaic disease caused by cucumber mosaic virus was 12.36 to 30.24%. Minimum disease index (12.36%) was recorded in genotype AHW/BR-5, followed by AHW/BR-37 (14.29% disease index) which were not statistically at par with each other. Maximum disease incidence (30.24% PDI) was recorded in genotype 'AHW/BR-14', followed by AHW/BR-30 (28.72%) which were also not statistically at par with each other.

The results presented in Table 2 reveal that out of 13 watermelon genotypes, none was found immune and tolerant against mosaic disease. Seven genotypes (AHMM/BR-5,

AHMM/BR-37, AHMM/BR-7, AHMM/BR-1, AHMM/BR-13, AHMM/BR-11 and AHMM/BR-16) were categorized as moderately resistant and 06 genotypes *viz.*, AHW/BR-31, AHW/BR-28, AHW/BR-17, AHW/BR-25, AHW/BR-30 and AHW/BR-14 were found as susceptible. Cucumber mosaic virus (CMV) poses a significant threat to various cucurbits, including watermelon and cucumber, causing substantial yield losses. Identifying and utilizing host resistance is widely regarded as the most effective strategy for managing this virus and mitigating its impact on crop production. In a similar study by Sugiyama *et al.* (2006) screened 152 melon accessions for resistance to Cucumber green mottle mosaic virus (CGMMV) and identified only *Chang Bougi* (*Cucumis melo* var. *makuwa*) as resistant. In contrast, Sharma *et al.* (2011) reported that none of the 20 watermelon varieties tested were resistant or immune to natural viral infections. While only two varieties *i.e.* Arka Jyoti and MHW-6 were found moderately resistant against viruses and 05 varieties *viz.*, Nath-102, Nath-202, Special Number-1, NS-246 and NS-295 were rated as moderately susceptible. Crespo *et al.* (2018) evaluated germplasm of *C. sativus*, *C. anguria* as well as *C. metuliferus* using CGMMV. Only two *C. sativus* accessions showed mild symptoms while rest had severe infections. Guner *et al.*, (2019) found resistant germplasm *viz.*, PI 595203, PI 386016, PI 386024, PI 386026, PI 244018, PI 244019, PI 485583, PI 494528, and PI 494529 against Zucchini yellow mosaic virus in the watermelon.

Table 1. Screening of watermelon genotypes for tolerance against mosaic disease

S. No.	Name of genotypes	PDI	Disease reaction
1	AHW/BR-1	17.82 (24.42)*	Moderately Resistant
2	AHW/BR-5	12.36 (20.54)	Moderately Resistant
3	AHW/BR-7	16.67 (24.02)	Moderately Resistant
4	AHW/BR-11	20.53 (26.83)	Moderately Resistant
5	AHW/BR-13	20.34 (26.72)	Moderately Resistant
6	AHW/BR-14	30.24 (33.22)	Susceptible
7	AHW/BR-16	21.38 (25.28)	Moderately Resistant
8	AHW/BR-17	26.73 (31.09)	Susceptible
9	AHW/BR-25	27.22 (31.66)	Susceptible
10	AHW/BR-28	25.57 (30.10)	Susceptible
11	AHW/BR-30	28.72 (32.18)	Susceptible
12	AHW/BR-31	25.36 (30.17)	Susceptible
13	AHW/BR-37	14.29 (22.11)	Moderately Resistant
		CD (5%) = 7.703	
		CV = 16.485	

*Figures in parenthesis are angular transformed value

Table 2. Disease reaction of different watermelon genotypes against mosaic disease

Disease reaction	Genotypes
Immune (I) (0.0%)	Nil
Resistant (R) (0.1 to 10%)	Nil
Moderately resistant (MR) (10.1 to 25%)	AHMM/BR-5, AHMM/BR-37, AHMM/BR-7, AHMM/BR-1, AHMM/BR-13, AHMM/BR-11 and AHMM/BR-16
Susceptible (S) (25.1 to 50%)	AHW/BR-31, AHW/BR-28, AHW/ BR-17, AHW/BR-25, AHW/BR-30 and AHW/BR-14
Highly susceptible (HS) (> 50%)	Nil

Conclusion

The study demonstrated that watermelon genotypes in Western Rajasthan exhibited low mosaic disease severity due to dry atmospheric conditions and erratic rainfall, which limited disease development. However, this disease has the potential to become a significant threat to watermelon cultivation if not addressed in a timely manner. It is concluded that moderately resistant watermelon genotypes, such as AHW/BR-5, AHW/BR-37, AHW/BR-7, AHW/BR-1, AHW/BR-13, AHW/BR-11, and AHW/BR-16, are effective in combating mosaic disease.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Influence of rhizosphere soil from various tree species on soil characteristics of jackfruit (*Artocarpus heterophyllus* L.) cv. Chandra

Sonali Gahlot¹, Jitendra Singh¹, Prerak Bhatnagar¹, Kavita Aravindakshan², Ashok Kumar³, S.K. Jat⁴ and Sunil Kumar Bairwa¹

¹Deptt. of Fruit Science, ²Deptt. of Vegetable Science, ³Deptt. of Basic Science, ⁴Deptt. of Entomology, College of Horticulture and Forestry, Jhalrapatan, Jhalawar-326 023 (AU, Kota), Rajasthan, India

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ABSTRACT

A field experiment was conducted during the year 2023-24 on Chandra variety of jackfruit, at the Instructional Farm, Department of Fruit Science, College of Horticulture and Forestry, Jhalawar. The result indicated that the application of treatment T₁ (soil under banyan tree canopy) was the most effective in increasing the soil porosity (47.84%) and it reduced the soil pH (7.14), electrical conductivity (0.22 dS m⁻¹), bulk density (1.13 g cm⁻³) and particle density (2.32 g cm⁻³). Thus, the T₁ (soil under banyan tree canopy) treatment significantly improved all soil parameters in orchard of jackfruit.

Introduction

The Jackfruit (*Artocarpus heterophyllus* L.) is well-known as “poor man’s food” fruit in Bangladesh. It is widely consumed by most of the rural people, and it is the national fruit of Bangladesh. Jackfruit contains anti-bacterial, anti-diabetic, anti-oxidant, anti-inflammatory, and anti-helminthic properties. Leaves are dark green, alternate, entire, simple, glossy, leathery, stiff, large (up to 16 cm in length), and elliptic to oval in form. Leaves are often deeply lobed when juvenile and on young shoots. The seed is rich in manganese, magnesium, potassium, calcium, iron, and lectins and thus meets up nutritional requirements for the rural people. (Khan *et al.*, 2021). Jackfruit is a medium-size, evergreen tree that typically attains a height of 8-25 m (26-82 ft) and a stem diameter of 30-80 cm (12-32 in). The canopy shape is usually conical or pyramidal in young trees and becomes spreading and domed in older trees. The canopy diameter at 5 years old ranges from 3.5-6.7 m (11-22 ft) and can reach

10 m or more in older trees. The tree casts a very dense shade. Heavy side branching usually begins near the ground. All parts of the tree exude sticky white latex when injured (Elevitch and Manner, 2006). The total area in India under jackfruit cultivation is 1.85 lakh hectares and production is 31.99 lakh metric tonnes (Anonymous, 2023-24). The major area under jackfruit is in the Kerala state. Recently Kerala declared jackfruit as the state fruit.

Research highlights that exudates persisting in the rhizosphere vary according to the stage of plant growth. High available water and mineral nutrients in the soil under tree canopy are favourable sites for numbers of microorganisms than elsewhere in the soil. The constitution and form of root exudates influence microbial action and population intensity which, might impact rest of microorganisms that survive in the environment. It has been found that soil of rhizosphere is considerably better than bulk soil, which protects roots from moisture loss and drying out. The canopy characteristics of trees directly or indirectly, affect the soil fertility (Hinsinger

et al., 2009). Now-a-days, the soil physico-chemical and bio-properties are observed to deteriorate due to higher use of inorganic fertilizer in the plant and ultimately poor effect on plant growth and development are observed. Rhizosphere soil has been reported useful in improving the soil microorganism for plants and subsequently growth and development. Hence, it is proposed to evaluate its impact on the growth and development of jackfruit.

Material and Methods

Jhalawar district is situated between 23°4" to 24°52" N latitude and 75°2" to 76°56" E longitude in South Eastern Rajasthan. Agro-climatically, it falls in Zone V, known as the Humid-South Eastern Plain.

The present investigation was carried out during the year 2022-23 to 2023-24 at the Instructional Farm, Department of Fruit Science, College of Horticulture and Forestry, Jhalrapatan, Jhalawar, in the newly established orchard of 1.5 year old Jackfruit (*Artocarpus heterophyllus* L.) cv. Chandra plants. The experiment consisted of 8 treatments, viz. T₀ (control), T₁ (soil under banyan tree canopy), T₂ (soil under palash tree canopy), T₃ (soil under babul tree canopy), T₄ (soil under jamun tree canopy), T₅ (soil under tamarind tree canopy), T₆ (soil under neem tree canopy), and T₇ (soil under mandarin tree canopy). The experiment was laid out in Randomized Block Design with three replications. A plantation of twenty four plants spaced at a distance of 8m x 8m under square system was selected for the purpose of study. Different tree species Rhizosphere soil samples were collected from the area of highest feeder root concentration (1-1.5 meters distance from the trunk) from a soil depth of 0-20 cm. A total of fifteen kilograms of soil from each identified tree species was collected during March, 2023. The rhizosphere soil was applied to the plants in the month of March (2023) at the start of the experiment. The treatments were administered in the root zone of the plants. These treatments were applied after recording the initial parameters of the plants, just before the treatment application.

Soil pH was determined by using 1:2 soil water suspensions by glass electrode pH meter. Soil water suspension of 1:2 was prepared by taking 20g of soil and 40ml distilled water in 100 ml beaker. Electrical conductivity of soil water suspensions (1:2.5) was measured using EC meter (Model Elico CL 180) as elaborated by Jackson (1973). These EC 2.5 values were converted later to saturation paste value (EC).

Bulk density of soil of 0-30 cm depth was determined. The core sampler was pressed in the soil for enough depth to fill the core. Carefully removed the sampler and trimmed the soil extending out of the core with a sharp knife. Soil was oven dried at 105 °C to a constant weight, cooled and weighed. Soil volume was taken equal to inner volume of core sampler. Bulk density was calculated using the following formula and

expressed as g cm⁻³ suggested by Piper (1950).

$$\text{Bulk density} = \frac{\text{Mass of oven dry soil}}{\text{Total volume of soil}}$$

To calculate soil particle density, the mass and the volume of the solid particles in a soil sample was measured. For this purpose, soil sample was put in a flask with distilled water. The soil and water were mixed and then boiled to remove all air from the sample. After the mixture was cooled, water was added to the mixture to obtain a specified volume. The mass of this mixture was then measured. The mass of the water was then subtracted from the mass of the soil and water. The particle density was calculated from the mass of the solid particles in a specified volume

$$\text{Particle density} = \frac{\text{Mass of soil}}{\text{volume of soil solid}}$$

The porosity was calculated at the end of experiment as per the formula as under:

$$\text{Porosity (\%)} = 1 - \frac{\text{Bulk density}}{\text{Particle density}} \times 100$$

Results and Discussion

In present study, all recorded parameters for soil nutrient status (Table 1 and Fig. 1) were found significantly influenced by rhizosphere soil. Data linked to the effect of rhizosphere soil on soil parameters like soil pH (7.14), EC (0.22 dS m⁻¹), bulk density (1.13 g cm⁻³), particle density (2.32 g cm⁻³), and porosity (47.84%) were observed comparatively better in treatment T₁ (soil under banyan tree canopy).

Banyan tree roots release organic acids (like citric acid, malic acid, and oxalic acid) into the soil sphere. These compounds can lower the soil pH by increasing the hydrogenion concentration. The organic acids and other compounds released by the roots provide a substrate for soil microorganisms. The increased microbial activity can lead to the production of additional organic acids and the faster decomposition of organic matter. All these effect of rhizosphere soil of banyan tree might be there behind lowering the soil pH. The increased microbial activity and the breakdown of organic matter in the rhizosphere can lead to the leaching of salts from the root zone, reducing the overall concentration of soluble salts and thereby decreasing the EC (Solanki *et al.*, 2020 and De Castro *et al.*, 2024).

Higher amount of organic mass under the influence of rhizosphere soil of banyan tree might have a substantial effect on increasing its pore space, which in turn might improve its porosity, reduce bulk density and also particle density. It may be further added that banyan rhizosphere soil holds nitrogen fixing (*Rhizobium* and *Azotobacter*), phosphorus (*Pseudomonas* and *Bacillus* spp.) and potash solubilizing bacteria (*Enterobacter* spp. and *Acinetobacter* spp.) which fix

the nutrients and increase the macro-nutrients particularly N, P and K in soil. Plant residues (leaves, fruits and roots etc.) form food of microbes. Treatment T1 (soil under banyan tree canopy) had a high portion of organic carbon in the soil that's why there might be maximum number of bacteria and fungi population in the soil. The observation of current experiment corroborates with the study as reported by Potphode *et al.* (2018) and Shlipkar *et al.* (2009).

Table 1. Effect of different tree species rhizosphere on soil parameters of jackfruit

Treatments	pH	Electric conductivity (dS m ⁻¹)	Bulk density (g cm ⁻³)	Particle density (g cm ⁻³)
Initial value	7.59	0.40	1.33	2.44
T ₀	7.59	0.40	1.38	2.47
T ₁	7.14	0.22	1.13	2.32
T ₂	7.30	0.32	1.20	2.35
T ₃	7.36	0.33	1.24	2.37
T ₄	7.42	0.35	1.30	2.40
T ₅	7.38	0.31	1.27	2.38
T ₆	7.25	0.27	1.18	2.34
T ₇	7.20	0.26	1.17	2.33
SEm±	0.01	0.01	0.01	0.01
CD at 5%	0.04	0.03	0.03	0.02

According to Khan *et al.* (2024) the decrease in electrical conductivity (EC), pH, bulk density, and particle density, along with the increase in porosity of jackfruit soil when influenced by banyan (*Ficus benghalensis*) rhizosphere soil can be explained through a combination of biological, chemical, and physical processes. The rich microbial activity within the banyan rhizosphere also contributes to changes in soil characteristics. Microorganisms break down organic matter, producing additional organic acids and releasing nutrients that plants can absorb. This microbial decomposition reduces soil EC by consuming soluble salts during various metabolic processes. Moreover, the microbial activity contributes to nutrient cycling; enhancing soil fertility while simultaneously reducing the concentration of free ions, which further decreases EC. As these microbes interact with the soil, they contribute to aggregate formation, improving soil structure and reducing compaction Pande and Tarafdar (2004).

Cheke *et al.* (2018) analysed that physically, the banyan tree's vast and deep root system exerts a significant impact on the

soil's structure. As the roots grow and expand, they create channels and break apart compacted soil layers, reducing bulk density and particle density. Bulk density decreases because of the presence of organic matter and root channels might lighten the soil mass per unit volume. This allows for better root penetration, water infiltration, and gas exchange, all of which improve soil health. The reduction in particle density occurs as organic matter, which is less dense than mineral particles, accumulates in the soil. The increase in organic matter and root penetration leads to greater soil porosity, which is the proportion of soil volume occupied by air and water spaces.

Furthermore, the banyan rhizosphere holds the ability to enhance soil aggregation through the secretion of polysaccharides by both roots and soil microorganisms. These substances bind soil particles together into stable aggregates, increasing porosity and improving water-holding capacity. Higher porosity also supports better microbial activity and root respiration, fostering a healthier soil ecosystem overall. This might improved structure and reduced soil compaction, making it easier for plant roots to access water and nutrients (Ghagare *et al.*, 2017).

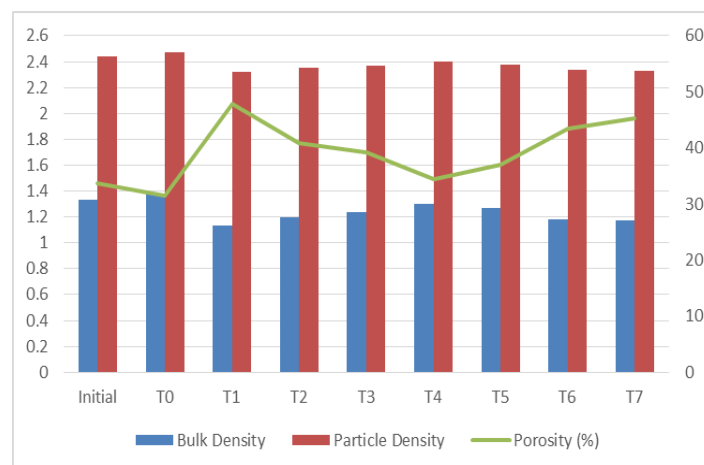


Fig.1. Effect of rhizosphere soil on bulk density, particle density and porosity of jackfruit orchard

Conclusion

The significant influence of *Ficus benghalensis* (banyan tree) rhizosphere soil on *Artocarpus heterophyllus* (jackfruit) soil characteristics is highlighted in the present research. The study found that using soil from the rhizosphere of the banyan tree significantly improved the soil properties of jackfruit plants. Applying soil under banyan tree canopy (T₁) led to increased porosity and notable reductions in soil pH, electrical conductivity, bulk density, and particle density. This treatment proved to be more effective than other rhizosphere soils and the control.

In conclusion, the banyan tree's rhizosphere soil enhances soil fertility and microbial diversity, which can significantly benefit the growth and resilience of jackfruit plants, making it a promising factor in integrated agroforestry systems.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

Reference

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Microbudding in mandarin (*Citrus reticulata* Blanco) as influenced by rootstocks, their age and growing media

Bharti Choudhary¹ and Rahul Dongre²

¹Senior Technical Officer (Hort.), AICRP on Arid Zone Fruits, Deptt. of Horticulture, JNKVV, Jabalpur, M.P., India

²Asstt. Prof. (Hort.), Deptt. of Forestry, JNKVV, Jabalpur, M.P., India

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ABSTRACT

This study evaluates the influence of rootstock type, age and growing media on the success of microbudding in Mandarin (*Citrus reticulata* Blanco). The results indicated that Rough Lemon rootstock at six months of age grown in Cocopeat + Vermicompost (1:1) ($R_1G_4A_3$) exhibited the highest microbudding success (79.12%), fastest sprouting (12.98 days), and superior growth parameters, including seedling height (21.35 cm), stock diameter (3.59 mm), and leaf area index (1.17). Additionally, five-month-old Rough Lemon seedlings ($R_1G_4A_2$) achieved the highest survival percentage (95.84%), confirming its viability as an alternative treatment. The findings suggest that Cocopeat + Vermicompost (1:1) is an ideal growing medium for maximizing microbudding success and seedling vigor, making it a promising strategy for commercial Mandarin propagation.

Introduction

Citrus is the third most important fruit crop in India after mango and banana, cultivated across tropical and subtropical regions. It belongs to the Rutaceae family and is grown in over 100 countries worldwide (Choudhary *et al.*, 2023). Rough lemon (*Citrus jambhiri*) and Rangpur lime (*Citrus limonia* Osbeck) is the most favourable rootstock for mandarin. Rough lemon is a cold-hardy citrus and commonly known as Jamberi is widely used rootstocks for propagating mandarin in Central India and it is quicker growing rootstock as compared to other rootstocks as well as having better success rate. Rangpur is a cross of *Citrus reticulata* × *medica* and it is the most utilized rootstock for its specific qualities i.e. due to its heavy and early bearing, and drought resistance.

A good quality growing media plays an important role for

obtaining luxuriant vegetative growth in various fruit crops and successful propagation of fruit crops in nurseries. The success of plant propagation depends largely on the quality of the growing media used (Choudhary *et al.*, 2023). Vermicompost, Azatobactor, Cocopeat, etc. are commonly used as growing media and soil amendments. Vermicompost is a product of a non-thermophilic bio-degradation of organic materials through interactions between earthworms and microorganisms. Cocopeat is an excellent organic component for container growing media and it has high water-holding capacity; excellent drainage; absence of weeds and pathogens; slow decomposition; easy wettability; and acceptable levels of pH, high cation exchange capacity, and electrical conductivity. Cocopeat contains natural *Trichoderma* which acts as a Bioagent against harmful pathogens. It provides a great environment for beneficial fungi and bacteria to grow. Better root growth results in

Corresponding author

Email: dongre.jnau@gmail.com (Dr. Rahul Dongre)

better plant growth.

Mandarins are easily peelable fruits and segments are conveniently consumed by hands. Among the mandarins, 'Nagpuri' or 'Nagpur' mandarin is cherished for its unique thirst quenching sweet and sour taste. Due to this uniqueness, it is considered as one district one product of Chhindwara district by the government of Madhya Pradesh. Vidarbha region of Maharashtra and adjoining parts of Madhya Pradesh and Rajasthan (Jhalawar district) have more or less similar agro-climatic conditions and hence cultivation of this mandarin cultivar is blooming and expanding in these areas (Ladaniya, 2021).

Microbudding is a novel propagation technique and standardized in *Citrus* spp. This propagation method produces the infant citrus trees, which could revolutionize the commercial citrus propagation industry by saving grower's time, space and money (Choudhary *et al.*, 2020). This technique was first developed by Skaria and Zhang. Microbudding is a grafting technique used in the development of citrus trees. Microbudding is done at a younger age, and because of apical hormonal dominance. Microbudding technique was standardized in *Citrus reticulata* Blanco cv. Nagpur mandarin which is also applicable for other *Citrus* species for fast and round the year multiplication of disease free planting material and also commercial citrus propagation for getting the marketable budded plants earlier with reduced cost (Vijayakumari and Singh, 2003). In the view of above facts the present study the effect of rootstocks age and growing media for success of microbudding in Mandarin (*Citrus reticulata* Blanco) on different root stock was carried out.

Material and Methods

Experimental site

The experiment was carried out at JNKVV, Zonal Agricultural Research Station, Chandangaon, Chhindwara (M.P.) in 2021-22. It is situated at 22°3'26.77" North (latitude) and 78°56'17.42" East (longitude) at an altitude of 675 m above the mean sea level.

