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Factors affecting production of quality grapes (*Vitis vinifera*) for domestic and export market: a review

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Abstract

Grape (*Vitis vinifera* L.) cultivars and hybrids of *V. vinifera* with *V. labrusca* L. and *V. amurensis* Rupr.) belonging to Vitaceae family of deciduous woody perennials are most widely consumed non-climacteric fruits globally. In India, table grapes are gaining popularity due to its various attributes and availability of nutritional compounds. The grape quality refers to various attributes, including appearance, colour, texture, flavour, and aroma. The ripening process begins at the veraison stage, marked by sugar accumulation, berry softening, anthocyanin production, metabolism of organic acids, and build-up of flavour compounds. The present review explores a wide range of factors that influence grape quality. The impact of cultural operations such as leaf removal, cluster thinning, shoot pinching, use of plant growth regulators and training system are of vital importance. The effect of temperature, light, water availability and rootstocks on grape quality are summarized.

Key words: Table Grape, Cultural practices, Fruit quality, Canopy Management, Vitis vinifera.

In recent years, especially in advanced economies, there has been a shift in food consumption trends as people have become more selective about their diets, showing an increased interest in health-oriented products. This health trend extends beyond just dietary needs and specific health conditions, encompassing various aspects of overall lifestyle (Nielsen, 2016). At the same time, consumers' healthy lifestyles are influenced not only by their health awareness but also environmental concerns. This shift in consumption is reflected in the increasing popularity of functional foods, organic products, foods produced with low environmental impact technologies, and biodegradable packaging (Markosyan *et al.,* 2009). To differentiate their products, agro-food companies have invested in health and environmental attributes, as consumers are willing to pay a premium for these features. Several food products that meet these criteria have been certified for their superior quality. In the fruit and vegetable sector, table grapes are a prime example of a food product with significant market potential in the functional food category. Grapes offer considerable health benefits due to their rich content of vitamins, minerals, lipids, fiber and is suitable for consumption by healthy people, given the large quantities of simple carbohydrates and calories (Skinner and Hunter, 2013). The beneficial effects of consuming table grapes are widely recognized.

Table grapes are abundant in bioactive compounds, but their concentration can be influenced by various factors, including grape variety, ripeness, post-harvest storage conditions, environmental aspects such as location, light exposure, temperature, nutrition, water availability, microorganisms, and viticultural practices (Chen *et al.,* 2020, Colombo *et al.,* 2020, Perestrelo *et al.,* 2012, Yang *et al.,* 2020). Colored grapes are particularly potent due to their high levels of phenolic compounds, which offer various biological effects and potential health benefits (Carrieri *et al.,* 2013). The quality of table grapes encompasses both intrinsic (such as visual, mechanical, and chemical characteristics) and extrinsic factors (including price, country of origin, cultivar, and production method). The consumer's perception of intrinsic attributes is often referred to as 'acceptability.' Consequently, perceptions of quality can vary along the marketing chain and among different consumer groups across various countries. Thus, sensory evaluation is an effective method for assessing consumer preferences and satisfaction.

Appearance plays a crucial role in how consumers assess the quality of table grapes, with visual factors like berry size, shape, and color being significant (Ferrara *et al.,* 2017). Additionally, taste, aroma, and texture are important, as consumers tend to prefer large, seedless grapes with a delightful flavor and aroma (Costenaro da Silva *et al.,* 2010). Seedlessness is a critical quality factor (Vargas *et al.,* 2013), as younger consumers favor seedless varieties because they are easier to chew, eliminating the astringency of seeds. Colour, ranging from pale green to nearly black, is a direct sensory attribute that affects the attractiveness of table grapes. Along with visual traits, physicochemical properties also play a role in assessing quality (Jayasena and Cameron, 2008). The texture of a table grape berry encompasses various attributes,

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including hardness, elasticity, shape, and the sensory experience during chewing. The sensory quality of table grapes is primarily influenced by total soluble solids (TSS), titratable acidity (TA), the composition of organic acids, and the balance among these factors. Total soluble solids, which correlate with ripeness, are a key grape property that aligns closely with consumer perceptions of berry quality and preference. While the balance of organic acids contributes to the overall mouthfeel and quality of table grapes, excessive acidity can reduce their palatability. Table grapes are harvested once the berries meet the minimum maturity criteria.

The aroma experienced while chewing grape berries is a crucial quality factor, which is mainly due to the unique volatile compounds present in each cultivar. Muscat aroma is highly valued in grapes intended for fresh consumption and is closely associated with monoterpenes like linalool, rose oxide, citral, geraniol, nerol, and citronellol. The quality of table grapes often declines, whether they are still on the vine or during storage, presenting a significant challenge for stakeholders. A major postharvest issue for table grapes is their vulnerability to grey mold, which can shorten their shelf life during storage and retail display.

Cultural practices

Under tropical condition, grapevine is pruned twice in a year (once after the harvesting of fruits called back pruning and after the cane maturity during October is called forward pruning). The cultural practices followed during each pruning are different as they are based on the objectives like achieving effective fruit bud differentiation and development of a grape bunch. Though the fruit bud differentiation is totally dependent on the practices followed during foundation pruning, production of quality grape depends on cultural practices followed after fruit pruning. The practices consist of pruning position, cluster thinning, crop load management, retention of berries in a bunch, girdling, thinning, etc.

Cluster thinning

Thinning is a standard viticulture practice used to manage yield levels to enhance the quality of harvested grapes and prevent over cropping, especially in regions with production yield restrictions. Cluster thinning involves removing a percentage of the developing grape clusters, typically between 30 and 40%, to promote better vine balance (Carmona-Jimenez *et al.,* 2021). Cluster thinning affects yield reduction, accelerates grape maturity, and enhances the phenolic content mostly in wine grapes. Several studies (Hannam *et al.,* 2015; Preszler *et al.,* 2013) have indicated that the "marginal profit" -the quality improvement that compensates for yield loss -resulting from cluster thinning is significantly diminished, while likelihood of negative side effects (such as increased growth from the remaining clusters, which may become more compact and produce larger berries with a lower skin-to-pulp ratio) is heightened. On the other hand, cluster thinning can be crucial in situations of over cropping, where there is a clear need to achieve or accelerate ripening, particularly in cooler climates (Zhuang *et al.,* 2014). In these studies, total soluble solids (TSS) and colour significantly increased in thinned vines, while titratable acidity (TA) decreased and pH increases. Cluster thinning is a common practice in managing table grape vineyards to enhance fruit quality (Somkuwar *et al.,* 2018). In Jumbo Seedless (Nana Purple), cluster thinning done after berry set showed positive effects on quality, with higher berry and cluster weight (Somkuwar *et al.,* 2014).

Shoot pruning

Shoot pruning is a widely used mechanical practice that helps to maintain the shape of the canopy, controls vine growth, control the incidence of diseases, and ease access for harvesting and machinery in vineyard rows. The impact of shoot pruning on grape quality is closely linked to the number of leaves left on the stem after cutting, as well as the quantity and effectiveness of lateral shoots stimulated by the pruning process which, in turn, are a function of timing and severity. VSP trellises are typically trimmed when the shoots surpass the top wires, so the timing is largely determined by the natural vigor of the shoots and the balance of the vine, rather than by the grower's choices. In a balanced vineyard, trimming would occur around fruit set, while a highly vigorous vineyard would reach that growth stage much earlier, potentially requiring additional trimming later in the season. The timing for trimming changes for sprawling canopies (such as a single high wire trellis), where pre-flowering trimming may be needed to encourage more upright shoot growth (Poni *et al.,* 2014). In various red and white grapevine cultivars grown on fertile soil and trained to a single high wire trellis, hedging at the 9th to 10th node on primary shoots one week after bloom resulted in higher levels of total soluble solids (TSS), phenols, and anthocyanins in the red cultivars, while also lowering the titratable acidity (TA) and juice pH across all cultivars (Cartechini *et al.,* 2000). Bondada *et al.* (2016) demonstrated that post-veraison shoot trimming can effectively reduce cluster compactness in Sangiovese without negatively impacting overall fruit quality. Under the tropical condition, table grape variety Thompson Seedless and its clones are imparting more vigor. Considering the production of quality grapes, maintaining source: sink balance is important after fruit pruning. The vegetative growth on a fruiting shoot will be up to flowering and will cease after the berry setting. Hence, the balance needs to be maintained by retaining 10-12 leaves (160-170 cm^2) above the grape bunch and pinching the remaining leaves.

Leaf removal

Basal defoliation, which involves removing leaves in the cluster zone, is a common canopy management practice used to modify the microclimates in the fruit zone. The effects of the timing and intensity of this practice vary with the use of variety and climate available in that area. Basal leaf removal effectively reduces foliage cover in dense canopies, improving light exposure for the clusters, increasing canopy porosity, and helping to control the incidence of bunch rot disease (Mosetti *et al.,* 2016; Wang *et al.,* 2018). Canopy management techniques such as shoot trimming, cluster thinning, and leaf removal alter fruit-zone microclimates and influence grape and wine quality by affecting the composition of primary and secondary metabolites. Additionally, clusters exposed to sunlight due to leaf removal typically show higher levels of soluble solids, anthocyanins, and flavonols, while having lower levels of malic acid and titratable acidity compared to control vines (Diago *et al.,* 2012; Sternad *et al.,* 2013). Basal defoliation is particularly prevalent in cool climate viticulture, where solar heat accumulation is low and humidity and rainfall are high (Frioni *et al.,* 2017). However, under tropical condition, the removal of excess leaf may lead to sunscald on the grape berries, early ripening of grape bunch, etc.

The timing and intensity of leaf removal significantly impact berry composition: late defoliation at veraison can lead to increased sunburn incidence, negatively affecting anthocyanin biosynthesis even under temperate condition. In contrast, early defoliation before blooming can positively influence berry composition by changing the source-to-sink ratio, reducing cluster compactness, and preventing solar overexposure of the clusters. Under high temperature and low humidity conditions after veraision stage of grape bunch, the leaf removal below and above the grape bunch does not require as it may lead to change of green colour to amber green. The leaf removal before berry setting may help to control the development of microclimate thereby supporting the effective spray coverage and disease control. Somkuwar *et al.* (2024) revealed that retaining 10-12 leaves above the bunch in Nanasaheb Purple Seedless grape variety provide maximum bunch weight, berry size, yield/vine and total soluble solids.

Shoot thinning

The aim of this management practice is to ensure optimal canopy density and/or crop level, typically carried out at 4-5 leaf stage, which is approximately about 16-17 days after fruit pruning. An enhanced canopy microclimate and improved physiology can be achieved with a shoot density of 15–25 shoots per meter of vine (Somkuwar *et al.,* 2014). Mainly, shoot thinning reduces vine yield and titratable acidity, whereas improves TSS, anthocyanins and aromatic compounds (Bernizzoni *et al.,* 2011). In Tas-A-Ganesh, Somkuwar *et al.* (2014) have shown that when shoot thinning reduced shoot density from 40 shoot per vine with or without leaf removal followed by shoot pinching had significant impact on photosynthesis and transpiration rates.

Cane girdling and application of plant growth regulators

Girdling (removing ring of bark) the trunk or cane is traditional horticultural practice can be done immediately after fruit set to improve berry size, sugar content, and again at the onset of fruit ripening or softening to boost color and to promote early berry maturation (Pereira *et al.,* 2020). The disruption of phloem vessels is temporary, lasting a few days, after which the vine repairs them by producing a callus. This technique is more commonly applied to seedless table grape varieties to enhance their size (Tyagi *et al.,* 2020). Gibberellic acid (GA3) has been used extensively to control berry size, berry set and weight, to decrease cluster compactness and to induce seedlessness in grapes (Ramteke *et al.,* 2010).

Application of GA3 at different concentrations to seedless table grape cultivars is a common practice for elongating the bunch, thinning flowers, and increasing berry size. Depending on the purpose, GA3 can be applied at different growth stages: 1) pre-flowering, to elongate the rachis length and panicle growth; 2) during flowering, for thinning flowers of seedless grapes; 3) post-flowering and fruit-set, to increase the berry size and production of loose bunch (Somkuwar *et al.,* 2019)). In recent year, there has been a significant use of plant growth regulators to increase berry size and yield. Cytokinins, commonly combined with gibberellins, are especially effective for enhancing berry growth by stimulating cell division and elongation.

The most widely used cytokinin in viticulture is forchlorfenuron, marketed under the trade name CPPU (Ramteke *et al.,* 2006; Yu *et al.,* 2021; Rojas *et al.,* 2021). Exogenous application of ABA is used in table grape production to accelerate ripening and enhance the color of various grape varieties (Lurie *et al.,* 2009;

Ferrara *et al.,* 2015: Koyama *et al.,* 2019). The effects of S-ABA on the color of Crimson Seedless grapes are due to changes in both the total anthocyanin concentration and the ratios of different anthocyanin types (Ferrara *et al.,* 2015). Additionally, the application of the ethylene-releasing compound 2-chloroethylphosphonic acid promoted anthocyanin accumulation and accelerated ripening. Other substances like methyl jasmonate, 1-aminocyclopropane-1-carboxylic acid (ACC), coronatine, and ethephon also triggered the abscission of mature grapes from raisin, table and wine varieties.

Training system

Implementing a suitable training system enhances the exposure of clusters and canopy to sunlight and air circulation, leading to improved berry quality. The choice of training system (such as bower, Y- trellis, expanded Y - trellis) can significantly influence various cultural practices, positively impacting the quality of table grapes (Somkuwar *et al.,* 2024). Training systems require varying leaf area to crop weight ratios to achieve the ideal levels of total soluble solids, berry weight, and berry colour at harvesting. Somkuwar *et al.,* (2019) revealed that vine trained on expanded Y training system with double cordon horizontal canopy modification performed better for growth and yield and reduced disease incidence. In some area of table grape cultivation, plastic covers are used as shade net to protect grape bunch from adverse climatic conditions or to accelerate the early ripening (Ramteke and Somkuwar, 2007).

Soil management and fertilization

Pre-veraison calcium applications had a significant impact on fruit mechanical characteristics, resulting in increased flesh firmness and berry breaking force, as well as reduced *B. cinerea* rot during storage, thereby preserving postharvest fruit quality (Ciccarese *et al.,* 2013; Yu *et al.,* 2021). Applying calcium in the early stages of fruit development also promotes an increase in final berry size. The recent use of cover crops in table grape vineyards has decreased vine vigor, leading to improved yield and berry quality (Muscas *et al.,* 2017).

Environmental factors

Temperature

Climate has a major impact on grapes, and extreme high-temperature events can affect grape berry development and, therefore, the quality of grape (Blancquaert *et al.,* 2019; Barnuud *et al.,* 2014; Somkuwar *et al.,* 2023). Some areas have good conditions for grapes production due to favorable climatic conditions that positively influence grape development. It is anticipated that the warmer and drier conditions expected in the future could negatively affect viticulture in Indian-climate regions. Mild climates favorable for grape production, and grapevines have adapted well to these conditions. However, shifting in grape production areas are occurring mainly due to climate change and the use of irrigation in vineyards. Selecting specific cultivars, training systems, soil cover, pruning methods, and mulch usage are crucial in grape production, as these factors are essential for extending grape cultivation to various areas and potentially overcoming environmental constraints. It has also been known that the climate influence grape quality. Warmer temperatures increase metabolic rates and impact the synthesis and accumulation of certain metabolites, including secondary ones such as polyphenols and flavonoids like anthocyanins (Blancquaert *et al.,* 2019). Elevated temperatures accelerate grape maturation, resulting in an increase in total soluble solids content. Additionally, phenolic compounds are also affected by temperature changes (Barnuud *et al.,* 2014). Climate change profoundly affects the phenylpropanoid pathway, which is crucial for polyphenol biosynthesis. These alterations can interfere with the synthesis and accumulation of these metabolites, as well as influence the activation of enzymes and genes involved in their production (Marchica *et al.,* 2020).

Enzymes responsible for anthocyanin biosynthesis function best at temperatures between 17°C and 26°C. However, temperatures above 35°C can lead to the degradation of anthocyanins and hinder their accumulation (Cevallos-Casals *et al.,* 2004). Numerous studies have demonstrated how varying climates affect the accumulation of anthocyanins and organic acids (Barros *et al.,* 2014; Torres *et al.,* 2016; Rodríguez Montealegre *et al.,* 2006; Boas *et al.,* 2014). Plants, including vines, are poikilothermic organisms, meaning they are influenced by temperature, which impacts the vine's phenology, vegetative cycles, and grape quality (Rouxinol *et al.,* 2023).

Light

Light influences the growth and composition of a wide variety of fruit, including grapes. Plant physiological processes, such as photosynthesis, chlorophyll production, transpiration, and carbon dioxide absorption, fluctuate with phenological stages and influence seasonal growth responses (Canton *et al.,* 2017). In the annual grapevine cycle, vegetative phenology plays a crucial role, as it relates to light capture and the conversion of that light into food reserves. Vines utilize carbohydrate reserves from the previous season to trigger bud burst and break dormancy, followed by the initiation of shoot growth and the commencement of photosynthesis (Campos *et al.,* 2016). An increase in reflected light may enhance the transport of photosynthetic products from leaves to grape berries, leading to greater sugar accumulation (Tian *et al.,* 2023). Additionally, light has been found to correlate with berry weight. Organic acids tend to be more sensitive to environmental conditions than other physicochemical parameters. Aroma is an important aspect of quality in grapes and can be regulated by the light intensity of the environment.

Water availability

Water availability is arguably the most important environmental factor limiting crop growth and productivity. The water requirement varies with different growth stages of vine. During the fruit pruning season, it is important to irrigate the vines promptly to encourage robust shoot growth and sufficient leaf area. In Indian vineyards, since fruit set is generally not an issue, applying mild stress from berry set to the shatter stage (berry dropping) can help manage berry set, reducing the need for thinning. The period from berry growth to veraison is critical, as cell division and elongation are taking place in the fruit. Water stress during this time can lead to smaller berries and lower yields. Hence, from veraison to harvest, care should be taken not to over-irrigate to prevent berry cracking and delays in harvesting. However, moisture stress during this phase can cause berry drop.

Rootstock

Rootstocks not only play a vital role in pest and disease management but also significantly contribute to improving grape quality by effectively addressing abiotic stresses, particularly drought and salinity tolerance (Somkuwar *et al.,* 2024). A wide variety of rootstocks are available for grape cultivation, each suited to different production challenges. Among the different rootstocks available, Dogridge rootstock has gained popularity among grape growers for its ability to withstand abiotic stresses and for its favorable stionic combinations. However, a rootstock that works well for one variety in a specific location may not be suitable for the same variety in a different area, leading to varied choices of rootstock across different cultivars (Somkuwar *et al.,* 2023). Rootstock significantly affects physical characteristics of grape bunches, such as size and compactness, as well as chemical properties like total soluble solids and acidity in the berries. While rootstock can influence titratable acidity in warmer climates, factors such as year and soil type may have a more substantial effect (Keller *et al.,* 2001). Vines grafted onto the 5C rootstock exhibited significantly lower sugar accumulation compared to other rootstocks, though sugar levels (Brix) at harvest were similar across all rootstocks; however, vines on 5C had reduced titratable acidity (Nuzzo and Matthews, 2006).

Somkuwar *et al.* (2013) noted that the quality and biochemical composition of cane varied with cane thickness in both own-rooted and grafted Tas-A-Ganesh grapes, observing that TSS in berries decreased as berry size increased. Additionally, berries from grafted vines had lower TSS compared to those from own-rooted vines, while reducing sugars, carbohydrates, and phenols were higher in grafted vines. Manjari Naveen grafted on Dogridge (*Vitis vinifera* L.) produced highest fruitfulness, TSS, yield and grape quality (Somkuwar *et al.,* 2024)

Technologies for assessing grape quality

Traditional monitoring of grape quality relies on measuring chemical and technological parameters, including total soluble solids, reducing sugars, pH, and titratable acidity, along with visual inspections. This information is primarily used to optimize the timing of the harvest. These methodologies are accurate and reliable, they are increasingly seen as limited due to their high costs, time requirements, destructiveness, and low environmental friendliness resulting from the chemical reagents involved. Recently, there has been significant interest in modern technologies that can address the limitations of traditional analytical methods while providing high robustness and precision in their results. Many of these new methods can be classified as non-destructive technologies, utilizing measurements that rely on the physical and chemical properties of sensors, such as light energy, irradiance, fluorescence, optics, and acoustics, and how they interact with plant tissues. Chemometry, a multivariate statistical approach, enables the integration of non-destructive data with destructive chemical attributes of grapes to create predictive models for assessing chemical parameters in intact and unfamiliar samples.

Non-destructive measurement sensors can be categorized based on their method of application into remote and proximal types. Remote sensors conduct measurements from a distance using aircraft, UAVs, or drones, while proximal sensors operate through direct contact, typically using ground vehicles like tractors or robots, or are operated manually with hand-held devices (Matese and Di Gennaro, 2015). Various workers have documented the use of NIR technology to assess compositional parameters and maturity indicators in homogenized grape samples, as well as in grape juices and musts. These parameters include total soluble solids, anthocyanins, ions, dry matter, condensed tannins, reducing sugars, electrical conductivity, pH, and volatile compounds.

Overall, the findings indicated that NIR spectroscopy is an effective technique for predicting reducing sugar content and TSS in homogenized grape samples and musts (Gonzalez-Caballero *et al.,* 2010). According to Dambergs *et al.* (2015), the determination of other parameters can be significantly influenced by how samples are presented and the low concentrations of the compounds being analyzed, such as volatiles and other secondary metabolites.

Advances in this field have enabled the spectral scanning of grape samples in various presentation modes, including intact grape berries and whole bunches, both in laboratories and in the field (Muganu *et al.,* 2013). Notably, a portable NIR-AOTF device, which utilizes acoustic-optical tunable filtering for spectral wavelength analysis, has shown promising results for monitoring the ripening process in intact grape berries. Regression models for analytical prediction were developed by linking spectral data with reference data from MIR spectroscopy (Barnaba *et al.,* 2014). Currently, the most commonly used laboratory equipment for analyzing grape musts is the WineScan from FOSS (Hillerød, Denmark), which employs MIR spectroscopy, Fourier transform (FT) techniques, and chemometric modeling (Patz *et al.,* 2004).

This device can accurately and robustly detect a wide range of grape parameters quickly and non-destructively. Giovenzana *et al.* (2013) successfully used a Vis/NIR device to predict ripening parameters such as TSS, titratable acidity, potential alcohol content, and extractable anthocyanins in both red and white grape samples directly in the field. NIR hyperspectral imaging is a technique that captures both spatial information and the spectral response for each pixel of the scanned object (Lorente *et al.,* 2012). It offers valuable insights into quality and maturity indicators in intact grapes and is especially well-suited for non-destructive applications in precision agriculture (Álvarez-Cid *et al.,* 2015). Recently, this method has been effectively used for the rapid and non-invasive assessment of anthocyanins, total soluble solids, pH, and sugar content (Fernandes *et al.,* 2015), as well as for evaluating grape aromatic ripening by integrating non-destructive detection with measurements of volatile compounds (Álvarez-Cid *et al.,* 2015).

All methods developed using vibrational spectroscopy technologies offer significant advantages, including non-destructive and rapid detection, reduced costs with repeated use, and environmental friendly analytical procedures. However, there are still limitations that may hinder their practical application, such as potential loss of spectral efficiency particularly in field settings and challenges in creating robust and reliable calibration models due to the extensive number of samples needed and the high biological variability of grape samples stemming from different varieties and origins.

These factors can also contribute to the relatively high costs of commercially available instruments. A technique known as chlorophyll fluorescence screening, which compares chlorophyll fluorescence emissions after excitation at two different wavelengths, has been tested and developed to indirectly measure grape phenolic content (Agati *et al.,* 2007; Cerovic *et al.,* 2008). A portable fluorescence sensor has been created and evaluated as an effective tool for determining phenolic content in various grapevine varieties in the vineyard (Ghozlen *et al.,* 2010). This device has also been manually used for mapping grape quality properties in the field (Baluja *et al.,* 2012) and for assessing anthocyanin content in grapes (Le Moigne *et al.,* 2010).

CONCLUSION

Recent advancements in grapevine genetics, biotechnology, physiology, and innovative cultural practices have provided a range of tools to achieve high quality, profitable yields, and controlled production costs. Quality is more readily attained by cultivating the right variety in the right place or region. However, the benefits of optimal terroir can be undermined by inadequate or poor cultural practices and canopy management. Key developments in grape quality management involve understanding the interactions between canopy microclimate and grape composition, as well as reinterpreting certain canopy management techniques to address specific challenges. With the wealth of knowledge available, applying the appropriate physiological principles and techniques tailored to each specific site can ensure quality grapes.

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Fruit crops of Indian semi-arid regions: significance, conservation and utilization strategies—a review

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Abstract

Today, there is a significant demand for nutrient-dense fruits to enhance nutritional and metabolic health in humans. The production of commercial fruit crops is becoming increasingly reliant on inputs-dependent to cope with the losses caused from biotic and abiotic stresses. The region is characterized by severe environmental constraints, making the cultivation of traditional crops unprofitable. Currently, climatic conditions in semi-arid regions are changing, with issues like frost and low temperatures posing challenges for cultivation of many crops. Underutilized semi-arid fruits refer as high nutritional value, medicinal properties, and resilience in adverse soil and climatic conditions; have not received the desired attention.These semi-arid fruits offer numerous advantages, including ease of cultivation, hardiness, and resilience to climate changes, compared to major commercially grown crops. Technologies have been standardized for the large-scale multiplication of quality planting material of semi-arid zone fruits. Moreover, local communities are well-informed about the nutritional and medicinal properties of these crops. However, these lesser- known semi-arid fruits are an essential part of traditional foods, particularly in rural areas and among tribal communities. This review provides an overview of the technologies developed on semi-arid fruit crops that can transform semi-arid ecosystems into horticultural hubs, offering food, nutrition, and livelihood security to the residents.

Key words: Semi-arid, Minor fruit, Biodiversity, Varieties, Production technology.

In semi-arid climates characterized where precipitation is lower than potential evapotranspiration, plants frequently experience water deficits, extreme temperature, poor soil significantly affecting their functioning and productivity (Singh *et al.* 2020). As per FAO classification, regions with a growing period of 75 to 119 days are categorized as semi-arid. In these areas, annual rainfall is half of the potential evapotranspiration. The effects depend on the duration, intensity, and progression rate of the stress, along with the plant's genotype, developmental stage, and interactions with other stress factors (Chaves *et al.* 2016). The high variability of weather in semi-arid climates increases the potential for plant stress. This is likely to be worsened by the rising frequency of extreme events, such as heat waves, driven by climate change. Climate change may impact the adaptability of semi-arid fruit trees, which contribute approximately 48% of global fruit production.

The impact of climate change varies across countries, posing greater food security risks in low-income regions (Medda *et al.* 2022). Climate change is causing an increase in air temperatures, UV radiation levels, and the frequency of extreme events like droughts and floods (Singh *et al.* 2016j). This is particularly detrimental in semi-arid regions, as it can exacerbate the negative effects of salinity, mineral deficiencies or toxicities, and the incidence of diseases and pest infestations in crops. Today, the biggest challenge is to ensure that the growing population has access to stable, safe, and nutritious food.

According to the current Global Hunger Index (GHI), India ranks 111 out of 125 countries, highlighting a dire situation to fight against malnutrition, which ultimately impacts socio-economic development (Meena *et al.* 2022). However, these conditions are crucial to mitigate the impacts of climate change by implementing sustainable land management practices to improve productivity through advanced fruit technology interventions, selection of drought-tolerant rootstocks, cultivar selection and inputs with or without irrigation, increasing income by harnessing solar and wind energy, optimizing human labor, and developing infrastructure that significantly contributes to doubling farmers' earnings (Singh *et al.*, 2020). There is significant potential for a substantial increase in fruit production in semi-arid regions.

These environmental conditions provide an excellent opportunity for cultivating hardy fruit species that are rich in antioxidants and other health-promoting phytochemicals (Krishna *et al.,* 2018; Tiwari *et al.,*2018), while enabling the production of high-quality fruit crops including ber, aonla, bael, pomegranate, tamarind, jamun, chironji, custard apple, wood apple, karonda, lasoda, and fig, as well as vegetables such as cucurbits, legumes, and Solanaceous crops, along with spices, flower crops, medicinal and aromatic plants, can be cultivated in

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semi-arid dryland areas for higher immense nutritional value, economic returns and essential part of the local inhabitants' diet (Saroj *et al.* 2018; Singh *et al.* 2020).

These next-generation crops are yet to be fully popularized and utilized as they currently remain plants of local significance (Singh *et al.* 2022).The expansion in cultivation area and yield potential of semi-arid fruit crops has significantly increased due to the development of new varieties, large-scale production of seeds, fruit basket can provide food, nutrition and livelihood security and quality planting material for dryland fruit crops can significantly enhance the fruit supply along with advancements in agro-techniques and processing methods for creating value-added products to farmers in arid and semi-arid regions, while greatly improving farm income (Singh *et al.* 2018).

Challenges in semi-arid regions

The semi-arid region is further categorized into dry and moist semi-arid zones.In India, the semi-arid zone covers approximately 37% of the country's total geographical area (131 million hectares out of 329 million hectares). This zone is primarily distributed across several states, including Maharashtra (19%), Karnataka (15%), Andhra Pradesh (15%), Rajasthan (13%), Gujarat (9.5%), Tamil Nadu (10%), Uttar Pradesh (7%), and Madhya Pradesh (6%)(Singh *et al.*, 2020). The area receiving annual rainfall ranges between 200-500 mm with a crop growing period of 90-150 days and rainfall two to three times lower than the potential evapotranspiration, are classified as moist semi-arid zones. The soils of these regions are characterized by moisture stress, predominantly light textured, and poor fertility.

Low and unpredictable rainfall, combined with high atmospheric evaporative demand and the soil's poor water retention capacity, restrict the crop growing period to a maximum of 90 days. Consequently, crops chosen for the region must be tolerant to abiotic stress and have their reproductive phase aligned with the period of maximum moisture availability.There is a broad variability in yield, as well as qualitative and quantitative traits, among different semi- arid crops fruit crops, such as bael (Saroj *et al.* 2004; Singh *et al.* 2015; Sharma et al. 2013; Singh *et al.* 2014f; 2014g; 2016; 2019; and Parthasarathy et al., 2021), jamun(Singh and Singh, 2005a, 2012b and 2019d; Singh *et al.*, 2020), tamarind (Singh *et al.* 2006; Sharma *etal.* 2015; Singh *et al.* 2021), khirni (Singh *et al.* 2016b), wood apple (Singh *et al.* 2016f; Yadav *et al.* 2018), mahua (Bhargava *et al.* 2017;Dhakar*et al.* 2015; Singh and Singh 2005c), custard apple (Yadav *et al.* 2017 & 2018).

The existing stress conditions demand specialized technologies, including the use of appropriate cultivars, propagation techniques, cultural practices, plant protection strategies, and utilization methods to achieve optimal value. In the semi-arid region, many farmers have small land holdings and limited resources, making it difficult for them to bear the burden of credit. However, they can generate income by applying scientific dryland horticultural technologies.

Major fruit crops

The region has the capacity to produce high-quality fruit crops, including bael (*Aegle marmelos*),ber (*Ziziphus mauritiana*), aonla (*Emblica officinalis*), tamarind (*Tamarindus indica*), jamun (*Syzygiumcumini*), lasoda (*Cordia dichotoma*), khirni(*Manilkara hexandra*) date palm (*Phoenix dactylifera*), pomegranate (*Punica granatum*), karonda (*Carissa congesta*), mulberry (*Morus* spp.), chironji (*Buchanania lanzan*), wood apple (*Feronia limonia*), custard apple (*Annona squamosa*), phalsa (*Grewia subinaequalis*), fig (*Ficus carica*), acid lime (*Citrus aurantifolia*), manila tamarind (*Pithecellobium dulce*), timru (*Diospyros melanoxylon*), mahua (*Madhuca indica*) and palmyra palm (*Borassus flabellifer*).

Research advances

The research and development journey for arid and semi-arid fruit crops in the tropics and sub-tropics started since 1976 with beginning of an adhoc scheme, which funded research on selected crops through the AP Cess fund of ICAR. Subsequently, this scheme was incorporated into Cell III of the All India Coordinated Fruit Improvement Project (AICFIP) during the 6th Five-Year Plan in 1978. However, during the 7th Five-Year Plan, Cell III of AICFIP was restructured once more to establish the All India Coordinated Research Project on Arid Zone Fruits. Currently, this project operates 18 centres across eleven states in the country, including Rajasthan (4), Maharashtra (4), Gujarat (2), Uttar Pradesh (2), Tamil Nadu (1), Karnataka (1), Andhra Pradesh (1), Punjab (1), Haryana (1), and Madhya Pradesh (1) (Singh *et al.*2022).

The primary objective of the project is to develop appropriate and sustainable technologies for cultivating fruit crops such as ber, aonla, bael, jamun, date palm, fig, pomegranate, custard Apple and tamarind. During the 7th Five-Year Plan, the Planning Commission of India approved the establishment of the National Research Centre on Arid Horticulture (NRCAH) in Bikaner, which was established on April 1, 1993, and was later upgraded to the Central Institute for Arid Horticulture (CIAH) on September 27, 2000.On October 1, 2000, the Central Horticultural Experiment Station, Vejalpur, Panchmahal (Godhra), Gujarat was merged with the CIAH as its Regional Station to focus on semi-arid fruit crops.However, the research and development of arid and semi-arid fruit crops in India was further propelled by the book "Arid Fruit Culture" (Chundawat, 1990) and Underutilized Fruits of India (Singh *et al.,* 2021), which laid the groundwork for research in minor fruit crops.

Varietal wealth

The hot arid and semi-arid fruit crops particularly in the western part of the country play a vital role in enhancing nutritional and livelihood security in rural and tribal areas, where fruit availability is often limited. In recent years, significant efforts have been undertaken by NARS organizations to develop improved varieties of arid and semi-arid fruit crops.Most of the varieties have been developed through clonal selections of locally adapted genotypes, which have proven to be valuable as they serve as potential sources of stress-related genes and exhibit broader adaptability along with desirable yield and quality traits in arid and semi-arid environments (Table 1).

Propagation technique

The demand for genuine planting material is increasing daily, and to meet this demand, vegetative propagation techniques have been standardized for commercial multiplication.Variability has been reported in plants grown from seeds. With a few exceptions, vegetative propagation methods are used for their multiplication. Techniques such as stem cutting, layering, stooling, and grafting have been standardized for many semi-arid fruit crops. To enhance the success and survival of semi-arid fruits, in-situ budding and grafting have proven to be more effective, resulting in vigorous growth of grafted plants in arid and semi-arid conditions. Details of propagation techniques and period of grafting has been given in Table 2.

