Review Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Current status of Fusarium wilt resistance research in watermelon (*Citrullus lanatus*): A review

Prachi Bista[1], Glennescia Tenner[1], Lokraj Joshi[2], Frank Mrema[1] and Bed Prakash Bhatta[1]

[1]College of Agriculture and Applied Sciences, Department of Agriculture, Alcorn State University, Lorman, Mississippi, USA
[2]Bhagawatimai Rural Municipality, Karnali Province, Nepal

ARTICLE INFO

Received: 04 April 2025
Accepted: 24 April 2025

Keywords: Fusarium wilt, watermelon, marker-assisted selection, inheritance studies

doi:10.48165/ijah.2025.7.1.1

ABSTRACT

Fusarium wilt is one of the widespread and important fungal diseases of cucurbit crops in the United States and worldwide. It is caused by the fungal pathogen *Fusarium oxysporum* f. sp. *niveum* (*Fon*) that causes significant yield loss in watermelon. There are many commercial cultivars of watermelon that are resistant to *Fon* races 0 and 1. However, no edible cultivars resistant to races 2 or 3 have been developed. There is a necessity to understand the genetic and molecular basis of Fusarium wilt resistance for crop improvement. Therefore, exploring genetic and molecular factors to determine the resistance to virulent *Fon* races 2 and 3 in diverse watermelon genotypes will be useful. The recent advances in marker-assisted selection, genomic selection, whole-genome sequencing, gene-editing tools, and genome-wide association studies provide broader insights for improvement of watermelon varieties. In this review paper, we discuss the biology of the Fusarium wilt pathogen (*Fon*) of watermelon, the history of the Fusarium wilt disease, inheritance studies on Fusarium wilt, quantitative trait loci mapping, bottlenecks in Fusarium wilt resistance breeding, marker-assisted selection and novel plant breeding tools to improve Fusarium wilt resistance in watermelon. This review paper aims to explore the current efforts, challenges, and suggest potential future research for the management of Fusarium wilt using traditional and molecular breeding tools.

Introduction

Watermelon (*Citrullus lanatus* [Thunb.] Matsum. and Nakai) is a widely cultivated cucurbit crop within the family Cucurbitaceae. Watermelon is a good source of biologically active compounds, such as lycopene, vitamins A and C, β-carotene, potassium, and total phenolic compounds. These compounds contain anti-inflammatory, anticancer, and antioxidant properties (Maoto *et al.*, 2019). In addition to these nutrients, it contains specific amino acids, notably arginine and citrulline. Citrulline is predominantly found in the peel, rind and flesh of fruit (Perkins-Veazie *et al.*, 2007). Along with nutritional importance, watermelon has substantial economic value. In 2024, it is estimated that the total production of watermelon was 3.69 billion pounds and it was grown on 110,900 acres of land in the United States (USDA, 2025). The leading watermelon-producing states in the United States (U.S.) are Florida, Texas, Georgia, and California, as the crop requires a warm growing season for optimal production (Wehner, 2008).

Fusarium wilt, caused by a soil-borne, ascomycete fungus *Fusarium oxysporum* f. sp. (forma specialis) *niveum* (*Fon*),

Corresponding author's Email: bbhatta@alcorn.edu (Dr. B.P. Bhatta)

is one of the most serious diseases of watermelon. It is one of the top five fungi of scientific importance (Dean *et al.*, 2012). Fusarium wilt has been designated as number one constraint in watermelon production in the U.S. (Kousik *et al.*, 2016). It is a major limiting factor in watermelon production worldwide, with yield loss ranging from 30% to 80% (Rahman *et al.*, 2021). Yield losses ranging up to 80-85% have also been reported (Zhang *et al.*, 2012; Hall & Holloway, 2000). Similarly, around 50% disease incidence has been observed in the commercial watermelon fields of southeastern US (Petkar & Ji, 2017). Individual vines or the entire watermelon plant is killed by the pathogen, thereby reducing the yield (Keinath *et al.*, 2010). There are several direct and indirect losses incurred due to Fusarium wilt disease. Direct losses include the loss of the marketable yield. Indirect losses arise due to costs associated with replanting, roguing, soil treatment, labor, keeping land fallow, etc. (Egel & Martyn, 2007).

Fon is both a seed-and soil-borne plant pathogen, and the infected plant shows symptoms like chlorosis, necrosis, leaf fall, browning of the vascular system, and eventually wilting of plants (Porter, 1928). The loss of turgor pressure in leaves and vines is seen as the early symptom of infected watermelon plants (Kurt *et al.*, 2008). As the condition deteriorates, the plant becomes dull green to yellow and necrotic (Pursley *et al.*, 2010). The continuous colonization of the xylem vessel by *Fon* forms enough tyloses that restricts the water movement, thus causing wilt in plants (Shaban & Abdelssalam, 2009). The optimum temperature for the growth and development of *Fon* is 24 to 32°C (Porter, 1928). *Fon* lacks a known sexual stage and is a root infecting vascular pathogen. It can survive extended periods in the absence of the host, mainly in the form of thick-walled chlamydospores (Pietro *et al.*, 2003). When susceptible watermelon cultivar interacts with *Fon* and develop wilt disease, it indicates a compatible interaction. However, resistant cultivars have an incompatible interaction with *Fon*, hence there is no disease development (Lü *et al.*, 2011).

Management practices such as resistant rootstock, grafting, soil fumigation, chemical treatment, use of cover crops, and biological control agents may help to reduce the incidence of Fusarium wilt in watermelon (Everts & Himmelstein, 2015). In addition, cover crops such as hairy vetch (*Vicia villosa*) are found to be effective in controlling Fusarium wilt in watermelon (Keinath *et al.*, 2010). Furthermore, fungicides like prothioconazole and pydiflumetofen are identified as potential strategies in controlling the Fusarium wilt (Miller *et al.*, 2020). Intercropping watermelon with aerobic rice reduces Fusarium wilt by preventing the *Fon* sporulation (Ren *et al.*, 2008). Late transplanting and selecting the *Fon* race 1 resistant 'Fascination' or the tolerant cultivar 'Melody' can help in controlling Fusarium wilt in watermelon and increase marketable yield in the Southern U.S. (Keinath *et al.*, 2019).

Taxonomy and biology of Fusarium wilt of watermelon

The binomial nomenclature for the genus *Fusarium* was first described in 1809 by Link (Morris & Nutting, 1923). The species was then termed *Fusarium niveum* by Smith in 1899 based upon his observations on wilt disease on watermelon, cotton, and cowpea (Sleeth, 1934). The species was later changed to *Fusarium oxysporum* (Hansford, 1926). In 1935, Wollenweber and Reinking reclassified the fungus isolated from watermelon and gave it the new name *Fusarium bulbigenum* var. *niveum* Woll (Cipolla, 1953). Synder and Hansen further refined this classification and further proposed that the specialized form of *F. oxysporum*, characterized by specific virulence to host plants, should be classified as distinct 'forma specialis' and considered watermelon wilt form 1 as *F. oxysporum* f. sp. *niveum* (*Fon*) (Snyder & Hansen, 1940). Till today, four distinct races (0, 1, 2, 3) of *Fon* have been identified in watermelon genotypes (Zhou *et al.*, 2010). Table 1 shows the responses of diverse watermelon genotypes (differentials) against different races of *Fon* (Egel & Martyn, 2007; Wechter *et al.*, 2016; Dutta & Coolong, 2017). Most of the resistance to Fusarium wilt race 2 was reported in wild relatives, *Citrullus amarus*, such as PI 296341-FR. Most of the sweet, edible watermelon cultivars (*Citrullus lanatus*) are resistant to races 0 and 1 of *Fon* (e.g., Calhoun Gray, Allsweet).

Table 1. Responses of differential watermelon genotypes to four races of Fusarium wilt fungus, *Fusarium oxysporum* f. sp. *niveum*

Genotypes	Taxonomy	Race 0	Race 1	Race 2	Race 3
Sugar Baby	*C. lanatus*	S	S	S	S
Black Diamond	*C. lanatus*	S	S	S	S
Charleston Gray	*C. lanatus*	R	S	S	S
Crimson Sweet	*C. lanatus*	R	S	S	S
Calhoun Gray	*C. lanatus*	R	R	S	S
Allsweet	*C. lanatus*	R	R	S	S
PI 296341-FR	*C. amarus*	R	R	R	S
USVL246-FR2	*C. amarus*	R	R	R	S
USVL252-FR2	*C. amarus*	R	R	R	S

R=Resistance; S=Susceptible

The *Fon* fungus can spread through soil, plant debris, and farm implements and seeds and can live in soil for almost a decade (Bruton *et al.*, 2007). As a germinating spore, the fungus initiates the infection process. Eventually, the hyphae enter the plant through wounds or any other natural opening. The hyphae then penetrate the vascular tissue, resulting in the production of microconidia. As microconidia enter the xylem, they infect by spreading into the watermelon's vascular system (Bishop & Cooper, 1983; Di Pietro *et al.*, 2003). These macroconidia form chlamydospores, also known as asexual structures or resting spores, as the fungus does not have a known sexual reproductive stage. Fusarium wilt disease is typically caused by the dissemination of chlamydospores (Egel & Martyn, 2007).

History of Fusarium wilt disease of watermelon

An unknown watermelon wilt disease was inflicting large losses in the Southern United States in the early 1890s, and at the same time, similar wilt symptoms were also seen in okra and cotton in Mississippi, Georgia and Alabama (Martyn, 2014). The Fusarium wilt disease was first reported in 1894 in watermelon fields of Georgia and South Carolina by Erwin. F. Smith, a USDA plant pathologist (Smith, 1894), and further researched upon (Smith, 1899). *Fon* race 2 was first reported in Texas in 1981 (Martyn, 1985), and later in Oklahoma (Bruton *et al.*, 1988), Florida (Martyn, 1989), Maryland and Delaware (Zhou & Everts, 2001), Indiana (Egel *et al.*, 2005), and Georgia (Bruton *et al.*, 2008). Fusarium wilt pathogen (*Fon*) now has four races (0, 1, 2, and 3) that have been identified based on their aggressiveness on different watermelon cultivars (Martyn, 1985, Zhou *et al.*, 2010). The use of watermelon differential lines to determine the race of different *Fon* strains has also been reported (Cirulli, 1972). Cucurbit wilt is caused by six distinct 'forma specialis', the most commercially significant of which are *F. oxysporum* f. sp. *niveum* in watermelon, *F. oxysporum* f. sp. *melonis* in muskmelon, and *F. oxysporum* f. sp. *cucumerinum* in cucumber (Okungbowa & Shittu, 2012). There are more than 100 host-specific strains of *Fusarium oxysporum* (Gordon, 2017).

Inheritance and mapping studies related to Fusarium wilt resistance

Orton developed the first *Fon*-resistant cultivar 'Conqueror' from a cross of *Fon*-resistant citron melon (*C. amarus*) with *Fon*-susceptible 'Eden' variety (Orton, 1907). However, this variety showed resistance against *Fon* in eastern Iowa but was observed to be susceptible in Oregon, showing the environmental effects on the cultivar (Bennett, 1937). The watermelon cultivar 'Summit' was reported to be a completely dominant source of resistance to *Fon* (Henderson *et al.*, 1970). Segregation analysis using different crosses of resistant cultivars (Calhoun Gray & Summit) with the susceptible cultivar (Mallali) along varying generations (F_1, F_2, and Back Cross or BC) showed a single dominant gene was likely conferring resistance to *Fon* race 1 (Netzer & Weintall, 1980). Most of the modern, elite diploid watermelon cultivars show resistance to races 0 and 1 of *Fon* (Martyn & Netzer, 1991; Zhou *et al.*, 2010) and the major resistance QTL (Fo-1.1) for *Fon* race 1 was reported at the end of short arm on chromosome 1 of watermelon genome (Lambel *et al.*, 2014)2014. Among the *Fon* races, race 2 is widely prevalent in the U.S. and is associated with huge yield and financial losses (Hall & Holloway, 2000; Zhang *et al.*, 2012). So, to develop the *Fon* resistant commercial watermelon cultivar, it is necessary to understand the inheritance pattern of race 2 resistance (Martyn, 2014). The resistance of watermelons to virulent *Fon* race 2 is polygenic with moderate heritability (Biswas *et al.*, 2025) and several quantitative trait loci (QTL) studies have reported *C. amarus* germplasm as the source of resistance (Table 2).

Table 2. Quantitative trait loci (QTL) mapping studies related to Fusarium wilt resistance in watermelon

Cross	Generations	Race	Chromosomes	Logarithm of odds (LOD) score	% Phenotypic variance (PV)	References
'HMw017' × 'HMw013' (R × S)	F_3	1	1, 3, 4, 9, & 10	4.26 to 33.31	11 to 59.9	Lambel *et al.*, 2014
'97103' × 'PI 296341-FR'	F_8 [RILs]	1	1	13.2	48.1	Ren *et al.*, 2015
'97103' × 'PI 296341-FR'	F_8 [RILs]	2	9 & 10	3.1 to 3.3	12.5 to 13.7	Ren *et al.*, 2015
'Calhoun Gray' × 'Sugar Baby' (R×S)	F_3	1	1	Not available	38.4	Meru & McGregor, 2016a

'Charleston Gray' × 'UGA147' (S × R)	$F_{2:3}$	2	11	3.89 to 5.93	9.6 to 16.2	Meru & McGregor, 2016b
'USVL246-FR2' × 'USVL114' (R × S)	$F_{2:3}$	2	2, 5, 8, 9, & 10	7.6 to 40.5	5.0 to 43.2	Branham *et al.*, 2017
'ZXG01478' x '14CB11' (R × S)	F_2	1	1	26.05	80.18	Na *et al.*, 2017
'HMw017' × 'HMw013' (R × S)	F_3	1	1 & 11	27.9	55.2	Branham *et al.*, 20182018
'USVL246-FR2' × 'USVL114' (R × S)	$F_{2:3}$ & RILs	1	9	5.6 to 10.7	14.1 to 24.7	Branham *et al.*, 2019
'USVL252-FR2' × 'PI 244019' (R × S)	F_2 & $F_{2:3}$	2	1	12.8	18.9	Branham *et al.*, 2020
'EC79442'1 x 'BIL-53) (R × S)	$F_{2:3}$	2	1 & 7	Not available	Not available	Pal *et al.*, 20232023

*S=susceptible; R=resistant; RIL=recombinant inbred lines

Marker assisted selection for Fusarium wilt resistance breeding in watermelon

Marker-assisted selection (MAS) can be used as a valuable tool to determine QTL linked to a particular trait (Ren *et al.*, 2015). Dominant, polymerase chain reaction (PCR)-based random amplified polymorphic DNA (RAPD) markers developed for *Fon* races 1 and 2 could not be used because of the large linkage estimate between the trait and the genetic marker (Hawkins *et al.*, 2001). The co-dominant SNP marker 'UGA1_502161' can be used as a useful marker for *Fon* race 1 resistance screening (Fall *et al.*, 2018). Similarly, co-dominant KASP (Kompetitive Allele Specific PCR) markers tightly linked to *Fon* race 1 resistance have also been developed and can be used to screen the watermelon parents and progenies during different early and advanced generations of the breeding cycle (Branham *et al.*, 2018). Further, Ren *et al.* (2015) developed a SNP marker 'Chr1SNP_5202124' that could be used for *Fon* race-1 resistance screening. Microsatellite markers have also been developed to facilitate MAS for *Fon* race 2 resistance in watermelon (Pal *et al.*, 2023).

Bottlenecks in Fusarium wilt resistance breeding in watermelon

Although the consumption of seedless watermelon varieties has increased (Wehner, 2008), most of the seedless triploid cultivars of watermelon are generally more susceptible to all the races of *Fon* (Egel & Martyn, 2007; Keinath *et al.*, 2010). Primers have been developed to distinguish races 1 and 2 of Fon and can detect the presence of pathogen at the earlier stages of wilting (Lin *et al.*, 2010). Many currently available commercial cultivars have resistance to *Fon* races 0 and 1, but until now, no edible cultivar resistant to *Fon* races 2 or 3 has been developed (Ganaparthi *et al.*, 2024). Resistance to race 2 *Fon* has been reported to be polygenic in wild watermelon species (Wehner, 2008). MAS for introgression of *Fon* race 2 resistant genes from PI 296341-FR to develop a resistant commercial cultivar was not successful in developing a sweet, edible cultivar due to a negative linkage drag between the resistant gene and poor-quality traits (Meru & McGregor, 2016b). Thus, there also arises a need to explore alternative technologies to reduce losses in watermelon production, productivity, and quality due to Fusarium wilt.

Novel approaches to enhance Fusarium wilt resistance in watermelon

The domesticated, seeded, sweet watermelon (*C. lanatus*) is a diploid with each of their cells containing two sets of 11 pairs of chromosomes. Reference genomes of pathogenic and non-pathogenic strains of *Fon* are also available (Fulton *et al.*, 2022). Several novel approaches could be utilized to enhance the resistance of watermelon to the virulent *Fon* race 2. For instance, the grafting of rootstock of cucurbit crops (squash, bottle gourd) with watermelon scions inhibited the races 1 & 2 *Fon* and increased the marketable yield of watermelon (Keinath & Hassell, 2014). Since *Fon* race 2 resistance is governed by multiple genes, another breeding strategy – genomic selection (GS) could be more effective to incorporate all the resistance genes at once than trying to incorporate few major QTL (Meuwissen *et al.*, 2001; Biswas *et al.*, 2025). Fungicide-based disease management practice can be effective to lower Fusarium wilt incidence and effect in watermelon fields (Everts *et al.*, 2014). Previously, methyl bromide – a popular soil fumigant used in controlling Fusarium wilt – had been banned owing to its ozone-depleting characteristics (EPA, 2006). Conventional PCR-based primers to differentiate race 3 from races 1 & 2 of *Fon* have been developed (Hudson *et al.*, 2021). Real-time PCR analysis to detect *Fon* race 1 of watermelon from plants and soil have also been reported (Zhong *et al.*, 2022). Precise genome editing technology (e.g., Clustered Regularly Interspaced Short Palindromic Repeats or CRISPR/Cas9 system) are crucial tools for the improvement of crops such as watermelons (Bhatta & Malla, 2020; Feng *et al.*, 2013). In watermelon, CRISPR/Cas9 has been already used to develop herbicide-resistance (Tian *et al.*, 2018; Tian *et al.*, 2017) and to perform knockout of the *Clpsk1* gene to increase resistance to *Fon* race 1 (Zhang *et al.*, 2020). A recent genome-wide association (GWAS) study using a diversity panel of 120 *C. amarus* accessions found several quantitative trait nucleotides (QTNs) on chromosomes 1, 5, 9, and 10 explaining up to 60% of *Fon* race 2 resistance (Ganaparthi *et al.*, 2023).

Conclusion

Continuous domestication and selective breeding for specific trait have led to a narrow genetic base and susceptibility to diseases such as Fusarium wilt in the cultivated sweet dessert watermelons (Levi *et al.*, 2001). The future studies should study interaction between different *Fon* races and host (watermelon) using molecular, biochemical, and physiological approaches. Further research on identifying *Fon* resistant sources besides *C. amarus*, such as the *C. mucosospermus* and other species, will expand the repertoire of disease resistant alleles to breed for Fusarium wilt-resistant, cultivated watermelons.

Acknowledgements

We would like to thank Ms. Amisha Bhatt for proofreading and providing valuable feedback on the review manuscript.

Contributions

P.B., G.T., & L.J.: *Literature Review, First Draft Preparation*; **B.P.B. & F.M.**: *Review and Editing*; **B.P.B.**: *Conceptualization, Supervision, and Final Review*

Conflict of interest

The authors declare no conflict of interest.

Data Sharing

This review article did not generate any supplementary data.

Informed Consent

All the authors agree with the content of this review article.

References

Bennett, L. 1937. Studies on the inheritance of resistance to wilt (*Fusarium niveum*) in watermelon *Journal of Agricultural Research,* 53:295.

Bhatta, B. P. and Malla, S. 2020. Improving horticultural crops via CRISPR/Cas9: current successes and prospects. *Plants,* 9(10):1360.

Bishop, C. and Cooper, R. M. 1983. An ultrastructural study of vascular colonization in three vascular wilt diseases I. Colonization of susceptible cultivars. *Physiological Plant Pathology,* 23(3):323-343.

Biswas, A., Wechter, P., Ganaparthi, V., Jarquin, D., Kousik, S., Branham, S., *et al.* 2025. Comparative genomic prediction of resistance to Fusarium wilt (*Fusarium oxysporum* f. sp. *niveum* race 2) in watermelon: parametric and nonparametric approaches. *Theoretical and Applied Genetics,* 138(1):1-11.

Branham, S. E., Levi, A., Farnham, M. W. and Patrick Wechter, W. 2017. A GBS-SNP-based linkage map and quantitative trait loci (QTL) associated with resistance to *Fusarium oxysporum* f. sp. *niveum* race 2 identified in *Citrullus lanatus* var. *citroides*. *Theoretical and Applied Genetics,* 130:319-330.

Branham, S. E., Levi, A. and Wechter, W. P. 2019. QTL mapping identifies novel source of resistance to Fusarium wilt race 1 in *Citrullus amarus*. *Plant Disease,* 103(5):984-989.

Branham, S. E., Patrick Wechter, W., Lambel, S., Massey, L., Ma, M., Fauve, J., *et al.* 2018. QTL-seq and marker development for resistance to *Fusarium oxysporum* f. sp. *niveum* race 1 in cultivated watermelon. *Molecular Breeding,* 38:1-9.

Branham, S. E., Patrick Wechter, W., Ling, K.-S., Chanda, B., Massey, L., Zhao, G., *et al.* 2020. QTL mapping of resistance to *Fusarium oxysporum* f. sp. *niveum* race 2 and Papaya ringspot virus in *Citrullus amarus*. *Theoretical and Applied Genetics,* 133:677-687.

Bruton, B., Fish, W., Zhou, X., Everts, K. and Roberts, P. 2007. Fusarium wilt in seedless watermelons. In: Proceeding 2007 Southeast Regional Vegetable Conference. Pp. 93-98.

Bruton, B., Patterson, C. and Martyn, R. 1988. Fusarium wilt (*F. oxysporum* f. sp. *niveum* race 2) of watermelon in Oklahoma. *Plant Disease,* 72(8).

Bruton, B. D., Fish, W. W. and Langston, D. B. 2008. First report of Fusarium wilt caused by *Fusarium oxysporum* f. sp. *niveum* race 2 in Georgia watermelons. *Plant Disease,* 92(6):983-983.

Cipolla, G. 1953. Wilt of melon and watermelon produced by *Fusarium bulbigenum* var. *niveum* Woll. *Idia*, 69:16-19

Cirulli, M. 1972. Variation of pathogenicity in *Fusarium oxysporum* f. sp. *niveum* and resistance in watermelon cultivars. Actas III Congress Mediterranean Phytopathologial Union (Oeiras, Portugal). Pp. 491-500.

Dean, R., Van Kan, J. A., Pretorius, Z. A., Hammond-Kosack, K. E., Di Pietro, A., Spanu, P. D., *et al.* 2012. The Top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology,* 13(4):414-430.

Di Pietro, A., Madrid, M. P., Caracuel, Z., Delgado-Jarana, J. and Roncero, M. I. G. 2003. *Fusarium oxysporum*: Exploring the molecular arsenal of a vascular wilt fungus. *Molecular Plant Pathology,* 4(5).

Dutta, B. and Coolong, T. 2017. Fusarium wilt of watermelon in Georgia. UGA Extension: Tifton, GA, USA. extension.uga.edu/publications/detail.html?number=B1485

Egel, D., Harikrishnan, R. and Martyn, R. 2005. First report of *Fusarium oxysporum* f. sp. *niveum* race 2 as causal agent of Fusarium wilt of watermelon in Indiana. *Plant Disease,* 89(1):108.

Egel, D. and Martyn, R. 2007. Fusarium wilt of watermelon and other cucurbits. *The Plant Health Instructor,* 10:1094.

EPA. 2006. Report of Food Quality Protection Act (FQPA) Tolerance Reassessment and Risk Management Decision (TRED) for Methyl Bromide, and Reregistration Eligibility Decision (RED) for Methyl Bromide's Commodity Uses. United States Environment Protection Agency.

Everts, K. L., Egel, D. S., Langston, D. and Zhou, X. G. 2014. Chemical management of Fusarium wilt of watermelon. *Crop Protection,* 66:114-119.

Everts, K. L. and Himmelstein, J. C. 2015. Fusarium wilt of watermelon: Towards sustainable management of a re-emerging plant disease. *Crop Protection,* 73:93-99.

Fall, L. A., Clevenger, J. and McGregor, C. 2018. Assay development and marker validation for marker assisted selection of *Fusarium oxysporum* f. sp. *niveum* race 1 in watermelon. *Molecular Breeding,* 38(11):130.

Feng, Z., Zhang, B., Ding, W., Liu, X., Yang, D.-L., Wei, P., *et al.* 2013. Efficient genome editing in plants using a CRISPR/Cas system. *Cell Research,* 23(10):1229-1232.

Fulton, J. C., Brawner, J. T., Huguet-Tapia, J. C., Smith, K. E., Fernandez, R. and Dufault, N. S. 2022. Six de novo assemblies from pathogenic and nonpathogenic strains of *Fusarium oxysporum* f. sp. *niveum*. *PhytoFrontiers™,* 2(1):3-9.

Ganaparthi, V. R., Rennberger, G., Wechter, P., Levi, A. and Branham, S. E. 2023. Genome-wide association mapping and genomic prediction of Fusarium wilt race 2 resistance in the USDA *Citrullus amarus* collection. *Plant Disease,* 107(12):3836-3842.

Ganaparthi, V. R., Wechter, P., Levi, A. and Branham, S. E. 2024. Mapping and validation of Fusarium wilt race 2 resistance QTL from *Citrullus amarus* line USVL246-FR2. *Theoretical and Applied Genetics,* 137(4):91.

Gordon, T. R. 2017. *Fusarium oxysporum* and the Fusarium wilt syndrome. *Annual Review of Phytopathology,* 55(1):23-39.

Hall, K. D. and Holloway, R. L. 2000. FQPA: Impact on Potatoes, Onions, Cabbage and Watermelon Produced in Texas. https://hdl.handle.net/1969.1/86892

Hansford, C. G. 1926. The fusaria of Jamaica. Bulletin of Miscellaneous Information (Royal Botanic Gardens, Kew): 257-288.

Hawkins, L. K., Dane, F., Kubisiak, T. L., Rhodes, B. B. and Jarret, R. L. 2001. Linkage mapping in a watermelon population segregating for Fusarium wilt resistance. *Journal of American Society for Horticultural Science,* 126(3): 344-350.

Henderson, W., Jenkins, S. and Rawlings, J. 1970. The inheritance of Fusarium wilt resistance in Watermelon, *Citrullus lanatus* (Thunb.) Mansf. *Journal of the American Society for Horticultural Science*, 95(3): 276-282.

Hudson, O., Waliullah, S., Fulton, J. C., Ji, P., Dufault, N. S., Keinath, A., *et al.* 2021. Marker development for differentiation of *Fusarium oxysporum* f. sp. *niveum* race 3 from races 1 and 2. *International Journal of Molecular Sciences,* 22(2):822.

Keinath, A. and Hassell, R. 2014. Control of Fusarium wilt of watermelon by grafting onto bottlegourd or interspecific hybrid squash despite colonization of rootstocks by Fusarium. *Plant Disease,* 98(2):255-266.

Keinath, A. P., Coolong, T. W., Lanier, J. D. and Ji, P. 2019. Managing Fusarium wilt of watermelon with delayed transplanting and cultivar resistance. *Plant Disease,* 103(1):44-50.

Keinath, A. P., Hassell, R. L., Everts, K. L. and Zhou, X.-G. 2010. Cover crops of hybrid common vetch reduce Fusarium wilt of seedless watermelon in the eastern United States. *Plant Health Progress,* 11(1):8.

Kousik, C. S., Brusca, J. and Turechek, W. W. 2016. Diseases and disease management strategies take top research priority in the Watermelon Research and Development Group members survey (2014 to 2015). *Plant Health Progress,* 17(1):53-58.

Kurt, S., Dervis, S., Soylu, E. M., Tok, F. M., Yetisir, H. and Soylu, S. 2008. Pathogenic races and inoculum density of *Fusarium oxysporum* f. sp. *niveum* in commercial watermelon fields in southern Turkey. *Phytoparasitica,* 36:107-116.

Lambel, S., Lanini, B., Vivoda, E., Fauve, J., Patrick Wechter, W., Harris-Shultz, K. R., *et al.* 2014. A major QTL associated with *Fusarium oxysporum* race 1 resistance identified in genetic populations derived from closely related watermelon lines using selective genotyping and genotyping-by-sequencing for SNP discovery. *Theoretical and Applied Genetics,* 127:2105-2115.

Levi, A., Thomas, C. E., Wehner, T. C. and Zhang, X. 2001. Low genetic diversity indicates the need to broaden the genetic base of cultivated watermelon. *HortScience,* 36(6):1096-1101.

Lin, Y.-H., Chen, K.-S., Chang, J.-Y., Wan, Y.-L., Hsu, C.-C., Huang, J.-W., *et al.* 2010. Development of the molecular methods for rapid detection and differentiation of *Fusarium oxysporum* and *F. oxysporum* f. sp. *niveum* in Taiwan. *New Biotechnology,* 27(4):409-418.

Lü, G., Guo, S., Zhang, H., Geng, L., Song, F., Fei, Z., *et al.* 2011. Transcriptional profiling of watermelon during its incompatible interaction with *Fusarium oxysporum* f. sp. *niveum*. *European Journal of Plant Pathology,* 131(4):585.

Maoto, M. M., Beswa, D. and Jideani, A. I. 2019. Watermelon as a potential fruit snack. *International Journal of Food Properties,* 22(1):355-370.

Martyn, R. 1985. An aggressive race of *Fusarium oxysporum* f. sp. *niveum* new to the United States. 69(1007):493-495.

Martyn, R. 1989. An Initial Survey of the United States for Races of *Fursarium oxysporum* f. *HortScience,* 24(4):696-698.

Martyn, R. and Netzer, D. 1991. Resistance to races 0, 1, and 2 of Fusarium wilt of watermelon in *Citrullus* sp. PI-296341-FR. *HortScience,* 26(4):429-432.

Martyn, R. D. 2014. Fusarium wilt of watermelon: 120 years of research. *Horticultural Reviews*, 42:349-442.

Meru, G. and McGregor, C. 2016a. Genotyping by sequencing for SNP discovery and genetic mapping of resistance to race 1 of *Fusarium oxysporum* in watermelon. *Scientia Horticulturae,* 209:31-40.

Meru, G. and McGregor, C. E. 2016b. A genetic locus associated with resistance to *Fusarium oxysporum* f. sp. *niveum* race 2 in *Citrullus lanatus*-type watermelon. *Journal of the American Society for Horticultural Science,* 141(6):617-622.

Meuwissen, T. H., Hayes, B. J. and Goddard, M. 2001. Prediction of total genetic value using genome-wide dense marker maps. *Genetics,* 157(4):1819-1829.

Miller, N. F., Standish, J. R. and Quesada-Ocampo, L. M. 2020. Sensitivity of *Fusarium oxysporum* f. sp. *niveum* to prothioconazole and pydiflumetofen in vitro and efficacy for Fusarium wilt management in watermelon. *Plant Health Progress,* 21(1):13-18.

Morris, H. and Nutting, G. B. 1923. Identification of certain species of Fusarium isolated from potato tubers in Montana. *Journal of Agricultural Research,* 24:339.

Na, L. N., JiMing, W., JianLi, S., NanNan, L., YongYang, X. and ShuangWu, M. 2017. Fine-mapping of QTL and development of InDel markers for *Fusarium oxysporum* race 1 resistance in watermelon. *Scientia Agricultura Sinica*, 50(1):131-141.

Netzer, D. and Weintall, C. 1980. Inheritance of resistance in watermelon to race 1 of *Fusarium oxysporum* f. sp. *niveum*. *Plant Disease,* 64:853-854.

Okungbowa, F. and Shittu, H. 2012. Fusarium wilts: An overview. *Environmental Research Journal,* 6(2):83-102.

Orton, W. 1907. On methods of breeding for disease-resistance. In: Proceedings of the American Society for Horticultural Science, 5:1-31.

Pal, S., Rao, E. S., Reddy, D. L. and Dayanandhi, E. 2023. QTL-seq identifies and QTL mapping refines genomic regions conferring resistance to *Fusarium oxysporum* f. sp. *niveum* race 2 in cultivated watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai]. *Scientia Horticulturae,* 319:112180.

Perkins-Veazie, P., Collins, J. K., Clevidence, B. and Wu, G. 2007. Watermelons and health. *Acta Horticulturae,* 731:121.

Petkar, A. and Ji, P. 2017. Infection courts in watermelon plants leading to seed infestation by *Fusarium oxysporum* f. sp. *niveum*. *Phytopathology,* 107(7):828-833.

Pietro, A. D., Madrid, M. P., Caracuel, Z., Delgado-Jarana, J. and Roncero, M. I. G. 2003. *Fusarium oxysporum*: exploring the molecular arsenal of a vascular wilt fungus. *Molecular Plant Pathology*, 4(5):315-325.

Porter, D. R. 1928. Infection studies with watermelon wilt caused by *Fusarium niveum* EFS. Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts. Pp. 348-368.

Pursley, D., Cooke, T. and House, S. 2010. Cucurbits. In: Diseases of Vegetable Crops in Australia. BioOne. Pp. 113-139.