Technical programme of the work

The experiment was laid out in an Asymmetric Factorial Completely Randomized Block Design with three replications. The study included three factors viz., Rootstock: (R₁: Rough Lemon and R₂: Rangpur Lime), Growing Media: (G₁: Soil + Vermicompost in 1:1 ratio), G₂: Soil + Azotobacter in 1:1 ratio, G₃: Soil + Vermicompost + Azotobacter in 1:1:1 ratio and G₄: Cocopeat + Vermicompost in 1:1 ratio) and Age of Rootstock: (A₁: 4 months, A₂: 5 months and A₃: 6 months). This design resulted in 24 treatment combinations. For

microbudding, bud sticks were taken from Nagpur Santra (Mandarin) - an important variety grown in the Madhya Pradesh region.

Preparation of rootstock seedlings

The 2 month (60 days) old seedlings were transplanted in poly bags (20 cm x 30 cm). Carefully uprooted the Rough lemon and Rangpur lime seedlings from tray after that roots were washed under running tap water and treated with fungicide (0.2 % Bavistin) solution for 5 minutes before transferring to poly bags. These seedlings were transplanted in polybag filled with different growing media as per treatment. 15 seedlings were transplanted in polybags, which contained different growing media as per the treatments. The recommended intercultural operations like hoeing, fertilizer application, foliar spray of urea, irrigation and spraying of pesticide were applied to raise vigorous and healthy rootstock seedlings.

Planting material for microbudding

For microbudding two different rootstocks (Rough lemon and rangpur lime) were transplanted in various growing media. Bud sticks of Mandarin cv. Nagpur Santra were taken in microbudding. Healthy and elite mother trees with sufficient new flush of Mandarin cv. Nagpur Santra were selected in the mother block of Zonal Agricultural Research Station, Chhindwara and the trees were tagged for collection of bud. The terminal shoots of current season growth with 15-20 cm length and nodal buds having pencil thickness were selected. Pre-curing such as removal of leaves was done with sterilized secateurs on the same day of microbudding. The scion shoots were collected from mother trees early in the morning on the day of budding. Immediately after separation of scions from mother trees, they were wrapped in moist cloth and carried in polythene cover to the site of budding.

Procedure of microbudding

The leaf petiole is cut off just above the bud, and the bud is removed from the bud stick with a razor-sharp knife. A flat cut is made just underneath the bud. Only the bud and a small piece of wood under it are used. Selected rootstock seedling is beheaded leaving 15-20 cm. On beheaded portion a wedge-shaped cut (2-2.5 cm) is given downward with a sharp knife and tender scion bud (3-4 mm width and 1 to 1.5 cm length) inserted on the de topped root stock in a wedge cut and immediately protected by covering with a micropipette tip to achieve close physical contact between scion and stock tissues was placed with slight pressure over top of bud union. After a week, microbuds are observed -and then micro tips are removed after their sprouting within

12-14 days. The plant growths of mandarin buddings were periodically assessed at monthly intervals up to 90 days after microbudding (DAM).

Observations recorded

Physiological parameters regarding growth were recorded i.e. seedling height (cm), stem diameter (mm), fresh weight of shoots (g), dry weight of shoots (g), fresh weight of roots (g), dry weight of roots (g), survival of seedlings (%) and leaf area index at the time of microbudding. Budding parameters observations was recorded i.e. days taken to first sprout, Microbudding success (%), length of micro budded sprout (cm), number of leaves/ plant and stock diameter (mm) at 90 days after microbudding. The data collected during the investigation were analyzed statistically by the method of analysis of variance. The significance of various treatments was judged as suggested by Fisher (1937) applying 'F' test.

Results and Discussion

The highest seedling height (21.35 cm), stem diameter (3.59 mm), fresh shoot weight (2.25 g), dry shoot weight (0.79 g), and leaf area index (1.17) were recorded in six-month-old Rough Lemon rootstocks ($R_1G_4A_3$) grown in Cocopeat + Vermicompost (1:1) at the time of microbudding (Table 1). The highest survival percentage (95.84%) was observed in four-month-old Rough Lemon seedlings ($R_1G_4A_1$) grown in the same medium, demonstrating its effectiveness in early-stage seedling establishment (Fig. 1). These results indicate that Cocopeat + Vermicompost provides an optimal growing environment for rootstock development, improving seedling vigor and adaptability for microbudding success. The

findings align with Bhagat *et al.* (2013), who reported that a combination of Soil + FYM + Cocopeat (2:1:1) significantly enhanced seedling growth parameters, including stem diameter, leaf area, and root system development in Rough Lemon rootstocks. Thus, adopting Cocopeat + Vermicompost (1:1) as a growing medium can significantly improve the physiological attributes of citrus rootstocks, ensuring better survival rates and successful propagation.

The six-month-old Rough Lemon rootstock ($R_1G_4A_3$) grown in Cocopeat + Vermicompost (1:1) exhibited superior budding performance, recording the shortest time to first sprouting (12.98 days) and the highest microbudding success rate (79.12%) (Table 2 & Fig. 2). This treatment also resulted in the longest micro-budded sprout (10.32 cm), the highest number of leaves per plant (3.54) at 30 days, and the largest stock diameter (3.49 mm) at 90 days post-microbudding, confirming its efficacy in citrus propagation. These findings align with Vijayakumari (2019), who reported that six-month-old Rough Lemon seedlings showed earlier sprouting and higher microbudding success. Similarly, Bhagat *et al.* (2013) and Dongre *et al.* (2014) observed that Rough Lemon seedlings grown in Soil + FYM + Cocopeat (2:1:1) had the highest proportion of early buddable seedlings and successful budding rates. Additionally, Singh *et al.* (2018) demonstrated improved growth and budding success in Rough Lemon when using Soil + FYM + Cocopeat (SFC) combined with Azospirillum and AM fungi consortium.

These results emphasize that using Cocopeat + Vermicompost (1:1) with six-month-old Rough Lemon rootstocks optimizes microbudding success, promoting faster sprouting, better seedling growth, and increased budding efficiency in citrus propagation systems.

Table 1. Growth and survival of rootstock as influenced by growing media and age at the time of microbudding

Treatment	Seedling height (cm)	Stem diameter (mm)	Fresh wt. of seedling (g)	Dry wt. of shoots (g)	Leaf area index	Survival of seedlings (%)
$R_1G_1A_1$	10.10	2.15	1.48	0.41	0.41	61.05
$R_1G_1A_2$	15.68	2.64	1.79	0.57	0.43	89.87
$R_1G_1A_3$	16.64	2.91	1.83	0.64	0.64	77.82
$R_1G_2A_1$	10.93	2.18	1.52	0.42	0.56	65.82
$R_1G_2A_2$	17.64	2.98	1.85	0.59	0.42	91.44
$R_1G_2A_3$	20.01	3.44	2.02	0.71	0.67	79.49
$R_1G_3A_1$	12.81	2.22	1.59	0.44	0.93	70.07
$R_1G_3A_2$	16.20	2.85	1.80	0.57	0.52	92.84
$R_1G_3A_3$	20.95	3.53	2.22	0.78	0.60	81.24
$R_1G_4A_1$	13.82	2.33	1.63	0.46	1.10	70.85
$R_1G_4A_2$	19.43	3.36	1.93	0.62	0.56	95.84
$R_1G_4A_3$	21.35	3.59	2.25	0.79	0.83	82.44
$R_2G_1A_1$	9.00	1.98	1.37	0.38	1.17	73.11

R ₂ G ₁ A ₂	14.25	2.42	1.68	0.54	0.38	84.02
R ₂ G ₁ A ₃	18.03	3.00	1.85	0.65	0.58	73.52
R ₂ G ₂ A ₁	9.34	2.12	1.41	0.39	0.72	62.82
R ₂ G ₂ A ₂	14.41	2.51	1.71	0.55	0.43	85.86
R ₂ G ₂ A ₃	16.85	2.96	1.83	0.64	0.60	75.48
R ₂ G ₃ A ₁	16.42	2.87	1.81	0.51	0.66	63.86
R ₂ G ₃ A ₂	14.97	2.56	1.78	0.57	0.62	89.25
R ₂ G ₃ A ₃	18.56	3.11	1.88	0.66	0.52	77.16
R ₂ G ₄ A ₁	13.39	2.25	1.57	0.44	0.70	64.86
R ₂ G ₄ A ₂	19.12	3.31	1.91	0.61	0.54	90.90
R ₂ G ₄ A ₃	20.51	3.50	2.13	0.75	0.74	78.57
SEm±	0.188	0.039	0.021	0.006	1.04	68.13
CD at 5%	0.527	0.108	0.059	0.017	0.009	0.331

Table 2. Effect of rootstock, growing media and age of rootstock at 90 days after microbudding

Treatment	Days taken to first sprout	Microbudding success (%)	Length of sprouted shoot after microbudding 90 days	Number of leaves/ plant days after microbudding at 90 days	Stock diameter (mm) days after microbudding at 90 days
R ₁ G ₁ A ₁	19.88	47.65	9.06	9.49	3.01
R ₁ G ₁ A ₂	18.52	50.42	9.34	9.76	3.26
R ₁ G ₁ A ₃	17.32	52.98	9.46	9.87	3.31
R ₁ G ₂ A ₁	19.75	44.75	9.13	9.52	3.13
R ₁ G ₂ A ₂	16.78	57.24	9.67	9.94	3.34
R ₁ G ₂ A ₃	14.65	68.33	10.09	10.15	3.44
R ₁ G ₃ A ₁	19.62	46.19	9.13	9.55	3.14
R ₁ G ₃ A ₂	18.32	51.20	9.35	9.80	3.27
R ₁ G ₃ A ₃	13.55	73.37	10.20	10.26	3.46
R ₁ G ₄ A ₁	19.35	48.94	9.17	9.62	3.18
R ₁ G ₄ A ₂	15.22	65.62	9.98	10.11	3.43
R ₁ G ₄ A ₃	12.98	79.12	10.32	10.43	3.49
R ₂ G ₁ A ₁	20.15	42.60	8.92	9.40	3.07
R ₂ G ₁ A ₂	19.22	49.03	9.20	9.65	3.21
R ₂ G ₁ A ₃	16.48	59.01	9.85	9.97	3.36
R ₂ G ₂ A ₁	19.98	43.31	8.95	9.45	3.09
R ₂ G ₂ A ₂	18.95	49.44	9.27	9.68	3.22
R ₂ G ₂ A ₃	16.92	53.30	9.49	9.91	3.32
R ₂ G ₃ A ₁	17.78	53.08	9.41	9.84	3.28
R ₂ G ₃ A ₂	18.82	49.98	9.28	9.72	3.24
R ₂ G ₃ A ₃	16.08	61.34	9.89	10.00	3.38
R ₂ G ₄ A ₁	19.52	50.07	9.13	9.58	3.16
R ₂ G ₄ A ₂	15.65	64.25	9.98	10.03	3.40
R ₂ G ₄ A ₃	14.02	72.07	10.15	10.23	3.46
SEm±	0.168	0.375	0.070	0.136	0.042
CD at 5%	0.471	1.051	0.195	0.380	0.117

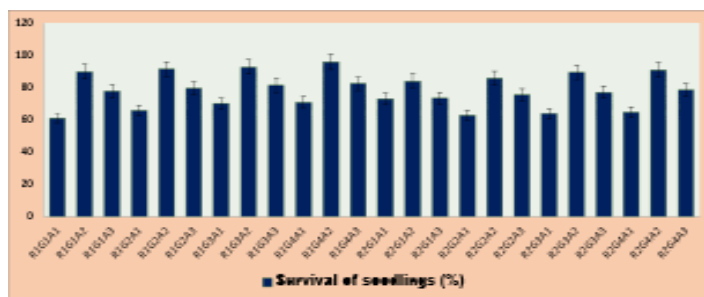


Fig. 1: Survival of seedlings (%) as influenced by growing media and age at the time of microbudding

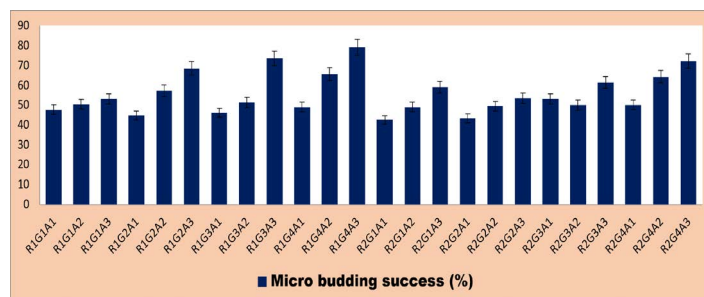


Fig. 2: Effect of rootstock, growing media and age of rootstock on microbudding success (%)



Preparation of rootstock



Wedge cut for inserting bud



Covering with micropipette cap

Conclusion

The study demonstrates that Cocopeat + Vermicompost (1:1) is the best growing medium for Rough Lemon rootstocks, with the age of six month old ($R_1G_4A_3$) showing superior performance in both physiological and post-budding parameters. This treatment exhibited 79.12% microbudding success, minimum days to first sprout (12.98 days), and maximum seedling height (21.35 cm), stock diameter (3.59 mm), and leaf area index (1.17). These results provide a strong basis for recommending Cocopeat + Vermicompost (1:1) as a sustainable and efficient growing medium for large-scale Mandarin propagation, reducing the nursery phase while improving overall plant health and success rates.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Response of irrigation and sulphur levels on yield and economics of radish grown under drip system in arid region of Rajasthan

Aakanksha Sharma¹, R. K. Narolia², Amaratpal Singh³, P. K. Yadav⁴ and Parvati Deewan⁵

^{1,3,4}Swami Keshwanand Rajasthan Agricultural University, Bikaner

^{2,5}Sri Karan Narendra Agriculture University, Jobner

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ABSTRACT

Studied the effect of various treatments of drip irrigation (60% PE, 80% PE, 100% PE and 120% PE) and sulphur (Control, 15 kg S ha⁻¹, 30 kg S ha⁻¹ and 45 kg S ha⁻¹) on yield and economics of radish. Among the treatments, the drip irrigation at 100% PE was comparable to 120% PE, yielding the highest root fresh weight (213.09 g), root diameter (4.12 cm), root length (30.11 cm), total fresh weight per plant (291.05 g), yield per hectare (313.93 q ha⁻¹), net returns (₹ 112,969 ha⁻¹), and B:C ratio (3.57). Application of 30 kg S ha⁻¹ resulted in maximum root fresh weight (211.75 g), root length (28.94 cm), and root diameter (3.98 cm), as well as the highest total fresh weight per plant (289.87 g), yield (301.57 q ha⁻¹), and net returns (₹ 106,248 ha⁻¹). The treatment combination of 100% PE irrigation with 30 kg S ha⁻¹ resulted in the highest yield per hectare (331.21 q ha⁻¹), though it was statistically comparable to the treatments of 100% PE with 45 kg S ha⁻¹, 120% PE with 30 kg S ha⁻¹, and 120% PE with 45 kg S ha⁻¹.

Introduction

Radish (*Raphanus sativus* L.) is most popular *rabi* season root crops which cultivated for its important medicinal and nutritive values. It belongs to Cruciferae family. Being a winter season crop, radish is sown in cool season from mid-September to mid-January in northern plains. Radish is the vegetable of both tropical and temperate regions of the world, widely cultivated for its root, tender leaves and green shoots (Alam *et al.*, 2010). It is rich in diverse amino acids and glucosinolate contents (Xie *et al.*, 2018). Glucosinolates are associated with a reduced cancers risks of the lung, pancreas, stomach, prostate, breast, colon and rectum (Herr and Buchler, 2010). The 100 g of edible roots contain 93.7 per cent water, 1.1 per cent fat and 4.2 per cent carbohydrates.

The radish leaves are rich in minerals, vitamin A (5 IU) and vitamin C (15 mg) and roots are rich in potassium (138 mg) and calcium (50 mg) (Baksh *et al.*, 2006 and Yadav *et al.*, 2019).

In recent years, the drip irrigation is mostly used to increase water use efficiency of vegetable crops. It enhances water use efficiency, alleviates moisture stress, and improves both the productivity and quality of crops. Sulphur deficiency is common in many crops, including vegetables, especially those grown in sandy soils prone to leaching. It also enhances the availability of other essential nutrients, promoting better growth and improving nutrient uptake (Nasreen *et al.*, 2007). Additionally, sulphur helps lower soil pH due to its acidic nature, improves soil structure, and increases the availability of other plant nutrients. It is vital for synthesizing secondary metabolites with high nutritional value, such

Corresponding author

Email: rknarolia.horti@sknau.ac.in (Dr. R K Narolia)

as glucosinolates, which accumulate in brassica species like radish. These compounds store sulphur, supporting normal plant metabolism, especially under sulphur-deficient conditions (Schonhof *et al.*, 2007).

In countries like India, where increasing vegetable production is a priority amidst limited irrigation resources, the role of sulphur can not be overlooked. Keeping in view, a study was undertaken to find out appropriate irrigation and sulphur level in radish.

Material and Methods

The field experiment was carried out at Instructional Farm, College of Agriculture, Bikaner (Rajasthan) during *rabi* season of 2020. The experimental site is situated at a latitude of 28° 01'N and a longitude of 73° 22'E, at an altitude of 234.70 meters above mean sea level, within Agro-climatic Zone Ic (Hyper Arid Partially Irrigated North Western Plain Zone). The soil of the experimental field was loamy sand in texture and slightly alkaline in reaction (pH 8.5), poor in organic carbon (0.12 per cent), low in available nitrogen (116 kg ha⁻¹) but medium in available phosphorus (15.3 kg ha⁻¹) and potassium (171.2 kg ha⁻¹). The experiment was laid out in split plot design and replicated thrice with combination of sixteen treatments. The treatments have four levels of irrigation (60% PE, 80% PE, 100% PE and 120% PE) and four sulphur levels (Control, 15 kg S ha⁻¹, 30 kg S ha⁻¹ and 45 kg S ha⁻¹) which were randomly allotted to main plots and sub plots, respectively using random number tables of Fisher (1950).

Applied the recommended dose of N, P₂O₅ and K₂O i.e. 30:58:87 kg ha⁻¹ through urea, DAP and MOP, respectively. Seeds of Pusa Reshmi variety were treated with 0.02 per cent thiram and sown on 05th November, 2020 at 1-2 cm depth. Maintained a distance of 30 cm between rows and 10 cm between plants. Applied irrigation through drip system immediately after sowing 40 mm water to ensure proper germination. The subsequent irrigations were applied at alternate days as per treatment schedule using four laterals per plot. The irrigation water was calculated by evaporation data on daily basis. The treatment wise observations were recorded on five randomly selected plants in replication. The net return and B:C ratio was calculated on the basis of prevalent market rate of radish. In order to test significance of variation, the data were statistically analyzed as per the procedure described by Panse and Sukhatme (1985).

Results and Discussion

The data presented in Table 1 showed that the yield attributes of radish increased significantly with higher irrigation levels. Irrigation at 120% PE resulted in the highest fresh weight of the root (214.15 g), root length (31.41 cm), and root diameter

(4.41 cm) compared to 60% PE and 80% PE, though it was statistically similar to the 100% PE irrigation level. Higher irrigation levels (100% and 120% PE) helped alleviate stressful conditions, promoting optimal plant growth and improving yield attributes such as root fresh weight, root length, and root diameter. These findings align with the research of Saini and Brar (2018).

Radish crop irrigated at 120% PE also recorded the highest total fresh weight per plant (292.22 g) and yield per hectare (314.34 q ha⁻¹) compared to 60% PE and 80% PE, with results statistically similar to those at the 100% PE irrigation level. This supports the findings of Saxena *et al.* (2004). The increased yield per hectare of radish at higher irrigation levels is likely due to the optimal moisture content maintained in the root zone throughout the crop's growing period, which enhanced both total fresh weight and overall yield. The similar results were previously reported by Solangi *et al.* (2016).

Net returns and the B:C ratio increased significantly with different levels of irrigation (Table 1). The highest net returns (₹112,969 ha⁻¹) and B:C ratio (3.57) were observed with the 100% PE irrigation, which was comparable to the 120% PE level. Among the irrigation levels, the highest B:C ratio and net returns were achieved at the 100% PE level due to its higher yield compared to the 60% and 80% PE levels.

As the PE levels increased, the total cost of production also rose. However, the cost of irrigation included in the experiment was comparatively lower than the additional income generated, leading to higher profits. Similar results were reported by Narayanmoorthy (2004), where the initial investment in the drip irrigation system was high, but it led to increased yield, water saving, and reduced cultivation cost, which ultimately resulting in the highest benefit-cost ratio.

The data further indicated that sulphur levels significantly influenced yield attributes. The highest fresh weight of the root (212.80 g), root length (29.97 cm), and root diameter (4.17 cm) were recorded at 45 kg S ha⁻¹, compared to the control and 15 kg S ha⁻¹, though it was statistically similar to 30 kg S ha⁻¹. The highest total fresh weight per plant (290.75 g) and yield per hectare (304.72 q ha⁻¹) were also recorded at 45 kg S ha⁻¹, compared to the control and 15 kg S ha⁻¹, but were at par with the 30 kg S ha⁻¹ level. The lowest yield and yield attributes were observed in the control (S₁). These findings are consistent with the results of Kumar *et al.* (2016). The increase in fresh weight of the root, root length, root diameter and total fresh weight per plant with higher sulphur levels was also reported by Yadav *et al.* (2008) and Nasreen *et al.* (2003).

The net returns and B:C ratio were significantly influenced by the application of different sulphur levels to the radish crop (Table 1). Sulphur application at 30 kg S ha⁻¹ recorded the highest net returns (₹ 106,248 ha⁻¹) compared to the control (₹ 90,289 ha⁻¹), 15 kg S ha⁻¹ (₹ 102,636 ha⁻¹), and 45 kg S ha⁻¹ (₹ 105,273 ha⁻¹). The B:C ratio was significantly higher (3.44)

with the 15 kg S ha⁻¹ treatment compared to the control and 45 kg S ha⁻¹, though it remained at par with the 30 kg S ha⁻¹ treatment. The lower cost of treatment at 15 kg S ha⁻¹ likely contributed to the higher B:C ratio (3.44).

The yield per hectare of radish was significantly influenced by the interaction between irrigation and sulphur levels

(Table 2 & Fig. 1). The treatment combination of 100% PE irrigation with 30 kg S ha⁻¹ resulted in the highest yield per hectare (331.21 q ha⁻¹), which was statistically comparable to the treatments of 100% PE with 45 kg S ha⁻¹, 120% PE with 30 kg S ha⁻¹, and 120% PE with 45 kg S ha⁻¹.