Table 1. Improved varieties of semi-arid fruit crops

Crop	Varieties	References
Aegle marmelos	Goma Yashi, Thar Neelkanth, Thar Prakriti, Thar Divya, Thar Gauri, Thar Srishti, Thar Bhavya, Thar Shivangi, NB-7, NB-5, NB-10, NB-8, NB-9,NB-11,NB-17, NB-16, CISHB-2, CISHB-1, CISHB-3, Pant Shivani, Pant Sujata,Pant Aparna, and Pant Urvashi	(Singh *et al.* 2019b; Singh *et al.* 2021a; Singh *et al.* 2014a; Singh *et al.* 2024; Singh *et al.* 2014b; Singh, 2023, Singh *et al.,* 2024a and Singh *et al.,* 2024b)
Emblica officinalis	Goma Aishwarya, NA-5,NA-4, NA-26, NA-7, NA-6, NA-25, NA-10, Laxmi 52, BSR-1, BSR-2,Anand-2and Anand-1	(Singh *et al* 2007; Singh *et al.*2019;Singh*et al.* 2014; Singh *et al.* 2007a)
Ziziphus mauritiana	Gola, Umran, Koma Kirti, Thar Malti, Thar Sevika, Seb and Thar Bhubhraj	(Haldar *et al.* 2019; Saroliya*et al.* 2024)
Syzygium cumini	Thar Kranti, Goma Priyanka, Jamwant,KonkanBahadoli, Paras,Rajendra Jamun-1 andRajamun,	(Singh *et al.*2019; Singh *et al.* 2022)
Annona squamosa	Pink Mammoth,Thar Amrit, Phule Janki, Balanagar, Yellow Sitaphal**,** Mammoth,NMK Gold, Red Sitaphal, and Sindhan	Yadav *et al.* 2023
Morus spp	Thar Harit,Thar Lohit, Chak Majra,Saharanpur Local-1, Saharanpur Local-2, S-146, S-13, S-1635, S-34 and S-7999	(Krishna *et al.* 2020; Saroliya*et al.* 2020)
Carissa congesta	Pant Sudarshan, Pant Manohar, Konkan Bold, Pant Suverna and Thar Kamal	(Singh *et al.* 2015; Singh *et al.* 2014)
Tamarindus indica	Goma Prateek, Prathisthan,Thar Rashmi,PKM-1, T 263, Ajanta,DTS 1,Yogeshwari, DTS 2and Anant Rudhira	Singh *et al.* 2021; Singh *et al.* 2021a
Cordia myxa	Thar Bold, Puskar Local, Karan Lasoda, Paras Gonda and Maru Samridhi	Meghwal *et al.* 2021
Manilkara hexandra	Thar Rituraj	Singh *et al.* 2019
Grewia subinaequalis	Thar Pragati	(Singh *et al.* 2018; Singh *et al.* 2020)
Buchanania lanzan	Thar Priya	(Singh *et al.* 2016; Singh and Singh, 2016)
Madhuca indica	Thar Madhu, NM-2, NM- 9, NM- 4 and NM-7,	Singh *et al.* 2016
Pithecellobium dulce	PKM (MT) 1	Singh *et al.* 2020
Ficus carica	Poona Fig, Excel,Dianna, Conadria, Dinkar and Chalisgaon	Singh and Singh, 2021
Feronia limonia	Thar Prabha and Thar Gaurav	Yadav *et al.*2023

Source: (Singh *et al.*, 2020; Meena *et al.,* 2022)

Table 2. Propagation techniques of semi-arid fruit crops

Fruit crop	Period of multiplication	Propagation methods	References
Aonla	May-June	Patch budding	(Singh *et al. 2019*; Singh *et al.*2014;Hiwale and Singh 2014; Singh *et.* 2019a; Singh *et al.* 2019c; Singh *et al.*2007)
Bael	May-June	Soft wood grafting and patch budding	(Singh *et al.* 2024; Singh *et al.* 2008; Singh,2023; Singh *et al.* 2011; Singh *et al.* 2018)
Ber	July-August	patch/ shield budding	(Sarolia *et al* 2019; Singh *et al.* 2004)
Chironji	July-August	Soft wood grafting	(Singh and Singh, 2014; Singh *et al.* 2021)
Jamun	April -May	Soft wood grafting, patch budding	(Singh *et al.* 2017; Singh and Singh, 2006; Singh and Singh, 2014)
Lasora	June-July	Seed, Patch budding and micro-propagation	(Meghwal *et al.* 2021; Kumar *et al* 2022)
Tamarind	July-August	Soft wood grafting and patch budding	(Singh and Singh, 2007; Singh and Singh, 2015)
Mahua	March-April	Soft wood grafting	(Singh and Singh, 2015; Singh and Singh, 2005; Singh and Singh, 2016; Singh and Singh, 2014; Singh and Singh,2019;Dhakar *et al.* 2015)
Custard apple	April- May	Soft wood grafting	(Singh and Singh, 2014)
Wood apple	May- June	Soft wood grafting, patch budding	Yadav *et al* 2021
Karonda	June -July	Seeds and cutting	(Singh *et al.* 2018; Singh *et al.* 2014)
Fig	October-November	Cutting	Saroliya *et al.* 2021
Wild noni	July-August	Air layering/seed	(Singh *et al.* 2018; Singh, 2014; Arya *et al.* 2014)
Manila tamarind	May-June	Seed and budding	Singh *et al.* 2020
Khirni	March-April	Softwood grafting	(Singh and Singh, 2015; Singh *et al.*2017; Singh *et al.* 2019)
Timru	May-June	Seed and softwood grafting	Singh *et al* 2022
Phalsa	July -August	Seed and cutting	(Singh *et al.* 2019; Saroliya *et al.* 2020)

Source: (Singh *et al.*2022, 2007b, 2017a & 2018c)

Production technology

Bael

Bael (*Aegle marmelos* Correa), a member of the Rutaceae family, has been widely used in traditional Indian medicine due to its various medicinal properties. In Hindu history, the bael tree is recognized as Vilvam or "Shivadruma," symbolizing the tree of Lord Shiva, and holds a special place of reverence among Hindus. The leaves of *Aegle marmelos* have been used in prayers to Lord Shiva since ancient times. It thrives in different agro-climatic conditions across the country. It shows remarkable resilience and adaptability, even when faced with challenges such as drought, nutrient-deficient soils, and problematic (salty/sodic) soils. Moreover, it exhibits tolerance to certain diseases and pests. Additionally, it successfully adapts to swampy, alkaline or rocky soils with pH levels between 5 and 10. In the *Siddha* system of medicine, the root, flower, leaves, fruit, and bark are use as medicinal substances. The nutritional components present in bael include protein, fat, minerals,fiber, carbohydrates, calcium, phosphate, potassium, iron, and vitamins A, B1, nicotinic acid, riboflavin, and Vitamin C. Varieties such as Goma Yashi, Thar Divya, Thar Neelkanth, Thar Srishti, NB-5, NB-7, NB-9, NB-16, NB-17, Pant Sujata, Pant Aparna, Pant Urvashi, and Pant Shivani are well-suited for semi-arid regions. Budded plants were transplanted during the monsoon season, with proper spacing at intervals of 8m × 8m. Flowering usually starts from March to May and Fruits take approximately 9 to 11 months to ripen on the tree after they set (Singh *et al* 2013). The fruits should be harvested individually, retaining a small portion of the stalk, and must not be allowed to fall to the ground. Grafted plants typically begin bearing fruit in the third year and can yield between 80 to 160 kg per tree per year by the age of 10 years.

Aonla

Aonla (*Emblica officinalis* Gaertn) is also known as Indian gooseberry, is a native fruit of India that belongs to the Euphorbiaceaefamily. India is the global leader in aonla production, cultivating about 100 thousand hectares with a total yield of 1,197 thousand tonnes. The primary cultivation areas in India include districts in Uttar Pradesh, Karnataka, Bihar, Haryana, Gujarat, Rajasthan, Madhya Pradesh, and West Bengal. It thrives in a wide range of agro-climatic conditions in India, from arid and semi-arid regions to dry and cool arid areas, as well as rainfed zones and regions with varied rainfall patterns.They can tolerate pH levels from acidic to saline/ sodic up to 9.5, an exchangeable sodium percentage (ESP) of up to 35, and electrical conductivity (EC) levels ranging from 6 to 9 ds/m (Pathak, 2003). It thrives on hillsides at elevations of up to 1800 meters above sea level. Mature trees can tolerate extreme temperatures, enduring up to 48°C, but are susceptible to frost in winter, especially in the hot and dry ecosystems of western Rajasthan (Pathak*et al*. 2006).

It contains ascorbic acid, phenolic compounds, along with a moderate amount of carotene, thiamine, riboflavin, carbohydrates, and essential minerals like calcium, iron, phosphorus, and magnesium. Varieties like Goma Aishwarya, NA-6, and NA-7 are recognized for their high yield, larger fruit size, and higher pulp content, making them suitable for commercial cultivation in semi-arid regions. Budded plants were transplanted during the monsoon season, spaced appropriately at intervals of 8m × 8m.Flowering typically starts from February to March in northern and western India, whereas in southern India, it occurs twice, usually in February-March and again in June-July.The fruits are harvested approximately 120 days after flowering. Aonla fruits, an essential element of traditional Indian herbal medicine, are well-known for their significant medicinal and therapeutic properties.

Jamun

Jamun (*Syzygium cuminii* L.) is a member of the Myrtaceae family, with a chromosome number of 2n=40. There are approximately 400 to 500 species. The properties of the species, especially those related to the pulp and seed, have been extensively studied. Jamun possesses numerous valuable properties, and nearly every part of the tree is utilized by both urban and rural communities.A small amount of jamun fruit syrup is effective in treating diarrhea. Vinegar made from juice of slightly unripe fruits has stomachic, carminative, diuretic, cooling, and digestive properties. Volatile oil can also be extracted from jamun fruits. The fruits are used to treat diabetes, heart, and liver issues. Jamun seeds contain jambosin and glycosides, which inhibit the conversion of starch into sugar, and their powdered form is beneficial to maintain diabetes.In India, the majority of jamun trees are found in tropical and subtropical regions, extending to the lower Himalayas up to 1300 meters and the Kumaon hills up to 1600 meters.

The fruit is good source of iron, sugars, minerals, protein, carbohydrate, etc. The flowers are hermaphroditic, light yellow, and grow in the axils of leaves on the branchlets. They have 4 calyx lobes, with the calyx tube not extending beyond the summit of the ovary. The flowers feature 4 white, spreading petals, numerous stamens, and a 2-celled, inferior ovary. Maximum anthesis and dehiscence occurred between 10 am and 12 noon, while the highest stigma receptivity was observed one day after anthesis. Pollination is facilitated by honeybees, houseflies, and wind. Jamun cultivation can expand to semi-arid, resource-poor areas, and wastelands unsuitable for other crops. It tolerates sodic, saline soils, ravines, degraded land, and waterlogged conditions, thriving better in lower salinity and shallow water tables. Jamun can survive in alkali soils with pH up to 10.5 and is suitable for semi-arid subtropical regions with annual rainfall between 350-500 mm.Jamun requires dry weather during flowering and fruit setting.

In subtropical regions, early rainfall benefits fruit ripening and improves size, color, and taste. The jamun varieties Goma Priyanka, Thar Kranti, CISHJ37 and CISHJ42 are suitable for cultivation. The fruit yield ranges from 60 kg per tree for 10-year-old trees to 100-120 kg per tree for trees over 20 years old, with fruit maturity varying from late May and early June. Fully ripe jamun fruits are consumed fresh or processed into beverages like jelly, jam, squash, wine, vinegar, and pickles. The fruit has a sub-acid, spicy flavor, and jamun squash is a refreshing drink perfect for quenching thirst in summer.

Ber

The Indian jujube, or ber (*Ziziphus mauritiana* Lamk.), is an ideal fruit tree for arid and semi-arid regions. Its successful cultivation in the harsh conditions of the Thar Desert in western Rajasthan highlights its remarkable adaptability to desert environments. According to De Candolle (1886) identified Central Asia as the center of origin for ber (*Ziziphus mauritiana* Lamk.), where the species thrives under diverse climatic conditions.It is one of the most nutritious fruits and is often referred to as the “poor man’s apple.” It is one of the richest sources of vitamin C and also good source of minerals, protein and carbohydrates (Gopalan et al. 1985). The popular ber cultivar Gola contains 80–82% moisture, 12.5% carbohydrates, 17–19°Brix TSS, and 0.40–0.70% acidity.The roots, stem bark, and leaves of ber possess medicinal properties.

Locally known as ‘pala,’ the leaves also serve as an excellent fodder source for sheep and goats.Ber thrives in a wide range of soils, from shallow gravelly soils to deep aridosols. It can tolerate pH levels above 9 and limited soil or water salinity. While ber prefers a drier climate for producing high-quality fruits, it also grows well in tropical and subtropical regions of the country. Known for its drought tolerance, ber trees can withstand extremely high temperatures. However, young plants are highly susceptible to frost during winter, and temperatures below freezing can damage both the fruits and young plants.Budding is the preferred commercial method for vegetative propagation of ber. Various techniques, including T-budding, I-budding, ring budding, patch budding, and forkert budding, have been tested. However, shield or T-budding is the most effective and widely used method.In India, ber is planted during monsoon season using the square system.

The ber varieties and hybridsuch as Goma kirti, Gola, Seb, Umran, Thar Savika, Thar Bhubraj etc are suitable for cultivation under arid and semi-arid conditions. The planting distance is maintained at 6m x 6m in rainfed conditions, while in irrigated orchards, it is increased to 7m x 7m or 8m x 8m.Pruning plays a crucial role in ber cultivation. During the first three years, pruning is carried out to establish a strong framework for the plant. Flowering and fruiting in ber occur on the growth of the current season.Flowering in ber typically begins from July, peaks in September, and continues with sporadic flowers appearing until mid-December.Budded ber plants begin fruiting within a year of planting, while seedling plants take 3-4 years to bear fruit. The yield potential of ber varies depending on agro-climatic conditions, tree age, and variety. A fully grown tree can yield between 30 to 60 tons per hectare, depending on the cultivar and location.The storage life of ber can be extended to 30–40 days when stored at 30°C with 80–90% humidity.

Tamarind

Tamarind (*Tamarindus indica* L.) is a monotypic tree belonging to the Fabaceae family. It originates from the Arabic word "Tamar-E-Hind," which means "Date of India." It is a popular avenue tree, appreciated for its valuable fruits, timber, as well as the shade. Tamarind fruit contains low water content but is rich in proteins, carbohydrates, and minerals. The pulp makes up 30-50% of the ripe fruit (Singh *et al.* 2006), while the shell and fiber comprise 11-30%, and the seeds account for approximately 25-40% (Singh and Singh, 2005b).It is a fruit characterized by low water content and high levels of proteins, carbohydrates, and minerals. The pulp is rich in vitamin C, thiamine, iron, calcium, phosphorus, and dietary fibre, and is enhanced by natural bioactive compounds such as polyphenols and flavonoids, which provide antioxidant and anti-inflammatory properties.

It flourishes in diverse tropical and subtropical regions with hot, dry climates, but it is also well-suited for areas with a monsoonal climate.The Goma Prateek variety has been recognized for its high yield, larger fruit size, and greater pulp content, making it recommended for commercial cultivation in semi-arid regions (Singh *et al.* 2013).Tamarind plants were grown from seed, both in situ and in a nursery, where patch budding was performed and transplanted at spacing 8m x 8m. The leaves are typically evergreen but may drop temporarily in extremely dry regions during the hot season. The inflorescence racemes are small, measuring 5-10 cm in length, and are terminal and lateral, often drooping and accompanied by panicles. The nectar-producing flowers attract honeybees to gather nectar and pollen, likely aiding in cross-pollination. Flower bud development occurs 20 days after the first visible initiation. The fruit yield ranged from 40-50 kg per tree for those aged 6-7 years to 150-200 kg per tree for trees over 20 years old, with fruit maturity differing among trees from early March to late May. Tamarind is high valuable fruits for its pulp, which serve various domestic and industrial purposes.

Custard apple

Custard apple (*Annona squamosa* L.) is a deciduous or semi-deciduous tall woody shrub, reaching a height of about 5-6 meters, with irregularly spreading branches. Belonging to the Annonaceae family, it is native to the tropical regions of the West Indies (Porwal *et al.* 2011). Known by various vernacular names such as sugar apple, sitaphal, sweet sop, and sharifa in the Indian subcontinent, it is a highly nutritious crop. Custard apple is rich in essential minerals like calcium, potassium, and phosphorus, as well as calories, vitamin C, and carbohydrates. In India, it is cultivated in regions including Assam, Bihar, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Uttar Pradesh, Andhra Pradesh, Telangana, and Tamil Nadu.

Custard apple is resilient to hot and drought conditions, but high atmospheric humidity is essential during flowering to enhance fruit set. However, continuous rainfall during fruit set is undesirable. The tree is sensitive to frost and prolonged cold periods. From December to February, it enters dormancy and sheds its leaves. The plant can thrive in a wide range of temperatures, from 10°C to 45°C. Custard apple trees grow well in light and medium-textured soils, such as sandy loams, loams, rocky or gravelly sandy soils, and clay loams. The tree tolerates moderately acidic to neutral soils, with a pH range of 5.5 to 8.5. Thar Amrit, Arka Sahan, Balanagar, and Mammoth are recommended cultivars for semi-arid climatic conditions. Budding and softwood grafting are successful methods of propagation for custard apple.

The best results for these methods are achieved during the months of March-April.Custard apple should be planted at a spacing of 5m x 5m (400 plants/ha). However, for high-density planting, a spacing of 6m x 3m (540 plants/ha) is considered ideal. Its seedling plants begin bearing fruit after three years of planting, whereas grafted and budded plants start flowering in the second year. Typically, custard apple plants take five or more years to develop a full canopy and achieve economic yield. Fruit yield can vary significantly from tree to tree. On average, a 7-year-old tree produces 100-150 fruits, with a total yield of around 7 tons per hectare.

Wood apple

Wood Apple (*Feronia limonia* Swingle), also known by vernacular names such as kaitha, kainth, bel, katha phal, kothbel, and monkey fruit, is an underutilized dryland fruit crop belonging to the Rutaceae family.The wood apple is native to South India and Sri Lanka. In India, it is commonly found in the forested areas of arid and semi-arid regions, including Maharashtra, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Madhya Pradesh, and the western Himalayas. Known for its medicinal properties, the wood apple is valued for its astringent qualities and its beneficial effects on the cardiovascular system. Its fruits and leaves are used to treat conditions such as vomiting, hiccups, dysentery, indigestion, and to promote bowel movements in children. The fruits are considered toning, refreshing, astringent, beneficial for the heart, and anti-scorbutic (Shyam Sunder, 2010).The nutritional composition of wood apple seeds per 100 grams of ripe edible pulp includes 4.0% moisture, 26.18% protein, 27% fat, 35.49% carbohydrates, 5.03% ash, 1.58% calcium, 1.43% phosphorus, 0.03% iron, and 0.08% tannins.

Wood apple is commercially propagated through seed, softwood grafting, or patch budding, both in the field and nursery conditions, typically during March-April. In situ softwood grafting in wood apple achieves over 80% success under the semi-arid conditions of Gujarat (Hiwale, 2015).Pits measuring 90 cm x 90 cm x 90 cm are dug during the summer months. Well-decomposed organic matter is mixed with the soil before planting. Planting is done during the monsoon, and the plants should be irrigated immediately after planting. To ensure high productivity, they should be spaced 8m x 6m apart. Initial plant growth is slow in arid regions.

Thar Prabha and Thar Gourav are suitable variety of wood apple for arid and semi-arid conditions.Wood apple plants should be trained by removing crossing branches during the initial growth stages, as grafted plants are prone to lanky and uneven growth habits.The fruit begins to mature in October and continues until January in various parts of the country. In arid and semi-arid conditions, fruit maturation starts in September and finishes by December. The fruit yield per plant varies between 70.0 and 120.0 kg in the 10th year of planting under rainfed conditions in semi-arid ecosystems.

Karonda

Karonda, scientifically known as *Carissa carandas* L, is a member of Apocynaceae family. It is an indigenous shrub,hardy, multipurpose shrub native to dry regions and can be grown in any type of soil in both tropical and subtropical climate regions of the Himalayas, as well as in Maharashtra, Madhya Pradesh, Rajasthan, Uttar Pradesh, Bihar, and West Bengal.Important species of *Carissa* include *Carissa grandiflora*, *Carissa bispinosa*, *Carissa edulis*, *Carissa ovata* and *Carissa spinarum*.The cultivars are categorized based on fruit color such as green, pink, and white. Karonda fruits are small, rounded, succulent, and fleshy, with a juicy pulp. Known for their bitter-sour and acidic taste, they are widely used in Indian cuisine. Mature fruits are commonly.

The fruits are consumed fresh but are more commonly used for processed into high-quality pickling, candies, making chutneys, and other culinary purposes. The fruits are highly nutritious, providing 1.1% protein, 2.9% carbohydrates, 1.5% fiber,2.9% fat, 0.6% minerals, and 42 kcal of energy per 100 g of the edible portion.It is a subtropical plant, sensitive to cold, and susceptible to damage in frost conditions. Itcommercially propagated through seeds but it can also be propagated using hardwood cuttings. Fresh seeds should be used for raising seedlings, as they typically lose viability within 4-5 weeks. Seedlings are grown in polythene bags during the rainy season and can be transplanted in main field after one year at a spacing of 4m x 4m.Thar Kamal variety of Karonda is the most suitable variety for a semi-arid ecosystem.Plants begin flowering in the third year, with the peak flowering period occurring in March. The fruits ripen in the month of June and continue up to September, and the fruit yield reaches 13.00 kg per plant by the ninth year under rainfed conditions in a hot semi-arid ecosystem.

Chironji

Chironji, or Charoli (*Buchanania lanzan* Spreng.), is an outstanding tree for agroforestry and social forestry systems. In wasteland development and dryland horticulture, it holds great importance due to its diverse uses and ability to withstand harsh climatic conditions. The kernel is highly nutritious, rich in protein, and produces sweet oil that can serve as a substitute for olive and almond oil. It contains 33.50% oil, with 1.90% being unsaponifiable (Singh *et al*. 2006).The total lipid content extracted from chironji kernels was 65.60% of the dry kernel, comprising 90.40% neutral lipids, 3.4% glycolipids, and 6.2% phospholipids (Singh *et al.*2020e).

Chironji is a very hardy plant that thrives in rocky, gravelly red soils, as well as saline and sodic soils. However, despite its resilience, the plants do not survive in waterlogged conditions. Trees are cultivated in degraded rocky areas, including salt-affected soils. However, for optimal growth and productivity, well-drained deep loam soil is ideal. 'Thar Priya' variety recommended for commercial use in the semi-arid and dryland areas. It can be easily propagated using softwood grafting. It is a highly heterozygous, cross-pollinated crop, resulting in seedlings that display a wide range of variations. Flowering begins in January-February on well-developed panicles that bear hermaphrodite and pseudo-hermaphrodite flowers and the fruit is a drupe. Fruits are ready for harvest in April and May. The kernel can be used to prepare sweets and also yields high-quality timber for various uses.

Khirni

Khirni (*Manilkara hexandra*Roxb.) is an important fruit tree that can be successfully cultivated in the wastelands and degraded lands of tropical and subtropical India. It is commonly referred to as 'Khirni' and 'Rayan' by tribal communities in various states of India. The fruits of Khirni hold significant economic value, as mature fresh fruits are sweet and provide a rich source of iron, minerals, sugars, protein, carbohydrates, and vitamin A (Singh *et al*. 2020). The tree is medium-sized, evergreen, and has a spreading growth habit. It is commercially utilized as a drought-resistant rootstock for sapota in various regions of the country. The plant can withstand drought conditions for a period and also tolerate heavy rainfall. Its cultivation can be expanded to arid and semi-arid regions, resource-poor areas, and wastelands where other crops cannot be successfully grown. 'Thar Rituraj' has been developed and is considered highly suitable for dryland conditions (Singh *et al.* 2015d). Its bark and fruits are utilized for various medicinal purposes, including the treatment of ulcers, dyspepsia, bronchitis, leprosy, and more. The seeds contain approximately 25% rayon oil, which is used for cooking and possesses medicinal properties. The bark contains 10% tannin, which is used to treat fever and can also be employed in tanning processes.

Phalsa

Phalsa (*Grewia subinaequalis*), a member of the Tiliaceae family, is one of the oldest fruits known in India. Ripe phalsa fruits are purple when mature and may turn black as they fully ripen on the bushes. These mildly acidic fruits are rich in vitamins A and C, as well as minerals. In Ayurveda, the ancient Indian medical treatise, phalsa fruits are considered a cooling tonic and an aphrodisiac. The mucilaginous extract from the bark is used in sugar clarification, and the fiber from phalsa is utilized for making ropes. It can thrive in neglected and water-scarce conditions where only a few other crops can survive. Additionally, it serves as an important catch crop in commercial orcharding. Phalsa is a tall shrub characterized by rough bark on its stem and numerous long, slender, drooping branches, with the young branchlets densely covered in hair. Freshly extracted seeds should be used for raising seedlings.

Consequently, several local varieties of phalsa have been reported in certain parts of the country, including Local and Sharbati. 'Thar Pragati' a high yielding has been developed for cultivation in semi-arid dry areas. The fruits start to ripen 40-45 days after flowering. In southern India, phalsa fruits begin to ripen during the hot summer months of March and April, while in northern India, they ripen by the end of May. Fruits are hand-picked individually and collected in baskets made of bamboo or pigeon pea plants, lined with polythene sheets or newspaper cuttings for cushioning.Fruits harvested at the red ripe stage can only be stored for a day, so they are promptly marketed in local markets.

Mahua

Mahua (*Bassia latifolia*), the Indian butter tree, is a socio-economically significant multipurpose tree widely grown in the plains and forests of central and northern India. Its flowers, fruits, and oil are utilized in various ways. The corolla, commonly known as mahua flowers, is a rich source of sugar and contains significant amounts of vitamins and minerals. Mahua is a very hardy plant that thrives in rocky, gravelly red soils, as well as saline and sodic soils Thar Madhu, NM-2, NM-4, NM-7, and NM-9 are high-yielding varieties developed for commercialization in semi-arid dry regions. Plants are transplanted during monsoon season at spacing 8m × 8m.Every part of the Mahua tree produces valuable economic products, making it a highly beneficial resource for tribal and impoverished communities in India.

Fruits can be consumed raw or cooked, while the pulp serves as a sugar source for alcoholic fermentation. The seeds are a rich source of oil. The oil extracted from the kernel is used for culinary purposes and is approved for the production of vegetable oil. The leaves are used to make plates for various purposes.Mahua seeds can also be processed into defatted flour, which has significant potential for use in bakery products. The saponin extracted from the seeds has industrial and commercial applications. The oil cake left after extraction serves as manure and has insecticidal properties. Additionally, the tree provides high-quality timber for various uses.

Fig

Fig (*Ficus carica* L.) is among the oldest cultivated fruit species in the world.It belongs to the Moraceae family, which includes over 1,400 species across approximately 60 genera.It has been an essential source of nutrition and health across various civilizations since ancient times, and its value continues to endure today. It spread to distant regions of the world, including China, India, Ethiopia, Arabia, Australia, and the Americas. The fig tree's remarkable adaptability to a wide range of soils, especially its tolerance to water scarcity and semi-tolerance to salinity, has made it increasingly important for cultivation in dry and semi-arid areas. It thrives in regions with an average annual temperature of 18-20°C, mild winters, and hot, dry summers (35-37°C).

A dry climate with optimal temperatures during fruit development and maturation yields the best quality figs. Fig fruit is highly nutritious, rich in dietary fiber, iron, calcium, protein, and calories. Dried figs also contain polyphenols, including anthocyanins and flavonoids, along with protein, fiber, carbohydrates, and essential minerals such as calcium, phosphorus, and iron.Fig can be cultivated in a variety of soil types, but deep clay-loams are the most suitable. Well-drained alluvial clay loams or medium black soils are also ideal for fig cultivation. Poona is one of the most commercially significant fig varieties. Rooting hardwood cuttings is the common propagation method for figs. The best rooting results are achieved with cuttings from 3-year-old wood, measuring 30-40 cm in length and 1.5 cm in diameter.

Additionally, figs can be propagated through air layering, shield or patch budding, and side grafting.The planting season varies by region: in South India, it is from August to September; in Western India, from June to July; and in North India, from January to February. Fresh figs are highly perishable, so slightly immature fruits should be harvested for transportation to distant markets. The harvesting season typically runs from mid-February to June, with yields ranging from 180 to 360 fruits per tree.

Manila tamarind

Manila tamarind (*Pithecellobium dulce* Roxb.) is commonly known as Madras thorn Monkey pod and *Jungle jalebi* and belongs to the *Fabaceae* family. It is a multipurpose, fast-growing, medium-sized thorny tree used as live fencing, animal fodder, hardwood timber, windbreak and a potential source of lac culture. Its fruit has a sweet acidic taste and high content of dietary fiber, proteins, Ca, Fe, P, unsaturated fatty acids and antioxidants. Manila fruit is used to treat toothaches, mouth ulcers, sore gums, dysentery, chronic diarrhea, stress, aging symptoms and dark skin spots.

Timroo

Timroo (*Diospyros melanoxylon* Roxb.) or tendu belongs to the family Ebenaceae and is native to India and Sri Lanka. It is found in endemic conditions within limited areas of Gujarat, Madhya Pradesh, Rajasthan, Jharkhand, Bihar, Chhattisgarh and Tamil Nadu. It is a long-lived, deciduous, dioecious, seedless parthenocarpic berry fruit. Its leaves are commercially used for bidis making (indigenous, traditional cigarette), agricultural implements and furniture. Most importantly, it is used as an indicator for high sulfur dioxide concentration. Timroo fresh fruit has high total phenolic content, flavonoids, scavenging activity, antioxidants and β-carotene content as equal or more to guava, plum, star fruit, mango, kiwi and apple fruit. Its bark extracts are used to treat dyspepsia, diarrhoea, and smallpox (burnt bark) by ethno medicine practitioners.

Palmyra palm

Palmyra palm (*Borassus flabellifer* L.) is a member of family Arecaceae and is native to tropical Africa and distributed from India across Southeast Asia to New Guinea. In India, it is found growing naturally across the country. It is a monocotyledonous and dioecious plant. Since ancient times, plants and trees have played a crucial role in enhancing human well-being. Various parts of plants and trees, including roots, stems, leaves, flowers, and seeds are utilized as medicines to treat a wide range of diseases. The young roots of the tree are used as a diuretic and anti-parasitic remedy and a decoction made from these roots is employed to treat respiratory and gastritis related disorders (Prasad *et al.* 2023).It is an underutilized palm that grows naturally in forests and barren lands. It is a large tree that can grow up to 30 m in height, with the trunk having a base circumference of 1.7 m.

Limited research has been conducted on the variety development of the Palmyra palm. Most planting is carried out using location-specific elite palms, primarily SVPR-1. It produces 298 liters of padaneer/tree annually, with a higher jaggery recovery rate of 144 g of jaggery per liter of padaneer. Local fruits are categorized as black-skinned and red-skinned palms. Black-skinned fruits have less red pigment, while red-skinned fruits exhibit varying black pigments with a high red pigment distribution.

High- Density Planting

The optimal plant density of orchard largely depends on factors such as the plant type, soil fertility, tree varieties, growth habits, rootstock selection, and management practices. According to various planting systems such as square, rectangular, triangular, quincunx, hexagonal, contour, and hedgerow methods can be selected for planting. In the plains, planting is typically carried out using the square or rectangular system, whereas on sloping lands, fruit trees are planted on contour terraces, half-moon terraces, trenches, bunds, or within micro-catchments. In a micro-catchment, which can be triangular or rectangular, trees are planted at the lowest point where runoff collects.The planting distance for Aonla (8 x 8 m), bael (8 x 8 m), jamun (8 x 8 m), mahua (8 x 8 m), ber (6 x 6 m), phalsa (2 m x 2 m) and karonda (4x4 m) cultivation is optimum.

The main reason for low productivity can be attributed to many factors, emphasizing the need to develop high-yielding varieties or hybrids that are resistant to biotic and abiotic stresses, have a dwarf stature, and respond effectively to pruning. High-density planting combined with effective canopy management can double the yield in less time and from a smaller area. Additionally, high-density orcharding promotes early bearing and helps reduce weed problems. High-density planting is adopting at a space of 5×5 m in bael, aonla, jamun, chironji, and mahua has proven effective in doubling yield and reducing harvesting challenges compared to traditional planting systems.

Moisture conservation and mulching

In arid and semi-arid ecosystems, where water is a major problem, the primary motive is to conserve available soil and rainwater. Harvesting, rainwater can provide sufficient water to enhance plant establishment and increase crop yields. Effective moisture conservation practices include the use of various mulching materials such as paddy straw, Husk, Maize straw, grasses etc, were applied to a thickness of 20 cm after the rainy season, which help increase soil moisture and water retention during intermittent rainfall or irrigation. Mulching helps to regulate soil temperature and moisture, suppress weed competition, and improve soil structure and biological activity, ultimately boosting crop yields. Furthermore, using organic materials as mulch also can impart manifold beneficial effect on earthworm and microbial population, soil fertility and growth and yield (20-25%) of plant under semi-arid ecosystem. Paddy straw mulch has been found effective in improving both the production and quality of aonla, including TSS, Vitamin C, and total sugar, under the semi-arid conditions of Gujarat (Singh *et al*. 2019).

Organic nutrient management

Soils in semi-arid regions are low in organic matter, which affects nutrient use efficiency and reduces soil's ability to retain moisture. Soils in semi-arid regions are often low in nutrients. Fruit plants are nutrient-demanding crops that deplete soil fertility significantly, highlighting the need for the judicious application of fertilizers. Providing balanced nutrition to fruit plants at the right time, based on their age, is essential for optimal growth and productivity. Organic fertilization enhances fruit crop tolerance to soil stresses such as drought, salinity, alkalinity, and toxic elements. Many studies have shown that applying organic manure improves soil's water and nutrient use efficiency by increasing organic matter and enhancing its physical, chemical, and biological properties. This promotes better plant growth and helps mitigate adverse conditions in the rhizosphere. Vermicompost is widely used in fruit crops due to the growing interest in organic farming. It is a rich source of micro and macronutrients, vitamins, growth hormones, and enzymes. Its application, along with FYM, significantly increases organic content and reduces bulk density.

Post- harvest management

Grading and packaging are essential practices for securing higher prices in the market. The packaging protects the produce from damage and loss by preserving its quality and maintaining its freshness. Corrugated fiberboard/boxes (CFB) and wooden boxes with appropriate cushioning materials are the most suitable and cost-effective packaging containers for transporting semi-arid horticultural produce. Proper storage facilities, such as cool storage, controlled atmosphere (CA) storage, and Zero Energy Cool Chambers (ZECC), can significantly reduce post-harvest losses and enhance farm income (Singh *et al.* 2018a, 2010a).

Fruits grown in semi-arid regions have been processed into various products using traditional knowledge, such as sun drying and pickling. However, the application of modern techniques can significantly enhance the quality of these products. Pre-treating many fruits with hormones and safe chemicals leads to higher quality end products. Solar drying and electric tray dehydration of fruits and vegetables help reduce dust contamination and preserve their natural colour. Techniques for producing various products from underutilized fruits have been standardized (Reddy *et al.* 2018).

Malnutrition is a significant issue in resource-poor areas of semi-arid regions, particularly affecting women and children. Fruits such as bael, ber, tamarind, mulberry, custard apple, karonda, khirni, mahua, phalsa, chironji, fig, wild noni, and wood apple are rich in vitamins, minerals, and dietary fiber. Bael (*Aegle marmelos*) is a rich source of bioactive compounds, which have been shown to be effective against several major ailments. It is also an important component in various traditional formulations for treating different diseases (Singh *et al.*, 2020, 2021). Wood apple also offers antioxidant, anticancer, antidiabetic, antimicrobial, and hepatoprotective benefits. Wood apple also containing contains a diverse array of bioactive compounds, including phenols, flavonoids, alkaloids, terpenoids, tannins, saponins, fatty acids, steroids, glycosides, gum mucilage, and fixed oils. Both the leaves and fruits of ber are significant from a nutritional perspective due to their high mineral content, vitamin C, and other essential nutrients (Saroliya *et al*. 2024).

Additionally, with an oversupply in the market, the prices of these fruits plummet, making it uneconomical for farmers to continue production. As a result, many farmers uproot their trees due to the low market prices. To prevent this situation, it is essential to extend the shelf life of these fruits and to develop simple, adaptable post-harvest value addition technologies at the farm level. This will not only foster the development of small-scale industries but also create year-round employment for the rural population, leading to increased income for both farmers and workers. The efforts undertaken at the CIAH Bikaner and the Regional Research Centre CHES in Godhra were successful, resulting in the development of various products, such as dried and dehydrated fruits, ready-to-serve (RTS) beverages, squash, fruit bars, candies, fruit concentrates, powders, wines, and condensed fruit juices through solar drying. These products were prepared and demonstrated to stakeholders for further commercialization. Products such as squash, ready-to-serve (RTS) beverages, and nectar can be made from fruit pulp(Table 3).

CONCLUSION

Considering the agro-climatic environment of semi-arid region, it is need of hour to create awareness among farmers regarding the various technologies like high-yielding varieties, water harvesting practices, use of organics, IPM, IDM, bio-pesticides, biofertilizers, preparation of value-added products and their marketing can enhance the farm income under prevailing conditions of semi-arid region. Unproductive land can be made productive by selecting the crops having ability to grow under aberrant agro-climatic conditions by proper planning and amalgamation of suitable technologies holistically. As most of the semi-arid fruits cannot be directly used for the table purpose, and thus fetches low prices in the market. Therefore, through processing and value addition and their efficient marketing, farmer's

Table 3: Value-added products of semi-arid fruits

Underutilized fruit crop	Value-added products
Bael	Preserve, nectar, RTS, slab, ice cream, cider, squash, canned bael slices, powder and pickles
Tamarind	Juice concentrate, jam, Tokku (chutney), panipuri masala, pulp powder, syrup, toffee, candy, tamarind karnel powder
Karonda	Pickle, preserve, jelly, candy, jam, chutney and wine
Jamun	Juice, squash, RTS, syrup, wine and carbonated drink
Khirni	RTS, Dehydrated fruits, jam, fruit bar
Wood apple	Powder, chutney, squash, jelly, pickle, fruit bar
Phalsa	Syrup, Juice and squash
Mulberry	Squash, Juice and syrup
Chironji	Dried kernels, fruit bar
Custard apple	beverages, Jam and ice cream
Mahua	Biscuits, dried powder, cakes, wine and seed oil
Aloe	Jelly, Candy, crack cream, cold cream, moisturizer, gel and pickle
Lasoda	Pickle, culinary
Fig	Jam, Fig paste, powder, concentrate and nuggets
Manila tamarind	Syrup, Biscuits and squash
Timru	dried fruit and Bidi

Hiwale, 2015, Singh *et al.* 2019, Yadav *et al.* 2018a & 2018b economic status can be effectively improved with better health and nutritional security. Therefore, focusing attention on such fruit crops is an effective way to help a diverse and healthy diet and to combat malnutrition, so called 'hidden hunger' and other dietary deficiency among the poor rural people and more vulnerable social groups specially tribes of country.

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Research Review Article

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Analysis of half-sib progenies of sapota (*Manilkara zapota*) for dwarf stature and fruit quality

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Abstract

The evaluation of 116 half-sib progenies of sapota (*Manilkara zapota* Royen) var. Cricket Ball was carried out for 6 years (2017-2022), at ICAR-IIHR,Bengaluru to develop a promising variety characterized by dwarf growth habit, high productivity, and quality fruits. All the progenies were evaluated for growth, yield, fruit, and biochemical parameters. Correlation among different yield-contributing traits in half-sib progenies revealed that yield was strongly correlated with the number of fruits (r=0.945) while the tree height showed a positive and significant correlation with tree volume (r=0.904) and tree spread (r=0.854). Regression analysis indicated a strong positive relationship between yield and both fruit weight and the number of fruits/tree. Half-sib progenies were grouped into seven clusters based on Euclidean distance, with the S-63 forming a separate single cluster with all desirable traits. Among half-sibs, one half-sib line, S-63, with desirable traits has been identified, multiplied and further evaluated in a row trial with Cricket Ball as the control for three years (2020-2022). In row trial, the progeny S-63 recorded a low tree height (1.95 m) and a high yield (90.21 fruits/tree), compared to Cricket Ball which recorded a tree height of 2.15 m and a yield of 10 fruits per tree at the sixth year. The average yield of S-63 was higher at 48.37 fruits per tree (5.9 kg) compared to Cricket Ball (13.67 fruits/tree; 1.4 kg). Fruit weight of S-63 (128.57 g) was higher compared to Cricket Ball (114 g). The TSS (20.33°Brix), and acidity (0.29%) were higher compared to Cricket Ball (19.66°Brix; 0.2%). Thus, S-63 was found to be the best performing line for yield, dwarf stature fruit and quality fruits

Key words: Half-sibs, Evaluation, Dwarf, Yield, Biochemical parameters

Sapota (*Manilkhara zapota* Royen) is a popular fruit belonging to family Sapotaceae. It is believed to have originated in tropical America, Mexico in particular, and spread to other countries due its sweet, tasty fruits. In India, is mainly grown in Andhra Pradesh, Gujarat, Maharashtra, Karnataka Tamil Nadu and to some extant in West Bengal and Orissa. Sapota is a diploid with basic chromosome number 2n=2x=26.A suitable dwarf tree will help in boosting the productivity. Improvement programs on sapota are being carried out at various research centers including Coimbatore, Periyakulam and Dharwad. The varieties CO-1, CO-2, CO-3, PKM-1, PKM-2, PKM-3, PKM-4, PKM-5, DHS-1 and DHS-2 are hybrids and/or clonal selections that bear better quality fruits with good yield potential and other desirable traits.