Rahman, M. Z., Ahmad, K., Bashir Kutawa, A., Siddiqui, Y., Saad, N., Geok Hun, T., *et al.* 2021. Biology, diversity, detection and management of *Fusarium oxysporum* f. sp. *niveum* causing vascular wilt disease of watermelon (*Citrullus lanatus*): A review. *Agronomy,* 11(7):1310.

Ren, L., Su, S., Yang, X., Xu, Y., Huang, Q. and Shen, Q. 2008. Intercropping with aerobic rice suppressed Fusarium wilt in watermelon. *Soil Biology and Biochemistry,* 40(3):834-844.

Ren, Y., Jiao, D., Gong, G., Zhang, H., Guo, S., Zhang, J., *et al.* 2015. Genetic analysis and chromosome mapping of resistance to *Fusarium oxysporum* f. sp. *niveum* (FON) race 1 and race 2 in watermelon (*Citrullus lanatus* L.). *Molecular Breeding,* 35(9):183.

Shaban, W. I. A. and Abdelssalam, M. 2009. Evaluation of combining ability of some agronomic traits and susceptibility to Fusarium wilt in watermelon hybrids. *Tunisian Journal of Plant Protection,* 4(1):15-28.

Sleeth, B. 1934. *Fusarium niveum*, the cause of watermelon wilt. West Virginia Agricultural and Forestry Experiment Station Bulletins. 257

Smith, E. F. 1894. The watermelon disease of the South. In: Forty-Third Meeting of the American Association for the Advancement of Science (Putnam, F. W., ed.). Brooklyn, New York: The Permanent Secretary, pp. Section G. 289-290.

Smith, E. F. 1899. Wilt disease of cotton, watermelon, and cowpea (Neocosmospora nov. gen.). Washington: Government Printing Office.

Snyder, W. C. and Hansen, H. 1940. The species concept in Fusarium. *American Journal of Botany*, 64-67.

Tian, S., Jiang, L., Cui, X., Zhang, J., Guo, S., Li, M., *et al.* 2018. Engineering herbicide-resistant watermelon variety through CRISPR/Cas9-mediated base-editing. *Plant Cell Reports,* 37:1353-1356.

Tian, S., Jiang, L., Gao, Q., Zhang, J., Zong, M., Zhang, H., *et al.* 2017. Efficient CRISPR/Cas9-based gene knockout in watermelon. *Plant Cell Reports,* 36:399-406.

USDA. 2025. Vegetables 2024 Summary. National Agricultural Statistics Service.

Wechter, W. P., McMillan, M. M., Farnham, M. W. and Levi, A. 2016. Watermelon germplasm lines USVL246-FR2 and USVL252-FR2 tolerant to *Fusarium oxysporum* f. sp. *niveum* race 2. *HortScience,* 51(8):1065-1067.

Wehner, T. C. 2008. Watermelon. In: Vegetables I: Asteraceae, Brassicaceae, Chenopodicaceae, and Cucurbitaceae. Springer. Pp. 381-418.

Zhang, M., Liu, Q., Yang, X., Xu, J., Liu, G., Yao, X., *et al.* 2020. CRISPR/Cas9-mediated mutagenesis of Clpsk1 in watermelon to confer resistance to *Fusarium oxysporum* f. sp. *niveum*. *Plant Cell Reports,* 39:589-595.

Zhang, M., Yang, X., Liu, G., Xu, J., Zhu, L., Gao, C., *et al.* 2012. Histological differences between watermelon grafted onto bottle gourd rootstock and self-rooted seedlings inoculated with *Fusarium oxysporum* f. sp. *niveum*. In: Cucurbitaceae 2012. Proceedings of the Xth EUCARPIA Meeting on Genetics and Breeding of Cucurbitaceae, Antalya, Turkey, 15-18 October, 2012. University of Cukurova, Ziraat Fakultesi. Pp. 299-305.

Zhong, X., Yang, Y., Zhao, J., Gong, B., Li, J., Wu, X., *et al.* 2022. Detection and quantification of *Fusarium oxysporum* f. sp. *niveum* race 1 in plants and soil by real-time PCR. *The Plant Pathology Journal,* 38(3):229.

Zhou, X. and Everts, K. 2001. First report of the occurrence of *Fusarium oxysporum* f. sp. *niveum* race 2 in commercial watermelon production areas of Maryland and Delaware. *Plant Disease,* 85(12):1291-1291.

Zhou, X., Everts, K. and Bruton, B. 2010. Race 3, a new and highly virulent race of *Fusarium oxysporum* f. sp. *niveum* causing Fusarium wilt in watermelon. *Plant Disease,* 94(1):92-98.

Review Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Sustainable management of fruit fly infestation in guava for quality fruit production:A review

Raj Kumar[1], Nirmal Singh[1*], Ashwani Kumar[1], Arvind Kumar[1], Prannath Barman[2], S.M. Haldhar[3] and Pratibha Poonia[4]

[1]ICAR-Central Soil Salinity Research Institute, Karnal
[2]ICAR-Research Complex for NEH Region, Tripura
[3]ICAR-National Research Centre for Integrated Pest Management, New Delhi
[4]ICAR-Indian Institute of Wheat and Barley Research, Karnal

ARTICLE INFO

Received: 05 March 2025
Accepted: 07 April 2025

Keywords: *Bactrocera correcta*, fruit fly, guava, integrated pest management (IPM), sustainability

doi:10.48165/ijah.2025.7.1.2

ABSTRACT

The guava is a tropical fruit that originated in Central and South America and has since been grown in many tropical and subtropical areas worldwide. In these regions, guava fruit fly, *Bactrocera correcta*, is a noteworthy pest of guava and other fruits. This particular species of fruit fly lays its eggs in ripening or ripe fruits of guavas, which may culminate in infestations which significantly damage crops. The female guava fruit fly normally releases the eggs within the fruit as part of the life cycle. After hatching, the larvae feed the fruit pulp, which makes it rot and unfit for human eating. In cases of severe infestation, this not only diminishes the fruit's yield and quality but also makes it unmarketable. Controlling the guava fruit fly often involves a combination of cultural, mechanical, biological, and chemical methods. These can include techniques such as fruit bagging, sanitation, trapping, para-pheromone lure, bait spray, biocontrol, bio-pesticide and the application of insecticides. Fruit fly populations can be effectively managed by using fewer chemical pesticides and implementing integrated pest management (IPM) techniques. Maintaining the productivity and quality of guava crops, as well as other susceptible fruits in affected areas requires efforts to control the guava fruit fly.

Introduction

Guava (*Psidium guajava* Linn.) is one of the economically significant fruit crops grown worldwide in tropical and subtropical regions. The guava ripe fruits are a good source of vitamin C, phosphorus, calcium and pectin. The fruit is also used to prepare several processed products such as ready-to-serve (juice), jams, jellies, guava juice wine, and guava pulp wine. Guava leaves have medicinal properties, which may be used in the curing of diarrhoea and also for dyeing and tanning (Kumar *et al.*, 2014; Kumar *et al.*, 2016; Kumar *et al.*, 2017). The area under guava cultivation has increased from 94 thousand ha in 1991-92 to 359 thousand ha in 2022-23, whereas the production increased from 11 lakh tones to 5.59 million metric tons. Guava fruit is severely affected by biotic and abiotic factors such as insects, plant pathogens, vertebrates, invertebrates, temperature, humidity, rainfall and other climatic factors. Approximately 80 species of insect-pests deteriorate the quality of guava fruits and finally affect production and productivity. Nearly 4,000 species of fruit flies (Tephritidae) are distributed in the world, and around 200 species are economically important. Particularly in

Corresponding author's Email: nirmalsingh@hau.ac.in (Dr. Nirmal Singh)

Asian countries, 22 species are listed as financially significant pest species. Collectively, in India, around 243 species of fruit flies have been reported (Agarwal and Sueyoshi, 2005). Three significant species, i.e. *Bactrocera zonata* (peach fruit fly), *Bactrocera dorsalis* (oriental fruit fly) and *Bactrocera correcta* (guava fruit fly), are considered a pest of economic importance in India and are responsible for 30 to 70 per cent losses. The severity of losses depends on fruit fly species, its population, host range, varietal resistance, high reproductive potential, and adaptability to various climates. (Arora *et al.*, 1998, Hussain *et al.*, 2022). Worldwide, tephritid fruit flies are the most critical threat to the horticultural industry (Abbas *et al.*, 2021) and particularly to guava-quality fruit production (Afzal and Javed, 2001; Vargas *et al.*, 2008). Notably, female flies lay their eggs in the flesh of fruits with the help of their needle-like ovipositor. Then eggs emerge as maggots that eat the pulp, resulting in further deterioration of fruits caused by secondary infections caused by bacterial and fungal diseases (White and Elson-Harris, 1992). The puncture site on fruit could be identified by a brownish patch and spread quickly in guava trees, which produce sweet-smelling with an edible rind and creamy white, yellow or pink flesh (Riaz and Sarwar, 2013). Fruit flies are attracted by the pungent/musky odour emitted by ripened fruits, and they remain active throughout the year but become most active in the summer months. Consequently, control measures should be applied before the summer months, and during low activity of fruit flies (winter months), hibernating places must be destroyed to avoid population outbreaks. Controlling fruit flies in guava is crucial as fruit fly lay their eggs in ripe and maturing fruits, and the hatched larvae feed on the fruit pulp, causing damage, reducing the fruit's market value, and making it unsuitable for consumption. This also leads to significant economic losses for guava farmers. Infestation of fruit flies also acts as vectors for various plant diseases. Infested fruits can become breeding grounds for pathogens, which can spread to healthy plants, leading to further crop damage. Thus, controlling fruit flies ensures that guava fruits maintain their quality and are safe for consumption. Consumers expect fruits to be free from pests and diseases, and adequate control measures help meet these expectations. In a nutshell, in this review paper, various methods of controlling fruit flies in guava cultivation for protecting crops, ensuring economic viability for farmers, and maintaining food safety and quality standards have been discussed.

Management techniques to mitigate guava fruit fly incursions

Fruit flies in guava require a combination of chemical, mechanical, biological, and cultural control techniques to manage completely because single control measures like the application of insecticides on guava fruits can't be controlled entirely since infestation is internal. Collectively, IPM is required for the overall control of fruit fly infestation in guava plantations (Vargas *et al.*, 2008), which includes cultural control, early harvest, crop sanitation, soil raking, bagging of fruits, sterile insect technique, trapping, male annihilation technique (MAT), bait annihilation technique (BAT), and chemical approach (Table 1).

Table 1. Management options for controlling guava fruit fly infestation

S. No	Management measure	Practice
1.	Sanitation	Collect, remove, destroy/ bury infested fruits in trenches
2.	Para-pheromone lure/ trap	Methyl eugenol: Mix ethyl alcohol 60 ml + methyl eugenol 39 ml + Spinosad 1 ml Commercial Cue lure: Mix ethyl alcohol 60 ml + Cure lure 39 ml + Spinosad 1 ml
3.	Bait sprays	About 100 g jaggery + 2 ml of Decamethrin 2.8EC in 1 litre water; sprayed on the tree trunks at weekly intervals; Azadiracthin 10,000 ppm @ 1.0 ml/ litre during the fruiting stage.
4.	Botanicals	Neem-based (Azadirachtin) (10-20 ml/ litre), karanj oil (5-10 ml/ litrewater) and tobacco extract (250 g dry leaf / 1000 ml) mixed in 5 litre of water. The methanolic leaf extracts diluted to 5% (v/v) of lantana, karanj, tulsi and datura at 7-day intervals are also very effective.
5.	Cultural methods	(i) Deep soil treatment/ tillage, (ii) Removal of co-host plants, like cucurbits, solanaceous; (iii) Crop rotation; (iv) Clean cultivation, regular weeding, (v) Pruning, (vi) Conservation of natural insect enemies, (vii) Early harvesting, (viii) Placing Traps, (ix) Planting repellent crops, and (x) Soil raking around the tree and drenching with chlorpyriphos @ 4.0 ml/ litre.

6.	Bagging of fruits	Wrapping of individual fruits with transparent polypropylene (20 μ gauge) bag, newspaper bag, and fruit fly net bag at egg stage until ripening.
7.	Exclusion measures	Netting of whole plants up to the trunk gives effective control.
8.	Food lure/ protein hydrolysate	Ripened fruits (pumpkin, banana + insecticide) as bait, protein hydrolysate (Nu-lure®) + livestock/ poultry manure. Nu-lure combined with borax in an aqueous solution containing 9% Nu-lure (vol: vol) with 3% borax (wt: vol) + propylene glycol (10% vol: vol) to prepare the bait solution.
9.	Bio-pesticides/ bio-agents	*Metarhizium anisopliae* (2 x 10^{-8} cfu/g commercial powder @ 2 tsp in 1.0 litre water), the release of parasitoids and weaver ants.
10.	Chemical insecticide	Spray 1250 ml Sumicidin 20 EC (fenvalerate) or Deltamethrin (0.025%) in 500 litres of water per hectare at weekly intervals on ripening fruits commencing from July onwards till the rainy season crop is over.

Sanitation

Crop sanitation should be an essential component of fruit fly control programs in guava orchards. Fruit fly infested over-ripened fruits help in the completion of the reproductive cycle of fruit flies. Therefore, to break down the reproductive cycle, it is advised that fallen and infested fruits should be collected on a regular basis and destroyed by deep-burying into the soil. Field sanitation helps to prevent fruit fly eggs and maggots from developing in infested fruit. Destroying the fruit ensures that maggots do not survive to pupate in the ground to emerge later as adult flies (Singh, 2008). Hasyim *et al.* (2016) reported that due to the adoption of sanitary practices, the percentage of damaged fruits gradually decreased to about 20 percent.

Male annihilation technique (MAT)

MAT is being used widely because it controls the male population of flies, so mating can't take place, and ultimately, the population decreases. A combination of 1% methyl eugenol along with 0.5 % Malathion or 0.1 % carbaryl is found effective against *B. dorsalis* (Balasubramaniam *et al.*, 1972). Methyl eugenol (ME) is a para-pheromone that attracts the male population of fruit flies from a distance of 700-900 meters (Roomi *et al.*, 1993), and it has been applied for the complete eradication of fruit flies in a particular area (Stonehouse *et al.*, 2002; Singh and Sharma, 2011).

BAT (Bait annihilation technique)

The female fruit flies require a protein source for their gonad's development as well as eggs (Hagen and Finney, 1950; Christenson and Foote, 1960). Consequently, a protein hydrolysate has been identified as an efficient attractant for female fruit flies. Previous literature indicates that a bait spray of 1.0 % malathion in 10 % sugar solution can be applied 2-3 times on each tree of guava orchards at 10-day intervals for effective control of fruit fly populations. Alternatively, a bait spraying of a combination of 500 g molasses and 50 g malathion in 50 litres of water at seven days of interval is also an effective method to control fruit flies (Agarwal *et al.*, 1987). Female attractive baits are also very effective against this serious damaging pest for direct control (Mazor *et al.*, 2002). Few compositions of poison bait to control different species of fruit fly are illustrated in Table 2.

Table 2. Baits recommended to attract female fruit flies

Composition of poison bait	Species of fruit fly	References
Coarse flour (middlings) 5 kg+borax five kg+ water (90 litre)	*Bactrocera oleae*	Bouhelier *et al.* (1935)
1% molasses + 0.02% fenvalerate	*B. tau*	Saikia and Dutta (1977)
Jaggery + 0.1% dichlorvos	*B. tau*	Sood and Nath (1998)
Solbait (protein hydrolysate)	*B. cucurbitae*	Fabre *et al.* (2003)
Sugar + ICN enzymatic yeast hydrolysate (3:1)	*B. dorsalis and B. cucurbitae*	Vargas and Prokopy (2006)
Protein hydrolyzate attractants (Agricince, Amaden, BioProx)	*Ceratitis capitate*	Moustafa (2009)

Chemical control

Chemical control should be considered as a last option or as a part of IPM strategies. Under chemical methods, the selection of chemicals is crucial as they must be selective and environmentally safe, i.e., they must avoid non-target organisms and should have significantly less half-life for degradation. It has been investigated that insecticides are only effective against fruit flies if they are applied alone and neighbours need to make an effort for the same in their orchards. (Manrakhan *et al.*, 2013) Evaluated the efficacy of six different insecticides, viz., abamectin, alpha-cypermethrin, fipronil, imidacloprid, spinosad and Malathion, against fruit flies. They found that a mixture of 2 % HymLure and Spinosad at 48 ppm was found effective against both *C. capitata* and *C. rosa* and recommended it as a replacement for malathion-based bait sprays (Haider, 2011) evaluated mortality in adult flies (noted at 24 and 48 h after the treatment application and LC_{50} values were estimated) by using insecticides like Talstar 10 EC, Confidor 70WS, Curacron 50 EC, Deltamethrin 2.5 EC, Diptrex 80 WP, Proclaim 1.9 EC, Karate 2.5 EC, Malathion 57 EC, Tracer 240 SC, Steward 360 SC; and results revealed that the field strain exhibited varying ratios of insecticide resistance; being highest against Diptrex (65.32) followed by Curacron (13.20), Confidor (7.12), Talstar (5.97), Karate (5.73), Malathion (5.54) and Deltamethrin (2.35) at 24 hr. For effective control of fruit fly infestation, three sprays of rogor @ 2 ml litre^{-1} water should be applied in the early stage of fruit development 21 days of intervals. Neem oil-based spray and botanicals can also be sprayed towards fruit maturity. Amongst new molecules, spraying 1.25 litre Sumicidin 20 EC (Fenvalerate) in 500 litres of water at weekly interval in the early fruit growth stages is the most effective.

Botanicals

In another experiment, the repellent action of neem oil, tobacco leaf solution, neem seed powder solution and solution made from eucalyptus leaves were compared against guava fruit fly infestation and maximum repellent efficiency was observed by neem oil followed by solution made from eucalyptus leaves, neem seed powder and tobacco leaf (Solangi *et al.*, 2011). A study conducted by Shah *et al.* (2016) reported that maximum (73%) mortality against male fruit flies was found when *Tagetes minuta* extract was used, while in the case of females, maximum mortality was shown by *C. camphora* and *I. rugosus* extract. In an experiment, Leaf extract, stem extract, inflorescence extract, and root extract of basil plant with methyl eugenol as control were applied to reduce the infestation of fruit flies, and it found that inflorescence extract was most effective in measuring the fruit flies (Singh *et al.*, 2020). Previous reports also reflected that water extract from fruits of different botanicals (mango, guava, cucumber and apple) also acted as a fruit fly attractant and helped control the fruit fly population (Mahmoud *et al.*, 2022). Neem Seed Kernel Extract (NSKE) is an efficient ovipositional deterrent for the oriental fruit fly when applied at 0.2 to 4.0 %, thus reducing the number of eggs from 87.5 to 99.2%. A spray of 0.5 to 1.0% neem oil (v/v) has also been found effective in reducing egg-laying by the fruit fly in guava. It is always better to apply repeat sprays after a 10-day interval towards maturity so that the issue of pesticide residues can be minimized (Chandana *et al.*, 2023).

Cultural methods/ environmental management

Cultural management practices are essential components of an IPM strategy, especially for controlling fruit fly infestations in guava orchards. However, a thorough understanding of the different components of the agro-ecosystem in which pests flourish is required. Here are several effective cultural management techniques to control fruit fly populations:

Early harvesting

Frequent harvesting at the fruit colour change stage reduces the availability of ripe fruits for the flies to infestation. It has been proved that the survival of fruit fly larvae in the colour change stage was lower in comparison to the over-ripening stage (Lakra *et al.*, 1991). In separate experiments conducted in Maharashtra and Karnataka, it was observed that early harvesting of guava fruits escaped fruit flies attack (Verghese *et al.*, 2006). Generally, fruit flies are more attracted to fully ripe fruits, so harvesting at an early stage can reduce the chances of infestation. In other words, fruit flies don't prefer green fruits for oviposition, they mostly attack over-ripened guava fruits.

Trap crops

It is an effective method to minimize fruit fly infestation in guava. Since fruit fly is a polyphagous pest and feeds on alternative hosts found in the vicinity of the main crop, the trap crops, for example, cucurbitaceous vegetables (79% infestation), most affected by fruit flies, can be grown in the guava orchards to escape the guava orchards from fruit fly infestations. The infested fruits on trap crops must be collected and destroyed regularly.

Pruning

Regular pruning improves air circulation and sunlight penetration by maintaining an open canopy. It not only helps in reducing the humidity required for the breeding of fruit flies but also makes the orchard less attractive for the flies to inhabit. It is also critical that horticultural operations lead to regulate the crop with the season and increase the yield and quality of fruits. Choudhary *et al.* (2022) reported that fruit fly infestation was higher in non-pruned orchards than in pruned orchards, and they added that timely pruning is most effective against fruit fly attacks.

Soil raking

Mature larvae enter the soil and go into hibernation stage during the winter season; raking of soil is essential to breaking the reproductive cycle of fruit flies by exposing them to sunlight (Vadivelu, 2014). Ploughing or raking of soil up to 6 cm two times in continuation and once three weeks later reduced the infestation level by around 80 % (Patel *et al.*, 2005; Stonehouse *et al.*, 2005).

Choice of variety

The selection of cultivars is the most effective and economical measure of fruit fly infestation. Available literature suggested that smooth skinned varieties, namely Red Flesh, Allahabad Safeda and local, are highly susceptible to fruit flies (infestation range from 64.2 to 80.4%) (Table 3). In contrast, rough-skinned pear-shaped varieties are the least susceptible (<35.1%). Similarly, fruit fly incidence on different white pulped cultivars revealed higher infestation, i.e. damage ranging from 37.2 to 53.5% (Chandana *et al.*, 2023). Commercial cultivars, viz., Sardar, Allahabad Safeda and Arka Amulya had a high incidence of fruit flies, whereas Arka Kiran, Shillong-1, and Arka Rashmi had relatively less fruit fly damage.

Table 3. Response of different varieties to guava fruit fly infestation

Response	Varieties
Tolerant	Cattleya guava, Shilong-1, KG 1, Thai Pink, Thai White
Moderately tolerant (20-30%)	Chittidar, VNR Bihi, Nridula, MPUAT-1, Barafkhana, Arka Amulya, Punjab Pink, Sweta, Hisar Surkha, Pear Shaped, Behat Coconut
Less susceptible (<10% infestation)	Nasik, Allahabad Surkha, Kamsa-ri, Spear Acid and Superior Sour, Arka Kiran, Arka Rashmi
Least susceptible (<4.8% infestation)	L-46, Lalit, Strawberry guava, Chinese guava
High incidence (>50%)	Sardar, Allahabad Safeda, Arka Amulya, Hisar Safeda, Banarsi Surkha, Pant Prabhat, Safed Jam, Kohir Safeda

(Chandana *et al.*, 2023)

Conservation of natural insect enemies

Conserving natural insect enemies to control fruit flies in a guava orchard is a sustainable and effective method that reduces the reliance on chemical pesticides. The release of *Fopius arisanus* in guava orchards decreased the population of fruit flies. It concluded that the establishment of *F. arisanus* is the most successful example of classical biological control of fruit flies in the Pacific area (Vargas *et al.*, 2007).

Fruit bagging

Covering of developing fruits entirely around one month prior to harvest with paper or cloth bags to stop fruit flies from laying their eggs on fruits. Wrapping fruits with polythene bags is also safer and more economical than wrapping them with cloth or paper bags. Wrapping of individual fruits in a transparent polypropylene (20μ gauge) bag and paper pieces within the polypropylene bag for partial cover from sunlight' is considered the best option for guava fruit fly management. Maximum fruit fly infestation was recorded under un-bagged fruits (96%), while 4 % is covered by polyethene bags, 5.70 % covered by newspaper bags and 7.65 % covered by muslin cloth bags (Abbasi *et al.*, 2014). Further, it was also noticed that covering fruits have no adverse effect on TSS and physical fruit quality, which were similar to unbagged healthy fruits (Sarker *et al.*, 2009). Conclusively, different bagging materials, viz., black polybag, transparent polybag, and brown paper bag, can be applied to protect the guava fruits completely (0 % infestation) from the attack of fruit flies.

Sterile insect technique (SIT)

It is considered an ecologically safe procedure and has been successfully used in broad areas. In this technique, sterile males of fruit flies are released in large numbers for mating with female fruit flies and due to mating with sterile males, female fruit flies either do not lay eggs or lay sterile eggs, so pest population is maintained through this procedure. Sterilization of male fruit flies can be achieved by irradiation, chemo-sterilization, or by genetic manipulation (Kebede *et al.*, 2015).

Biological control

Natural enemies of the fruit flies, such as predators, parasitoids, and pathogens, reduced their population. Biological control has been the most commonly researched control tactic within fruit fly management programs.

Among all the natural enemies, parasitoids are the main natural enemies and have been used against pestiferous fruit fly species. Cai *et al.* (2022) reported that *Fopius arisanus* is the most suitable biological control agent of fruit flies in multi-crop orchards (main crop - guava). Effective searching behaviour and high foraging efficiency are features of *F. arisanus* that lead to higher parasitism rates and explain the success of this parasitoid in the control of tephritids in many crops (Wang and Messing, 2003). Coelho *et al.* (2022) stated that a combination of *Fopius arisanus* (Sonan) and *Diachasmimorpha longicaudata* (Ashmead) provided higher efficacy (76.58%) in controlling *C. capitata* populations, rather than used alone *F. arisanus* (53.76%) and *D. longicaudata* (44.95%). Firake *et al.* (2013) indicated that raking the soil and application of *Metarrhizium anisopliae* @ 5 kg/ha to the soil underneath the tree canopy reduced fruit fly infestation. Sookar *et al.* (2014) also reported that infection by *M. anisopliae* resulted in the reduction of the number of eggs produced by females of fruit fly.

Conclusion

The quality and quantity of guava can only be produced efficiently by reducing fruit fly infestations using sustainable IPM modules. Various control measures have been adopted for the improvement in the productivity and quality of guava produce in different agro-ecological regions. Although fruit fly has a wide host range and the ability to fly long distances, consequently, any control strategy, if applied area-wide, level will be more effective and successful. Efficient IPM modules should be implemented at community level like field sanitation, early harvesting, wrapping of fruits, MAT (Male annihilation technique), BAT (Bait annihilation technique), SIT (Sterile insect technique) and soft insecticides. Preventing the entry of infested material during transportation is also a great source of the spread of the infestation.

Acknowledgements

The authors express their sincere grateful to the authorities of CSSRI, Karnal; NRC on IPM, New Delhi; IIWBR, Karnal and Research Complex for NEH Region, Tripura for providing the support to compile the information.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

This review article did not generate any supplementary data.

References

Abbas, M., Hussain, D., Saleem, M., Ghaffar, A., Abbas. S., Hussain, N. and Ghaffar, A. 2021. Integrated pest management of guava, citrus and mango fruit flies at three districts of Punjab. *Pakistan Journal of Zoology*, 53(3): 1-9.

Abbasi, N.A., Chaudhary, M.A., Ali, M.I., Hussain, A. and Ali, I. 2014. On tree fruit bagging influences the quality of guava harvested at different maturity stages during summer. *International Journal of Agriculture and Biology,* 16: 543–549.

Afzal, M. and Javed, H. 2001. Evaluation of soaked wooden killer blocks for male annihilation (MA) on fruit fly *Bactrocera spp*. (Diptera: Tephritidae). *Journal of Biological Sciences,* 1(7):577–579.

Agarwal, M.L., Sharma, D.D. and Rahman, O. 1987. Melon fruit fly and its control. *Indian Horticulture,* 32: 10-11.

Arora, P.K., Batra, R.C., Mehrotra, N.K. and Thind, S.K. 1998. Screening of some promising guava varieties against fruit fly. In: Proceedings of the first national symposium on pest management in horticultural crops: environmental implication and thrusts. Bangalore. Pp. 43-44.

Balasubramaniam, G., Abraham, E.V., Vijayaraghavan, S., Subramaniam, T.R., Santhanaraman, T. and Gunasekaran C.R. 1972. Use of male annihilation technique in the control of the oriental fruit fly, *Dacus dorsalis* Hendel. *Indian Journal of Agricultural Research*, 42: 975-977.

Billah, M.K., Wilson, D.D., Cobblah, M.A., Lux, S.A. and Tumfo, J.A. 2006. Detection and preliminary survey of the new invasive fruit fly species *Bactrocera invadens* (Diptera: Tephritidae) in Ghana. *Journal of the Ghana Science Association*, 8(2): 139-149.

Cai, P., Peng, Y., Song, Y., Lin, J., Nie, C., Li, Y., Ma, C. and Ji, Q. 2022. Is *Fopius arisanus* (Hymenoptera: Braconidae) a suitable biological control agent of *Bactrocera dorsalis* (Diptera: Tephritidae) in multi-crop orchards? *International Journal of Pest Management*, 70(4): 1-9. DOI: 10.1080/09670874.2022.2151055

Chandana, M.R., Menaka, M., Singh, S.K., Goswami, A.K. and Sree, M.R. 2023. Eco-friendly management of fruit fly for quality guava production. *Indian Horticulture,* 68(1): 43-46.

Christenson, L.D. and Foote, R.H. 1960. Biology of fruit flies. *Annual Review of Entomology*, 5(1): 171-192.

Firake, D.M., Behere, G.T., Deshmukh, N.A. and Thakur, N.S. 2013. Recent Scenario of Insect-pests of Guava in North East India and their Eco-friendly Management. *Indian Journal of Hill Farming*, 26 (1): 55-57.

Hagen, K.S. and Finney, G.L. 1950. A food supplement for effectively increasing the fecundity of certain tephritid species. *Journal of Economic Entomology*, 43: 735.

Haider, H. 2011. Determination of level of insecticide resistance in fruit fly, *Bactrocera zonata* (Saunder) (Deptera; Tephritidae) by bait bioassay. *International Journal of Agriculture and Biol-*

ogy, 13: 815-818.

Hasyim, A., Muryati, M. and De Kogel, W.J. 2008. Population fluctuation of adult males of the fruit fly, Bactrocera tau Walker (Diptera: Tephritidae) in passion fruit orchards in relation to abiotic factors and sanitation. *Indonesian Journal of Agricultural Science,* 9(1): 29-33. http://pustaka.litbang.deptan.go.id/publikasi/as091085.pdf

Hussain, D., Saleem, M., Abbas, M., Ali, Q., Qasim, M., Hafeez, F., Ashrif, M., Zubair, M. and Ghouse, G. 2022. Monitoring and management of fruit fly population using the male annihilation technique with different types of cost-effective traps in guava orchards of Punjab, Pakistan. *International Journal of Pest Management*, 71(2): 1-9.

Kebede, A., Ashenafi, H. and Daya, T. 2015. A review on sterile insect technique (SIT) and its potential towards tsetse eradication in Ethiopia. *Advances in Life Science and Technology*, 37: 24-44.

Kumar, R., Tiwari, J. P. and Lal, S. 2014. Effect of zinc and boron on fruit yield and quality of winter season guava (*Psidium guajava* L.) cv. Pant Prabhat. *Annals of Agri-Bio Research,* 19(1): 105-108.

Kumar, R., Tiwari, J.P., Lal , S., Kumar, M., Singh, A. and Kumar. A. 2017. Effect of boron and zinc application on nutrient uptake in guava (*Psidium guajava* L.) cv. Pant Prabhat leaves. *International Journal of Current Microbiology and Applied Sciences*, 6(6): 1991-2002.

Kumar, R., Kaur, G., Mann, A., Lata, C., Singh, A. and Kumar, A. 2016. Biochemical changes in guava (*Psidium guajava*) cv. Allahabad Safeda fruits as a function of maturity stages. *Indian Journal of Agricultural Research,* 86(12): 1595-1600.

Lakra, R.K., Sangwan, M.S. and Singh Z. 1991. Effect of application of some insecticides on the incidence of ber'fruit fly (*Carpomyia vesuviana* Costa). *Narendra Deva Journal of Agriculture Research*, 6(1): 71-79.

Mahmoud, M.E., Kambal, M.A., Abukashwaa, S.M., Mohammed, S.A. and Ekesi, S. 2022. Field response of tephritid fruit flies (Diptera) to fruit juice of some botanicals and implications for bio-rationale pest management in Sudan. *Global Journal of Agricultural Innovation, Research & Development,* 9: 1-9.

Manrakhan, A., Kotze, C., Daneel, J.H., Stephen, P.R. and Beck, R.R. 2013. Investigating a replacement for malathion in bait sprays for fruit fly control in South African citrus orchards. *Crop Protection*, 43: 45-53.

Mazor, M., Peysakhis, A. and Reuven, G. 2002. Release rate of ammonia-a key component in the attraction of female Mediterranean fruit flies to protein–based food lures. *Environmental Science, Biology, Agricultural and Food Sciences*, 25: 1-6.

Nikumbhe, P.H., Uchoi, J. and Mali, D.S. 2020. Effects on tree vigor, fruit quality, yield and fruit fly infestation of different times of pruning with genotypes in guava (*Psidium guajava* L.). *International Journal of Current Microbiology and Applied Sciences,* 9: 1769-1780.

Patel, R.K., Verghese, A., Patel, V.M., Joshi, B.K., Stonehouse, J.M. and Mumford, J.D. 2005. Bait, Lure and cultural IPM of fruit flies in mango in Gujarat. *Pest Management in Horticultural Ecosystems*, 11: 155-158.

Riaz, M. and Sarwar, M. 2013. A new record of fruit fly *Trupanea amoena* (Frauenfeld) within genus Trupanea schrank of subfamily Tephritinae (Diptera: Tephritidae) from Pakistan. *Journal of Zoological Sciences,* 1(2): 7-12.

Roomi, M.W., Abbas, T., Shah, A.H., Robina, S., Qureshi, A.A. and Sain, S.S. 1993. Control of fruit flies (*Dacus* sp.) by attractants of plant origin. *Anzeiger fiir Schadlingskunde, Pflanzeschutz, Umwelschutz*, 66: 155-157.