Table 1. Effect of irrigation and sulphur levels on yield attributes, yield and economics of radish

Treatments	Fresh weight of root (g)	Length of root (cm)	Diameter of root (cm)	Total fresh weight/ plant (g)	Yield/ ha (q)	Net returns (₹ ha ⁻¹)	B:C ratio
Irrigation levels							
60% PE	196.16	20.69	2.49	265.24	243.92	80894	2.98
80% PE	207.06	26.21	3.64	282.05	282.80	98872	3.33
100% PE	213.09	30.11	4.12	291.05	313.93	112969	3.57
120% PE	214.15	31.41	4.41	292.22	314.34	111711	3.45
SEm±	0.80	0.44	0.07	1.70	2.20	1098.7	0.03
CD at 5%	2.78	1.51	0.23	5.87	7.60	3802.10	0.09
Sulphur levels							
Control	197.90	23.42	2.90	269.26	259.45	90289	3.29
15 kg S ha ⁻¹	207.92	26.07	3.60	280.68	289.25	102636	3.44
30 kg S ha ⁻¹	211.75	28.94	3.98	289.87	301.57	106248	3.38
45 kg S ha ⁻¹	212.88	29.97	4.17	290.75	304.72	105273	3.23
SEm±	0.85	0.40	0.09	1.21	2.55	1274.6	0.03
CD at 5%	2.47	1.16	0.26	3.54	7.44	3720.2	0.08

Table 2. Interaction effect of irrigation and sulphur levels on yield of radish (q ha⁻¹)

Control	60% PE	80% PE	100% PE	120% PE	Mean
15 kg S ha ⁻¹	256.67	285.64	300.97	313.71	289.25
30 kg S ha ⁻¹	247.00	293.41	331.21	334.67	301.57
45 kg S ha ⁻¹	245.00	294.22	336.67	343.00	304.72
Mean	243.92	282.80	313.93	314.34	
				SEm±	CD at 5%
Irrigation at same level of sulphur				4.93	4.40
Sulphur at same level of irrigation				5.10	14.88

Conclusion

The study concluded that applying drip irrigation at 100% PE provided optimal yield and economic returns for radish, performing at par with 120% PE. Similarly, the application of 30 kg S ha⁻¹ resulted in the highest yield and net returns, though it was statistically similar to 45 kg S ha⁻¹. The interactive

effect with application of irrigation level at 100% PE and 30 kg S ha⁻¹ proved superior in terms of yield. However, the highest B:C ratio was recorded at 15 kg S ha⁻¹, making it the most cost-effective option. The results emphasize the importance of balanced irrigation and sulphur application for maximizing radish productivity and profitability in arid regions.

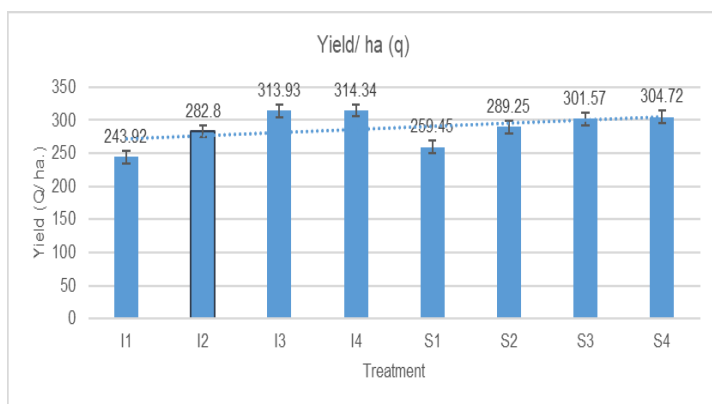


Fig. 1. Effect of irrigation and sulphur levels on yield of radish

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript

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***In-vitro* study of different solid media, pH and temperature on mycelial growth and sporulation of *Alternaria alternata* causal of *Alternaria* leaf blight of bael**

Umesh Kumar Chanderia¹, Shivani Raghuvarshi², Deepak Singh³ and Kartikey Pandey⁴

¹Scientist (Plant Pathology), Deptt. of Horticulture, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur (M. P.) - 482004

²P.G. Scholar, Deptt. of Plant Pathology, JNKVV, Jabalpur (M. P.) - 482004

³Field Extension Officer, Deptt. of Horticulture, JNKVV, Jabalpur (M. P.) - 482004

⁴Research Scholar, Deptt. of Plant Pathology, JNKVV, Jabalpur (M. P.) - 482004

⁵Senior Technical Officer, Deptt. of Horticulture, JNKVV, Jabalpur (M. P.) - 482004

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ABSTRACT

Among the seven solid media, potato dextrose agar (PDA) exhibited the highest radial mycelial growth, with a pH range of 4.5-7.5 being optimal, particularly at pH 6.0 for both growth and sporulation. Richard's agar also favored significant growth *Alternaria alternata* causal of alternaria leaf blight of Bael. Temperature trials conducted at 15°C, 20°C, 25°C, 30°C and 35°C revealed that 25°C was the optimal temperature for mycelial growth and sporulation. Significant reductions in growth and sporulation were observed at temperatures below 20°C and above 30°C. These findings provide valuable insights into the ecological preferences of *A. alternata*, contributing to the development of effective management strategies for Alternaria leaf blight in bael cultivation.

Introduction

The bael tree, scientifically known as *Aegle marmelos*, holds significant cultural, religious and medicinal importance in India. Belonging to the Rutaceae family, it exhibits a chromosome number of $2n=36$ ($n=18$). Bael tree, referred to as bael in India, has been revered in Indian mythology since prehistoric times and is particularly consecrated to Lord Shiva. Its prominence is noted in ancient texts such as the Jain scriptures, Buddhist literature, the *Ramayana* and the *Yajurveda* (Singh *et al.*, 2023). Geographically, the bael tree thrives throughout most Indian states with higher

concentrations in regions like Madhya Pradesh, West Bengal, Uttar Pradesh, Bihar and Odisha (Teaotia *et al.*, 1963). The bael plant is both nutritionally rich and therapeutically valuable, thriving in regions of India with limited water resources.

The fruit is a rich source of carbohydrates, vitamin A, riboflavin, alkaloids, coumarins and steroids. Marmelosin, a key bioactive compound, is believed to be highly effective in treating stomach disorders. The concentration of bael's therapeutic bioactive component, which varies based on variety (0.03-0.37%) and environmental conditions, plays a crucial role in its medicinal properties (Dixit and Dutt,

Corresponding author

Email: kmr.uk@rediffmail.com (Dr. U.K. Chanderia)

1932). The bael plant exhibits a strong resistance to diseases with the only major documented issue being leaf spot disease caused by *Alternaria alternata* in northern India (Madaan and Gupta, 1985). Fungal infections during storage are the only significant threat to bael fruit. *Alternaria* leaf spots, which commonly affect the tree, are characterized by small, dark lesions (4 to 8 mm) that typically appear near the leaf margins. These lesions are often surrounded by concentric rings, further distinguishing the disease.

Material and Methods

The experiment was conducted during 2023-24 in the Laboratory of the Department of Plant Pathology, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India. The laboratory study aimed to evaluate the effects of various solid culture media, pH levels and temperature on the radial mycelial growth and sporulation of *Alternaria alternata*, the causal agent of *Alternaria* leaf blight in bael (*Aegle marmelos*). Seven different solid media viz., Potato Dextrose Agar (PDA), Corn Meal Agar, Czapek's Dox Agar, Oatmeal Agar, Richard's Agar, Bael Leaf Extract Agar and Water Agar were evaluated for their effects on radial mycelial growth and sporulation of *Alternaria alternata*. The formulations of each medium were weighed and prepared accordingly, with all media sterilized prior to use. Sterilized cork borers were used to inoculate 5 mm mycelial discs into petriplates containing the sterilized media. The plates were then incubated at $25 \pm 2^\circ\text{C}$ for seven days with three replications for each medium. Radial growth was assessed by measuring the colony diameter and two diagonals passing through its center, excluding the initial 5 mm disc. Mycelial growth and sporulation on the seven media were observed at regular intervals throughout the incubation period. Colony characteristics were also recorded during the assessment.

The study of varying pH levels was conducted to determine the effect of different hydrogen ion concentrations in the medium on the fungal growth of *Alternaria alternata*. The pH of the PDA medium was adjusted to 5.0, 5.5, 6.0, 6.5, 7.0 and 7.5 using N/10 NaOH to increase the pH and N/10 HCl to decrease it. After autoclaving, the medium was poured into Petri plates and inoculated with fungal cultures. The plates were incubated at $25 \pm 1^\circ\text{C}$ and radial mycelial growth and sporulation were recorded at regular intervals. In addition, the effect of five different temperatures (15°C , 20°C , 25°C , 30°C and 35°C) on the growth of *A. alternata* was also examined. For this, 20 ml of sterilized PDA was poured into each Petri dish. The inoculated plates were incubated at the specified temperatures with four replications for each condition. Mycelial growth and sporulation were observed and recorded after seven days of incubation. The data

collected during the experiment were statistically analyzed using the methods given by Panse and Sukhatme (1995).

Results and Discussion

The radial growth of *Alternaria alternata* varied significantly across all media tested. Maximum radial growth was observed on Potato Dextrose Agar (72.6 mm), which was statistically at par with the growth on Corn Meal Agar (72.3 mm) after eight days of incubation, followed by Czapek's Dox Agar (58.0 mm) and Bael Leaf Agar (54.6 mm) (Table 1, Fig. 1 and Fig. 4). The data indicated that the highest mean radial growth occurred on Corn Meal Agar (40.25 mm), followed by Potato Dextrose Agar (36.4 mm). The lowest radial growth was recorded (Table 1) on Richard's Agar (32.2 mm), which was similar to Bael Leaf Agar (32.2 mm) with Water Agar showing the least growth (16.0 mm). In terms of sporulation, the highest number of spores per microscopic field (28) was observed on Potato Dextrose Agar, followed closely by Bael Leaf Agar (27). These findings are consistent with those reported by Hubballi *et al.* (2010), Apet *et al.* (2014), Reddy *et al.* (2019) and Solanki *et al.* (2023), which support the results of this study.

The experimental results showed that the maximum radial growth (60.6 mm) of *Alternaria alternata* was recorded at pH 6.5 followed by pH 5.5 (57.3 mm) and pH 7.0 (55.3 mm) on the 7th day of incubation (Table 2, Fig. 2 and Fig. 5). The lowest radial growth was observed at pH 4.5 (32.6 mm). The highest sporulation occurred at pH 6.5 with an average of 38 spores per microscopic field followed by pH 7.5 with 35 spores per microscopic field. The lowest sporulation was recorded at pH 6.0 with an average of 27 spores per microscopic field. These findings align with previous research conducted by Samuel *et al.* (1972), Saeed *et al.* (1995), Hubballi *et al.* (2010), Madhavi *et al.* (2012), Ramjegathesh and Ebenezar (2012), Gholve *et al.* (2017), Gayithri *et al.* (2021), Kurhade *et al.* (2021), Mahalakshmi *et al.* (2021) and Fagodiya *et al.* (2022).

The results indicated that a temperature of 25°C was optimal for the radial growth of *Alternaria alternata* with a maximum growth of 73.7 mm. Temperatures of 30°C and 20°C also supported significant radial growth, measuring 50.7 mm and 41.2 mm, respectively (Table 3, Fig. 3 and Fig. 6). The temperature range of 20 – 30°C was found to be most favorable for fungal growth. In terms of sporulation, the highest number of spores (35 per microscopic field) was observed at 25°C . Sporulation was also substantial at 20°C and 30°C with 27 and 30 spores per microscopic field, respectively. These findings are consistent with the reports of Waghunde and Patil (2010), Gholve *et al.* (2017), Kurhade *et al.* (2021), Mahalakshmi *et al.* (2021) and Fagodiya *et al.* (2022).

Table 1. Effect of solid media on growth of *A. alternata*

S.No.	Media	Radial growth (mm) after (days)								Mean	Spores per microscopic field	Index
		1	2	3	4	5	6	7	8			
1.	Potato Dextrose Agar	15.0	20.6	23.0	29.3	34.3	40.0	57.0	72.6	36.4	28	Very good
2.	Corn Meal Agar	13.6	21.3	24.3	36.0	41.6	51.3	61.3	72.3	40.25	19	Good
3.	Czapek's Dox Agar	14.0	20.3	24.0	30.6	36.3	42.6	49.6	58.0	34.4	20	Very good
4.	Oat Meal Agar	14.0	26.6	32.0	39.6	43.6	48.0	43.0	44.0	36.3	17	Good
5.	Richard's Agar	10.3	17.3	23.6	31.0	35.3	45.0	51.0	44.6	32.2	23	Very good
6.	Bael Leaf Agar	14.3	22.6	23.6	27.6	32.6	38.0	45.0	54.6	32.2	27	Very good
7.	Water Agar	6.6	8.3	11.0	13.3	16.0	21.3	24.3	27.6	16.0	03	Fair
SEm±		0.7	0.9	0.8	0.9	0.9	2.0	0.7	0.6	0.6		
CD (p=0.05)		2.1	2.7	2.6	2.9	2.7	0.6	2.2	1.9	1.8		

Table 2. Effect of pH on growth of *A. alternata*

S.No.	pH	Radial growth (mm) after (days)							Mean	Spores per microscopic field	Index
		1	2	3	4	5	6	7			
1.	4.5	11.1	15.6	22.3	27.3	31.0	32.6	32.6	25.6	33	Excellent
2.	5.0	12.0	20.0	24.6	27.8	34.0	36.0	52.5	32.7	33	Excellent
3.	5.5	11.3	15.3	19.6	25.6	31.6	36.0	57.3	31.8	28	Very good
4.	6.0	14.0	17.3	22.0	26.3	33.3	36.0	51.6	31.6	27	Very good
5.	6.5	8.6	17.6	25.3	31.0	43.6	45.6	60.6	37.2	38	Excellent
6.	7.0	11.0	16.6	21.3	25.0	35.0	37.3	55.3	32.5	29	Very good
7.	7.5	8.3	14.6	17.6	20.3	25.0	25.3	46.0	25.5	35	Excellent
SEm±		0.6	0.9	0.6	0.9	0.9	0.7	0.9			
CD (p=0.05)		2.1	2.7	2.1	2.9	2.7	2.4	2.7			

Table 3. Effect of temperature on growth of *A. alternata*

S.No.	Temperature (°C)	Radial growth (mm) after (days)							Mean	Spores per microscopic field	Index
		1	2	3	4	5	6	7			
1.	15	18.7	24.0	27.5	32.75	36.0	37.0	37.7	30.6	6	Fair
2.	20	14.0	19.5	24.2	29.0	33.2	36.0	41.2	28.1	27	Very good
3.	25	13.2	22.2	33.0	43.5	61.2	65.0	73.7	44.5	35	Excellent
4.	30	11.7	18.0	25.5	31.25	35.5	42.0	50.7	30.9	24	Very good
5.	35	14.2	17.2	20.7	24.75	27.7	27.0	29.5	23.0	16	Good
SEm±		0.6	0.5	0.7	0.6	0.7	0.6	0.9			
CD (p=0.05)		1.8	1.6	2.3	2.0	2.2	1.9	2.9			

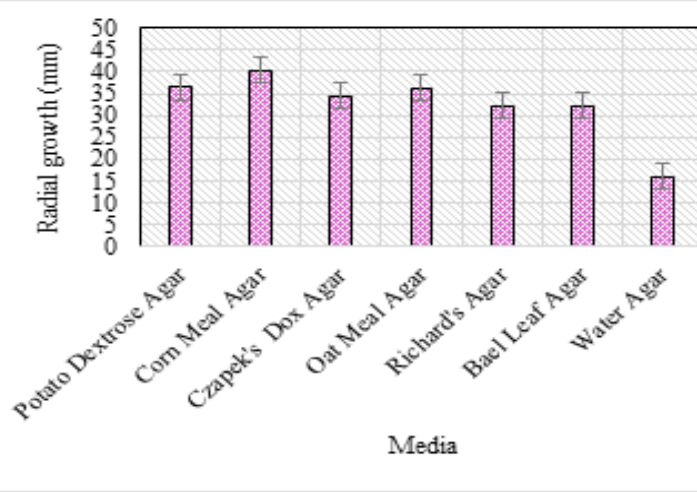


Fig. 1. Effect of solid media on radial growth of *A. alternata*

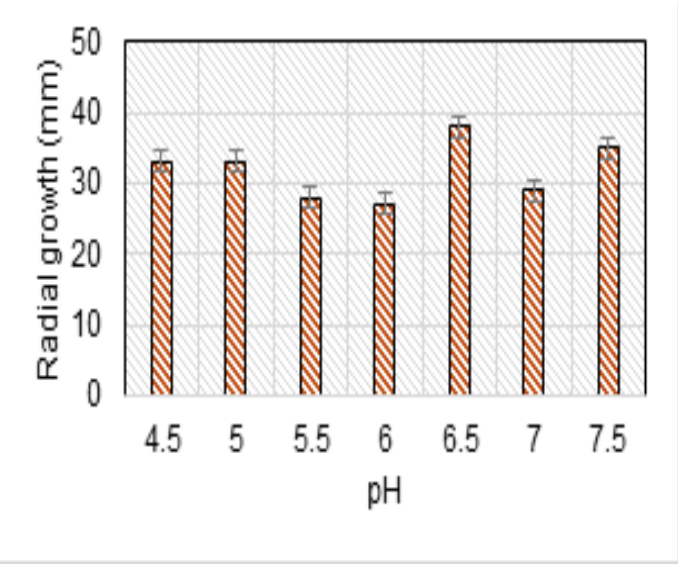


Fig. 2. Effect of pH on radial growth of *A. alternata*

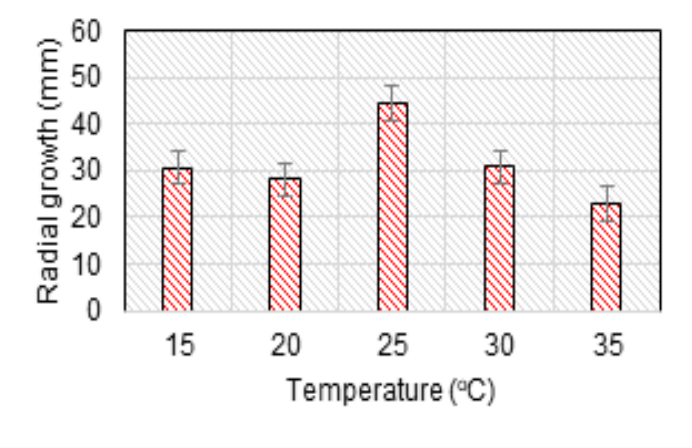


Fig. 3. Effect of temperature on radial growth of *A. alternata*

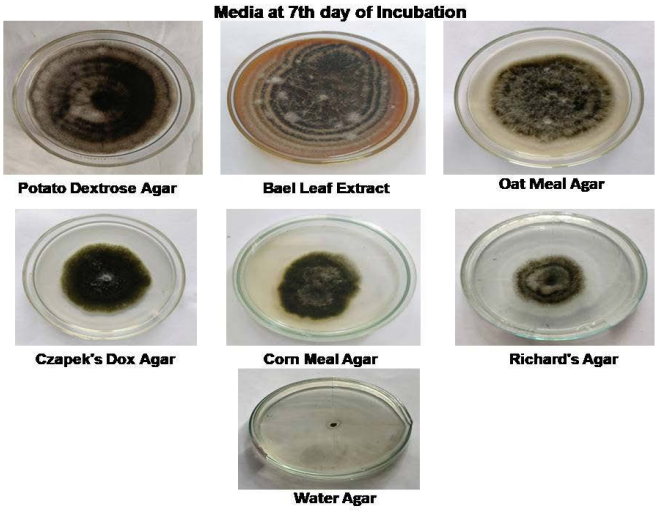


Fig. 4: Effect of solid media on growth of *A. alternata*

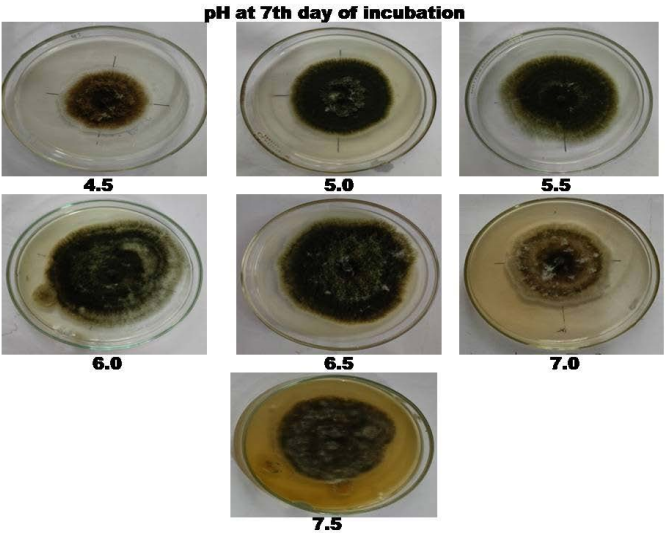


Fig. 5: Effect of pH on growth of *A. alternata*

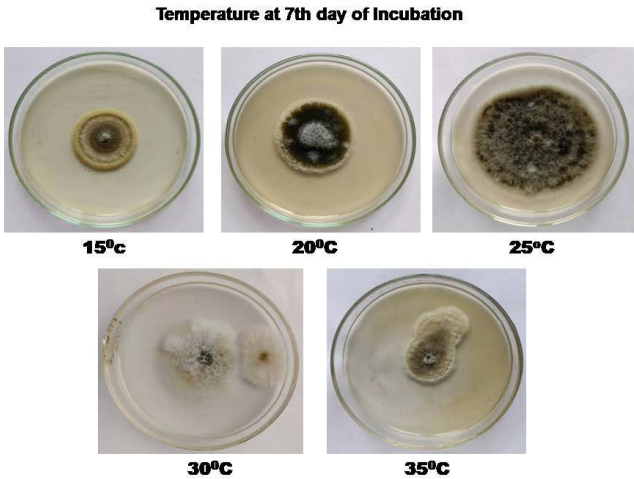


Fig. 6: Effect of temperature on growth of *A. alternata*

Conclusion

The study highlighted the impact of varying growth conditions i.e., media type, pH and temperature-affect *Alternaria alternata*'s radial growth and sporulation. Potato Dextrose Agar (PDA) and Corn Meal Agar (CMA) promoted optimal mycelial growth, while PDA and Bael Leaf Agar enhanced sporulation, indicating nutrient-specific influences on fungal reproduction. Optimal growth occurred at pH 6.5, which maximized both mycelial expansion and spore production, whereas acidic conditions (pH 4.5) severely inhibited fungal development. Temperature played a critical role with 25°C identified as ideal for growth and sporulation. Though growth persisted at 20°C and 30°C, extreme deviations from the optimal temperature reduced fungal performance. These findings underscore the importance of environmental factors in *Alternaria alternata*'s physiology, offering insights for managing its proliferation in agricultural settings. The results suggest tailored strategies, such as adjusting pH or temperature in storage environments, could mitigate fungal growth. Future studies should explore molecular pathways underlying these responses to advance targeted disease control methods, potentially reducing reliance on chemical treatments.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Estimation of genetic variability parameters in aloe (*Aloe barbadensis* Mill.) genotypes to improve economic traits

Pavani Narigapalli¹ and Geetha K.A.²

¹B.A. College of Agriculture, Anand Agricultural University, Gujarat, India - 388110

²ICAR-Directorate of Medicinal and Aromatic Plants Research, Boriavi, Anand, India - 387310

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ABSTRACT

A study was conducted on twenty-six accessions of *Aloe barbadensis* Mill. at ICAR-DMAPR, Boriavi, from 2019 to 2021 to assess morphological, chemical, and yield traits for identifying elite lines suitable for herbal drugs and cosmetics. Significant variation among accessions was observed among the evaluated genotypes. IC 310623 demonstrated superior gel and aloin yield, with high aloin content, making it ideal for medicinal and cosmetic applications. High genetic and phenotypic coefficients of variation (GCV and PCV) were noted for leaf thickness and exudates yield per plant, suggesting that direct selection for these traits could enhance future breeding programs. This study identifies promising accessions with potential for commercial exploitation in herbal and cosmetic industries.