The Cricket Ball variety of sapota is usually grown in Tamil Nadu, Karnataka, Maharashtra, West Bengal and Andhra Pradesh. Its fruits are large in size, round and sweet with granular pulp. Several attempts were made to select superior types from existing clones. There is no variety with dwarf stature and single fruit instead of clusters. Fruits in clusters have other disadvantages like uneven size and higher infestation of pests. With the objective of developing dwarf type varieties, a breeding program using Cricket Ball, PKM-1 and Kalipatti as parents and their half-sibs were raised and evaluated for yield, fruit quality, and dwarf stature.

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MATERIALS AND METHODS

The experiment was conducted at ICAR-IIHR, Bengaluru (13° 7'N latitude and 77° 84 29'E longitude, 890 m above MSL). The Climate of the area is semi-arid climate with mean temperature range between 18^0C and 35^0C. The annual rainfall is 850 mm (bimodal with June-July and September). The soils of area are classified as red sandy loams. The soils contain about 0.52 % organic carbon, 163, 84, 164 kg/ha available N and P_2O_5 and exchangeable K_2O, respectively, 6.65 pH, Ec of 0.23 dS/m The half- sib population were derived from open pollinated seedlings of the sapota variety Cricket Ball. Initially 1000 open pollinated seeds of Cricket Ball were sown in polybags containing sand:soil:FYM (1:1:1ratio).

After sowing the polybags were drenched with 0.2%copper fungicide to control fungal infection. One year old half-sibs were planted in pits measuring 40 cm × 40 cm × 40 cm during February 2006 in a square system method at a spacing of 5 m × 5 m. These seedlings were managed according to standard practices, and watered as needed using a drip irrigation system. Fertilization was managed based on recommended nutrient doses. These doses were divided into two halves and applied in June and October. Pest populations were kept under control by recommended pest management measures.

Initially growth and yield parameters of 116 half-sib progenies of Cricket Ball planted were recorded during 2012-2017. The growth and yield parameters were recorded for all progenies. Tree height (m) was measured from the base to the tip and expressed in m. The canopy size was determined by measurements taken in four cardinal directions both north-south and east-west and expressed in m. Tree height and canopy spread were converted into tree spread and tree volume.

Tree spread (m^2) = plant spread (N-S) × plant spread (E-W/2)

The tree volume (m^3) = (tree spread × plant height) ×0.85).

The scion trunk circumference was measured at 10 cm above the bud union and converted into trunk cross-sectional area (TCSA, cm^2). The trunk cross-sectional area was calculated by using formula (TCSA= $Girth^2/4$) given by Kumar *et al.* (2008). All fruit samples of half-sibs were assessed for 6 years (2012–17) using standard procedures. In the month of October-March, which is commercial harvesting season of sapota in Bangalore, 10 matured fruits/tree were randomly sampled for recording data on physical parameters. The average fruit weight (g) was measured using an electronic weighing balance. The fruit length, width and thickness (in cm) were measured on these sampled fruits using a digital vernier calipers. Fruit shape was recorded based on visual observation. The pulp recovery (%) was calculated by subtracting fruit weight and pulp weight. Yield (kg/tree) were recorded annually during 6 years of production. Tree yield by canopy volume (kg/m^3) and trunk cross-sectional area (kg/cm^2) were also estimated.

Promising haf-sib line, S-63 was identified based on desired traits and multiplied by grafting using 16-months-old khirni (*Manilkhara hexandra*) seedling stock. Approach grafting was done by taking 6 month old scion from new flush and grafting was carried out in February and kept in shade net (50%) near the mother plant till successful graft union and graft establishment. Twenty grafts of selected progeny, S-63, were evaluated in replicated trials along with the parent variety, Cricket Ball during 2020 to 2022. Data were recorded on tree height (m), tree girth, canopy spread N/S (m), canopy spread E/W(m), number of fruits/plant, yield/tree, fruit weight, fruit length, fruit width, TSS (°Brix), acidity, reducing sugars, non-reducing sugars and total sugars.

The soluble solid content TSS was determined in ripe fruits using a hand refractometer and expressed in Brix. Acidity (%) and vitamin C (mg/100g pulp) were estimated as per Ranganna (1986). The method developed by Lane and Eynon (1923) was used to determine sugar concentration.

$$\text{Total sugars (\%)} = \frac{\text{Factor} \times \text{volume made up (ml)} \times \text{volume taken (ml)}}{\text{Titre value} \times \text{weight of sample (g)}}$$

Reducing sugars (%) was calculated using the formula (Ranganna, 2001)

$$\text{Reducing sugars (\%)} = \frac{\text{Glucose factor x volume made up (ml)}}{\text{Titre value} \times \text{weight of sample (g)}}$$

The quantity of non-reducing sugars was calculated by deducting the value reducing sugars from total sugars. The distribution of half sib progenies of under each category was shown by totaling the number of individuals which belonged to each scale. Range, mean, and standard deviation of half-sibs were calculated by descriptive statistics using Excel. Pearson correlation coefficient among growth and yield characters, and regression analysis for yield and its contributing characters was done using PAST software (Hammer *et al*., 2001). The Euclidean distance matrix and Ward technique were used in a cluster analysis to achieve the grouping progenies according to their similarities, including quantitative and qualitative traits using PAST software. Dendrogram was developed using tree height, yield and fruit quality.

RESULTS AND DISCUSSION

Growth parameters of half-sibs

One hundred and sixteen half-sibs of Cricket Ball along with parent Cricket Ball as check variety were evaluated for growth and yield parameters during 2012-2017. Pooled analysis data over 6 years indicated that variability was observed for plant height, canopy spread, plant girth, tree volume, and Trunk Cross-Sectional Area (TCSA), as shown by a high coefficient of variation (CV). Tree height varied from 100.5 cm to 750 cm, with a mean of 276.21 cm (Table 1). Based on height, progenies were categorized as dwarf (100-350 cm), semi-tall (350-500 cm), and tall (>500 cm). The majority of progenies (93) were in the range of 100-350 cm that falling under dwarf category (Fig.1). Seventeen progenies were in the range of 350 cm to 500 cm and were considered as semi-tall. Only six progenies had plant height more than 500 cm and were treated as tall. Padi *et al.* (2012) found that the rate of increase in tree trunk cross-sectional area (TCSA) prior to bearing was an effective parameter in identifying families with large cumulative yields over the first five or six production years.

Mean stem girth was 27.81cm with highest recorded as 60.14 cm and a minimum of 8.38 cm. Thirty-four progenies had <20 cm girth; Fifty-nine progenies had 20-40 cm whereas twenty-three had >40 cm plant girth (Fig.1). The distribution pattern of growth parameters such as plant height, girth, canopy spread, and tree volume in half sib progenies showed that all these characters are segregating upon open-pollination.

Table 1. Descriptive statistics for growth parameters among half-sib progenies (N=116)

	Tree height (cm)	Tree girth (cm)	Canopy spread (cm) N-S	Canopy spread (cm) E-W	Tree spread (m^2)	Tree volume (m^3)	TCSA (cm^2)
Mean	276.21	27.81	219.67	228.04	3.22	10.66	73.48
Min	100.50	8.38	55.83	54.17	0.15	0.16	5.59
Max	750.00	60.14	546.67	654.00	17.88	97.5	287.96
SD	119.28	12.27	118.28	127.47	3.53	16.55	63.02
CV (%)	43.18	44.12	53.84	55.90	109.63	155.25	85.76

Mean canopy spread both NS and EW directions were 3.22 m^2 (Fig.1). The minimum canopy spread was 0.15 m^2 and maximum was 17.88 m^2. Mean tree volume was 10.66 m^3 and minimum was 0.16 m^3 and maximum recorded was 97.5 m^3. Low TCSA observed was 5.59 cm^2 and high being 287.96 cm^2 with a mean of 73.48 cm^2. The coefficient of variation was very high (>100%), indicating that values are exceeding the mean value (Table 1). The CV was >50 % for TCSA (85.76%) and canopy spread (55%). The CV for plant height and plant girth was 43 and 44 % respectively indicating magnitude of variability in these characters. The summary statistics which showed that half-sib progenies are highly heterogeneous for all the parameters as coefficient of variation was very high (Table 1). Numerous breeding programmes throughout the world have made different tree designs and genetic control of tree size as the main objective. The three basic genetic characteristics for regulating tree size are compact, semi-dwarf, and dwarf. Trunk cross-sectional area, indicative

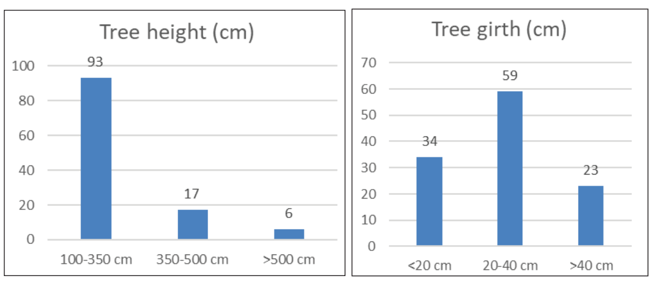

Fig.1. Variability in tree height and girth in half-sibs (N=116) of Cricket Ball

of vegetative growth intensity is the regular trait used to estimate cumulative growth in perennial tree species.

Fruit characters

The fruit evaluation was carried out in 59 half-sib progenies that came to fruiting. Fruiting started during sixth year after planting. Similarly in Punjab condition, Cricket Ball came to fruiting at 6 yrs after planting (Rattanpal *et al.* 2013). Fruit weight ranged from 40 g to 190g with a mean of 81.5 g (Table 2). We categorized fruit weight into three categories, viz., < 80g, 80-120g, 120-160g and >160g (Fig.2). The 33 progenies had fruit weight with <80g; 19 progenies had fruit weight between 80-120g and five progenies had 120-160g (S-7, S-16, S-23, S-26 and S-63) and only 2 progenies (S- 6 and S-18) had fruit weight with > 160g. The fruit length was 5.93 cm with minimum of 4.6 cm and maximum of 9.33 cm. Majority of progenies (52) had fruit length between 5-7 cm. Only three progenies had < 5 cm, and three had 7-9 cm and only one had >9 cm. Mean Fruit diameter was 5.64 cm with minimum being 4.08 and maximum 7.90 cm. Eleven progenies exhibited fruit width < 5cm; 4 progenies had 5-7cm and only 5 progenies had > 7cm fruit width. Similarly longest fruit length (5.51±0.33), highest fresh weight (75.22±2.24), highest total soluble solids (26.79±0.95) and highest fruit yield (8.64±1.34) were found in BAU Sapota 3 (Rafiul Islam *et al.* 2016).

Fruit size index ratio denotes the shape of fruit. Twenty-one progenies had <1, while 38 progenies had ratio of >1. Fruit index ratio was positively corroborated with visual recording of fruit shape. Fruit index ratio of 1 and <1 was recorded as round and oval if the ratio is more than 1. In watermelon, Takayuki Tanaka *et al.* (1995) found that spherical and oval were controlled by a single allele with incomplete dominance.

Fruit yield in terms of number of fruits/pl was classified into 5 categories. Maximum progenies recorded <30 fruits/plant. Five progenies produced 30-60 fruits and six progenies had 60-90 fruits. Only 2 progenies produced 90-120 (S-13, S-63) fruits and only one progeny (S-12) recorded highest number of fruits/ plant (>120 fruits). Number of fruits recorded maximum variability with CV >100%. Maximum number of fruits/plants recorded was 122.50 with yield of 14.75 kgs. Fruit weight and number of seeds/fruits also exhibited variability with CV >30%. Similar studies on evaluation of 17 years old 22 sapota cultivars under Arabhavi in North Karnataka revealed that Cricket Ball showed superior results with respect to growth and yield parameters like canopy volume (154.90 m^3), fruit weight (102.83 g), fruit yield (111.67 kg/tree), fruit volume and shelf-life (6.50 days). In Mango the fruit yields per unit

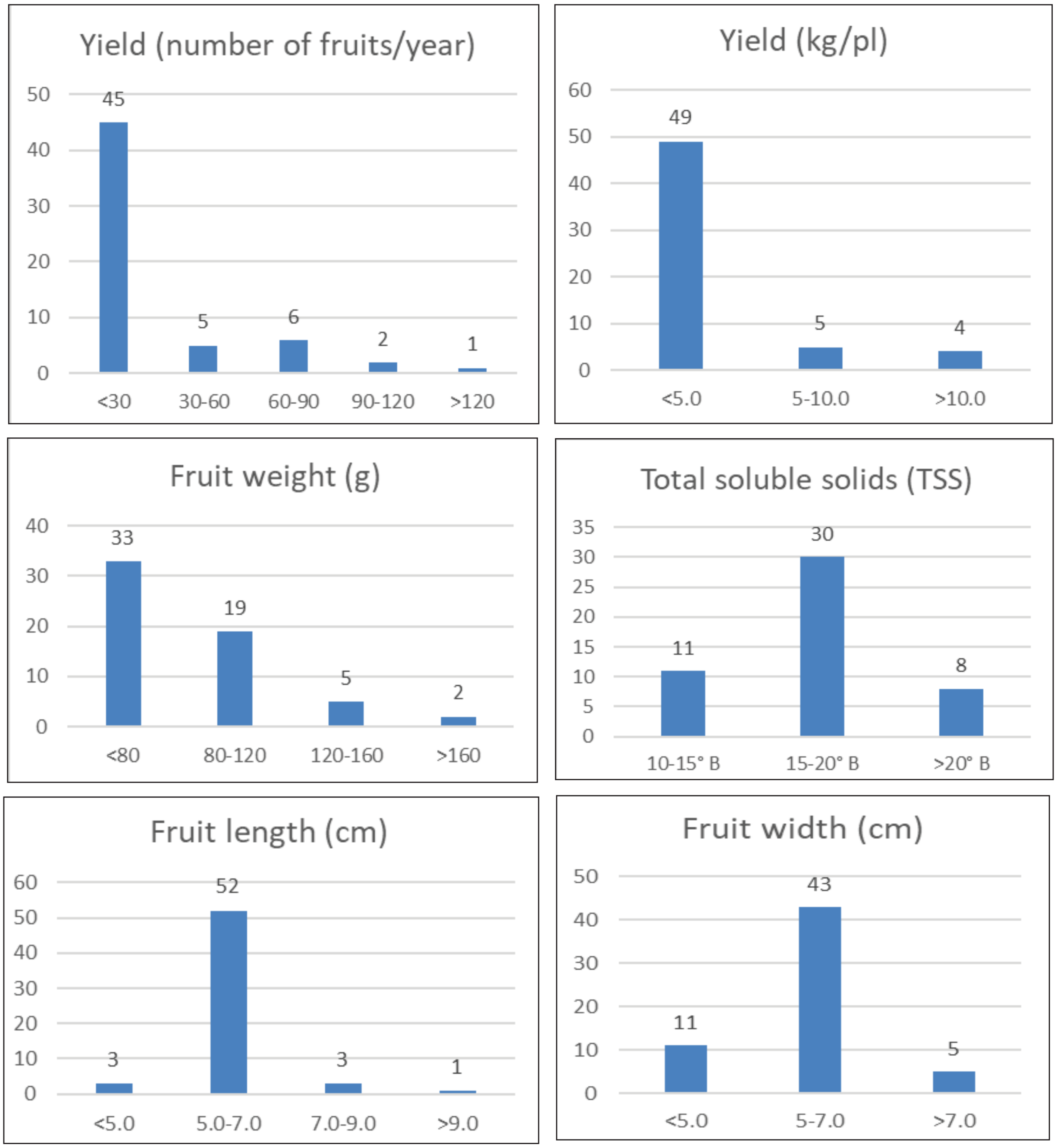

Fig.2. Distribution of progenies for different fruit parameters (N=59)

canopy volume and per unit land area were higher with the dwarfing 'Vellaikulamban' rootstock.

Number of seeds/fruits was as low as 1.8 and as high as 8.40. Number of seeds/fruits was 2-4 in majority of the progenies (42). Low seed number is a desirable trait and only one progeny (S-63) had <2 seeds/fruit. Fourteen progenies had 4-6 seeds, 22 had 6-8 seeds/fruit, while one progeny had >8 seeds/fruit (S- 40).

Pooled fruit yield was 2.41 kg/ tree with lowest of <1 kg (121) and highest of 14.75 kg (S-63). Fruit yield in terms of was classified into 5 categories. Forty-nine progenies were poor yielding (<5 kgs/pl), 5 moderately yielding (5-10 kg/plant), 4 progenies (S-6, S-7, S-12, S-13, S-63) high yielding (10-15 kg/plant) and progeny, S- 63 exhibited highest yield of 14.75 kg/plant.

The TSS ranged from 10.9 to 23° Brix with a mean of 17.46. The 11 progenies had 10-15 ° Brix; 30 contained 15-20 ° Brix and 8 half sibs had > 20 ° Brix (S-12, S-54, S-63, S-94, S -122, S-108, S-116 and S-120). The progenies, S-13, S-6 and S-7 had other desirable traits such as fruit weight

Table 2. Fruit and yield parameters among seed progenies (N= 59)

Seedling No.	Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	Fruit length: width ratio	TSS (°B)	Number of seeds/ fruit	Number of fruits/plant	Yield/ tree (kg)	Yield (kg/ m^3 tree vol.)	Yield (kg/ m^2TCSA)
Mean	81.52	5.93	5.64	1.06	17.46	3.56	24.56	2.41	0.23	224.69
Min	40.08	4.60	4.08	0.78	10.90	1.80	2.00	0.11	0.01	19.54
Max	189.50	9.33	7.90	1.50	23.00	8.40	122.50	14.75	3.31	1381.16
SD	29.57	0.87	0.84	0.15	2.46	1.16	29.44	3.49	0.45	246.64
CV (%)	36.27	14.67	14.89	14.15	14.09	32.58	119.87	144.81	195.65	109.77

and fruit size with desirable traits like big size fruits with fruit weight, higher TSS, with low yield and exhibited tall growth habit.

Variability in open-pollinated seedlings was quite large with desirable characters like fruit yield and quality. Similar results were reported on 20 sapota accessions collected from different parts of India. Similarly in Punjab condition, Cricket Ball produced round-shaped large fruits (147.0g), gritty granular pulp, TSS (22.8 °Brix), acidity (0.21%) 4.3 seeds/fruit and average yield of 85.0 kg fruits/tree (Rattanpal *et al.* 2013).

In mango, dwarfness induced EMS concentration included reduced plant height along with other morphological changes such as thicker stem, more branching, shorter internodal length in dwarf mutant populations (Jome Rime *et al.*, 2019). Thus, it is clear that substantial differences exist among progenies for growth and yield characters. The open-pollinated half-sibs generated by seed propagation became the basis of variability. Most of cultivars and varieties are originated by selection. Presence of high degree of variation (due to high degree of heterozygosity) is an opportunity for improvement in sapota cultivars by selection. Our results indicate that selection of sapota seedlings for yield and dwarf is possible, based on vegetative characteristics assessed very early in their development. Out of 116 open-pollinated seedling progenies of Cricket Ball, S-63 seedlings was selected based on desirable traits such as high yield, big size fruits, fruit quality (high TSS) and dwarf stature.

Correlation was worked out for different growth and yield parameters (Table 3). The existence of correlations between the growth traits and time to first flowering, yield and dwarfness was investigated.

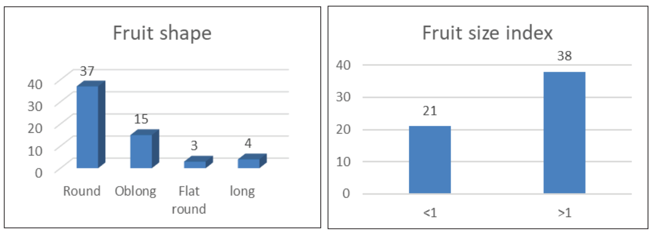

Fig. 3. Variability in fruit shape and fruit size index among half-sib progenies (N=59)

Table 3. Correlation among growth and yield in sapota.

	TH	SG	TS	TV	FW	FL	FD	FL/FD	TSS	NS	NF	Y
TH	1											
SG	0.784**	1.000										
TS	0.854**	0.786**	1.000									
TV	0.904**	0.739**	0.963**	1.000								
FW	0.509**	0.533**	0.589**	0.561**	1.000							
FL	0.176 NS	0.275 NS	0.244 NS	0.233 NS	0.616**	1.000						
FD	0.414**	0.440**	0.494**	0.479**	0.818**	0.552**	1.000					
FL/FD	-0.276NS	-0.187 NS	-0.267 NS	-0.268	-0.212 NS	0.450**	-0.478**	1.000				
TSS	0.061 NS	0.173 NS	0.078 NS	0.067 NS	0.145 NS	0.041 NS	0.226 NS	-0.202 NS	1.000			
NS	0.163 NS	0.256 NS	0.188 NS	0.145 NS	0.053 NS	-0.065 NS	0.049 NS	-0.129 NS	-0.218 NS	1.000		
NF	0.538**	0.603**	0.664**	0.650**	0.472**	0.299 NS	0.453**	-0.178 NS	0.233 NS	0.075 NS	1.000	
Y	0.567**	0.644**	0.693**	0.674**	0.678**	0.464**	0.586**	-0.150 NS	0.208 NS	0.071	0.94**5	1.000

Tree height was positively and highly significantly correlated with tree volume (0.904), tree spread (0.854), and girth (0.784). It is moderately correlated with fruit weight (0.509), number of fruits/tree (0.538) and yield (0.567). Low/no correlation was observed for TSS and number of seeds/fruit. Similar results were reported by Rekha et al. (2011). Number of seeds/fruit had significant negative correlation with fruit length, indicating that it can influence fruit shape. Yield was highly correlated with number of fruits (0.945). It was moderately correlated with tree spread (0.693), fruit weight (0.678), tree volume (0.674), girth (0.644) and tree height (0.567). It was negatively correlated with fruit length/fruit width ratio.

There was a positive correlation between tree height and canopy spread. The number of fruits/ tree and canopy spread had positive correlation with fruit yield/tree. The biochemical traits such total sugars and ascorbic acid content had negative correlation with fruit yield, indicating that simultaneous improvement of yield and quality were not possible.

A positive Pearson correlation between total yield number of fruits/plants, and flower length was strongly correlated with fruit size in *Annona squamosa* (Nogueira *et al.,* 2022). The fruit weight, fruit length, fruit width, pulp weight and seed weight showed highly significant positive correlations with fruit yield, while peel per cent showed negative correlation with fruit yield in avocado (Muralidhara *et al.*, 2024).

From the correlations it may not be possible to simultaneously select for dwarfness and high yield. Among half-sibs. S-63 recorded most of the desirable traits.

Regression analysis

The Multiple Linear Regression (MLR) analysis was carried out by considering all the independent variables that contribute to dwarfness, yield and fruit quality (Table 4) such as plant height, girth, tree spread, tree volume, fruit weight, fruit length, fruit width, number of fruits/tree and yield. It was found that coefficient of determination (R^2) of MLR model was very high (Table 4). Although the R^2 value of MLR model was very high, most of the variables in model were non -significant.

Table 4: Multiple linear regression model

Source of variation	DF	Sum of squares	Mean squares	F-calculated	Significance
Regression	9	708.474	78.719	166.591	0
Error	49	23.154	0.473		
Total	58	731.628			

R-square value : 0.9684
Multiple R-value : 0.9840

Only fruit weight and number of fruits were highly significant which infer that as fruit weight and number of fruits increases, the yield also increases (Table 5). Thus, it can concluded that selection should be based on fruit weight and number of fruits/tree. Similar result was obtained in guava (Padilla-Ramírez *et al.,* 2007)

Table 5: Regression analysis of sapota yield- contributing characters.

Variable	Coefficients	Standard error	t-value	Significance	
Tree height (cm)	-0.002	0.002	-0.816	0.418	NS
Stem girth (cm)	0.016	0.015	1.053	0.297	NS
Tree spread (m^2)	-0.1	0.099	-1.01	0.317	NS
Tree volume(m^3)	0.019	0.023	0.818	0.416	NS
Fruit wt	0.039	0.006	6.298	0	HS
Fruit length	0.235	0.138	1.703	0.094	NS
Fruit width	-0.315	0.195	-1.621	0.111	NS
TSS	-0.028	0.04	-0.699	0.487	NS
No of fruits/ tree	0.097	0.004	22.037	0	HS
Yield	-2.039				

The stability analysis based on regression coefficient (b_i) of nine sapota varieties including cricket ball revealed that all the sapota varieties exhibited a regression coefficient close to one and had a stable yield (Dhakar *et al.,* 2023).

Genetic relationships between half-sibs

A Dendrogram was developed based on tree height, canopy spread, stem girth, fruit weight, fruit size (length and width), number of fruits/tree and total yield per plant. Based on similarity coefficient, progenies were grouped into 7 clusters (Fig.4). First cluster consists of 8 progenies (S-18, S-4, S-20, S-1, S-5, S-10, S-11, S-28). The progenies in this group were semi tall, moderate to thick girth, medium fruit weight, medium fruit length and width, medium TSS**,** and very low yield. Second cluster comprised 7 progenies (S- 6, S-7, S-8, S-17, S-12, S-16 and S-19). These progenies were tall to semi-tall, thick girth, medium to big fruits, medium to large fruit size, moderate TSS and moderate yielders. Third cluster consist of 17 progenies (S- 9, S-29, S-46, S-2, S-24, S-34, S-55, S-31, S-32, S-50, S-47, S-42, S-37, S-57, S-39, S-45 and S-40).

Here most of them were dwarf, moderate girth, small to medium fruit weight, medium fruit size, low to medium TSS and very low yielders. Fourth cluster consists of 7 progenies (S-14, S-52, S-15, S-41, S-21, S-36, S-22). They were semi-tall, moderate to thick girth, low to medium fruit weight (except S-22), medium fruit size, moderate TSS, very low yielding except S-36 and S-52. Fifth cluster comprised 17 progenies (S-3, S-56, S-58, S-26, S-48, S-51, S-54, S-25, S-49, S-43, S-44, S-27, S-33, S-38, S-59, S-53,and S-30). They were dwarf, medium thick girth, small to medium fruit weight, medium fruit size, moderate to high TSS, very low yielding except S-48, S-53, S-25, S-26.

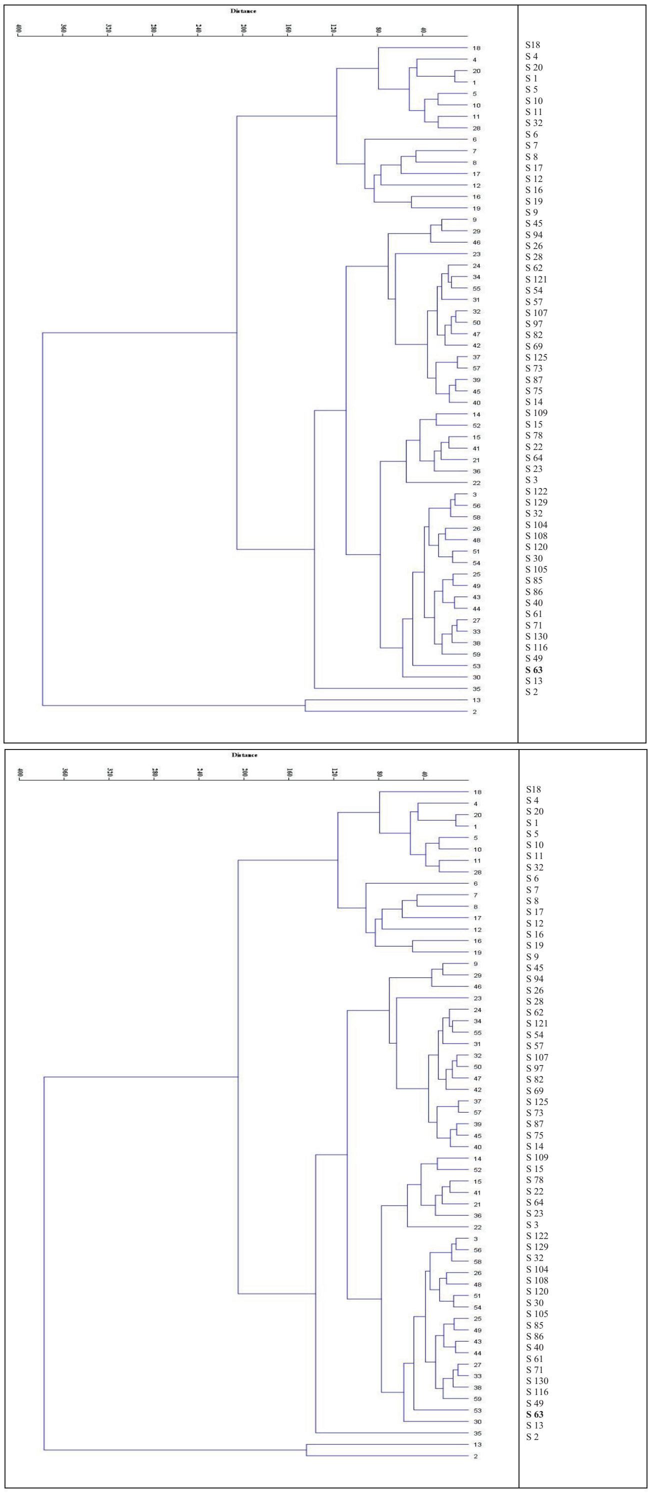

Fig.4. Dendrogram showing genetic relationships based on morphological traits among half-sibs of Cricket Ball

Sixth cluster consists of only one genotype (S-63) that was dwarf, thick girth, big fruits of medium size, high TSS and high yielder. Seventh cluster consists of 2 progenies (S-13 and S-2) which were tall, thick girth, medium fruit weight with medium fruit size, medium TSS and low yielding.

To ascertain the superiority of S-63, a row trial was taken up and 25 grafts of S-63 were planted along with Cricket Ball for further evaluation. The tree height of 4-year old plants was 1.95 m in S-63 as compared to 2.15 m in Cricket Ball. Pooled data on tree height, girth, canopy spread, yield, fruit weight, fruit size, TSS, acidity is presented in Table 6.

Table 6. Comparative evaluation of IIHR S 63 with Cricket Ball for growth, yield and fruit quality parameters (pooled data from 2020-2022)

	IIHR S 63	Cricket ball	SD	T test
Tree height (m)	2.26	2.52	0.3	13.019**
Stem girth(cm)	13.33	13.67	1.528	15.119 **
Canopy spread N/S (m)	2.41	2.80	0.611	6.825 **
Canopy spread E/W(m)	2.34	2.86	0.512	7.914**
Av. no. fruits/Plant	48.37	13.67	12.973	6.457**
Yield/Tree Kg	5.91	1.40	0.881	11.62**
Fruit Weight(g)	128.57	114.00	16.92	13.161**
Fruit length (cm)	6.34	5.27	0.58	18.919
Fruit Diameter (cm)	6.34	5.62	0.265	41.505**
TSS (^{O}Brix)	20.33	19.66	0.289	122**
Acidity (%)	0.29	0.20	0.044	11.52**
Reducing sugars (%)	8.60	10.43	0.501	29.753**
Non reducing sugars (%)	11.28	7.49	0.462	42.303**
Total sugar (%)	19.55	17.93	0.784	43.171

Total sugars, non-reducing sugars and reducing sugars analysed by t test for 3 years (2020-2022) showed significant difference between the selected progeny (S-63) and the check (cricket ball) for all the parameters (Table 6).

The S-63 exhibited comparatively lower tree height (2.26 m) compared to Cricket Ball (2.52 m) (Fig.5).It was found that the S-63 has dwarf plant type with single fruit bearing habit. Yield in terms of number of fruits/tree and total weight of fruits/tree were high in S-63 (48.37 fruits; 5.91 kgs) compared to cricket ball (13.67; 1.40 kg). The fruit yield, size, colour and quality were found equivalent to cv. Cricket Ball. Based on similar studies in arecanut, Ananda *et al.* (2017) stated that dwarf varieties (VTLAH-1 and VTLAH- 2) were bred with high yield potential from open pollinated progenies and the selected progeny is likely to benefit the growers by enhanced returns and reduced cost (40%) of various cultural operations. VTLAH–2 yielded

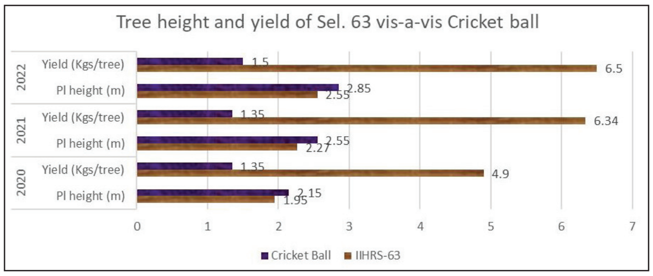

Fig. 5. Comparative evaluation on tree height and yield of IIHR S-63 and Cricket Ball

2.64 kg and grew up to 4 m in height and plant density can be increased to 800 from 600/acre.

The stem girth was almost same with 13.33 cm and 13.67 cm in S-63 and Cricket Ball respectively (Fig.6). Canopy spread was comparatively less in S- 63 (2.41*2.34 m) compared to the cricket ball (2.80*2.86 m).

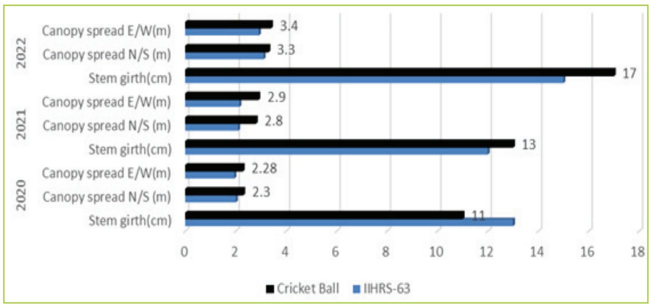

Fig.7. Comparative evaluation on canopy spread and girth of IIHR S-63 and Cricket Ball

Canopy spread (in both directions) was more in cricket ball through the study period compared to S-63. Stem girth higher in S-63 during the third year and fourth and fifth year the increase was less compared to cricket ball. Fruit quality parameters were evaluated to ascertain the superiority of the desirable parameters in the selected progeny (Table 6). Fruit weight was more in S-63 (128.57 g) compared to cricket ball (114 g). Fruit size was also more in the S-63 (6.34*6.34 cm) compared to the Cricket Ball (5.27 * 5.62 cm).

Biochemical parameters: Total sugars, non-reducing sugars and reducing sugars analysed by t test for 3 years (2020-2022) showed significant difference between the selected progeny (S-63) and the check (Cricket Ball) for all the parameters (Table 7). Sweetness measured as TSS was comparatively high in S-63 (20.33 B) compared to check (19.66) (Table 7). Fruit acidity expressed as citric acid was slightly more in S-63 (0.29 %) compared to cricket ball (0.20%). Fruit taste and flavour is determined by TSS/acidity ratio. Total sugars expressed in % was also high S-63 (19.55%) compared to cricket ball (17.93 %). In the selected progeny, S-63, reduced sugars accounted to 8.6% and non-reducing sugars accounted for 11.28%. Cricket ball variety recorded higher value for reducing (10.43%) and lower value for non-reducing sugars (7.49%) compared to S-63. The sugar/acid blend contributes to the taste and flavor of the fruits compared to the individual levels of sugars and acidity. Tripathi *et al.*, (2024) reported a carbohydrate content of 30.12 g/100g in the ripe fruits of avocado.

High morphological variability and genetic diversity were obtained by open-pollination in sapota. The S-63 is a high-yielding, with big fruits round fruits having sweet, soft pleasant flavoured, orange brown pulp and less number of seeds. Its tree is dwarf, compact and suitable for high-density planting. The half sibs generated would be used as parents in breeding program of sapota, to obtain more genotypes that are productive and with good fruit quality. The S-63 has also been planted at different centers across India for evaluation under various agro climatic regions to study its performance and stability for dwarf stature, yield and fruit quality.

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CRediT AUTHOR STATEMENT

Rekha: Conceptualization, Methodology, Data recording P C Tripathi: Data curation, Writing- Original draft preparation. Anuradha Sane: Data analysis, Writing-Reviewing and Editing. M R Dinesh: Methodology, Validation.

Table 7. Biochemical parameters of IIHRS-63 *vis- a- vis* Cricket Ball

	TSS (^{O}Brix)	Acidity (%)	Reducing sugars (%)	Non reducing sugars (%)	Total sugar (%)
IIHRS-63	20.33	0.29	8.60	11.28	19.55
Cricket Ball	19.66	0.20	10.43	7.49	17.81
Mean	20.00	0.25	9.52	9.39	18.74
SD	0.48	0.06	1.06	2.11	1.09
Min	19.38	0.20	8.12	7.10	17.25
Max	20.50	0.32	10.60	11.56	20.13
CV (%)	2.39	22.30	11.16	22.45	5.79

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Comparative study of conventional and organic farming of coriander (*Coriandrum sativum*) -radish (*Raphanus sativus*) cropping sequence

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Abstract

An experiment was conducted to compare performance of organic and conventional management practices in coriander (*Coriandrum sativum* L.) and radish (*Raphanus sativus* L.) cropping system at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan during 2017–18, 2018-19 and 2019–20. The conventional practices comprising integrated use of organic amendments, nutrients through chemical fertilizers and plant-protection chemicals were compared with organic management practices which comprised nutrient and pest management through organic amendments and practices. Experiment consisted of 7 treatments laid out in randomized block design. Pooled analysis revealed that, safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha (T_7) resulted in significantly higher coriander fresh green leaves yield (94.03 q/ha) and radish root yield (237.61 q/ha). It was followed by conventional practices (recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg/ha (T_4) in coriander, while T_6 (FYM equivalent to 100 % N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg/ha (plant protection with organic methods) in case of radish. Return per rupee invested (4.00) and net return (₹.2.55 lakh/ha.) in the sequence were also maximum with treatment T_7.

Key words: Cropping sequence, Microbial consortium, Organic, Radish-coriander, Vermicompost

Radish (*Raphanus Sativus* L.) is an important vegetable crop. It is consumed as raw or as a salad. It is rich in calcium, potash, phosphorus and Vitamin C. Coriander (*Coriandrum sativum* L.), a member of the family Apiaceae, is one of the important spice crops grown throughout the world. It is an annual herb. Its plant characterization is based on morphological, chemical, biochemical and molecular traits. Morphological characterization of a variety is based on morphological traits such as plant growth, stem, leaves, flower seed, etc (Kumar *et al.,* 2022). It is mainly grown in Rajasthan, Gujarat, Madhya Pradesh, Tamilnadu and Uttar Pradesh. Coriander is an important seed spice crop of Rajasthan which is mostly grown in Kota, Bundi, Jhalawar and Baran.