Sarker, D., Rahman, M.M. and Barman, J.C. 2009. Efficacy of different bagging materials for the control of mango fruit fly. *Bangladesh Journal of Agricultural Research,* 34(1): 165-168.

Satarkar, V.R., Faleiro, J.R., Krishnamurthy, S.V., Ramesh, R. and Verghese, A. 2009. A review on the behaviour of Bactrocera fruit flies. *Current Biotica*, 3(2): 264-277.

Shah, M.M., Khan, S., Ahmad, R. and Haq, I.U. 2016. The insecticidal potential of botanical extracts for management of Peach fruit fly, *Bactrocera zonata* Saunders, 1842. *Turkish Journal of Entomology*, 40(4): 445-453.

Singh, M.P. 2008. Managing menace of insect pests on ber. *Indian Horticulture,* 53(1): 31

Singh, S. and Sharma, D.R. 2011. Comparison of the trapping efficacy of different types of methyl eugenol based traps against fruit flies, *Bactrocera* spp. infesting Kinnow mandarin in the Indian Punjab. *Journal of Insect Science,* 24: 9-14.

Singh, S.P., Agrawal, N., Singh, R.K. and Singh, S. 2020. Management of fruit flies in mango, guava and vegetables by using basil plants (*Ocimum sanctum* L.) as attractant. *Journal of Entomology and Zoology Studies*, 8(1): 311-314.

Solangi, B.K., Sultana, R., Wagan, M.S. and Ahmed, N. 2011. Repellent action of botanical pesticides against fruit fly, Bactrocera zonata Saunders in laboratory. *Pakistan journal of entomology,* 26(1): 41-45.

Sookar, P., Bhagwant, S. and Allymamod, M.N. 2014. Effect of *Metarhizium anisop*liae on the fertility and fecundity of two species of fruit flies and horizontal transmission of mycotic infection. *Journal of Insect Science*, 14(1): 467-477.

Srivastava, K.P. and Dhaliwal, G.S. 2010. A Text Book of Applied Entomology. Concepts in Pest Management. Kalyani Publishers, New Delhi.

Stonehouse, J., Mahmood, R., Poswal, A., Mumford, J., Baloch, K. N., Chaudhary, Z. M. and Huggett, D. 2002. Farm field assessments of fruit flies (Diptera: Tephritidae) in Pakistan: distribution, damage and control. *Crop Protection*, 21(8): 661-669.

Stonehouse, J.M., Verghese, A., Mumford, J.D., Thomas, J., Jiji, T., Faleiro, R., Patel, Z.P., Jhala, R.C., Patel, R.K., Shukla, R.P. and Satpathy, S. 2005. Research conclusions and recommendations for the on–farm IPM of Tephritid fruit flies in India. *Pest Management in Horticultural Ecosystems*, 11(2): 172-180.

Vadivelu, K. 2014. Biology and Management of ber fruit fly, *Carpomyia vesuviana* Costa (Diptera: Tephritidae): A review. *African Journal of Agricultural Research,* 9(16): 1310-1317.

Vargas, R.I. and Prokopy, R. 2006. Attraction and feeding responses of melon flies and oriental fruit flies (Diptera: Tephritidae) to various protein baits with and without toxicants. *Proceedings of the Hawaiian Entomological Society,* 38: 49–60.

Vargas, R.I., Leblanc, L., Putoa, R. and Eitam, A. 2007. Impact of introduction of *Bactrocera dorsalis* (Diptera: Tephritidae) and classical biological control releases of *Fopius arisanus* (Hymenoptera: Braconidae) on economically important fruit flies in French Polynesia. *Journal of Economic Entomology,* 100(3): 670-679.

Vargas, R.I., Mau, R.F., Jang, E.B., Faust, R.M. and Wong, L. 2008. The Hawaii fruit fly area wide pest management programme. In: Area wide pest management: theory and implementation. Wallingford UK: CABI. Pp. 300-325.

Verghese, A., Sreedevi, K. and Nagaraju, D.K. 2006. Pre and post-harvest IPM for the mango fruit fly, Bactrocera dorsalis (Hendel). In: Fruit Flies of Economic Importance: From Basic to Applied Knowledge-Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance, 10-15 September, Salvador, 2006.

Wang, X.G. and Messing, R.H. 2003. Foraging behavior and patch time allocation by *Fopius arisanus* (Hymenoptera: Braconidae), an egg-larval parasitoid of tephritid fruit flies. *Journal of Insect Behavior,* 16(5): 593-612.

Wee, S.L., Chinvinijkul, S., Tan, K.H. and Nishida, R. 2018. A new and highly effective male lure for the guava fruit fly *Bactrocera correcta*. *Journal of Pest Science,* 91: 691-698. doi:10.1007/s10340-017-0936-y

White, I.M. and Elson-Harris, M.M. 1992. Fruit flies of economic significance: their identification and bionomics. CAB International. Wallingford, UK. https://www.cabidigitallibrary.org/doi/full/10.5555/19921161954

Review Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January-June)

Sweet potato *(Ipomoea batatas* L.): Climate resilient crop for food security in arid and semi-arid regions - A review

C. Prabakaran[1] and R. Kalaivani[2]

[1]Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore
[2]Department of Computer Science, National College, Tiruchchirappalli

ARTICLE INFO

Received: 15 February 2025
Accepted: 29 April 2025

Keywords: Sweet potato, drought tolerance, climate resilience, arid regions, crop improvement

doi:10.48165/ijah.2025.7.1.3

ABSTRACT

Sweet potato is a crucial crop for enhancing food security, particularly in arid and semi-arid regions where climate change and water scarcity pose significant challenges to agriculture. However, osmotic stress severely impacts its agronomic and economic productivity by triggering morphological, physiological and biochemical alterations. In response to drought, sweet potato activates various adaptive mechanisms, including growth regulation, antioxidant defense, osmolyte accumulation and stress protein synthesis. These physiological, metabolic, and genetic responses serve as essential indicators for selecting drought-tolerant genotypes. The primary goal of breeding programs in drought-prone regions is to develop high-yielding, drought-resistant varieties. Understanding the physiological and biochemical traits of drought-tolerant genotypes is critical for improving selection strategies. By integrating conventional breeding, molecular techniques, and biotechnological innovations, drought-resilient sweet potato varieties can be developed, making cultivation more sustainable and cost-effective for smallholder farmers. This review explores the effects of drought stress on sweet potato productivity, its adaptation strategies, crop management practices, and advanced breeding approaches to enhance drought tolerance.

Introduction

Climate change, marked by rising global temperatures, presents a significant challenge to agricultural production. Since crop growth is highly influenced by climatic factors, failure to implement adaptive strategies may result in severe productivity losses in the near future. To mitigate the effects of abiotic stress on crops, there is an urgent need to promote the cultivation of crops that utilize water resources efficiently. Among such crops, sweet potato stands out due to its resilience, versatility, and nutritional benefits. However, despite its potential, sweet potato productivity is adversely affected by abiotic stress conditions. Nevertheless, compared to other economically important crops, sweet potato possesses several advantages that make it well-suited for enhancing global food security, particularly in extensive agricultural systems in developing countries.

Sweet potato (*Ipomoea batatas* L.) is a vital staple, fodder, and horticultural crop widely cultivated in tropical regions. Ranking seventh globally in terms of production (Sinkovic *et al.*, 2024), it belongs to the Convolvulaceae family and is primarily grown for its nutrient-rich tuberous roots. While *Ipomoea batatas* is the predominant cultivated species, other Convolvulaceae members are mostly localized or classified as invasive weeds. The plant itself is a herbaceous liana with alternating leaves and tubular flowers. Tuberous roots of sweet potato vary in shape and color. Depending on the variety and environmental conditions colour range from white to purple.

Corresponding author's Email: kalaivanics@nct.ac.in (Dr. R. Kalaivani)

Sweet potato has a high water-use efficiency (WUE). It helps stop soil erosion. This makes it useful as a cover crop. It is also grown for food. It grows well in places without frost and where the growing season is at least four months long. Due to its exceptional adaptability to poor soil conditions and its high nutritional value, sweet potato plays a crucial role in addressing food shortages and improving food security. It also holds promise for promoting healthier diets, particularly in developing countries. Additionally, compared to other staple crops, sweet potato requires fewer chemical inputs such as pesticides and fertilizers, further enhancing its sustainability (Kwak, 2019).

Origin place of *I. batatas* is the tropical regions of South America. People have cultivated it for about 5,000 years. Farmers cultivate sweet potato on about 9 million hectares. Global sweet potato production is about 131 million tons per year, yielding 13.7 tons per hectare. Notably, around 97% of the world's sweet potato production occurs in developing countries, with China alone accounting for 52% of global output, cultivating the crop on approximately 4.7 million hectares. Thousands of sweet potato varieties are cultivated across tropical and subtropical climates worldwide. Rich in carbohydrates, vitamins A and C, fiber, iron, potassium, and protein, sweet potato is a highly nutritious food source.

People are starting to see the value of sweet potatoes. They are useful as food for both humans and animals. Because of this, research on how to grow and use sweet potatoes is increasing. Sweet potato thrives best in warm tropical climates with average temperatures around 24°C, demonstrating resilience to a wide range of environmental conditions (Duque *et al.*, 2022). Its ability to produce high yields per unit area within a short growing season, particularly during brief rainy periods, gives it an advantage over other staple crops. Furthermore, it offers flexible planting and harvesting times, tolerates high-temperature and low-fertility soils, and exhibits strong resistance to pests and diseases (Iese *et al.*, 2018). Due to its relatively low labor requirements, sweet potato is especially well-suited for smallholder farming systems (Mcewan *et al.,* 2020). As a fast-maturing crop (three to five months), it serves as an effective rotational crop, thriving in diverse ecological conditions and demonstrating notable drought resistance.

In recent years, sweet potato has been introduced to regions with extreme continental climates, such as Kazakhstan, where agricultural systems face multiple abiotic stress challenges, including drought, salinity, high temperatures, and occasional low temperatures during the growing season (Zhapar *et al.*, 2021). Its ability to withstand such conditions highlights its potential as a climate-resilient crop for food security in arid and semi-arid regions.

Effect of drought stress on sweet potato yield

Drought stress is a significant global challenge that limits sweet potato yields, particularly in semi-arid regions where the crop is commonly cultivated. Due to the intricate genetic and physiological mechanisms involved in water deficiency resistance, enhancing our genomic understanding of sweet potato's response to drought stress is crucial for developing strategies to sustain productivity under such conditions.

Certain sweet potato types handled drought very well. They also had a good yield index (%) under drought conditions. These genotypes also demonstrated higher values for geometric mean productivity (GMP), stress tolerance index (STI), and mean productivity (MP), indicating their superior adaptability under both drought-stressed and optimal conditions. Correlation analysis showed a strong positive association. STI, MP, and GMP related to yield under optimal conditions (YP) and yield under stress (YS). These traits are useful for selecting drought-tolerant varieties. Additionally, STI has been recognized as a valuable indicator for evaluating genotypes in severely drought-affected areas.

High-yielding sweet potato genotypes have desirable tuber quality and drought tolerance. They recorded high STI values. They also showed low susceptibility index values. Correlation analysis further confirmed significant positive relationships between YP, YS and the selection indices (STI, MP, and GMP) reinforcing their utility in drought tolerance screening.

Beyond directly impacting yield, drought stress can also diminish the effectiveness of agronomic practices, such as fertilizer application and pest and disease management. Severe drought conditions necessitate increased irrigation, escalating production costs. Insufficient water supply, especially during the early growth stages, negatively affects tuber formation, leading to reduced yields and inferior tuber quality. Prolonged drought can reduce sweet potato yield. It can also lower the quality of root tubers. This leads to major economic losses for farmers. Therefore, enhancing water-use efficiency is essential, particularly in regions experiencing water scarcity and where supplementary irrigation is required. Furthermore, in warmer climates, high temperatures exacerbate the effects of water stress on crop productivity.

Drought-induced stunted growth significantly affects sweet potato yield. A study investigating medium drought stress exposure found that while it negatively influenced all plant characteristics, it allowed differentiation between genotypes. Conversely, severe drought stress masked these differences. The study demonstrated that maintaining adequate crown cover, stomatal conductivity and stem length is essential for achieving a good yield. Strong correlations between stem length, leaf area index and yield suggest that these traits can serve as valuable screening tools in future research (Laurie *et al.*, 2022).

Developing sweet potato varieties that combine high yield potential with drought tolerance remains a primary breeding objective, particularly in drought-prone regions.

Understanding the physiological and biochemical traits associated with drought resistance is essential for implementing effective breeding strategies. Additionally, integrating yield modeling can help optimize selection processes, reducing the time and costs required for extensive field trials.

Drought tolerance mechanisms in sweet potato: physiological and biochemical adaptations

Drought, salinity, and low temperatures are among the most significant environmental stressors limiting sweet potato productivity worldwide. Drought alone is responsible for an estimated 25% yield loss annually, with the crop being particularly vulnerable during its establishment phase, including the vining stage and root initiation. However, once rooted, sweet potato exhibits notable drought resistance, contributing to its higher yield potential compared to other staple crops grown in developing countries. In addition to its productivity advantages, sweet potato's rich nutritional profile makes it a valuable food source for farmers in drought-prone regions.

Despite its adaptability, drought stress triggers various morphological, physiological and biochemical changes in sweet potato, often negatively impacting its agronomic and economic performance. Drought conditions reduce root development, branching, leaf area index, stem height and length, stomatal conductance, leaf size, and overall photosynthetic efficiency. Additionally, drought-induced oxidative stress leads to the excessive production of reactive oxygen species (ROS), which can be harmful to plant cells. To mitigate these effects, sweet potato activates enzymatic and non-enzymatic antioxidant defense mechanisms, including increased activity of ascorbate peroxidase (APX) (Zhang *et al.*, 2022), glutathione reductase (Laurie *et al.*, 2022), catalase (Huang *et al.*, 2022), superoxide dismutase (SOD), carotenoids, ascorbic acid, glutathione, and tocopherols. These antioxidant compounds help regulate ROS levels, enhancing the plant's drought tolerance.

Comprehensive studies on sweet potato's drought response have identified several physiological and biochemical markers that contribute to its drought resilience. Key indicators such as nitrate reductase (NR) activity, free proline accumulation, and chlorophyll concentration at 60 days after planting have been suggested as effective screening tools for selecting drought-tolerant genotypes. Additionally, research on orange-fleshed sweet potato varieties has shown significant variation in tuber weight under drought conditions, while other traits such as tuber quantity, beta-carotene content, starch content, and moisture levels remained relatively stable. Orange-fleshed varieties also exhibit higher concentrations of essential minerals such as magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn) and calcium (Ca), whereas creamy-fleshed varieties tend to have higher starch and carbohydrate content. The high carbohydrate content and abundance of essential vitamins further highlight sweet potato's importance in maintaining a nutritious diet, especially in water-limited regions (Kwak, 2019).

In addition to these biochemical adaptations, secondary metabolites synthesized under drought stress serve as valuable markers for germplasm selection in breeding programs. Traditional breeding efforts to improve sweet potato varieties have historically focused on increasing yield rather than enhancing stress tolerance. However, given the increasing threat of climate change to global food security, modern breeding strategies are now integrating physiological and molecular insights to develop drought-resistant cultivars (Kapoor *et al.*, 2020). Advancing sweet potato breeding through these approaches will be critical in ensuring sustainable production and food security in drought-prone environments.

Physiological and biochemical adaptations of sweet potato to drought stress

Drought, along with salinity and low temperatures, is a major environmental stress that significantly reduces sweet potato productivity worldwide. Drought alone accounts for an estimated 25% annual yield loss, with the crop being particularly vulnerable during the establishment phase, including the vining stage and root initiation. However, once fully rooted, sweet potato exhibits strong drought tolerance, contributing to its higher yield potential compared to other staple crops grown in developing countries. Additionally, its rich nutritional content makes it an essential food source for farmers in water-scarce regions.

Despite its resilience, drought stress induces several morphological, physiological, and biochemical alterations in sweet potato, often leading to reduced agronomic performance. Under drought conditions, root development, branching, leaf area index, stem height, stomatal conductance, leaf expansion, and photosynthetic efficiency all decline. Furthermore, drought triggers oxidative stress, leading to excessive production of reactive oxygen species (ROS), which can damage plant cells. To counteract these effects, sweet potato activates a complex antioxidant defense system involving both enzymatic and non-enzymatic mechanisms. Increased activity of antioxidant enzymes such as ascorbate peroxidase (APX), glutathione reductase, catalase, and superoxide dismutase (SOD) plays a crucial role in detoxifying ROS. Additionally, non-enzymatic antioxidants such as carotenoids, ascorbic acid, glutathione, and tocopherols help maintain cellular balance and enhance drought tolerance.

Studies on sweet potato's response to drought stress have identified key physiological and biochemical markers associated with drought resilience. Indicators such as nitrate reductase (NR) activity, free proline accumulation, and chlorophyll concentration at 60 days after planting have been proposed as effective screening tools for selecting drought-tolerant genotype. Research on orange-fleshed sweet potato varieties has revealed that, while tuber weight varies significantly under drought conditions, other traits such as tuber quantity, beta-carotene content, starch content, and moisture levels remain largely unaffected. Additionally, orange-fleshed varieties exhibit higher concentrations of essential minerals such as magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), and calcium (Ca), whereas creamy-fleshed varieties tend to have higher starch and carbohydrate content. The high carbohydrate and vitamin content of sweet potato further underscores its value in promoting food security, especially in drought-prone regions (Kwak, 2019).

Beyond these physiological and biochemical adaptations, secondary metabolites synthesized in response to drought stress serve as critical markers for germplasm selection in breeding programs (Mgcibelo, 2014). While traditional breeding efforts have primarily focused on enhancing yield, there is a growing emphasis on developing drought-tolerant varieties by integrating knowledge of plant physiological responses and molecular mechanisms. Given the increasing frequency of drought events and their impact on global agriculture, modern breeding strategies are being designed to improve sweet potato's resilience to environmental stresses, ensuring long-term food security (Kapoor *et al*., 2020).

Chlorophyll content index (CCI)

Drought stress was applied 60 days after planting. It did not reduce CCI values. The observation was made in sweet potato (Sapakhova *et al*., 2023). CCI values2usually decline under drought stress. In this case, the decline was smaller. This decline was recorded at 40, 60, 80, and 100 days after planting.The Hernandez variety had a small improvement in its chlorophyll levels when it was grown under regular, non-stressful conditions. They were higher than the values under severe drought conditions.Variations in CCI levels across different sweet potato varieties under both control and high-stress treatments at 60 days after planting suggest genetic differences and variations in photosynthetic activity (Zhang *et al*., 2022).

A significant decline in CCI values was observed 120 days after planting in all genotypes under drought stress. Wheat also showed a big decrease in CCI levels under drought, similar to other findings. Sweet potato varieties, including Monate, Resisto, and Bophelo, showed drop in CCI levels. These plants had less chlorophyll than the control plants. Since drought impacts the photosynthetic system, it may also hinder growth, particularly in crown and stem development. Chlorophyll breakdown can affect how well the antioxidant enzyme system works in sweet potato. Earlier studies reported that this system was not very strong. CCI could serve as a potential marker for heat tolerance selection.

Reactive oxygen species (ROS)

Certain metabolites play key roles in plant adaptation to various abiotic stressors. The accumulation of osmolytes or compatible solutes, such as polyamines, free proline, trehalose, glycine betaine, and sugar alcohols, can help protect plants from adverse environmental conditions. Sweet potato is rich in β-carotene, vitamin C, and antioxidants, which contribute to its resilience under stress. Sweet potato varieties produce, use, and contain these secondary metabolites.

To mitigate the negative impact of abiotic stress, plants employ different signaling pathways, adjust growth patterns, accumulate compatible solutes, activate antioxidants, and produce chaperones and stress proteins. ROS are oxygen molecules that are formed when oxygen is partly changed into other forms. These molecules can be very reactive or less reactive. Excess ROS production under abiotic stress can lead to oxidative damage, affecting proteins, lipid membranes, and nucleic acids, ultimately causing cell death. To counteract these effects, plants utilize enzymatic and non-enzymatic antioxidant mechanisms to minimize oxidative stress and enhance tolerance to abiotic stressors. Antioxidant system activity—both enzymatic and non-enzymatic—acts as a reliable indicator of drought tolerance in plants (Laurie *et al*., 2022).

Betaines

Betaines are non-protein amino acids containing a quaternary ammonium and carboxyl group. These compounds help stabilize the quaternary structures of enzymes, complex proteins, and membrane systems, including the photosystem II complex. Their synthesis is induced under stress conditions, with concentrations correlating to stress tolerance. The accumulation of glycine betaine, the most widely studied betaine, enhances plant resilience to multiple abiotic stressors while also improving yields under non-stress conditions (Chen *et al*., 2008). Researchers used *Agrobacterium tumefaciens* to insert the BADH gene. BADH stands for betaine aldehyde dehydrogenase. They transferred the gene from spinach into sweet potato's embryonic suspensions. Transgenic plants over expressing this gene exhibited increased glycine betaine synthesis, leading to improved tolerance to oxidative, salt, and low-temperature stress (Fan *et al*., 2015). Transgenic sweet potato plants with the BADH gene showed better resistance to osmotic stress, low temperatures, and oxidative stress (Fan *et al*., 2012).

Trehalose

Trehalose, a sugar composed of two glucose molecules, functions as an osmoprotectant and supports plant survival under adverse environmental conditions. It has been implicated in regulating stomatal movement and enhancing water use efficiency in higher plants. Sufficient trehalose levels in plant cells are crucial for growth under stress.

Trehalose synthesis occurs in two stages, catalyzed by trehalose-6-phosphate synthase (TPS) and trehalose-6-phosphate phosphatase (TPP). Trehalose-6-phosphate is then dephosphorylated to trehalose by the TPP enzyme. Researchers isolated the IbTPS gene. The gene was from *Ipomoea batatas*. They overexpressed this gene in transgenic plants. These transgenic plants showed improved salinity resistance. The resistance was better compared to control plants (Jiang *et al*., 2014).

Polyamines

Polyamines are small polycations. They play vital roles in organisms. At physiological pH, they interact with negatively charged molecules such as membrane phospholipids, nucleic acids, and specific proteins, stabilizing them under abiotic stress. Plants contain several common polyamines. These include putrescine, spermidine, and spermine. Putrescine is a diamine. Spermidine is a triamine. Spermine is a tetramine. These compounds can be synthesized from amino acids such as L-ornithine, L-lysine, and L-arginin.

A study reported about transgenic sweet potato plants. These plants had the FSPD1 gene. This gene is called the spermidine synthetase gene. The plants expressed this gene. The gene came from *Cucurbita ficifolia*. The transgenic plants showed elevated spermidine levels. They had tolerance to heat stress. The tolerance was increased. It was better than in normal plants. They had better tolerance to chilling stress. They had tolerance to heat stress. This tolerance was enhanced. These traits were better compared to wild-type plants (Kasukabe *et al*., 2006).

Sugar alcohols

Inositol, a well-known osmolyte, plays a role in signal transduction under stress. Myo-inositol is made through a biosynthesis process. A key limiting step occurs in this process. This step is done by an enzyme. The enzyme has a name. It is called l-myo-inositol-1-phosphate synthase (MIPS). Researchers isolated the IbMIPS1 gene. The gene was from *I. batatas*. They found that overexpressing this gene significantly improved salinity tolerance. It also improved water stress tolerance. This was observed in transgenic sweet potato plants. The plants were tested under field conditions.

Free proline content

Proline accumulation is a key mechanism for plant stress tolerance, helping stabilize proteins, membranes, and neutralize free radicals. As an osmoprotectant, proline helps maintain osmotic balance under stress. Proline can be applied externally. This is called exogenous proline application. It can enhance drought resistance.

The enzyme pyrroline-5-carboxylate reductase (P5CR) plays a crucial role in proline biosynthesis. Scientists used transgenic sweet potato plants. They over-expressed the IbP5CR gene in these plants. The gene was more active than normal. This over-expression improved their salt tolerance. Increased free proline levels in drought-stressed plants, with concentrations rising from 2 µmol/ g to 22 µmol/ g, representing a fivefold increase compared to controls was observed. The Bophelo variety was used in the study. The study involved drought stress. It showed higher proline accumulation.

Antioxidant enzymes

Ascorbate peroxidase (APX): Water stress significantly increases APX activity, with ninefold increase under drought stress. APX expression in chloroplasts enhances drought tolerance.

Superoxide dismutase (SOD): Different sweet potato varieties exhibited increased SOD activity under water stress, with values ranging from 0.350 to 0.85 units/mg protein.

Glutathione reductase (GR): GR is an enzyme. Drought stress increased GR levels in sweet potato. The GR activity ranged from 2 to 73 nmol NADPH min^{-1} mg $protein^{-1}$.

Nitrate reductase (NR): Severe drought stress significantly reduced NR activity, affecting nitrogen assimilation and photosynthesis.

Crop management strategies for drought mitigation

Crop management under water-limited conditions involves two primary approaches: agronomic and genetic. The selection and enhancement of genotypes suited to specific environments can be achieved using appropriate selection indicators for water deficiency tolerance. Developing drought-tolerant varieties presents a cost-effective genetic strategy, particularly beneficial for small-scale farms.

An efficient selection method is needed to evaluate water deficiency tolerance. To do this, various indicators should be assessed. These indicators should be checked early in the growing season. These include SOD activity, NR activity, APX activity, stomatal conductance, leaf area, chlorophyll content, leaf water content, free proline content, and water use efficiency (WUE). Studies have utilized these indicators in crops such as sugar beet, potato, cotton, and wheat, aiding in cost- and time-efficient genotype selection. These parameters, either individually or in combination, can enhance genotype selection and breeding methods.

Several approaches have been employed to evaluate drought tolerance and WUE in crops, including measurements of potential relative humidity, diffusion pressure deficit, chlorophyll stability index, and carbon isotope discrimination (Gitore *et al*., 2021). However, these methods are often time-consuming, limiting their effectiveness for screening large numbers of varieties. Earlier drought tolerance studies focused on overall drought effects without isolating specific component traits (Osmolovskaya *et al*., 2018). These traits, however, can be leveraged to refine screening methodologies. Despite some challenges, including limited understanding of drought tolerance genetics and variation in plant protection mechanisms, physiological and phenotypic screening methods have been applied to assess genotype-environment interactions.

Although research on developing drought tolerance evaluation methods for sweet potato remains limited, significant progress has been made in identifying optimal selection strategies. Drought conditions using a line-source sprinkler system to examine its effects on yield and leaf water potential in eight sweet potato varieties were simulated. Drought experiments in pot-grown sweet potatoes, investigating photosynthesis, leaf surface development, stomatal conductance, leaf water potential, and soil water potential were conducted. Sweet potato's stomatal movement remained unaffected by water stress. Its nitrate reductase activity declined. The decline happened as soil water potential decreased. The most effective approach for assessing sweet potato's drought tolerance involves field trials where irrigation is managed without interference from natural precipitation. In addition to field-based evaluations, implementing strategies such as optimizing water use efficiency, selecting drought-tolerant genotypes, large-scale screening, conventional and marker-assisted selection (MAS), exogenous hormone applications, osmoprotectant treatments for seeds or plants, and advancements in genetic engineering for drought resilience are highly recommended.

Developing drought tolerant sweet potato varieties

When breeding crops, it is essential to consider the key factors that limit productivity. As highlighted earlier, drought is a major constraint on sweet potato yield, causing significant annual losses. This challenge arises from morphological, biochemical, physiological, and molecular changes triggered by water deficiency. These changes serve as valuable indicators for breeding and developing drought-tolerant sweet potato genotypes. Sweet potato cultivation conditions vary widely. Root yield under optimal conditions is not enough for selecting germplasm. Therefore, selection should not be based solely on root yield under optimal conditions. With the increasing impact of climate change, the selection of drought-tolerant varieties has become a priority for growers. Small-scale farmers, in particular, must take multiple factors into account for successful production. These include selecting varieties that can adapt to poor soil fertility, limited pest control, and, most importantly, restricted irrigation. Research plays a vital role in identifying and developing the most suitable varieties for commercial use.

Traditional breeding approaches face several limitations in enhancing sweet potato traits. Many sweet potato varieties exhibit reduced flowering and fertility or fail to bloom altogether. High levels of male sterility, along with self- and inter-specific incompatibility, hinder breeding efforts. Additionally, the hexaploid nature (outcrossing polyploidy) of sweet potato complicates conventional breeding processes (Yang *et al*., 2022).

Breeding sweet potato for drought tolerance requires a thorough understanding of drought stress effects, the availability of genetic diversity, and the implementation of effective breeding and selection methods to identify and develop promising clonal varieties. Drought poses a significant environmental challenge for sweet potato cultivation, particularly in non-irrigated agricultural areas. Different varieties respond variably to limited groundwater, emphasizing the need to breed varieties with strong drought tolerance.

Developing effective genetic management technologies requires reliable, reproducible, and efficient field and laboratory screening methods. These tools enable researchers to identify drought tolerance traits in sweet potato germplasm and incorporate them into high-yielding, stress-tolerant varieties (Xiao *et al*., 2022). Irrigation effects on sweet potato growth parameters and the impact of mulching and pruning on mitigating heat stress was evaluated. The findings from such studies offer practical strategies to minimize water loss during sweet potato cultivation.

Using drought and yield indices to select germplasm for different production environments has shown promising results. This approach is particularly effective when applied early in the breeding cycle. Plant breeders must carefully consider critical stages of plant growth and development. To maximize sweet potato yield in regions like Kenya, experts recommend planting tubers early in the rainy season to avoid water shortages during the crucial first four months of growth (Abdallah *et al*., 2020).

Drought tolerance of 50 sweet potato genotypes was evaluated under both laboratory and field conditions, identifying 12 genotypes as drought-tolerant based on wilting duration. Additionally, five highly productive genotypes were selected for use as parents in breeding programs for drought tolerance. Cultivated sweet potato varieties exhibit greater stress tolerance than their wild counterparts, largely due to their ability to develop storage roots, which play a key role in their response to environmental stress. Wild *I. batatas* species do not produce storage roots. They also do not display significant drought tolerance. Therefore, improving cultivated sweet potato varieties remains the most effective strategy for enhancing yield and drought resistance (Nhanala and Yencho, 2021). Various molecular and genetic mechanisms contribute to plant stress tolerance, with environmental factors influencing their interactions. However, research on the phenotyping and genotyping of sweet potato for water stress resistance remains limited. Epigenetic modifications introduce variability in plants. Genetic element mobility also introduces variability. This variability affects plant stress resistance (Akomeah *et al*., 2019). Despite significant advancements, substantial opportunities remain to further enhance plant resilience to abiotic stressors.

The insights presented here can aid in screening sweet potato for drought sensitivity and tolerance. They also support breeding programs aimed at improving sweet potato adaptability to climate change through targeted selection and genetic improvements.

Enhancing stress tolerance through stress protein expression

Heat shock proteins (HSPs) play key roles in abiotic stress tolerance by acting as molecular chaperones that assist in protein folding and transport while preventing cellular damage under stressful conditions. Over expression of stress protein-encoding genes enhances plant survival under abiotic stress. The Arabidopsis thaliana cDNA gene AtP3B, encoding a ribosome-associated chaperone, improves tolerance in transgenic plants. Cell wall stabilization proteins are crucial for structural integrity during osmotic stress. The Sap1 gene is from *Xerophyta viscosa*. This gene encodes a stress protein. The gene helps improve sweet potato plants through lab-based changes. It leads to improved growth under drought conditions.

Late-embryogenesis-abundant (LEA) proteins, expressed during seed maturation, contribute significantly to stress responses. IbLEA14, encoding the LEA14 protein, enhances tolerance to drought and salt stress and is expressed in various tissues under water stress conditions. It's over expression in transgenic calli enhances drought tolerance by increasing lignin content, which plays a vital role in drought resistance. Further studies are needed to understand the role of lignin accumulation under stress conditions.

Enhancing tolerance through transport protein expression

Na^+/H^+antiporters are membrane proteins. They are located in the plasma or vacuolar membranes. Antiporters are transport proteins. They help move sodium ions. This helps maintain ion homeostasis. It also prevents excessive Na^+ accumulation. The IbNHX2 gene comes from *I. batatas*. It is a vacuolar Na^+/H^+ antiporter gene. This gene helps in ion transport within the cell and overexpressed in transgenic sweet potato plants. Overexpression of the gene significantly enhanced salt tolerance. The plants became better at handling dry conditions because of the gene. Similarly, introducing the Na+/H+ anti-transporter gene from *Arabidopsis thaliana* into sweet potato increases resistance to cold and salt stress.

Mitigating oxidative stress

Plants produce reactive oxygen species (ROS). ROS levels must be regulated. Plants experience stress. They respond to this stress. These molecules are constantly generated in mitochondria and chloroplasts and can cause oxidative cell death (Movahedi *et al*., 2024). They can be harmful at high amount. The plant's antioxidant defense system mitigates oxidative stress through ROS detoxification. One example for gene involved in ROS management and stress tolerance is IbNFU1 gene comes from a salt-tolerant *I. batatas* variety. This gene produces a protein. The protein acts like a helper or base for making tiny structures (iron–sulfur clusters) that the plant needs to stay healthy and active. It helps in assembling iron–sulfur clusters. The gene was overexpressed in transgenic plants. The gene was made more active, and this helped the plants deal with salt stress. Iron–sulfur cluster scaffold proteins play essential roles in energy metabolism and ROS scavenging (Mansoor *et al*., 2022).