Introduction

Aloe barbadensis Mill. (2n = 14) is a xerophytic, perennial species belonging to family *Asphodelaceae*. Aloe is a native of South Africa, now indigenous to dry sub-tropical and tropical climates, including the southern United States (Viljoen *et al.*, 2000). Due to its pharmaceutical and industrial uses it is also called as “Miracle Plant” and “Healing Plant” (Okareh *et al.*, 2012). There are about 500 species in the genus Aloe. Among the various species, *Aloe barbadensis* Mill. is widely known for its medicinal properties. According to an assessment by the International Aloe Science Council (IASC), nearly 23,600 hectares of aloe are cultivated globally, with 19,100 hectares located in the America (Samsai and Praveena, 2016).

A. barbadensis is successfully grown in all kinds of soil *i.e.*, from well drained sandy to loamy soils with a pH of 7.0 to 8.5. *Aloe vera* plants are prominent by their high-water content, which ranges from 99 to 99.5% (Atherton, 1998), 0.5–1.0%

of the solid material contains about 75 distinct potentially active substances, including vitamins, minerals, enzymes, simple and complex polysaccharides, phenolic compounds, and organic acids. The leaves are thick and fleshy, green to grey green with serrated margins with prominent spines. Fruits are loculicidal capsules bearing an average of 4-9 seeds per fruit, but the seeds are mostly sterile and the crop is mainly propagated vegetatively by suckers (Manvitha and Bidya, 2014).

A. barbadensis has a vast traditional role in indigenous system of medicine like *Ayurveda*, *Siddha*, *Unani* and Homoeopathy. Aloe leaf consists of fleshy gel which helps in the synthesis of carbohydrates and proteins (Misir *et al.*, 2014). The anti-inflammatory and the local anesthesia properties of gel have made it a household name. The exudates contain the anthraquinones which are active ingredients and glycosides which are important in pharmaceutical industry. Aloin, aloe emodin and aloe lectin are the important anthraquinones present in aloe. Aloin or barbaloin (C₂₁H₂₂O₉) is the major

Corresponding author

Email: pavaninarigapalli20@gmail.com (Pavani Narigapalli)

portion of the exudates which is yellow-brown in color (Saeed *et al.*, 2004). Some of the anthraquinones are used as cathartic (Bhat and Devi, 2010).

It contains about 75 potentially active constituents: vitamins, enzymes, minerals, sugars, lignin, active enzymes, saponins, salicylic acids, amino acids (Atherton, 1998) and phenolic compounds (Okamura *et al.*, 1996). Aloe polysaccharides have therapeutic properties such as immune-stimulation, anti-inflammatory, anti-obesity preparation, wound healing, anti-bacterial, anti-viral, anti-fungal and anti-oxidant (Reddy *et al.*, 2011). Aloin and polysaccharide present in the leaves are medicinally and commercially useful (Liu *et al.*, 2011).

In view of various industrial uses in cosmetic and pharmaceutical industries, leaf yield and aloin content are of paramount importance in aloe. Developing improved cultivars/ varieties with higher leaf yield and aloin content is an important step for promoting aloe cultivation. To date, there has been very little information available regarding genetic variability studies in *Aloe barbadensis*. Therefore, this study was mainly focused on assessing the genetic variability studies for morphological, chemical, reproductive and yield characters of *Aloe barbadensis*.

Material and Methods

Twenty-six accessions of *Aloe barbadensis* Mill. were evaluated from September 2019 to March 2021 at ICAR-Directorate of Medicinal and Aromatic Plants Research (ICAR-DMAPR), Boriavi, Anand, Gujarat. A total of twenty-six accessions were evaluated a randomized complete block design with two replications. Suckers of length 8-10 cm of each accession were used for planting with a spacing of 60 × 45 cm accommodating 21 plants in 1.8 × 3.15 m plot. All the recommended agronomic practices and plant protection measures were followed to ensure uniform, healthy and stable crop growth.

Five competitive plants (18 months old) from each plot were randomly selected to record observations from the net area of each replication. Observations related to the characteristics of inflorescence/ flowers were recorded during the months of February-March, 2021. Inflorescence emergence was observed from the axils of 2nd or 3rd from the base. Observations related to the characteristics of leaf and biochemical parameters were recorded at the time of harvest. Harvesting was done when the plants attained age of about 18 months. For morphological characters three leaves were used from the selected five plants of the net area from each replication. For yield related parameters *viz.*, leaf yield, gel yield and exudates yield, all the mature leaves (leaf length >15 cm) of the plants from the net plot area (n=5) were used from each replication.

Chemical parameter aloin content (%) was estimated from the dry exudates collected from the leaf as reported by Gajbhiye

and Maiti (2010). Gel obtained from each replication was weighed separately and were converted into fresh gel yield per hectare (kg).

Fresh gel yield (t ha^{-1}) = Fresh gel per plant Number of plants per hectare.

For expressing the gel yield on dry weight basis, gel dry matter % was obtained. Fresh gel of about 50 g (n=3) was kept in the hot air oven at 50°- 60°C for about 10-12 hours. The final dry weight was taken and the dry matter percent was calculated using the following formula:

Dry matter % of gel= Total weight of final dried gel obtained/ Fresh gel weight taken x 100

The mean values of different characters recorded from each accession per replication were used for statistical analysis. The analysis of variance was carried out for randomized complete block design separately for all the characters as per the standard procedure described by Panse and Sukhatme (1978).

Further, the statistical analysis for genotypic, phenotypic and environmental variances were calculated as per Johnson *et al.* (1955). GCV and PCV were computed using the following formula given by Burton (1952) and heritability (h^2) in the broad sense was estimated by the formula specified by Hanson *et al.* (1956). The expected genetic advance (GA) was calculated for each character as suggested by Allard (1960) and assessed the traits as high, medium and low as per Johnson *et al.* (1955).

Results and Discussion

The analysis of variance for morphological parameters (Table 1) and yield parameters (Table 3) showed significant differences except for reproductive traits (Table 2). Among them, IC 283943 (67.34 cm) and IC 112527 (66.70 cm) exhibited the greatest plant height, while IC 310596 (11.31) had the highest number of leaves per plant. Regarding chemical parameters, IC 310623 (27.07%) recorded the highest aloin content, followed by NMRM 2, IC 310594, IC 283655 and IC 283652. Meanwhile, IC 310609 (97.68%) along with 17 other accessions, demonstrated exceptional gel content, enhancing their medicinal value. In terms of biomass production, IC 310618 (339.63 g), IC 310619 (325.88 g) and IC 310623 (290.91 g) exhibited the highest leaf weights, with these same accessions also recording the highest leaf yield per hectare. Similarly, IC 310623 produced the highest exudates per plant (10.31 g), followed by NMRM 2 (9.86 g) and IC 112531 (9.69 g), while IC 112527, IC 283932 and IC 283655 had the highest exudates yield per hectare. For fresh gel yield, IC 310618 (93.55 t ha^{-1}), IC 310619 (90.20 t ha^{-1}) and IC 310623 (91.07 t ha^{-1}) were the top performers, whereas GUJ 2, IC 283652 and IC 310618 superior in dry gel yield.

Aloin yield was highest in IC 310623 (74.80 kg ha^{-1}), followed by IC 285629 and GUJ 1 with NMRM 2 also demonstrating

high aloin content. Overall, IC 310618, IC 310619 and IC 310623 emerged as outstanding accessions due to their superior leaf yield, gel yield and aloin content. Additionally, GUJ 2 and IC 283652 were notable for dry gel production, while IC 285629, IC 310623 and NMRM 2 were ideal for aloin extraction, making them highly valuable for medicinal and industrial applications. In terms of yield, IC 310618, IC 310623 and IC 310619 proved to be exceptional. However, in medicinal plants, commercial success is ultimately determined by the yield of active ingredients rather than total biomass. Accessions with remarkable morphological, chemical and yield characteristics can be classified as elite varieties, making them ideal candidates for breeding programs focused on genetic enhancement or direct cultivation as high-yielding aloe selections.

The variation among accessions in this study was assessed using the coefficient of variation. The Genotypic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV) are essential for determining the extent of variability within accessions. Minimal differences were observed between GCV and PCV for most recorded traits, except for a few where PCV was significantly higher than GCV (Table 4 and Fig. 1).

In this study, high GCV was recorded for all yield-related traits, including leaf weight, leaf thickness, and the number of leaves per plant. The high GCV values suggest that direct selection may be effective for improving these traits. Conversely, traits such as flowers per inflorescence, inflorescence length, and gel content (%) exhibited low GCV, indicating that direct selection for these characteristics may not be effective. These findings align with those of Nejatzadeh *et al.* (2012). Heritability plays a crucial role in understanding

a trait's response to selection. In this study, broad-sense heritability ranged from 2.27% (inflorescence length) to 97.78% (plant height). Similar results for leaf yield and gel content (%) were reported by Alagukannan and Ganesh (2008) and Ahmad and Gupta (2016). High heritability was observed for all studied traits, suggesting that selection based on phenotypic values could be effective. However, selection is most efficient when high heritability is coupled with high genetic advance (Falconer, 1981; Johnson *et al.*, 1955).

High heritability combined with high genetic advance as a percentage of the mean was recorded for plant height ($h^2_{bs} = 97.78\%$, GAM = 25.49%), fresh gel yield ($h^2_{bs} = 93.60\%$, GAM = 49.98%), leaf yield ($h^2_{bs} = 88.50\%$, GAM = 55.19%), number of leaves per plant ($h^2_{bs} = 91.95\%$, GAM = 39.26%), leaf thickness ($h^2_{bs} = 90.44\%$, GAM = 50.72%), leaf weight ($h^2_{bs} = 86.82\%$, GAM = 61.16%), exudates yield per plant ($h^2_{bs} = 90.56\%$, GAM = 49.27%), leaf breadth ($h^2_{bs} = 89.57\%$, GAM = 38.66%), aloin content ($h^2_{bs} = 89.93\%$, GAM = 30.95%), aloin yield ($h^2_{bs} = 89.31\%$, GAM = 50.23%), dry gel yield ($h^2_{bs} = 91.11\%$, GAM = 64.41%) and leaf rind thickness ($h^2_{bs} = 80.00\%$, GAM = 26.25%). These results indicate the predominance of additive gene action, suggesting that direct selection for these traits would be effective.

However, gel content (%) exhibited high heritability with low genetic advance, suggesting the influence of non-additive gene action. In such cases, high heritability is likely due to environmental factors rather than genetic factors, making selection for these traits less effective. This study highlights that traits with high heritability and substantial genetic advance are ideal for direct selection, while those influenced by non-additive genetic effects require alternative breeding strategies to achieve genetic improvement.

Table 1. Mean performances in morphological and chemical characters among *Aloe barbadensis* genotypes

Accessions	Morphological characters							Chemical characters	
	Plant height (cm)	Leaves/plant	Leaf length (cm)	Leaf breadth (cm)	Leaf thickness (cm)	Spines/leaf	Suckers/plant	Gel content (%)	Aloin content (%)
IC 112521	53.70	6.61	44.94	6.32	1.31	44.61	8.56	96.94	16.79
IC 112527	66.70	10.28	53.82	7.61	3.47	53.48	5.72	97.30	23.08
IC 112531	54.37	8.61	47.48	7.57	1.32	47.15	7.63	96.06	20.97
IC 112532	54.94	9.61	44.98	8.67	2.31	44.65	6.74	96.86	19.22
IC 283652	65.04	11.61	55.14	10.62	3.44	54.26	4.75	94.98	25.40
IC 283655	49.37	11.28	54.87	10.60	3.38	53.54	5.84	96.00	25.64
IC 283670	62.37	8.45	54.48	8.06	2.06	44.15	6.50	97.64	20.48
IC 283928	62.00	9.95	46.93	9.34	2.24	46.60	5.17	97.07	20.20
IC 283932	52.34	10.55	47.04	9.67	2.06	46.71	6.00	96.88	24.13
IC 283934	63.34	8.71	51.71	7.41	1.00	41.37	7.45	94.00	15.53
IC 283943	67.34	9.38	50.48	7.88	1.91	50.15	8.79	96.46	17.00
IC 283945	61.34	9.55	50.82	9.73	2.05	50.48	6.96	97.43	19.24

IC 285626	50.34	9.55	43.52	9.50	2.15	43.18	5.67	97.41	23.46
IC 285629	55.67	10.66	45.74	8.77	2.11	45.41	5.00	96.02	23.82
IC 285630	51.80	9.11	48.76	8.42	2.24	48.42	6.61	96.92	21.55
IC 310594	38.27	6.88	31.96	6.02	2.27	31.63	7.41	96.88	25.75
IC 310596	47.10	13.31	43.81	10.01	2.09	43.47	7.57	97.12	19.44
IC 310609	43.20	8.91	41.12	9.50	1.75	40.78	6.17	97.68	20.54
IC 310618	52.60	11.35	50.85	8.00	2.41	40.52	6.34	96.46	20.04
IC 310619	59.94	9.98	47.63	9.93	2.01	37.30	8.09	97.20	22.50
IC 310623	58.27	10.98	45.72	9.03	1.91	40.38	8.57	97.29	27.07
GUJ 1	57.27	9.58	47.66	8.67	2.08	45.83	7.31	97.38	22.95
GUJ 2	54.60	10.81	45.94	8.90	2.72	45.61	5.45	94.68	21.90
K 98	55.94	8.81	45.38	9.12	2.17	45.05	9.34	97.35	13.96
MP 1	56.94	10.48	45.61	9.52	2.61	45.27	5.62	96.57	17.69
NMRM 2	50.27	8.81	42.61	8.13	2.31	42.27	6.17	97.50	26.90
SEm±	0.32	1.52	0.28	0.14	0.62	0.01	0.31	0.36	0.81
CD at 5%	0.93	4.42	0.80	0.39	1.81	0.02	0.91	1.04	2.34

Table 2. Mean performances in reproductive characters among *Aloe barbadensis* genotypes

Accessions	Inflorescence/ plant	Flowers/ inflorescence	Length of inflores- cence (cm)	Capsules/ inflores- cence	Seeds/ capsule
IC 112521	2.20	123.50	97.20	11.15	6.24
IC 112527	1.50	103.20	104.44	8.84	8.15
IC 112531	1.67	115.80	110.35	0.22	10.09
IC 112532	1.60	124.17	106.04	0.50	9.17
IC 283652	1.20	115.64	142.47	3.50	8.74
IC 283655	1.65	116.45	109.40	0.50	8.07
IC 283670	1.60	103.50	111.00	0.30	9.27
IC 283928	1.00	89.08	104.75	0.20	6.78
IC 283932	1.80	130.30	112.85	0.00	0.00
IC 283934	1.17	90.30	90.70	17.80	7.47
IC 283943	1.75	99.30	106.48	17.80	8.64
IC 283945	1.40	87.65	107.04	0.50	7.78
IC 285626	1.25	107.25	97.75	0.52	6.24
IC 285629	1.50	114.20	112.80	2.20	8.15
IC 285630	1.60	138.40	117.20	3.10	10.09
IC 310594	1.50	122.70	114.90	25.00	9.17
IC 310596	1.68	99.75	110.40	1.10	9.20
IC 310609	1.33	97.75	92.00	1.00	7.78
IC 310618	0.90	96.65	81.85	1.55	7.10
IC 310619	1.79	89.30	108.20	8.30	7.06
IC 310623	2.20	145.90	102.00	10.15	7.51
GUJ 1	1.10	94.80	104.00	3.10	10.59
GUJ 2	1.90	110.90	100.40	0.00	0.00
K 98	1.00	95.50	101.84	3.50	8.15
MP 1	0.63	60.38	52.88	4.90	7.07

NMRM 2	1.10	104.38	107.25	1.25	7.78
SEm±	0.286	15.43	14.71	1.17	0.46
CD at 5%	0.83	44.92	42.87	3.41	1.34

Table 3. Mean performances in yield characters among *Aloe barbadensis* genotypes

Accessions	Leaf weight (g)	Leaf yield (t ha ⁻¹)	Exudates yield plant ⁻¹	Exudates yield (kg ha ⁻¹)	Fresh gel yield (t ha ⁻¹)	Dry gel yield (t ha ⁻¹)	Aloin yield (kg ha ⁻¹)
IC 112521	151.99	45.93	4.47	189.45	44.56	1.39	31.95
IC 112527	261.86	88.84	9.69	258.89	70.31	1.91	59.64
IC 112531	146.93	55.64	5.94	220.00	45.30	1.78	46.27
IC 112532	148.48	58.71	5.12	165.56	47.86	1.51	31.95
IC 283652	278.11	91.46	8.15	251.67	68.27	3.43	63.82
IC 283655	245.18	98.20	8.62	248.26	78.12	3.14	63.62
IC 283670	243.35	76.73	6.35	235.19	45.59	1.09	48.23
IC 283928	248.18	76.88	6.28	232.60	61.36	1.84	47.04
IC 283932	252.74	103.20	9.94	257.63	81.16	2.53	62.21
IC 283934	106.11	44.00	7.23	196.12	36.50	2.20	30.52
IC 283943	162.27	56.18	4.75	324.07	56.24	1.90	55.00
IC 283945	253.54	85.47	7.58	299.26	67.48	1.74	57.51
IC 285626	199.53	79.44	7.69	276.67	62.56	1.63	64.87
IC 285629	242.13	89.6	9.63	289.67	70.24	2.81	69.00
IC 285630	171.63	75.13	6.65	246.30	60.22	1.86	53.13
IC 310594	96.45	41.74	5.05	186.74	34.69	1.10	47.79
IC 310596	182.60	82.64	8.31	307.59	67.31	1.95	59.51
IC 310609	120.01	56.55	4.91	181.86	45.79	1.06	37.33
IC 310618	339.63	117.6	8.32	315.00	93.55	3.32	62.50
IC 310619	325.88	114.48	8.11	269.63	90.20	2.54	60.66
IC 310623	290.91	114.52	10.31	270.37	91.07	2.48	74.80
GUJ 1	245.04	89.15	8.00	296.30	70.35	1.86	68.15
GUJ 2	189.67	93.86	7.13	263.89	72.70	3.87	57.71
K 98	127.00	60.89	3.56	131.85	50.39	1.33	18.41
MP 1	189.99	83.38	7.49	277.04	66.80	2.30	49.26
NMRM 2	127.14	63.80	9.86	278.15	52.39	1.32	73.10
SEm±	18.05	3.54	0.42	16.97	3.53	0.25	3.38
CD at 5%	52.57	10.31	1.22	49.41	10.26	0.71	9.86

Table 4. Genetic parameters for various traits in *Aloe barbadensis* genotypes

Traits	Mean ± SE	Range	σ^2_g	σ^2_p	GCV (%)	PCV (%)	$h^2_{(bs)}$ (%)	$h^2_{(bs)}$ inference	GA %	GA % inference
Plant height (cm)	55.58± 0.75	38.27 - 67.34	48.35	49.45	12.51	12.66	97.78	High	25.49	High
Leaves per plant	9.65±0.32	6.61 - 13.31	2.31	2.52	19.88	20.73	91.95	High	39.26	High
Leaf length (cm)	47.27±1.52	31.96 - 55.14	22.35	26.95	10.01	10.99	82.93	High	18.77	Moderate

Leaf breadth (cm)	8.74±0.28	6.02 - 10.62	1.30	1.45	19.83	20.95	89.57	High	38.66	High
Leaf thickness (cm)	2.21±0.14	1.00 - 3.47	0.33	0.36	25.89	27.22	90.44	High	50.72	High
Spines/ leaf	45.09±0.62	31.63 - 54.26	25.01	25.77	11.09	11.26	97.02	High	22.51	High
Leaf rind thickness (cm)	0.15±0.01	0.12 - 0.19	0.01	0.01	14.23	15.91	80.00	High	26.25	High
Suckers/ plant	6.75±0.31	4.75 - 9.34	1.47	1.66	17.95	19.09	88.41	High	34.77	High
Inflorescence/ plant	1.43±0.286	0.63 - 2.20	0.35	1.62	37.19	79.98	21.61	Low	35.62	High
Flowers/ inflorescence	106.79±15.43	60.38 - 145.9	91.58	567.48	8.96	22.30	16.13	Low	7.41	Low
Length of inflorescence (cm)	104.08±14.71	52.88 - 142.47	10.07	443.39	3.04	20.23	2.27	Low	0.94	Low
Capsules/ inflorescence	4.87±1.17	0.00 - 25.00	48.25	48.35	155.3	155.48	99.79	High	319.6	High
Seeds/ capsule	7.55±0.46	6.24-10.54	6.02	6.44	32.51	33.63	93.4	High	64.70	High
Gel content (%)	96.7±0.36	94.00 - 97.68	0.75	1.00	0.90	1.03	74.77	High	1.59	Low
Aloin content (%)	21.36±0.81	13.96 - 27.07	11.44	12.72	15.84	16.71	89.93	High	30.95	High
Leaf weight (g)	205.63±18.05	96.45-339.63	4293.82	4945.55	31.86	34.20	86.82	High	61.16	High
Leaf yield (t ha ⁻¹)	78.62±3.54	41.74 - 117.6	467.33	492.39	27.5	28.23	88.50	High	55.19	High
Exudates yield plant ⁻¹	7.28±0.42	3.56 - 10.31	3.35	3.69	25.14	26.41	90.56	High	49.27	High
Exudates yield (kg ha ⁻¹)	248.83±16.97	131.85 - 324.07	2122.10	2697.85	18.51	20.87	78.66	High	33.82	High
Fresh gel yield (t ha ⁻¹)	62.74±3.53	34.69 - 93.55	254.24	279.05	25.42	26.63	93.60	High	49.98	High
Dry gel yield (t ha ⁻¹)	2.08±0.25	1.06 - 3.87	0.52	0.64	34.6	38.29	91.11	High	64.41	High
Aloin yield (kg ha ⁻¹)	53.61±3.38	18.41-74.80	191.40	214.30	25.80	27.30	89.31	High	50.23	High

σ_g^2 : Genotypic variance; σ_p^2 : Phenotypic variance; GCV: Genotypic Coefficient of Variation; PCV: Phenotypic Coefficient of Variation; $h^2_{(bs)}$: Heritability (Broad Sense); GA: Genetic Advance.