The productivity of radish and coriander in India is very less which may be due to unavailability of quality water in arid and semi-arid regions. It is influenced by several factors such as soil, varieties, fertilizer management and various agro-techniques used for growing crop. Nutrients play a vital role in functioning of normal physiological processes during growth and development of plants. However, for obtaining higher economic yield, balanced supply of nutrients is one of the key factors (Kumar *et al.,* 2015). Ahlawat and Gangaiah (2010) reported higher system productivity in chickpea intercropped with linseed over sole chickpea. Mustard and chickpea intercropping have exhibited higher land equivalent ratio (1.41) over in sole crops (Thomas *et al.,* 2010). Shortages of vegetables in the country have focused the attention on intercropping systems which have capacity to improve the physical, biological and chemical properties of soil (Mehta *et al.* 2010). Thus, productivity of system can be enhanced with change in crop configuration for inclusion of other crops in the existing cropping system. Organic farming is the old method of farming, which maintains the natural potential of the land. With organic farming, the environment remains pure, water holding capacity of the soil increases. It is bulky in nature and containing small quantity of nutrients which are required in large quantities; however it also contains trace or micronutrients (Yawalkar *et al.,* 2002) in sufficient amount, the deficiency of which cannot be supplemented by others. Since vermicomposting supply all the nutrients in readily available form, it enhances uptake of nutrients by plants (Rai and Pandey, 2007). Vermicomposting influences the physio-chemical and biological properties of the soil, which, in turn improves the fertility. It is cost effective and renewable source of plant nutrients to supplement the chemical fertilizers. Biofertilizers in combination with organic manures found as effective component in organic farming for reliable and cheap supply of nutrients. These combinations were

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ecologically safe and improve soil fertility by improving the soil physical, chemical and biological condition. Microbial consortium is a carrier based microbial product that contains N fixing, P and Zn solubilizing and plant growth promoting microbes in single carrier. Azospirillum is a micro-europhilic nitrogen fixer. Keeping in view, comparative study of conventional and organic farming of coriander-radish cropping sequence was carried out.

MATERIALS AND METHODS

The field experiment was conducted at Rajasthan Agricultural Research Institute (SKN Agriculture University), Durgapura, Jaipur, Rajasthan, during winter (*rabi*) seasons of 2017–18, 2018-19 and 2019–20. The randomized block design with seven treatments and three replications was used. There were 21plots each of 10 m x 0.75 m size. The variety Mahak of coriander and Ivory White of radish were used. The sowing of seeds was done on 22, 20 and 24 November of 2017, 2018 and 2019 respectively. All recommended package of practices were followed. The treatment combinations were T_1: conventional practices (recommended FYM + fertilizer + plant-protection chemicals), T_2: vermicompost equivalent to 100% N recommended for each of the crop + plant protection with organic methods, T_3:FYM equivalent to 100% N recommended for each of the crop + plant protection with organic methods, T_4: conventional practices (recommended FYM + fertilizer + plant-protection chemicals) + IIHR microbial consortium @ 12.5 kg/ha, T_5:vermicompost equivalent to 100 % N recommended for each of the crop+ IIHR microbial consortium @ 12.5 kg/ha (plant protection with organic methods), T_6:FYM equivalent to 100%N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg/ha (plant protection with organic methods) and T_7: safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha. The five plants from each plot were selected randomly. The observations were taken on their yield attributes. The observations were analyzed by using standard statistical techniques (Panse and Sukhatme, 1985). On the basis of total variable cost and gross returns, net returns and B:C ratio were calculated as per Devasenapathy *et al.* (2008). The critical difference at 5% probability level was also calculated to draw the valid conclusion.

The soil was sandy loam, having pH of 8.0-8.2, low in organic carbon (0.18%), available N (156.0 kg/ha), medium in phosphorus (26.02 kg/ha) and potassium (184.0 kg/ha). The available N, P and K contents in vermicompost were 1.46, 0.45 and 1.38% and in FYM, these were 0.46,0.25 and 0.53% respectively. Coriander crop was grownfor fresh green leaves. Organic manures and IIHR microbial consortium were applied at the time of field preparation of coriander as per treatment. Microbial consortium contained nitrogen fixing, phosphorus and zinc solubilizing and plant growth-promoting microbes in single formation and is used to increase the nutrient-use efficiency as well as yield.

Results and Discussion

Yield parameters

The results revealed that fresh green leaves yield of coriander was influenced significantly by different treatments during all the three years (Table 1). Application of safe production practices (recommended dose of FYM+ fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha (T_7) resulted in significantly highest yield of fresh green leaves of 94.03 q/ha. It was followed by conventional practices (recommended + fertilizer + plant-protection chemicals) +IIHR microbial consortium @ 12.5 kg/ ha (T_4) with production of 79.07 q/ha. While FYM equivalent to 100%N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg/ha plant protection with organic methods (T_6) and vermicompost equivalent to 100% N recommended for each of the crop + consortium @12.5 kg / ha plant protection with organic methods (T_5) gave the yield of 71.58 q/ha and 66.39 q/ha respectively. The increase in yield was highest(28.92q/ ha) or 44.42 % in treatment T_7, whereas lowest (0.96q/ha) or 1.47 % in T_5.The yield of coriander leaves reduced inT_2 and T_3. Yield was increasedin safe production practices (recommended dose of FYM+ fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha (T_7) as compared to conventional practices. It might be attributed to the availability of nutrients for crop use (Meena *et al.*, 2013). Organic manures are not only the good source of major and micronutrients but also improve physico-chemical properties of soil (Reust and Neyround, 2003). These results corroborate with the findings of Narayan *et al.* (2014).

Different treatments significantly influenced the radish yield. Application of safe production practices (recommended FYM+ fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha (T_7) proved better for yield (237.37q/ha)among all the treatments followed by treatment T_6 (FYM equivalent to 100%N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg/ha (plant protection with organic methods) and treatment T_4 (conventional practices (recommended FYM+ fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg/ha.)

Table1. Effect of management practices on coriander green leaves yield (pooled data over 3 years)

Treatment	Details	Yield (q/ ha)	Increase/decrease in yield from conventional practices	
			(q/ha)	(%)
T_1	Conventional practices (FYM+ Fertilizer +P.P.	65.11	-	-
T_2	Vermicompost + P.P. with organic method	54.56	(-) 10.55	(-) 16.20
T_3	FYM + P.P. with organic method	55.89	(-) 9.22	(-) 14.16
T_4	Conventional practices (FYM + fertilizer +P.P. chemicals+ IIHR microbial consortium @12.5 kg / ha	79.07	(+) 13.96	(+) 21.44
T_5	Vermicompost + consortium @12.5 kg / ha P.P. with organic method	66.39	(+) 0.96	(+) 1.47
T_6	FYM + IIHR microbial consortium @12.5 kg / ha P.P. with organic matter	71.58	(+) 6.45	(+) 9.91
T_7	Safe production practices (FYM +Fertilizer+ P.P. with organic method + IIHR microbial consortium @12.5 kg	94.03	(+) 28.92	(+) 44.42
	SEm (±)	**2.26**	-	-
	CD at (5 %)	**6.86**	-	-
	CV(%)	**5.90**	**-**	**-**

with the yield of 221.39 q/ha and 214.80 q/ha respectively (Table 2). Kumar *et al.* (2014) also found that adding vermicomposting with poultry manure significantly increased growth parameters, yield characteristics and yield in radish *cv.* Japanese White. Jadhav *et al.* (2014) found that vermicompost and microbial consortia enhances the growth and yield of radish. Application of safe production practices (recommended FYM+ fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha (T_7) resulted in higher yield. This might be owing to increased availability of nutrients to plants. Yadav *et al.* (2017) observed that inoculation of biofertilizers resulted in higher weight of tubers/plant over without inoculated treatment with same level of organic manure in potato. Kumar *et al.* (2013) also reported similar results in rainfed potato.

Economics

The treatment T_4: conventional practices (recommended FYM+ fertilizer + plant-protection chemicals) required highest cultivation cost(₹ 0.71 lakh/ ha) compared to other treatments. It might be attributed to higher cost of FYM and NPK fertilizers. Among other treatments,application of vermicompost + IIHR microbial consortium required higher cost perhaps because of vermicompost cost(Table 3, Fig. 1). The similar findings were also reported by Narayan *et al.* (2014) in respect to cost of cultivation being higher in FYM or vermicompost application in potato cultivation. The net returns (₹ 2.55 lakh/ha) and B:C ratio (4.0) were significantly higher with treatment T_7 (safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha),followed by

Table2. Effect of management practices on radish yield (pooled data over 3 years)

Treatment	Details	Yield (q/ ha)	Increase/decrease in yield from conventional practices	
			(q/ha)	(%)
T_1	Conventional practices (FYM+ Fertilizer +P.P.	180.27	-	-
T_2	Vermicompost + P.P. with organic method	174.77	(-) 5.50	(-) 3.05
T_3	FYM + P.P with organic method	164.96	(-) 15.31	(-) 8.49
T_4	Conventional practices (FYM+ Fertilizer +P.P. chemicals+ IIHR microbial consortium @12.5 kg /ha	214.80	(+) 34.53	(+) 19.16
T_5	Vermicompost + consortium @12.5 kg / ha P.P. with organic method.	195.67	(+) 15.40	(+) 8.54
T_6	FYM + IIHR microbial consortium @12.5 kg / ha P.P. with organic matter	221.39	(+) 6.45	(+) 3.58
T_7	Safe production practices (FYM +Fertilizer + P.P. with organic method + IIHR microbial consortium @12.5 kg	237.61	(+) 41.12	(+) 22.81
	SEm (±)	**3.84**	-	-
	CD at (5 %)	**11.64**	-	-
	CV(%)	**3.44**	**-**	**-**

treatment T_4 (conventional practices (recommended FYM+ fertilizer + plant-protection chemicals) + IIHR microbial consortium @ 12.5 kg/ha) . Application of FYM + IIHRmicrobial consortium resulted in lower net returns than vermicompost + IIHR microbial consortium. It showed the superiority of vermicompost to FYM among organics. Net return is the resultant of gross income and cost of cultivation where gross income dominated over cultivation cost in present study. Return per rupee invested and per day return (PDR) were also remarkably higher with vermicompost + IIHR microbial consortium than other treatments. It might be owing to higher gross income in vermicompost + IIHR microbial consortium. These results are in close agreement to those of Sarkar *et al.* (2011) and Narayan *et al.* (2014).

CONCLUSION

It can be concluded that, application of safe production practices (recommended FYM + fertilizer+ plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg/ha for each of the crop are profitable alternatives of conventional practices in coriander *cv.*Mahak and radish *cv.* Ivory White system for agroclimatic condition of Rajasthan. It alsoensures the sustainability in production and soil health along with pollution free environment.

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Table 3. Economic analysis for organic farming in coriander – radish sequence (2017–18, 2018-19 and 2019–20)

Treatment	Details	Cost of Cultivation (₹ lakh/ha)	Gross income (₹)	Net income (₹)	B.C. ratio
T_1	Conventional practices (FYM+ fertilizer +P.P.	0.50	1.81	1.31	2.6
T_2	Vermicompost + P.P. with organic method	0.54	2.09	1.55	2.8
T_3	FYM + P.P. with organic method	0.55	1.95	1.40	2.5
T_4	Conventional practices (FYM + fertilizer +P.P. chemicals+ IIHR microbial consortium @12.5 kg / ha	0.71	2.97	2.26	3.1
T_5	Vermicompost + consortium @12.5 kg / ha P.P. with organic method	0.56	2.23	1.67	3.0
T_6	FYM + IIHR microbial consortium @12.5 kg / ha P.P. with organic matter	0.61	2.44	1.83	2.9
T_7	Safe production practices (FYM + fertilizer+ P.P.with organic method + IIHR microbial consortium @12.5 kg	0.63	3.18	2.55	4.0

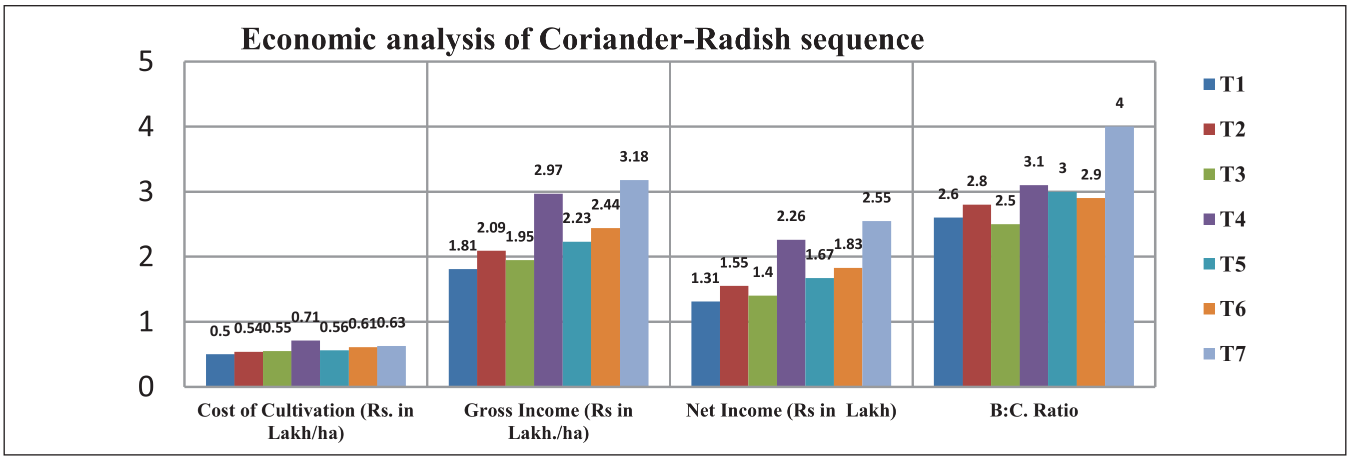

Fig. 1: Economic analysis of Coriander-Radish sequence

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Standardization of cryopreservation in coconut (*Coconut nucifera*) plumule based on vitrification technique using V-cryomesh

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Abstract

A technique was tried for cryopreservation of coconut (*Cocos nucifera* L.) plumular regions based on vitrification technique using aluminium V-cryomesh as an anchoring material. Coconut plumular regions, excised from mature zygotic embryos, were pre-cultured in a solid Y3 medium supplemented with 0.2 M to 0.6 M sucrose. After pregrowth, explants were treated with loading solution (Y3 medium with 0.4 M sucrose + 2 M glycerol) and transferred to V-cryomesh and embedded using calcium alginate. Explants adhered to V-cryomesh were subjected to dehydration using PVS3 (40 minutes) and transferred to cryovials for storing in liquid nitrogen. After 48hr of liquid nitrogen treatment, material was thawed at 40°C for 2 minutes and later treated with unloading solution for 30 minutes and explants were inoculated to retrieval media. The optimal protocol involved preculture of plumules for 72 hr on medium with 0.4 M sucrose followed by PVS3 treatment for 40 minutes, rapid cooling and rewarming and treating with unloading solution for 30 minutes. Under these conditions, 33% post thaw recovery and 7% plantlet recovery was observed. Accommodation of smaller sized explants in large number and easy handling were the major advantages of cryomesh. The method can be useful for conservation of valuable coconut germplasm in the form of plumules.

Key words: Liquid Nitrogen, Cryopreservation, Plumule, Vitrification procedure, V-cryomesh

Coconut (*Cocos nucifera* L.) is a significant tropical and monotypic species. Despite being a monotypic species, this palm exhibits substantial variability due to its cross-pollinating nature and high heterozygosity. Given its enormous economic importance, various conservation measures have been implemented to safeguard the genetic diversity of coconut, with the support of the International Coconut Genetic Resources Network (COGENT). According to Coconut Genetic Resources Database (CGRD), coconut germplasm is conserved primarily in field gene banks under *ex situ* conditions across 25 sites in 23 countries, encompassing approximately 1,416 accessions (Engelmann *et al.,* 2005). In addition to field conservation (both *in- situ* and *ex- situ*), cryopreservation presents an ideal alternative for the long-term conservation of coconut germplasm. Research has been conducted on the cryopreservation of coconut genetic resources, focusing on zygotic embryos, plumules, pollen and embryogenic calli (Welewanni *et al.,* 2017). Various protocols including dehydration, encapsulation-dehydration and vitrification have been employed for standardizing cryopreservation techniques for coconut embryos and plumules (Welewanni *et al.,* 2017).

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Plumule or embryonic shoots are considered ideal materials for the cryopreservation of coconut germplasm because of their small size and presence of only meristematic cells (Malaurie *et al.,* 2002, Aparna *et al.,* 2023). Unlike other tissues, plumules do not carry pathogens like viruses due to the absence of phloem tissues (Maularie *et al.,* 2002; N'Nan *et al.,* 2008). Additionally, the disintegration of intact cells during the cryopreservation process, which can occur in zygotic embryos were not observed in plumules. The encapsulation dehydration technique has been commonly used for cryopreservation of coconut plumules (Malaurie and Borges, 2001; Hornung *et al.,* 2001; Malaurie *et al.,* 2006, Bandupriya *et al.,* 2007; N'Nan*et al.,* 2008; Bandupriya *et al.,* 2010; Nan *et al.,* 2014). Various studies have reported a post-thaw recovery rate of 20-80% for plumules using this procedure. The recovery of cryopreserved plumules has been improved by adding ABA and ascorbic acids to preculture media containing sucrose (Bandupriya *et al.,* 2007; Malaurie *et al.,* 2006). There is limited knowledge about vitrification-based procedures and use of cryoplate and cryomesh materials for cryopreservation of plumules.Hence study was undertaken to test the effectiveness of cryopreservation using V-cryomesh technique under various sucrose concentrations during preculture.

MATERIALS AND METHODS

The study was conducted at ICAR-Central Plantation Crops Research Institute (CPCRI), Kasaragod, Keral, from November 2021 to February 2023. Treatments (T_1, T_2, T_3, T_4 and T_5) differed in their preculture sucrose concentration (Table 1).

Plant material preparation and inoculation:

Matured nuts (11-12 months old) of West Coast Tall (WCT) variety were selected. Embryos along with endosperm plugs were carefully excised from dehusked and cut open nuts. The endosperm plugs containing embryos were washed under tap water four to five times and treated to 0.01% mercuric chloride for three minutes (Neema *et al.,* 2023). The explant material was subsequently rinsed with distilled water three to four times to remove any traces of mercuric chloride. The washed material was transferred to a laminar airflow chamber where embryos were carefully separated from the endosperm plugs. The separated embryos were washed twice with autoclaved distilled water followed by a 15-minute wash with 20% sodium hypochlorite on a shaker at 100 rpm. After the hypochlorite treatment, embryos were thoroughly rinsed with autoclaved distilled water to eliminate all traces of the chemical. From the sterilized embryos, plumules were carefully excised using a surgical blade and directly inoculated into a preculture media supplemented with 0.2- 0.6 M sucrose, Eeuwen's Y3 basal medium, 5.8 g/L Agar + 1g/L charcoal. The explants were incubated for three days in preculture medium under dark conditions. A complete procedure of plumule separation and inoculation showed in Fig.1.

Pregrowth, vitrification and cryopreservation of coconut plumules

The precultured coconut plumules (in 0.2-0.6M sucrose medium) were placed on cryomesh and encapsulated by pouring a 3% sodium alginate solution over the mesh containing the plumules. The petri plate containing the cryomesh was then flooded with 0.01 M calcium chloride solution. After 15-20 minutes of treatment with calcium chloride solution, plumule material was encapsulated along with cryomesh. The cryomesh containing encapsulated plumules was treated with a loading solution of 'Y3 medium with 0.4 M sucrose + 2 M glycerol' for 20 minutes at room temperature (Fig.2). Following this, the encapsulated material was treated with PVS3 vitrification solution (Y3 basal medium + 50% glycerine + 50% sucrose) in test tubes and incubated for 40 minutes at room temperature. The cryomesh with

Table 1. Different treatment (T_1 to T_5) / methods followed in the experiment

Treatment	Preculture (Sucrose concentration -M)	Preculture duration (hours)	Loading duration (minutes)	PVS3 treatment duration (minutes)	Freezing -196°C duration (hours)	Unloading duration (minutes)
T_1	0.2	72	20	40	48	30
T_2	0.3	72	20	40	48	30
T_3	0.4	72	20	40	48	30
T_4	0.5	72	20	40	48	30
T_5	0.6	72	20	40	48	30

Table.2: Post thaw recovery and plantlet formation of cryopreserved coconut plumules

Treatments	Post thaw recovery , (%) of plumules		Plantlet recovery (%)	
	-LN	+ LN	-LN	+ LN
T_1	76.66±3.33	11.66±1.66	60.00±2.88	4.00±1.00
T_2	73.33±3.33	11.66±1.66	58.33±4.41	6.00±0.57
T_3	76.66±3.33	33.33±3.33	58.33±4.41	7.66±0.66
T_4	73.33±3.33	28.33±1.66	60.00±5.77	6.00±0.57
T_5	75.00±2.88	21.66±4.41	70.00±0.02	5.33±0.33
CD	NS	8.74	NS	2.12
SE(m)	3.24	2.80	4.01	0.66
SE(d)	4.59	3.96	5.67	0.94
CV	7.50	14.45	11.33	19.90

Values represent survival percentage ± SE.
P (survival) < 0.0001; treatment differences were evaluated at 5% probability.
LN: liquid nitrogen

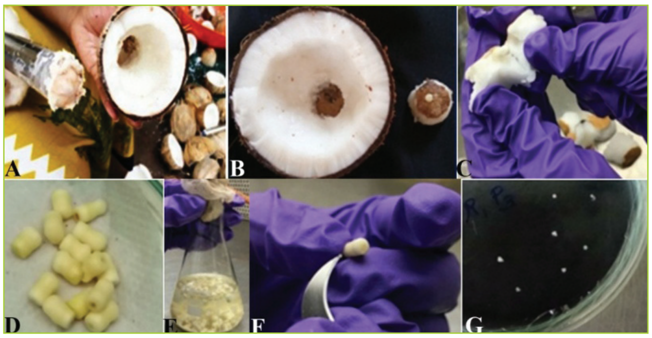

Fig. 1: Extraction of plumule and inoculation; A: extracting endosperm plug using scooper, B. extracted endosperm plug, C: extracting endosperm from the endosperm plug, D: extracted embryo, E: embryo sterilization, F: plumular extraction using sickle blade, G: plumule inoculated into media

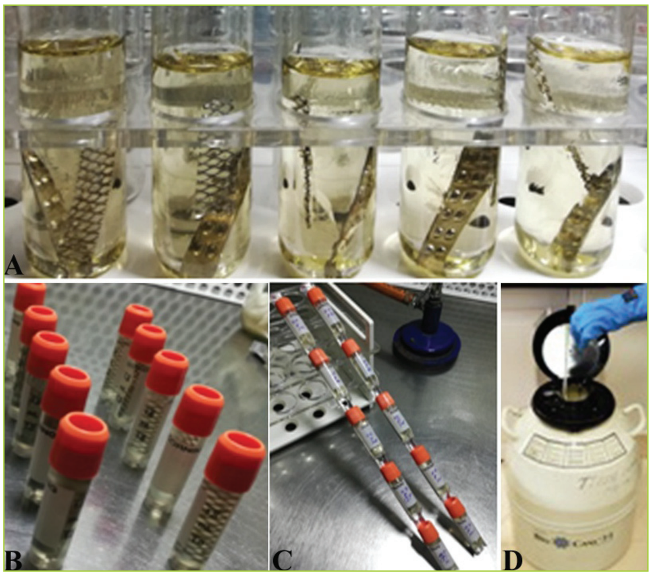

Fig. 2: Vitrification and cryopreservation of coconut plumules; (A) vitrification of coconut plumules using V-cryomesh; (B, C, and D) cryopreservation of treated plumules in cryovials

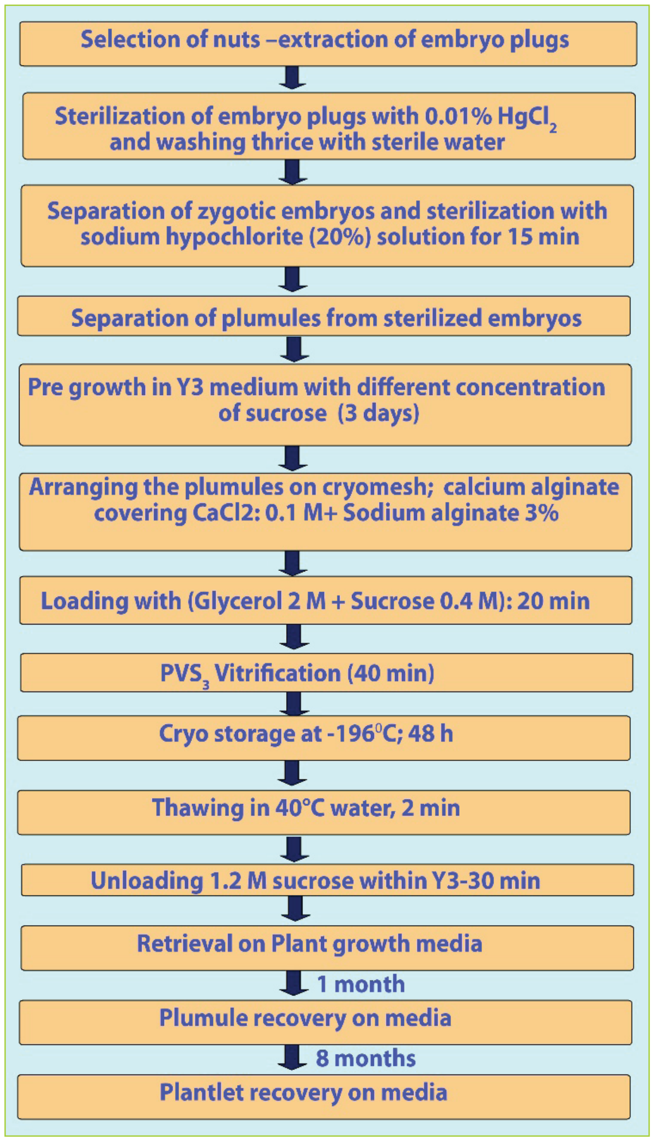

Fig. 3: Flow chart showing cryopreservation of coconut plumules using V-cryomesh technique

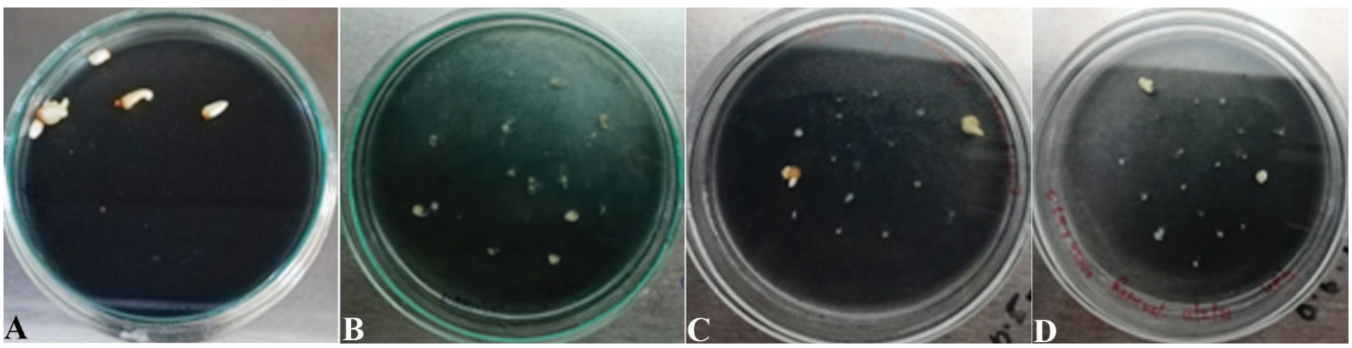

Fig. 4: Post thaw recovery of cryopreserved embryonic shoot portions of coconut (A). control; (B) 0.4 M sucrose with PVS3-40 minutes; (C) 0.5 M sucrose- PVS3-40 minutes; (D) 0.6 M sucrose- PVS3-40 minutes

Fig. 5: Plantlet recovery from the cryopreserved plumules after 8 months of recovery

encapsulated plumules was then transferred to cryovials filled with fresh PVS3 solution and immersed in liquid nitrogen (+LN) for a minimum period of 48 hr. Explants that were not cryostored served as control.

Rewarming and post-cryopreservation recovery

After 48hr of liquid nitrogen storage (+LN), the samples were taken out and then rewarmed in a water bath at 40°C for 2 minutes at room temperature. The cryomesh with explants (+LN/-LN) was placed in an unloading solution (Y3 medium with 1.2 M sucrose) for 30 minutes, with the unloading solution changed every 15 minutes at room temperature. Sodium alginate gel was removed carefully from the explants which were then inoculated onto a recovery medium containingY3 basal medium, 60 g/L sucrose, 1g/L activated charcoal and 5.8 g/L agar. After two weeks of incubation, explants were transferred to Y3 basal media with 30 g/L sucrose, 1 g/L activated charcoal, and 5.8 g/L agar. Once germination occurred, the plumules were transferred to test tubes supplemented with 2 mg/L NAA and 0.5 mg/L IBA in Y3 medium with 30 g/L sucrose, 1 g/L activated charcoal, and 5.8 g/L agar. Plantlets were sub-cultured every two months on the same media prepared in test tubes. Observations on the recovery of plumules (Fig.4) and plantlets (Fig.5) were recorded after one and eight months of culture after changing on to recovery medium. A complete procedure followed the current experiment was showed in flowchart (Fig.3).

RESULTS AND DISCUSSION

The post-thaw recovery of coconut plumules after cryopreservation using V cryo mesh ranged from 11.66% to 33.33% across different treatments. Treatment T_3, with 0.4 M sucrose preculture, showed the highest recovery rate at 33.33%, followed by T_4 (0.5 M sucrose, recovery of 28.33%) and T_5 (0.6 M sucrose, recovery of 21.66%). Lower recovery rates of 11.66% were observed in T_1 and T_2 with 0.2 M and 0.3 M sucrose, respectively. In terms of plantlet recovery, 75% recovery was observed in the control group treated with PVS3 (without liquid nitrogen, -LN). However, for cryopreserved material (+LN), maximum recovery of plumules was 33%, but only 4-7% of the recovered plantlets exhibited healthy growth.

The study demonstrates that the V-cryomesh technique is a viable method for cryopreservation of coconut plumules. The success of technique is significantly influenced by the sucrose concentration in preculture medium. Cryopreservation has been successfully applied to conserve genetic resources in recalcitrant seed species like coconut. Various cryopreservation techniques have been employed for tissues such as immature and mature zygotic embryos, embryogenic calli, and pollen, including air desiccation, pregrowth desiccation, low-freezing, chemical dehydration with programmable-freezing, chemical-freezing, and vitrification (Sisunandar, 2013; Sisunder *et al.*, 2014; Karun *et al.*, 2014; N'Nan *et al.*, 2012; N'Nan, 2003; Sajini *et al.,* 2006; Bajaj, 1984; Chin *et al.,* 1989; Engelmann, 2011; Nguyen *et al.*, 2015; Sajini *et al.,* 2011; Cueto *et al.,* 2014). However, genetic variability, explant size, and pathogen transmission concerns have made plumules an attractive alternative to zygotic embryos due to their smaller size and meristematic tissue, which is less prone to carry pathogens.

The current study demonstrated that a 0.4 M sucrose preculture provided the best recovery results, aligning with previous studies that identified sucrose concentrations between 0.5 M and 1 M as optimal for the slow drying of encapsulated plumules (Sajini *et al.*, 2011). By reducing the sucrose concentration and increasing the incubation time to 72 hours without encapsulation, this study provided new insights into the cryopreservation process. The V-cryomesh technique, which involves direct exposure of plumule tissues to vitrification solutions, offers an advantage over earlier methods that used encapsulation-dehydration. However, longer exposure to vitrification solutions might have contributed to reduced recovery rates and plantlet abnormalities, as previously noted in other studies using encapsulation dehydration techniques (Hornung *et al.*, 2001; N'Nan *et al.,* 2008).

The use of vitrification-based techniques, particularly with PVS3, has shown promising results in other studies for both zygotic embryos and plumules. Karun et al., (2022) reported a 35% plantlet recovery using droplet vitrification with PVS3, while this study achieved 33% recovery in cryopreserved plumules and 75% recovery in non-cryopreserved controls. However, the presence of plantlet abnormalities suggests that the plumules were sensitive to prolonged exposure to vitrification solutions. Earlier research by Ledo *et al.*, (2020) and Sajini *et al.*, (2011) indicated that using PVS3 and PVS2 in vitrification can sometimes result in callogenesis instead of plantlet recovery, which aligns with the current study's findings of abnormal growth.

Despite these challenges, study demonstrated that vitrification-based V-cryomesh technique is a viable method for the long-term conservation of coconut plumules. Modifications such as adjusting exposure times to vitrification solutions and incorporating PGRs like ABA into the preculture media may further improve recovery rates and plantlet health.

CONCLUSION

This study demonstrated the feasibility of using the V-cryomesh technique for long-term conservation of coconut plumules. The optimal protocol involved preculturing the plumules for 72 hr in a medium containing 0.4 M sucrose, followed by a 20-minute loading duration. This was followed by PVS3 treatment for 40 minutes, rapid cooling at -196°C, and rewarming at 40°C for 2 minutes. The plumules were then unloaded in 1.2 M sucrose liquid medium for 30 minutes. Under these conditions, 33% post-thaw recovery and 7% plantlet recovery were observed in cryopreserved plumules. The use of V-cryomesh enabled a simplified approach to vitrification, though further adjustments to the protocol could lead to higher recovery rates and healthier plantlet formation.

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Evaluation of intercropping elephant-foot yam (*Amorphophallus paeoniifolius*) with pulses for yield, economics, corm quality and soil health

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Abstract

The field experiments were conducted at ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, to assess the feasibility of intercropping elephant-foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] with various pulse crops, during 2017-19. The factorial randomized block design with three elephant-foot yam varieties (Gajendra, Sree Padma and Sree Athira), three pulse crops [greengram, *Vigna radiata* (L.) R. Wilczek. (var. Co-Gg-7), blackgram, *Vigna mungo* (L.) Hepper (var. Co-6), and soybean, *Glycine max* (L.) Merr. (var. JS-95-60)], and two fertility levels. Averaging over two years, yield of elephant-foot yam under intercropping (32.82 t/ha) was comparable to sole cropping (35.90 t/ha), with a slight decrease of 8.58%. The combination of elephant-foot yam var. Gajendra + soybean under full fertility level resulted in higher yield (66.40 t/ha), corm equivalent yield (66.77 t/ha), production efficiency (247.30 kg/ha/day), equivalent energy (239.91 × 10^3 MJ/ha), net income (₹ 10, 09, 856/ha), B:C ratio (3.20) and added profit of ₹ 2,33,164/ha over sole cropping of elephant-foot yam var. Gajendra (46.48 t/ha, 172.45 kg/ha/ day, 167.33 × 10^3 MJ/ha). These intercropping systems did not adversely affect the soil chemical properties or biochemical constituents of corms, underscoring the viability of intercropping elephant-foot yam with pulses as a sustainable practice.

Key word: Intercropping, Productivity, Profit, Corm quality, Soil fertility, Sole crop

Elephant-foot yam, [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] is valued for its economic and nutritional benefits in south India's tropics. This crop has a long growth cycle and requires substantial space. Still, it is adaptable to various agroecological zones and resistant to pests and diseases, making it vital for food security and profitable farming (Suja *et al.* 2012). It yields significant returns, enhancing its status as a food and commercial crop (Suja *et al.* 2012; Nedunchezhiyan *et al.* 2008). Crop diversification is an adaptation strategy to increase productivity, especially under climate change (Nedunchezhiyan *et al.* 2022; Suja *et al.* 2025). However, potential of elephant-foot yam in cropping systems, which could boost yield and profits, still needs to be explored (Sunitha and Kumar 2018).

In tropical agriculture, integrating elephant-foot yam into existing farms is increasingly seen as a sustainable solution to challenges like shrinking land for smallholders in Kerala and rising input costs (Krishnakumar *et al.* 2013; Remya and Suja 2018). Intercropping with bananas, for instance, increases yield and profits, improves soil health, supports biodiversity, and uses land more efficiently (Krishnakumar *et al.* 2013; Remya and Suja 2024). Intercropping elephant-foot yam, while beneficial, also poses challenges, such as managing crop-weed interactions and nutrient dynamics, which influence the soil microclimate and crop productivity (Remya and Suja 2024). The success of integrating elephant-foot yam with short-duration leafy vegetables, varies significantly with environmental factors, including soil quality improvement (Babu *et al.* 2017).

Advancing elephant-foot yam intercropping in tropical regions requires novel agricultural practices and effective management to enhance its profitability and environmental sustainability (Suja *et al.* 2023). Although research points to potential productivity and soil health benefits, detailed studies on intercropping elephant foot yam with pulses are sparse. This research gap is critical, as understanding the interactions between elephant foot yam and pulses across diverse conditions could improve crop yields and soil health, informing sustainable agricultural strategies and policies.

The lack of data on specific intercropping combinations of elephant-foot yam varieties and pulse crops under different fertility levels in south India's humid tropics underscores the need for focused research. Exploring these plant interactions within different nutrient management frameworks is essential for optimizing yields and enhancing profitability, ultimately contributing to more effective cropping strategies and better agricultural outcomes in tropical regions. The present experiment was thus undertaken to find out the suitability of pulses like greengram, blac gram and soybean as intercrops.

MATERIALS AND METHODS

Field experiments to evaluate the productivity of intercropping systems with elephant- foot yam

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were conducted from March to December across two consecutive years (2017-2019) at ICAR-Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram, Kerala, India, situated at 8°29' N latitude, 76°57' E longitude, and an elevation of 52 meters. This location is characterized by a humid tropical climate, with average annual rainfall of 1672 mm and mean annual maximum and minimum temperatures of 31.82°C and 23.82°C, respectively. The relative humidity averaged 85.97%. During the crop growth periods of the first and second years, rainfall recorded was 1695 mm and 1575 mm, with maximum temperatures of 31.44°C and 32.07°C and minimum temperatures of 23.24°C and 24.41°C, respectively. The relative humidity was 81.58% during the first year and 88.77% during the second year. The soil of the research site is a well-drained acid Ultisol with pH 4.92 and is characterized by low available N (187.93 kg/ha), high available P (232.92 kg/ha), available K (368.28 kg/ha) and organic C (0.79%) contents.