A study utilizing Copper/Zinc superoxide dismutase (Cu/Zn-SOD) and APX genes demonstrated improved ROS deactivation and oxidative stress resistance in transgenic sweet potato plants compared to controls.

Activation of phytohormone signaling pathways

Abscisic acid (ABA) is a key chemical in plants that helps them deal with stress. The LOS5/ABA3 gene, encoding a molybdenum cofactor sulfurase enzyme, is essential for ABA biosynthesis and enhances salt tolerance in transgenic sweet potato plants. The α/β-hydrolase gene IbMas, encoding maspardin protein, plays a role in osmotic balance regulation, and its over expression improves salinity tolerance.

Regulation of gene expression for stress resistance

Plant resistance mechanisms involve complex regulatory networks. Several transcription factors (TFs), including

NAC, bZIP, WRKY, and AP2/ERF, play vital roles in abiotic stress resistance. Plants have many coding sequences. Nearly 7% belong to the group of transcription factors (TFs. Transcription factors help control gene expression. Many of these transcription factors help plants respond to stress. They help the plant respond quickly when something stressful happens (Jia *et al.*, 2022; Khoso *et al.*, 2022).

Sugar Will Eventually be Exported Transporters (SWEET) are key regulators of sugar transport and plant stress responses. IbSWEET genes have been identified in I. batatas (27 SWEETs), I. triloba (25 SWEETs), and *I. trifida* (27 SWEETs), influencing growth, hormone interactions, and abiotic stress responses (Dai *et al.*, 2022). High IbSWEET expression correlates with improved drought and salt tolerance, making them candidates for stress-resistant breeding programs.

Gene expression profiling identified receptor-like kinases inhibited at 24 hr post-stress but not at 48 hr post-stress, indicating their role in dehydration responses. Down regulation of LHCSB6 and SLAC1 orthologs in sweet potato suggests their importance in stomata closure during drought stress (Lau *et al.*, 2018). Several studies have investigated genes like p-hydroxyphenylpyruvate dioxygenase (IbHPPD). IbHPPD enhances stress resistance. Other studies have looked into IPT. IPT is involved in cytokinin biosynthesis. It also plays a role in drought tolerance (Kim *et al.*, 2021a; Hrmova *et al.*, 2021; Tang *et al.*, 2023). The DUF668 gene family has several members. These include IbDUF668-6, IbDUF668-7, IbDUF668-11, and IbDUF668-13. These genes are found in sweet potato. They help plants survive when there's not enough water or when the soil is too salty. They encode membrane proteins (Liu *et al.*, 2023).

Transcription factor-based stress regulation

WRKY TFs, initially isolated from sweet potato as Sweet Potato Factor1, play major roles in stress signaling. Multiple IbWRKY genes regulate abiotic stress responses, and their co-expression is highly complex (Liu *et al.*, 2022). GRAS TFs also contribute to stress responses, with IbGRAS71 identified as a key player in salt and drought tolerance. Phytochrome-interacting factors (PIFs) regulate responses to various stressors, and IbPIF3.1 is induced under drought, salinity, cold, and heat stress, as well as biotic stressors.

Carotenoid associated stress tolerance

The sweet potato orange gene (IbOr-R96H) enhances carotenoid accumulation and stress resistance. Overexpression of IbOr-R96H increases antioxidant activity and heat tolerance in transgenic plants (Kim *et al.*, 2021b). *Agrobacterium tumefaciens* mediated transformation to develop IPT - expressiveness sweet potato lines, resulting in enhanced drought tolerance (Nawiri *et al.*, 2017).

Molecular responses to drought stress

Proteomic studies identified 389 deferentially expressed genes (DEGs) and 1168 deferentially expressed proteins (DEPs) in response to drought (Tang *et al.*, 2023). These are linked to carbon, phenylalanine, starch, and cellulose metabolism, as well as heat shock proteins. Plants respond to drought by producing signal molecules such as ABA, Ca2+, inositol-1,4,5-triphosphate (IP3), and cyclic adenosine diphosphate ribose (cADPR) (Kakimoto, 2001). Functional gene products, including proline (Pro), glycine betaine (GB) (Fan *et al.*, 2015), soluble sugars (SS), and late embryogenesis abundant (LEA) proteins (Mertenz *et al.*, 2018), play essential roles in stress adaptation.

Molecular breeding offers promising pathways for improving sweet potato's tolerance to abiotic stress through genetic modifications. Advances in stress protein expression, transport protein regulation, oxidative stress mitigation, phytohormone signaling, and TF-based regulation collectively enhance the crop's resilience. Future research should focus on refining these genetic strategies to develop high-yielding, stress-resistant sweet potato varieties.

Genetic engineering approaches for abiotic stress tolerance in sweet potato

Various strategies have been developed to enhance abiotic stress tolerance, such as introducing genes encoding late-embryogenesis-abundant proteins, transcription factors (TFs), transport proteins, heat shock and cold shock proteins, enzymes that accumulate osmolytes and antioxidants, and hormone-related gene expression regulators. Many stress-resistance genes have been characterized in *I. batatas*, opening possibilities for cis-genic approaches (Ahamed *et al.*, 2024).

The limited focus on genetic transformation in sweet potato stems from the complexity of its hexaploid genome and the historical challenges in establishing efficient transformation and regeneration protocols. However, significant breakthroughs occurred in 2016 with the complete sequencing of one of the haplogenomes of sweet potato (Yang *et al.*, 2022), accelerating the development of functional genomics for this crop. Recent advancements have also optimized transformation and regeneration processes, enhancing the potential for genetic improvements in sweet potato (Yan *et al.*, 2022).

Advancements in understanding the genetic mechanisms that help plants withstand abiotic stress have significantly progressed in recent decades. The identification and cloning of key genes have enabled both private and public researchers to develop plant varieties capable of enduring environmental stress without compromising yield (Kim *et al.*, 2021a; Tang *et al.*, 2023). Genetic modifications could lead to new varieties with improved tolerance to abiotic stress, enhancing water use efficiency and productivity under adverse conditions.

Regeneration and transformation in sweet potato

The transformation and regeneration of various sweet potato genotypes were explored. The study found that somatic embryogenesis remains genotype-dependent, influencing the frequency and variability of regeneration among sweet potato varieties. Transgenic sweet potato plants were successfully produced using selected calli and somatic embryo formation on modified media. The results highlight that existing regeneration and transformation protocols depend heavily on the in vitro response of specific genotypes, Notably, leaf explants demonstrated superior modification and regeneration potential compared to other tissue types, making somatic embryogenesis the most effective regeneration technique for sweet potato. The study also underscored sweet potato tissue's sensitivity to mannose, requiring extended culture periods to observe its effects, as its lethal impact does not manifest in early growth stages. Furthermore, an effective transgenic PSARK-IPT sweet potato plant developed, which exhibited delayed aging under drought conditions and outperformed wild species in water retention, chlorophyll content, tuber development, and overall growth.

Proline assisted in stress adaptation

Proline, a key osmolyte apart from carbohydrates, plays a crucial role in plant stress adaptation. Studies have established a positive correlation between proline levels and resistance to environmental stressors, including intense ultraviolet radiation, soil salinity, extreme temperatures, and oxidative stress.

Plants synthesize proline in the cytosol via either the ornithine or glutamate pathways, with the latter primarily activated in response to environmental stress. Genetic engineering has successfully introduced genes involved in proline biosynthesis, resulting in plants resistant to cold, salinity, and osmotic stress. Moreover, proline accumulation under stress conditions is not solely due to enhanced synthesis but also due to inhibited degradation. Proline dehydrogenase, the key enzyme in proline bio-degradation, has been silenced in *Arabidopsis*, leading to substantial proline accumulation and improved resistance to frost and high salinity.

Enhancing sweet potato germplasm for global food security

Expanding the genetic diversity of sweet potato germplasm is crucial for ensuring food security, particularly in developing nations with high populations and persistent malnutrition (Kou *et al.*, 2023; Haque *et al.*, 2020). Recent research integrating genotyping and phenotyping has provided valuable insights for breeding stress-tolerant germplasm, fostering the development of genetic resources and improving sweet potato diversity (Liu *et al.*, 2022; Daurov *et al.*, 2018; Slonecki *et al.*, 2023; Huo *et al.*, 2023).

Varietal achievements made in India

India has made significant strides in developing climate-resilient sweet potato varieties to combat the challenges posed by climate change, including drought, salinity, pest infestation, and nutrient-poor soils. One such notable variety is NSP-7, developed for the semi-arid regions of South Gujarat. It yields approximately 23.39 tonnes per hectare and shows strong resistance to the sweet potato weevil, making it ideal for stress-prone areas (Patel *et al.*, 2024). Another widely adopted variety is Sree Arun, developed by ICAR-CTCRI (Central Tuber Crops Research Institute), which is drought-tolerant and performs well in Southern Indian states like Kerala, Tamil Nadu, and Karnataka. It matures in about 90–100 days and yields around 25–28 tonnes per hectare (Anil *et al.*, 2025).

Sree Nandini is another promising variety suitable for both rainfed and irrigated conditions, popular in Andhra Pradesh and Odisha, with high beta-carotene content and a maturity of 80–90 days (Ranasingh *et al.*, 2024). Konkan Ashwini, primarily grown in coastal Maharashtra and Karnataka, thrives in saline soils and shows resistance to viral diseases and root rot, making it suitable for the western coastal belt. Co-3, developed in Tamil Nadu, is an early-maturing variety with good tuber size and dry matter content, ideal for short-duration cropping systems (Gahane *et al.*, 2024).

For eastern India, Sree Kanaka offers a dual benefit of high yield and pest resistance, especially against sweet potato weevils, while Rajendra Sakarkand-5, developed in Bihar and Uttar Pradesh, is drought-tolerant and performs reliably in stress-prone soils (Kumar *et al.*, 2025). Gauri, cultivated in Odisha and West Bengal, is known for its high beta-carotene and resistance to common pests and diseases. Lastly, Kala Dhan is suitable for North and Central Indian dryland areas and is valued for its resistance to root rot and adaptability to rainfed cultivation ((Jana *et al.*, 2024). These varieties underscore India's commitment to enhancing food and nutritional security through crop diversification and climate-resilient agriculture.

Conclusion

Drought poses a major challenge to crop production in arid regions, significantly reducing yields and increasing cultivation costs. As climate change intensifies, developing drought-tolerant crops has become essential for sustaining agriculture in these water-scarce environments. Sweet potato, with its natural resilience and adaptability, presents a valuable opportunity for enhancing food security in arid regions. Recent advancements in sweet potato genomics and metabolomics provide a strong foundation for breeding improved drought-resistant varieties. Accelerating this progress will require an integrated approach that combines traditional breeding techniques with modern genetic and biotechnological innovations. Additionally, optimizing agronomic practices to suit the harsh conditions of arid landscapes is critical. By reducing the need for irrigation and minimizing production costs, drought-tolerant sweet potato varieties can improve farmer livelihoods while ensuring a stable food supply for growing populations in arid and semi-arid regions.

Acknowledgements

The authors would like to thank Tamil Nadu Agricultural University/ Department of Environmental Sciences for providing the necessary academic environment and support during the preparation of this review.

Conflict of Interest

The authors have no conflict of interest.

References

Abdallah, B., Githiri, S.M., Kariuki, W. and Saha, H.M. 2020. Evaluation of the performance of sweet potato (*Ipomoea batatas*) clones under water stress in the coastal lowlands of Kenya. *World Journal of Agricultural Research*, 8:114-120.

Ahmed, S., Khan, M.S.S., Xue, S., Islam, F., Ikram, A.U., Abdullah, M., Liu, S., Tappiban, P. and Chen, J. 2024. A comprehensive overview of omics-based approaches to enhance biotic and abiotic stress tolerance in sweet potato. *Horticulture Research*, 11(3):uhae014. doi: 10.1093/hr/uhae014.

Akomeah, B., Quain, M.D., Ramesh, S.A., Anand, L. and Rodríguez Loópez, C.M. 2019. Common garden experiment reveals altered nutritional values and DNA methylation profiles in micropropagated three elite Ghanaian sweet potato genotypes. *PLoS ONE*, 14: e0208214.

Anil, S.R., Sheela, M.N., Mohan, C., Jyothi, A.N., Chandra, C.V., Shanawas, S. and Sreekumar, J., 2025. Assessment of sweet potato germplasm for selection of day-neutral genotypes for tropical India. *Euphytica*, 221(4): 1-14.

Dai, Z., Yan, P., He, S., Jia, L., Wang, Y., Liu, Q., Zhai, H., Zhao, N., Gao, S. and Zhang, H. 2022. Genome-wide identification and expression analysis of SWEET family genes in sweet potato and its two diploid relatives. *International Journal of Molecular Science,* 23: 15848.

Daurov, D., Zhapar, K., Daurova, A., Volkov, D., Bakbergenova, M., Tolegenova, D., Shamekova, M. and Zhambakin, K. 2018. Production of virus-free sweet potato planting material for the southeast of Kazakhstan. *International Journal of Agriculture and Biology*, 20: 851-856.

Duque, L.O., Sánchez, E., Pecota, K. and Yencho, C. 2022. A win-win situation: Performance and adaptability of Petite sweet potato production in a temperate region. *Horticulture*, 8: 172.

Fan, W., Deng, G., Wang, H., Zhang, H. and Zhang, P. 2015. Elevated compartmentalization of Na^+ into vacuoles improves salt and cold stress tolerance in sweet potato (*Ipomoea batatas*). *Physiologia Plantarum*, 154: 560–571.

Fan, W., Zhang, M., Zhang, H. and Zhang, P. 2012. Improved tolerance to various abiotic stresses in transgenic sweet potato (*Ipomoea batatas*) expressing spinach betaine aldehyde dehydrogenase. *PLoS ONE*, 7: e37344.

Gahane, S., Relekar, P., Kadam, J., Shirke, G.D., Ranveer, D.R. and Rane, S., 2024. Development of sweet potato (*Ipomoea batatas* L.) and mango (*Mangifera indica* L.) blended bar. *International Journal of Advanced Biochemistry Research*, 8: 551-557.

Gitore, S.A., Danga, B., Henga, S. and Gurmu, F. 2021. Evaluating drought tolerance indices for selection of drought tolerant orange fleshed sweet potato (OFSP) genotypes in Ethiopia. *International Journal of Agricultural Science and Food Technology,* 7: 249-254.

Haque, E., Tabuchi, H., Monden, Y., Suematsu, K., Shirasawa, K., Isobe, S. and Tanaka, M. 2020. QTL analysis and GWAS of agronomic traits in sweet potato *(Ipomoea batatas* L.) using genome wide SNPs. *Breeding Science*, 70: 283-291.

Hrmova, M. and Hussain, S.S. 2021. Plant transcription factors involved in drought and associated stresses. *International Journal of Molecular Sciences*, 22: 5662.

Huang, C., Liao, J., Huang, W. and Qin, N. 2022. Salicylic acid protects sweet potato seedlings from drought stress by mediating abscisic acid-related gene expression and enhancing the antioxidant defense system. *International Journal of Molecular Science,* 23: 14819.

Huo, R., Zhao, Y., Liu, T., Xu, M., Wang, X., Xu, P., Dai, S., Cui, X., Han, Y., Liu, Z. and Li., Z. 2023. Genome-wide identification and expression analysis of two-component system genes in sweet potato (*Ipomoea batatas* L.). *Frontiers in Plant Science*, 13: 1091620.

Iese, V., Holland, E., Wairiu, M., Havea, R., Patolo, S., Nishi, M., Hoponoa, T., Bourke, R.M., Dean, A. and Waqainabete, L. 2018. Facing food security risks: The rise and rise of the sweet potato in the Pacific Islands. *Global Food Security*, 18: 48-56.

Jana, A., Panchal, C. and Mehta, B. 2024. Utilization of sweet potato solids for value-addition to chocolate ice cream. *Indian Journal of Traditional Knowledge (IJTK)*, *23*(4): 362-371.

Jia, X., Zhen, Z., Lyu, Y. and Zhao, S. 2022. Drought-responsive NAC transcription factor RcNAC72 is recognized by RcABF4, interacts with RcDREB2A to enhance drought tolerance in *Arabidopsis*. *International journal of Molecular Science*, 23: 1755.

Jiang, T., Zhai, H., Wang, F., Zhou, H., Si, Z., He, S. and Liu, Q. 2014. Cloning and characterization of a salt tolerance-associated gene encoding trehalose-6-phosphate synthase in sweet potato. *Journal of Integrative Agriculture*, 13: 1651–1661.

Kapoor, D., Bhardwaj, S., Landi, M., Sharma, S., Ramakrishnan, M. and Sharma, A. 2020. The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. *Applied Sciences*, 10: 5692.

Kasukabe, Y., He, L., Watakabe, Y., Otani, M., Shimada, T. and Tachibana, S. 2006. Improvement of environmental stress tolerance of sweet potato by introduction of genes for spermidine synthase. *Plant Biotechnology*, 23: 75–83.

Khoso, M.A., Hussain, A., Ritonga, F.N., Ali, Q., Channa, M.M., Alshegaihi, R.M., Meng, Q., Ali, M., Zaman, W. and Brohi, R. D. 2022. WRKY transcription factors (TFs): Molecular switches to regulate drought, temperature, and salinity stresses in plants. *Frontiers in Plant Science,* 13: 1039329.

Kim, S.E., Bian, X., Lee, C.J., Park, S.U., Lim, Y.H., Kim, B.H., Park, W.S., Ahn, M.J., Ji, C.Y. and Yu, Y. 2021a. Over expression of 4-hydroxyphenylpyruvate dioxygenase (IbHPPD) increases abiotic stress tolerance in transgenic sweet potato plants. *Plant Physiology Biochemistry*, 167: 420-429.

Kim, S.E., Lee, C.J., Park, S.U., Lim, Y.H., Park, W.S., Kim, H.J., Ahn, M.J., Kwak, S.S. and Kim, H.S. 2021b. Over expression of the golden snp-carrying orange gene enhances carotenoid accumulation and heat stress tolerance in sweet potato plants. *Antioxidants*, 10: 51.

Kou, M., Li, C., Song, W., Shen, Y., Tang, W., Zhang, Y., Wang, X., Yan, H., Gao, R. and Ahmad, M.Q. 2023. Identification and functional characterization of a flavanol synthase gene from sweet potato [*Ipomoea batatas* (L.) Lam.]. *Frontiers in Plant Science*, 4: 1181173.

Kumar, J.S., Saravanan, R., Ravi, V., Sreekumar, J., Sunitha, S. and More, S.J., 2025. Interactive effects of CO_2 enrichment and nitrogen levels on leaf gas exchange capacities of sweet potato. *Journal of Agronomy and Crop Science*, 211(2): e70029.

Kwak, S.S. 2019. Biotechnology of the sweet potato: Ensuring global food and nutrition security in the face of climate change. *Plant Cell Reports,* 38: 1361-1363.

Lau, K.H., del Rosario Herrera, M., Crisovan, E., Wu, S., Fei, Z., Khan, M.A., Buell, C.R. and Gemenet, D.C. 2018. Transcriptomic analysis of sweet potato under dehydration stress identifies candidate genes for drought tolerance. *Plant Direct,* 2: e00092.

Laurie, S.M., Bairu, M.W. and Laurie, R.N. 2022. Analysis of the nutritional composition and drought tolerance traits of sweet potato: Selection criteria for breeding lines. *Plants*, 11: 1804.

Liu, J., Xia, H., Gao, Y., Pan, D., Sun, J., Liu, M., Tang, Z. and Li, Z. 2022. Potassium deficiency causes more nitrate nitrogen to be stored in leaves for low-K sensitive sweet potato genotypes. *Frontiers in Plant Science*, 13: 1069181.

Liu, M., Zhang, Q., Jin, R., Zhao, P., Zhu, X., Wang, J., Yu, Y. and Tang, Z. 2023. The role of IAA in regulating root architecture of sweet potato (*Ipomoea batatas* [L.] Lam) in response to potassium deficiency Stress. *Plants*, 12: 1779.

Mansoor, S., Ali Wani, O., Lone, J.K., Manhas, S., Kour, N., Alam, P., Ahmad, A. and Ahmad, P. 2022. Reactive oxygen species in plants: From source to sink. *Antioxidants*, 11: 225.

Mcewan, M.A., Almekinders, C.J.M., Matui, M.S., Lusheshanija, D., Massawe, M., Chirimi, B. and Ogero, K. 2020. Decentralized sweet potato (*Ipomoea batatas*) vine multiplication in lake zone, Tanzania: Five years later. *Open Agriculture*, 5: 677-689.

Movahedi, A., Kadkhodaei, S. and Yang, L. 2024. Transcriptional regulation and post translational modifications in plant growth and development under abiotic stresses. *Frontiers in Plant Science*, 15:1-3. https://doi.org/10.3389/fpls.2024.1454335

Nhanala, S.E.C. and Yencho, G.C. 2021. Assessment of the potential of wild Ipomoea spp. for the improvement of drought tolerance in cultivated sweet potato *Ipomoea batatas* (L.) Lam. *Crop Science*, 61: 234-249.

Osmolovskaya, N., Shumilina, J., Kim, A., Didio, A., Grishina, T., Bilova, T., Keltsieva, O.A., Zhukov, V., Tikhonovich, I. and Tarakhovskaya, E. 2018. Methodology of drought stress research: Experimental setup and physiological characterization. *International Journal of Molecular Sciences*, 19: 4089.

Patel, H. B., Intwala, C. G., Desai, G. B., Suthar, K. P. and Karmakar, N. 2024. Genotype assessment of NSP-7 sweet potato for climate resilience. *Biochem Journal*, Sp. 8(9S):1075-1078

Ranasingh, N. and Singh, D. 2024. Economic assessment of different varieties of sweet potato (*Ipomoea batatas* (L.) Lam) under the Prayagraj region of India. *International Journal of Plant Soil Scie*nce *36*(6): 178-182.

Sinkovic, L., Neji, M., Kunstelj, N., Pipan, B. and Meglic, V. 2024. Variations in the nutritional profile and colour parameters of sweet potato varieties with different flesh colours: Effects of cropping system, mulching and growing season. *Scientia Hor-*

ticulturae, 338:113807.

Slonecki, T.J., Rutter, W.B., Olukolu, B.A., Yencho, G.C., Jackson, D.M. and Wadl, P.A. 2023. Genetic diversity, population structure, and selection of breeder germplasm subsets from the USDA sweet potato (*Ipomoea batatas*) collection. *Frontiers in Plant Science*, 13: 1022555.

Tang, W., Arisha, M.H., Zhang, Z., Yan, H., Kou, M., Song, W., Li, C., Gao, R., Ma, M. and Wang, X. 2023. Comparative transcriptomic and proteomic analysis reveals common molecular factors responsive to heat and drought stresses in sweet potato (*Ipomoea batatas*). *Frontiers in Plant Science*, 13: 1081948.

Xiao, Y., Zhu, M. and Gao, S. 2022. Genetic and genomic research on sweet potato for sustainable food and nutritional security. *Genes*, 13: 1833.

Yan, M., Nie, H., Wang, Y., Wang, X., Jarret, R., Zhao, J., Wang, H. and Yang, J. 2022. Exploring and exploiting genetics and genomics for sweet potato improvement: Status and perspectives. *Plant Communications*, 3: 100332.

Yang, Y., Zhang, X., Zou, H., Chen, J., Wang, Z., Luo, Z., Yao, Z., Fang, B. and Huang, L. 2022. Exploration of molecular mechanism of intra-specific cross-incompatibility in sweet potato by transcriptome and metabolome analysis. *Plant Molecular Biology*, 109: 115-133.

Zhang, C., Liu, S., Liu, D., Guo, F., Yang, Y., Dong, T., Zhang, Y., Ma, C., Tang, Z. and Li, F. 2022. Genome-wide survey and expression analysis of GRAS transcription factor family in sweet potato provides insights into their potential roles in stress response. *BMC Plant Biology*, 22: 232.

Zhapar, K., Daurov, D., Volkov, D., Daurova, A., Tolegenova, D., Abay, Z., Argynbaeva, A., Kim, H.S., Kwak, S.S. and Shamekova, M. 2021. Selection of sweet potato cultivars with high yields in Almaty region, Kazakhstan. *Experimental Biology*, 88: 45-52.

Research Article

ISAH Indian Journal of Arid Horticulture

Year 2025, Volume-7, Issue-1 (January - June)

Variability in date palm (*Phoenix dactylifera* L.) genotypes in Kachchh, India: a study on morphological and fruiting characteristics

Kapil Mohan Sharma, D. A. Baidiyavadra and C. M. Muralidharan

Date Palm Research Station, Sardarkrushinagar Dantiwada Agricultural University, Mundra-Kachchh, Gujarat

ARTICLE INFO

Received: 21 February 2025
Accepted: 07 April 2025

Keywords: Cluster analysis, date palm, genetic diversity, morphological traits, PCA

doi:10.48165/ijah.2025.7.1.4

ABSTRACT

This study investigates the morphological diversity among 38 date palm genotypes grown in Kachchh, India, using Principal Component Analysis (PCA) and Hierarchical Clustering. A dataset comprising 27 quantitative and qualitative traits were analysed. The correlation analysis revealed significant associations between key traits such as pulp thickness, fruit weight, and pulp-to-stone ratio, which are crucial for fruit quality improvement. PCA identified major traits contributing to morphological variability, with the first three principal components explaining over 52% of total variance. Hierarchical clustering grouped genotypes into four distinct clusters, demonstrating significant genetic diversity. The findings highlight the importance of fruit-related traits in genetic differentiation and provide a framework for breeding superior date palm genotypes.

Introduction

Date palm (*Phoenix dactylifera* L.) is one of the oldest fruit crops cultivated in arid and semi-arid regions of the world (Gros-Balthazard & Flowers, 2021). It plays a crucial role in the economy, food security, and cultural heritage in many Arabian countries, where it is a key commercial crop. India is a major importer of dates, but the Kachchh region of Gujarat has a significant genetic resource of date palm, estimated to have been introduced in the 16^{th}-17^{th} century CE (Baidiyavadra *et al.*, 2019). Despite its economic importance, studies on Indian date palm genetic diversity remain limited (Muralidharan *et al.*, 2019).

Morphological characterization is essential for genetic evaluation and breeding programs, helping in the identification of superior cultivars (Anonymous, 2005). Principal Component Analysis (PCA) and hierarchical clustering are advanced statistical tools that allow precise classification of genotypes. Correlation analysis further helps in understanding linkages among traits, facilitating informed breeding decisions (Ahmed *et al.*, 2011). This study aims to analyze morphological diversity in Kachchh date palm genotypes using these statistical tools.

Material and Methods

The study was conducted at the Date Palm Research Station, Sardarkrushinagar Dantiwada Agricultural University, Mundra-Kachchh, Gujarat India, during 2022-2023. The region has an arid climate with high temperatures and low rainfall, making it an ideal location for date palm cultivation. A total of 38 genotypes were selected comprising of local and exotic origin (Table 1).

Corresponding author's Email: k.m.sharma456@sdau.edu.in (Dr. K.M. Sharma)

Table 1. List of date palm genotypes used in the study

S. No.	Genotypes	Indigenous/ exotic	S. No.	Genotype	Indigenous/ exotic
1	ADP-1	Indigenous	20	MDP-8	Indigenous
2	Barhee	Exotic	21	MDP-9	Indigenous
3	Bhugso	Indigenous	22	MDP-10	Indigenous
4	Dayri	Exotic	23	MDP-11	Indigenous
5	Gulchatti	Exotic	24	MDP-12	Indigenous
6	Halawy	Exotic	25	MDP-21	Indigenous
7	Hatemi	Exotic	26	MDP-22	Indigenous
8	Khadrawi	Exotic	27	Medjool	Exotic
9	Khalash	Exotic	28	Meznaz	Exotic
10	Khasab	Exotic	29	Panjab Red	Indigenous
11	Khuneji	Exotic	30	Ruziz	Exotic
12	Kotho	Indigenous	31	Saidy	Exotic
13	MDP-1	Indigenous	32	Samraan	Exotic
14	MDP-2	Indigenous	33	Sayar	Exotic
15	MDP-3	Indigenous	34	Sopari	Indigenous
16	MDP-4	Indigenous	35	Tayar	Exotic
17	MDP-5	Indigenous	36	Trofo	Indigenous
18	MDP-6	Indigenous	37	Zaglool	Exotic
19	MDP-7	Indigenous	38	Zahidi	Exotic

Morphological data collection

Morphological characterization was performed on 27 quantitative traits, which includes fruit characteristics (fruit length, fruit width, fruit weight, pulp thickness, pulp-to-stone ratio, and TSS (°Brix)), bunch characteristics (average bunch weight, number of strands per spathe, number of berries per strand, and strand length), leaf characteristics: leaf length, leaflet length, spine number, spine length, rachis length, and distance between spines) and seed characteristics (stone length, stone width, stone depth, and stone weight). Measurements were taken using standard horticultural procedures, including digital Vernier callipers, weighing scales, and manual counting as per the trait. Each genotype was evaluated based on at least three randomly selected trees, with three replicates per tree. Measurements were taken following the guidelines as proposed by Anonymous (2005) and DUS test guidelines of PPV&FRA (Anonymous, 2018) with necessary modifications.

Statistical analysis

A comprehensive statistical analysis was conducted to evaluate the morphological diversity among the genotypes. Correlation analysis was based on Pearson's correlation coefficients were determined to assess relationships between traits. Principal component analysis (PCA) was performed to identify major sources of variation and to reduce the dimensionality of the dataset. The first few principal components explaining the highest variance were selected for further analysis. Hierarchical cluster analysis was conducted using Ward's method based on Euclidean distances to construct a dendrogram illustrating genetic relationships.
All statistical analyses were conducted using R (randomforest, ggplot2, ggpubr, corrplot and lattice libraries). Data visualization, including heatmaps and dendrograms, was used to enhance the interpretability of results.

Results and Discussion

Correlation analysis

The correlation of different characters is presented in Fig. 1. The correlation matrix revealed significant relationships between several morphological traits. Notably, pulp thickness exhibits a strong positive correlation with fruit weight (r = 0.86), indicating that thicker pulp significantly contributes to heavier fruits. This trait is crucial for enhancing fruit quality in breeding programs (Ahmed *et al.*, 2023). Similarly, the pulp-to-stone ratio correlates positively with fruit weight (r = 0.80), suggesting that genotypes with heavier fruits generally possess a higher pulp-to-stone ratio, which is desirable for consumer preferences and market value (Alahyane *et al.*, 2022).

Other important positive correlations include fruit width and fruit weight (r = 0.68), showing that larger fruit dimensions contribute to overall fruit mass (Baidiyavadra *et al.*, 2019). The relationship between TSS (°Brix) and pulp thickness (r = 0.61) suggests that thicker pulp enhances the sweetness and overall quality of the fruit. Moreover, strand-related traits, such as the length of strand and the number of berries per strand (r = 0.45), highlight the longer strand may accommodate higher number of berries and can play role in determining fruit production potential (Jaradat & Zaid, 2004). In seed characters, stone length and stone diameter (r = 0.76) shows uniformity in stone dimensions, which could influence seed viability and market traits (Elhoumaizi *et al.*, 2002).

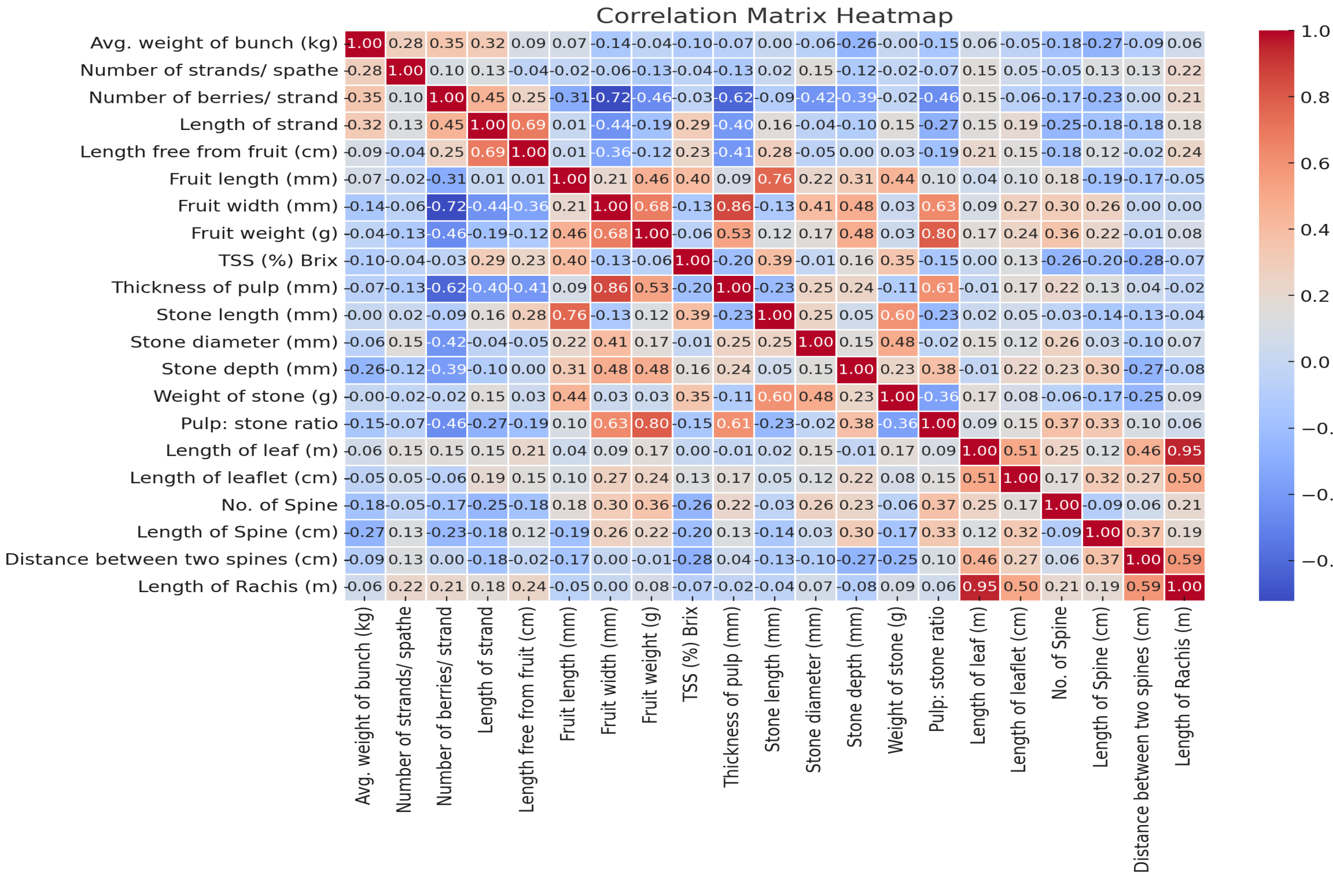


Fig. 1. Correlation matrix of different date palm characters

Conversely, some traits show negative correlations. The number of berries per strand shows a negative correlation with fruit weight (r = -0.46), suggesting that a higher number of berries can reduce the size of individual fruits, likely due to resource competition. Similarly, the length free from fruit is negatively correlated with the number of berries per strand (r = -0.42), implying that strands with more berries efficiently utilize their length for fruiting. Another negative correlation exists between the distance between spines and the number of spines (r = -0.30), where more compact spines are associated with shorter distances (Bedjaoui & Benbouza, 2020).