Conclusion

Among the accessions studied, IC 310623 is superior in terms of leaf yield, gel yield and aloin yield with high aloin content and hence can be selected as a superior genotype for both medicinal and cosmetic purposes. Considering GCV,

heritability and genetic advance, it can be concluded that selection for increasing leaf yield should be made by giving the highest priority to characters *viz.*, leaves per plant, leaf breadth, leaf thickness, leaf weight and exudates yield per plant. These characters should be given due importance during the planning of breeding strategy in aloe.

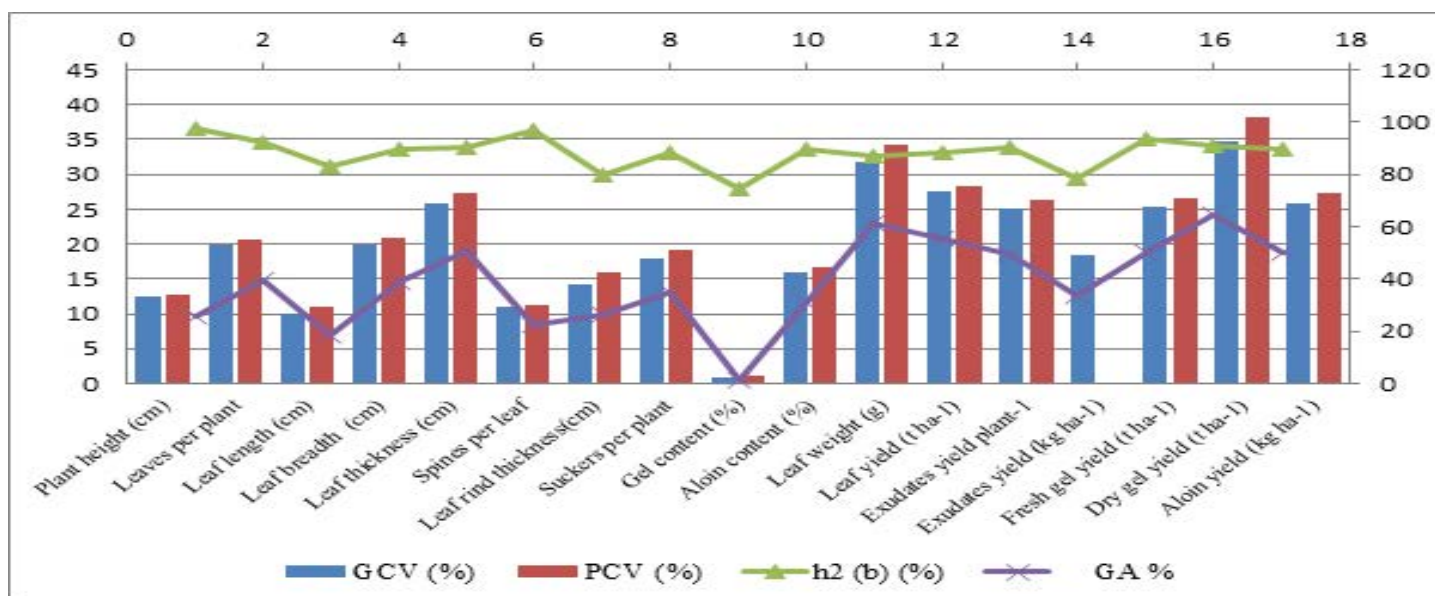


Fig. 1. Genetic parameters of morphological and yield characters

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Enhancing performance and profitability of bottle gourd (*Lagenaria siceraria*) through growing methods and bio-regulators in semi-arid region

Pooja Devi Meena¹, O.P. Garhwal², L.N. Bairwa³, R.K. Bagri⁴, O.P. Meena⁵, R.N. Sharma⁶, Uadal Singh⁷ and R.K. Sharma⁸

^{1,2,3}Deptt. of Horticulture, SKNAU, Jobner, Jaipur-303329, Rajasthan

⁴Deptt. of Plant Pathology, RARI, Durgapura

⁵Deptt. of Agronomy, RARI, Durgapura

⁶Deptt. of Extension Education, SKNAU, Jobner

⁷Deptt. of Horticulture, RARI, Durgapura

⁸Deptt. of Seed technology, COH&F, Jhalawar

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ABSTRACT

The study revealed the different treatment combination of growing methods (vertical and horizontal) and foliar application of bio-regulators (control, NAA at 200 ppm, GA₃ at 150 ppm, ethrel at 200 ppm, and salicylic acid at 150 ppm) in bottle gourd significantly influenced the yield, quality and profitability of bottle gourd in semi-arid conditions. The results indicated that the vertical trailing system registered significantly higher vine length (70.12 cm), number of nodes (25.86), number of leaves (24.73), leaf area (518.18 cm²), fruit length (17.70 cm), number of fruits/ vine (4.08), fruit weight (0.78 kg), fruit yield/ vine (3.19 kg), TSS (3.96 %), total sugar (3.07 g/100 g), crude protein (0.51%) and Ascorbic acid (11.72 mg/100g). Similarly, foliar application of GA₃ at 50 ppm registered maximum vine length (67.83 cm), number of nodes (25.76), number of leaves (24.30), leaf area (523.14 cm²), fruit length (17.92 cm), number of fruits/ vine (4.13), fruit weight (0.77 kg), fruit yield/ vine (3.16 kg), TSS (3.91%), total sugar (3.08 g/100 g), crude protein (0.52 %) and Ascorbic acid (11.44 mg/100g) and greater net returns as compared to control.

Introduction

Bottle gourd [*Lagenaria siceraria* (Mol.) Stand L.] is a commonly grown and used vegetable in India. It belongs to the family Cucurbitaceae. Besides being an important vegetable crop, it also has good medicinal as well as nutritional value. The fruits are also used as a vegetable or for making sweets (*halwa*, *kheer*, *petha*, *barfi*, and pickles). It is economically found growing in Ethiopia, Africa, and Central America. In India, bottle gourd is grown on an area of 200,000 hectares with an annual production of 3274,000 metric tonnes (Anonymous, 2023). It occupies 5200 hectares

of land in Rajasthan, producing 26982 metric tonnes (Anonymous, 2023).

The traditional method of planting bottle gourd tends to restrict light penetration to lower leaves and thus reduce the photosynthetic efficiency. The dense vine canopy also hampers proper air circulation and enhances high humidity, which can promote the occurrence and spread of diseases. As vining plant, bottle gourd grows best with support, which keeps them off the ground and encourages straight fruit growth. Since trailing allows vertical growth instead of sprawling all over the plot, it not only keeps the produce off the ground, but it also allows for the growth of more plants

Corresponding author

Email: poojameena480@gmail.com (P.D. Meena)

in a smaller area.

The yield of cucurbit depends to a great extent on sex expression and sex ratio. Early nodes bear male flowers and higher amounts, whereas hermaphrodites and pistillate flowers are found in later nodes. These results in delaying harvesting as well as yield reduction. The problem can be overcome by the exogenous application of plant growth regulators as well as bio-regulators. The host of physiological processes involved in crop development, such as blooming and fruiting, are controlled by plant growth regulators. Additionally, they are employed in the germination, inhibition of growth and post-harvest ripening of assimilates. Bio-regulators are employed in very tiny amounts to control plant development. They also govern the development of the shoot and the root. Bio-regulators directly affect male and female flower ratio, fruit set, fruit drop, and ultimately yield (Bose *et al.*, 1999). Therefore, the use of bio-regulators like NAA, ethrel, and GA₃ in bottle gourd may become an important tool for yield enhancement as well as timely harvest. Thus, the study was undertaken to investigate the effect of vertical trailing system and bio-regulators on yield and quality of bottle gourd.

Material and Methods

The field experiment was conducted during the summer seasons of 2022 and 2023 on bottle gourd cv. Pusa Santushti at the Horticulture Farm, Rajasthan Agricultural Research Institute, Jaipur, Rajasthan, India. The experimental site is situated at 26.50° North latitude and 75.47° East longitude at an altitude of 390 meters above mean sea level. In Rajasthan, this region falls under agro-climatic zone-III A (Semi-Arid Eastern Plains). The region has a typically semi-arid climate characterized by dry atmosphere.

The experiment consisted of 10 treatment combinations with two growing methods and five levels of bio-regulators in a factorial randomized block design with three replications. In growing method, vertical trailing system (G₁) and horizontal/traditional system (G₂) were used to raise the crop. The five levels of bio-regulators viz., control (B₁), NAA at 200 ppm (B₂), GA₃ at 50 ppm (B₃), ethrel at 200 ppm (B₄), and salicylic acid at 150 ppm (B₅) were applied as a foliar spray at 2-true leaf stage. Appropriate standard and uniform agronomical and cultural practices and plant protection measures were adopted for raising a healthy crop. The observations on growth and yield parameters were recorded during the investigation on five plants, which were randomly selected from each treatment.

Total soluble solids (TSS) per cent of randomly selected fruits was determined with the help of a digital refractometer at the time of harvesting fruits. The total sugar content, protein content, and ascorbic acid content of the fruit were determined following the procedures outlined by A.O.A.C. (1980).

In calculating the benefit:cost, only fruit yield has been considered as the product. The total cost of cultivation and gross income were estimated on the basis of the average fruit yield per hectare for each treatment. The cost of cultivation included money spent on preparatory tillage, seed costs, plant growth regulators (NAA, GA₃, ethrel, and salicylic acid), manures and fertilizers, irrigation, weeding, interculture operations, plant protection, harvesting, and various labour charges, etc. The gross income was estimated by calculating returns from the sale of fruits. The net income was calculated by deducting the total cost of cultivation from the gross income.

Results and Discussion

The growing method and foliar spray of bio-regulators had a significant impact on the growth parameters of bottle gourd (Table 1). The vertical trailing system registered higher vine length (70.12 cm), number of nodes (25.86), number of leaves (24.73), leaf area (518.18 cm²) and number of secondary branches (4.04) at 45 DAS over the traditional method of growing. However, it did not affect the number of primary branches, which remained consistent at 5.34, showing no significant difference. The trailing system provided better scope for plants to exploit sunlight, which resulted in higher photosynthetic activity, assimilation of carbohydrates and increased plant growth. The results corroborate the findings of Kalyanrao *et al.* (2012), Sharma *et al.* (2016) and Singh *et al.* (2023) in bottle gourd.

The results clearly demonstrate that foliar application of GA₃ at 50 ppm significantly increased the vine length (67.83 cm), number of nodes (25.76), number of leaves (24.30), leaf area (523.14 cm²) and number of primary branches (5.52) as compared to other treatments in pooled analysis. However, the number of secondary branches were recorded higher with the foliar application of ethrel at 200 ppm, followed by GA₃ at 50 ppm. The results are in agreement with Soni *et al.* (2015) and Ansari and Chowdhary (2018).

The pooled data on yield and yield-attributing characters presented in Table 2 indicate a significant difference in the effect of growing methods and bio-regulators on bottle gourd. It indicated that significantly higher fruit length (17.70 cm), number of fruits/ vine (4.08), average fruit weight (0.78 kg), fruit yield/ vine (3.19 kg) and marketable fruit yield/ ha (255.06 q) were recorded with the trailing method as compared to the traditional method. The better fruit length in trailing may be due to the gravitational force and the better fruit weight may result from the translocation of more dry matter from the source to these components, which have significant growth characteristics. These results are in conformation with the results of Kalyanrao *et al.* (2012) in bottle gourd, Ahmed *et al.* (2021) in ridge gourd, and Khan *et al.* (2021) in bitter gourd.

Table 1. Effect of growing methods and bio-regulators on growth parameters of bottle gourd

Treatments	Vine length (cm) (45 DAS)			No. of nodes			No. of leaves			Leaf area (cm ²)			No. of primary branches			No. of secondary branches		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
(A.) Growing methods																		
Trailing method (G ₁)	70.25	70	70.12	25.71	26.02	25.86	24.66	24.80	24.73	513.60	522.77	518.18	5.25	5.43	5.34	4.07	4.02	4.04
Traditional method (G ₂)	57.78	59.46	58.62	23.00	23.15	23.07	21.73	22.29	22.01	467.44	477.59	472.51	5.03	5.19	5.11	3.66	3.95	3.81
SEm±	1.06	1.01	0.73	0.37	0.38	0.26	0.33	0.51	0.30	6.93	7.81	5.22	0.07	0.08	0.05	0.05	0.06	0.04
CD (P=0.05)	3.14	2.99	2.09	1.09	1.12	0.76	0.99	1.51	0.87	20.60	23.22	14.98	NS	NS	NS	0.16	0.17	0.11
(B.) Bio-regulators																		
Control (water spray) B ₁	57.65	58.44	58.05	22.15	22.69	22.42	20.92	21.12	21.02	442.14	453.48	447.81	4.61	4.75	4.68	3.43	3.55	3.49
NAA @ 200 ppm (B ₂)	66.76	67.19	66.98	25.26	25.35	25.31	23.81	24.21	24.01	512.42	515.62	514.02	5.32	5.49	5.41	3.98	4.16	4.07
GA ₃ @ 50 ppm (B ₃)	67.56	68.1	67.83	25.69	25.82	25.76	24.10	24.49	24.30	516.81	529.46	523.14	5.42	5.61	5.52	4.10	4.18	4.14
Ethrel @ 200 ppm (B ₄)	67.1	67.82	67.46	25.46	25.51	25.49	23.92	24.35	24.14	515.69	523.85	519.77	5.39	5.56	5.48	4.12	4.21	4.17
Salicylic acid @ 150 ppm (B ₅)	61.01	62.1	61.56	23.20	23.54	23.37	22.23	22.54	22.39	465.52	478.49	472.01	4.96	5.12	5.04	3.69	3.82	3.76
SEm±	1.67	1.59	1.15	0.58	0.60	0.42	0.52	0.80	0.48	10.96	12.36	8.26	0.12	0.12	0.08	0.08	0.09	0.06
CD (P=0.05)	4.97	4.73	3.31	1.72	1.78	1.19	1.56	2.38	1.37	32.57	36.71	23.69	0.34	0.36	0.24	0.25	0.26	0.18

Table 2. Effect of growing methods and bio-regulators on yield attributes and yield of bottle gourd

Treat- ments	Fruit length (cm)			No. of fruits/ vine			Fruit weight (kg)			Fruit yield/ vine (kg)			Fruit yield (q/ ha)		
	2021- 22	2022- 23	Pooled	2021- 22	2022- 23	Pooled	2021- 22	2022- 23	Pooled	2021- 22	2022- 23	Pooled	2021- 22	2022- 23	Pooled
Growing methods															
Trailing method (G ₁)	17.62	17.78	17.70	4.06	4.11	4.08	0.77	0.79	0.78	3.12	3.26	3.19	249.39	260.73	255.06
Tradi- tional method (G ₂)	16.93	17.06	17.00	3.98	4.03	4.01	0.68	0.69	0.68	2.69	2.76	2.73	214.95	221.19	218.07
SEm±	0.19	0.2	0.14	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.05	0.03	3.25	3.42	2.38
CD (P=0.05)	0.57	0.58	0.39	0.06	0.07	0.04	0.02	0.03	0.02	0.11	0.16	0.09	9.67	10.17	6.83
(B.) Bio-regulators															
Control (water spray) B ₁	16.25	16.42	16.34	3.88	3.93	3.91	0.68	0.69	0.68	2.62	2.69	2.65	209.32	215.21	212.26
NAA @ 200 ppm (B ₂)	17.45	17.64	17.55	4.05	4.10	4.08	0.73	0.75	0.74	2.94	3.06	3.00	235.14	244.63	239.89
GA ₃ @ 50 ppm (B ₃)	17.88	17.96	17.92	4.1	4.15	4.13	0.76	0.78	0.77	3.10	3.22	3.16	247.95	257.6	252.78
Ethrel @ 200 ppm (B ₄)	17.65	17.72	17.69	4.08	4.13	4.11	0.73	0.76	0.74	2.96	3.12	3.04	237.02	249.78	243.4
Salicylic acid @ 150 ppm (B ₅)	17.16	17.35	17.26	3.99	4.04	4.02	0.73	0.74	0.73	2.89	2.97	2.93	231.44	237.57	234.5
SEm±	0.3	0.31	0.22	0.03	0.04	0.02	0.01	0.02	0.01	0.06	0.08	0.05	5.15	5.41	3.76
CD (P=0.05)	0.9	0.92	0.62	0.1	0.11	0.07	0.04	0.05	0.03	0.17	0.25	0.15	15.29	16.09	10.79

Table 3. Effect of growing methods and bio-regulators on quality parameters of bottle gourd

Treatments	TSS content (%)			Total sugar content (g/100g)			Crude protein (%)			Ascorbic acid (mg/100g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
(A.) Growing methods												
Trailing method (G ₁)	3.95	3.98	3.96	3.08	3.06	3.07	0.5	0.52	0.51	11.7	11.73	11.72
Traditional method (G ₂)	3.44	3.46	3.45	2.67	2.79	2.73	0.44	0.47	0.46	10.05	10.18	10.11
SEm±	0.05	0.04	0.03	0.02	0.03	0.02	0	0.01	0.00	0.12	0.12	0.09
CD (P=0.05)	0.16	0.11	0.09	0.07	0.08	0.05	0.01	0.02	0.01	0.37	0.37	0.25
(B.) Bio-regulators												

Control (water spray) B ₁	3.32	3.34	3.33	2.57	2.61	2.59	0.43	0.46	0.45	9.82	9.88	9.85
NAA @ 200 ppm (B ₂)	3.84	3.81	3.83	2.95	3.01	2.98	0.48	0.5	0.49	11.26	11.36	11.31
GA ₃ @ 50 ppm (B ₃)	3.88	3.94	3.91	3.05	3.1	3.08	0.51	0.52	0.52	11.41	11.46	11.44
Ethrel @ 200 ppm (B ₄)	3.86	3.88	3.87	2.99	3.05	3.02	0.49	0.51	0.51	11.35	11.42	11.39
Salicylic acid @ 150 ppm (B ₅)	3.58	3.61	3.60	2.82	2.85	2.84	0.45	0.48	0.47	10.54	10.65	10.60
SEm±	0.08	0.06	0.05	0.04	0.04	0.03	0.01	0.01	0.01	0.20	0.20	0.14
CD (P=0.05)	0.25	0.17	0.15	0.12	0.13	0.08	0.02	0.03	0.02	0.59	0.58	0.40

Table 4. Effect of growing methods and bio regulators on economics of bottle gourd

Treatments	Season	Common cost (₹/ ha)	Treatment cost (₹/ ha)	Total cost (₹/ ha)	Yield (q/ ha)	Gross return (₹/ ha)	Net returns (₹/ ha)	B:C ratio
G ₁ B ₁	2022	81568	24800	106368	188.00	206928	100560	1.95
	2023	81568	24800	106368	196.63	235953	129585	2.22
G ₁ B ₂	2022	81568	25008	106576	262.00	287993	181417	2.70
	2023	81568	25008	106576	277.92	333506	226930	3.13
G ₁ B ₃	2022	81568	26000	107568	282.00	309770	202202	2.88
	2023	81568	26000	107568	294.71	353648	246080	3.29
G ₁ B ₄	2022	81568	25248	106816	277.00	304632	197816	2.85
	2023	81568	25248	106816	289.95	347945	241129	3.26
G ₁ B ₅	2022	81568	24998	106566	235.00	258900	152334	2.43
	2023	81568	24998	106566	241.25	289503	182937	2.72
G ₂ B ₁	2022	81568	0	81568	224.00	246740	165172	3.02
	2023	81568	0.00	81568	227.51	273014	191446	3.35
G ₂ B ₂	2022	81568	208	81776	208.00	229326	147550	2.80
	2023	81568	208	81776	211.34	253610	171834	3.10
G ₂ B ₃	2022	81568	1200	82768	214.00	235729	152961	2.85
	2023	81568	1200	82768	220.50	264601	181833	3.20
G ₂ B ₄	2022	81568	448	82016	197.00	216808	134792	2.64
	2023	81568	448	82016	209.61	251535	169519	3.07
G ₂ B ₅	2022	81568	198	81766	218.00	239832	158066	2.93
	2023	81568	198	81766	224.27	269121	187355	3.29

Bottle gourd sold @ ₹ 11/- per kg

The yield and yield attributes were significantly enhanced by the foliar application of GA₃ at 50 ppm. The maximum fruit length (17.92 cm), number of fruits/ vine (4.13), average fruit weight (0.77 kg), fruit yield/ vine (3.16 kg), and fruit yield/ ha (252.78 q) were recorded with the application of GA₃ at 50 ppm over other treatments in pooled data. The results obtained are in agreement with Hidayatullah *et al.* (2012), Wamiq *et al.* (2020) and Rapha (2022) in bottle gourd. It is evident from Table 3 that the growing methods and

bio-regulators also had a significant effect on the quality parameters of bottle gourd. The combined data on quality measures maximum TSS (3.96%), total sugar (3.07 g/100 g), crude protein (0.51 %) and ascorbic acid (11.72 mg/100g) content showed a considerable improvement in the trailing method compared to the traditional bottle gourd-growing method (Table 3). These results are in agreement with Kartika and Karyana (2017) in Sphagetti squash and Rajalingam *et al.* (2017) in cucumber.