The factorial randomized block design with treatments consisting of factorial combinations of three elephant-foot yam varieties: 'Gajendra,' 'Sree Padma,' and 'Sree Athira'; three pulse crops: green gram (var. Co-Gg-7), black gram (var. Co-6), and soybean (var. JS-95-60); and two fertility levels was followed. The first fertility level included full farmyard manure (FYM) and full nitrogen (N), without phosphorus (P) but with full potassium (K) (FYM at 25 t/ha, NPK at 100:0:150 kg/ha). The second fertility level was half of FYM and N with full K (FYM at 12.5 t/ha, NPK at 50:0:150 kg/ha). The P was provided to legume in the system. Sole crops of all elephant-foot yam varieties were grown with a full dose of FYM and NPK (FYM at 25 t/ha, NPK at 100:50:150 kg/ha) as the controls for comparative purposes.

Elephant-foot yam was planted annually in March 2017 and 2018. Each plot, measuring 4.5 m × 4.5 m, was arranged with plants spaced at 90 cm × 90 cm, following the cultural practices recommended (KAU 2016). In between two rows of elephant-foot yam, two rows of the respective pulse crops were sown the following day, using an inter-row spacing of 30 cm and intra-row spacing of 15 cm, with a seeding rate of 20 kg/ha, thus establishing an additive intercropping system. Before planting, farmyard manure was applied directly to planting pits for elephant-foot yam, consistent with the assigned treatments. The pulse crops received a basal application of NPK at 20:30:30 kg/ha, with full doses of P and K and half the N dose administered at planting. The remaining N was top dressed 15-20 days after sowing (DAS). For elephant-foot yam, half doses of N and K were applied one week after sprouting, with the remaining fertilizers applied one month later, coinciding with routine weeding and earthing-up operations.

Pulse yields were recorded in kg/ha, while fresh corm yield of elephant-foot yam was estimated in tons per hectare from the net plants at harvest. Biochemical analyses of yam corms for dry matter, starch, total sugars, crude protein, ash and crude fibre were conducted following standard methods (AOAC, 2005; Dubios *et al.* 1956). Soil chemical properties —pH, organic carbon, and available nutrients (N, P, K)—were evaluated using standard protocols (Page *et al.* 1982) at the end of each cropping year. Based on the yield of the component crops, corm equivalent yield, production efficiency and energy equivalent yield were worked out.

Economic performance was analyzed by calculating total cost of cultivation and gross return, which included all average input and labor costs against the market price of the produce during the study period. Net return per hectare was computed as the difference between gross return and total cost of cultivation. The benefit:cost ratio was calculated by dividing gross income by total cost. Additionally, added profit from intercropping relative to the respective sole cropping systems was determined.

Differences among treatments were analysed using a two-way analysis of variance (ANOVA) in a randomized block design, for each year separately. Treatment means were compared using the critical difference at the 0.05 significance level, utilizing SAS statistical software (Version 9.3).

RESULTS AND DISCUSSION

Yield of elephant foot yam and pulse crops: In the first year, the yield of elephant foot yam under intercropping with pulses (14.16 t/ha) maintained close parity with that of sole cropping (15.53 t/ha), with a marginal reduction of 8.82% (Fig. 1). Among the elephant foot yam varieties, Gajendra (18.78 t/ha) proved superior to Sree Padma (13.16 t/ha) and Sree Athira (10.54 t/ha). Effect of pulse crops on yield of elephant foot yam was not significant. Fertility levels too did not impart significant effect on the yield of elephant foot yam, suggesting that a potential reduction in fertility requirements could be considered. Interestingly, a half fertility regime led to an 18% boost in elephant foot yam yields (Fig. 2). When assessing pulse crops, black gram emerged as the most compatible for intercropping with elephant foot yam as evidenced by a significantly higher yield (228.58 kg/ha). However, neither the varieties of elephant foot yam nor the fertility levels significantly affected the grain yield of the pulse crops (Fig. 3). In the subsequent year, the yield of elephant foot yam under intercropping with pulse crops (51.49 t/ha) were again comparable to sole cropping (56.27 t/ha), with only 8.5% decrease (Fig. 1). The effect of varieties of elephant foot yam and the type of pulse on the yield of elephant foot-yam was not significant.

On an average, over the two years, the yield of elephant foot yam when intercropped with pulses (32.82 t/ha) closely matched the yield from sole cropping systems (35.90 t/ha), with a slight reduction of 8.58% (Fig. 1). This consistency over two years suggests that intercropping elephant foot yam with pulses could be a viable practice without significant yield penalties, potentially enabling reduced fertilizer inputs and associated cost savings.

System productivity and profitability: With respect to system productivity, in the first year, among the treatment combinations, elephant foot yam var. Gajendra + black gram under full fertility level resulted in corm yield (21.60 t/ha), corm equivalent yield (22.10 t/ha), production efficiency (122.80 kg/ha/day) and equivalent energy (79.82 × 10^3 MJ/ha) on par with sole cropping of elephant foot yam var. Gajendra (22.53 t/ ha, 125.16 kg/ ha/day, 81.11 × 10^3 MJ/ha) (Table 1).

In the second year, control vs treatment was not significant for corm yield, corm equivalent yield, production efficiency and equivalent energy. This suggests that the treatment effects on these system efficiency parameters were less pronounced compared to control and treatment groups. However, combination of elephant-foot yam var. Gajendra with soybean under full fertility resulted in remarkable improvements with higher yield (66.40 t/ha), corm equivalent yield (66.77 t/ha), production efficiency (247.30 kg/ha/day) and equivalent energy (239.91 × 10^3 MJ/ha), over sole cropping of elephant foot yam var. Gajendra (46.48 t/ha, 172.45 kg/ ha/day, 167.33 × 10^3 MJ/ha) (Table 1).

The study on intercropping elephant-foot yam with pulses reveals that despite a minor yield reduction compared to sole cropping, the impact is sufficiently tiny to suggest intercropping as a feasible practice with minimal yield compromises (Dodiya *et al.* 2018). Similarly, Misra *et al.* (2016) reported that intercropping does not significantly diminish the productivity of the main crop and can remain economically viable. Research by Ilakiya *et al.* (2023) supports that intercropping in elephant foot yam, especially with short-duration vegetable crops, optimizes land use and suppresses weeds, enhancing yield efficiency under integrated management systems.

The good performance of Gajendra, consistently observed across various studies, underscores its suitability for intercropping with pulses, contributing positively to both economic returns and soil health by potentially reducing fertilizer requirements (Blomme *et al.* 2016). Furthermore, research indicates that integrating elephant foot yam with crops like black gram does not adversely affect the main crop yield or economic viability, thus endorsing the sustainability of such agricultural practices (Jogi and Lahre 2020).

Averaging over two years, among the treatment combinations, elephant foot yam var. Gajendra + soybean under full fertility level resulted in higher net income (₹ 10, 09, 856 per ha), B:C ratio (3.20) and added profit of ₹ 2,33,164 per ha over sole crop (Table 2). The observed increases in net income and benefit-cost ratios illustrate the financial benefits of these systems. Specifically, intercropping with soybeans can fix atmospheric nitrogen, reduce the need for synthetic fertilizers, and cut production costs (Ghosh *et al.* 2009).

Corm quality and soil chemical properties: As depicted in Fig. 4 and Fig. 5, the comparative analysis indicates that intercropping did not significantly alter the corm biochemical composition or the soil chemical properties. The parameters evaluated included soil pH, organic C content, electrical conductivity, available N, P and K, as well as exchangeable Ca. The stability of these parameters across different cropping systems suggests that intercropping elephant foot yam with pulses does not detrimentally affect the quality of the corms or the fertility and health of the soil. This finding reinforces the viability of intercropping as a sustainable agricultural practice that maintains crop quality (Glaze-Corcoran *et al.* 2020) and soil fertility (Mousavi and Eskandari 2011).

The treatments resulted in a range of outcomes for dry matter content, with no significant deviations from control observations. Starch percentages varied slightly, indicating that specific treatments may influence carbohydrate accumulation within the corms. Sugar content, reflective of immediate corm sweetness and post-harvest quality, remained stable across treatments, suggesting that intercropping does not adversely affect the palatability of the corms. Crude protein levels, essential for nutritional value assessments, exhibited negligible fluctuations, ensuring that the protein quality of the corms was preserved. Similarly, ash content, indicative of the total mineral content, showed consistency across the different treatments. Lastly, crude fibre percentages were maintained, suggesting that the corms' structural integrity and dietary fibre content were unaffected.

The preservation of soil and corm quality in elephant-foot yam-pulse intercropping system points to efficient resource utilization and reduced nutrient competition, characteristics of well-managed intercropping systems (Fung *et al.* 2019). By stabilizing crop biochemical attributes and promoting soil health, intercropping fits into sustainable agricultural strategies, aligning with international efforts to improve food security and environmental sustainability (Silva *et al.* 2022). The, intercropping elephant-foot yam with pulses like soybean is a feasible and sustainable option for higher productivity, profit and soil restoration. Thus, the study has resulted

Table 1. Effect of cropping systems involving elephant foot-yam and fertility levels on system productivity

Treatment	Corm yield (t/ha)		Pulse yield (kg/ha)		Equivalent energy (*10^3 MJ/ha)		Corm equivalent yield (t/ha)		Production efficiency (kg/ha/day)	
	First year	Second year	First year	Second year	First year	Second year	First year	Second year	First year	Second year
GajendraGgF1	16.82	54.83	143.50	180.50	62.22	199.51	17.08	55.51	94.91	205.58
GajendraGgF2	19.50	51.02	81.86	105.60	71.11	184.91	19.64	51.42	109.11	190.43
GajendraBgF1	21.60	55.56	174.10	240.00	79.82	202.82	22.10	56.43	122.80	208.98
GajendraBgF2	18.34	39.13	83.80	97.90	67.00	142.03	18.58	39.49	103.22	146.25
GajendraSbF1	16.84	66.40	32.59	75.30	61.00	239.91	16.96	66.77	94.23	247.30
GajendraSbF2	19.59	54.81	33.30	90.00	70.92	198.37	19.72	55.26	109.54	204.66
PadmaGgF1	10.06	56.19	152.58	190.30	38.01	204.54	10.35	56.91	57.48	210.78
PadmaGgF2	15.20	44.71	75.77	128.00	55.62	162.48	15.34	45.19	85.25	167.39
PadmaBgF1	13.58	48.71	329.93	428.80	52.77	180.40	14.53	50.27	80.71	186.17
PadmaBgF2	9.57	53.13	372.86	413.00	38.83	196.13	10.64	54.63	59.11	202.33
PadmaSbF1	15.12	56.37	63.99	70.60	55.19	203.76	15.36	56.72	85.35	210.08
PadmaSbF2	15.43	58.59	55.95	62.50	56.21	211.66	15.64	58.90	86.89	218.16
AthiraGgF1	7.10	49.84	125.67	140.10	27.03	181.08	7.33	50.37	40.74	186.55
AthiraGgF2	15.86	56.92	112.38	125.30	58.43	206.40	16.07	57.39	89.30	212.56
AthiraBgF1	10.28	44.49	148.25	205.60	38.76	162.59	10.71	45.24	59.50	167.54
AthiraBgF2	13.95	45.66	262.51	422.20	53.31	169.35	14.70	47.19	81.69	174.79
AthiraSbF1	5.56	51.96	33.90	98.20	20.40	188.22	5.68	52.45	31.57	194.28
AthiraSbF2	10.49	38.44	28.58	120.50	38.11	139.79	10.60	39.04	58.89	144.59
Sole Gajendra	22.53	46.48	-		81.11	167.33	22.53	46.48	125.16	172.15
Sole Sree Padma	12.96	61.05	-	-	46.66	219.76	12.96	61.04	72.01	226.09
Sole Sree Athira	11.11	61.28	-	-	40.00	220.59	11.11	61.28	61.73	226.95
CD (0.05)	NS	NS	NS	45.20	NS	NS	NS	NS	NS	NS

Table 2. System profitability as affected by cropping systems involving elephant-foot yam and fertility levels (average of two years)

Treatment	Corm yield (t/ha)	Pulse yield (kg/ha)	Gross income (₹/ha)	Gross cost (₹/ha)	Net income (₹/ha)	B:C ratio	Added profit (₹/ha)
GajendraGgF1	35.82	124.54	1272443	462980	809463	2.75	32771
GajendraGgF2	35.25	160.93	1258007	452330	805677	2.78	28985
GajendraBgF1	38.58	136.00	1370012	468830	901182	2.92	124490
GajendraBgF2	28.74	79.56	1017276	458180	559096	2.22	-217596
GajendraSbF1	41.62	61.32	1468856	459000	1009856	3.20	233164
GajendraSbF2	37.20	111.81	1324357	448350	876007	2.95	99315
PadmaGgF1	33.13	140.32	1180542	462980	717562	2.55	-146559
PadmaGgF2	29.96	252.30	1086386	452330	634056	2.40	-230064
PadmaBgF1	31.15	371.49	1143942	468830	675112	2.44	-189008
PadmaBgF2	31.35	221.72	1129380	458180	671200	2.46	-192921
PadmaSbF1	35.75	63.24	1263752	459000	804752	2.75	-59369
PadmaSbF2	37.01	98.04	1314980	448350	866630	2.93	2510
AthiraGgF1	28.47	125.48	1015283	462980	552303	2.19	-283449
AthiraGgF2	36.39	159.11	1297622	452330	845292	2.87	9540
AthiraBgF1	27.39	285.25	999906	468830	531076	2.13	-304675
AthiraBgF2	29.81	180.38	1069382	458180	611202	2.33	-224549
AthiraSbF1	28.76	77.20	1022020	459000	563020	2.23	-272731
AthiraSbF2	24.46	28.58	861982	448350	413632	1.92	-422120
Sole Gajendra	34.51		1207692	431000	776692	2.80	
Sole Sree Padma	37.00	-	1295120	431000	864120	3.00	
Sole Sree Athira	36.19	-	1266751	431000	835751	2.94	

Table 3. Effect of cropping systems on corm biochemical composition

Treatment	Dry matter %	Starch FW %	Sugar FW (%)	Crude protein FW (%)	Ash DW (%)	Crude fibre DW (%)
GajendraGgF1	23.27	16.92	0.42	4.55	4.37	1.25
GajendraGgF2	21.35	15.63	0.38	4.42	4.00	1.40
GajendraBgF1	27.70	16.35	0.40	4.54	5.40	1.35
GajendraBgF2	24.07	15.64	0.40	3.21	4.28	1.35
GajendraSbF1	26.05	17.98	0.40	4.34	4.33	1.55
GajendraSbF2	24.21	14.60	0.35	4.06	4.61	1.50
PadmaGgF1	21.43	15.71	0.40	3.77	3.64	1.45
PadmaGgF2	24.24	18.45	0.41	4.09	4.54	1.60
PadmaBgF1	24.04	17.68	0.43	3.63	4.39	1.41
PadmaBgF2	19.00	14.50	0.36	3.33	5.18	1.71
PadmaSbF1	21.24	14.77	0.37	3.62	4.88	1.47
PadmaSbF2	22.67	17.41	0.39	3.64	4.42	1.45
AthiraGgF1	18.07	14.08	0.32	4.36	5.07	1.93
AthiraGgF2	22.76	15.56	0.39	4.67	4.21	1.80
AthiraBgF1	24.03	17.80	0.45	4.38	4.42	1.47
AthiraBgF2	23.46	15.73	0.40	3.81	4.25	1.45
AthiraSbF1	28.40	17.54	0.45	4.56	3.52	1.45
AthiraSbF2	21.91	13.12	0.32	3.43	5.07	1.40
Sole Gajendra	25.07	17.47	0.42	4.35	4.22	1.45
Sole Sree Padma	21.53	15.05	0.37	4.01	4.25	1.60
Sole Sree Athira	22.32	16.39	0.42	3.81	4.16	1.80
CD (0.05)	NS	NS	NS	NS	NS	NS

Gg-Greengram; Bg-Blackgram; Sb-Soybean; F_1-full dose of FYM and N, no P, full K (FYM @ 25 t/ha; NPK @ 100:0:150 kg/ha); F_2-half dose of FYM and N, no P, full K (FYM @ 12.5 t/ha; NPK @ 50:0:150 kg/ha)

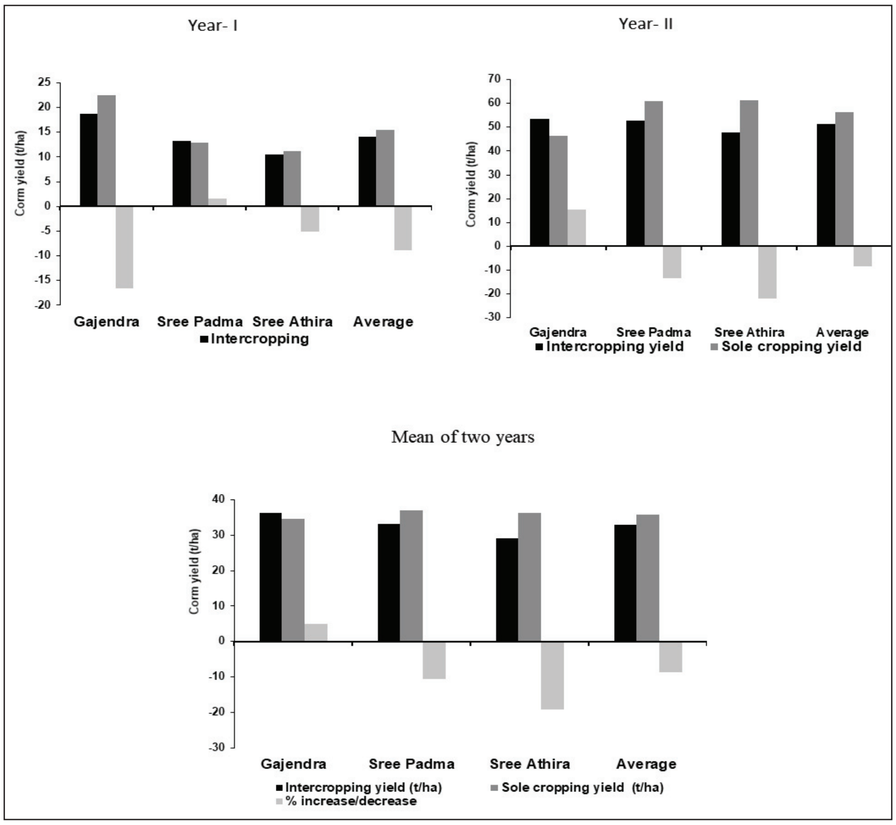

Fig. 1. Corm yield: intercropping vs sole cropping in elephant-foot yam

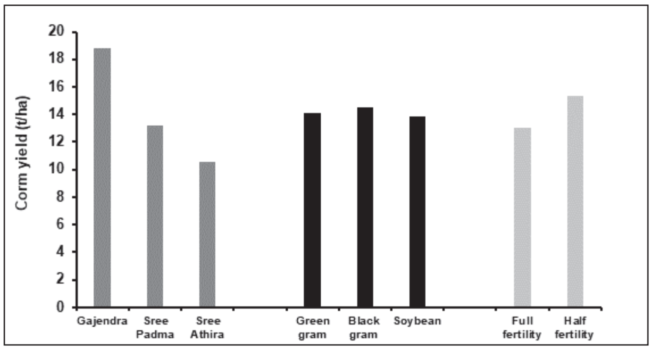

Fig. 2. Effect of varieties, type of pulse crop and fertility levels on corm yield of elephant-foot yam

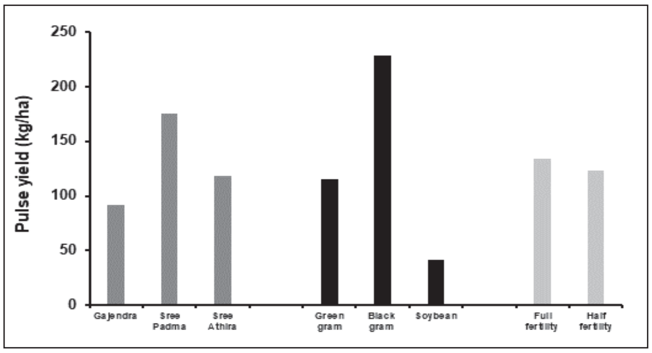

Fig. 3. Effect of varieties, type of pulse crop and fertility levels on grain yield of pulse

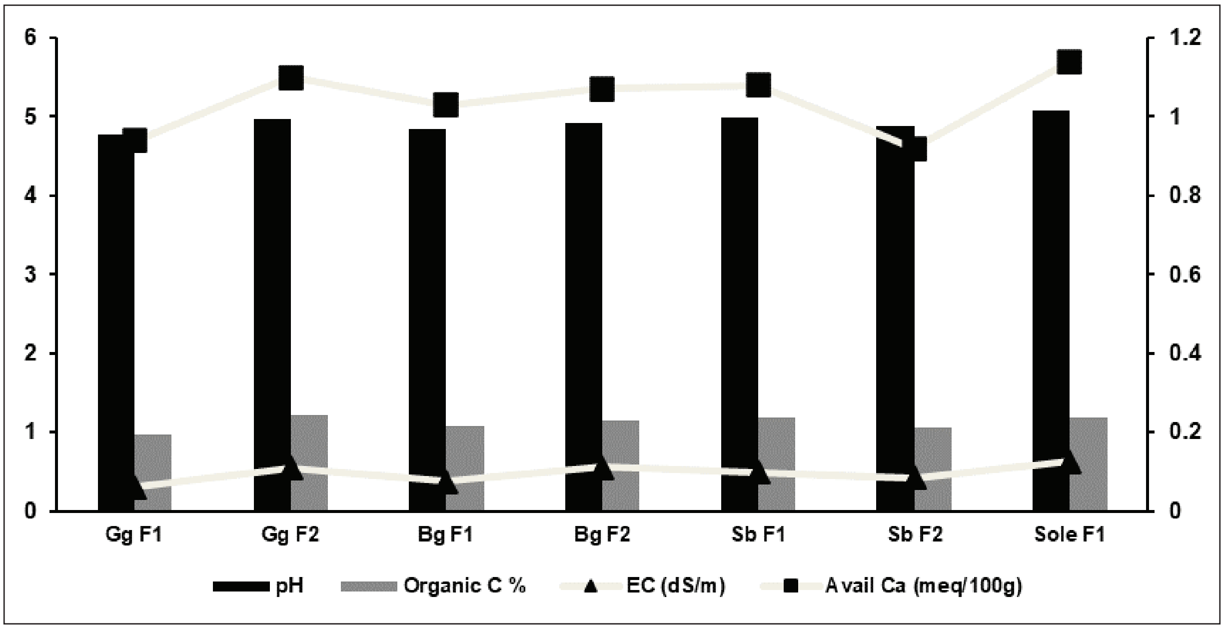

Fig. 4. Effect of pulses × fertility levels on pH, organic C, EC and exchangeable Ca

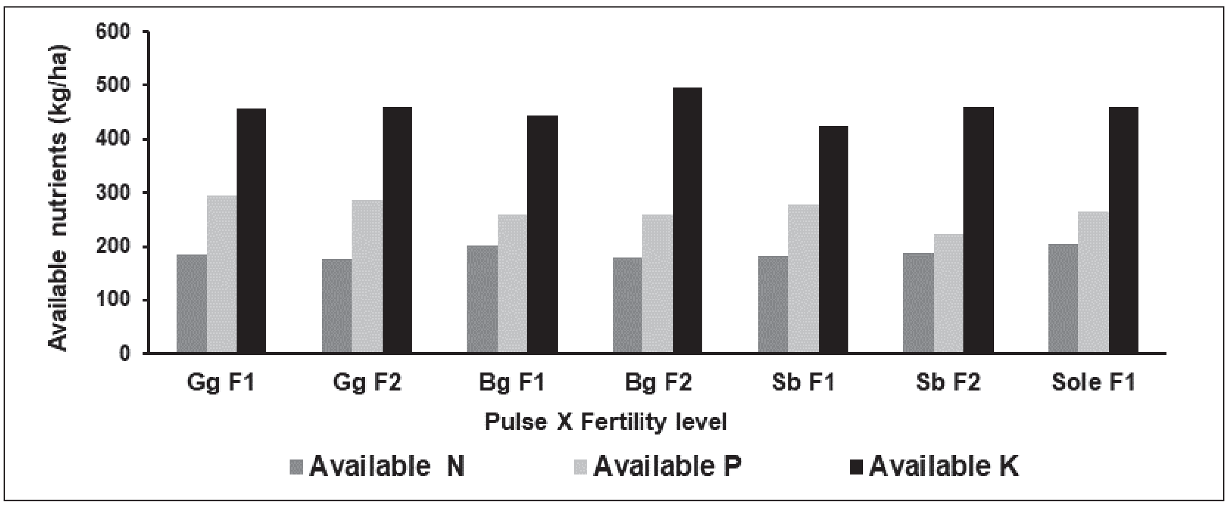

Fig. 5. Effect of pulses × fertility levels on available N, P and K in soil

in the development of a feasible elephant-foot yam-based cropping system involving pulses that will help to diversify our food basket, achieve self-sufficiency and offer resilience under climate change.

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Evaluation of propagation technique of Dragon fruit (*Hylocereus polyrhizus*) on various media

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Abstract

A study was carried out on dragon fruit (*Hylocereus polyrhizus* L.) with two factor randomized block design replicated five times at School of Agricultural Sciences, Nagaland University, Medziphema, Nagaland, during 2022-23. The treatments consisted of four types of media (sand, sand + FYM, sand + vermicompost and sand + leaf compost) and two cladode parts (upper half and lower half). The shoot parameters such as number of primary and secondary shoots (5.66 and 1.99), number of aereoles (30.77) and fresh weight and dry weight of shoots (103.66 g and 0.94 g) were recorded best under sand + compost, which were statistically at par with sand + vermicompost. The lower cladode part resulted in better shoot parameters, *viz.* number of primary and secondary shoots (4.84 and 1.68), length of primary and secondary shoots (36.30 cm and 27.14 cm), number of aereoles (27.72), fresh weight and dry weight of shoots (99.86 g and 0.80 g) over the upper cladode part. Similarly, highest number of primary and secondary roots (7.90, 29.08), longest root length (23.36 cm) and fresh and dry weight of roots (2.04 g, 0.80 g) resulted in lower cladode cuttings. The number of primary and secondary roots (8.29, 35.73), fresh and dry weight of roots (2.27 g, 0.94 g) were significantly more under sand + compost. Sand medium triggered the longest root length (28.79 cm). The use of sand + compost or sand + vermicompost with lower half cladode part can effectively enhance the growth of dragon fruit cuttings.

Key words: Media, Cladode part, Shoot and root growth , Aereoles, Fresh and dry weight

Dragon fruit (*Hylocereus* spp.) is a quick-growing, perennial and exotic crop grown in tropical regions of the world. It belongs to Cactaceae family and is a native of Central America, Mexico and South America (Koli *et al.,* 2022). Its cultivation is a lucrative proposition as it fetches high price in market (₹ 250-300 /kg) up to ₹ 350 /kg depending on the demand. The Northeastern region of India has scope for diversifying dragon fruit. There is a need of high-quality, disease free planting material of dragon fruit. A proper media composition serves as a good anchor to the plant and permits the exchange of gases between roots and atmosphere surrounding the rooting media (Rahad *et al.,* 2016). Propagation through cuttings is simple, rapid and cheaper than other sexual or asexual methods of plant propagation (Stokes *et al*., 2020). The piece of the stem that is utilized for cutting also plays an important part in rooting of cuttings, with the basal or proximal portion being the area that has the highest rooting percentage (Hartmann *et al*., 2011). The paper elucidates the results on the use of best cladode part and media in propagation of dragon fruit.

MATERIALS AND METHODS

The experiment was conducted in a shade net house at Horticulture Cenre, Chite, Aizawl, Department of Horticulture, Government of Mizoram, during October 2022 to June 2023 with eight treatments replicated five times under two factor randomized block design. The first factor consisted of four different growing media, *viz.* clean coarse sand (control), sand + FYM, sand + vermicompost and sand + leaf compost mixed in 1:1 ratio each, while second factor consisted of two cladode parts, *viz,* upper half and lower half parts. The percentage of NPK content in FYM was 0.5:0.2:0.2, vermicompost having 2.5:2.0:2.0 and leaf compost with 1.25:0.25:0.5. The planting material were obtained from two year old mother plants of red flesh and red skin cv. Dark Star and cuttings of 25-30 cm were dipped in 0.5% Bavistin (Carbendazim) solution cured for a couple of days in shade. The treated cuttings were then planted in rows in polybags of 8 x 8 inches and thereafter their progressive growth was evaluated. The final data of each character recorded were analysed statistically as per Sukhatme and Panse (1995). The significance of different sources of variation were tested by error mean square using Fisher Snedecor 'F' test of probability at 0.05 level of significance.

RESULTS AND DISCUSSION

The media consisting of sand + leaf compost recorded highest number of shoots throughout the study. The maximum number (5.66) of primary shoots and secondary shoots (1.99) were found at 8 MAP (months after planting), which were statistically at par with sand + vermicompost (4.52 and 1.59 primary and secondary shoots respectively). Significantly least number of primary and secondary shoots were recorded in sand at 8 MAP and were also found to be the lowest amongst other

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treatments. The resultant effect of compost may be due to its humic acid content that contributed to the increase in shoot growth, as it influences soil structure, ecology and soil fertility (Chen *et al.,* 1996). It was found that lower half cladode part recorded maximum of 4.84 primary shoots and 1.68 secondary shoots and was significantly superior over the upper half cladode part on all days (Table 1 and Fig 1). The effect of lower half cladode part may be due to more nutritional content, presence of rooting co-factors as well as growth promoters that resulted in desirable shoot growth of cuttings. The interactive effect of media and cladode part was also found significant.

The more shoot length at 8 MAP was recorded in sand + FYM media and lower cladode produced more primary and secondary shoot length (40.87 cm and 36.30 cm respectively). The increase in length of shoots as affected by lower cladode part is also supported by Dachlan *et al.* (2020), which can be attributed to its higher level of auxins and carbohydrate content, resulting in increased shoot lengths. There was significantly more number of aereoles in cuttings grown in sand + leaf compost and lower half cladode produced maximum fresh and dry weight (Table 2). Similar effects of media on shoot characteristics was reported by Atiyeh *et al.* (2000) while Bacilio *et al.* (2006) reported increased dry shoot weight of cordon cacti grown in compost added barren soil.

The fresh weight of cuttings is a significant component in determining the success of the cuttings. This is because the cuttings include food resources that are stored, which aid in the rooting process. Longer cutting sizes (15 cm) produced significantly greater fresh and dry weight of shoot which progressively lessened with smaller cutting sizes (Malsawmkimi *et al*., 2019) The number of primary and secondary roots was recorded highest with sand + leaf compost media followed by sand + vermicompost. Similarly fresh and

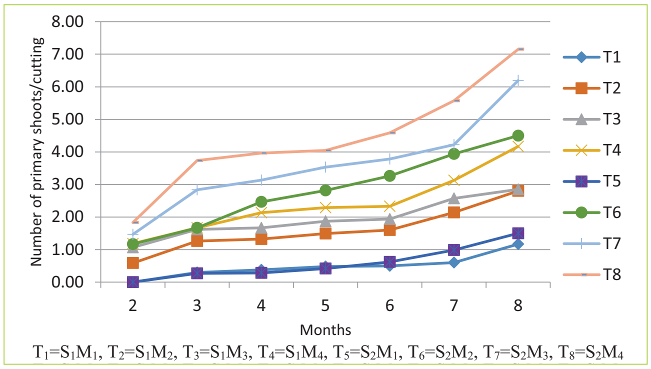

Fig. 1: Interactive influence of media and cladode part on number of primary shoots with progress in time

dry weight of roots were found highest in sand + leaf compost which was found statistically at par with sand + vermicompost (Table 2 and Fig 2). The present findings lend credence to reports of Vijaya and Syariful (2018).

In our study, least fresh and dry weight of roots but the highest root length was recorded in sand media which may be due to loose nature of sand allowing unrestricted growth of roots. Similar root length was reported by Nandi *et al.* (2019). There were significant variations in interaction between cladode part and media used on root characteristics. These findings are supported by Fumoro (2011) where higher root fresh weight was obtained from basal segment of dragon fruit cuttings over upper and middle segments in mature as well as immature herbaceous cuttings. Interactive influence of both the factors on fresh and dry weight of roots was also found significant. There was cent per cent survival of all cuttings irrespective of cladode part and various media evaluated 12 months after planting.

CONCLUSION

It may be concluded that media consisting of sand

Table 1. Number of primary and secondary shoots of cuttings as influenced by media and cladode part

Treatment	Primary shoots							Secondary shoots
	Months after planting							
	2	3	4	5	6	7	8	8
Media (M)								
Sand	0.00	0.28	0.33	0.45	0.56	0.79	1.33	0.58
Sand + FYM	0.88	1.46	1.89	2.16	2.43	3.04	3.65	1.26
Sand+vermicompost	1.27	2.23	2.40	2.70	2.86	3.40	4.52	1.59
Sand +leaf compost	1.51	2.70	3.05	3.17	3.46	4.35	5.66	1.99
SEm (±)	0.18	0.34	0.42	0.45	0.29	0.17	0.32	0.23
LSD (p=0.05)	0.55	1.03	1.19	1.37	0.87	0.52	0.97	0.69
Cladode part (S)								
Upper half	0.71	1.21	1.37	1.53	1.59	2.11	2.75	1.03
Lower half	1.12	2.13	2.46	2.70	3.06	3.68	4.84	1.68
SEm (±)	0.13	0.24	0.30	0.32	0.20	0.12	0.23	0.16
LSD (p=0.05)	0.39	0.73	0.90	0.97	0.61	0.37	0.69	0.49
Interaction (media x cladode part)								
SEm (±)	0.25	0.48	0.59	0.66	0.40	0.24	0.45	0.32
LSD (p=0.05)	0.77	1.46	1.79	1.99	1.22	0.74	1.37	0.98

Table 2. Influence of treatments on shoot and root characteristics of dragon fruit cutting

Treatment	Length of shoot at 8 MAP	Number of aereoles	Shoot weight (g)		Number of roots		Root length (cm)	Root weight (g)	
			Fresh	Dry	Primary	Secondary		Fresh	Dry
Media (M)									
Sand	19.23	13.36	66.12	0.43	6.80	16.03	28.79	0.94	0.43
Sand + FYM	40.87	22.42	97.44	0.51	7.32	19.49	19.38	1.38	0.51
Sand + vermicompost	29.10	23.03	101.35	0.75	8.13	34.01	18.21	2.11	0.75
Sand + compost	31.71	30.77	103.66	0.94	8.29	35.73	18.11	2.27	0.94
SEm (±)	1.29	1.55	5.21	0.09	0.22	1.13	1.82	0.20	0.09
LSD (p=0.05)	3.92	4.71	15.81	0.26	0.67	3.42	5.52	0.59	0.26
Cladode part (S)									
Upper half	24.15	17.07	83.97	0.52	7.37	23.55	18.88	1.31	0.52
Lower half	36.30	27.72	99.86	0.80	7.90	29.08	23.36	2.04	0.80
SEm (±)	0.91	1.10	3.68	0.06	0.16	0.80	1.29	0.14	0.06
LSD (p=0.05)	2.77	3.33	11.18	0.19	0.47	2.42	3.9	0.42	0.19
Interaction (media x cladode part)									
SEm (±)	1.83	2.20	7.37	0.14	0.31	1.59	2.57	0.28	0.14
LSD (p=0.05)	5.54	6.66	22.35	0.44	0.95	4.83	7.81	0.84	0.44

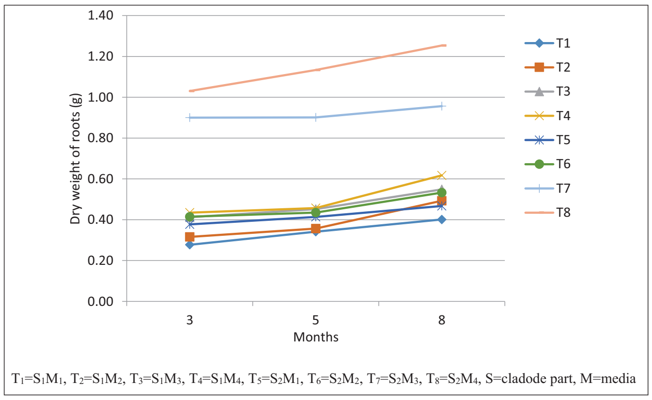

Fig. 2. Interactive influence of media and cladode part on dry weight of roots

+ leaf compost and sand + vermicompost provided more or less equal desirable shoot and root growth qualities which may be attributed to their rich organic nutrient content. Leaf compost also has high soil-binding ability and therefore may be recommended to be used in the northeastern region.

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Optimization and storage study of value-added vinegar from guava (*Psidium guajava*) cultivars

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Abstract

Two strains of *Acetobacter aceti* (MTCC 2945 and MTCC 3245) were compared on the basis of variation in inoculation size (5, 10 and 15%) and incubation time (22, 48 and 72 hours) to produce vinegar from guava (*Psidium guajava* L.) cv. Hisar Surkha and Hisar Safeda at CCS Haryana Agricultural University, Hisar, Haryana. Vinegar was further value-added by ginger (*Zingiber officinale* L.), garlic (*Allium sativum* L.), and beetroot (*Beta vulgaris* subsp. *Vulgaris*). Value-added garlic vinegar had maximum overall acceptability, hence was further stored for 45 days and examined for its physicochemical analysis. During storage value-added garlic vinegar had low acetic acid, ascorbic acid, antioxidant activity and alcohol content. The value-added garlic vinegar can be served as a functional food, and can be used for preservation of food products like pickles, gherkins, sauerkraut etc.