Traits such as the length of the leaf and length of rachis exhibit weak or negligible correlations with most other traits, indicating their limited direct influence on yield or fruit quality. These findings suggest that while some traits are critical for breeding efforts, others may be less impactful on the overall performance of genotypes (Ahmed *et al.,* 2011).

Principal component analysis (PCA)

The scree plot for principal component analysis is illustrated in Fig. 2 and details presented in Table 2 explaining the variance of each principal component (PC). The first principal component (PC1) accounts for the largest proportion of variance, followed by a sequential decrease in variance for subsequent components. In this analysis, PC1 explains 22.92% of the variance, while PC2 and PC3 explain 15.04% and 14.56%, respectively. The first three principal components collectively account for over 52% of the total variance, which is sufficient to capture the majority of the dataset's variability. The elbow in the scree plot, occurring at PC3, suggests that additional components contribute marginally to the total variance, making it reasonable to focus on the first three components for further analysis. Similar trends in PCA variance distribution have been reported in previous studies, where the first three PCs explained 50–60% of the total variation in date palm genotypes (Ahmed *et al.*, 2011; Bedjaoui & Benbouza, 2020)

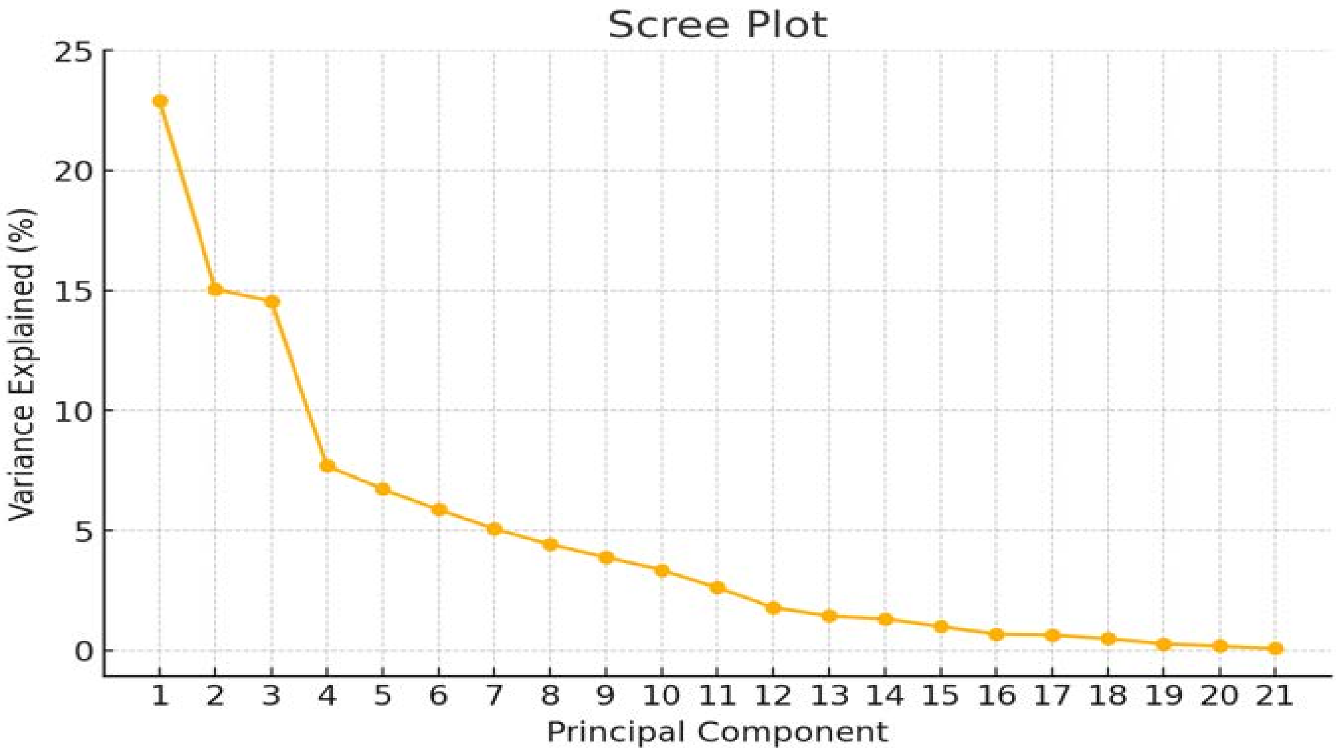


Fig. 2. Scree plot of principal components

Table 2. Eigen value and variance of principal components

Principal component	Eigenvalue	Variance explained (%)
PC1	4.94	22.92
PC2	3.24	15.04
PC3	3.14	14.56
PC4	1.66	7.69
PC5	1.45	6.71
PC6	1.27	5.87
PC7	1.09	5.07
PC8	0.95	4.41
PC9	0.84	3.88
PC10	0.72	3.35
PC11	0.56	2.62
PC12	0.39	1.79
PC13	0.31	1.43
PC14	0.28	1.32
PC15	0.21	0.99
PC16	0.15	0.68
PC17	0.14	0.64
PC18	0.10	0.48
PC19	0.06	0.28
PC20	0.04	0.18
PC21	0.02	0.08

The results of the Principal Component Analysis (PCA) and scree plot provide valuable insights into the morphological diversity of the 38 date palm genotypes. The scree plot indicates that the first three principal components (PCs) explain a substantial proportion of the total variance, accounting for over 52%. PC1 contributes the largest share (approximately 23%), dominated by traits such as fruit weight, pulp thickness, and stone dimensions. These findings emphasize the importance of fruit-related characteristics in defining variability among genotypes, which aligns with the findings of Simozrag *et al.* (2016), who reported that fruit traits like pulp weight and flesh-to-seed ratio had the highest influence on PC1. Similarly, studies by El-Kadri *et al.* (2019) and Ahmed *et al.* (2023) have demonstrated that reproductive traits play a dominant role in PCA-based differentiation of date palm genotypes.

PC2, which explains 15% of the variance, is influenced by bunch-related traits like bunch weight and strand length, reflecting the structural contribution of reproductive traits to overall variability. A similar contribution of bunch-related traits to PC2 was also noted by Raza *et al.* (2020) and Alahyane *et al.* (2022), indicating the significant role of inflorescence characters in morphological differentiation. PC3, contributing 14% of the variance, highlights the role of leaflet and rachis traits, are relevant for morphological classification. Previous studies have also reported that leaflet dimensions, rachis width, and petiole length significantly contribute to the later PCs in PCA analyses of date palm diversity (Hammadi *et al.*, 2009; Ennouri *et al.*, 2018).

The PCA scatter plot (Fig. 3) further elucidates the relationships among the genotypes. Genotypes such as Dayri and Panjab Red are clustered in the upper-right quadrant, indicating shared traits such as larger fruit weight and thicker pulp, making them potential candidates for breeding programs focused on improving fruit quality. Similar clustering patterns have been observed in previous studies, where high fruit weight and pulp content led to distinct groupings in PCA projections (Elsafy *et al.*, 2015; Alrashidi *et al.*, 2023). Conversely, genotypes such as MDP-6 and Khasab, located in the lower-left quadrant, exhibit unique morphological traits, which can be valuable for enhancing genetic diversity in hybridization efforts. Clustering of morphologically unique genotypes based on PCA has also been reported by Ahmed *et al.* (2011) and Raza *et al.* (2020), supporting the role of this technique in identifying genetically diverse accessions. Intermediate genotypes like MDP-2 and MDP-7, situated near the origin, display balanced traits without extremes, suggesting their adaptability for multiple purposes. Similar observations were made by El-Kadri *et al.* (2019), where intermediate genotypes showed stable performance across different environments.

Overall, the PCA results underscore the importance of fruit-related traits in genetic differentiation while showcasing the potential of structural and leaf-related traits to enhance diversity. These findings are consistent with prior reports highlighting the dominance of fruit size, pulp thickness, and inflorescence traits in determining the morphological variation of date palms (Simozrag *et al.*, 2016; Ahmed *et al.*, 2023).

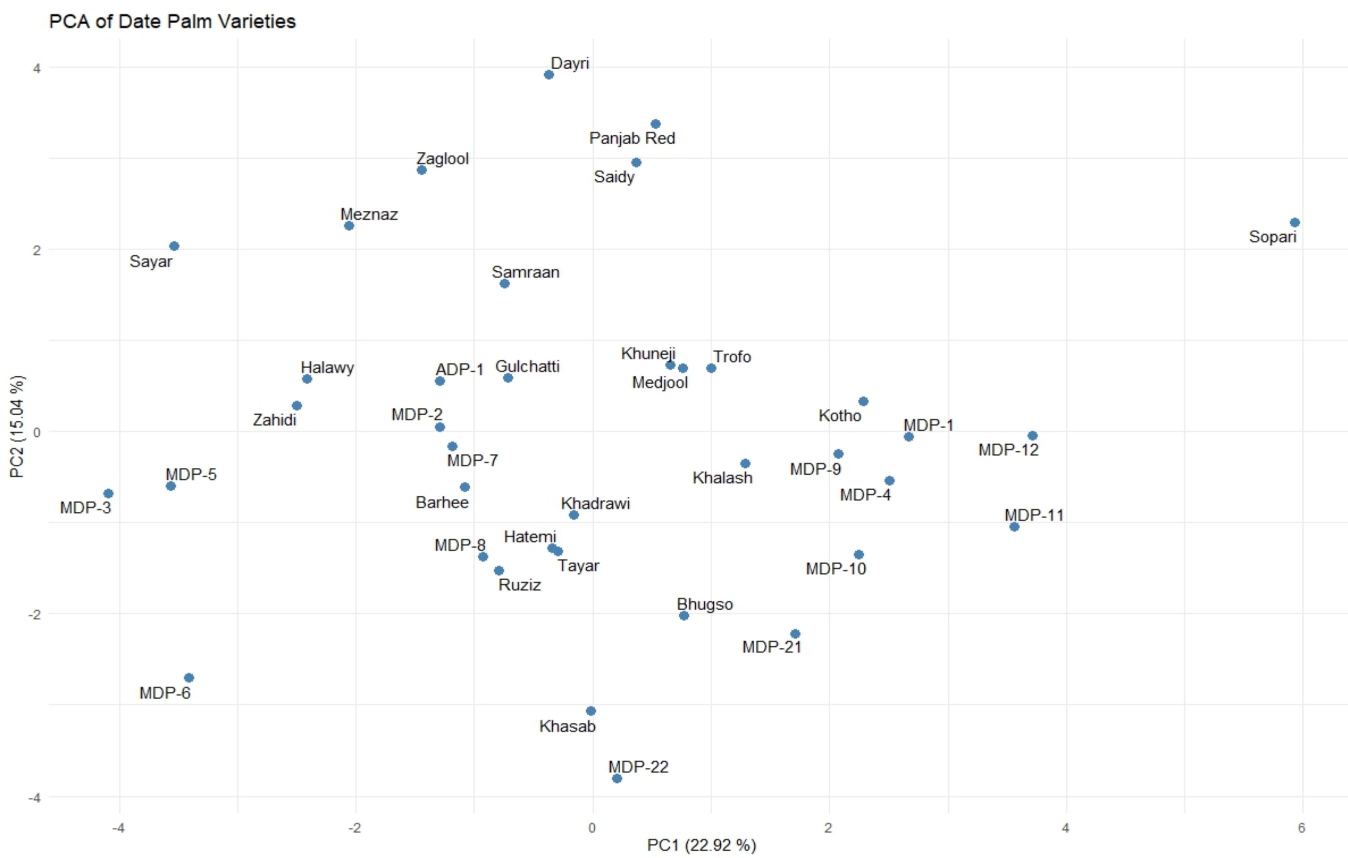


Fig. 3. Principal component analysis of date palm variability

Hierarchical cluster Aaalysis

The hierarchical clustering dendrogram provides a clear representation of the morphological relationships among the 38 date palm genotypes. Based on the dendrogram, the genotypes were grouped into four distinct clusters, reflecting their phenotypic similarities and differences. Each cluster represents a group of genotypes that share key morphological traits, making them potential candidates for specific breeding strategies. Similar hierarchical clustering results have been reported in earlier studies, where genotypes were consistently grouped into clusters based on reproductive and vegetative traits (Ahmed *et al.*, 2011; Raza *et al.*, 2020).

The first cluster, which includes genotypes such as Bhugso, Barhee, MDP-6, etc. is characterized by genotypes with unique fruit-related and bunch characteristics. A similar clustering of genotypes based on fruit-related traits was observed by Ennouri *et al.* (2018), where cluster formation reflected significant variations in pulp thickness and fruit weight. This group may include genotypes suitable for hybridization programs aimed at enhancing traits like fruit quality and bunch size. The second cluster includes widely spaced genotypes such as Dayri, Zaglool, Panjab Red, etc.

which appear to be morphologically distinct based on their fruit characters. The third cluster, containing genotypes such as Khuneji, Tayar, Khadravi, etc. groups genotypes with characters like rachis length and leaf morphology. The fourth cluster, with genotypes such as Sopari, MDP-11, MDP-9, etc. is characterized by distinctive features such as fruit dimensions and high pulp-to-stone ratios. These traits make this group particularly attractive for commercial cultivation due to their potential marketability, similar grouping aligns with observations made by Simozrag *et al.* (2016) and Alrashidi *et al.* (2023).

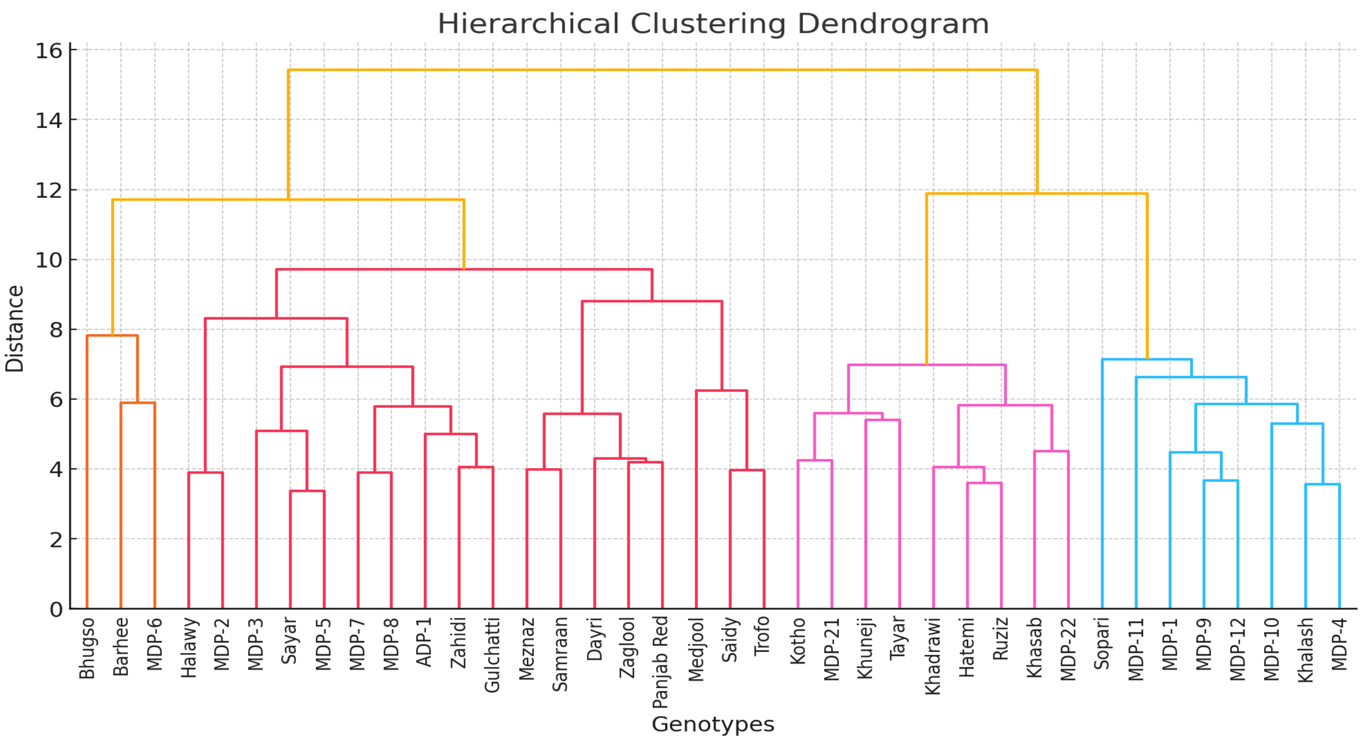


Fig. 4. Hierarchical clustering of date palm genotypes

The clustering results also align well with the PCA findings, which emphasize the importance of traits like fruit weight, pulp thickness, and strand length in defining variability. The dendrogram reinforces the diversity present in the genotypes and highlights clusters with significant potential for targeted breeding.

The PCA results align with the hierarchical clustering findings, where distinct groups of genotypes were identified based on morphological similarities. The grouping and separation observed in the PCA scatter plot validate the diversity among the studied genotypes, highlighting specific trait-based clusters that can inform targeted breeding and conservation strategies. Previous studies using both PCA and cluster analysis have confirmed that genotype groupings based on fruit and vegetative traits are consistent with traditional classification systems (Bedjaoui & Benbouza, 2020; Ahmed *et al.*, 2023).

In conclusion, the hierarchical clustering results provide a robust framework for understanding the genetic and phenotypic diversity of date palm genotypes. These findings can be directly applied to breeding programs aimed at improving fruit yield, quality, and adaptability. The identification of distinct clusters underscores the potential for leveraging genetic diversity to address specific breeding objectives, ensuring long-term sustainability in date palm cultivation (Raza *et al.*, 2020; Bedjaoui & Benbouza, 2020).

Conclusion

This study highlights the morphological diversity among date palm genotypes using PCA and hierarchical clustering. The findings confirm that fruit-related traits significantly contribute to genetic differentiation, and hierarchical clustering effectively groups genotypes based on shared attributes. These insights are valuable for breeding programs and conservation efforts aimed at maintaining genetic diversity in date palm cultivation.

Acknowledgements

The authors are grateful to the authorities of university and AICRP on AZF, Bikaner for providing the fund and other necessary facilities to conduct this research.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Ahmed, M. V. O. M., Bouna, Z. E. O., Lemine, F. M. M., Djeh, T. K. O., Mokhtar, T. and Salem, A. O. M. 2011. Use of multivariate analysis to assess phenotypic diversity of date palm (*Phoenix dactylifera* L.) cultivars. *Scientia Horticulturae*, 127: 367-371. https://doi.org/10.1016/j.scienta.2010.11.011

Ahmed, R., Anjum, M. K., Ercisli, S., M., Malik, W., Sakar, E., Marc, R. A. and Karunakaran, R. 2023. Physico-chemical properties revealed huge diversity in 50 date palm (*Phoenix dactylifera* L.) genotypes. *Folia Horticulturae*, 35(1): 107-122. https://doi.org/10.2478/fhort-2023-0008.

Alahyane, A., Elateri, I., Alahyane, H., Ayour, J., Meddich, A., Ait-Oubahou, A., Benichou, M. and Abderrazik, M. E. 2022. Assessment of phenotypic diversity of some local Moroccan date palm varieties and clones (*Phoenix dactylifera* L.) from Zagora region, Southern Morocco. *Jordan Journal of Biological Sciences*, 15(4): 671-678. https://doi.org/10.54319/jjbs/150416

Alrashidi, A. H. M., Jamal, A., Alam, M. J., Gzara, L., Haddaji, N., Kachout, M., Abdelgadir, A., Badraoui, R. and Elkahoui, S. 2023. Characterization of palm date varieties (*Phoenix dactylifera* L.) growing in Saudi Arabia: Phenotypic diversity estimated by fruit and seed traits. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 51(1): 12996. https://doi.org/10.15835/nbha51112996

Anonymous. 2005. Descripteurs du Palmier dattier (*Phoenix dactylifera* L.). IPGRI, Rome, Italy; Global Environment Fund, Washington, USA; United Nations Development Program, New York, USA; National Institute of Agronomic Research, Algeria, Morocco and Tunisia.

Anonymous. 2018. Guidelines for the conduct of test for Distinctiveness, Uniformity and Stability on date palm (*Phoenix dactylifera* L.). Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), New Delhi, Government of India. Pp. 1-28.

Bedjaoui, H. and Benbouza, H. 2020. Assessment of phenotypic diversity of local Algerian date palm (*Phoenix dactylifera* L.) cultivars. *Journal of Saudi Society of Agricultural Sciences*, 19: 65-75. https://doi.org/10.1016/j.jssas.2018.06.002

Elhoumaizi, M. A., Saadi, M., Oihabi, A. and Cilas, C. 2002. Phenotypic diversity of date palm cultivars (*Phoenix dactylifera* L.) from Morocco. *Genetic Resources and Crop Evolution*, 49: 483-490.

El-Kadri, N., Mimoun, M. B. and Hormaza, J. I. 2019. Genetic diversity of Tunisian male date palm (*Phoenix dactylifera* l.) genotypes using morphological descriptors and molecular markers. *Scientia Horticulturae*, 253: 24-34. https://doi.org/10.1016/j.scienta.2019.04.026.

Elsafy, M., Garkava-Gustavsson, L. and Mujaju, C. 2015. Phenotypic diversity of date palm cultivars (*Phoenix dactylifera* L.) from Sudan estimated by vegetative and fruit characteristics. *International Journal of Biodiversity*, 610391: 1-7.

Ennouri, K., Ayed, R. B., Ercisli, S., Smaoui, S., Gouiaa, M. and Triki, M. A. 2018. Variability assessment in *Phoenix dactylifera* L. accessions based on morphological parameters and analytical methods. *Acta Physiologiae Plantarum*, 40:5. https://doi.org/10.1007/s11738-017-2583-6.

Gros-Balthazard, M. and Flowers, J. M. 2021. A brief history of the origin of domesticated date palms. In: Al-Khayri, J. M.; Jain, S. M. and Johnson, D. V. (eds.). The date palm genome Vol. 1: Compendium of plant genomes. Springer, Cham. Pp. 55-74. https://doi.org/10.1007/978-3-030-73746-7_3

Hammadi, H., Mokhtar, R., Mokhtar, E. and Ali, F. 2009. New approach for the morphological identification of date palm (*Phoenix dactylifera* L.) cultivars from Tunisia. *Pakistan Journal of Botany*, 41(6): 2671-2681.

Jaradat, A. A. and Zaid, A. 2004. Quality traits of date palm fruits in a center of origin and center of diversity. *Journal of Food Agriculture and Environment*, 2: 208-217.

Muralidharan, C. M., Baidiyavadra, D. A. and Sharma, K. M. 2019. Variability in date groves of Kachchh and conservation through field gene bank. In: Technical Bulletin 05/2019, Date Palm Research Station, Sardarkrushinagar Dantiwada Agricultural University, Mundra-Kachchh, Gujarat, India. Pp. 1-32.

Raza, M. K., Jaskani, M. J., Naqvi, S. A. and Awan, F. S. 2020. Exploitation of phenotypic diversity in male accessions of date palm (*Phoenix dactylifera*) and its use in germplasm conservation. *International Journal of Agriculture and Biology*, 24: 133-144.

Simozrag, A., Chala, A., Djerouni, A. and Bentchikou, E. M. 2016. Phenotypic diversity of date palm cultivars (*Phoenix dactylifera* L.) from Algeria. *Gayana Botanica*, 73: 42-53.

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Optimizing guava (*Psidium guajava* L.) breeding programs: The role of genotype selection in enhancing growth, yield and nutrient content

Daya Shankar Mishra[1*], Vikas Yadav[1], L. P. Yadav[1], V.V. Apparao[1], Prakashbhai Ravat[1], Prakash Kumar[2] and Jagadish Rane[3]

[1]ICAR-Central Horticultural Experiment Station, Vejalpur-389340, Panchmahal, Gujarat, India
[2]ICAR-Indian Agricultural Statistics Research Institute (IASRI), New Delhi-110012, India
[3]ICAR-Central Institute for Arid Horticulture, Beechwal, Bikaner-334006, Rajasthan, India

ARTICLE INFO

Received: 12 March 2025
Accepted: 07 April 2025

Keywords: Guava, genetic variability, cross combination, yield

doi:10.48165/ijah.2025.7.1.5

ABSTRACT

This study examines genetic variation and its impact on key growth, yield, and quality traits in guava genotypes through analysis of variance and *per se* performance of cross combinations. The results indicate significant genetic effects on most traits, with the highest variations observed for days to first flowering (DTFF), days to first harvest (DTFH), number of seeds per fruit (NSPF), total phenols (TPH), and total antioxidant activity (TAA), highlighting the potential for selection based on these traits. The study also identifies traits with lower genetic variability, such as acidity (Acid) and pulp thickness (PT), suggesting their dependence on environmental or management factors. The ANOVA results revealed significant impacts of genotypes on key traits related to growth, yield, and fruit quality, with extremely high F-values ($p < 0.0001$) for most traits, suggesting that genotype plays a dominant role in the expression of these characteristics. Notably, the cross combinations, including G-28 × Lalit and G-15 × VL, showed strong potential for improving growth and quality parameters. G-28 × Lalit demonstrated superior growth and nutrient content, while G-15 × VL excelled in quality traits such as sugar content, total soluble solids (TSS), and antioxidant properties. Additionally, other cross combinations like VL × G-15 and G-31 × TP offered promising results for increasing biomass, yield, and fruit quality. Further multi-generational evaluations and environmental studies are essential to assess the stability and heritability of these traits under diverse conditions. The study highlights the importance of genotype selection for developing high-performing guava cultivars, emphasizing the need for further research to optimize breeding strategies for improved yield, quality, and resilience.

Introduction

Guava (*Psidium guajava* L.) is known as a 'super fruit' and the 'apple of the tropics' (Bishnoi *et al.*, 2024) because of its significant nutritional benefits. The agro-food sector currently exhibits significant interest in plant sources abundant in phytochemicals (Paras *et al.*, 2024). Guava ranks as the third-highest source of vitamin C (299 mg/100 g) and is also a provider of vitamin A (0.46 mg/100 g), calcium (17.8-30 mg/100 g), iron (200-400 IU/100 g), and phosphorus (0.30–0.70 mg/100 g). Its seeds are abundant in omega-3, omega-6, polyunsaturated fatty acids, and dietary fiber (0.9-1.0 g/100 g) (Kamath *et al.*, 2008). Because of these factors, along with the low farming expenses and improved

Corresponding author's Email: dsmhort@gmail.com (Dr. D.S. Mishra)

suitability for less productive areas (Bezerra *et al.*, 2019), the guava farming is economically significant in numerous tropical and sub-tropical nations (Singh *et al.*, 2015; Mishra and Singh, 2022).

Coloured pulp guava is more nutritious than white pulp guava because it contains various pigments. These pigments offer appealing color as well as numerous health advantages (Bishnoi *et al.*, 2024, Speer *et al.*, 2020; Woodside *et al.*, 2015). Lycopene and/or anthocyanins, in conjunction with carotenoids, contribute to the pink pulp color of guava (Bose *et al.*, 2019; Kumari *et al.*, 2020; Shukla *et al.*, 2021; Singh *et al.*, 2019; Thakre *et al.*, 2016). Lycopene and anthocyanins are possible antioxidants and possess anti-cancer, anti-inflammatory, and heart-protective properties (Naseer *et al.*, 2018). Thus, we can explore superior and essential genotypes that exhibit high yields along with favorable quality traits, benefiting developed nations globally.

Guava demonstrates out-crossing levels of 35-40% (Singh and Sehgal, 1968; Nakasone and Paull, 1998; Mishra *et al.*, 2024), leading to heterozygous open-pollinated seedling populations that possess significant genetic diversity for important horticultural traits (Mishra *et al.*, 2019). Accurate characterization of genetic diversity is essential for creating enhanced guava cultivars. An adequate understanding of the gene pool applicable in genetic enhancement initiatives, together with morpho-genetic profiling of specific accessions/cultivars, can significantly assist in choosing the parental lines for genetic advancements (Singh *et al.*, 2015; Kumari *et al.*, 2018).

One of the primary objectives of current guava enhancement programs in various nations is the creation of high-yielding, nutrient-rich cultivars that feature fewer and softer seeds, along with improved shelf-life (Correa *et al.*, 2012; Pommer, 2012, Mishra *et al.*, 2019).

Only few improved and released varieties like Lalit, Shweta, Arka Kiran etc. are available, while different seedling selections like L-49, Apple colour and other local varieties are still under cultivation (Sarkar and Sarkar, 2022). Therefore, we presumed that new improved guava genotypes could be developed with the introgression among the widespread locally available genotypes/varieties with desirable traits. The aim of enhancing guava crops by utilizing various breeding techniques, such as hybridization, selection, and introduction, was to develop new cultivars with superior traits (Paras *et al.*, 2023). Efforts in plant breeding for guava fruit crops aim to increase fruit yield, improve fruit quality, and boost resistance to major pests and diseases. For high-yielding guava genotypes, it is essential to have high output, uniform size and shape, and superior quality fruit. Uniform guava genotypes, whether homozygous or heterozygous, can yield uniform traits. Pure genotypes consist of homozygotes, whereas hybrid germplasm includes heterozygotes. Cross hybrid genotypes are chosen for their enhanced traits, appeal, and greater yield, rendering them more sought after than pure guava genotypes. By executing a random cross among various parental genotypes that are distinct in their attributes, it becomes feasible to develop guava hybrid cultivars with preferred characteristics and identify the most innovative combinations (Badami *et al.*, 2020). This study represents the initial research conducted under semi-arid tropical conditions using superior guava genotypes in random hybridization to create improved guava genotypes.

Material and Methods

This study was conducted at the ICAR-CIAH Central Horticultural Experiment Station (CHES), Vejalpur, Panchmahal, Gujarat, India (22°41'N, 73°33'E with altitude 113 m above sea level) The climate of the experimental site is hot semi-arid with a mean annual precipitation of about 750 mm, and the soil is derived from basic rocks, calcareous in nature, clay loam to clay in texture and has a pH of about 6.5 with organic matter content 0.45-0.73%. Ten guava parental genotypes (Table 1) which were already established at CHES, Godhra experimental farm were used for crossing program. Crosses were made among the genotypes, 50 flowers in each female parent were crossed with the selected male parent. Flower buds, which were expected to open the following day, were selected from female and male parents. All the anthers of the female buds were emasculated and bagged and flower buds of male parent were also bagged. Pollination was done the following morning between 6.30-8.30 am. Pollinated flowers were bagged and kept until fruits were formed. Single fruit from each cross combination was taken (Harvested during Dec.) and all the seeds of that fruit were used for raising the seedlings (sown in the month of January 2017-18). Number of seedlings per fruit representing a progeny in each cross varied 60-120. Finally healthy seedlings of different crosses were planted at 5 m x 2.5 m spacing during July, 2017-18. Fifteen plants were kept in each replication (blocks) which was replicated thrice. In each block all progenies were randomly arranged. These were observed for 2-3 years and data on growth, yield and quality parameters were taken, winter season crop was used for recording the data on fruit yield and quality parameters.

Tree growth and yield parameters, including tree height (TH), stem girth (SG), trunk cross-sectional area (TCSA), tree spread (SPD), number of fruits per tree (FNP), fruit yield per plant (YP), production efficiency (PE), other physical and bio-chemical quality parameters and mineral contents on fresh weight basis (FW) were recorded following standard procedures (Mishra *et al.*, 2022). Fruit yield per plant observation were recorded on 3 replication of each guava cross combination on randomly selected 2-3 trees. For experimental design and analysis of variance (ANOVA), the "proc glm" procedure in SAS was utilized. This procedure assesses the significance of differences among group means and generates an ANOVA table detailing the sources of variation in the data. Post hoc tests, such as the Least Significant Difference (LSD) test, were performed using the "means" statement with the "LSD" option in the "proc glm" procedure, allowing for pairwise comparisons of treatment means to identify significant differences (Tripathi *et al.*, 2025). The variation among the crosses was partitioned further into sources attributable to Analysis of variance (ANOVA) and *per se* performance of cross combinations.