Among the bioregulators the highest values of the TSS (3.91%), total sugars (3.08 g/100 g), crude protein (0.52%) and ascorbic acid content (11.44 mg/100 g) in pooled analysis of bottle gourd fruit tissues were gained by foliar spray of GA₃ as compared to other treatments and control. The findings corroborate the results obtained by Shafeek *et al.* (2016) in summer squash, Kadi *et al.* (2018) in cucumber, Anayat *et al.* (2020) in bitter gourd and Pandey *et al.* (2021) in cucumber.

The data presented in Table 4 clearly indicates that the net returns and B:C ratio of bottle gourd were significantly impacted by the growing methods and bioregulators. In a pooled analysis, the maximum and significantly higher net returns (₹ 186824 per ha) were recorded using the trailing way of growing as opposed to the traditional method. With the exception of ethrel at 200 ppm, which was deemed to be at par in the pooled analysis, the application of GA₃ at 50 ppm obtained the largest and noticeably greater net returns (₹ 195919 per ha) over control.

In a pooled examination, bottle gourd grown using the traditional approach had a maximum and noticeably better B:C ratio (3.06) than those grown using the trailing method. The foliar spraying of GA₃ at 50 ppm considerably boosted the B:C ratio. During the testing, it registered the highest and noticeably better bottle gourd B:C ratio (3.06) than control in pooled analysis. Nonetheless, in the pooled analysis, the foliar application of NAA at 200 ppm, ethrel at 200 ppm and salicylic acid at 150 ppm remained comparable to one another.

Conclusion

In conclusion, the bottle gourd cultivar 'Pusa Santusthi', when grown using the trailing method (vertical system) and sprayed at 2-true leaf stage with a 50 ppm foliar spray of GA₃, produced a significantly higher marketable fruit yield and superior quality fruits, resulting in maximum net returns under semi-arid conditions.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Effect of planting time and variety on growth and yield attributes of tomato in semi-arid conditions of Rajasthan

Uadal Singh, Y.K. Sharma, R.K. Bagri, A.K. Choudhary and A.K. Mahawar

Rajasthan Agricultural Research Institute, Durgapura, Jaipur (Rajasthan)

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ABSTRACT

During the experimentation studied the effect of five planting time and three varieties of tomato during winter season of 2019-2020, 2020-21 and 2021-22. During the experiment three tomato variety viz. WS-1299 (V_1), Krishna (V_2) and Bavandar (V_3) were studied with five different dates of planting viz. 30 December (D_1), 15 December (D_2), 15 January (D_3), 30 January (D_4) and 15 February (D_5). In which the yield of tomato was significantly affected by different sowing dates and varieties. Among varieties and planting dates the variety Bavandar (V_3) planted on 15 January (D_3) produced significantly higher number of fruits/ plant (39.70), fruit weight (83.25 g) and fruit yield (727.20 q/ ha) with the maximum B:C ratio (4.05).

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important and second largest cultivated vegetable crop and one of the most widely consumed vegetable crop in the world after potato, with cultivation covering an area of 5.03 million hectare and a production of about 180 million MT (FAO, 2022). It played an important role in human diet and known as protective food because of its special nutritive value (Boeing *et al.*, 2012 and Kibr, 2022).

In India, tomato crop occupies an area of 0.81 million ha with an annual production of 20.57 million MT (Anonymous, 2020). However, the production is far away from the requirement of the Indian population, if balanced diet is

provided to every individual. In Rajasthan state, tomato is an important vegetable crop that fetches great remuneration to the farmers and it is cultivated in open as well as in protected environment. In Rajasthan, total production of tomato is 2,32,864 Metric tons from an area of 20,504 hectares primarily under irrigated conditions with a productivity of 11.36 tons per hectare (Anonymous, 2021).

The commercial production of tomato particularly grown under open field conditions is severely affected by various weather parameters like temperature, rainfall and humidity etc., and ultimately affect the yield and quality of fruits. The temperature plays an important role in the growth and setting of the fruits in tomato crop (Yadav *et al.*, 2021). The fruits in tomato sets in certain varieties with temperature as low (7.2°C) and with temperature as high (26.6°C) had created

Corresponding author

Email: usingh.horti@sknau.ac.in (Dr. Uadal Singh)

more flexible situation in respect of the variety temperature interactions (Curme, 1992; Schaible, 1990).

Climate change is a major challenge for tomato growing farmers not only in India but all over the world also. The productivity of Tomato at particular location depends on the potential of the variety grown and timely availability of resources (Isah *et al.*, 2014). Considering the aforementioned background, the present study aims to identify a suitable planting date for a particular variety assess the impact of variety of tomato to increase production and economic return to the farmers under Rajasthan conditions.

Material and Methods

The field experiment was conducted at Horticulture Research Farm, Rajasthan Agricultural Research Institute, Durgapura, Jaipur (Rajasthan) during 2019-2020, 2020-21 and 2021-22 from mid-April to the end of October. It is situated at 390 meter above mean sea level on latitude 26.50°N and longitude 75.47°E. The soil of the experimental field is characterized as a sandy-loam with pH (8.0), electrical conductivity (0.17 d Sm⁻¹), organic carbon (0.26%), available nitrogen (135 kg/ha), available phosphorus (48 kg/ha) and available potassium (90 kg/ha).

The experiment was laid out in factorial randomized block design replicated thrice with five dates of planting and three varieties. The planting dates comprised of 15 December (D₁), 30 December (D₂), 15 January (D₃), 30 January (D₄) and 15 February (D₅). The three varieties viz., WS-1299 (V₁), Krishna (V₂) and Bavandar (V₃) were included as sub treatments. A total of 15 treatment combinations were studied. Varieties were selected based on their adaptability to the environmental conditions of the experimental site, resistance to pests, and potential for higher net returns.

The 30 days old, seedlings raised in pro-trays following organic regulation were transplanted in the field at a spacing of 60 cm (RxR) x 50 cm (PxP). The recommended dose of nitrogen, phosphorus, and potassium was applied @ 120:80:80 kg per hectare, respectively. The full dose of phosphorus and potassium was applied as a basal dose, while nitrogen was applied in three equal split doses.

Data on different characters like plant height (cm), number of fruits/ plant, fruit weight (g), TSS (%), fruit length (cm), fruit girth (cm) and fruit yield (q/ha) were recorded on five randomly selected plants from each treatment. Net returns and the B:C ratio were calculated based on total variable cost and gross returns, following the methods suggested by Devasenapathy *et al.* (2008). The data were analyzed statistically using one-way ANOVA. Significant differences between treatments were determined using Duncan's test with a 95% confidence level ($p \leq 0.05$), employing SPSS software.

Results and Discussion

The analysis of the data presented in Table 1 revealed that the combined effect of planting date and variety had a significant impact on the growth, yield, and quality traits of tomato. The maximum plant height was recorded in Bavandar variety when planted on 30 December, which was at par with planting of 15 January. While it was lowest in the variety Bavandar planted on 15 February. Shrivika *et al.* (2020) reported the significant effect on growth parameters of among the tomato varieties and planting dates.

The maximum number of marketable fruits per plant (39.70) and fruit weight (83.25 g) were observed in variety 'Bavandar' with planting on 15 January which is at par with 30 December planting date with Bavandar (38.38 and 82.50 g) which were statistically significant compared to other planting dates. Shreejana (2021) also reported that the number of fruits showed a positive correlation for early and normally sown plants, while it decreased for late-sown plants.

In the present experiment, TSS of the tomato fruits varied from 2.20 to 3.04°Brix among the tomato varieties and planting dates (Table 1). The TSS of fruits was found to be influenced by all the planting dates and tomato varieties throughout the experiment. The maximum TSS was recorded in the 'Bavandar' variety for all planting dates, except for February 15. In contrast, the lowest TSS was observed in the 'Krishna' variety for all sowing dates, except for the planting on February 15. The results are in corroboration with the findings of Purkayastha and Mahanta (2011).

Among the tomato varieties and planting dates, significantly lengthy tomato fruits (5.55 cm) were observed in tomato variety 'Bavandar' when planted on 30 December, followed by the same variety when planted on 15 January as compare to the other treatments (Table 1). Similar results were also reported by Sahoo *et al.* (2021). The highest fruit girth (5.56 cm) was significantly higher in the variety Bavandar when planted on 30 December (D₁V₃) at par with the variety 'Krishna' (5.50) when planted on 15 January (D₃V₂).

The highly significant differences were observed among the varieties for marketable fruit yield. Among all tomato varieties, the maximum fruit yield was recorded in Bavandar variety (727.20 q/ha) planted on 15 January which was significantly superior over all other varieties followed by the same variety when planted on 30 December (704.31 q/ha).

The economics of the experiment presented in Table 2 & Figure 1, revealed a wide variation in gross return as well as net return obtained by the sale price of the tomatoes. Tomato variety 'Bavandar' earned comparatively higher net return of Rs. 8.0 Lakh/ha, Rs. 4.39 Lakh/ha, Rs. 8.75 Lakh/ha, and Rs. 6.21 Lakh/ha with the planting time of D₁, D₂, D₃ and D₄, respectively. 'Bavandar' variety recorded highest B:C ratio of 4.06 when planted on 15 January (D₃V₃) followed by 3.13 in Bavandar variety planted on 30 December.

Table 1. Effect of date of planting and different varieties on growth and yield parameters of tomato (3 years pooled data)

Treatment	Plant height (cm)	No. of fruits/ plant	Fruit weight (g)	TSS (%)	Fruit length (cm)	Fruit girth (cm)	Fruit yield (q/ ha)
D ₁ V ₁	55.00	32.14	76.47	2.62	4.86	4.78	387.01
D ₁ V ₂	54.42	32.41	76.85	2.20	4.41	5.26	458.99
D ₁ V ₃	64.46	38.38	82.50	3.04	5.55	5.56	704.31
D ₂ V ₁	51.22	29.53	71.32	2.35	4.09	5.04	307.19
D ₂ V ₂	46.38	30.57	75.05	2.29	4.57	5.11	302.81
D ₂ V ₃	54.41	31.64	76.25	2.55	4.46	5.05	463.17
D ₃ V ₁	56.70	34.81	78.10	2.58	5.09	4.87	468.23
D ₃ V ₂	60.73	35.21	79.69	2.82	5.32	5.50	591.08
D ₃ V ₃	62.83	39.70	83.25	2.96	5.40	5.30	727.20
D ₄ V ₁	44.64	33.34	77.15	2.37	4.54	5.04	432.09
D ₄ V ₂	49.04	34.08	79.39	2.26	4.54	5.06	474.03
D ₄ V ₃	56.24	35.71	81.11	2.84	5.28	5.18	558.32
D ₅ V ₁	43.02	23.96	69.35	2.38	4.44	5.04	344.18
D ₅ V ₂	47.85	26.89	68.94	2.48	4.43	4.70	305.94
D ₅ V ₃	40.80	28.59	69.20	2.28	4.21	4.49	303.85
SEm±	2.50	0.69	0.76	0.08	0.33	0.70	7.24
CD at 5%	7.23	2.00	2.21	0.22	0.97	2.03	20.96
CV (%)	8.23	3.68	1.73	5.28	1.22	2.39	2.75

Table 2. Effect of date of planting and different varieties on net returns and B:C ratio of tomato (3 years pooled data)

Treatments	Cost of cultivation (Rs. in Lakh/ ha)	Gross returns (Rs. In Lakh /ha)	Net returns (Rs. in Lakh/ ha)	B:C Ratio
D ₁ V ₁	2.56	5.80	3.24	1.27
D ₁ V ₂	2.56	6.89	4.33	1.69
D ₁ V ₃	2.56	10.56	8.00	3.13
D ₂ V ₁	2.56	6.14	3.58	1.40
D ₂ V ₂	2.56	6.06	3.50	1.36
D ₂ V ₃	2.56	6.95	4.39	1.71
D ₃ V ₁	2.16	7.02	4.86	2.25
D ₃ V ₂	2.16	8.87	6.71	3.11
D ₃ V ₃	2.16	10.91	8.75	4.06
D ₄ V ₁	2.16	6.48	4.32	2.00
D ₄ V ₂	2.16	7.11	4.95	2.29
D ₄ V ₃	2.16	8.37	6.21	2.88
D ₅ V ₁	2.16	5.16	3.00	1.39
D ₅ V ₂	2.16	4.59	2.43	1.12
D ₅ V ₃	2.16	4.56	2.40	1.11

Conclusion

In conclusion, the study revealed that the tomato yield for the Bavandar variety was significantly overestimated based on different planting dates. It was observed that transplanting

tomatoes between December 30 and January 15 proved beneficial. This timing helps avoid harsh environmental conditions, reduces pest and disease attacks, and ultimately enhances total production. Therefore, adjusting the planting dates within this window can lead to better yield and net return.

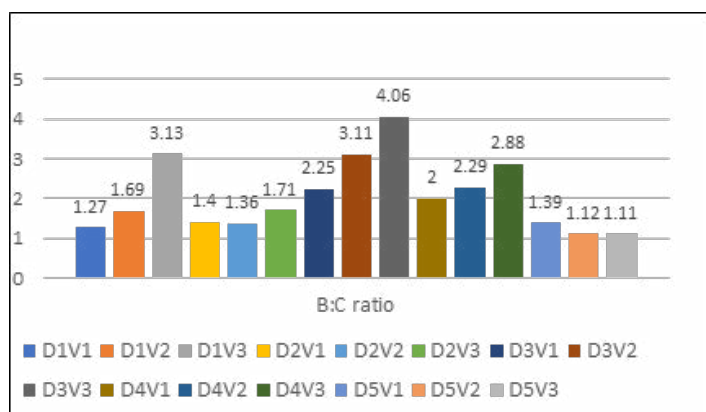


Fig. 1. Effect of planting date and varieties on B:C ratio

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Effect of organic manures and zinc in enhancing the growth, yield and quality of carrot (*Daucus carota* L.)

Neeru Rao, S. P. Singh and Kamlesh Kumar Yadav

Department of Horticulture, SKN Agriculture University, Jobner, 303329, Rajasthan, India

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ABSTRACT

The application of poultry manure applied at 4 t/ ha significantly improved plant height, number of leaves per plant, leaf area, root weight, root diameter, root length, root yield, as well as nitrogen and zinc content in carrot roots. Similarly, foliar application of ZnSO_4 @ 0.75% significantly improved the growth attributes, yield parameters, and quality characteristics such as nitrogen and zinc content in carrot roots. The combined application of poultry manure @ 4 t/ ha with ZnSO_4 @ 0.75% proved to be the most effective in improving growth, yield and quality of carrot.

Introduction

Carrot (*Daucus carota* L.) is an important vegetable crop widely consumed due to its high nutritional and medicinal value, as well as its role in disease prevention. It is a member of Apiaceae family. It is considered to be native of Mediterranean region. It consists of above 250 genera and approximately 2800 species of widely distributed, generally herbaceous plants (Rubatzky *et al.*, 1999). From a nutritional perspective, carrot is a highly valuable root crop. It contains appreciable amount of carotene, thiamine and riboflavin. It is an excellent source of carotene (10 mg/100g), thiamine (0.04 mg/100g), riboflavin (0.05 mg/100g) and also serves as source of carbohydrate, protein, fat, minerals, iron, Vitamin A, Vitamin B, Vitamin C and sugar. Carrot is one of the important and major root vegetable used as salad and cooked vegetable, pickles, preserve, sweets, carrot powder, kanji an appetizing drink (Chadha, 2001).

Although carrots are known as medium feeders, they still

require a fertile soil, allowing for normal growth of plants. FYM is a source of food for the innumerable number of microorganisms and creatures like earthworm who breaks down these to micronutrients, which are easily absorbed by the plants. It plays a direct role in plant growth as a source of all necessary macro and micronutrient in available forms during mineralization, improving the physical and physiological properties of soils. Poultry manure is rich in nutrient content than many bulky manures. On an average, it contains 3 per cent N, 2.6 per cent P, 1.4 per cent K (Singh *et al.*, 2020).

Vermicompost is a nutrient-rich, microbiologically-active organic amendment that results from the interactions between earthworms and microorganisms during the breakdown of organic matter. It is stabilized, finely divided peat-like material with a low C:N ratio, high porosity and high water holding capacity.

Zinc affects many functions of the plant such as hormone movement, flowering and fruiting process, pollen

germination, carbohydrates and nitrogen metabolism and water relations in the plants. Zinc is a trace element that plays an essential role in several organisms, being essential for human and plants growth (Mohanta *et al.*, 2013).

Therefore, in the present research an attempt was made to investigate the effect of organic manures and zinc on growth, yield and quality related traits in order to get higher yields and economic returns per unit area.

Material and Methods

The current study was carried out at Experimental Farm of Department of Horticulture, SKN College of Agriculture, Jobner during October to January months of 2020-21. This location is geographically positioned at 26°5' North latitude, 75°20' East longitude and at an altitude of 427 meters above mean sea level. It falls under Agro-Climatic Zone-III A (Semi-Arid Eastern Plain Zone) of Rajasthan. The experiment was set up in a factorial randomized block design with three replications. It consisted of 16 treatment combinations comprising four levels of organic manure (control, FYM @ 12 t/ ha, vermicompost @ 3.5 t/ ha, and poultry manure @ 4 t/ ha) and four levels of zinc (control, ZnSO₄ @ 0.25%, ZnSO₄ @ 0.50%, and ZnSO₄ @ 0.75%). The treatments were applied during October 2020-21. Five randomly chosen and labelled plants per plot were used to collect the data before harvesting while after harvest five roots from each plant were taken for recording growth, yield and quality parameters. In order to evaluate the importance of variance in data derived from different growth, yield and quality characteristics, the Fisher (1950) randomized block design technique was utilized to apply analysis of variance.

Results and Discussion

The results presented in Table 1 demonstrate the effects of organic manures and zinc on the vegetative growth characteristics of carrot. The treatment T₃ (poultry manure @ 4 t/ ha) led to the maximum plant height at 50 DAS (41.16 cm), the highest number of leaves per plant at 50 DAS (8.64) and the largest leaf area per plant (1710.9 cm²), significantly surpassed T₀ (control), T₁ (FYM @ 12 t/ ha) and T₂ (vermicompost @ 3.5 t/ ha). These results are in close conformity with the findings of Duncan (2005), Bhattarai and Maharjan (2013) and Pal *et al.* (2021).

It is evident that the treatment Z₃ (ZnSO₄ @ 0.75 %), significantly maximum the plant height at 50 DAS (40.32 cm), number of leaves per plant at 50 DAS (8.27) and leaf area per plant (1696.45 cm²) which was significantly superior over Z₀, Z₁ and Z₂. The data showed that application of ZnSO₄ @ 0.75 % significantly increased the plant height, number of leaves per plant and leaf area per plant over control, ZnSO₄ @ 0.25% and ZnSO₄ @ 0.50%. The results are in align with the findings of Catmak (2000) and Dhaka *et al.* (2022).

Application of different organic manure and zinc significantly affected the average weight of root, diameter of root, length of root and root yield (Table 2 and Fig. 1). The administration of treatment of T₃ (poultry manure @ 4 t/ ha) yielded the highest attainment in average weight of root (186.95 g), length of root (22.19 cm), diameter of root (3.71 cm) and root yield (278.34 q/ha). The application of poultry manure at 4 t/ ha significantly improved root weight, diameter, length, and overall yield compared to the control. Previous studies of Dawuda *et al.* (2011), Mbatha *et al.* (2014) and Pal *et al.* (2021) support these findings. Additionally, the combination of organic matter with NPK improved root diameter (Mehedi *et al.*, 2012). Poultry manure promotes better arable growth and food production, aligning with prior research (Yourtchi *et al.*, 2013; Kumar *et al.*, 2014 and Rahman *et al.*, 2018).

The application of Z₃ (ZnSO₄ @ 0.75%) yielded the highest attainment in average weight of root (183.17 g), length of root (22.00 cm), diameter of root (3.65 cm) and root yield (277.39 q/ ha). The application of ZnSO₄ at 0.75% significantly improved carrot yield and attributes, including root weight, diameter, length, and overall yield. These findings align with previous studies on carrots and other vegetables as reported by Mohanta *et al.* (2013), Deepika *et al.* (2015), Pongener *et al.* (2018) and Alam *et al.* (2021).

It is amply clear from the data (Table 3) that different levels of organic manures and zinc significantly increased the N content and zinc content in roots of carrot. The maximum N content (0.351%) and zinc content (77.92 ppm) was recorded under treatment T₃ (poultry manure @ 4 t/ ha) which was significantly better than rest of the organic manures. These findings align with previous studies conducted by El-Tohamy *et al.*, 2011; Kumar *et al.* (2014) and Kashyap *et al.* (2014). The maximum N content (0.339%) and zinc content (78.39 ppm) was recorded under treatment Z₃ (ZnSO₄ @ 0.75%) which was significantly better than rest of the zinc application. These results are in agreement with the findings of Ramesh *et al.* (2015), Singh (2016) and Singh *et al.* (2020).