Key words: Acetic acid bacteria, Value-added vinegar, Storage, Incubation time, Probiotic

Guava (*Psidium guajava* L.) is a tropical fruit (Chopra *et al.*, 2024), highly consumed in Indian diet. It contains high amount of vitamin C, flavonoid, antioxidant and phenols (Harendra, 2023). Just like strawberry, mango, pineapple *etc.*, guava can also be used for an integrated development protocol for production of diversified products, *viz.* probiotic drink, sqaush, jam, jelly, candy and wine (Garg *et al.*, 2024). If vinegar is prepared from guava, it will be of better quality. On the other hand, to enrich the nutritional properties of vinegar or to produce value-added vinegar, it can be fortified with some extracts of functional food like ginger, garlic and beetroot. Ginger is a commercial spice crop (Chhetri *et al.*, 2023). Ginger and garlic extracts are used as medicine, whereas beetroot extract possess natural pigments and they all contain high amount of flavonoids, anti-oxidants and said to have anti-inflammatory properties (Timba *et al.,* 2019). In the present study, screening of different *Acetobacter* strain was performed to produce guava vinegar. Further, fruit vinegar was value-added with extracts of ginger, garlic and beetroot.

MATERIALS AND METHODS

Guava cultivars Hisar Surkha and Hisar were procured from local market of Hisar, Haryana. Lyophilised cultures of *Acetobacter aceti* (MTCC 2945 and MTCC 3245) were obtained from Institute of Microbial Technology, Chandigarh. Culture was maintained on Yeast extract Peptone Mannitol (YPM) medium. *Acetobacter aceti* cultures were maintained by sub-culturing them on YPM agar slants and thereafter stored in refrigerator at 4°C till further use. Fruits were processed to obtain juice, total soluble solids (TSS) adjusted to 20^0B by addition of sugar and pH was adjusted to 5 for alcoholic fermentation. Potassium metabisulfite was added @ 100 ppm, and kept for 48 hours to inactivate unwanted microflora.

Fruit juice was inoculated with 5% of 10^6 cells/ml of *Saccharomyces cerevisiae* (MTCC 170) strain. It was then kept in incubation for 14 days at 28°C, for alcohol production under anaerobic condition. Alcohol content was determined as per method of Zoeckleim *et al.* (1990) with slight modification. After alcoholic fermentation, fermented worts were allowed to settle at 4-5^0C and before proceeding for acetous fermentation, wine was diluted with water in a 1:1 ratio so the final ethanol content in wine is reduced to half, further divided equally and kept in different trays, in order to increase surface area and oxygen availability for acetous fermentation.

On the other hand, loopful culture of each *Acetobacter aceti* strain (MTCC 2945 and MTCC 3245) from slants were inoculated in sterilized YPM broth and kept for 24 h at 28°C on shaker at 150 rpm. Then were added separately to partially clarified wine by varying the inoculum size (5, 10 and 15% of 10^4cells/ml) and incubation time (22, 48 and 72 hours). Sterile wooden shavings were added at 1% level which served as platform for *Acetobacter* cells to grow and helped in reducing time for acetous fermentation. Acidity was periodically measured till constant value was obtained. After acetous fermentation, vinegar was stored at 4^0C for 3-4 days. Then it was clarified by passing through muslin cloth.

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For value addition, chopped garlic (100 g), grated beet root (100 g) and grated ginger (100g) were packed separately in clean muslin cloth and allowed to remain suspended in each 2 litre of vinegar for 48 hr to produce value-added vinegar. After it, spice containing bags were removed and vinegar was filled in glass bottles. Samples were pasteurized at 65^0C for 15 minutes and stored at room temperature. Value-added garlic vinegar had maximum overall acceptability, hence it was further stored for 45 days and examined for physico-chemical and sensory parameters at fortnightly intervals.

Titratable acidity, pH and acetic acid in vinegar were estimated by AOAC, 2019. Ascorbic acid and antioxidant activity was estimated as described by Ranganna, (2014). Yield of vinegar was calculated in terms of acetic acid by determining the amount of ethanol converted to acetic acid. Turbidity (NTU) was recorded by using Nephlometer. Total plate count was estimated on plate count agar by serial dilutions technique. Sensory evaluation was performed in terms of overall acceptability of value-added vinegars by a panel of semi-trained judges using 9-point hedonic scale. Treatments were performed in triplets and the statistical analysis done by ANOVA using OPSTAT software.

RESULTS AND DISCUSSION

Maximum amount of alcohol content was estimated in guava cv. Hisar Surkha (9.62%) followed by Hisar Safeda (7.36%). Highest amount of acetic acid was recorded in Hisar Surkha after 72 hours of incubation with 15% inoculum of MTCC 3245 strain *i.e.* 4.56% (Fig. 1).

Both the strains depicted to produce high amount of titratable acidity in Hisar Surkha after 72 hour of incubation (Table 1). A significant increase in acidic acid was observed as the inoculum size and incubation temperature increased (Table 1). MTCC 2945 when kept for 113 hours at 10% concentration produced maximum amount of mango vinegar (Harika *et al.*, 2017). CV 01 *Acteobacter* strain produced high alcohol at high temperature (Mounir *et al.*, 2016). When 40% concentration of mother vinegar added in papaya pulp produced highest acetic acid after 70 hours (Kong *et al.*, 2018). Maximum soursop vinegar was produced after incubating for 120 hours at pH 5.5 (Ho *et al.*, 2017).

Table 1. Effect of inoculums size and incubation time on titrable acidity of vinegar (%) with *Acetobacter aceti* (MTCC 3245)

Cultivar	Inoculum size (%)	Incubation period (h)		
		24	48	72
Hisar Surkha	5	2.54	3.05	3.62
	10	2.69	3.26	4.06
	15	2.84	3.78	4.56
Hisar Safeda	5	2.46	2.82	3.14
	10	2.54	3.26	3.57
	15	2.67	3.48	4.06

The vinegar yield was observed maximum in guava cv. Hisar Surkha. However, acetic acid content and antioxidant activity in vinegar was higher for guava cv. Hisar Safeda than others (Table 2).

Table 2. Yield and quality of wine and vinegar obtained from guava

Parameter	Hisar Surkha	Hisar Safeda
Yield of vinegar (% v/w)	34.8	31.6
Turbidity of vinegar (NTU)	972	852
Acetic acid content (% v/v)	4.02	4.36
pH of vinegar	2.0	2.1
Colour of vinegar	Pinkish	Creamish
Antioxidant activity of vinegar (% scavenging of DPPH)	35.4	38.6

After value-addition, guava cv. Hisar Surkha value-added with garlic possessed maximum overall acceptability than others; therefore, it was further kept for storage. During storage, a significant and progressive increase in turbidity and TSS of vinegar was observed. Increased turbidity during may be due to presence of large particles like bacterial cells, polyphenols, carbohydrates and improper filtration. The acidity, ascorbic acid, acetic acid and alcohol contents of vinegar decreased during storage. The decrease in ascorbic acid may be due to decline in vitamin C as during storage in open with aerobic environment vitamin C degrade easily (Davies *et al.*, 2017). The antioxidant activity decreased during storage and the results were in similarity with Davies *et al.*, 2017. The total plate count increased with increasing storage period.

Value addition by garlic resulted in significant increase in turbidity and TSS with the increase in storage period. However, the acidity, ascorbic acid, acetic acid and alcohol contents of vinegar were lower in value-added vinegar over control. The antioxidant activity and total plate count were also found lower in value-added vinegar (Table 3). There was slight but significant decrease in overall acceptability with the increase in storage duration. The vinegar remained acceptable upto 45 days period of storage.

CONCLUSION

In acetous fermentation, highest amount of acetic acid (4.56%) was recorded in Hisar Surkha after 72 hours of incubation with 15% inoculum of MTCC 3245 strain. Value-added vinegar with spices and aromatic herbs complements its taste and medicinal value. The value-added vinegar obtained can be further be used in preparation of functional drink which can be useful for diseased patients.

Table 3. Effect of storage period on various parameters of guava vinegar

Treatment	Storage period (days)								
	0	**45**	**Mean**	**0**	**45**	**Mean**	**0**	**45**	**Mean**
	Turbidity (NTU)			TSS (%)			Acidity (%)		
Control	769	942	855	3.33	3.57	3.45	4.80	4.46	**4.63**
Garlic +	781	1062	921	4.39	4.57	4.48	4.67	4.36	**4.51**
Mean	775	1002		3.86	4.07		4.73	4.41	
CD(5%)	T= 7.4; S = 7.4; T × S = 14.9			T= 0.03; S = 0.03; T × S = 0.06			T= 0.02; S = 0.02; T × S = 0.04		
	Acetic acid (%)			Alcohol content (%)			Ascorbic acid (mg/100 ml)		
Control	3.75	3.29	3.52	0.73	0.47	0.60	18.4	11.6	**15.0**
Garlic +	3.76	3.21	3.48	0.72	0.43	0.57	16.5	10.6	**13.5**
Mean	3.75	3.25		0.72	0.45		17.4	11.1	
CD(5%)	T= 0.02; S = 0.02; T × S = 0.05			T= 0.04; S = 0.04; T × S = 0.08			T= 0.08; S = 0.08; T × S = 0.17		
	Antioxidant (%)			Overall acceptability (9-point hedonic)			Total plate count (log_{10}cfu/ml)		
Control	38.1	19.3	28.7	7.9	7.5	7.7	4.31	4.61	**4.5**
Garlic +	34.2	18.3	26.3	8.2	8.1	8.2	4.10	4.40	**4.3**
Mean	36.1	18.8		8.1	7.8		4.2	4.5	
CD(5%)	T= 0.44; S = 0.44; T × S = NS			T= 0.14; S = 0.14; T × S = NS			T= 0.007; S = 0.007; T × S = 0.015		

NS, Non-significant

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Estimation of heterosis and combining ability for yield and yield- attributing traits in spine gourd (*Momordica dioica*)

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Abstract

Heterosis for quantitative characters in 31 spine gourd genotypes, including 10 parents and 21 F_1s, was investigated in spine gourd (*Momordica dioica* Roxb.) during 2016-2018. Analysis of variance revealed highly significant differences among parents and hybrids for 10 characters. Considerable coefficient of variation for various characters was observed to distinguish among various genotypes. The cross, NDM-5 x AJSG-2, showed heterosis over mid-parent and NDM-5 x AJSG-2 over better parent for single fruit weight. Crosses Ambika 13-5 X Chhattisgarh Kankoda-2 (69.24 q/ha), Ambika 13-6 X AJSG-2 (68.30 q/ha), RMDSG-4 x Chhattisgarh Kankoda-2 (66.60 q/ha), NDM-5 X AJSG-2 (66.19 q/ha), RMDSG-3 X Chhattisgarh Kankoda-2 (62.89 q/ha), AJSG-1 x IK-1 (61.47 q/ha), NDM-5 X IK-1 (59.26 q/ha), Ambika 13-5 X AJSG-2 (58.15 q/ha) and RMDSG-3 X IK-1 (55.56 q/ha) can be used to get good heterotic combination and it will be multiply through stem cuttings after fixation of heterosis in the form of asexual propagating material, *i.e.* tubers. Therefore, these cross combinations could be utilized in isolation of superior parents for incorporating yield-attributing and qualitative traits in spine gourd.

Key words: Heterosis, Combining ability, Parents, Stem cuttings, Yield-attributing traits

Spine gourd (*Momordica dioica* Roxb.) belonging to the family Cucurbitaceae with chromosome number of $2n$=28, is a highly valued wild yet edible vegetable with rich nutraceutical properties consisting of proteins, lectins, triterpenes and ascorbic acid (Kushwaha *et al*., 2005; Ameen *et al*., 2022a). Since, spine gourd is one of the least exploited vegetables among cucurbits, it offers immense scope for exploitation of hybrid vigour to increase the production and productivity on commercial scale. (Rasul, 2003; Saroj *et al*., 2020). Spine gourd is highly cross-pollinated and has high levels of heterozygosity due to dioecious nature, male plant has heterozygous (XY) and female has homozygous (XX) sex type. So, after fertilization in a single fruit both male and female seeds are present in 1:1 ratio (Tiwari *et al*., 2022; Ameen *et al*., 2022b). It is easy to raise healthy planting materials of true-to-type plants (Tiwari *et al*., 2022). The diallel, partial diallel and line x tester are commonly used. So many reports on combining ability and heterosis breeding are available in different gourds (Kundu *et al*., 2022), except spine gourd. Line × tester analysis is a useful tool for preliminary evaluation of genetic stock for use in hybridization programmes with a view to identify good combiners (Mondal *et. al*., 2009). Therefore, study was undertaken to select elite parental lines to explore heterosis for fruit yield and other attributes through line × tester analysis.

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MATERIALS AND METHODS

The study was carried out at RMD College of Agriculture and Research Station, Ambikapur, India, during rainy season of 2016-18. Seven diverse lines and 3 testers (Table 1) were crossed during rainy season 2016-17 in a line x tester mating fashion to produce 21 F_1s. The test material was grown in a complete randomized block design with three replications, in each replication 9 (8 female and 1 male) plants were maintained for each cross. After final land preparation, pits of (30 cm × 30 cm × 30 cm) were prepared in each plot with a spacing of 2 × 2 m. The pits were filled with 200 kg FYM, NPK 100:60:40 kg/ha and 3g chloropyriphos to prevent termite and three times topdressing of urea @ 50:25:25kg/ha. Since spine gourd is a dioecious crop, the male/ female ratio needs to be essentially maintained in the field. The female and male plant tubers were planted in the field at 8:1 ratio (female: male). This can be easily achieved by design advised by Tiwari *et al*., 2022.

Observations were recorded on five random plants selected from each plot on ten quantitative traits, *viz.* days to first flowering, days to first flowering node, number of branches per plant, ovary length (cm), ovary diameter (cm), fruit length (cm), single fruit weight (g), number of fruits per plant and fruit yield (q/ha). To measure fruit traits, fruits were harvested at matured green stage suitable for marketability. The mean value of data was subjected to analysis of variance (ANOVA) using the standard procedures of Panse and Sukhatme (1985). Combining ability analysis was done by using Kempthorne (1957).

Table 1. Analysis of variance (mean squares) for economic traits of spine gourd parents and hybrids.

Source	df	Days to first flowering	No. of first flowering node	No. of branches per plant	Fruit length (cm)	Ovary length (cm)	Ovary diameter (cm)	Fruit diameter (cm)	Single fruit weight (g)	No. of fruit per plant	Fruit yield (q/ha)
Parents	9	1.92*	5.81**	2.07*	0.26	0.25	0.00	0.28	1.64	19.20**	26.60**
Females	6	69.92**	4.93**	15.49**	0.75	0.35	0.02	0.15	3.43**	653.88 **	563.39 **
Males	2	4.55**	1.57	6.19**	2.99**	0.21	0.01	0.18	1.56	118.02 **	73.33**
Female vs. male	12	4.43**	8.04**	3.76**	0.74	0.19	0.00	0.33	5.02**	50.52**	98.53**
Hybrids	20	24.09**	6.46**	7.52**	0.97	0.24	0.01	0.26	4.20**	238.28 **	235.47 **
Parent vs. hybrids	1	22.45**	8.69**	52.30**	0.60	0.14	0.00	0.00	0.00	1523.8**	1063.45**
Error	30	9.12**	2.14*	0.64	0.13	0.03	0.00	0.06	0.36	3.27**	4.35**
$2\sigma^2g/(2\sigma^2g + \sigma^2s)$		0.73	0.24	0.47	0.41	0.17	0.72	0.19	0.17	0.73	0.48

Mid parent/average, better parent/ heterobeltiosis and standard heterosis were calculated according to method suggested by Shull (1909), Fonseca and Patterson (1968) and Meredith and Bridge (1972), respectively. Variety "Indira Kankoda-1 and Chhattisgarh Kankoda-2 was used as the standard check.

RESUTS AND DISCUSSION

The analysis of variance indicated that the mean squares for days to first flowering, number of first flowering node, number of branches/plant, number of fruits/plant and fruit yield of parents and hybrids were significantly different. In addition to above traits, mean squares for single fruit weight of hybrids was also significant (Table 1). The total genetic variability found among genotypes was partitioned to general combining ability (GCA) and specific combining ability (SCA). The GCA variances due to females was significant for days to first flowering, number of first flowering node, number of branches/plant, number of fruits/plant, single fruit weight and fruit yield while days to first flowering, number of branches/plant, fruit length, single fruit weight, number of fruits/plant, fruit yield GCA variances due to males was significant. This revealed the important role of additive type gene effects.

Mean squares of SCA for crosses were significant for days to first flowering, number of first flowering node, number of branches/plant, number of fruits/plant, single fruit weight and fruit yield. The variance due to GCA was lower than SCA for fruit diameter, single fruit weight and first flowering node, indicated non-additive gene action (dominant or epistatic). The GCA variance was higher than SCA for number of fruits/plant, days to first flowering, number of branches/plant, fruit length and fruit yield, indicating role of additive type of gene action. The variation due to parent vs hybrids was significant for all traits, indicating a substantial difference between parental and hybrid means (Table 2).

The relative importance of GCA and SCA was also assessed by estimating the components of variance and expressing them in the ratio, $2\sigma^2g/(2\sigma^2g + \sigma^2s)$. This ratio is known as Predictability Ratio. The closer this ratio is to unity, the greater the predictability based on GCA. The proportion of additive genetic variance in the total genetic variance ranged from 0.17 to 0.73 for different characters, expressed the predominance of additive gene action in determining the progeny performance. These economically important traits can be improved through direct selection for their higher mean values in subsequent segregating generation.

GCA and *per se* performance

The parents differ in their GCA. Indira Kankoda-1 and Ambika13-6, both high-yielding genotypes, differed in their GCA even though they were originated from the same cross. Parents differ in their breeding value. However, it was possible to select parents showing favorable GCA for days to first flowering to fruit yield, and genotypes that proved to be good general combiners for fruit yield on the basis of their desirable GCA effects and *per se* performance were Indira Kankoda-1 among the females and Ambika13-5 and Ambika13-6 among the testers. When parents were assessed for their overall combining ability for fruit diameter, fruit length and single fruit weight, Chhattisgarh Kankoda-2, NDM-2 and NDM-5 were identified as good combiners that could be utilized in breeding programmes specifically to improve the yield-contributing traits under rainfed conditions.

Heterosis and SCA

All crosses showed positive MPH, BPH and CCH 100% heterosis for days to first flowering and number of branches/plant, showing a positive heterosis for number of first flowering node as 33.33%, 52.38% and 95.23%, respectively. Moreover, crosses also exhibited positive MPH, BPH and CCH with 47.61, 71.42 and 4.76, respectively, for fruit length. In fruit diameter, there was positive 66.66% MPH, 28.57% BPH and 33.33% CCH.

Table 2. Mean performance of parent for various traits of economic importance in spine gourd

Genotype	Days to first flowering		No. of first flowering node		No. of branches/ plant		Fruit length (cm)		Ovary length (cm)		Ovary diameter (cm)		Fruit diameter (cm)		Single fruit weight(g)		No. of fruits/ plant		Fruit yield (q/ ha)	
	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
Line																				
AJSG-1	48.6	-2.00*	11.2	0.26	6.9	-5.99**	3.64	-0.19	1.7	5.80**	0.66	5.80**	3.37	-2.86**	17.1	-18.15**	50.5	3.17**	43.06	-11.16**
RMDSG-3	46.3	-3.16**	14.2	1.04	6.6	-0.34	4.54	-3.37**	2.4	3.39**	0.63	3.39**	4.01	-1.24	18.3	-9.13**	50.5	-2.72*	46.07	-9.03**
RMDSG-4	47.4	-2.26*	14.9	0.65	6.7	-6.24**	5.08	1.43	2.7	-0.56	0.59	-0.56	3.6	0.51	17.8	-15.45**	50.5	-1.76	44.82	-12.51**
AMBIKA13-5	45	-0.08	15.2	1.65	8.2	-1.16	3.66	3.94**	2.4	-2.16*	0.64	-2.16*	4.09	-0.38	16.2	3.06**	61	-2.38*	49.40	0.28
AMBIKA13-6	46.2	1.76	15	-1.31	9.05	3.07**	3.84	1.04	2.2	-1.70	0.71	-1.70	4.29	1.23	16.5	10.29 **	60	-2.92**	49.47	4.27**
NDM-2	46.8	0.95	11.5	0.48	8.5	4.39**	4.34	-1.49	1.7	-2.66*	0.61	-2.66*	3.07	1.68	16.1	15.48 **	50.5	2.48**	40.52	13.79**
NDM-5	46.2	4.79**	15.4	-2.76*	7.9	6.27**	4.84	-1.36	2.1	-2.11*	0.69	-2.11*	3.37	1.06	15.4	13.90 **	51.5	4.13**	39.52	14.37**
CD (5%)	2.90	2.98	1.40	1.44	0.77	0.79	0.34	0.35	0.17	0.17	0.05	0.05	0.22	0.23	0.57	0.59	1.73	1.79	1.21	2.06
Tester																				
INDIRA KANKODA-1	49.35	-0.67	9.9	0.63	6.4	-3.01**	5.5	-5.05**	1.4	1.31	0.63	1.61	4.08	-1.64	19.5	-4.38**	55.5	-1.96*	54.10	-4.49**
CHHATTISGARH KANKODA-2	45.8	0.74	15.7	0.34	5.65	-0.18	3.64	4.38**	1.9	-2.92**	0.67	-1.58	4.51	1.87*	14.6	6.85**	50.5	-0.25	36.87	3.58**
AJSG-2	47.1	-0.07	13.6	-0.97	6.9	3.19**	4.07	0.67	1.9	1.61	0.62	-0.03	3.52	-0.23	15.3	-2.46*	52.5	2.21*	40.02	0.91
CD (5%)	2.90	2.68	1.40	1.30	0.77	0.71	0.34	0.32	0.17	0.15	0.05	0.05	0.22	0.21	0.57	0.53	1.73	1.60	1.21	**1.85**

Various crosses exhibited a positive MPH, BPH and CCH with 50.00, 45.54 and 43.24, respectively, for number of fruits/plant. For fruit yield, crosses revealed positive MPH, BPH and CCH with 66.80, 65.38 and 30.81, respectively. All the crosses showed positive MPH, BPH and CCH with 100% positive showed in fruit yield.

The average MPH was 12.19 for days to first flowering, ranging from 7.28 to 25.23. The average BPH was 12.40 (7.48-23.44). Similarly, average CCH was 5.27 with a range of 1.32-15.30. The average MPH, BPH and CCH recorded for number to first flowering node was -3.88, 7.54 and 28.48, respectively. The average MPH for number of branches/plant was 47.76 with a range of 6.67-18.91. The average BPH was 34.62, while, average CCH was 61.01. The average MPH, BPH and CCH were 2.55, 13.00 and -19.79, respectively, for fruit length; fruit diameter was 4.53, -2.23 and -1.73, respectively. Single fruit weight 3.50, -2.47 and -12.59. For the number of fruits/plant, the mean MPH, BPH, and CCH were 39.35, 34.82, and 33.34, respectively, while for fruit yield, these values were 44.07, 33.54, and 16.49, respectively. The range for fruit length varied from 0.60 to 53.30 (MPH), 0.21 to 53.30 (BPH), and 0.91 to 1.45 (CCH). The range for fruit diameter was recorded as 0.13 to 34.40 (MPH), 0.25 to 31.53 (BPH), and 0.25 to 13.48 (CCH). Single fruit weight varied between 2.17 to 20.92 (MPH), 0.82 to 20.52 (BPH), and 0.51 to 24.62 (CCH). The number of fruits/plant ranged from 24.23 to 50.00 (MPH), 15.57 to 45.54 (BPH), and 25.23 to 43.24 (CCH). Fruit yield showed a range of 10.92 to 66.80 (MPH), 2.70 to 65.38 (BPH), and 1.47 to 30.81 (CCH).

Low levels of heterosis for fruit yield might be due to high *per se* performance of parents. The rationale for this is that heterosis depends on mean performance of parents involved and, therefore, there can be a cross with high *per se* performance but low heterosis if parental performance is also high. The single fruit weight, ovary length, fruit length and higher magnitude of MPH and BPH for number of fruits/plant indicate that scope for increasing fruit yield. The crosses showed significant positive heterosis for days to first flowering, number of fruits/plant and ovary length, fruit length.

The direction and magnitude of heterosis showed the possibility of developing hybrids to increase fruit yield and enhance productivity.

Table 3. Per se performance, relative mid parent heterosis, relative better parent heterosis, relative useful heterosis and estimation of SCA effect for different economic traits in spine gourd hybrids.

Hybrid	Number of branches/ plant					Fruit length (cm.)					Single fruit weight (g.)					Fruit yield (q/ha)				
	$\bar{X}$	MP	BP	CC	SCA	$\bar{X}$	MP	BP	CC	SCA	$\bar{X}$	MP	BP	CC	SCA	$\bar{X}$	MP	BP	CC	SCA
AJSG-1 X IK-1	9.3	39.85**	34.78**	45.31**	1.43	5.45	19.26**	49.73**	-0.91	-1.12	16.5	-9.71**	-15.38**	-15.38**	1.66	61.47	26.54**	13.63**	13.63**	1.92*
RMDSG-3 X IK-1	8.8	35.38**	33.33**	37.50**	0.46	4.99	-0.60	9.91**	-9.27	0.79	14.7	-22.12**	-24.62**	-24.62**	4.65**	55.56	10.92**	2.70	2.70	11.45**
RMDSG-3 X CK-2	11.55	88.57**	75.00**	80.47**	0.89	4.82	17.85**	32.42**	-12.36**	-2.07*	18.1	10.20**	-0.82	-7.18	-0.37	62.89	51.65**	36.49**	16.26**	2.14*
RMDSG-4 X CK-2	12.9	108.91**	92.54**	101.56**	-0.37	4.58	5.05	25.82**	-16.73**	1.61	18.5	14.37**	4.23	-5.13	-0.24	66.60	63.04**	48.56**	23.11**	18.14**
AMBIKA13-5 X CK-2	11.6	67.51**	41.46**	81.25**	1.80	3.55	-2.74	-2.47	-35.45**	-0.04	18.6	20.78**	14.81**	-4.62	3.93**	69.24	60.52**	40.16**	27.99**	10.74**
AMBIKA13-5 X AJSG-2	11	45.70**	34.15**	71.88**	-0.44	4.76	23.16**	30.05**	-13.45**	1.87*	16.5	4.93	1.85	-15.38**	5.10**	58.15	30.05**	17.71**	7.49**	14.26**
AMBIKA13-6 X AJSG-2	11.6	45.45**	28.18**	81.25**	2.06*	4.17	5.44	8.59**	-24.18**	0.59	18	13.39**	9.09**	-7.69	-0.63	68.30	52.62**	38.04**	26.25**	9.70**
NDM-5 X IK-1	9.45	32.17**	19.62**	47.66**	0.70	4.85	-6.19**	0.21	-11.82**	0.29	15.6	-10.47**	-20.00**	-20.00**	0.74	59.26	26.60**	9.54**	9.54**	14.51**
NDM-5 X AJSG-2	10.1	36.49**	27.85**	57.81**	0.29	4.08	-8.42**	0.25	-25.82**	-2.96**	18.5	20.92**	20.52**	-5.13	1.19	66.19	66.43**	65.38**	22.36**	4.95**
$\bar{X}$	**10.30**	47.76	34.62	61.01		**4.41**	2.55	13.00	-19.79		**17.05**	3.50	-2.47	-12.59		**63.02**	44.07	33.54	16.49	
Range	7.2-12.9	6.67-18.91	4.35-92.54	12.50-101.56	0.17-3.67	3.55-5.48	0.60-53.30	0.21-53.30	0.91-1.45	0.04-2.67	14.7-19.4	2.17-20.92	0.82-20.52	0.51-24.62	0.09-5.10	**55.5-70.7**	10.92-66.80	2.70-65.38	1.47-30.81	0.82-18.14
+Heterosis (%)		100	100	100			47.61	71.42	4.76			61.90	52.38	0			100	100	100	
IK-1 (C)	6.4					5.5					19.5					**54.10**				
CD (5%)	0.77	1.27	1.48		0.56	0.34	0.55	0.66		0.25	**0.57**	0.94	1.09		0.42	**1.21**	3.33	3.84		1.47

*, **Significant at 1% and 5% Level of Significance, respectively

However, high-performing heterotic cross combinations involving parents with at least one good general combiner that produced superior F_1 progenies in spine gourd and thus could be advantageously utilized in breeding programmes. As *per se* performance is realized value and the heterotic response is an estimate, former should also be given preference when making a selection in cross combinations (Table 3). In our study, all crosses showed significant MPH, BPH and CCH in desirable direction for days to first flowering,

Crosses AJSG-1 × IK-1, RMDSG-3 × IK-1, RMDSG-3 × Chhattisgarh Kankoda-2, RMDSG-4 × Chhattisgarh Kankoda-2, Ambika 13-5 × Chhattisgarh Kankoda-2, Ambika 13-5 × AJSG-2, Ambika 13-6 X AJSG-2, NDM-5 × IK-1 and NDM-5 X AJSG-2 were showed a significant positive SCA for single fruit weight.

The specific combining ability (SCA) effects for fruit length and single fruit weight were non-significant in most crosses. However, crosses exhibiting significant positive mid-parent heterosis (MPH), better-parent heterosis (BPH), and commercial heterosis (CCH) for traits such as days to first flowering, first flowering node, number of branches plant, fruit length, ovary length, ovary diameter, fruit diameter, single fruit weight, number of fruits plant, and fruit yield also showed significant positive SCA effects. Heterotic crosses involving good × good general combining ability (GCA) parents with insignificant SCA effects suggest the predominance of additive × additive interactions in heterosis. Therefore, direct selection for superior single fruit weight (Ambika 13-5, Ambika 13-6, NDM-2, NDM-5, and Chhattisgarh Kankoda-2) and a higher number of fruits per plant (Ambika 13-6, NDM-2, NDM-5, and Chhattisgarh Kankoda-2) is recommended in advanced generations, as additive gene effects contribute significantly to trait variation.

All crosses, except one involving poor × poor GCA parents, exhibited negative or low positive MPH, BPH, and CCH for single fruit weight, indicating that high-performing parents with poor GCA may not yield highly heterotic crosses. Similar findings were reported by Mahla *et al.* (2023) in *Allium* and Thangamani *et al.* (2011) in bitter gourd, where hybrids derived from good × good and medium × poor or medium × medium combiners exhibited significant SCA effects.

The selection of parents should be based on per se performance as well as combining ability and heterosis. RMDSG-4 × CK-2 (66.60 q/ha), Ambika 13-5 × CK-2 (69.24 q/ha), Ambika 13-5 × AJSG-2 (58.15 q/ha), Ambika 13-6 × AJSG-2 (68.30 q/ha), NDM-5 × IK-1 (59.26 q/ha) and NDM-5 × AJSG-2 (66.19 q/ha) were the crosses with desirable yield attributing traits and good combining ability. Ambika 13-5, Ambika 13-6, NDM-2, NDM-5 and Chhattisgarh Kankoda-2 were identified as good parent for single fruit weight and fruit yield.

The Propagation of spine gourd through stem cutting was standardized by Tiwari *et al.* (2022). Once the best combiner identified there is no need to go for hybrid seed production in proper parental combination. Though seed germination is also a problem along with early-stage male and female identification (Amin *et al.*, 2022). Crosses Ambika 13-5 × Chhattisgarh Kankoda-2 (69.24 q/ha), Ambika 13-6 × AJSG-2 (68.30 q/ha), RMDSG-4 × Chhattisgarh Kankoda-2 (66.60 q/ha), NDM-5 × AJSG-2 (66.19 q/ha), RMDSG-3 × Chhattisgarh Kankoda-2 (62.89 q/ha), AJSG-1 × IK-1 (61.47 q/ha), NDM-5 × IK-1 (59.26 q/ha), Ambika 13-5 × AJSG-2 (58.15 q/ha) and RMDSG-3 × IK-1 (55.56 q/ha) can be used to get good heterotic combination and it will be multiply through stem cuttings after fixation of heterosis in the form of asexual propagating material, *i.e.* tuber. Therefore, these cross combinations could be utilized in isolation of superior parents for incorporating yield attributing and qualitative traits.

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Evaluation of sponge gourd (*Luffa cylindrica*) hybrids for yield-contributing traits

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Abstract

The study was undertaken to find the performance of 28 hybrids of sponge gourd [*Luffa cylindrica* (L.) Roem.] through diallel mating design excluding reciprocals at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan. Observations were recorded on days to initiation of first female flower, days to 50% flowering, number of nodes at which first female flowers appear, number of primary branches/vine, vine length at final harvesting, days to first fruit harvesting, fruit size, average fruit weight, average fruit yield (g/plant), average fruit yield (kg/plot), total fruit yield (q/ha.). Among the hybrids, 'VRSG-17-27 × Pusa Chikni', 'VRSG-17-27 × Kashi Shreya', 'Kashi Shreya × PSG-40', 'Kashi Shreya × Pusa Chikni', 'VRSG-17-4 × VRSG-17-27 and 'VRSG-17-27 × PSG-40'excelled n number of nodes at which first female flower appears, days to initiation of first female flowers appear and fruit yield. Thus, first generation hybrids can be well-utilized for exploiting hybrid vigor to achieve higher yield with improved quality.

Key words: Evaluation, Genotype, Hybrids, Generation, Diallel

Sponge gourd [*Luffa cylindrica* (L.) Roem.] belonging to family Cucurbitaceae, has chromosome number 2n=26. Due to their excellent nutritional content and hardy fibrous vascular system, sponge gourds have become popular for harvesting both mature green and dry fruit. Heterosis resulting from crosses between strains or between different races or varieties is theoretically known as the reverse of inbreeding depression, and forms an important means of genetic improvements (Singh *et al.*, 2023). Through heterosis breeding, it is often possible to combine desired alleles in regular fashion without waiting for longer term as in case of development of open-pollinated cultivars. Despite its importance and diversified use, very little attention has been made for improvement in horticultural traits. (Bairwa *et al.,* 2017). Hence, present study was undertaken to evaluate performance of its hybrids along with their parents for yield related traits.

MATERIALS AND METHODS

The experiment was conducted at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, during summer 2020 with eight diverse parents, *viz.* VRSG-17-4, VRSG-17-27, Kashi Shreya, PSG-40, Pusa Supriya, Pusa Chikni, Pusa Sneha and Phule Prajakta of sponge gourd to make crosses in diallel fashion excluding reciprocals. The resulting hybrids of 28 cross combinations were evaluated in a randomized block design with three replications during *kharif* and late- *kharif* 2020. A total of 36 genotypes (28 F_1s hybrid and 8 parents) were grown under drip system on raised bed by sowing two seeds per hill with an inter row spacing of 1.2 m and plant- to- plant spacing of 0.60 m, accommodating 16 plants per treatment in (4.80 m long) raised bed.

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All the recommended cultural practices were followed. The observations were recorded on five randomly selected plants of each genotype and average was taken under each environment avoiding border plants. The pooled data of both environments were subjected to statistical analysis to derive information on relative heterosis and better parent heterosis/ heterobeltiosis. The analysis of variance was carried out for randomized block design as per the procedure (Panse and Sukhatme,1985). Relative heterosis and heterobeltiosis were calculated according to the method suggested by Fonseca and Patterson (1968).

RESULTS AND DISCUSSION

The analysis of variance was carried out to test the significance of differences among parents and their hybrids. This result clearly indicated that there were significant variations in mean performance among parents and their hybrids for all characters studied growth and yield parameters, thus offering scope for selecting high-yielding hybrids with good quality traits. The days to initiation of first female flower, days to 50% flowering, number of nodes to first female flower appearing and days to first fruit harvesting were used as criteria for earliness. Besides, yield attributes possessed direct impact on yield and heterosis behaviour, with number of primary branches/vine, vine length, fruit size, average fruit weight and average fruit yield (Table 1).

There was significant negative heterosis for E_1 (-13.15%) VRSG-17-27 × Pusa Chikni to 8.76% (Kashi Shreya ×PSG-40) and for E_2 (-10.91%) (VRSG-17-27 × Kashi Shreya) to 16.73% (VRSG-17-27 × Phule Prajakta).

Heterobeltiosis values for E_1 fluctuated from -12.94% (VRSG-17-27 × Kashi Shreya) to 12.02% (PSG-40 × Pusa Sneha) and for E_2 from -12.12% (VRSG-17-27 × Kashi Shreya) to 18.62% (PSG-40 × Pusa Sneha).

Heterosis values ranged from -17.44% (Kashi Shreya × Pusa Chikni) to 5.14% (Pusa Chikni × Pusa Sneha) in E_1 and from -13.51% (Kashi Shreya X Pusa Chikni) to 19.66% (Pusa Chikni × Pusa Sneha) in E_2. Significant negative heterobeltiosis was observed in nine crosses for environment E_1 and five crosses for environment E_2, while positive heterobeltiosis was evident in six crosses for E_1 and five crosses for E_2. Heterobeltiosis values for E_1 fluctuated from -13.23% (VRSG-17-27 × Kashi Shreya) to 7.25% (VRSG-17-27 × Pusa Sneha) and for E_2 from -10.99% (VRSG-17-27 × Kashi Shreya) to 17.8% (VRSG-17-27 × Pusa Sneha). Similar findings were also reported by Patil *et al.* (2019). "Number of nodes at which first female flower appears" showed highly significant and negative heterosis ranged from -24.89 % (Kashi Shreya × PSG-40) to 11.19% (Pusa Supriya×Pusa Chikni) and its varied range from -16.46% (Kashi Shreya × PSG-40) to 16.40% (Pusa Supriya × Pusa Chikni) under both environmental conditions. Heterobeltiosis ranged from -18.12 % to 8.69%, and the cross combination VRSG-17-27 × PSG-40 showed negative and highly significant results over better parents in E_1 while in E_2, varied range from -14.08 % (Kashi Shreya × Pusa Chikni) to 16.30% (Pusa Chikni × Pusa Sneha).

The highest value of positive and significant heterosis for "number of primary branches/ vine" was found in hybrid VRSG-17-27 × Phule Prajakta (18.32%) in E_1 and in E_2 range was observed between -21.99% (Pusa Sneha × Phule Prajakta) to 17.31% (VRSG-17-27 × Pusa Chikni). Heterobeltiosis range was exhibited between -17.96% to 21.03 % and -32.49% to 14.69% in both environments E_1 and E_2, respectively (VRSG-17-4 × Kashi Shreya). In the evaluation of hybrid combinations for vine length at final harvest (m), significant positive heterosis was observed in eight crosses for environment E_1 and five crosses for environment E_2 compared to mid-parent (MP) (Table 1). Heterosis values ranged from -19.02% (Pusa Sneha × Phule Prajakta) to 21.74% (VRSG-17-4 × VRSG-17-27) in E_1 and from -20.44% (Pusa Sneha × Phule Prajakta) to 16.70% (VRSG-17-27 × Pusa Chikni) in E_2.