Result and Discussion

Analysis of variance (ANOVA) for cross combinations

The results of the analysis of variance (ANOVA) for various traits in guava genotypes are presented Table 1 to Table 3. The mean sum of squares for genotypes revealed significant genetic effects on most traits. The highest values were observed for DTFH (39599.86) followed by DTFF (36411.02), NSPF (17214.37), TAA (16015.43) and TPH (8104.38) suggesting that these traits are strongly influenced by genetic variation. Other traits, such as PT (0.03), PE (0.06), FSI (0.02), and Acid (0.02) showed smaller mean sum of squares, indicating that these traits are less influenced by genotype differences, but still exhibit some genetic variability. Replication mean sum of squares shows the environmental influence on the traits. Traits like FWt (14354.20), NSPF (17050.90), TPH (5406.56), had relatively high replication mean sum of squares, indicating that environmental or management factors might play a substantial role in these traits, while Acid (0.02), FSI (0.01) and PT (0.05) had relatively smaller replication effects, reflecting less environmental variability for these traits (Mishra *et al.*, 2022; Chiveu *et al.*, 2019). The R-square values, representing the proportion of variability explained by the model, were generally high, especially for RF (0.95), WF (0.94), Mg (0.92) and K (0.87), indicating that the genotypes contribute substantially to the observed variation in these traits. Traits like FL (0.43), TSS (0.43), Acid (0.43) and TA (0.44) had somewhat lower R-squares, suggesting that other factors may also contribute to the variability in these traits. The coefficient of variation (CV) values indicates the degree of variability in the traits. Traits such as PE (52.43%), WF (33.14%), Btaoy (32.40%), Lyc (27.73%) and Asc (21.24%) showed higher coefficients of variation, indicating greater variability between genotypes. In contrast, Btaty (7.91%), K (8.20%), FW (9.07%), TS (9.80%) and PT (9.85%), had lower coefficients of variation, indicating more consistent performance across genotypes for these traits. The extremely notable F-values for every trait ($p< 0.0001$) indicated that genotype explained a considerable portion of the variance in the dependent variables (Table 1). The F-values were significantly high for all traits ($p< 0.0001$) with the exception of DTFF (F = 8.61, p=<0.0001), RF (F = 31.61, p=<0.0001), WF (F = 26.85, p=<0.0001), K (F = 11.85, p=<0.0001), Mg (F = 17.96, p=<0.0001) and Lyc (F = 7.85, p=<0.0001) (Kumari *et al.*, 2018). The analysis of variance (ANOVA) results reveals significant genetic variability across guava genotypes, influencing key growth, yield, and quality traits. The observed extremely high F-values ($p<0.0001$) for most traits, such as TCSA, TSS, and Lycopene content, indicate that genotype plays a pivotal role in shaping these characteristics. The exceptions, including DTFF, RF, and WF, still show a notable influence of genotype on trait expression but with somewhat lower F-values compared to others, which suggests the possibility of environmental or management factors playing a larger role in these particular traits (Kherwar and Usha, 2016).

Per se performance of cross combinations

The *per se* performance of cross combinations further emphasizes the potential for breeding programs aimed at improving specific agronomic or quality traits (Table 4 to 6 and Fig. 1). G-28 × Lalit strong performance across multiple traits, including SG (8.29), DTFF (550.67), DTFH (664.33), FNP (104.10), P (24.24), Ca (29.40) and Mg (49.48), while showing decreased levels in traits such as Btaoy (30.52) and TA (20.53). These results suggest that G-28 × Lalit may be a valuable combination for enhancing growth and nutrient content, albeit with a trade-off in traits like Btaoy and TA. The high values for essential growth parameters such as SG (8.29) and P (24.24) suggest that this cross may be ideal for cultivating guava with high productivity and quality (Kumari *et al.*, 2018). In contrast, the G-15 × VL combination demonstrated superiority for quality-related traits, such as TSS (13.56), Acid (0.66), Asc (266.20), TS (9.82) and K (289.94), along with enhanced yield potential TPH (375.14), TCSA (56.88) and TAA (454.83), while displaying the lowest for FSI (0.92), P (16.00) and Flav (15.45). These findings suggest that G-15 × VL may be particularly useful for breeding guava varieties with higher sugar content and overall quality, making it an attractive candidate for improving the fruit's organoleptic properties (Chiveu *et al.*, 2019).

The VL × G-15 cross combination, with the highest Btaoy (95.55), YP (20.01), PE (0.56) and Lyc (12.16) values, highlights the potential of this combination for increasing biomass and yield potential, although this comes at the expense of earlier fruit maturity DTFF (149.67) and DTFH (233.67). This finding supports the notion that selecting for both early-maturing genotypes and high-yielding genotypes requires balancing various traits to meet the diverse objectives of guava breeding programs.

Similarly, the G-31 × TP combination exhibited promising results for FSI (1.19), RF (100) and quality, Flav (26.32), but with lower performance in traits like FW (6.57), SCD (3.66), WF (0.00), K (168.81) and Fe (22.19). This combination may be beneficial for improving fruit characteristics such as flavor and texture, but breeders would need to account for the lower levels of potassium in the resulting progeny (Kherwar and Usha, 2016; Kumari *et al.*, 2020).

The combination of VL × G-31 also displayed substantial potential for FWt (287.29), FL (8.82), SCD (4.63) as well as the number of seeds per fruit (277) making it valuable for increasing fruit size and yield per tree, However, it showed lower values for FNP (28.67), Asc (88.81) which may limit its potential for enhancing antioxidant properties and fruit fertility. VL × SP is greater for FW (8.02), SH (12.46) and TA (29.14), but lesser for NSPF (122.33) and Acid (0.38). VL × MP-2 exhibited the highest TH (3.28), SPD (3.24), HSW (1.55), WF (100) and Fe (40.23), while recording the lowest in RF (0.00), Ca (13.98), Mg (10.87), Lyc (0.12) and TPH (202.20). Several crosses, such as SP × G-28 and MP-2 × G-15, presented varying degrees of strengths and weaknesses across traits. While SP × G-28 exhibited higher PT (1.69), indicating potential for enhancing postharvest quality, it showed decreased growth parameters like TCSA (26.42) and SG (5.75). Conversely, the MP-2 × G-15 combination exhibited reduced performance for certain traits, such as Btaty (80.00), FWt (196.27), FL (7.02), PT (1.49), YP (5.39), PE (0.16) and TSS (9.87), but may have value in terms of other agronomic or postharvest traits not captured in this study. The BL × SP combination had consistently lower values for certain traits, including TH (2.23), SPD (2.35), HSW (1.01) and SH (9.51), indicating that it may not be as promising for improving overall plant stature and growth in comparison to other combinations. Nonetheless, this combination might still be valuable for specific breeding goals focused on improving traits like flower density or fruit size, even if other areas of performance are less robust (Kumari *et al.*, 2020).

The cross combinations analyzed demonstrate the potential for improving various growth, yield, and quality parameters by selecting appropriate genotypes that complement each other's strengths. However, further research, including multigeneration evaluations and environmental studies, will be necessary to fully understand the stability and heritability of these traits in different agro-climatic conditions. Such information is critical for developing high-performing guava cultivars suited for diverse production environments and consumer preferences.

Table 1. Analysis of variance for different characters in guava

Source	df	Mean Sum of Square											
		TH	SPD	SG	TCSA	DTFF	DTFH	Btaoy	Btaty	FWt	FL	FW	FSI
Genotypes	9	0.21	2.47	0.29	348.57	36411.02	39599.86	1084.94	122.25	3067.01	0.75	0.68	0.02
Replication	2	0.58	9.11	0.45	1098.57	31922.50	23798.53	286.37	10.75	14354.20	0.86	1.83	0.01
R-Square		0.59	0.69	0.70	0.68	0.84	0.82	0.55	0.51	0.52	0.43	0.55	0.48
Coeff. of Var.		12.46	14.75	10.60	30.69	21.90	17.31	32.40	7.91	22.30	10.13	9.07	11.14
F- value		2.37	3.58	3.79	3.45	8.61	7.25	2.02	1.73	1.79	1.24	1.96	1.53
Pr>F		0.050	0.010	0.006	0.010	<.0001	0.0001	0.099	0.150	0.131	0.328	0.190	0.210

TH-Tree height (m), SPD-Spread (m), SG-Stem girth (m), TCSA-Trunk cross sectional area, DTFF-Days to 1st flowering, DTFH- Days to 1st harvest, Btaoy- Bearing trees after 1 year (%), Btaty- Bearing trees after 2 year (%), FWt- Fruit weight (g), FL- Fruit length (cm) FW- Fruit width (cm), FSI- Fruit shape index

Table 2. Analysis of variance for different characters in guava

Source	df	Mean Sum of Square											
		SCD	PT	NSPF	HSW	SH	RF	WF	FNP	YP	PE	TSS	Acid
Genotypes	9	0.30	0.03	17214.37	0.10	4.19	2451.87	2442.24	1712.07	61.01	0.06	3.84	0.02
Replication	2	0.20	0.05	17050.90	0.11	7.25	81.23	113.23	180.03	9.85	0.05	2.90	0.02
R-Square		0.51	0.44	0.68	0.55	0.48	0.95	0.94	0.72	0.65	0.48	0.43	0.43
Coeff. of Var.		9.92	9.85	29.06	18.20	15.00	10.78	33.14	31.39	33.29	52.43	15.23	28.52

F- value	1.68	1.30	3.45	1.97	1.54	31.61	26.85	4.24	3.00	1.51	1.23	1.22
Pr>F	0.160	0.298	0.0098	0.0971	0.2018	<.0001	<.0001	0.0034	0.019	0.210	0.334	0.343

SCD-Seed core diameter (cm), PT-Pulp thickness (cm), NSPF-No. of seed/ fruit, HSW-100 seed weight (g), SH-Seed hardness (kg/ cm^2), RF-Red fleshed (%), WF-White fleshed (%), FNP-Fruits number/plant, YP-Yield/ plant (kg), PE-Production efficiency (kg/ cm^2), TSS-Total soluble solids, Acid-Acidity (%)

Table 3. Analysis of variance for different characters in guava

Source	df	Mean Sum of Square											
		TA	Asc	TS	K	P	Ca	Mg	Fe	Lyc	TPH	Flav	TAA
Genotypes	9	19.59	6806.63	3.85	4657.78	27.29	80.09	336.70	103.66	33.97	8104.38	48.88	16015.43
Replication	2	8.14	2633.17	0.74	640.82	16.84	5.94	19.43	1.00	8.58	5406.56	7.51	1092.88
R-Square		0.44	0.76	0.77	0.87	0.75	0.80	0.92	0.77	0.83	0.80	0.80	0.82
Coeff. of Var.		14.88	21.24	9.80	8.20	11.95	14.55	16.36	14.72	27.73	11.57	13.42	11.50
F- value		1.29	5.07	5.62	11.35	4.92	6.71	17.96	5.34	7.85	6.66	6.51	7.42
Pr > F		0.3034	0.0012	0.0007	<.0001	0.0015	0.0002	<.0001	0.0009	<.0001	0.0002	0.0003	0.0001

TA-TSS: Acidity, Asc-Ascorbic acid (mg/100g), TS-Total sugar (%), K-Potassium (mg/100g FW), P-Phosphorus (mg/100g), Ca-Calcium (mg/100g), Mg-Magnesium (mg/100g), Fe-Iron (ppm FW), Lyc-Lycopene (mg/100g). TPH-Total phenols (GAE/100g), Flav-Flavonoids (CE/100g), TAA-Total antioxidant activity (AAE/100g)

Table 4. *Per se* performance of cross combinations for different characters in guava

Genotypes	TH	SPD	SG	TCSA	DTFF	DTFH	Btaoy	Btaty	FWt	FL	FW	FSI
G-28 × Lalit	2.88ab	2.75ab	8.29a	55.69ab	550.67a	664.33a	30.52c	98.25a	230.27a	7.86ab	7.32ab	1.08a-c
G-15 × VL	2.66bc	2.48b	8.23a	56.88a	225.67de	345.67d-e	80.11ab	100.00a	248.69a	7.19b	7.84a	0.92c
VL × G-15	2.79a-c	3.11a	6.77ab	36.02bc	149.67e	233.67e	95.55a	100.00a	271.45a	7.73ab	7.63ab	1.01a-c
G-31 × TP	2.88ab	3.08a	7.23ab	42.17a-c	349.00bc	459.67bc	60.00a-c	100.00a	199.52a	7.74b	6.57b	1.19a
VL × G-31	2.84ab	2.74ab	6.58ab	34.38c	270.33b-d	462.33bc	86.67a	100.00a	287.29a	8.82a	7.98a	1.11a-c
VL × SP	2.73a-c	2.82ab	5.99b	28.17c	265.00b-d	381.00b-d	66.67a-c	93.33a	273.20a	7.90ab	8.02a	0.98bc
SP × G-28	2.55bc	2.39b	5.75b	26.42c	291.00b-d	400.00b-d	66.67a-c	100.00a	222.95a	7.72ab	7.21ab	1.07a-c
VL × MP-2	3.28a	3.24a	7.44ab	43.48a-c	220.33de	336.33de	73.33ab	100.00a	251.78a	7.47b	7.72ab	0.97c
MP-2 × G-15	2.79a-c	2.56b	6.49b	33.47c	369.00b	475.00b	46.67bc	80.00b	196.27a	7.02b	7.16ab	1.00a-c
BL × SP	2.23c	2.35b	5.97b	29.93c	245.33c-e	354.33b-e	60.00a-c	100.00a	213.06a	8.11ab	6.95ab	1.17ab

TH-Tree height (m), SPD-Spread (m), SG-Stem girth (m), TCSA-Trunk cross sectional area, DTFF-Days to 1st flowering, DTFH- Days to 1st harvest, Btaoy- Bearing trees after 1 year (%), Btaty- Bearing trees after 2 year (%), FWt- Fruit weight (g), FL- Fruit length (cm) FW- Fruit width (cm), FSI- Fruit shape index

Table 5. *Per se* performance of cross combinations for different characters in guava

Genotypes	SCD	PT	NSPF	HSW	SH	RF	WF	FNP	YP	PE	TSS	Acid
G-28 × Lalit	4.23a-c	1.56a	220.33b-d	1.24a-c	11.64a-c	60.00e	40.00b	104.10a	14.87a-c	0.37ab	11.83ab	0.58ab
G-15 × VL	4.03a-c	1.67a	198.33b-d	1.23a-c	12.01a-c	92.67ab	7.33ef	78.67ab	18.32ab	0.46ab	13.56a	0.66a
VL × G-15	4.26a-c	1.75a	258.67a-c	1.14bc	10.25bc	92.33ab	7.67ef	80.53ab	20.01a	0.56a	12.08ab	0.44ab
G-31 × TP	3.66c	1.55a	235.00a-d	1.04c	12.07a-c	100.00a	0.00f	46.33c-e	9.63cd	0.22ab	9.93b	0.40b
VL × G-31	4.63a	1.74a	277.00ab	1.46ab	13.59a	76.67dc	23.33cd	28.67e	7.94cd	0.23ab	10.37b	0.41b
VL × SP	4.06a-c	1.77a	122.33d	1.33a-c	12.46a-c	71.67de	28.33bc	53.00b-e	13.68a-c	0.49a	11.02ab	0.38b
SP × G-28	3.73bc	1.69a	151.67cd	1.22a-c	11.50a-c	78.33cd	21.67c-e	42.67c-e	10.01cd	0.38ab	11.31ab	0.45ab
VL × MP-2	4.22a-c	1.74a	259.33a-c	1.55a	12.74ab	0.00f	100.00a	60.67b-d	12.49b-d	0.29ab	12.11ab	0.48ab
MP-2 × G-15	4.38ab	1.49a	355.33a	1.07c	11.35a-c	90.00a-c	10.00d-f	29.67de	5.39d	0.16b	9.87b	0.45ab
BL × SP	3.74bc	1.54a	352.00a	1.01c	9.51c	80.00b-d	23.33cd	61.67bc	12.29b-d	0.51a	11.17ab	0.49ab

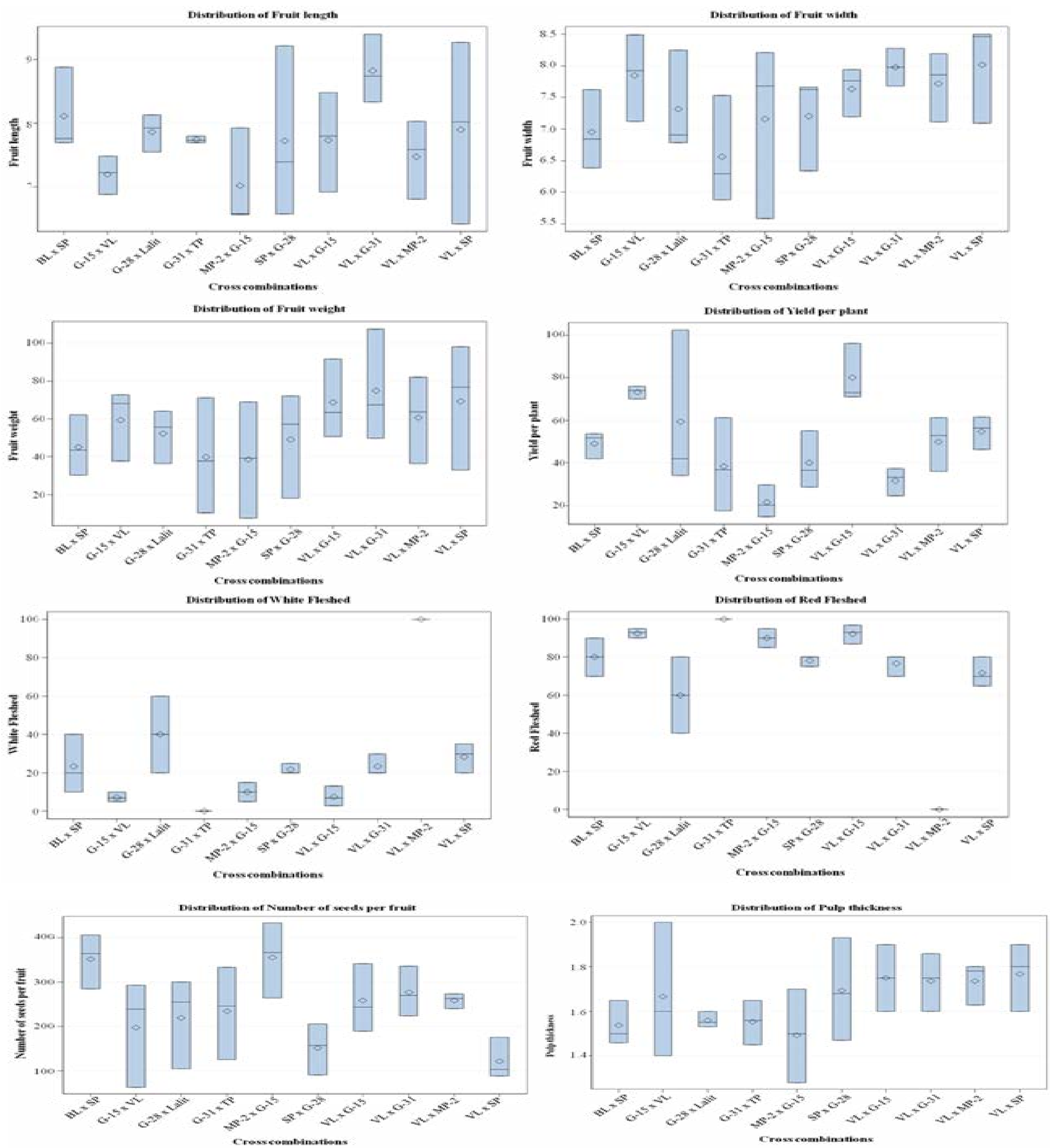
SCD-Seed core diameter (cm), PT-Pulp thickness (cm), NSPF-No. of seed/ fruit, HSW-100 seed weight (g), SH-Seed hardness (kg/cm^2), RF-Red fleshed (%), WF-White fleshed (%), FNP-Fruits number/ plant, YP-Yield/ plant (kg), PE-Production efficiency (kg/cm^2), TSS-Total soluble solids, Acid-Acidity (%)

Table 6. *Per se* performance of cross combinations for different characters in guava

Genotypes	TA	Asc	TS	K	P	Ca	Mg	Fe	Lyc	TPH	Flav	TAA
G-28 × Lalit	20.53c	156.64bc	7.96b-d	214.55de	24.24a	29.40a	49.48a	25.80cd	5.23de	266.21cd	15.81e	369.37b
G-15 × VL	21.83bc	266.20a	9.82a	289.94a	16.00c	22.83bc	22.87bc	29.09bc	9.96ab	375.14a	15.45e	454.83a
VL × G-15	27.49ab	175.39b	7.64cd	241.62b-d	19.36bc	25.29ab	26.19b	23.43cd	12.16a	357.66ab	15.58e	379.80b
G-31 × TP	24.94a-c	114.83cd	7.10c-e	168.81f	16.16c	18.74cd	23.04b	22.19d	6.88bc-e	305.69b-d	26.32a	258.21d
VL × G-31	25.48a-c	88.81d	6.77de	170.55f	20.55ab	26.06ab	28.32b	23.75cd	6.41c-e	261.85cd	20.86bc	283.08cd
VL × SP	29.14a	143.25b-d	7.68cd	215.11de	19.05c	25.09ab	22.55bc	22.53cd	7.41b-d	316.47bc	20.35b-d	353.10bc
SP × G-28	25.56a-c	147.26b-d	7.31c-e	232.41c-e	18.10bc	16.88d	14.39d	22.53cd	3.98e	316.39bc	24.54ab	407.36ab
VL × MP-2	25.03a-c	195.18b	8.40bc	256.16bc	16.06c	13.98d	10.87d	40.23a	0.12f	202.20e	16.36de	473.80a

MP-2 × G-15	22.68bc	166.83bc	6.01e	268.65ab	17.03bc	15.17d	16.25cd	33.55ab	8.89a-c	266.59cd	16.84c-e	289.95cd
BL × SP	24.58a-c	171.10bc	9.23ab	209.25e	23.64a	23.16bc	26.90b	28.03b-d	8.69bc	254.24de	15.62e	413.23ab

TA-TSS: Acidity, Asc-Ascorbic acid (mg/100g), TS-Total sugar (%), K-Potassium (mg/100g FW), P-Phosphorus (mg/100g), Ca-Calcium (mg/100g), Mg-Magnesium (mg/100g), Fe-Iron (ppm FW), Lyc-Lycopene (mg/100g). TPH-Total phenols (GAE/100g), Flav-Flavonoids (CE/100g), TAA-Total antioxidant activity (AAE/100g)



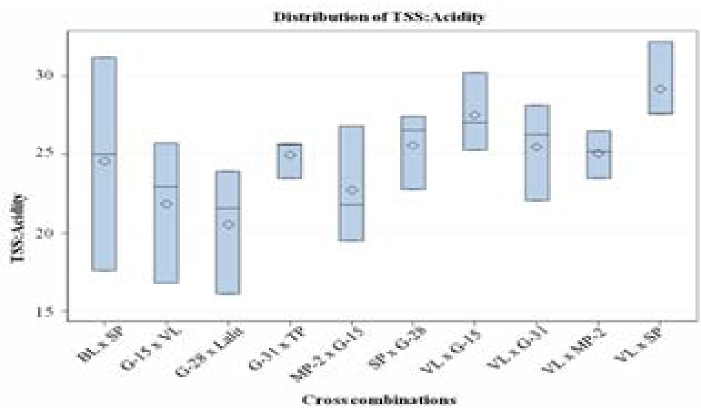


Fig 1. Mean value (Mean ± SD) distribution between major growth, yield and quality parameters and cross-combination genotypes of guava

Conclusion

The findings from this study underline the significant genetic variability among guava genotypes which showed that genotype plays a key role in determining important traits related to growth, yield, and fruit quality. The extremely high F-values across most traits emphasize the importance of genetic factors in influencing these characteristics, although environmental factors may also contribute, as seen in some traits such as DTFF, RF and WF. The *per se* performance of the cross combinations further reinforces the potential of targeted breeding strategies aimed at enhancing specific traits.

Several cross combinations demonstrated notable strengths, including G-28 × Lalit, which showed promise in terms of growth and nutrient content, and G-15 × VL, which excelled in quality-related traits and yield. These combinations indicate that strategic crosses can significantly improve guava cultivars for both agronomic performance and fruit quality. Conversely, some crosses, such as BL × SP, showed less potential for growth improvements, but may still offer value for specific breeding objectives. The trade-offs between growth, yield, and quality parameters highlight the need for a balanced approach in breeding programs to meet diverse goals. For future use, breeding efforts should consider genotypes like G-28 × Lalit for high productivity and nutrient enrichment, and G-15 × VL for superior fruit quality, particularly in flavor and sugar content. It is suggested that breeders further refine these crosses by balancing early maturity with high yield, ensuring adaptability to various agro-climatic conditions. Overall, this study contributes valuable insights into the genetic diversity and potential of guava genotypes for breeding high-performance cultivars. However, further investigations, including multigeneration studies and environmental assessments, are essential to evaluate the stability and heritability of these traits under different growing conditions. Such knowledge will be crucial for developing guava varieties that meet both agricultural needs and consumer demands.

Acknowledgements

The authors express gratitude to the ICAR, New Delhi and Director, ICAR-CIAH, Bikaner for providing the financial support, necessary facilities with constant encouragement and guidance to undertake this research program.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Azam, M.G., Uddin, M.S., Chowdhary, S.M.K., Rashid, Hasan, Harunor, A.S.M., Barua, H., Chhanda, R.A., Rahman, S., Bagum, S.A., Shamsunnahar, M., Islam, M.N. 2020. Variability studies of guava (*Psidium guajava* L.) genotypes for growth, yield and quality attributes in Chattogram region of *Bangladesh Journal of Agricultural Science & Engineering Innovation (JASEI)*, 1(2): 3-9.

Badami, K., Daryono, B. S., Amzeri, A. and Khoiri, S. 2020. Combining ability and heterotic studies on hybrid melon (*Cucumis melo* L.) populations for fruit yield and quality traits. *SABRAO Journal of Breeding and Genetics*, 52 (4): 402-417.

Bishnoi, P., Thakre, M., Maurya, P., Jagga, S., Gangappa, N. D., Nagaraja, A., Verma, M.K., Krishnan, S.G., Varghese, E. and Mithra Sevanthi, A. 2024. Pulp colour and pigment composition have no genetic correlation with seed hardness in guava (*Psidium guajava* L.). *The Journal of Horticultural Science and Biotechnology,* 1-14. https://doi.org/10.1080/14620316.2024.2392090

Bose, S. K., Ahmed, S., Howlader, P. and Ali, M. 2019. Flowering, fruiting behavior and nutritional quality of selected guava genotypes. *International Journal of Horticultural Science and Technology*, 6(1): 11-25.

Chiveu, J., Naumann, M., Kehlenbeck, K. and Pawelzik, E. 2019. Variation in fruit chemical and mineral composition of Kenyan guava (*Psidium guajava* L.): Inferences from climatic conditions, and fruit morphological traits. *Journal of Applied Botany and Food Quality*, 92: 151–159.

Correa, L.C., Santos, C.A.F. and Lima, G.P.P. 2012. Chemical and biochemical characterization of guava and araca fruits from different regions of Brazil. *Acta Horticulturae*, 959: 103-109.

Kamath, J. V., Rahul, N., Kumar, C. A. and Lakshmi, S. M. 2008. *Psidium guajava* L: A review. *International Journal of Green Pharmacy*, 2(1): 9-12. https://doi.org/10.4103/0973-8258.39155

Kherwar, D. and Usha, K. 2016. Genetic variations, character association and path analysis studies in guava (*Psidium guajava* L.) for bioactive and antioxidant attributes. *Indian Journal of Plant Physiology*, 21:355-361.

Kumari, P., Mankar, A., Karuna, K., Homa, F., Meiramkulova, K. and Siddiqui, M. W. 2020. Mineral composition, pigments, and postharvest quality of guava cultivars commercially grown in India. *Journal of Agriculture and Food Research*, 2: 100061. https://doi. org/10.1016/j.jafr.2020.100061

Kumari, S., Arumugam, N., Singh, R., Srivastav, M., Banoth, S., Mithra, A.C., Arun, M.B., Goswam, A.K. and Khan, Y.J. 2018. Diversity analysis of guava (*Psidium guajava*) germplasm collection. *Indian Journal of Agricultural Sciences*, 88 (3): 489-497.

Mishra, D. S., Berwal, M. K., Singh, A., Singh, A. K., Rao, V. A., Yadav, V. and Sharma, B. D. 2022. Phenotypic diversity for fruit quality traits and bioactive compounds in red-fleshed guava: Insights from multivariate analyses and machine learning algorithms. *South African Journal of Botany*, 149: 591-603.

Mishra, D.S. and Singh, A.K. 2022.Crop regulation in guava: a review. *Annals of Arid Zone*, 61(2): 75-82.

Mishra, D.S., Singh, A.K. and Rane, J. 2024. Guava breeding for future challenges. In: Dwibedi *et al.* (Eds.), Frontiers in Horticultural Technologies, Daya Publishing House, New Delhi. Pp. 87-112.

Mishra, D.S., Singh, S., Singh, A.K., Appa Rao, V.V. and Saroj, P.L. 2019. Assessment of genetic diversity in guava. *Indian Journal of Horticulture*, 75(3): 362-368.

Nakasone, H.Y. and Paull, R.E., 1999. Tropical fruits. Crop production in Science in Horticulture. CAB International, Wallingford, UK. P. 159.

Naseer, S., Hussain, S., Naeem, N., Pervaiz, M. and Rahman, M. 2018. The phytochemistry and medicinal value of (*Psidium guajava*) guava. *Clinical Phytoscience*, 4: 32-34. https://doi. org/10.1186/s40816-018-0093-8

Paras, Kaur, K., Kaur, G., Singh, D. and Brar, J. S. 2024. Heritability and principal component analysis of phytochemical traits in guava under Indian subtropics. *Applied Fruit Science*, 66(1): 193-202.

Pathak, R.K. and Ojha, C.M. 1993. Genetic resources of guava. In: Chadha, K.L., Pareek, O.P. (Eds.), Advance in Horticulture. Fruit Crops, Part 1, vol. I. Malhotra Publishing House, New Delhi. Pp. 143-147.

Pommer, C.V. 2012. Guava world-wide breeding: major techniques and cultivars and future challenges. *Acta Horticulturae*, 959: 81-88.

Sarkar, T.and Sarkar, S.K. 2022. Pollination characteristics and intervarietal hybridization of *Psidium guavaja*. *Journal of Crop and Weed*, 18(1): 96-103.

Shukla, S., Kushwaha, R., Singh, M., Saroj, R., Puranik, V., Agarwal, R. and Kaur, D. 2021. Quantification of bioactive compounds in guava at different ripening stages. *Food Research*, 5(3): 183-189. https://doi.org/10.26656/ fr.2017.5(3).554

Singh, D., Gill, M. I. S., Boora, R. S. and Arora, N. K. 2015. Estimates of genetic variability, heritability, genetic advance, correlation coefficients and their prospects for crop improvement in guava (*Psidium guajava* L.). *Journal of Applied Horticulture*, 17(1): 76-78.

Singh, R. and Sehgal, O.P. 1968. Studies on blossom biology of *Psidium guajava* L. (guava). II. Pollen studies, stigma receptivity, pollen and fruit set. *Indian Journal of Horticulture*. 25: 52-59.

Speer, H., D'Cunha, N. M., Alexopoulos, N. I., McKune, A. J. and Naumovski, N. 2020. Anthocyanins and human health-a focus on oxidative stress, inflammation and disease. Antioxidants, 9(5): 366. https://doi. org/10.3390/antiox9050366

Thakre, M., Hanamant, S., Ramkumar, M. K., Senapati, R., Rudra, S. G., Saha, S., Nagaraja, A., Verma, M. K., Krishnan, G. S., Varghese, E. and Amitha Mithra, S. V. 2023. Pigment composition analysis of fruit pulp in the recombinant progenies reveals the polygenic nature of pulp color inheritance in guava (*Psidium guajava* L.). *Tree Genetics and Genomes*, 19: 20. https://doi. org/10. 1007/s11295-023-01595-w

Tripathi, P.C., Sane, A., Kumar, P, Kanupriya, C., Mishra, D.S. and Ravat, P. 2025. Phenotypic and genetic characterization of *Cordia myxa* L. using multivariate analysis. *Flora*, 323:15263. https://doi.org/10.1016/j.flora.2025.152673

Woodside, J. V., McGrath, A. J., Lyner, N. and McKinley, M. C. 2015. Carotenoids and health in older people. *Maturitas*, 80(1): 63-68. https://doi.org/10. 1016/j.maturitas.2014.10.012

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Response of different potato genotypes to deficit irrigation in North-Western plains of India

Sugani Devi[1], Vijay Kishore Gupta[2], Ratna Preeti Kaur[1], Devender Kumar[2] and Anil Sharma[1]

[1]ICAR-Central Potato Research Institute (RS), Jalandhar, Punjab
[2]ICAR-Central Potato Research Institute (RS), Modipuram, Uttar Pradesh

ARTICLE INFO

Received: 10 March 2025
Accepted: 15 April 2025

Keywords: Water deficit, potato, tuber yield, tuber number

doi:10.48165/ijah.2025.7.1.6

ABSTRACT

Field-based experimental trials were undertaken to assess the influence of water deficit stress on the tuber yield performance of nine distinct potato (*Solanum tuberosum* L.) genotypes. The genotypic set comprised officially released indigenous cultivars, advanced-stage breeding clones, and two standard control varieties. The experimental design incorporated two irrigation regimes: a fully irrigated control treatment (FI) representing optimal water supply, and two deficit irrigation treatments - alternate skip irrigation (DI) and complete cessation of irrigation during the tuber bulking phase (CS) - to simulate varying intensities of water stress. Among the genotypes evaluated under water-limited conditions, the cultivar 'Kufri Gaurav' exhibited the highest total tuber yield, followed sequentially by 'Kufri Ganga', 'Kufri Thar-2', and 'Kufri Kiran', indicating superior adaptive responses to water deficit stress.