Table 1. Effect of organic manures and zinc on growth attributes of carrot

Treatments	Plant height at 50 DAS (cm)	Number of leaves per plant at 50 DAS	Leaf area (cm ²)
Organic manures			
T ₀ (Control)	30.12	5.45	1239.34
T ₁ FYM (12 t/ ha)	35.66	6.75	1551.64
T ₂ Vermicompost (3.5 t/ ha)	38.65	7.74	1668.67

T ₃ Poultry manure (4.0 t/ ha)	41.16	8.64	1710.85
SEm±	0.81	0.20	38.02
CD (P=0.05)	2.33	0.58	109.79
Zinc spray at 30 DAS			
Zn ₀ (Control)	30.07	5.44	1263.88
Z ₁ (ZnSO ₄ @ 0.25%)	36.27	6.94	1549.23
Z ₂ (ZnSO ₄ @ 0.50%)	38.93	7.93	1660.94
Z ₃ (ZnSO ₄ @ 0.75%)	40.32	8.27	1696.45
SEm±	0.81	0.20	38.02
CD (P=0.05)	2.33	0.58	109.79

Table 2. Effect of organic manures and zinc on yield attributes of carrot

Treatments	Average weight of root (g)	Length of root (cm)	Diameter of roots (cm)	Yield of roots (q/ ha)
Organic manures				
T ₀ (Control)	144.00	19.12	3.03	204.09
T ₁ FYM (12 t/ ha)	163.90	20.38	3.32	244.24
T ₂ Vermicompost (3.5 t/ ha)	177.26	21.42	3.53	267.95
T ₃ Poultry manure (4.0 t/ ha)	186.95	22.19	3.71	278.34
SEm±	2.99	0.41	0.05	5.08
CD (P=0.05)	8.64	1.19	0.16	14.67
Zinc spray at 30 DAS				
Zn ₀ (Control)	146.53	19.01	3.03	207.14
Zn ₁ (ZnSO ₄ @ 0.25%)	164.17	20.45	3.34	244.95
Zn ₂ (ZnSO ₄ @ 0.50%)	178.24	21.64	3.56	265.13
Zn ₃ (ZnSO ₄ @ 0.75%)	183.17	22.00	3.65	277.39
SEm±	2.99	0.41	0.05	5.08
CD (P=0.05)	8.64	1.19	0.16	14.67

Table 3. Effect of organic manures and zinc on N and Zn content in carrot

Treatments	N content (per cent)	Zn content (ppm)
Organic manures		
T ₀ (Control)	0.218	59.93
T ₁ FYM (12 t/ ha)	0.281	69.61
T ₂ Vermicompost (3.5 t/ ha)	0.321	75.89
T ₃ Poultry manure (4.0 t/ ha)	0.351	77.92
SEm±	0.004	0.71
CD (P=0.05)	0.013	2.05
Zinc spray at 30 DAS		
Z ₀ (Control)	0.218	59.92
Z ₁ (ZnSO ₄ @ 0.25%)	0.283	68.38
Z ₂ (ZnSO ₄ @ 0.50%)	0.330	76.66
Z ₃ (ZnSO ₄ @ 0.75%)	0.339	78.39
SEm±	0.004	0.71
CD (P=0.05)	0.013	2.05

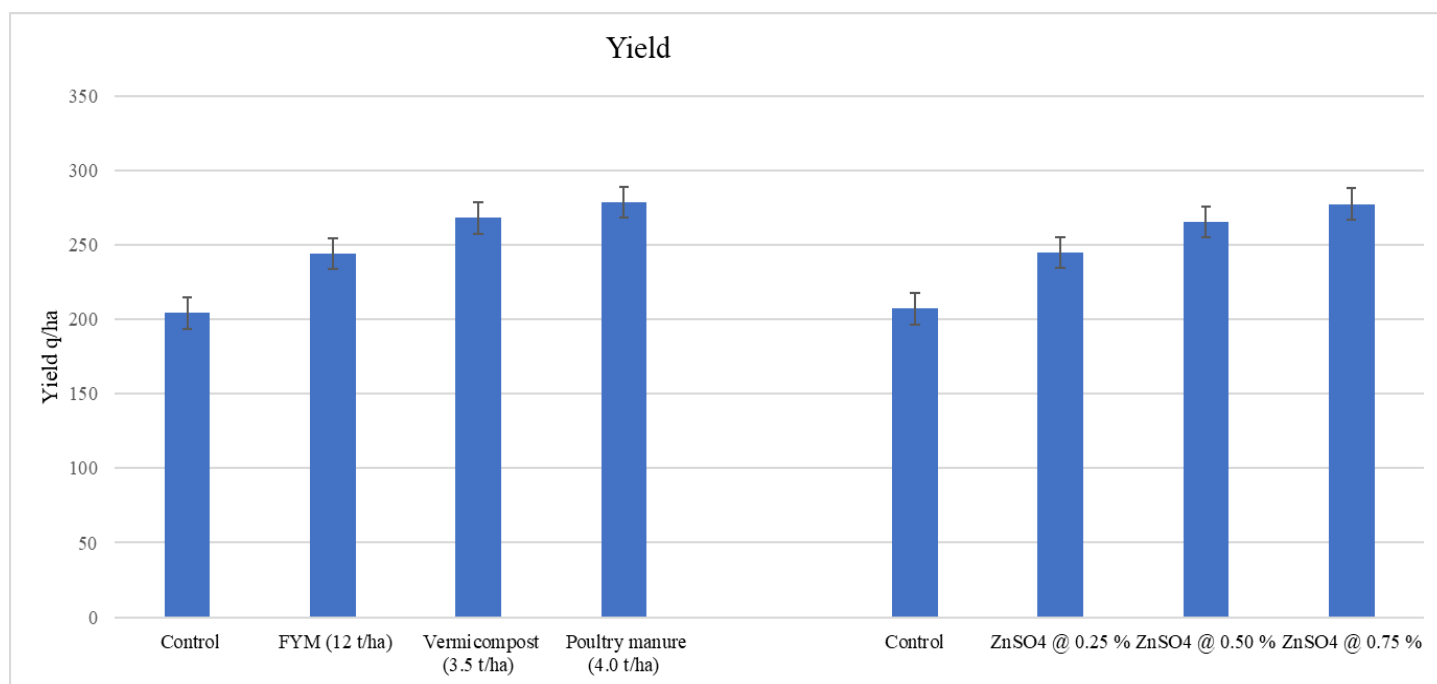


Fig. 1. Effect of organic manures and zinc on yield of carrot

Conclusion

The study concluded that the application of poultry manure @ 4 t/ ha combined with ZnSO₄ @ 0.75% significantly enhanced carrot growth, yield and quality. However, suggesting that farmers can adopt either combination based on resource availability and economic feasibility. Further studies are recommended to validate these findings across different soil types and agro-climatic conditions.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Yield gap analysis and economics of onion (*Allium cepa* L.) cultivation in western Arid Kachchh of Gujarat

Ramniwas¹, Manish Kanwat², M. Suresh Kumar² and Abhishek Patel²

¹SMS-Horticulture, ICAR-CAZRI, Krishi Vigyan Kendra, Bhuj-Kutch-370 105 (Gujarat), India

²Head, ICAR-CAZRI, RRS, Bhuj-Kutch-370 105 (Gujarat), India

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ABSTRACT

Thirty-seven demonstrations on onion cultivation were executed to assess the impact of improved farming practices on yield outcomes. Results indicated that onions grown under the enhanced agricultural practices produced yields ranging from 254.62 to 275.50 q/ha, significantly surpassing the yields under traditional farmer practices, which varied from 205 to 216 q/ha. The yield increase under the improved practices ranged from 24.20% to 27.55%. Economic assessments revealed that the benefit-cost ratio in demonstration plots varied from 2.23 to 4.26, compared to 2.02 to 3.80 in farmer-managed plots. The study emphasizes that adopting these improved practices not only increases onion yield but also enhances the profitability of onion farming.

Introduction

The onion (*Allium cepa* L.) is one of the earliest bulbous vegetable crops cultivated by humans and belongs to the monocotyledonous plant family Amaryllidaceae. It has been domesticated for its culinary, medicinal, and religious uses since prehistoric times, earning it the title of the “Queen of the kitchen” is another name of onion. The distinct flavor and aroma of onions are primarily attributed to their sulfur compounds, which are also responsible for their medicinal properties (Robinowitch and Currah, 2002). Historical references, such as the Charak Samhita (3rd–4th century A.D.), highlight the therapeutic uses of onions (Ray *et al.*, 1980a, 1980b). Furthermore, the Sanskrit term “Palandu,” used in the Vedic era, further illustrates its cultural and historical significance (Aiyar and Vaganarayana, 1956).

Onions are known for their high nutritional value, surpassing

several common vegetables in terms of beneficial compounds (Ngomle *et al.*, 2020). Rich in sulfites, allicin, ajoene, thiosulfates of allixin, and other bioactive components, onions are recognized as both a food and a medicinal herb. Regular consumption has been associated with the prevention of various health conditions, including cancer, rheumatoid arthritis, digestive disorders, hypertension, and diabetes (Corzo-Martinez *et al.*, 2007). Additionally, onions exhibit antifungal properties and, to a lesser degree, insecticidal capabilities (Block, 2010). While Central Asia is considered the primary region of origin for onions, the Near East also plays a significant role in its cultivation (McCollum, 1976).

Onions are not only an important vegetable crop but also a key contributor to the global economy. In the fiscal year 2017–18, India exported over 1.58 million metric tons of onions, valued at Rs. 308882.23 lac (Anonymous, 2018). India

Corresponding author

Email: ramniwas@icar.gov.in (Dr. Ramniwas)

ranks as the second-largest producer of onions worldwide, following China. In 2021, the country produced 26.64 million tons of onions across 1.62 million hectares, with an average yield of 16.40 t/ha. Notably, Gujarat is a leading onion-producing state, contributing 2.46 million metric tons from 99,413 hectares with a productivity rate of 247.9 q/ha (Anonymous, 2021-22). Other major onion-producing states in India include Maharashtra, Karnataka, Madhya Pradesh, Rajasthan, Andhra Pradesh, and Tamil Nadu.

Despite the substantial production of onions, challenges such as the use of low-yielding traditional varieties and a lack of hybrid development hinder the potential for improving productivity. Several factors, including variety selection, integrated nutrient management (INM), integrated weed management (IWM), water management, and plant protection, influence the overall productivity of onion crops. Among these, the selection of appropriate varieties plays a critical role in enhancing crop yield. The poor availability of quality seeds and the slow replacement rate of conventional varieties are additional obstacles to increasing onion production.

To address these challenges, Front Line Demonstrations (FLDs) have been initiated to promote the adoption of high-yielding varieties and advanced crop management practices. FLDs offer a platform to introduce the latest agricultural technologies and improve the management of onion fields under diverse agro-climatic conditions (Singh and Varshney, 2010; Verma *et al.*, 2010). The adoption of improved seed varieties, proper seed treatment, appropriate planting techniques, balanced nutrition, effective weed control, and an integrated pest and disease management approach has been shown to significantly enhance crop yields. Furthermore, FLD programs facilitate the dissemination of research-based technologies from ICAR and Agricultural Universities (AUs), helping to bridge the yield gap, technological gap, and extension gap between demonstrated practices and farmers' conventional methods (Nagarajan *et al.*, 2001).

In response to these limitations, Krishi Vigyan Kendra (KVK) has initiated FLD programs aimed at increasing the adoption of high-yielding onion varieties such as Hybrid Rosy, coupled with improved cultivation practices and packaging methods to boost productivity and financial returns. This study also explores the economic aspects of onion cultivation, including yield gaps, technological gaps, and the extension gaps between farmers' practices and demonstration plots.

Method and Materials

The ICAR-CAZRI, Krishi Vigyan Kendra, Bhuj-Kachchh-II (Gujarat), undertook Front Line Demonstrations (FLDs) in farmer's fields spanning the *rabi* seasons from 2013-14 to 2015-16. A total of 37 farmers participated in this study, which was conducted across several selected villages,

including Jambudi, Khambra, KotdaChakar, Kukma, Lohariya, Pantiya, Ratnal, ReldiNani, and Tharawada, situated within the Anjar and Bhuj Talukas. The cumulative area of these selected villages amounted to 14.8 acres. Soil samples were collected from the farmers' fields prior to the commencement of the study, and subsequent analysis revealed that the soils were predominantly saline to alkaline in nature. The pH values of the soils ranged between 7.5 and 8.5, indicating a moderately alkaline to alkaline character. The electrical conductivity (EC) values varied between 0.9 to 2.2 dSm⁻¹, further confirming the saline-alkaline status of the soils. Additionally, the organic carbon content was found to be low to medium, with values ranging from 0.12% to 0.5%. These soil characteristics played a crucial role in influencing the crop growth and performance during the demonstration trials.

The Hybrid Rosy onion seeds were supplied by the National Seeds Corporation Limited and distributed to selected farmers for the successful implementation of Front-Line Demonstrations (FLDs). Prior to the FLDs, a series of training workshops were organized for the beneficiary farmers, encompassing all aspects of onion cultivation, ranging from nursery management to successful crop harvest techniques. The specific technology employed for the FLDs, as compared to the traditional methods used by the farmers, is summarized in Table 1 and detailed in the subsequent sections. Throughout the demonstration process, a horticulture scientist provided consistent supervision by visiting the farmers' fields to ensure the proper implementation of the technology, covering all stages from nursery preparation to harvesting. This regular monitoring was crucial to guarantee adherence to the recommended practices and ensure optimal crop management.

Farmer selection, site identification, the efficient application of inputs, and the overall demonstration process followed the methodologies outlined by Choudhary (1999). These methods ensured the successful execution of the FLDs, enabling the accurate assessment of technology adoption. Data were systematically collected from both demonstration and control plots, capturing key parameters such as cultivation costs, gross returns, net returns, and benefit-cost ratios. These data were then tabulated for comparative analysis to assess the economic viability of the introduced technology in contrast to conventional farming practices.

To identify the yield gaps - specifically the extension and technology gaps - the yields from the demonstration plots were compared with those from the farmers' traditional check plots. The yield gap was quantified using the equations proposed by Sagar and Chandra (2004) and Samui *et al.* (2000), which also facilitated the calculation of the technology gap and technology index. These analyses provided insights into the effectiveness of the demonstrated technology in bridging the gap between traditional and improved onion cultivation practices.

Technology gap = [Potential yield - Demonstration yield]
 Extension gap = [Demonstration yield - Farmer's practice yield]
 Additional return = [Demonstration return - Farmer's practice return]

Technology index = [(Potential yield - Demonstration yield)/ Potential yield] x 100
 Benefit cost ratio (BCR) = $\frac{\text{Gross return (Rs. ha}^{-1}\text{)}}{\text{(Total cost of cultivation (Rs. ha}^{-1}\text{))}}$

Table 1. A comparison study between applied technology intervention and farmer's practice under FLD of onion crop in the study area

Cultivation operations	Practices used by farmer	Intervention applied under demonstrated plot	Indication of gap
Soil and water testing	Not in practice	Have done in all locations	Full gap
Variety	Local	Hybrid Rosy	Full gap
Treatment of seed	None	Trichoderma @ 10 g/ kg seed	Full gap
Rate of seed applied	14 kg/ha	7 kg/ ha	Partial gap
Methods of sowing	Flat bed	Raised Bed	Partial gap
Nutrition Management	Without recommendation	Farm yard Manure: 20-25 ton/ ha Recommended dose of 100:50:50 NPK ha ⁻¹ . Half dose of nitrogen & full dose of phosphorus and Potash applied at the time of transplanting and half dose of N 1 month after transplanting.	Partial gap
Weeding	One Hand weeding	A Pre-emergence weedicide application of oxyfluorfen 23.5% @ EC 0.10-0.15 kg a.i./ha + One hand weeding at 45 DAT	Partial gap
Micronutrient Spray	Not practiced of micro-nutrient spray	2 foliar spray of micro mix @ 0.25%	Full gap
Plant Protection measures	Only chemical spray without recommendation	Integrated pest and disease management practices applied	Partial gap

Results and Discussion

Bulb yield: The results from the demonstration practices have shown a significant improvement in onion bulb yield due to the adoption of advanced agricultural technologies. These outcomes suggest that the farmers benefited from the new techniques encouraged in the demonstration region. As detailed in Table 2, the onion bulb production exhibited a consistent increase over the years of the demonstration. The data indicated that the onion bulb yield from the demonstration plots was superior to that from the local check, with an average increase of 26.06%. The maximum average onion bulb yield recorded was 266.04 q/ha, highlighting the effectiveness of the demonstrated practices.

These findings are in line with the results of several studies in onion production. Similar increases in yield have been reported by Hiremath and Nagraj (2010); Hiremath *et al.* (2011); Gaharwar *et al.* (2017); Gaharwar and Ughade (2018), Gupta *et al.* (2015), Kumar (2014), and Warade *et al.* (2006), supporting the positive impact of modern

agricultural practices on onion yields. Additionally, yield improvements in various other crops have been observed in similar contexts. For instance, Balai *et al.* (2013) reported enhanced yields in vegetables, Kumar *et al.* (2010) in bajra, Mishra *et al.* (2009) in potatoes, Ramniwas *et al.* (2022a) in drumsticks, Singh *et al.* (2011) in solanaceous vegetables, and Tandel *et al.* (2014) in brinjal, further emphasizing the broader applicability of these practices. The increase in onion bulb yield in the demonstration plots also suggests the suitability of the onion hybrid variety Rosy for the climatic conditions of Kachchh. This observation corroborates the findings of Modi *et al.* (2023), who attributed that introduction of high yielding varieties, created awareness among beneficiaries for scientific cultivation practices like timely owing, recommended spacing, balanced use of manure, fertilizers and weed management as well as integrated pest and disease management. Thus, the success of the demonstration plots not only supports the viability of the adopted technologies but also underscores the potential for their widespread adoption in similar agro-ecological regions.

Table 2. Year wise details and yield performance of onion under front-line demonstrations

Year	No. of Demo	Area (ha)	Yield (q ha ⁻¹)			Increased yield over local check (%)
			Potential yield (PY)	Demo yield (IP)*	Check yield (FP)	
2013-14	17	6.8	300	254.62	205	24.20
2014-15	10	4.0	300	268.00	212	26.42
2015-16	10	4.0	300	275.50	216	27.55
Average			300	266.04	210	26.06

*IP=Improved practice; FP= Farmer's practice

Table 3. Extension gap, technology gap and technology index of onion under FLDs

Year	Technology gap (q ha ⁻¹)	Extension gap (q ha ⁻¹)	Technology index (%)
2013-14	45.38	49.62	15.13
2014-15	32.00	56.00	10.67
2015-16	24.50	59.50	08.17
Average	33.96	55.04	11.32

Technology gap analysis: The technology gap, in comparison to other cultivation criteria, assumes a critical role as it underscores the challenges faced when attempting to implement a comprehensive package of methods. This gap reflects the limitations encountered in the face of environmental and varietal changes. The technology gap is defined as the difference between potential yields and demonstration yields under actual field conditions. Based on the data presented in Table 3, the technology gap observed during the study period ranged from 24.50 to 45.38 q/ha, with an average value of 33.96 q/ha. This indicates a considerable discrepancy between the potential yields that could theoretically be achieved under ideal conditions and the yields observed during the demonstration phase. The significant gap suggests the existence of constraints that hinder the realization of potential yields in practice. The fluctuation in the technology gap across different years of demonstration can be attributed to multiple factors, including variations in soil fertility, local meteorological conditions, and differing farming practices across the study sites. These environmental and agronomic factors may have led to a disparity in performance, as crop productivity is highly sensitive to such variations. To address this gap, it is

essential to reduce the yield gap between demonstrated yields and potential yields through focused interventions such as the conduct of Front Line Demonstrations (FLDs). These demonstrations serve as an important tool for showcasing optimal practices and bridging the gap between research and real-world implementation. Furthermore, tailored recommendations based on local conditions are critical to closing the technology gap. It is, therefore, recommended to employ site-specific technologies and implement precision-based farming techniques, as highlighted by Ghosh *et al.* (2024), Kumar *et al.* (2021), and Singh *et al.* (2011).

Extension gap analysis: Prior to the study period, a significant extension gap was identified among farmers, as the majority were not utilizing high-yielding onion varieties or optimized agronomic practices. This resulted in a noticeable disparity between the potential technological advancements in onion cultivation and the practices employed by farmers. To bridge this gap, Krishi Vigyan Kendra (KVK) initiated Front-Line Demonstrations (FLDs) on various farmers' fields, showcasing improved onion cultivation techniques. The implementation of these enhanced practices resulted in an increase in bulb yield when compared to traditional methods previously employed by the farmers. Table 3 presents data that clearly illustrate a large extension gap, with yield differences between the demonstration plots and the local control plots ranging from 49.62 to 59.50 q ha⁻¹. This discrepancy underscores the underutilization of high-yielding cultivars and modern farming techniques, which were not widely adopted by the farming community. The adoption of these technologies remains limited, thereby contributing to the substantial extension gap observed between the demonstrated technologies and the locally practiced methods. The persistence of this extension gap emphasizes the urgent need for widespread awareness and adoption of high-yielding onion varieties and an improved set of agronomic practices. These results are consistent with findings reported by Teggelli *et al.* (2015), who suggested that the gradual introduction and adoption of superior crop production technologies, including high-yielding varieties, can effectively reverse the trend of expanding extension gaps. Moreover, the successful closing of such gaps necessitates focused extension efforts through educational outreach and technology demonstration, which encourage farmers to embrace scientifically validated practices. The findings from this study are also in alignment with earlier research on other crops. For instance, Ramniwas *et al.* (2022b) demonstrated similar extension gap phenomena in Isabgol, while Bhoraniya *et al.* (2017) and Lal *et al.* (2013) reported similar challenges in coriander cultivation. Furthermore, Mukharjee (2003) highlighted the importance of context-specific problem identification and the development of targeted solutions to significantly enhance crop productivity.