Heterobeltiosis values for E_1 fluctuated from -4.24% (VRSG-17-4 × Pusa Chikni) to 34.92% (PSG-40 × Pusa Chikni) and for E_2 from -12.40% (VRSG-17-4 × Pusa Chikni) to 32.11% (PSG-40 × Pusa Chikni). These findings are also in conformity with those of Masud *et al.* (2021) and Venugopala Reddy *et al.* (2019). Negative and significant value of heterosis over mid parent for days to first fruit harvesting was exhibited by VRSG-17-27 × Kashi Shreya in E_1 (-11.62%) and -11.13% in E_2. Similar as, heterobeltiosis ranged from the -12.72% (VRSG-17-27 × PSG-40) to 2.97% (VRSG-17-27 × Pusa Supriya) under the E_1 and E_2 varied range from -12.51 % to 9.42%. For "fruit size (length x girth) cm^2" the cross- combination VRSG-17-27 × Pusa Chikni (38.71%) and VRSG-17-27 × PSG-40 (37.13%) showed positive and significant maximum value for relative heterosis, particularly in both environments E_1 and E_2, respectively.

A positive and highly significant value of heterobeltiosis was recorded for hybrid VRSG-17-27 × PSG-40 (40.99%) in E_1 and 39.29% in E_2. The findings are accordance with Hedau and Sirohi (2004) and Chauhan *et al.* (2018). Heterosis value ranged from -30.66% to 29.53% in E_1 and from -32.15% to 25.96% in E_2. Similar observations were also recorded by Islam *et al.* (2008). For average fruit yield (g/plant) an assessment of hybrid combinations revealed significant positive heterosis values for E_1 ranged from -28.46% (Pusa Sneha × Phule Prajakta) to 34.43% (VRSG-17-27 × Kashi Shreya) and for E_2 from -32.11% (Pusa Sneha × Phule Prajakta) to 30.58% (VRSG-17-27 × Pusa Chikni).

Heterobeltiosis values for E_1 fluctuated from -29.72% (Pusa Sneha × Phule Prajakta) to 42.17% (VRSG-17-27 × Kashi Shreya) and for E_2 from -31.33% (VRSG-17-4 × Kashi Shreya) to 36.21% (VRSG-17-27× Pusa Chikni). These results are in conformity with the findings of Sanandia *et al.* (2008); Singh and Singh (2018). According to the results, enhanced heterotic effect on fruit yield was largely attributed to the number of fruits per vine and fruit weight. The number of branches on each vine, vine length, and fruit length were additional characteristics that contributed in a secondary but still significant way to improved yield (Table 2).

CONCLUSION

VRSG-17-27 × Pusa Chikni, VRSG-17-27 × Kashi Shreya and Kashi Shreya × PSG-40 produced maximum significant relative heterosis and heterobeltiosis for most of the yield -attributing characters. So, these could be recommended for breeding programme.

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Table 1: Estimates of heterosis and heterobeltiosis for days to initiation of first female flower (DIFFF), days to 50% flowering (DF), number of nodes at which first female flowers appear (NNFFFA), number of primary branches/vine (NPB) and vine length at final harvesting (VLFH)

Cross	DIFFF				DF				NNFFFA				NPB				VLFH			
	Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
P1×P2	-1.75	8.56**	-5.39*	2.78	-2.37	4.17	3.91	10.8**	4.61	8.29	0.24	3.64	-2.62	-12.01**	-11.77*	-27.51**	21.74**	9.85	13.01*	6.48
P1×P3	2.32	11.67**	-3.58	3.69	-1.16	3.24	4.47*	8.5**	-1.62	-0.89	-2.02	-1.34	-8.51*	-19.8**	-17.96**	-32.49**	0.3	-7.48	14.55**	5.9
P1×P4	-7.35**	-1.33	-0.99	7.83**	2.98	9.17**	3.63	11.09**	-6.57	3.09	-2.28	3.38	5.89	-4.24	-6.21	-19.47**	3.31	-7.65	20.25**	12.16*
P1×P5	-3.28	-2.38	-6.69**	-6.32*	-1.95	-1.47	5.93**	7.12**	2.45	7.66	6.11	9.51*	-5.31	-9.26	-12.03*	-21.78**	4.67	1.5	10.8	8.07
P1×P6	-1.33	5.99*	-0.62	7.97**	-6.19*	2.85	0.99	8.89**	4.46	4.84	-1.11	-0.93	-1.36	-11.56*	-8.04	-20.85**	-0.33	-9.01	-4.24	-12.4*
P1×P7	-7.13**	-2.98	-7.74**	-5.24	-6.55**	-3.28	2.63	5.53*	-9.12*	3.51	-2.55	4.48	-8.35	-17.05**	4.21	-7.97	5.94	0.42	7.11	3.06
P1×P8	-9.2**	-7.12**	-8.73**	-5.55*	-7.08**	-2.33	1.05	6.62**	5.05	10.5*	-0.96	6.34	1.69	-4.78	18.94**	8.87	0.9	-2.72	5.91	0.52
P2×P3	-11.92**	-10.91**	-12.94**	-12.12**	-15.21**	-13.46**	-13.23**	-10.99**	-18.46**	-16.22**	-13.49**	-11.2*	18.29**	14.34**	13.47**	13.24**	19.28**	16.43**	24.57**	22.08**
P2×P4	4.44	8.14**	-8.28**	-8.06**	-12.74**	-12.21**	-11.09**	-10.65**	-24.76**	-13.8**	-18.12**	-10.28*	17.1**	16.99**	17.08**	11.04*	17.9**	16.67**	24.22**	22.9**
P2×P5	-2.71	8.6**	-2.43	6.44*	-1.88	4.15	5.21*	10.89**	-2.42	6.31	-2.84	3.77	3.11	-3.05	12.41**	2.65	-4.73	-11.56*	-1.26	-9.12
P2×P6	-13.15**	-10.83**	-9.69**	-9.68**	-15.1**	-12.9**	-4.5	-3.5	2.66	6.67	-16.26**	-13.26**	18.32**	17.31**	18.13**	11.71*	18.22**	16.7**	25.46**	21.57**
P2×P7	1.09	6.68*	-0.05	5.57	1.33	12.14**	7.25**	17.8**	-10.04**	6.51	4.38	15.96**	-6.48	-6.66	11.52*	2.56	1.07	-4.07	-1.75	-10.71
P2×P8	8.23**	16.73**	1.04	5.9*	-1.95	10.3**	0.27	13.19**	1.99	11.24*	-5.91	4.68	5.66	1.68	19**	5.57	3.76	-3.16	-0.04	-10.31
P3×P4	8.76**	11.31**	2.09	3.3	-14.6**	-13.38**	-11.8**	-9.07**	-24.89**	-16.46**	-15.07**	-9.49*	17.02**	13.01**	18.19**	12.3*	14.94**	11.06*	25.24**	24.05**
P3×P5	-10.34**	-1.16	-4.28	3.38	-2.47	1.35	3.14	5.89*	2.15	8.17	-1.68	2.19	-5.26	-13.7**	6.16	-2.88	4.17	-1.07	11.45*	0.7
P3×P6	-11.36**	-10.04**	-12.33**	-11.49**	-17.44**	-13.51**	-12.6**	-9.38**	-16.82**	-15.9**	-14.83**	-14.08**	14.27**	11.38**	21.05**	14.69**	16.75**	15.44**	20.85**	19.47**

Cross	DIFFF				DF				NNFFFA				NPB				VLFH			
	Heterosis		Heterobeltiosis		Heterosis		Heterobeltiosis		Heterosis		Heterobeltiosis		Heterosis		Heterobeltiosis		Heterosis		Heterobeltiosis	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
P3×P7	-2.8	1.37	-4.88*	-0.5	-9.68**	-2.22	-0.55	6.3*	-2.42	12.07*	4.01	12.34**	-13.51**	-16.55**	3.11	-5	6.1	3.09	3.31	-7.8
P3×P8	-6.95**	-0.85	-4.41	-0.78	0.9	11.01**	-2.98	6.51*	-14.82**	-9.7*	-12.15**	-4.97	2.56	-4.47	-2.48	-13.34**	1.06	-3.49	-0.94	-12.69*
P4×P5	-2.98	4.33	1.16	10.65**	-0.48	4.96	2.27	8.35**	-8.85*	-4.5	-2.16	0.23	1.89	-4.11	8.41	4.15	-10.6*	-17.82**	18.45**	7.96
P4×P6	4.61*	5.47*	-7.08**	-6.87*	-16.22**	-13.51**	-8.54**	-8.04**	-22.21**	-14.51**	-15.6**	-10.89*	17.13**	16.02**	12.9**	12.56*	13.04**	10.43*	34.92**	32.11**
P4×P7	2.72	4.63	12.02**	18.62**	-14.96**	-6.51*	-12.1**	-2.94	-3.43	-0.58	0.65	1.93	10.45**	10.35*	6.1	2.7	-2.9	-8.75	9.74	-1.23
P4×P8	-2.1	1.84	0.35	5.44	-6.57**	4.39	2.97	16.87**	-2.07	2.49	-0.16	1.25	2.65	-1.12	-0.62	-7.41	0.65	-6.97	10.63	-1.68
P5×P6	-6.57**	1.36	-0.79	8.25**	-4.42	4.23	2.38	9.09**	11.19**	16.4**	-0.12	2.88	-12.2**	-18.1**	10.27*	6.24	2.11	-4.07	6.41	-4.84
P5×P7	-0.56	4.89	-4.73*	-1.76	1.69	5.78*	-5.57**	-1.79	-11.96**	-4.92	-3.68	-0.05	3.71	-2.31	4.82	4.01	9.21	6.67	5.7	4.25
P5×P8	-6.99**	-3.96	-4.53*	-0.8	1.85	7.61**	-4.3*	2.16	-3.14	-3.05	-4.31	-0.55	8.72*	6.12	6.62	3.26	17.37**	16.68**	-4.28	-6.92
P6×P7	-5.31*	-2.75	-3.25	2.2	5.14*	19.66**	-0.87	10.11**	-8.09*	4.27	8.69*	16.3**	0.25	-0.8	10.17*	6.95	6.92	2.75	2.25	-9.67
P6×P8	-9.96**	-5.54*	-3.48	1.17	2.3	18.4**	-4.7*	8.83**	-10.85**	-6.58	-4.32	2.54	3.75	-0.98	13.45**	5.99	-4.39	-9.67	19.29**	4.09
P7×P8	4.49*	6.68**	-2.51	-1.78	-5*	-3.57	-6.82**	-4.44	-5.56	1.89	4.29	4.43	-19.08**	-21.99**	13.77**	9.36	-19.02**	-20.44**	10.62	9.05
S.Em.±	**0.92**	**1.06**	**1.20**	**1.38**	**1.15**	**1.33**	**1.13**	**1.30**	**0.46**	**0.53**	**0.53**	**0.61**	**0.21**	**0.24**	**0.32**	**0.37**	**0.27**	**0.32**	**0.26**	**0.31**

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Table 2: Estimates of heterosis and heterobeltiosis for days to first fruit harvest (DFFH), fruit size (cm^2) (FS), average fruit weight (g) (AFW) and average fruit yield (g/plant) (AFY).

Cross	DFFH				FS				AFW				AFY			
	Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis		Heterosis		Hetero-beltiosis	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
P1×P2	-4.82*	-1.83	2.22	5.45*	8.08	-10.17*	8.67	-10.74*	26.45**	11.73*	30.93**	9.48	32.65**	15.84*	33.78**	10.85*
P1×P3	-4.75*	-2.31	-5.91**	-2.15	10.9*	-9.89*	11.72*	-10.42*	0.37	-8.99	-16.11**	-26.97**	5.47	-5.44	-20.84**	-31.33**
P1×P4	-8.5**	-5.94*	-6.78**	-3.6	23.47**	1.69	-11.95*	-28.35**	4.02	-9.08	8.22	-10.11*	9.05	-5.83	7.57	-11.54*
P1×P5	-5.57**	-5.53*	-8.32**	-7.66**	24.76**	11.11*	34.17**	18.45**	5.79	1.85	-12.46*	-15.83*	8.19	0.42	-14.74*	-15.21
P1×P6	0.18	3.42	-2.27	-0.22	17.52**	-1.23	18.86**	-1.26	-0.4	-10.79	-3.72	-17.81**	4.57	-7.41	-6.32	-20.54**
P1×P7	-10.32**	-7.36**	-11.03**	-7.78**	-12.97*	-25.08**	-14.21**	-26.92**	7.32	0.51	28.63**	15.08**	12.99	4.73	31.41**	17.7**
P1×P8	-4.99**	-2.93	-4.33*	-3.35	-19.13**	-26.44**	-20.13**	-27.39**	-4.31	-8.52	1.08	-9.27	4.18	1.62	-0.89	-10.9
P2×P3	-11.62**	-11.13**	-10.83**	-10.12**	36.59**	32.76**	38.76**	34.54**	29.53**	25.85**	36.59**	30.26**	34.43**	30.47**	42.17**	34.63**
P2×P4	-10.37**	-10.08**	-12.72**	-12.51**	38.71**	37.13**	40.99**	39.29**	21.28**	19.78**	26.68**	25.63**	25.68**	24.06**	30.49**	29.26**
P2×P5	4.02*	7.34**	2.97	7.01**	3.71	-4.18	3.98	-4.36	-5.72	-13.78*	-1.2	-14.62**	-4.48	-10.61	0.94	-16.72**
P2×P6	-9.09**	-9.02**	-7.98**	-7.05**	35.07**	33.22**	37.3**	35.37**	27.91**	25.96**	34.96**	31.64**	32.69**	30.58**	40.15**	36.21**
P2×P7	-6.47**	-0.25	-6.74**	-0.17	8.42*	3.94	8.81*	4.11	9.98*	3.32	8.49	0.45	14.29*	7.11	9.83	0.52
P2×P8	-5.78**	-0.65	-6**	-2.01	16.06**	4.93	17.87**	5.24	4.54	-3.76	7.83	-0.49	11.78	-0.23	9.07	-0.56
P3×P4	-9.04**	-8.83**	-11.26**	-10.77**	18.02**	16**	18.96**	16.71**	17.85**	13.12*	26.8**	19.97**	22.25**	17.17**	30.84**	22.8**
P3×P5	-3.8	-1.29	-5.01**	-0.47	7.05	-3.65	7.28	-4.07	16.83**	9.76	24.3**	12.04*	11.63	7.51	32**	13.98*
P3×P6	-5.85**	-5.25*	-5.03**	-3.29	31.5**	26.09**	33.25**	27.42**	20.11**	18.49**	26.45**	23.56**	24.73**	22.98**	30.6**	27.16**
P3×P7	0.23	6.27**	1.37	9.42**	7.62	0.4	8.14	0.46	7.39	3.72	13.29**	9.83	11.73	7.77	15.52**	11.42
P3×P8	-5.43**	-0.86	-2.83	2.13	6.65	-6	7.62	-6.49	1.29	-4.19	14.46**	10.57*	8.55	-0.45	16.89**	12.28*
P4×P5	-2.72	0.06	-2.45	1.63	-2.79	-11.12*	-3.07	-11.82*	-17.68**	-25.56**	-7.55	-20.66**	-16.61**	-22.9**	-6.69	-23.59**
P4×P6	-7.26**	-6.88**	-8.27**	-7.11**	27.39**	24.23**	28.92**	25.6**	15.54**	12.38*	21.45**	17.5**	19.79**	16.4**	24.6**	19.98**
P4×P7	-3.32	2.75	-5.26**	1.68	4.07	-1.32	4.32	-1.33	-3.48	-10.39*	-18.85**	-25.43**	-0.02	-7.42	-21.79**	-29.03**
P4×P8	-1.79	3.21	-0.02	4.48*	25.1**	11.95**	27.43**	12.58**	0.79	-8.27	1.21	-7.3	7.67	-4.99	1.4	-8.34
P5×P6	3.36	6.75**	1.04	3.91	-20.59**	-25.68**	-22.03**	-27.34**	2.55	-4.87	1.75	-10.15*	3.92	-1.26	4.57	-11.7*
P5×P7	2.35	5.68**	-5.1**	-2.35	-31.71**	-34.3**	-33.76**	-36.44**	11.28*	8.13	22.14**	13.29*	12.84*	12.67	29.65**	15.56*
P5×P8	3.66*	5.85**	-2.42	-2.13	-9.75*	-11.86*	-9.98	-12.87*	16.25**	15.42*	3.35	-3.82	21.5**	15.46*	6.75	-4.49
P6×P7	-0.59	6.12**	-1.82	3.98	13.66**	10.44*	14.3**	10.88*	8.35	3.29	12.81**	6.94	12.67*	7.21	14.89**	8
P6×P8	1.34	6.95**	-4.05*	-1.02	5.93	-3.02	31.43**	18.85**	8.49	1.32	3.43	-2.29	-0.61	-10.02	3.99	-2.64
P7×P8	-5.42**	-4.39*	0.48	3.07	-12.27**	-17.49**	-10.48*	-16.74**	-30.66**	-32.15**	-25.3**	-25.57**	-28.46**	-32.11**	-29.72**	-30.01**
S.Em.±	**1.05**	**1.22**	**1.18**	**1.36**	**13.69**	**15.81**	**13.50**	**15.58**	**7.32**	**8.45**	**5.84**	**6.74**	**148.14**	**171.06**	**98.47**	**113.70**

Where,						
	P_1	=	VRSG-17-4	P_5	=	Pusa Supriya
	P_2	=	VRSG-17-27	P_6	=	Pusa Chikni
	P_3	=	Kashi Shreya	P_7	=	Pusa Sneha
	P_4	=	PSG-40	P_8	=	Phule Prajakta

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Assessment of sensory attributes of value-added products of karonda (*Carissa carandas*)

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Abstract

The study evaluated the sensory attributes of value-added products derived from Karonda (*Carissa carandas* L.) fruits focusing on the effect of fruit type and value added-product on overall organoleptic acceptance during (2022 and 2023) at S.K.N. Agriculture University, Jobner, Rajasthan. The Factorial Completely Randomized Design was used to analyse the data. Physiologically mature fruits were harvested, processed and evaluated by a panel of 15 members, using a 9-point hedonic scale for sensory attributes. The results indicated that maroon Karonda fruits consistently showed higher organoleptic acceptance scores compared to green fruits. Among value-added products, candy showed highest overall acceptance, while chutney the lowest. Significant variations in overall acceptance were observed, while candy made from maroon fruits showed the highest acceptance scores (8.40 and 8.47). The preserve prepared from green fruits showed lowest (7.28 and 7.43) acceptance during both the years. The study highlights the effect of fruit type and value-added products on sensory qualities, providing insights for optimizing karonda fruit-based products to enhance consumer preference.

Key words: Value-added products, Sensory qualities, Fruit type, Organoleptic acceptance

Karonda (*Carissa carandas* L.) belongs to the family Apocynaceae (Bhowmick *et al.*, 2023). It is an evergreen shrub, dichotomously branched with short stem and strong thorns (Tripathi *et al.*, 2023). It is a hardy, drought tolerant plant of dryland, growing in various parts of India, viz. Bihar, West Bengal, Rajasthan, Uttar Pradesh and South India (Banik *et al.* 2012; Singh *et al.*, 2024). Because of its soft flesh and high moisture content, the storage life of its fruits is very short (a week at 13 °C and 95% relative humidity) (Mitra *et al.* 2010). The ascorbic acid content (10.26 -17.94 mg/100 g) reducing sugars (0.93- 2.4%), non-reducing sugars (0.57 -1.33%) and total soluble solids (3 - 4.5%) enrich its fruits (Meti and Sunita, 2023).

Mature or ripe fruits are used in processing industry for preparation of value-added products (Srivastava *et al.* 2017). Owing to substantial pectin content in ripe fruits, it is also utilized in creation of jelly, jam, squash, sauces, pies, syrup, tarts and chutney, all of which are highly sought after global market (Wani *et al.*, 2013). The color, aroma, flavor, taste and texture, assist as critical indicators of quality and are integral to overall consumer experience (Kyriacou and Rouphael, 2018; Sharma *et al.*, 2023). Karonda is known for rich cultural heritage and nutritional benefits, embodies a range of organoleptic qualities that contribute to its distinctiveness in the culinary benefits (Maheshwari and Nirgude, 2021). This study explores and analyse the significance of organoleptic properties in determining consumer perceptions and acceptance of various value-added products of Karonda.

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MATERIALS AND METHODS

The study consisted of two factors, *i.e.* factor A is type of fruits (green (G) and maroon (M)) and factor B, *i.e.* six value-added products. Factor B specifies the different value-added products, viz., jam (V_1), jelly (V_2), chutney (V_3), pickle (V_4), preserve (V_5) and candy (V_6). However, the data were analysed using a Factorial Completely Randomized Design because it is a robust experimental approach for the examination of multiple factors and their interactions under controlled condition. The fruits were procured from orchards of farmers near to region of Jobner, Jaipur, Rajasthan. Physiologically mature fruits of each type were harvested during August-September. They were immediately washed with water, dried and used for preparation of value-added products as per the standardized procedures.

Organoleptic acceptance scoring was done by a panel of 15 members using a scorecard for sensory acceptability of 9 points hedonic scale with corresponding descriptive terms ranging from 9 'like extremely' to 1 'dislike extremely', for appearance, colour, taste, texture, flavour and overall acceptability (Marek *et al.*, 2007). Score card was prepared keeping in view of the quality characteristics of value-added products.

All the products were replicated three times. Mean and standard deviation for the different parameters were computed. Analysis of Variance (ANOVA) at 5%

significance level was calculated by using Statistical Analysis Tool Pack (Montgomery, 2017) and SPSS 16 (statistical package for social sciences) (IBM Corporation, 2019).

RESULTS AND DISCUSSION

The value-added products were analysed for overall organoleptic acceptance 0, 30, 60 and 90 DAS during both years (Tables 1 and 2). There was significant difference in overall organoleptic acceptance among value-added products during the storage period. The higher overall organoleptic acceptance was observed for products prepared from maroon (8.26 and 8.30) fruits as compared to green ones (8.10 and 8.17). Value-added products prepared from maroon fruits exhibited slightly higher overall organoleptic acceptance compared to green ones fruits during the storage (Fig. 1). However, significant difference was in overall organoleptic acceptance at 0, 30, 60 and 90 DAS for each value-added product. During 2022-23, mean overall organoleptic acceptance was in jam (8.35), jelly (8.21), chutney (7.93), pickle (8.17), preserve (8.00) and candy (8.45). Similarly during 2023-24, mean overall organoleptic acceptance for jam (8.36), jelly (8.28), chutney (8.01), pickle (8.21), preserve (8.05) and candy (8.50) were recorded. The candy exhibited highest overall organoleptic acceptance during all storage periods while the chutney had the least value. Whereas, the interaction between fruit type and value-added products showed the significant effect on overall organoleptic acceptance (Table 2). The candy prepared from maroon fruits showed highest organoleptic acceptance (8.40 - 8.47), whereas, preserve prepared from green fruits had lowest overall organoleptic acceptance of 7.28 and 7.43 among all products 90 DAS during 2022 and 2023, respectively.

Throughout the storage period, products derived from maroon fruits consistently exhibited slightly higher overall organoleptic acceptance scores compared to green fruits. The highest overall acceptability of products might be due to best acceptable colour, flavour, texture and taste. These findings are crucial for optimizing product formulations and enhancing consumer acceptance of fruit-based products in the market. Similar results have been reported by Hegde *et al.* (2020), Rafique *et al.* (2023) and Garg *et al.* (2024). This difference suggested that maroon fruits may possess superior sensory attributes that enhance the overall organoleptic acceptance.

These findings showed the influence of fruit type on sensory attributes of value-added products. Maroon fruits generally contributed to higher overall organoleptic acceptance scores, particularly evident in candy, jam and jelly, while product of green fruits had slightly lower scores as observed in preserve. The overall organoleptic acceptance quality of value-added products derived from green and maroon types of fruits.

The decreasing trend of overall acceptability of product might be due to decrease in colour and flavour of product during storage. The results underscored significant differences in sensory attributes between both fruit types. Similar results have been reported by Hegde *et al.* (2020) and Dinde *et al.* (2020).

CONCLUSION

The results consistently showed that products derived from maroon fruits generally exhibited higher overall organoleptic acceptance compared to those from green fruits. Candy consistently emerged as the most favoured product across all storage periods. Whereas, interaction between fruit type and value-added product

Table 1. Organoleptic acceptance of value - added products of karonda fruits

Treatment	Overall organoleptic acceptance									
	2022-23					2023-24				
	0 DAS	30 DAS	60 DAS	90 DAS	Mean	0 DAS	30 DAS	60 DAS	90 DAS	Mean
Factor A: fruit type										
F_1 Green	8.27	8.19	8.07	7.89	8.10	8.31	8.26	8.15	7.97	8.17
F_2 Maroon	8.39	8.34	8.25	8.07	8.26	8.43	8.37	8.27	8.13	8.30
SEm±	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01	-
CD (5%)	0.02	0.02	0.02	0.03		0.03	0.02	0.02	0.02	-
Factor B: value- added products										
V_1 Jam	8.48	8.40	8.33	8.19	8.35	8.48	8.42	8.34	8.22	8.36
V_2 Jelly	8.39	8.28	8.16	8.01	8.21	8.45	8.35	8.23	8.08	8.28
V_3 Chutney	8.12	8.08	7.90	7.62	7.93	8.15	8.16	8.00	7.75	8.01
V_4 Pickle	8.30	8.22	8.14	8.01	8.17	8.34	8.27	8.18	8.05	8.21
V_5 Preserve	8.15	8.12	7.99	7.75	8.00	8.18	8.16	8.03	7.83	8.05
V_6 Candy	8.56	8.49	8.43	8.30	8.45	8.61	8.55	8.47	8.37	8.50
SEm±	0.01	0.01	0.01	0.02		0.02	0.01	0.01	0.01	-
CD (5%)	0.04	0.03	0.04	0.04		0.04	0.04	0.04	0.04	-

Table 2. Interactive effect of type of fruit and value-added products on overall organoleptic acceptance

	Overall organoleptic acceptance							
	0 DAS		30 DAS		60 DAS		90 DAS	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
				2022-23				
V_1	8.35	8.61	8.25	8.55	8.17	8.49	8.02	8.35
V_2	8.23	8.56	8.08	8.49	7.92	8.39	7.75	8.27
V_3	8.31	7.93	8.19	7.97	8.04	7.76	7.87	7.38
V_4	8.51	8.10	8.43	8.01	8.34	7.94	8.21	7.80
V_5	7.76	8.53	7.79	8.46	7.61	8.37	7.28	8.23
V_6	8.48	8.65	8.42	8.57	8.32	8.54	8.19	8.40
SEm±	0.02		0.02		0.02		0.02	
CD (5%)	0.05		0.05		0.06		0.06	
				2023-24				
V_1	8.35	8.62	8.31	8.53	8.22	8.46	8.07	8.36
V_2	8.27	8.64	8.14	8.55	8.01	8.46	7.82	8.34
V_3	8.32	7.98	8.29	8.02	8.15	7.85	7.96	7.53
V_4	8.55	8.13	8.48	8.06	8.40	7.96	8.28	7.82
V_5	7.85	8.52	7.88	8.44	7.71	8.35	7.43	8.22
V_6	8.53	8.70	8.46	8.63	8.39	8.56	8.27	8.47
SEm±	0.02		0.02		0.02		0.02	
CD (5%)	0.06		0.05		0.05		0.05	

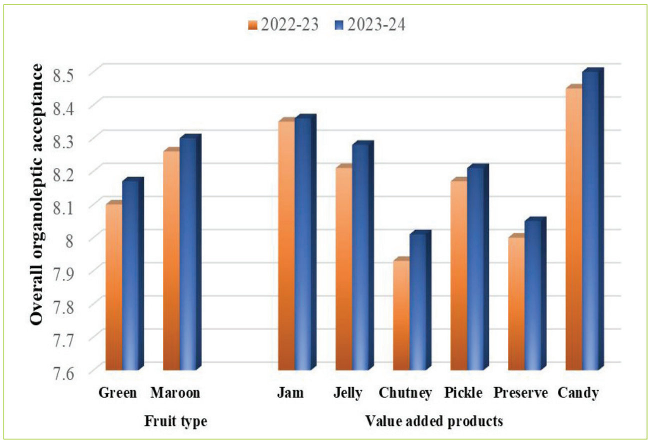

Fig. 1 Comparative analysis of overall organoleptic acceptance of value -added products

significantly influenced and revealed candy prepared from maroon fruits consistently showed the highest scores highlighting their superior sensory appeal.

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Short Communication

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Standardization of soilless media for brinjal (*Solanum melongena*) plug tray nursery

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Abstract

An experiment was conducted at Polytechnic in Horticulture, ACHF, NAU, Paria (Gujarat), during winter season, 2017-20 in net house condition. The experiment was laid out in a Complete Block Design in 16 treatments with three replications. Among difference soilless media ratio for brinjal(*Solanum melongena* L.) plug tray nursery, the treatment T_4 (vermicompost: cocopeat 1:1) was found best for the maximum seed germination (88.11%), seedling survival percentage in main field (91.24%), seed vigour index (1138.12) and highest B:C ratio (1.39). Treatment T_1 (vermicompost alone) was found best for early germination (5.73 days), while treatment T_5 (vermicompost: vermiculite, 1:1) showed maximum shoot length (14.04cm), root length (9.31cm), stem girth (1.89cm) and highest dry matter content (6.69g).The minimum damping off infection was found (0.03%) in treatment T_3 (Vermiculite alone), T_{10} (vermicompost: cocopeat 1:2) and T_{11} (vermicompost: vermiculite 1:2). The farmers and nurserymen raising brinjal seedling in plug tray nursery are advised to use media of vermicompost: cocopeat as 1:1 ratio for maximum germination percentage, good seedling vigour, highest BCR and maximum survival of seedling in plug tray as well as main field.

Key words: Soilless media, Plug tray, Shoot length. Root ratio

Brinjal (*Solanum melongena* L.) is one of the most important Solanaceous crop of India. Choice of plant growing media and fertilizer are important when propagating plants from seed or cuttings in containers. Various other materials may be mixed instead to create "soilless" media to be used in container propagation. Quality of seedlings is the key element in successful vegetable cultivation. Quality is particularly related to good root development and a balanced shoot to root ratio. Transplants stocky, with healthy foliage, producing new roots quickly and having good Carbohydrate reserves are appropriate for planting, and additionally they should not have any nutrient deficiency or pest and disease problems (Kubato *et al.*, 2013). Hence an experiment was conducted to find out the best soil less media for brinjal plug tray nursery.

The experiment was laid out in a Complete Block Design in 16 treatments and three replications. The treatment consisted of T_1= vermicompost, T_2= cocopeat , T_3=vermiculite (horticulture grade 2), T_4= vermicopost: cocopeat (1:1), T_5= vermicompost : vermiculite (1 :1), T_6 = cocopeat : vermiculite (1 :1) T_7 = vermicompost : cocopeat (2 :1) T_8 =vermicompost : vermiculite (2 :1), T_9 = cocopeat : vermiculite (2 :1) T_{10} = vermicompost : cocopeat (1 :2), T_{11} = vermicompost : vermiculite (1 :2), T_{12} = cocopeat : vermiculite (1 :2), T_{13} = vermicompost : cocopeat : vermiculite (1 :1 :1), T_{14} = vermicompost : cocopeat : vermiculite (2 :1 :1), T_{15} = vermicompost : cocopeat : vermiculite (1 :2 :1) and T_{16} = vermicompost : cocopeat : vermiculite(1 :1 :2).

The data for days to germination were significantly affected by different ratio of soilless media on brinjal plug tray nursery. The minimum days (5.73) for germination was recorded in treatment T_1, while maximum days (8.57) for germination was recorded in T_{15}. The maximum seed germination (88.11 %) in T_4 and minimum (73.42%) in T_9. The maximum shoot length (14.04 cm) was found in treatment T_5 and minimum (7.47cm) in treatment T_3. The analysis of variance revealed significant difference in root length among treatments. The treatment T_5 recorded highest root length (9.31cm). The minimum root length (5.55cm) was found in T_3.The treatment T_6 recorded maximum number of leaves/seedling (6.69), while minimum leaves/seedling (4.42) was recorded in T_{11} (Table 1). The maximum stem girth (1.89cm) was recorded in treatment T_5, while minimum (0.90cm) in T_3. The highest seed vigour index (1138.12) was found in treatment T_4 and minimum (545.10) was found in T_3. The maximum survival percentage (91.24 %) was recorded in T_4. The data pertaining to damping off showed significant difference among the treatments. Minimum damping off infection was found in treatment T_3, T_{10}, T_{11} (0.03 %). The treatment T_5 recorded highest (6.69g) dry matter content while minimum (3.89 g) in treatment T_3. Maximum (1.39) benefit cost ratio (B:C) recorded with treatment T_4 while minimum (0.80) in treatment T_3 (Table 2).

Similar result were found by Yadav and Bajpay 2019 , the use of protrays on growing of different seedlings

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is very helpful in ensuring increased development of roots, germination rate, proper spacing, seed viability, individual area for each seed, avoids contamination or any mixtures possibilities etc. It was found that coir pith growing media has 99% germination rate, vermicompost has 87%, and coir pith+ vermicompost has 92%. It is because coir pith has very good EC , pH etc. The oxygen circulation in coir pith is far better than the other media. With coir pith it was recorded as shoot length having 89.3mm, root length having 37.9mm, stem diameter having 1.77mm,and number of leaves having 4 at the age of 30 days. The next experiment is based on organic fertilizers and growing medias. According to Tuzel *et al.*2014, poor impact of vermicompost in the quality of seedlings of tomato, but when used in mixture with peat, and FYM shows better results. The next experiment is based on growth impacts of tomato with nutriseeds. According to Hota and Selvan 2017, it was noted that for growing tomato. Vermicompost has also potential to germinate in higher quantity i.e;98.6%.The media having vermicompost, coir pith, in which vermicompost has soya chunks shows higher germination as compared to vermiculite. The next experiment is based on impact of pine bark, goat manure, pine bark only composition vegetable seedlings growth. According to Mupondi, *et al.* 2010, it was observed that pine bark goat manure has very good effect on growth of the vegetable seedlings, that results in improved nutrients, weight contents etc, and can be used in selected vegetables. The next experiment is based on growth impacts due to mixing of Spent Coffee Grounds (SCG) with media. Chrysargyris *et al* 2019, it was found that SCG has very bad impact on the *Brassica olerecia* species, less plant height, number of leaves, fresh weight etc.

Table 1: Effect of different ratio of soilless media on growth parameters of brinjal seedlings (plug tray nursery)

Treatment	Days to germination	Germination (%)	Shoot length (cm)	Root length (cm)	Number of leaves/ Seedling
T_1	5.73	85.68	10.70	6.78	5.31
T_2	6.52	87.97	10.38	6.70	4.99
T_3	6.88	82.43	7.47	5.55	5.03
T_4	5.91	88.11	12.66	8.21	5.65
T_5	7.24	80.96	14.04	9.31	6.17
T_6	7.50	81.09	12.51	9.08	6.69
T_7	6.73	84.30	13.17	7.75	5.58
T_8	6.88	77.74	12.04	7.42	5.00
T_9	6.68	73.42	11.13	7.13	5.53
T_{10}	6.15	81.02	8.70	7.28	4.77
T_{11}	7.29	81.15	8.43	5.73	4.42
T_{12}	7.21	78.53	10.68	6.97	5.63
T_{13}	7.53	82.79	10.91	6.08	5.13
T_{14}	6.48	78.87	11.26	7.00	5.75
T_{15}	8.57	82.56	11.15	7.65	5.99
T_{16}	7.56	79.40	9.69	5.98	5.22
S.E.m ±	0.33	0.69	0.73	0.56	0.33
C.D.@ 5%	0.96	1.94	2.09	1.63	0.95
C.V.%	7.15	2.54	6.40	7.91	9.06
YxT					
SEm ±	0.29	1.19	0.40	0.33	0.28
CD@ 5%	0.80	3.38	1.13	0.91	0.79

CONCLUSION

The treatment T_4 (vermicompost: cocopeat 1:1) was found best for maximum seed germination (88.11%), seedling survival percentage in main field (91.24%), seed vigour index (1138.12) and highest B:C ratio (1.39). Treatment T_1 (Vermicompost alone) was found best for early germination (5.73 days), while treatment T_5 (Vermicompost: Vermiculite, 1:1) showed maximum shoot length (14.04cm), root length (9.31cm), stem girth (1.89cm) and highest dry-matter content (6.69g).