Introduction

Potato (*Solanum tuberosum* L.) is one of the most water-sensitive crops due to its shallow root system, which typically penetrates only 50–60 cm into the soil (Levy, 1983). As a result, water deficiency is a major constraint, significantly affecting both tuber yield and quality. With the looming threat of climate change, which is expected to bring higher temperatures, extended dry periods, and unpredictable rainfall patterns, potato production is increasingly vulnerable. These climatic changes threaten the productivity of potato crops in many regions worldwide (Evers *et al.*, 2010).

Despite these challenges, potatoes remain a staple in the global food supply chain. Extensively grown and consumed, they provide a substantial source of calories, essential vitamins, and vital minerals for populations around the world. Potatoes are highly adaptable, able to thrive in a variety of climatic conditions and diverse soil compositions. This adaptability allows them to be cultivated in areas with limited agricultural resources, where other crops may struggle.

Due to their high yield potential and resilience under harsh conditions, potatoes play a critical role in food security. As one of the most widely grown and versatile crops, they help nourish billions of people and ensure a reliable global food supply. However, the ongoing issue of water scarcity has significantly impacted potato farming, leading to decreased yields and quality in many regions. This underscores the urgent need for sustainable water management practices and climate-resilient agricultural techniques to secure the future of potato cultivation, which remains a cornerstone of global

Corresponding author's Email: sugani.ars15@gmail.com (Dr. Sugani Devi)

food systems.

As climate change continues to exacerbate water scarcity and alter growing conditions, addressing the water needs of potato crops will be crucial for maintaining their role in global food security. Innovations in irrigation, soil management, and drought-resistant potato varieties will play a key role in adapting to these challenges and ensuring that potatoes remain a vital food source in the years to come.

Tuber yield remains the principal trait of interest in potato cultivation, and as such, is the most extensively studied parameter in potato production research. Achieving optimal yield under water-limited conditions is a critical goal in developing resilient cultivars. Keeping these issues in mind a study was conducted to evaluate the response of advanced clones and released varieties of ICAR-Central Potato Research Institute (CPRI), Shimla to deficit irrigation.

Material and Methods

Field experiments were conducted at ICAR-Central Potato Research Institute (Regional Station), Jalandhar, Punjab during *rabi* season of 2021-22 located at 31.27ºN latitude and 75.54ºE longitude, 237 meters above mean sea level. The experiment was laid out in Factorial Randomized Block Design with two factors and replicated thrice. First factor included nine advanced hybrids/parents/varieties viz., Kufri Thar-1, Kufri Kiran, HT 7/-620, MP/9-11, Kufri Ganga, Kufri Thar-2, HT/7-1105 along with two controls (Kufri Surya and Kufri Gaurav). The second factor was water stress treatment with three levels viz., recommended irrigation (FI), complete stop of irrigation after 55 DAP (CS) and deficit or alternate irrigation (DI) where we skipped alternate irrigation as compared to recommended irrigation.

The crop was irrigated through flood irrigation and in treatment with skip irrigation every alternate irrigation was skipped. Planting was done on 20 October and haulm cutting was done 80 days after planting. Yield observations were recorded in different treatments in terms of tuber number of tubers (‘000/ha) and yield (t/ha) in different grades according to weight. After harvesting the tubers were graded in under sized (<25 g), seed sized (25-125 g) and over-sized (>125 g) grades based on the tuber weight.

Results and Discussion

In the present study, significant reductions in both total and marketable tuber yields were observed under water stress across all evaluated varieties and clones (Table 1). However, substantial genotypic variability was evident. The highest total tuber yields were recorded in cultivars Kufri Ganga (55.093 t/ha) and Kufri Gaurav (54.129 t/ha), with the latter also exhibiting the maximum yield of seed-size tubers, followed closely by Kufri Ganga; these differences were not statistically significant. Kufri Kiran and Kufri Thar-2 also showed comparatively better performance under stress conditions in terms of both tuber yield and number. Conversely, HT/7-1105 and Kufri Thar-1 recorded the lowest yields under the same conditions.

Irrigation regime had a significant effect on yield performance. Full irrigation (FI) resulted in the highest tuber yield, while control stress (CS) treatment produced the lowest yield (41.56 t/ha), followed by deficit irrigation (DI) (44.85 t/ha) at 80 days after planting. The reduction in tuber yield under stress conditions is consistent with previous findings (Hassan *et al.*, 2002; Tourneux *et al.*, 2003; Schafleitner *et al.*, 2007), and is likely attributable to reduced vegetative growth, including diminished foliage development and canopy coverage. Significant interaction was recorded between genotype x irrigation treatment for number of oversize tubers and yield of oversized tubers. Where maximum yield and tuber number was recorded in Hybrid MP/9-11 with FI followed by K. Ganga with FI.

Tuber size distribution was also significantly influenced by genotype, with water stress exerting a pronounced effect on the yield of seed-size tubers. Analysis of tuber number (Table 2) revealed that Kufri Gaurav produced the highest total tuber count (807.47), followed closely by Kufri Ganga (803.25); these values were statistically comparable. In contrast, HT/7-1105 recorded the lowest tuber number and poorest yield performance under stress. Although the total tuber count was not significantly affected by water stress treatments, the number of seed-size tubers was markedly reduced. The highest number of seed-size tubers was observed under full irrigation, while the lowest was recorded under DI and CS treatments, with no significant difference between the latter two. These results are partially in agreement with Jefferies and MacKerron (1986), who reported no significant effect of drought on tuber number when water was withheld post-tuber initiation, but contrast with findings by Minhas and Bansal (1991), who documented reductions in tuber count under drought stress

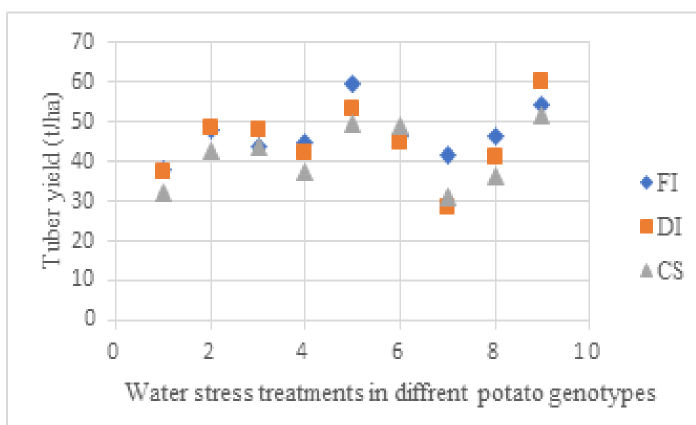


Fig. 1. Total tuber yield in different genotypes of potato with water stress treatments

Table 1. Tuber yield as influenced by water stress treatments in different varieties of potato

Treatments	Over-size tuber yield (t/ ha)	Seed-size tuber yield (t/ ha)	Under-size tuber yield (t/ ha)	Total tuber yield (t/ ha)
Varieties/ genotypes				
Kufri Thar-1	4.295	24.890	6.643	35.830
Kufri Kiran	7.142	37.312	1.885	46.342
HT 7/-620	5.107	35.468	4.687	45.262
MP/9-11	9.858	27.732	3.857	41.447
Kufri Ganga	9.493	40.623	4.977	55.093
Kufri Thar-2	9.895	35.092	1.645	46.635
HT/7-1105	7.618	23.595	2.372	33.588
Kufri Surya	6.893	33.278	1.013	41.187
Kufri Gaurav	6.742	43.257	4.130	54.129
SEm±	0.759	1.463	0.508	1.431
LSD	2.217	4.276	1.486	4.182
Water stress treatments				
Full Irrigation (FI)	7.373	35.601	3.293	46.869
Deficit irrigation/ Alternate irrigation (DI)	7.726	33.491	3.628	44.846
Complete stop of irrigation at bulking stage (CS)	7.248	31.323	3.582	41.557
SEm±	0.438	0.844	0.294	0.826
LSD	NS	2.468	NS	2.414

Table 2. Tuber Number as influenced by water stress treatments in different varieties of potato

Treatments	Over-size tuber number (‘000/ ha)	Seed-size tuber number (‘000/ ha)	Under-size tuber number (‘000/ ha)	Total tuber number (‘000/ ha)
Varieties/ genotypes				
Kufri Thar-1	19.483	298.373	343.185	661.050
Kufri Kiran	31.730	458.693	112.447	602.867
HT 7/-620	25.328	401.913	176.742	603.983
MP/9-11	57.058	279.725	151.135	487.933
Kufri Ganga	58.450	486.527	258.293	803.250
Kufri Thar-2	42.585	384.935	121.353	548.883
HT/7-1105	32.843	282.508	141.672	457.067
Kufri Surya	34.792	374.915	105.488	515.217
Kufri Gaurav	31.452	499.330	276.663	807.467
SEm±	3.943	13.604	23.163	31.398
LSD	11.527	39.766	67.707	91.777
Water stress treatments				
Full Irrigation (FI)	38.132	409.428	173.494	621.067

Deficit irrigation/ Alternate irrigation (DI)	38.039	383.265	196.782	618.095
Complete stop of irrigation at bulking stage (CS)	35.070	362.947	192.050	590.078
SEm±	2.277	7.855	13.373	18.128
LSD	NS	22.959	NS	NS

Conclusion

It was observed that the highest yield and maximum tuber count were recorded in the Kufri Gaurav and Kufri Ganga varieties followed by Kufri Kiran and Kufri Thar-2. Therefore, these varieties are highly suitable for cultivation in regions experiencing water scarcity. They can be promoted in areas where irrigation water is limited, as they require fewer irrigations - potentially saving one to two irrigation cycles without significantly compromising yield. Given their resilience to water-deficit conditions, these varieties present a promising option for sustainable potato cultivation in the face of future climate change challenges.

Acknowledgements

The authors express their gratitude to the Indian Council of Agricultural Research (ICAR), New Delhi and ICAR-CPRI, Shimla for providing the necessary facilities.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Evers, D., Lefevre, I., Legay, S., Lamoureux, D., Hausman, J., Rosales, R. O. G., *et al.* 2010. Identification of drought responsive compounds in potato through a combined transcriptomic and targeted metabolite approach. *Journal of Experimental Botany*, 61: 2327–2343.

Hassan, A. A., Sarkar, A. A., Ali, M. H. and Karim, N. N. 2002. Effect of deficit irrigation at different growth stages on the yield of potato. *Pakistan Journal of Biological Sciences*, 5: 128–134.

Jefferies, R. A. and MacKerron, D. K. L. 1986. The Influence of soil water restrictions on tuber numbers. *Potato Research,* 29: 262.

Levy, D. 1983. Varietal differences in the response of potatoes to repeated short periods of water stress in hot climates. 2. Tuber yield and dry matter accumulation and other tuber properties. *Potato Research,* 26: 315-21.

Minhas, J. S. and Bansal, K. C. 1991. Tuber yield in relation to water stress at different stages of growth in potato (*Solanum tuberosum* L.). *Journal of Indian Potato Association*, 18: 1–8.

Schafleitner, R., Gutierrez, R., Gaudin, A., Perez, J., Martinez, M., Dominguez, A., *et al.* 2007. Field screening for variation of drought tolerance in *Solanum tuberosum* L. by agronomical, physiological, and genetic analysis. *Potato Research*, 50: 71–85.

Tourneux, C., Devaux, A., Camacho, M. R., Maani, P., & Ledent, J. F. 2003. Effects of water shortage on six potato genotypes in the highlands of Bolivia (1): Morphological parameters, growth, and yield. *Agronomie*, 23:169–179.

Research Article

ISAH Indian Journal of Arid Horticulture

Year 2025, Volume-7, Issue-1 (January - June)

Impact of integrating summer vegetables with major cropping systems for profitability and sustainability

Navjot Singh Brar[1] and Manpreet Jaidka[2]

[1]Vegetable Breeder, Vegetable Research Farm, Khanaura, Punjab
[2]Assistant Professor (Agronomy), KVK, Moga, Punjab

ARTICLE INFO

Received: 05 March 2025
Accepted: 15 April 2025

Keywords: Cropping systems, summer vegetables, crop diversification, crop intensification, sustainability

doi:10.48165/ijah.2025.7.1.7

ABSTRACT

Punjab, contributing 35-40% of rice and 40-70% of wheat to the central pool, has a high cropping intensity (196-200%). This study evaluates the economic impact of integrating short-duration summer vegetables with major cropping systems. Survey data revealed that paddy-potato crop rotation recorded the highest net returns (Rs.1,18,467/acre), whereas paddy-wheat had the highest B:C (2.71). Inclusion of summer vegetables significantly increased economic indices like net returns and B:C in paddy-wheat by 84.87 and 4.06 per cent, and in paddy-mustard by 126.23 and 21.46 per cent, respectively. Cultivation of summer vegetables enhanced the land use efficiency from 71.23 to 95.89 per cent in case of paddy-wheat crop rotation. Summer vegetable cultivation increased land use efficiency from 68.49 to 93.15 per cent in paddy-mustard cropping system. Inclusion of summer vegetables significantly enhanced the system productivity of all the existing crop rotations. In paddy-wheat rotation an increase in system productivity by about 179.96 per cent was recorded due to cultivation of summer vegetables. Results of the study clearly show immense potential of short duration summer vegetables in enhancing the farm profitability and sustainability while justifying the objectives of crop diversification in Punjab state.

Introduction

Punjab occupies 1.54% of India's total geographical area (Pushkarna, 2017) and has played a crucial role in national food security, especially after the Green Revolution. The state boasts a well-organized irrigation system, access to quality seeds, efficient crop nutrient management, advanced mechanization, and a strong network of agricultural market centers. Punjab contributes approximately 35-40% of the rice and 40-70% of the wheat to the central food pool, reinforcing its significance in national grain production (Dhiman *et al.*, 2010). While the national average cropping intensity is around 150%, Punjab's cropping intensity stands at 196-200%. However, the introduction of short-duration crops, particularly improved varieties, can further enhance cropping intensity to ensure food and nutritional security for India's rapidly growing population.

With limited scope for horizontal expansion of agricultural land, increasing cropping system productivity must be prioritized (Choudhary *et al.*, 2024). Over time, the dominance of mono-cropping has highlighted the urgent need for crop diversification by integrating best-fit crops into existing cropping systems. Despite its small geographical area, Punjab features diverse agro-ecological zones, allowing farmers to cultivate a wide range of crops, including paddy, wheat, potato, maize, sugarcane, and mustard, through various crop rotations such as paddy-wheat, paddy-potato, and paddy-mustard. Additionally, short-season crops like

Corresponding author's Email: navjotsbrar@pau.edu (Dr. N.S. Brar)

summer green gram, spring maize, and mentha are cultivated after the *rabi* season.

In recent years, instead of cultivating crops themselves after the *rabi* harvest, many farmers have started leasing out their land to fellow farmers for short-term cultivation. During this period, farmers cultivate short-duration summer vegetables such as bottle gourd, ash gourd, pumpkin, cluster bean, longmelon, snap melon, and wanga, which fetch high market prices due to their seasonal scarcity. The inclusion of these vegetables provides a dual economic benefit, generating income for both landowners and tenant farmers while further increasing cropping intensity (Brar *et al.*, 2019; Krishna *et al.*, 2024). Punjab has a geographical advantage with the availability of resources to support vegetable production during the peak summer months before the onset of the monsoon. Since green vegetables are in high demand during this season in North Indian markets, Punjab has the potential to capitalize on this opportunity.

Keeping in the view of economic significance of short-duration summer vegetables, whether on leased or owned land, it appears to be a viable approach for increasing cropping intensity while promoting resource conservation farming. To assess the impact of these vegetables on the economics of different cropping systems and explore their future prospects, a survey-based study was conducted to evaluate their role in Punjab's prevailing agricultural landscape.

Material and Methods

This study focused on six cropping systems commonly practiced by farmers in Punjab. The selection of these cropping systems was based on their inclusion of paddy, wheat, mustard or potato in combination with summer vegetables (Table 1). During the summer season, farmers cultivated short-duration vegetables such as bottle gourd, ash gourd, pumpkin, wanga, cluster bean, longmelon, and snapmelon. After the summer crop, they proceeded with *kharif* crop cultivation. A survey was conducted during the agricultural year 2023-24 by randomly selecting 150 farmers from Punjab, as detailed of cropping systems in Table 1:

Table 1. Different cropping systems surveyed for the study

Cropping system	Number of farmers
Paddy-Wheat	25
Paddy-Potato	25
Paddy-Mustard	25
Paddy-Wheat-Summer vegetables	25
Paddy-Potato-Summer vegetables	25
Paddy-Mustard-Summer vegetables	25

The data were collected by using a pre-designed interview cum questionnaire schedule containing queries pertaining to type of crops, cropping system, date of sowing, method of sowing, seed rate, usage of fertilizers, herbicides, pesticides, fungicides, sale price, etc. The land use efficiency (LUE) was calculated by dividing the total duration of crops in given cropping system by 365 and was expressed as percentage. Production efficiency was computed to assess the yield output concerning crop duration with the formula as given below.

$$\text{Production efficiency (kg/ha/day)} = \frac{\text{Economic yield of the crops in cropping system}}{\text{Crop duration (days)}}$$

The economic viability of different cropping systems was evaluated based on the data collected from farmers. The benefit-cost ratio (B: C) was determined using the following formula:

$$\text{B:C} = \frac{\text{Net returns}}{\text{Total cost of cultivation}}$$

Data compilation of the survey was done using online OPSTAT software. All the parameters such as cost of cultivation, net returns, production efficiency etc. were compared by running basic statistical analysis in the software. The p-value at 5 per cent level of significance was calculated by randomly selecting 10 farmers in each cropping system as replications.

Results and Discussion

The survey data showed that in sole cropping systems other summer vegetables, highest net returns was recorded in paddy-potato cropping system but, on the contrary, highest B:C was observed in paddy-wheat rotation (Table 2). Even paddy-mustard cropping system also registered higher B:C than paddy-potato rotation. Paddy-potato crop rotation had lowest B:C although this system recorded highest net returns. The decrease in B:C of paddy-potato rotation can be attributed to increase in cost of cultivation, especially in case of potato crop. This increase in cost of cultivation of potato crop corresponds to those farmers who purchase the seed potato tubers either from government or private agencies. Generally, farmers cultivate potato crop for 3-4 years after purchasing the potato seed tubers. After harvesting of potato crop, they store the produce in cold store to be used as seed in next season. Therefore, use of self produced seed for 3-4 years decreases the cost of cultivation up to 60 per cent, which in turn makes the potato cultivation an economically viable option over the years. As compared to paddy-mustard rotation, high B:C in paddy-wheat cropping system can be attributed to better gross and net returns even under scenario of high cost of cultivation. Further, inclusion of short duration summer vegetables in all the prevailing cropping systems positively affected the economic indices thereby increasing the net returns and B:C in comparison to sole crop rotation without vegetables. For instance, cultivation of summer vegetables in paddy wheat crop rotation enhanced the net returns and B:C ratio by 84.87 and 4.06 per cent, respectively. Similarly, inclusion of summer vegetables in paddy-mustard rotation registered increase in net returns and B:C ratio by 126.23 and 21.46 per cent, respectively. This enhancement in returns and B:C due to cultivation of summer vegetables can be attributed to better selling price of vegetables fetched by the farmers due to early arrival in the market which in turn provides avenues for having more returns per unit time and area. Due to better returns, farmers of the region opt for leasing out of their land for a period of 3-4 months to cultivate summer vegetables. While conducting the survey, it was also noted that availability of short duration varieties of paddy or basmati also provides sufficient time to the farmers to raise nursery and transplant.

Table 2. Economics of different cropping systems

Cropping systems	Cost of cultivation (Rs./ acre)	Gross returns (Rs./ acre)	Net returns (Rs./ acre)	B:C ratio
Paddy-Wheat	35500	131863	96363	2.71
Paddy-Potato	82833	201300	118467	1.43
Paddy-Mustard	30700	102300	71600	2.33
Pady-Wheat-Summer vegetbles	63068	241812	178144	2.82
Paddy-Potato- Summer vegetables	110401	306926	196848	1.78
Paddy-Mustard- Summer vegetables	57268	218926	161981	2.83
p- value (0.05)	0.0001	0.0021	0.0003	0.0001
CV (%)	10.23	9.71	10.06	10.17

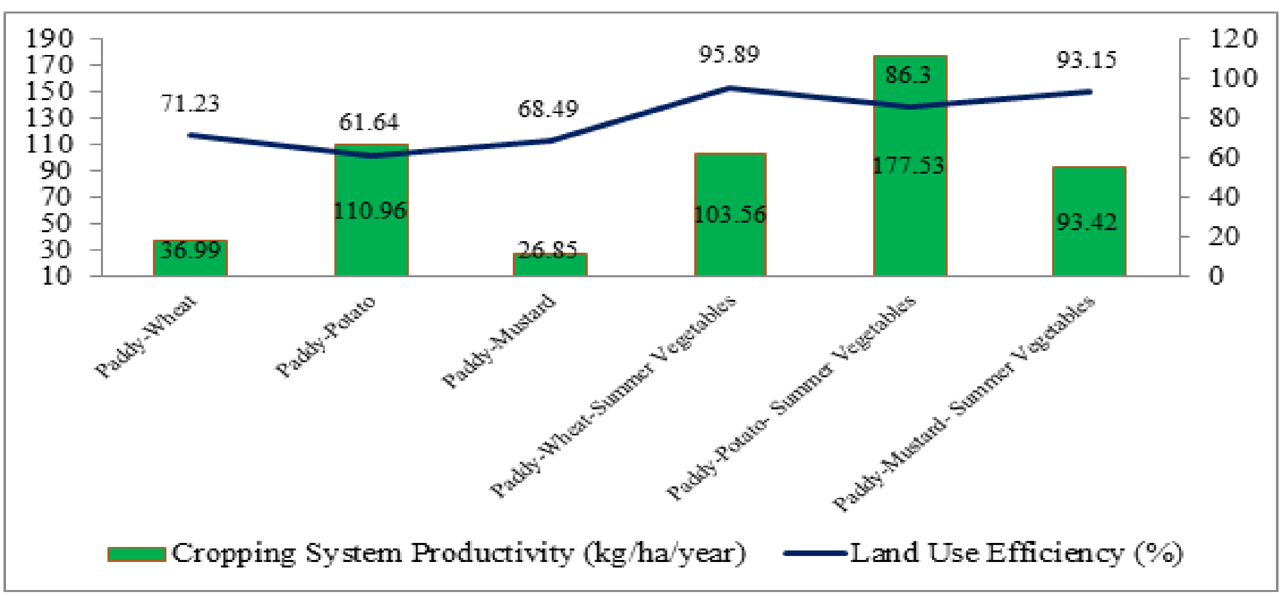


Fig. 1. Effect of summer vegetable cultivation on land use efficiency and cropping system productivity

As a result, it was observed that the inclusion of short-duration varieties and crops enhanced the sustainability of cropping intensity while optimizing input utilization in major cropping systems. This approach also provided farmers with an additional source of income during the gap months between major crop cycles. The cultivation of summer vegetables proved to be financially beneficial for both land-owning and lease-holding farmers. Moreover, some farmers generated income by leasing out their land for short-term vegetable cultivation during the three-month gap between major crop rotations, further maximizing land use efficiency (LUE) and profitability. Data regarding land use efficiency (Fig. 1) depicted that cultivation of summer vegetables enhanced the LUE from 71.23 to 95.89 per cent in case of paddy-wheat crop rotation. Likewise, summer vegetable increased LUE from 68.49 to 93.15 per cent in paddy-mustard cropping system.

Under the changing scenario of urbanization and industrialization, this enhancement in LUE due to summer vegetables provide opportunities to the leading farmers to maximize their resource use efficiency as well as cropping intensity by multifold use of same piece of land in a given crop year. Furthermore, the integration of summer vegetables with existing crop rotations showed considerable increase in system productivity (Fig. 1). For instance, inclusion of summer vegetables in paddy-wheat rotation resulted in ~179.96 per cent increase in cropping system production efficiency. Enhancement in system efficiency creates avenues to yield more per unit area in a given period of time, which in turn can further be important to farmers who cultivate land on lease basis. Leasing land for summer vegetables provided additional income, while supply of produce during peak hot months of summer ensured better prices. Producing more per unit area along with fetching good price in the market certainly helps those farmers to repay their rental value on timely basis. Crop diversification though vegetable has been reported to enhance the productivity and profitability of traditional cropping systems (Kumar *et al.,* 2005; Upadhaya *et al.*, 2022).

Conclusion

From the study it can be concluded that cultivation of summer season vegetable is an economically viable option which not only increase cropping intensity with conservation technologies of the field but also improvise the returns and B:C in comparison to prevailing crop rotations without summer season vegetables. However, recent advances in various fronts of plant science such as natural resource conservation, crop diversification, and integration of artificial intelligence have made it possible to have sustainable growth in terms of farmer income and environment under rainfed as well as irrigated conditions. Furthermore, adoption of short duration field crops/vegetables/varieties would be more remunerative to the farming community of the Punjab state having an array weather conditions in a given calendar year. At the same time, cultivation of summer vegetables certainly proves propitious in achieving higher level of resource use efficiency, system productivity, dietary diversity, which no doubt remains the ultimate objective of the technological interventions taken in the agriculture production systems to address the food and nutritional security of the nation.

Acknowledgements

The authors express their gratitude to the Punjab Agricultural University, Ludhiana for providing the necessary facilities.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Brar, N.S., Saini, D. K., Kaushik, P., Chauhan, J. and Kamboj, N.K. 2019. Directing for Higher Seed Production in Vegetables. In: *Agronomy- Climate Change and Food Security*, IntechOpen. doi: 10.5772/intechopen.90646

Choudhary, A. K., Saxena K. B. and Kumari, S. 2024. Accelerating cropping intensity to feed ever-growing population in India. *Current Science*, 126 (7): 756-758.

Dhiman, J. S., Kang, M. S., Parshad, V. R., Khanna, P. K., Bal, S. S. and Gosal S.S. 2010. Improved seeds and green revolution. *Journal of New Seeds*, 11 (2): 65-103. doi:10.1080/1522886X.2010.481777

Krishna, H., Hebbar, S., Kumar, P., Sharma, S., Kumar, R., Tiwari, S. K., Maurya, S., Srivastava, K., Pal, G., Bahadur, A. and Behera, T. K. 2024. Navigating challenges and prospects in off-season vegetable production. *Vegetable Science*, 51: 97-105. doi.org/10.61180/vegsci.2024.v51.spl.09

Kumar, S., Pandey, D. S. and Rana, N. S. 2005. Economics and yield potential of wheat (*Triticum aestivum*) as affected by tillage, rice (*Oryza sativa*) residue and nitrogen management options under rice-wheat system. *Indian Journal of Agronomy,* 50: 102-105.

Pushkarna, M. 2017. Literacy Patterns in Punjab: Rural- Urban Differentials. *IOSR Journal Of Humanities and Social Science*, 22 (7): 32-39.

Upadhaya, B., Kishor, K., Kumar, V., Kumar, N., Kumar, S., Yadav, V. K., Kumar, R., Gaber, A., Laing, A. M., Brestic, M., *et al.* 2022. Diversification of rice-based cropping system for improving system productivity and soil health in eastern gangetic plains of India. *Agronomy*, 12(10): 2393. doi.org/10.3390/agronomy12102393

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Impact of integrated nutrient management on growth and yield of cumin (*Cuminium cyminium* L.) in western Rajasthan

Chandan Kumar[1], A.S. Tetarwal[1], Aishwarya Dudi[1], M.K. Ahirwar[1] and Dheeraj Singh[2]

[1]ICAR-CAZRI, Krishi Vigyan Kendra, Pali, Rajasthan
[2]Division II, ICAR-CAZRI, Jodhpur, Rajasthan

ARTICLE INFO

Received: 24 March 2025
Accepted: 19 April 2025

Keywords: Cumin, integrated nutrient management, fertilizers, sustainable

doi:10.48165/ijah.2025.7.1.8

ABSTRACT

The study on impact assessment of integrated nutrient management practices in cumin revealed that application of NPK @ 50:30:20 kg/ ha with FYM @ 15 t/ ha FYM (T_{11}) performed better at 45 DAS, 90 DAS and at harvest respectively, in terms of plant height, number of branches per plant, and plant population. Treatment T_{11} was also shown to have the best results for test weight, seed yield, quantity of umbels and seeds per plant. This demonstrate the effectiveness of INM in increasing cumin production and growth, providing important information for growing cumin in western Rajasthan.

Introduction

The cumin, commonly known as *jeera* (*Cuminium cyminium* L.), is a member of the Apiaceae family. With over 22% of the country's spice acreage, it is the most extensively grown spice and it also makes up over 48% of the country's seed spice acreage, leading to the largest crop. In parts of M.P. and U.P., along with predominantly in Rajasthan and Gujarat, cumin is growing as a *rabi* crop. With 99% of India's cumin production, Gujarat and Rajasthan occupy significant production and area position (Meena *et al*., 2021). Gujarat state has an excellent productivity, producing 2.74 lakh tonnes of cumin crop on 2.76 lakh hectares of area whereas, Rajasthan is the state with the largest area (6.59 lakh ha) and the highest production (3 lakh tonnes). India produces 5.77 lakh tonnes of cumin annually on 9.37 lakh hectares of area (Spice Board, 2023-24). In India in 2022-2023, cumin is the most widely cultivated seed spice and the second most widely grown spice, beneath chilli (8.44 lakh ha). According to Meena *et al*. (2022), the yield of cumin in India is 647 kg ha^{-1}, having variations from district to district in Gujarat (995 kg ha^{-1}) and Rajasthan (424 kg ha^{-1}). Cumin production is expected to decline in 2025 in both Gujarat and Rajasthan as compared to the year earlier. It is expected that the area used for cumin cultivation would decrease by 20% in Gujarat and by around 5% in Rajasthan. The main causes of this area reduction are weather-related problems and delayed sowing, both of which are predicted to result in poorer yields (Anonymous, 2025). There are fewer high-yielding and resistant varieties available, recommended plant production and protection technologies are not being adopted as widely, and farmers are not well-informed about the recommended package of practices specific to their area, which results in the crop's average productivity being extremely low both nationally and in Rajasthan. Using better practices techniques can have significant effects on the expanding area. Timely and sufficient fertilizer application is crucial for cumin yield,

Corresponding author's Email: astetarwal@gmail.com (Dr. A.S. Tetarwal)

in addition to other suggested measures (such irrigation and intercultural activities). Furthermore, adopting easily available chemicals and organic methods to efficiently manage biotic and abiotic stresses at crucial times is vital to increasing crop yield and growth. It is well acknowledged that using chemical fertilizers in conjunction with organic composts is a significant agricultural approach that can yield additional benefits or at least effects that are equal to those obtained from using chemical fertilizers alone (Chouhan *et al.*, 2023). Crop production and nutrient availability are significantly improved when manure is used in place of some manufactured fertilizers. In addition to improving various soil properties and crop productivity, the combined use of chemical fertilizers and organic compost also significantly reduces the use of chemical fertilizers, which in turn saves energy, reduces the risk of pollution, increases fertilizer use efficiency, minimizes costs for farmers, particularly in low-income countries, and ensures ecosystem sustainability against the decline of soil and water resources (Kumar *et al.*, 2024).

Well-decomposed farm yard manure (Organic manure) should be applied and evenly distributed across the field before ploughing in order to improve soil fertility, productivity, and aeration as well as to maintain the C: N ratio in the field, which leads to a better yield. If rainwater falls in excess before the crop is seeded, the nutrients might flow off. Well-rotted farm yard manure should be thoroughly incorporated into the soil just before to the crop being sown. Like any other commercial fertilizer, FYM has a direct impact on plant development since it contains plant-based nutrients. It also contains traces of micronutrients in addition to essential nutrients (Kumar and Singh, 2023). The current study was conducted to examine the impact of N, P, K, and FYM on cumin growth and yield while taking all of these factors into consideration.

Material and Methods

Pali lies in western plain of luni basin agro climatic zone of India. The soil of the experimental field was sandy clay loam in texture while depth of soil is moderate too deep about 50 to 75 cm. It is suitable for cultivation but for low rainfall and high evaporation causes saline (pH 7.9 to 8.0) nature. Organic carbon at the farm field soil ranges from 0.22 to 0.33% and Nitrogen in surface layer is low (231.7 to 277.0 kg/ ha) whereas P_2O_5 (14.3 to 15.0 kg/ ha) and K_2O (210.3 to 214.3 kg/ ha) is medium. The last year (2021-22) lowest annual temperature was 4.1°C, while maximum annual temperature was 41.2°C and total rainfall was 224 mm at experimental site. The treatments accompanied with absolute control (T_1), 25 t/ ha FYM (T_2), NPK – 40:20:20 kg/ ha + 5 t/ ha FYM (T_3), NPK – 40:25:20 kg/ ha + 10 t/ ha FYM (T_4), NPK – 40:30:20 kg/ ha + 15 t/ ha FYM (T_5), NPK – 45:20:20 kg/ ha + 5 t/ ha FYM (T_6), NPK – 45:25:20 kg/ ha + 10 t/ ha FYM (T_7), NPK – 45:30:20 kg/ ha + 15 t/ ha FYM (T_8), NPK – 50:20:20 kg/ ha + 5 t/ ha FYM (T_9), NPK – 50:25:20 kg/ ha + 10 t/ ha FYM (T_{10}) and NPK – 50:30:20 kg/ ha + 15 t/ ha FYM (T_{11}). Full doses of all organic and inorganic fertilizers were applied at the time of sowing except, nitrogen which was applied in two split doses. All the parameters were noted at 45, 90 days after sowing and at harvest. Regular analysis of variance was performed for each trait for all three seasons and the combined (Pooled) analysis over seasons after testing error variance homogeneity was carried out according to the procedure outlined by Gomez and Gomez (1984), using the MSTATC version 2.1 (Michigan State University, USA) statistical package design. Significant differences between the treatments were compared with the critical difference at ± % probability by LSD.