Technology index analysis: The technology index is a critical measure of the applicability and practicality of a specific

agricultural technology for farmers. As demonstrated in Table 3, the technology index values exhibited a declining trend, ranging from 15.13% at the beginning to 8.17% by the conclusion of the demonstration period. This indicates a growing feasibility and relevance of the technology under field conditions over time. The reduction in technology index values suggests that farmers were increasingly able to adopt and apply the demonstrated technologies with greater success as the demonstration progressed. The overall average technology index of 11.32% further supports this trend, reflecting the efficacy of the demonstrated technologies in real-world conditions. A key factor contributing to this outcome could be the accurate application of the technologies during the demonstration period, combined with favorable weather conditions, which likely enhanced the demonstration's success. As highlighted by Jeengar *et al.* (2006), Hiremath and Nagraj (2010), and Sagar and Chandra (2004), a lower technology index indicates a closer alignment between research farm technologies and their practical application on farmer fields, thereby making them more accessible and usable for agricultural practitioners. The current results are consistent with previous studies on the impact of Frontline Demonstrations (FLDs) in various crops. Research by Choudhary *et al.* (2018), Chauhan *et al.* (2020), Dayanand *et al.* (2012), Mishra *et al.* (2009), and Raj *et al.* (2013) also observed similar trends in the successful adaptation and adoption of demonstrated technologies, underscoring the importance of technology transfer and its impact on enhancing agricultural practices.

Economic analysis: The economic viability of the demonstration technologies was evaluated using several

key economic variables, including the cost of cultivation, net return, and the benefit-cost (B:C) ratio. The net return exhibited significant year-to-year variability, primarily driven by fluctuations in the market price of onion bulbs. This price variability had a direct impact on the financial returns observed in the study. Over the course of the demonstration period, it was evident that both the production cost and the market price of the produce played substantial roles in determining the profitability of the farming systems. Analysis of the data revealed that the demonstrated technologies consistently outperformed the local farmer's practices in terms of all key economic indicators, including benefit-cost ratio, net financial returns, and gross financial return. The demonstrated technology produced a higher average net monetary return (NMR) of Rs. 170,280, alongside a B:C ratio of 2.94, compared to the farmer's checks, which achieved an NMR of Rs. 126,226.67 and a B:C ratio of 2.61. This improvement can largely be attributed to the higher bulb yields obtained through the demonstrated technology, which resulted in more favorable economic outcomes compared to the control plots. The findings of this economic analysis suggest that the demonstrated technology offers superior profitability and is economically viable for adoption. These results align with similar findings reported by Ghosh *et al.* (2024), Hiremath and Nagraj (2010) and Hiremath and Hilli (2012), who noted comparable economic benefits with advanced agricultural technologies. Additionally, the results are consistent with those reported by Bhargav *et al.* (2015), Dhaka *et al.* (2010), and Ramniwas *et al.* (2022c) for other crops such as chickpea, maize, and fennel, where the adoption of improved practices led to enhanced financial returns.

Table 4. Economic analysis of front-line demonstrations in onion

Year	Cost of cultivation (Rs./ ha)		Gross return (Rs./ ha)		Net return (Rs./ ha)		Additional return (Rs./ ha)	B:C Ratio	
	IP*	FP	IP	FP	IP	FP		IP	FP
2013-14	80000	70920	178234	143500	98234	72580	25654	2.23	2.02
2014-15	88000	78000	375200	296800	287200	218800	68400	4.26	3.80
2015-16	95000	85500	220400	172800	125400	87300	38100	2.32	2.02
Average	87666.67	78140.00	257944.67	204366.67	170278.00	126226.67	44051.33	2.94	2.61

*IP=Improved Practice; FP= Farmers Practice

Conclusion

In conclusion, the Front-line Demonstration (FLD) of the Hybrid Rosy onion variety, conducted over three years (2013–14 to 2015–16) in a farmer's field using improved technology, clearly indicates the potential to enhance onion bulb yield, resulting in higher financial returns and improved benefit-to-cost (B:C) ratios. Furthermore, the adoption of the demonstrated technology contributed to a reduction in both the technology gap and technology index values.

These findings underscore the superiority of locally tested technologies when implemented in real-world farming conditions, specifically in Kachchh. The FLD approach not only enhanced productivity and quality but also positively impacted farmers' attitudes, skills, knowledge, and competence. Additionally, it fostered stronger interactions between scientists and farmers, thus contributing to the dissemination of contemporary agricultural technologies. FLDs play a critical role in encouraging the adoption of innovative practices, thereby increasing agricultural output and income. Overall, this study affirms that FLDs are

an effective extension strategy for introducing validated technologies at the village level, narrowing the extension gap, and empowering the agricultural community with sustainable growth prospects.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Crude pectinase parameter optimization for enhancing bael juice clarification

Anju Kumari¹, Rakesh Gehlot¹, Rekha Phogat¹, Rakesh Kumar² and Ritu Sindhu¹

¹Centre of Food Science and Technology, CCS HAU, Hisar, Haryana

²Department of Microbiology, CCS HAU, Hisar, Haryana

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ABSTRACT

This study investigates the optimization of crude pectinase concentration for clarifying bael juice, which contains fibrous pulp that limits juice recovery. The effects of different pectinase concentrations, incubation times, and temperatures on juice yield and turbidity were analyzed. The results showed that a 3% crude pectinase concentration, incubated for 60 minutes at 45°C, produced the highest juice yield (67.8%) and the lowest turbidity (568 NTU). The study underscores that the optimal conditions for maximizing juice yield while minimizing turbidity involve a careful balance of enzyme concentration and incubation parameters.

Introduction

Bael fruit juice, derived from the wood apple (*Aegle marmelos*), is packed with nutrients and offers several health benefits. Bael is a native Indian fruit from the Rutaceae family (Bhardwaj and Nandal, 2015). It originated in Northern India but is now found across the Indian subcontinent, as well as in countries such as Sri Lanka, Burma, Bangladesh, Thailand, and Indo-China (Brijesh *et al.*, 2009). Bael fruit holds significant medicinal and nutraceutical value and is often mentioned in ancient texts like the Vedas, Ramayana, and Buddhist and Jain literature. It is extensively used in Ayurvedic, Unani, and Siddha medicine systems for its healing properties.

Juice of bael fruit is highly valued for its exceptional nutritional, functional, and therapeutic qualities, making it an important part of many people's diets (Singh *et al.*, 2013). It is rich in vitamins (A, B, C, folate), minerals (iron, copper, potassium, iodine, zinc, selenium, sulfur, manganese, boron, molybdenum, magnesium), dietary fibre, antioxidants,

amino acids, and bioactive compounds, all crucial for good nutrition and disease prevention. In addition to being regarded as a remedial plant, it has good nutritional value and is rich in carbohydrates, fibre, minerals and vitamins (Bhardwaj and Nandal, 2015).

Bael juice is an excellent source of fluids, which helps maintain hydration levels in the body. It is easily digestible, non-toxic, and has a cleansing effect on the blood and digestive tract. In short, bael fruit juice is a powerhouse of nutrition with numerous health benefits, contributing to taste and wellness. Bael fruit pulp is highly fibrous and complex, containing seeds (Singh *et al.*, 2014). The yellow-orange, flavorful pulp is rich in minerals like phosphorus, calcium, and vitamins such as vitamin C, thiamine, riboflavin, and niacin. Various products like wine, powder, toffee, marmalade, candy, slab, jelly, jam, and nectar can be made from bael fruit pulp for both therapeutic and food purposes (Bhattacharjee *et al.*, 2015).

However, the fibrous pulp of bael fruit poses a challenge for juice extraction. The complex texture and high pulp viscosity

Corresponding author

Email: anjugaina@hau.ac.in (Dr. Anju Kumari)

make it difficult to extract juice efficiently, leading to pulp losses. In the beverage industry, the enzymatic-mechanical extraction method is considered the best approach (Ghosh *et al.*, 2016). Enzymes like pectinase break down the cell walls and pectin substrates, releasing sap from the cells by enzymatic hydrolysis (Gurung *et al.*, 2013). Several researchers have reported the application of commercial enzymes to clarify different juices. Using crude enzyme (spore-free and produced from GRAS fermentation) is more economical to improve juice yield and clarity (Singh *et al.*, 2014). Therefore, the present study was undertaken to use crude enzyme from *A. niger* for the bael juice clarification. The present work optimized bael juice clarification using various partially purified pectinase enzyme concentrations at different incubation times and temperatures.

Material and Methods

The present investigation was conducted in the Centre of Food Science and Technology, CCS Haryana Agricultural University, Hisar during 2018-2019. Bael fruits were procured from the local market, Hisar. The chemicals used in the investigation were analytical reagents from CDH Chemicals, Sisco Research Lab and Himedia Ltd.

Juice extraction

Bael fruits were washed thoroughly in running water and broken by striking against a hard surface. The fruit pulp, along with its seeds and fibres, was scooped out with the help of a stainless steel spoon. The pulp was blended with distilled water in the ratio of 1:2 (w/v). The mixture of pulp and water was passed through a fruit pulper to obtain homogeneous pulp. The process flowchart for producing clarified juice from bael pulp is presented in Fig. 1.

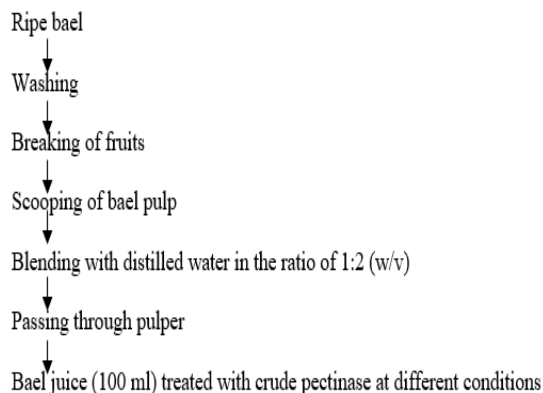


Fig. 1. Flow sheet for the preparation of bael juice

Chemical analysis of extracted bael juice

Bael juice was analyzed for chemical constituents. Hulme and Narain's method (1931) estimated total and reducing sugars. Acidity was determined using the method of Ranganna (2014). Total carotenoids were analyzed using the Rodriguez-Amaya method (1999). Total phenols were estimated using the methods given by Amorium *et al.* (1997), and browning was estimated using the method of Ranganna (2014). The extracted bael fruit juice TSS in °Brix was determined using a hand refractometer (Erma Inc., Japan).

Effect of crude pectinase enzyme treatment

Erlenmeyer flasks (250 ml) with 100 ml of bael juice were inoculated with different concentrations of crude enzyme extract (1, 2, and 3% v/v) having pectinase activity of 8.12U/ml. The flasks were incubated at 35 °C, 40 °C and 45°C for 30, 45, and 60 minutes. The effect of the above enzyme treatments was observed on juice yield and turbidity.

Bael juice yield

The percentage and ratio of clarified juice to the bael pulp are defined as the clarified juice yield (%).

Clarified juice yield (%) = $\frac{\text{Weight of clarified juice}}{\text{Initial weight of bael juice}} \times 100$

Bael Juice turbidity

Turbidity (NTU) of juice was determined by Digital Turbidity Meter (Model: MT-134, India) (Sin *et al.*, 2006).

Statistical analysis

Each juice analysis was carried out in triplicates and converted to average values. The present investigation's data were analyzed according to a completely randomized design.

Results and Discussion

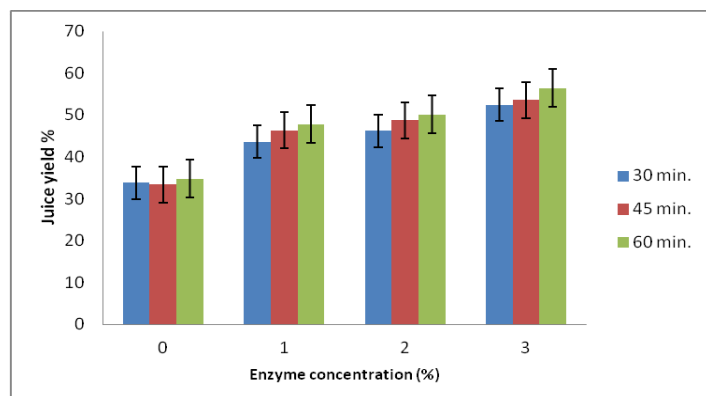
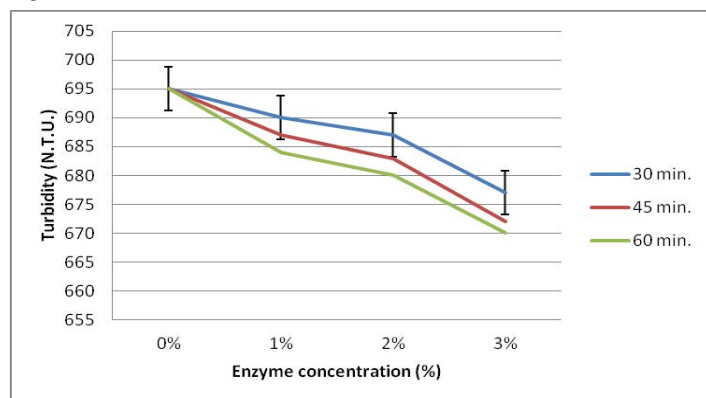
Fresh bael juice was analyzed for various chemical constituents (Table 1). Different studies have shown that *bael* fruit juice contains 28-39 per cent total soluble solids (TSS), 19-21 per cent carbohydrates, 11-17 per cent sugar, 1 per cent protein, 0.2 per cent fat and 7-21 mg 100 per g vitamin C (Singh *et al.*, 2014). The bael pulp is a base for various products like squash, jam, toffee, slab, powder, nectar, beverages and RTS. Bael fruit pulp of cultivar NB-5, CISH Bael-2 and Goma Yashi was used to make ready-to-serve drinks (Singh *et al.*, 2013). The physico-chemical studies revealed the little difference between fruit and fruit juice in bael's proximate composition and nutritional properties (Bhardwaj *et al.*, 2014).

Table 1. Chemical constituents of fresh bael juice (without enzymatic and incubation treatment)

S. No.	Parameter	Value $\pm$ SD
1.	Total sugars (%)	37.08 $\pm$ 1.02
2.	Reducing sugars (%)	25.42 $\pm$ 1.04
3.	pH	5.2 $\pm$ 0.12
4.	Acidity (%)	0.75 $\pm$ 0.97
5.	Total carotenoids (mg/100 g)	1.24 $\pm$ 2.14
6.	Total phenols (mg/100 g)	22.01 $\pm$ 1.96
7.	Browning (440 nm)	0.65 $\pm$ 1.01
8.	Total soluble solids ($^{\circ}$ B)	12 $\pm$ 0.97
9.	Juice yield (%)	36 $\pm$ 1.02
10.	Turbidity (NTU)	446 $\pm$ 12.03

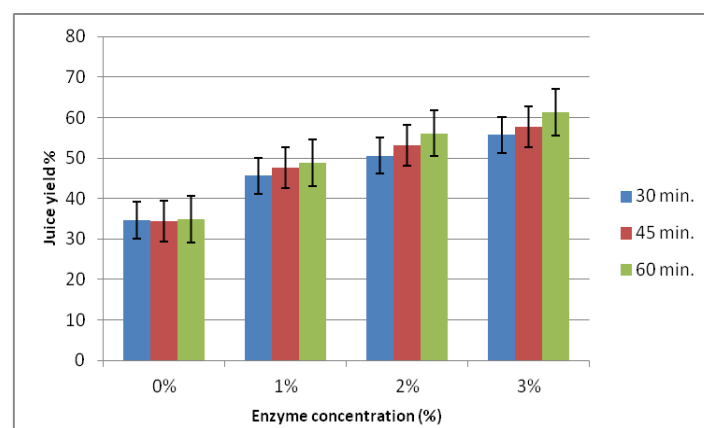
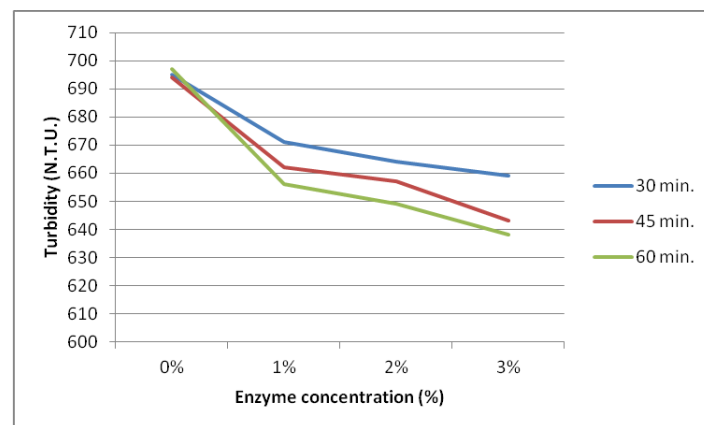
Effect of crude enzyme concentration on juice clarification

Minimum turbidity, 670 NTU and maximum juice yield (56.4%) were observed after 60 minutes of incubation with 3% crude pectinase concentration at 35°C (Fig. 2). The enzyme concentration was significant, and the incubation time was non-significant for turbidity, but for juice yield, both the pectinase concentration and incubation time were significant.

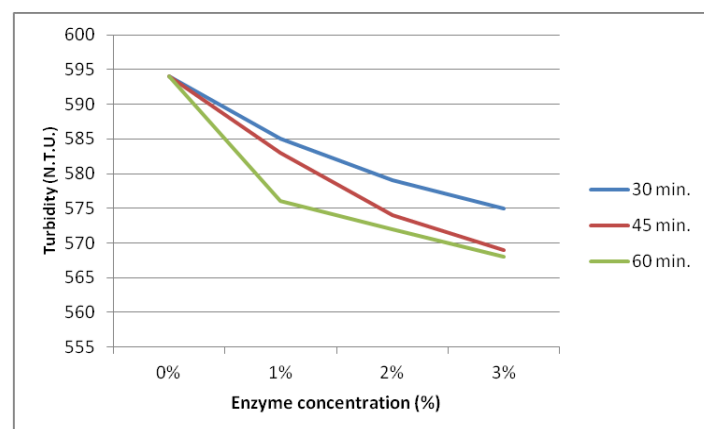
**Fig. 2.** Effect of enzyme concentration and incubation time on bael juice on turbidity (NTU) and yield (%) at 35°C

Minimum turbidity (638 NTU) and maximum juice

yield (61.3%) were observed with 3% crude pectinase concentration after 60 minutes of incubation time at 40°C (Fig. 3). The enzyme concentration, incubation time, and temperature were significant factors in turbidity and juice yield. The variation in yield was due to the increase in the amounts of pectin and starch and the reduction of sugars in bael pulp.

**Fig. 3.** Effect of enzyme concentration and incubation time on bael juice turbidity (NTU) and yield (%) at 40°C

After 60 minutes of incubation, 3% crude pectinase produced minimum turbidity (568 NTU), while maximum juice yield (67.8%), was observed after 30 minutes of incubation at 45°C (Fig. 4). The enzyme concentration, incubation time, and temperature were significant for turbidity and juice yield.



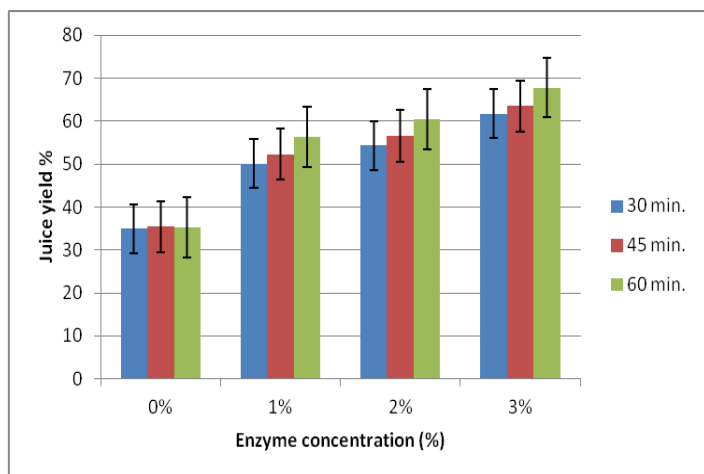


Fig. 4. Effect of enzyme concentration and incubation time on bael juice turbidity (NTU) and yield (%) at 45°C

This may be due to the higher tissue breakdown and the release of soluble solids. Abdullah *et al.* (2021) reported similar results in the study of pectinase-assisted extraction of cashew apple juice. Pectinase helps break down the pectin in bael fruit, reducing the cloudiness of the juice and resulting in a more transparent product. By breaking down the cell walls, pectinase allows for better juice extraction, increasing the yield. The enzyme helps reduce the juice's viscosity, making it smoother and palatable. Pectinase concentration, temperature, and time have shown a positive linear effect on juice yield.

The higher concentration of pectinase allows more cell wall breakdown, resulting in a higher release of sap from a cell. In addition, the fibres' solubility increases at the higher pectinase enzyme concentration, promoting a higher juice yield. Pectinase is a versatile and effective tool in the juice industry, providing a reliable method for juice clarification of different fruit types like apple, guava, jamun, pineapple, etc. This kind of trend for juice yield was obtained by Surajbhan *et al.* (2012) and Ghosh *et al.* (2016) for guava and Jamun juice. Crude enzyme with pectinase activity of 8.12U/ml was obtained by *Aspergillus niger* (MTCC 281) under solid state fermentation (Sadiq *et al.*, 2021).

The juice tends to be cloudy with sedimentation, which can be unappealing to consumers (Bhattacharjee *et al.*, 2015). Fresh bael juice has a relatively short shelf life, requiring proper preservation techniques to maintain its quality. Enzyme treatments (like pectinase) are often necessary to clarify the juice, which adds complexity to the extraction process. The juice and its nutrients can be sensitive to heat, requiring careful handling during pasteurization to retain its nutritional value.

The higher pectinase concentration would degrade the complex compounds, which may increase the juice yield. The viscosity and turbidity were minimal at higher enzyme concentrations and a high range of temperature and time. It is due to the breakdown of pectin and cellulose at higher pectinase concentrations, which gives a higher juice yield

and dilutes existing juice. Thus, it results in lower viscosity and, consequently, the turbidity (Ghosh *et al.*, 2016). The pectinase concentration, temperature, and time have shown a negative linear effect on turbidity. Vivek *et al.* (2019) have reported similar turbidity behaviour in Sohiong fruit juice.

Conclusion

In conclusion, the clarification of bael fruit juice was optimized by adjusting key variables, including pectinase enzyme concentration, incubation temperature, and time. The highest juice yield (67.8%) and lowest turbidity (568 NTU) were achieved with 3% crude pectinase, incubated for 60 minutes at 45°C. This highlights the critical role of enzyme concentration and temperature in the clarification process of bael juice.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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