Table 2: Effect of different ratio of soilless media on growth parameters of brinjal seedlings (plug tray nursery)

Treatment	Stem girth (cm)	Seed Vigour Index-I	Survival of seedling in main field (%)	Damping off infection (%)	Dry matter content (g)	BCR
T_1	1.35	916.96	10.70	1.39(1.53)	5.19	1.33
T_2	1.20	913.40	10.38	0.55(1.24)	4.69	1.28
T_3	0.90	617.18	7.47	0.03(1.02)	3.89	0.80
T_4	1.71	1138.12	12.66	0.91(1.36)	6.12	**1.39**
T_5	1.89	1137.13	14.04	0.19(1.08)	6.69	1.17
T_6	1.47	1013.84	12.51	0.07(1.03)	5.70	1.01
T_7	1.46	1111.81	13.17	1.85(1.69)	5.42	1.38
T_8	1.48	934.05	12.04	0.10(1.05)	5.05	1.16
T_9	1.30	812.42	11.13	0.04(1.02)	4.81	1.03
T_{10}	1.13	704.44	8.70	0.03(1.02)	4.03	1.08
T_{11}	1.13	685.49	8.43	0.03(1.02)	4.06	0.89
T_{12}	1.18	837.16	10.68	0.05(1.03)	5.14	0.98
T_{13}	1.17	902.59	10.91	0.68(1.29)	4.84	1.28
T_{14}	1.25	888.72	11.26	0.52(1.23)	5.13	1.16
T_{15}	1.30	920.98	11.15	1.04(1.43)	5.34	1.21
T_{16}	1.23	769.06	9.69	0.62(1.70)	5.07	1.06
SEm ±	0.10	61.26	0.73	0.18	0.30	
CD@ 5%	0.31	176.94	2.09	0.52	0.87	
CV%	8.77	6.11	6.40	62.32	4.82	
YxT						
SEm ±	0.07	31.89	1.22	0.19	0.14	
CD@ 5%	0.19	89.53	3.43	0.53	0.39	

T_1: vermicompost
T_2: cocopeat
T_3: vermiculite
T_4: vermicompost + cocopeat (1 :1)
T_5: vermicompost + vermiculite(1:1)
T_6: cocopeat + vermiculite (1:1)
T_7: vermicompost+ cocopeat (2:1)
T_8: vermicompost+vermiculite (2:1)
T_9: cocopeat +vermiculite (2 :1),
T_{10}: vermicompost + cocopeat (1:2)
T_{11}: vermicompost+vermiculite (1:2)
T_{12}: cocopeat +vermiculite (1 :2)
T_{13}: vermicompost + cocopeat +vermiculite (1:1:1)
T_{14}: vermicompost + cocopeat + vermiculite (2:1:1)
T_{15}: vermicompost + cocopeat + vermiculite (1:2:1)
T_{16}: vermicompost + cocopeat + vermiculite (1:1:2)

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Effect of organic and inorganic substances on plant growth and survival in khirni (*Manilkara hexandra*)

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Abstract

The study was carried out to find out the effect of organic and inorganics on growth and survival of khirni (*Manilkara hexandra* L.) at Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, during 2023-2024. Among treatment combinations, seeds soaked in cow dung slurry for 24 hr showed better stem diameter (3.18 mm), seedling vigour index I (3122.55) and seedling vigour index II (107.92), survival (93.42 %) and lesser incidence of damping off (6.58 %), whereas seedling height (18.04 cm), number of leaves (9.97), leaf area (21.36 cm^2), plant fresh weight (3.09 g) and plant dry weight (1.44 g) were observed best in treatment seeds soaked in GA_3 300 ppm for 12 hr.

Key words: Cow dung, Cow urine, Gibberellic acid, Thiourea, Potassium nitrate.

Khirni (*Manilkara hexandra* L.) belonging to the family Sapotaceae, is a native of tropical South-East Asia. The major khirni growing states in our country are Madhya Pradesh. Gujarat, Rajasthan, Karnataka, Maharashtra and Tamil Nadu. It is mainly propagated by seeds. It is drought hardy and slow growing species commonly grown in laterite soil. It is used as rootstock for sapota propagation.

The non-availability of sufficient rootstock of khirni in southern region of Maharashtra is a limiting factor and it is due to less germination percentage, slow growth of seedlings to attain the graftable size. An attempts has been made to improve the germination of its seeds and subsequent growth. The use of bioregulators in enhancing seed germination and seedling growth of numerous plant species is well known (Malshe *et al.* 2014). Beside, synthetic chemicals and other naturally available bio-products of organics (cow dung and cow urine) are known to contain vital plant growth substance, which enhance the growth and development of plants. Keeping in view, an experiment was conducted to see effect of different chemicals, plant growth regulators, cow-dung slurry and cow urine on germination, growth and development of khirni seeds (Shinde and Malshe, 2015).

The seeds were sown in 20 cm x 15 cm size polythene bags. They were filled with potting mixture, *ie*. soil, FYM and sand (2:1:1 ratio) and uniform sized healthy pre-treated khirni seeds by organics and inorganic substances were sown in bags which were then properly labelled with tags for observation. The Randomized Block Design with 13 treatments and 3 replications was used. The treatments were T_1: seed soaking in cow urine (20 %) for 12 hrs, T_2: seed soaking in cow urine (20 %) for 24 hrs, T_3: seed soaking in cow dung slurry for 12 hrs (1:2 cow dung + water), T_4: seed soaking in cow dung slurry for 24 hrs (1:2 cow dung + water), T_5: seed soaking in cow urine (20 %) for 12 hrs + cow dung slurry for 12 hrs, T_6: seed soaking in GA_3 @ 100 ppm for 12 hrs, T_7: seed soaking in GA_3 @ 200 ppm for 12 hrs, T_8: seed soaking in GA_3 @ 300 ppm for 12 hrs, T_9: seed soaking in KNO_3 (1 %) for 12 hrs, T_{10}: seed soaking in KNO_3 (2 %) for 12 hrs, T_{11}: seed soaking in Thiourea (1 %) 12 hrs, T_{12}: seed soaking in Thiourea (2 %) for 12 hrs, T_{13}: Control (without soaking).

Observations on growth and survival percentage were taken. The statistical analysis was done by following the ANOVA technique (Panse and Sukhatme, 1967). The data pertaining on seedling height of khirni at 60 and 180 days after sowing influenced by different organics and chemicals. There was significant effect of chemicals and organics on seedling height (Table 1). At 60 days after sowing maximum seedling height (6.01 cm) was recorded in treatment T_4 (Seed soaking in cow dung slurry for 24 hrs) which was statistically at par with treatment T_8 (5.56 cm) and T_5 (5.49 cm), while minimum seedling height (4.24 cm) was recorded in treatment T_{13} (control). At 180 DAS, maximum seedling height (18.04 cm) was recorded in T_8 (seed soaking in GA_3 @ 300 ppm for 12 hrs) which was statistically at par with T_7 (17.57 cm),T_4 (17.50 cm) and T_5 (17.13 cm), while minimum seedling height (11.26 cm) was recorded in treatment T_{13} (control).

The increase in seedling height was due to effect of GA_3 which stimulates vegetative growth by cell multiplication and cell elongation. It is also reported by Lockhart (1960) that GA_3 induces plasticity in cell wall

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Table . 1: Effect of organic and inorganic substances on plant growth and survival in khirni.

Treatment	Seedling height (cm)		Stem diameter (mm)		Number of leaves		Leaf area (cm2)		Plant fresh weight (g)	Plant dry weight (g)	Seedling Vigour index I	Seedling Vigour index II	Survival (%)	Incidence of damping off (%)
	60 DAS	180 DAS	60 DAS	180 DAS	60 DAS	180 DAS	60 DAS	180 DAS						
T_1	5.12	16.4	1.25	2.74	2.33	7.42	2.85	18.23	2.11	0.91	2454.08	58.61	81.14	18.86
T_2	5.20	16.49	1.26	2.78	2.25	7.42	2.92	18.36	2.27	0.98	2597.74	67.24	81.69	18.31
T_3	5.36	16.82	1.28	2.8	2.51	8.60	3.05	19.75	2.9	1.29	2688.32	90.21	88.04	11.96
T_4	**6.01**	**17.50**	**1.43**	**3.18**	**2.92**	9.22	**3.39**	20.43	3.01	1.41	3122.55	107.92	93.42	6.58
T_5	5.49	**17.13**	1.31	2.85	2.60	8.26	3.13	19.27	2.49	1.10	3046.26	79.00	88.27	11.73
T_6	4.95	16.14	1.23	2.81	2.11	8.15	2.70	18.83	2.38	1.06	2361.06	65.57	82.17	17.83
T_7	5.06	**17.57**	1.24	2.88	2.22	8.49	2.80	19.42	2.74	1.16	2518.24	73.26	85.18	14.82
T_8	5.56	**18.04**	1.35	3.02	2.72	**9.97**	3.21	**21.36**	3.09	1.44	3073.94	106.28	90.72	9.28
T_9	4.90	15.45	1.21	2.68	2.01	7.09	2.66	17.5	1.89	0.83	1987.52	45.83	75.71	24.29
T_{10}	4.93	15.73	1.22	2.71	2.06	7.20	2.68	17.75	2.05	0.88	2195.3	52.76	80.50	19.5
T_{11}	4.78	14.89	1.19	2.67	1.55	6.42	2.48	16.92	1.68	0.70	1815.41	35.87	73.89	26.11
T_{12}	4.81	15.14	1.21	2.68	2.00	6.87	2.59	17.14	1.79	0.79	1901.65	42.14	77.89	22.11
T_{13}	4.24	11.26	1.02	2.31	1.33	6.31	2.28	16.00	1.52	0.58	1434.56	27.88	71.67	28.33
Mean	5.11	16.04	1.24	2.77	2.20	7.80	2.83	18.45	2.3	1.01	2399.74	65.58	82.33	17.67
SEm(±)	0.22	0.37	0.05	0.12	0.14	0.50	0.18	0.66	0.13	0.05	132.09	4.43	3.55	1.33
CD (5 %)	0.63	1.08	015	0.36	0.41	1.46	0.53	1.93	0.38	0.15	385.57	12.92	10.36	3.88

similar to that of auxins. Thus, it creates water diffusion pressure deficit which results in water-uptake, causing cell elongation and increasing seedling height. These results align with those of Vachhani *et al.* (2014) and Dilip *et al.* (2017).

At 60 DAS, T_4 (seed soaking in cow dung slurry for 24 hrs) recorded maximum number of leaves/plant (2.92) which was statistically at par with T_8 (2.72), T_5 (2.60) and T_3 (2.51). The lowest number of leaves/plant (1.33) was recorded in treatment T_{13} (control). The treatment T_8 (seed soaking in GA_3 @ 300 ppm for 12 hrs) showed highest number of leaves/plant (9.97) at 180 DAS, which was statistically at par with treatment T_4 (9.92) and T_4 (8.60). The least number of leaves/plant (6.31) was in treatment T_{13} (control). The maximum number of leaves was in GA_3 treatment due to its presence at apical meristem which results in more synthesis of nucleoprotein responsible for increasing leaf initiation (Sen and Gunthi, 1976). Similar findings were recorded by Sable and Waskar (2009) and Vachhani *et al* (2014).

At 60 DAS maximum leaf area (3.39 cm^2) was recorded in T_4 (seed soaking in cow dung slurry for 24 hrs) which was statistically at par with T_8 (3.21 cm^2), T_5 (3.13 cm^2), T_3 (3.05 cm^2) and T_2 (2.92 $cm^2$2.92 cm^2). The minimum leaf area (2.28 cm^2) was recorded in treatment T_{13} (control). At 180 days after seed sowing maximum seedling height (21.36 cm^2) was recorded in T_8 (seed soaking in GA_3 @ 300 ppm for 12 hrs) which was statistically at par with T_4 (20.43 cm^2) and T_3 (19.75 cm^2) The minimum leaf area (16.00 cm^2) was recorded in treatment T_{13} (control). The increase in leaf area of khirni is due to seeds treated with GA_3. The activity of GA_3 at the apical meristem resulting in more synthesis and accumulation of nucleoprotein responsible for increasing leaf initiation and leaf area expansion (Sen and Gunthi, 1976). The similar findings were recorded with Vachhani *et al.* (2014).

The stem diameter (1.43 mm) at 60 days from seed sowing was maximum in T_4 (seed soaking in cow dung slurry for 24 hrs) which was statistically at par with T_8 (1.35 mm), T_5 (1.31 mm) and T_3 (1.28 mm), while minimum stem diameter (1.02 mm) was recorded in T_{13} (control). Similar trend was observed for stem diameter at 180 days after sowing seed. The increase in stem diameter is due to presence of nitrogen, phosphorus and potassium, essential for plant growth (Khan *et al.* 2010) in cowdung. It was found that increased in stem girth was related to increase in leaf area. It seemed possible that increase in leaf area increased photosynthetic activities and the photosynthatates might have been utilized in increasing girth of stem (Mishra and Varma 1980).

The maximum plant fresh weight (3.09 g) at 180 days after sowing was found in T_8 (seed soaking in GA_3 @ 300 ppm for 12 hrs) which was at par with T_4 (3.01 g), T_3 (2.90 g), while minimum plant fresh weight (1.52 g) was recorded under T_{13} (control).

The increase in fresh weight was observed in seedling treated with GA_3 which resulted in mobilization of water and nutrients transport at higher rate. This might be due to primary cause of stem elongation that enhances more vigour and growth. These results are in confirmation with those of Bajaniya *et al*. (2018), Sable and Waskar (2009). The maximum plant dry weight was noticed in treatment T_8 (1.44 g) which was at par with T_4 (1.41 g), T_3 (1.29 g), whereas the minimum plant dry weight (0.58 g) was recorded under treatment T_{13} (control). The maximum seedling vigour index- I (3122.55) at 180 DAS was found in T_4 (seed soaking in cow dung slurry for 24 hrs), which was at par with T_8 (3073.94) and T_5 (3046.26). The minimum seedling vigour index- I (1434.56) was recorded in T_{13} (control).

At 180 days of sowing maximum seedling vigour index- II (107.92) was found in T_4 (seed soaking in cow dung slurry for 24 hrs), which was at par with treatments T_8 (106.28). The minimum seedling vigour index- II (27.88) was recorded in treatment T_{13} (control). Seeds treated with cowdung showed the maximum improvement in vigour index of the khirni rootstock. This increase is likely due to the essential nutrients in cow dung such as nitrogen, phosphorus and potassium, essential for plant growth (Khan *et al*. 2010). These nutrients probably enhanced seedling vigour, resulting in better growth characteristics, including more plant height, stem diameter, number of leaves, and leaf area. The similar results were recorded by Desai (1988). The highest survival percentage (93.42 %) was found in T_4 (seed soaking in cow dung slurry for 24 hrs), which was at par with T_8 (90.72 %) , T_5 (88.27 %) and T_3 (88.04 %). The least survival percentage (71.67 %) was recorded in T_{13} (control).

The treatment T_4 (seed soaking in cow dung slurry for 24 hrs) showed lowest incidence of damping off (6.58 %), which was at par with T_8 (9.28 %) seed soaking in GA_3 @ 300 ppm for 12 hrs. The highest incidence of damping off (28.33 %) was recorded in T_{13} (control).

The increase in survival percentage and decrease of damping percentade is due to seed treated with cowdung which contain nutrients, such as nitrogen, phosphorus and potassium, essential for plant growth (Khan *et al.* 2010) in addition to these nutrients, cow dung contains plant growth-promoting bacteria (PGPB) which can further enhance plant growth (Mukhuba *et al*. 2018). This PGPB live in rhizosphere (area around plant roots) and help promote plant growth by improving nutrient uptake, reducing plant stress and protecting against pathogens (Bashan and De-Bashan, 2005) which increase the vigour of seedlings, which intern increases survival percentage of seedling. The results are in close conformity with findings of Desai (1988) and Patel *et al*. (1996) in khirni.

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Assessment of genetic divergence in pumpkin (*Cucurbita moschata*)

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Abstract

Eighteen diverse genotypes of pumpkins (*Cucurbita moschata* Duch expoiq.) were evaluated for phenotypical variations and assessment of genetic diversity during the kharif season 2022 at Vegetable Research Farm, Banda University of Agriculture and Technology, Banda, Uttar-Pradesh. Randomized Complete Block Design with three replications was used for divergence, 18 genotypes were grouped into 4 clusters using Tocher's method. Out of the 6 clusters, cluster I was the largest, comprising 8 genotypes, followed by cluster III, comprising 5 genotypes, cluster IV, 4 genotypes, and cluster II with 1 genotype only. Based on distances between clusters, i.e. inter-cluster distances, maximum divergence was observed between cluster III and cluster IV. Maximum inter-cluster D^2 values between clusters indicated that genotypes included in these clusters can be used as a parent in hybridization programme to get higher heterotic hybrids from the segregating population. The maximum intra-cluster D^2 values were observed for cluster I. Maximum intra-cluster distance indicates that genotypes are very diverse. Presence of sufficient phenotypic and genotypic diversity showed the scope in pumpkin for further improvement.

Key words: Cluster, Diversity, Inter, Intra, Phenotypic variation, Divergence

Vegetables are essential for human nutrition, offering key nutrients such as vitamins, minerals, fiber, and antioxidants that promote health (Pandey *et al.* 2024). Pumpkin (Cucurbita moschata Duch. ex. Poir.) is also highly nutritious and a cucurbitaceous vegetable of significant economic importance. It belongs to the Cucurbitaceae family and has a somatic chromosome number of 2n=4x=40. The genus *Cucurbita* consists of 27 species, with five cultivated species under the *Cucurbita* genus. China and India lead in global pumpkin production, followed by countries U S, Egypt, Mexico, Ukraine, Cuba, Italy, Iran, and Turkey (Ferriol and Pico, 2008). India has a rich germplasm source for various vegetable crops (Tripathi and Yogeesha, 2018) despite the vast diversity of local pumpkin cultivars in India, which exhibit variations in fruit size, shape, and colour, limited attention has been given to genetic improvement. Pumpkin has received less focus in crop improvement in comparison to other cucurbitaceous vegetables.

The concept of D^2 statistics, initially developed by P.C. Mahalanobis in 1928, is widely used in plant breeding and genetics to study genetic divergence. Precise information about genetic divergence is critical because phenotypic selection depends upon the range of genetic diversity (Singh *et al.* 2023), as genetically diverse plants have been shown to produce high heterotic effects and yield desirable segregates. It helps assess the relative distance between strains for the characters under study and provides essential information for launching viable improvement programs. Successful breeding programs require a reasonable range of genetic diversity among parents, and understanding the nature of gene effects for yield and associated characters facilitates the selection of effective and efficient breeding methods.

The study was carried out at College of Horticulture, Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India, during *kharif* 2022-23. The observations were recorded for node number at first male flower appear, node number at first female flower appear, internodal length (cm) , days for first male flower anthesis , days for first female flower anthesis, days for first fruit harvesting, number of primary branches/plant, vine length (cm), leaf area (cm^2), male/female bud ratio, average fruit weight (kg), number of fruits/plant, peripheral thickness of fruit (cm), fruit polar diameter, fruit pericarp thickness (cm), pericarp/seed ball ratio, fruit yield (q/ha) and TSS. The observations recorded were statistically analyzed for different characters.

By using the pivotal condensation approach to convert correlated variables to uncorrelated ones, the evaluation of D^2 is made simpler (Singh and Chaudhary 1977). The actual values of D^2 were obtained by taking sum of square of differences of values of transformed uncorrelated variable for two genetic stocks thus the total D^2 values for all possible pairs from 18 genotypes were obtained. The genetic divergence among genotypes was estimated by using D^2 statistics (Mahalanobis, 1936). All the genotypes used were clustered into different groups by following Tocher's method (Rao, 1952).

Out of four clusters formed, cluster I was the largest group comprising 8 genotypes, followed by cluster III with 5 genotypes, cluster IV with 4 genotypes and clusters

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II was monotypic or solitary. Although, genotypes of the same origin or geographic region were also found to be grouped together in the same cluster, the instances of grouping of genotypes of different origin or geographic region in the same cluster were frequently observed. This suggested that there is no parallelism between genetic and geographic diversity. Therefore, selection of parental materials for hybridization programme, simply based on geographic diversity may not be successful experience. The choice of suitable distinct parent selected on the basis of genetic divergence analysis would be more rewarding than the choice made on the basis of geographic diversity. This finding is in agreement with those of Hossain *et al.*, (2010); Naik and Prasad (2015); and Sundaram and Vadivel, (2007). The D^2 values revealed that genotypes of the same cluster had little divergence from each other with respect to aggregate effect of 18 characters under study (Table 1). Therefore choice of obtaining good recombinants in segregating generations by crossing member of the same cluster is very low. It is therefore, suggested that crosses should be between the genotypes belonging to cluster separated by large inter-cluster distances.

The average intra cluster distance ranged from 1.52 (cluster II) to 3.706 (cluster I), suggesting that genotypes in cluster I were relatively more diverse than the genotypes in other clusters. Maximum intra cluster distance was recorded in cluster I (3.706), followed by cluster III (3.352), cluster IV (3.322) and cluster II (1.520). The maximum inter cluster distance was between cluster IV and cluster II (5.885), followed by that between cluster II and cluster I (5.379), cluster II and III (4.737), cluster III and IV (3.818) and cluster IV and I (3.676), suggesting a large difference between these groups. On the other hand, minimum distance was recorded between cluster III and cluster I (3.60).

The average intra cluster distance ranged from cluster II to cluster I, suggesting that genotypes in cluster I were relatively more diverse than the genotypes in other clusters. Maximum intra cluster distance was recorded in cluster I, followed by cluster III, cluster IV and cluster II. The maximum inter cluster distance was between cluster IV and cluster II, followed by cluster II and cluster I, cluster II and III, cluster III and IV and cluster IV and I, suggesting a large difference between these groups. Thus crossing between genotypes belonging to cluster pairs separated by very high inter-cluster distance as discussed above may be through desirable deviant segregates. On the other hand, minimum distance observed between cluster III and cluster I, indicated that genotypes present in these cluster pair were genetically closed to each other. The crosses between genotypes belonging to clusters separated by low inter-cluster distances are unlikely to produce promising recombinant in segregating generations. Similar reports were also made by (Masud *et al.*, 1995; and Rahman 2006).

Cluster I showed maximum mean value for fruit harvest (78.18), days for first female flower anthesis (53.76), fruit polar diameter (12.36) and internodal length (11.06). Cluster II showed maximum mean value for leaf area (337.52), days for first male flower anthesis (50.67), pericarp/seed ball ratio (11.78), node number, at first male flower appear (9.80), TSS (4.86), number of primary branches/plant (4.07), pericarp thickness (3.16), and fruit weight (2.50). Cluster III showed maximum mean value for node number, at first female flower appear (22.68) and number of fruits/plant (6.16). Cluster IV showed maximum mean value for fruit yield (235.79), vine length (227.68), peripheral thickness of fruit (53.29) and male/female bud ratio (11.87). Cluster I showed maximum mean value for days for first fruit harvesting, days for first female flower anthesis, fruit polar diameter and internodal length. Cluster II showed maximum mean value for leaf area, days for first male flower anthesis, pericarp/seed ball ratio, node number at first male flower appear ,TSS, number of primary branches per plant, fruit pericarp thickness, and fruit weight. Cluster III showed maximum mean value for node number at first female flower appear and number of fruits/plant. Cluster IV showed maximum mean value for fruit yield, vine length, peripheral thickness of fruit and male:female bud ratio. Similar finding was also observed by (Muralidhara *et al.*, 2014 and Shivanandha *et al.*, 2013).

Table 1: Cluster mean values for eighteen characters of 18 pumpkin genotypes: -

Cluster	I	II	III	IV
Primary branches	3.73	4.07	3.70	3.81
Male/female bud ratio	6.80	5.96	5.90	11.87
Internodal length	11.06	10.80	10.07	10.60
Node no, at first female flower appear	20.49	21.73	22.68	20.95
Node no, at first male flower appear	9.07	9.80	8.80	7.73
Fruit weight (kg)	1.69	2.50	1.68	1.62
Pericarp/seed ball ratio	8.24	11.78	9.86	5.76
Vine length (cm)	169.48	226	220.67	227.78
Leaf area (cm²)	298.77	337.52	262.3	335.29
Days for first male flower anthesis	48.08	50.67	41.11	40.52
Days for first female flower anthesis	53.76	48.27	51.68	48.27
No of fruits per plant	5.67	6.13	6.16	5.98
TSS (°brix)	4.31	4.86	4.84	4.16
Fruit polar diameter (cm)	12.36	11.26	10.35	11.87
Peripheral thickness (cm)	45.20	52.67	52.43	53.29
Days for first fruit harvest	78.18	64.33	75.67	69.23
Pericarp thickness (cm)	2.28	3.16	2.54	2.29
Fruit yield (q/ha)	200.44	161.61	202.39	235.79

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Effect of foliar application on potato yield

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Abstract

A study was carried out to explore the response of foliar nutrients on economic yield and tuber quality of potato (*Solanum tuberosum* L., cv. Kufri Surya) at GBPUA&T, Pantnagar, Uttarakhand, during *rabi* season of 2017-18. The experiment had eleven treatments replicated four times. Among all treatments, based on overall performance treatment T_{11} (75% N of RDF as basal + 2% foliar spray of 20:20:20 water-a soluble fertilizer at 30 and 45 DAP) was found best concerning marketable yield (36.71 t/ha), dry-matter content of tubers (20.42%), protein content in tubers (8.05%), specific gravity of tubers (1.11 g cc^{-1}) and benefit:cost ratio (1.96). It is concluded that foliar application of nutrients had a notable impact on both yield and quality of potato tubers.

Key words: Potato, Foliar application , Nutrients, Marketable yield, Benefit:cost ratio.

Potato (*Solanum tuberosum* L.) has emerged as a valuable crop for enhancing food security, particularly in densely populated areas, as it offers higher yield, well-balanced protein, and more calories per unit of land and time compared to other major food crops (Ahmadu *et al*., 2021). The challenges of population pressure and malnutrition in India can be effectively addressed by recognizing the potato as a primary food source rather than merely a vegetable (Jatav *et al*., 2023; Youdol *et al*., 2024). Since, it is a nutrient exhaustive crop, use of balanced doses with best application strategy of fertilizers are necessary for receiving higher yield and better tuber quality (Sharma *et al*., 2017; Bhatt *et al*., 2020a). The foliar application provides several advantages and serves as a crucial alternative to soil fertilization (Sowmya *et al*.,2024). It eliminates concerns related to nutrient fixation and immobilization, thereby contributing to maximizing crop yields and enhancing crop quality (Tomar and Kalra 2018; Bhatt *et al*., 2020b). The foliar application also helps minimize nutrient losses, providing an effective means of nutrient delivery (Fageria *et al*., 2009). Therefore, study was carried out to determine the most effective nutrient application to get higher net returns in low land conditions.

The study was undertaken on potato Kufri Surya during *rabi* season of 2017-2018 at Vegetable Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Pantnagar, located in a humid subtropical zone at 29.5°N latitude, 79.3°E longitude, and 243.84 m above sea-level, experiences maximum temperatures of 32 - 44°C in summer and a minimum of 4.4°C in winter, with an annual rainfall of approximately 1300 mm, primarily during monsoon season from late-June to mid-September. The experimental soil, a sandy loam mollisol with neutral pH (7.4), contained 0.87% organic carbon, 183.69 kg/ha nitrogen, 31.17 kg/ha phosphorus, and 185.36 kg/ha potash. The Randomized Block Design with 4 replications and 11 treatments, comprised 44 plots of 16.8 m² gross size and 10.8 m² net size, with rows spaced 60 cm apart and plants 20 cm apart.

The treatments included various combinations of nitrogen (N) application methods and foliar sprays. For example, T_1 received 100% recommended dose of fertilizer (160:100:120 kg/ha N:P:K), while other treatments varied the basal N application and included foliar sprays of urea or water-soluble fertilizers (19:19:19 or 20:20:20). Soil preparation involved deep plowing, harrowing, and leveling, followed by basal application of N, P_2O_5, and K_2O. Sprouted, disease-free tubers of Kufri Surya were treated with boric acid and planted at 60cm × 20cm spacing. Phorate was applied to control tuber moths, while Dimethoate and Mancozeb were used to manage aphids and diseases.

Cultural practices such as weeding, hoeing, irrigation, and chemical spraying were manually regulated. After 15 days of de-haulming, tubers were harvested and sorted into four grades (A >75g, B 51-75g, C 26-50g, D <25g). Marketable yield was calculated by summing the weights of A, B, and C grade tubers, converted to Tonnes/ha. The oven drying method was used to determine the dry-matter content of tubers and calculated by using the formula (Saini, 1964):

$$\text{Dry-matter content (\%)} = \frac{\text{Oven dried weight of tuber (g)}}{\text{Fresh weight of tuber (g)}} \times 100$$

For the estimation of protein content, Micro-kjeldhal method was used (Ranganna, 1986). The protein content

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was determined after the estimation of nitrogen content in tubers (%) and used the following conversion formula:

$$\text{Protein (\%)} = 6.25 \times \text{nitrogen (\%)}$$

where,

$$\text{Nitrogen (\%)} = \frac{\text{Sample titre} - \text{Blank titre}}{\text{Weight of sample (g)} \times 1000} \times 100 \times N \times 14$$

And, 6.25 = conversion factor for protein

For specific gravity, following formula was used in which volume of tubers was estimated by water displacement method (Kleinkopf *et al.*, 1987):

$$\text{The specific gravity of tubers} = \frac{\text{Weight of tubers (g)}}{\text{Weight of same given volume of tubers (g)}}$$

For estimation of economics of potato production in different treatments, using market price of input and produce prevailing at that time. The benefit: cost ratio estimates the production efficiency of treatments. It indicates the profit value or value of rupees obtained in the production system per rupee invested and is computed by the following formula:

$$\text{Benefit: cost ratio} = \frac{\text{Gross income (₹/ha)}}{\text{Total expenditure (₹/ha)}}$$

The recorded data were subjected to analysis of variance (ANOVA) through the computer using the STPR3 programme, designed and developed by the G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand.

The grade-wise weight of tubers was significantly affected for grades A (>75g), B (50-75g), C (25-50g) and D (<25g) by various foliar application of nutrients (Table 1). Potato tubers graded as grade A (>75g) recorded highest weight (17.73 t/ha) in treatment T_3 which was statistically at par with treatment T_{10} (16.95 t/ha), T_{11} (16.39 t/ha), T_9 (16.35 t/ha) and T_2 (15.74 t/ha) whereas, the minimum weight was recorded in treatment T_1 (11.88 t/ha). In grade B (50-75g), highest weight was in treatment T_{11} (12.87 t/ha) which was statistically at par with treatment T_1 (11.62 t/ha), T_2 (11.41 t/ha) and T_9 (11.41 t/ha), whereas, lowest weight was recorded in treatment T_3 (8.56 t/ha). The highest weight (25-50g) was recorded in treatment T_2 (9.21 t/ha), which was at par with treatment T_{10} (9.17 t/ha), T_3 (8.69 t/ha), T_6 (8.56 t/ha) and T_4 (8.41 t/ha) whereas, the lowest was observed in treatment T_5 (6.71 t /ha). The maximum weight (<25g) of tubers was recorded in treatment T_9 (3.22 t/ha) which was at par with treatment T_8 (2.83 t/ha), whereas, the minimum weight was observed in treatment T_2 (1.79 t/ha).

The weight of tubers of grade A (>75g) and C (25-50g) was highest with treatment having basal + top-dress + one foliar spray, whereas, B (50-75g), and D (<25g) grade potato tubers was recorded maximum with treatment having basal + two foliar sprays. The maximum total tuber yield was recorded with treatment T_{11} (38.85 t/ha) supplied with 75% N of RDF as basal + 2% foliar spray of 20:20:20 water-soluble fertilizer at 30 and 45 DAP have yielded 18.01 % more yield/ha than the recommended practices, *i.e.,* RDF (Table 1 and Fig.1).

The foliar application of nutrients gave a better response in increasing the yield under all grades. It might be due to early root development and growth of plants because of better availability and efficient use of nutrients by plants at all growth stages which resulted in better growth of photosynthetic organs, translocation of nutrients and photosynthates to developing plant parts (Chowdhury

Table 1: Effect of different foliar treatments on grade-wise weight, total yield, marketable yield, dry-matter content, protein content and specific gravity in tubers

Treatment	Grade-wise weight of tubers (tonnes/ha)				Total yield of tubers (tonnes / ha)	Marketable yield (tonnes /ha)	Dry matter content in tubers (%)	Protein content in tubers (%)	Specific gravity of tubers
	A (>75g)	B (50-75g)	C (25-50g)	D (<25g)					
T_1	11.88	11.62	7.18	2.25	32.92	30.67	19.78	7.86	1.06
T_2	15.74	11.41	9.21	1.79	38.15	36.37	19.70	7.97	1.08
T_3	17.73	8.56	8.69	2.49	37.48	34.99	19.79	7.81	1.09
T_4	13.61	9.65	8.41	2.31	33.97	31.67	19.66	7.62	1.06
T_5	15.23	10.42	6.71	2.45	34.81	32.36	20.07	7.81	1.09
T_6	13.61	9.33	8.56	2.55	34.05	31.50	19.56	7.88	1.13
T_7	15.37	10.05	7.46	1.99	34.86	32.87	19.85	8.09	1.08
T_8	16.88	10.33	7.32	2.83	37.35	34.52	19.35	7.62	1.11
T_9	16.35	11.41	7.45	3.22	38.43	35.22	20.32	8.00	1.12
T_{10}	16.95	9.72	9.17	2.25	38.08	35.83	20.09	7.86	1.12
T_{11}	16.39	12.87	7.46	2.14	38.85	36.71	20.42	8.05	1.11
SEm (±)	0.73	0.75	0.49	0.21	1.10	1.10	0.17	0.13	0.02
CD (5%)	2.12	2.19	1.43	0.61	3.19	3.21	0.49	NS	NS

Table 2: Economics and net profit as influenced by different foliar treatments

Treatment	Fixed cost of cultivation (₹)	Additional cost (₹)	Total expenditure (₹)	Tuber yield (tonnes / ha)	Gross income (₹)	Net profit (₹/ ha)	BC ratio
T_1	122058	29865	151923	32.92	263333	111411	1.73
T_2	122058	34971	157029	38.15	305231	148202	1.94
T_3	122058	34431	156489	37.48	299852	143363	1.92
T_4	122058	30497	152555	33.97	271778	119223	1.78
T_5	122058	33075	155133	34.81	278509	123377	1.80
T_6	122058	30578	152636	34.05	272417	119780	1.78
T_7	122058	33156	155214	34.86	278843	123629	1.80
T_8	122058	33657	155715	37.34	298759	143044	1.92
T_9	122058	36478	158536	38.43	307463	148927	1.94
T_{10}	122058	34307	156365	38.08	304630	148265	1.95
T_{11}	122058	36641	158699	38.85	310806	152107	1.96

*Selling price of potato is (₹ 8000/tonne).

et al., 2002). The foliar application of fertilizer remains far better than soil-applied fertilizer regarding potato yield (Qadri *et al.,* 2015). These conclusions are also supported by Mona *et al.* (2012), Sun *et al.* (2012) and Bhatt *et al.* (2020b).

The maximum marketable yield (36.71 t/ha) was observed in treatment T_{11} which was statistically at par with treatments T_2 (36.37 t/ ha), T_{10} (35.83 t/ha), T_9 (35.22 t/ha), T_3 (34.99 t/ha) and T_8 (34.52 t/ha) whereas, the lowest yield (30.67 t/ha) was recorded in treatment T_1 (Table 1 and Fig.1). The marketable yield of tubers increased with different treatments of foliar application, whereas maximum marketable yield (19.69%) under treatment T_{11}. The increase in marketable yield might be due to availability of nutrients at regular interval, resulting in better growth and development of tubers. Our results are in agreement with those of Kumar *et al.* (2017) and Pandey *et al.* (2018).

The maximum dry-matter content (20.42 %) of tubers was observed in treatment T_{11} which was at par with treatments T_9 (20.32 %), T_{10} (20.09 %), T_5 (20.07 %) and T_7 (19.85%), whereas, minimum dry matter content (19.35%) was recorded in treatment T_8. The treatment T_{11} has 3.24 % more dry-matter content of potato tubers than recommended practices due to the application of such nutrients as foliar at regular intervals, which, directly absorbed by leaf and helped to promote photosynthesis consequently more dry-matter formation. Sun *et al.* (2012) concluded that higher tuber dry-matter accumulation was associated with a high transportation efficiency of assimilates from plant to tubers after tuberization. Pandey *et al.* (2018) reported that foliar application of urea at a higher level resulted in better dry weight of tubers rather than using the lower level. These results correspond to those of Kumar *et al.* (2017) and Pandey *et al.* (2018).

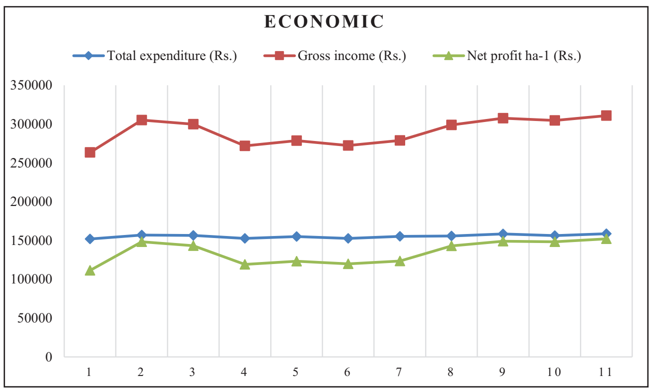

Fig. 1. Economics and net profit per hectare as influenced by different foliar application treatments

The treatment, T_7, recorded higher (8.09 %) protein contents in tubers, whereas, the lowest (7.62 %) was in tubers in T_4 and T_8. The effect of foliar applications was non-significantly increasing the protein content of tubers. It might be due to more accumulation of nutrients in tuber due to foliar sprays at later stages of growth. (Chandra *et al.,* 2014) also concluded that the effect on protein percent could be related to vital role of nitrogen in plants that is associated directly and indirectly with protein synthesis.

There was non-significant difference in specific gravity of the potato tubers due to the effect of different foliar applications treatments. However, it was observed that specific gravity of tubers applied with low amount of nutrients with foliar sprays in growth period was recorded higher. It might be due to better vegetative growth of plants and translocation of photosynthates which resulted in more reserve food accumulation in tubers. Our results confirm those of Tajner-Czopek *et al.* (2008) and Pandey *et a.,* (2018). The foliar application of nutrients was found more beneficial to potato crop as compared to RDF (basal + topdressing). It not only saved valuable nutrients but also produced maximum marketable tubers as well as maximum net.

The highest total expenditure (₹ 158699/ha) was recorded in treatment T_{11} due to high additional cost (₹ 36641), whereas the lowest total expenditure (₹ 151923/ha) was recorded with treatment T_1 due to less additional cost (₹ 29865). The maximum total output or gross income of (₹ 310806/ha) was associated with treatment T_{11} and the lowest gross return (₹ 263333/ha) was recorded with treatment T_1 (Table 2). The net profit was obtained higher (₹ 152107/ha) with treatment T_{11} while the minimum was obtained (₹ 111411/ha) with treatment T_1 (Table 2 and Fig.1). The highest benefit-cost ratio (1.96) was obtained from the treatment T_{11} (75% N of RDF as basal + 2% foliar spray of 20:20:20 water-soluble fertilizer at 30 and 45 DAP). The lowest benefit:cost ratio (1.73) was obtained under T_1 [100% Recommended Dose of Fertilizer (RDF) 160:100:120 kg/ha N: P: K (50% basal N + 50% top dressing at 30 DAP)] (Table 2).

CONCLUSION

Thus, it can be concluded that treatment T_{11} (75% N of RDF as basal + 2% foliar spray of 20:20:20 water-soluble fertilizer at 30 and 45 DAP) not only recorded 19.69% more marketable yield but also recorded more dry-matter, protein content and specific gravity in tubers as compared to that of recommended treatment. Hence, farmers can apply less nutrient to their fields through foliar method to get maximum return.

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