Results and Discussion

The data collected on various growth and yield attributes from three replications of eleven treatment combinations were statistically analyzed, and the results are presented below under different subheadings

Growth and development parameters

According to the data in Table 1 on cumin growth and development characteristics, significant variations in plant height were observed at different growth stages, influenced by varying concentrations of FYM and NPK. At 45 DAS, treatment T_{11} (50:30:20 kg/ ha NPK+15 t/ ha FYM) had the considerably most significant plant height (9.19 cm), which was at par to treatment T_8 (45:30:20 kg/ ha NPK+15 t/ ha FYM (9.00), but much better than the other treatments. At 90 DAS, the treatment T_{11} had the maximum plant height (35.76 cm), substantially above treatments T_5 (31.33 cm), T_{10} (30.47 cm), and T_2 (29.84 cm). Increased plant height is the ultimate result of improved plant growth and development (Singh *et al.*, 2022). The results of the study supported with the findings of Shivran *et al.* (2017) in cumin and Ali *et al.* (2015).

The number of main branches per plant during the different growth phases was significantly impacted by the treatment of varying doses of FYM and NPK. Treatment T_{11} (4.39) had the most primary branches per plant at 45 days after sowing, followed by treatment T_8 (4.36). These treatments were comparable to treatments T_5 (4.14), T_{10} (4.11), T_2 (4.10), and T_7 (4.02), but much better than the other treatments. According to the data, at 90 DAS, treatment T_{11} had 8.90 primary branches per plant, which was comparable to treatments T_8 (8.70) and T_9 (8.49), but far superior to all other treatments. At harvest, the significantly higher primary branches was recorded under treatment T_{11} (11.26) than treatments T_6 (10.83), T_9 (10.68), T_8 (10.51) and T_7 (10.44). Waskela *et al.* (2017) and Meena *et al.* (2020) saw a similar rise in growth indices with higher fertilizer levels.

In Table 1, the results indicated that the various treatments had a substantial impact on the plant population per metre row length at 45 DAS, 90 DAS, and harvest. The highest plant population per metre row length (15.34) at 45 DAS was under treatment T_{11}, which was considerably better than the other treatments and on par with treatments T_8 (14.50), T_9 (14.49), T_{10} (14.45), T_7 (14.34), T_2 (14.26), and T_6 (14.04). The maximum plant population per metre row length (14.33) at 90 DAS was found to be at par with treatment T_9 (13.67), according to the analysis of variance. At harvest time, however, T_{11} (14.27) continued to be considerably superior to the other treatments. This could be due to the gain in morphological characteristics and higher chlorophyll content of leaves (Muvel *et al.*, 2015).

Yield attributing parameters

The test weight (g) data was significantly impacted by the application of different NPK and FYM amounts (Table 2). Treatment T_{11} (50:30:20 kg/ ha NPK+15 t/ ha FYM) was statistically the highest test weight (4.14), according to the data in Table 2. This was comparable to T_8 (45:30:20 kg/ ha NPK+15 t/ ha FYM; 4.07), and T_5 (40:30:20 kg/ ha NPK+15 t/ ha FYM; 4.02), but it was noticeably better than the other treatments. T_1 (absolute control) was used to record the lowest test weight (3.73). These findings are in close conformity with the results of Godara *et al.* (2014) and Yimam *et al.* (2015).

According to the results shown in Table 2, the highest seed yield (g plant^{-1}) was recorded under treatment T_{11}- 50:30:20 kg/ ha NPK+15 t /ha FYM (29.34). This was significantly better than the other treatments, but on par with treatments T_8- 45:30:20 kg/ ha NPK+15 t/ ha FYM (28.92), T_5- 40:30:20 kg/ ha NPK+15 t/ ha FYM (28.40), T_{10}- 50:25:20 kg/ ha NPK+10 t/ ha FYM (26.88), T_2- 25 t/ ha FYM (26.47), and T_7- 45:25:20 kg/ ha NPK+10 t/ ha FYM (26.18). In T_1 (absolute control), the lowest seed output (22.62 g plant^{-1}) was noted. The same results were reported by Sathyanarayana *et al.* (2017) in ajwain and Desai *et al.* (2020) in cumin.

Table 2 indicates that the number of umbels per plant was significantly influenced. The highest number of umbels per plant was recorded under treatment T_{11}, which was 50:30:20 kg/ ha NPK+15 t/ ha FYM (22.42). This was comparable to treatment T_8 (45:30:20 kg/ ha NPK+15 t/ ha FYM; 21.96), T_5 (20.91), T_{10} (20.53), and T_2 (19.54), but it was noticeably better than the other treatments. The findings of the treatment of different levels of NPK and FYM indicated that the treatment T_{11} - 50:30:20 kg/ ha NPK+15 t/ ha FYM produced the highest seed yield (5.32 q ha^{-1}), which was comparable to treatments T_8 - 45:30:20 kg/ ha NPK+15 t/ ha FYM (5.01) and T_7 - 45:25:20 kg/ ha NPK+10 t/ ha FYM (4.99), but significantly better than the other treatments. The results are consistent with those reported by Desai *et al.* (2020) in cumin.

Table 1. Effect of INM on plant growth and development of cumin

Treatments	Plant height (cm)			No. of primary branches/ plant			Plant population (per meter row length)		
	45 DAS	90 DAS	At harvest	45 DAS	90 DAS	At harvest	45 DAS	90 DAS	At harvest
Absolute control (T_1)	7.20	23.07	30.72	3.12	5.42	9.03	10.12	9.00	8.14
25 t/ ha FYM (T_2)	7.67	29.84	33.68	4.10	6.06	9.55	14.26	12.67	10.95
40:20:20 kg/ ha NPK+5 t/ ha FYM (T_3)	7.37	28.12	32.82	3.13	6.60	9.29	13.60	11.67	10.22
40:25:20 kg/ ha NPK+10 t/ ha FYM (T_4)	7.61	28.46	33.39	3.97	7.04	9.62	13.03	11.33	10.81
40:30:20 kg/ ha NPK+15 t/ ha FYM (T_5)	7.94	31.33	35.02	4.14	7.57	10.34	14.23	11.00	10.15
45:20:20 kg/ ha NPK+5 t/ ha FYM (T_6)	7.40	29.70	36.80	3.79	8.04	10.83	14.04	12.00	10.65

45:25:20 kg/ ha NPK+10 t/ ha FYM (T_7)	7.63	29.56	37.17	4.02	7.89	10.44	14.34	13.00	10.89
45:30:20 kg/ ha NPK+15 t/ ha FYM (T_8)	9.00	28.41	36.99	4.36	8.70	10.51	14.50	11.67	11.23
50:20:20 kg/ ha NPK+5 t/ ha FYM (T_9)	7.54	28.16	40.14	3.83	8.49	10.68	14.49	13.67	10.81
50:25:20 kg/ ha NPK+10 t/ ha FYM (T_{10})	7.77	30.47	42.91	4.11	8.22	10.06	14.45	12.33	11.10
50:30:20 kg/ ha NPK+15 t/ ha FYM (T_{11})	9.19	35.76	44.81	4.39	8.90	11.26	15.34	14.33	14.27
SEm±	0.105	0.423	0.125	0.030	0.112	0.049	0.312	0.289	0.323
CD at 5%	0.310	1.914	1.449	0.375	0.607	0.205	1.505	0.892	1.024

Table 2. Effect of INM on yield attributes parameters of cumin

Treatments	Test weight (g)	Seed yield/ plant (g)	Number of umbels/ plant	Seed yield (q/ ha)
Absolute control (T_1)	3.73	22.62	16.51	4.35
25 t/ ha FYM (T_2)	3.91	26.47	19.54	4.20
40:20:20 kg/ ha NPK+5 t/ ha FYM (T_3)	3.76	23.72	17.60	4.16
40:25:20 kg/ ha NPK+10 t/ ha FYM (T_4)	3.86	25.93	19.33	4.80
40:30:20 kg/ ha NPK+15 t/ ha FYM (T_5)	4.02	28.40	20.91	4.63
45:20:20 kg/ ha NPK+5 t/ ha FYM (T_6)	3.77	24.36	18.91	4.64
45:25:20 kg/ ha NPK+10 t/ ha FYM (T_7)	3.88	26.18	19.40	4.99
45:30:20 kg/ ha NPK+15 t/ ha FYM (T_8)	4.07	28.92	21.96	5.01
50:20:20 kg/ ha NPK+5 t/ ha FYM (T_9)	3.80	25.65	19.30	4.59
50:25:20 kg/ ha NPK+10 t/ ha FYM (T_{10})	3.93	26.88	20.53	4.50
50:30:20 kg/ ha NPK+15 t/ ha FYM (T_{11})	4.14	29.34	22.42	5.32
SEm±	0.056	1.138	0.480	0.112
CD at 5%	0.164	3.357	2.891	0.453

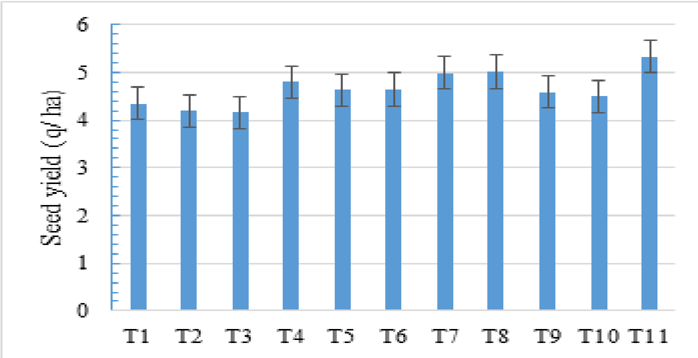


Fig. 1. Effect of INM on seed yield of cumin

Conclusion

The integrated nutritional approach to cumin cultivation was the most successful in terms of growth and yield indicators, according to the data above. Based on one year of study and the findings above, it can be said that the growth and yield characteristics of cumin were both considerably and non-significantly impacted by the different levels of key nutrients and organic manure. Therefore, T_{11} (50:30:20 kg/ ha NPK+15 t/ ha FYM) was the most effective of the eleven integrated nutrition treatments for improving cumin growth and production. It allowed the cumin crop the best growth potential and yield.

Acknowledgements

The authors would like to express their thanks and gratitude to the Director, ICAR-CAZRI, Jodhpur and ICAR-ATARI, Jodhpur (Rajasthan) India for their assistance, support and providing necessary facilities throughout the study of technology demonstration.

Conflict of Interest

All authors agree to publication and there is no any conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Ali, M.M.K., Hasan, M.A. and Islam, M.R. 2015. Influence of fertilizer levels on the growth and yield of black cumin (*Nigella sativa* L.). *The Agriculturist*, 13(2): 97-104.

Anonymous. 2025. https://www.thehindubusinessline.com/economy/agri-business/indias-cumin-output-for-2024-25-may-shrink-on-dip-in-area-weather-woes/article69247896.ece.

Chouhan, S., Meena, K.C., Soni, N., Patidar, D.K., Kachouli, B.K., Patidar, B.K. and Haldar, A. 2023. Response of recommended dose of fertilizers with organic manures on growth, yield and economics of kalmegh (*Andrographis paniculata* Nees.): A way to reduced use of chemical fertilizers. *The Pharma Innovation Journal*, 12(3):119-124.

Desai, S.S., Chaudhary, M.G., Patel, R.S. and Joshi, J.R. 2020. Effect of integrated nutrient management on growth, yield and economics of cumin (*Cuminum cyminum* L.). *International Journal of Current Microbiology and Applied Sciences*, 9(11): 3712-3719.

Godara, A.S., Gupta, U.S., Lal, G. and Singh, R. 2014. Influence of organic and inorganic sources of fertilizers on growth, yield and economics of fennel (*Foeniculum vulgare* Mill.) cultivation under semi-arid conditions. *Journal of Spices and Aromatic Crops,* 23(2): 200–204.

Gomez, K.A. and Gomez, A.A. (Eds.). 1984. Statistical Procedures for Agricultural Research. John Willey & Sons, New York. Pp. 97–107.

Kumar, C. and Singh, D. 2023. Strengthening the livelihoods security through technological interventions by frontline demonstrations of papaya (*Carica papaya* L.) production in the Pali district of Rajasthan. *Current Advances in Agricultural Sciences,* 15(1): 61-64. DOI: 10.5958/2394-4471.2023.00011.4.

Kumar, C., Singh, D., Chaudhary, M.K., Tetarwal, A.S. and Kuri, B.R. 2024. Performance and impact of front line demonstrations of papaya in western Rajasthan. *Annals of Arid Zone* 63(1): 67-71.

Meena S.S., Lal G., Sharma, Y.K., Meena, M.D. and Lal, S. 2020. Effect of spacing and fertilizer levels on growth, yield and yield attributes of different ajwain (*Trachyspermum ammi* L.) genotypes. *International Journal Seed Spices*, 10(1): 47-51.

Meena, M.D., Lal, S., Choudhary, N., Meena, R.D., Meena, S.S., Shyam, S. Meena, Jangid, C.K., and Agrawal, P.K. 2022. Assessment of yield gap and remedial measures in cumin. *International Journal of Seed Spices*, 12(2): 23-33. doi.org/10.56093/IJSS.v92i1.4

Meena, R.S., Anwer, M.M., Lal, G., Kant, K. and Mehta, R.S. 2021. Advanced production technology of cumin. ICAR-National Research Centre on Seed Spices, Tabiji. Ajmer, Rajasthan.

Muvel, R., Naruka, I.S., Chundawat, R.S., Shaktawat, R.P.S., Rathore, S.S. and Verma, R. 2015. Production, productivity and quality of ajwain (*Trachyspermum ammi* L. Sprague) as affected by plant geometry and fertilizer levels. *International Journal of Seed Spices*, 5(2): 32-37.

Sathyanarayana, E., Hadole, S.S. and Ghawade, S.M. 2017. Effect of nutrient levels on nutrient uptake by ajwain crop (*Trachyspermum ammi* L. Sprague). *International Journal of Chemical*

Studies, 5(4): 1987-1990.

Shivran, A.C., Jat, N.L., Singh, D. and Rajput, S.S. 2017. Influence of integrated nutrient management on yield, quality and economics of cumin (*Cuminum cyminum*) production under semi-arid conditions. *Indian Journal of Agricultural Sciences,* 87(1): 29–35.

Singh, D., Chaudhary, M.K., Kumar, C., Kuri, B.R. and Tetarwal, A.S. 2022. Impact of FLD intervention on yield, adoption and horizontal spread of oilseed crops in Pali district of Rajasthan, India. *Annals of Arid Zone*, 61(2): 117-122.

Waskela, P., Naruka, I.S. and Shaktawat, R.P.S. 2017. Effect of row spacing and level of NPK on growth and yield of fennel (*Foeniculum vulgare*). *Journal of Krishi Vigyan*, 6(1): 78-82.

Yimam, E., Nebiyu, A., Mohammed, A. and Getachew, M. 2015. Effect of nitrogen and phosphorus fertilizers on growth, yield and yield components of black cumin (*Nigella sativa* L.) at Konta district, South West Ethiopia. *Journal of Agronomy*, 14(3): 112-120.

Research Article

ISAH Indian Journal of Arid Horticulture

Year 2025, Volume-7, Issue-1 (January - June)

Impact assessment of integrated pest management technology for ber fruit fly (*Carpomya vesuviana* Costa) under arid and semi-arid regions of Rajasthan

A.S. Tetarwal[1], Chandan Kumar[1], Aishwarya Dudi[1], M.K. Ahirwar[1] and Dheeraj Singh[2]

[1]ICAR-CAZRI, Krishi Vigyan Kendra, Pali-Marwar, Rajasthan
[2] Division-II (Integrated Farming System), ICAR-CAZRI, Jodhpur, Rajasthan

ARTICLE INFO

Received: 28 March 2025
Accepted: 19 April 2025

Keywords: Ber, front line demonstrations (FLDs), fruit fly, integrated pest management (IPM), methyl eugenol trap, net return

doi:10.48165/ijah.2025.7.1.9

ABSTRACT

The adoption of IPM approaches in ber resulted in a lower incidence of fruit damage, with a 65% mean reduction compared to farmer's practices. Mean higher yield of 111.2 q/ ha was recorded in the demonstration compared to 77.84 q/ ha in farmer's practice, representing a 42.86% increase. This has resulted in higher mean net returns of Rs. 1,79,640/- ha with a Benefit Cost Ratio (BCR) of 3.76 in the demonstration, compared to Rs. 1,08,248/- ha in farmer's practice with a BCR of 2.72. The current study's findings clearly indicated that using IPM technology against the ber fruit fly was more effective and economical than conventional methods.

Introduction

The ancient fruit known as ber (*Ziziphus mauritiana* Lamk) is native to India and many other Asian nations, it has been cultivated nationwide for hundreds of years. Ber is the fruit crop that requires the least amount of care and inputs to grow. It is a significant fruit crop that is widely cultivated throughout the country's arid and semi-arid regions, including Rajasthan, Haryana, Punjab, Gujarat, and others. The National Horticulture Board reports that in 2018–19, India produced 5,39,000 MT of ber crop on 50,000 hectares of land (Anonymous, 2018-19). It is a long-standing and reputable fruit crop in the state of Rajasthan.

Approximately 80 insect pest species have been known to attack ber trees (Butani, 1979). Depending on the location, type, and time of year, these pests directly harm significant export crops, resulting in losses ranging from 40% to 80% (Kibira *et al.*, 2010). New insect species have emerged because of climate change, severely harming crops. The peak activity period of a given insect species can differ significantly depending on the location. With the exception of the ber fruit fly, *Carpomyia vesuviana* Costa, the majority of these have been classified as minor pests. This major insect pest is well-established in all countries where ber is grown. In India, it is one of the most infamous monophagous pests. The majority of *Ziziphus* species cultivated worldwide are infested by fruit flies, which inflict internal harm. In extreme situations, it can result in yield loss of up to 80% or even 100% (Karuppaiah, 2014). Fruit fly losses are so severe that

Corresponding author's Email: chandan.kumar@icar.gov.in (Dr. Chandan Kumar)

they are now proving to be a limiting factor in the successful cultivation of ber in all districts of Rajasthan and Haryana that produce ber. Very few ber trees are immune to its attacks (Lakra and Singh, 1984).

Integrated pest management (IPM) technology has been shown to be the best alternative to minimise fruit fly infestation while lowering the load of chemical pesticides to achieve higher yield and income. This is because increased reliance on pesticides for pest control has been shown to be unsustainable and cost-ineffective. IPM techniques that were found to be effective against conventional practice were demonstrated in the demonstration, including deep summer ploughing in orchards, soil racking to expose pupae, the use of methyl eugenol lure traps at 12 traps/ha for fly monitoring and collection, the application of quinalphos 25 EC @ 2 ml/ liter water at the pea size stage of fruits, and the use of neem oil 1500 ppm @ 4 ml/ litre water 20 days after the initial spray. The majority of farmers were found to not employ integrated approaches for pest management, which led to a significant extension gap between farmer's techniques and demonstrated technology. In order to close that gap, KVK, Pali used FLDs to demonstrate integrated pest management (IPM) technology, which aims to increase both marketable yield and quality production, to control ber fruit flies at farmer's fields.

Material and Methods

The current study was conducted by the ICAR-CAZRI, Krishi Vigyan Kendra, Pali-Marwar (Rajasthan) during three consecutive years 2021 to 2023 at KVK farm (Lat. 25.802174°; Long. 73.288608°) and farmer's fields (Gajangarh: Lat 25.824319°, Long 73.200850°; Jadan: Lat 25.841148°, Long 73.483889° and Hingola Kalan: Lat 25.654284°, Long 73.506476°). Before conducting FLDs, gathered the basic information on ber cultivation techniques, acceptable high yielding varieties, and the occurrence of insect-pests in ber ecosystem through field surveys and farmer meetings to determine the current pest management tactics and, as a result, IPM practices for fruit fly management were implemented. The yield data was obtained from FLD orchards along with local farming practises for comparative analysis. Under demonstration plots, we have provided critical inputs such as neem oil 1500 ppm, methyl eugenol trap and quinalphos 25 EC to manage the fruit fly and provided technical advice on other IPM practices like cultural and mechanical practices throughout the season.

To monitor the activity of flies' methyl eugenol trap were installed at the time of first flowering and the lure of trap were change at 25-30 days interval. According to fly activity, one foliar spray with neem oil 1500 ppm @ 4 ml per litre water done before the flowering as precautionary measure and subsequent spray of quinalphos 25 EC @ 2 ml per litre water was applied at the pea size stage of fruits to prevent the egg laying of fruit flies. Thereafter, another spraying of neem oil with same concentration applied after 20 days of second spray. On the other hand, farmers were allowed to continue with their conventional techniques in the event of a local check where majority of farmers were relied on the use of Monocrotophos 36 SL to control this pest which is already banned in orchard crops. Field days and farmer meetings were conducted so that other farmers could learn about the benefits of the varieties and technologies on display. For comparison study, data on several parameters such as fruit yield and per cent damage by fruit fly were gathered separately from both improved practise (IP) and farmer's practise (FP). Furthermore, data were tabulated and analysed by using statistical tools like frequency and percentage. The extension gap, technology gap and technology index were worked out as per formulas given by the Samui *et al.* (2000) and Prasad *et al.* (2022).

$$\text{Per cent increase in yield (kg/ha)} = \frac{\text{Yield gain in IP plot} - \text{Yield gain in FP plot}}{\text{Yield gain in FP plot}} \times 100$$

$$\text{Technology gap} = \text{Potential yield} - \text{Demonstration yield}$$

$$\text{Extension gap} = \text{Demonstration yield} - \text{Yield under existing practice}$$

$$\text{Technology index} = [(\text{Potential yield} - \text{Demonstration yield}) / \text{Potential yield}] \times 100$$

$$\text{Impact on yield (\% change)} = \frac{\text{Yield of demonstration plot} - \text{Yield of farmer's practice}}{\text{Yield of farmer's practice}} \times 100$$

Results and Discussion

Yield performance

The marketable ber fruit yield was considerably higher in the demonstrated plots with IPM technology compared to existing practices during all three years of the study, according to the findings of frontline demonstrations (FLDs) held at farmer's fields during *Kharif*, 2021-22 to 2023-24 (Table 1). The severity of insect pests, the microclimate that prevailed during the season, variations in orchard management techniques, and other social and economic problems all contributed to ber's annual fluctuations in fruit yield. In 2021-22, 2022-23, and 2023-24, the average yield (Fig. 1) under improved practice (IP) was 10885, 11099, and 11376 kg ha^{-1}, respectively, compared to 7160, 7672, and 8521 kg ha^{-1} under farmer's practice (FP). The mean yield for all three years was 42.85% higher in demonstration plots (11120 kg ha^{-1}) than in existing practice (7784 kg ha^{-1}). Similar yield increases were noted by Kumar *et al.* (2024) in papaya and Nyangau *et. al.* (2017) when evaluating the IPM technology for mango fruit flies. The results also showed that the district's ber growers, who embraced the latest agricultural technologies implemented in the KVK's frontline demonstration plots, saw a notable increase in the average marketable fruit yield of ber throughout the study period as a result of IPM practices.

Table 1. Yield gap analysis of ber

Year	No. of FLD	Area (ha)	Demo (IP)*yield(kg/ ha)	Local (FP) yield (kg/ ha)	% Yield increase over FP	Ext. gap (kg/ ha)	Tech. gap (kg/ ha)	Tech. index (%)
2020-21	20	10	10885	7160	52.03	3725	3115	22.25
2021-22	20	10	11099	7672	44.67	3427	2901	20.72
2022-23	20	10	11376	8521	33.51	2855	2624	18.74
Average			11120	7784	42.85	3335.67	2880	20.57

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

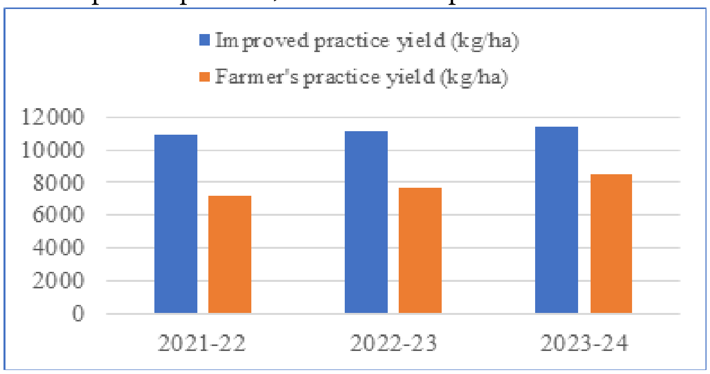


Fig. 1. Yield comparison in improved practice and farmer's practice

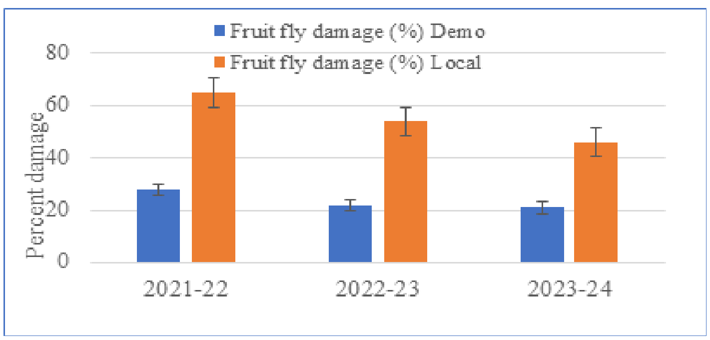


Fig. 2. Per cent damage caused by fruit fly in ber

According to the data (Fig. 2), fruit fly infestation was at its worst in farmer's practices (46–65% damage), whereas in demonstration plots, it ranged from 21-28%. This indicates that Integrated Pest Management (IPM) technology significantly reduced fruit fly damage in demo plots. The results of Kibira *et al.* (2010) corroborate the data regarding the extent of fruit fly infestation.

Gap analysis

The technological gap, which quantifies the discrepancy between the potential and demonstrated yield, was higher in 2021-22 (3115 kg ha^{-1}), 2022-23 (2901 kg ha^{-1}), and 2023-24 (2624 kg ha^{-1}). As indicated in Table 1, the average technology gap during the three years of technology investigation was Rs. 2880 kg ha^{-1}.

It has been demonstrated that there is still a gap in technology demonstration, which prevents adopting farmers from realising the potential yield of improved practices. Differences in orchard management, such as soil fertility, irrigation water availability and quality, insect-pest attack, and fluctuating weather conditions throughout the crop season at various locations, may be the cause of the technological gap assessment. Singh and Sharma (2018) and Kumar *et al.* (2024) reported similar results. The yield difference between a demonstration plot and a conventional plot is measured by this extension gap. The 2021 extension gap was the highest at 3725 kg ha^{-1}, while in 2023 extension gap was the lowest at 2855 kg ha^{-1} (Table 1).

The average extension gap in the improved practices orchard was 3336 kg ha^{-1}. This gap needs to be reduced using a variety of extension strategies, such as frontline demonstrations, capacity building initiatives, *Kisan Gosthies*, etc. on IPM and scientific orchard management practices. These initiatives could help farmers to implement IPM for managing ber fruit flies, which would close the extension gap. The results of Prasad *et al.* (2022), Singh and Sharma (2018), and Sagar and Chandra (2004) corroborated the current studies.

The technological gap as a percentage of potential yield was displayed by the technology index. It also shows how advanced technologies can be used in the fields of farmers. The findings (Table 1) show that the year 2021 had the highest technology index value (20.25%), while the year 2023 had the lowest rate (18.74%). The average ber crop technology index over the three years of demonstration was 20.57%. According to Sagar and Chandra (2004), a technology's acceptability and practicality are always inversely correlated with its technology index value; the more widely accepted the proven technology, the lower its index value. Tetarwal (2021) and Kumar *et al.* (2014) came to similar conclusions.

Economic performance

The essential requirement for an enhanced technology to be shown on farmers' fields to calculate the profit margin over current technology is economic viability. ber production and cultivation costs under frontline demonstrations were gathered and analysed to determine the benefit cost ratio, net return (Rs./ ha), gross return (Rs./ ha), and additional income (Rs./ ha). It is essential to comprehend the economic viability of each strategy demonstrated on farmers' fields to assess their profit over current technology.

Table 2. Economic analysis of front line demonstrations on ber

Year	Cost of cultivation (Rs./ ha)		Gross return (Rs./ ha)		Net return (Rs./ ha)		Additioal return (Rs./ ha)	B:C Ratio	
	IP*	FP	IP	FP	IP	FP		IP	FP
2021-22	62735	60613	239470	157520	176735	96907	79828	3.82	2.60
2022-23	68764	66378	266376	184128	197612	117750	79862	3.87	2.77
2023-24	75581	72425	284400	213025	208819	140600	68219	3.76	2.94
Average	69027	66472	263415	184891	194389	118419	75970	3.82	2.78

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

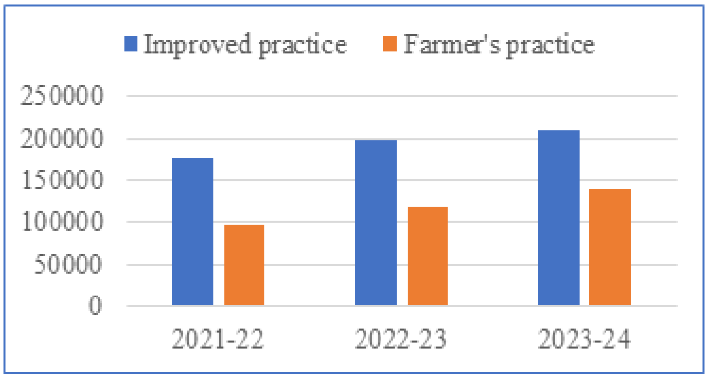


Fig. 3. Net return received from ber crop

Over a three-year period (Table 2 & Fig. 3), proven IPM techniques generated a higher net return of Rs. 194389 ha^{-1} than farmers' techniques (Rs. 118419 ha^{-1}). Furthermore, despite an increased input cost of Rs. 2555 ha^{-1}, the FLD plots provided an average additional return of Rs. 75970 ha^{-1} and a higher average benefit cost ratio of 3.82 when compared to farmers' practice (2.78). The current results are consistent with those of Muriithi *et al.* (2016) and Patel et al. (2013).

Conclusions

IPM demonstrations for the ber fruit fly were effective in reducing (132 per cent) pest damage, increasing yield by 42.85 per cent, and improving farmer's economic condition with an additional return of Rs. 75,970 ha^{-1}. The economic analysis results indicate that the demonstrated technology is more profitable and commercially viable. The use of IPM practices such as methyl eugenol traps, botanicals, and cultural practices can aid in the production of more marketable quality fruits at lower costs. Using this technology, farmers can increase their profits while incurring fewer additional input costs. Scaling up such demonstrations, combined with training programs, has the potential to accelerate IPM adoption while ensuring long-term quality ber production. Future research should concentrate on improving trap designs, botanicals, and biological controls that are specific to regional fruit fly species.

Acknowledgements

The authors would like to express their thanks and gratitude to the Director, ICAR-CAZRI, Jodhpur and ICAR-ATARI, Jodhpur (Rajasthan) for their assistance, support and providing necessary facilities throughout the study of technology demonstration.

Conflict of interest

All authors agree to publication and there is no any conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Anonymous 2018-19. National Horticulture Board (NHB), Ministry of Agriculture & Farmers Welfare, Government of India. http://www.nhb.gov.in

Butani, D. K. 1979. Pests of sub-tropical fruits (Ber). Indian Insects and Fruits. Periodical Expert Book Agency, New Delhi, pp 173.

Karuppaiah V. 2014. Biology and management of ber fruit fly, *Carpomyia vesuviana* Costa (Diptera: Tephritidae): A review. *African Journal of Agricultural Research*, 9(16):1310-1317.

Kibira, M., Affognon, H., Njehia, B., Muriithi, B., Mohamed, S. and Ekesi, S. 2010. Economic evaluation of integrated management of fruit fly in mango production in Embu County, Kenya. *African Journal of Agricultural and Resource Economics*, 10: 343–353.

Kumar, C., Singh, D., Choudhary, M. K., Tetarwal, A. S. and Kuri, B.R. 2024. Performance and impact of front line demonstration of papaya in Western Rajasthan: *Annals of Arid Zone*, 63(1): 67-71.

Lakra, R. K. and Singh, Z. 1984. Calendar of losses due to ber fruit fly, *Carpomyia vesuviana* Costa (Diptera: Tephritidae) in different *Ziziphus* spp. in Haryana. *Indian Journal of Entomology*, 46: 261-264.

Muriithi, B. W., Affognon, H. D., Diiro, G. M., Kingori, S. W., Tanga, C. M., Nderitu, P. W., Mohamed, S. A. and Ekesi, S. 2016. Impact assessment of Integrated Pest Management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. *Crop Protection*, 81: 20-29.

Nyangau, P., Muriithi, B., Irungu, P., Nzuma, J. and Diiro, G. 2017. Assessing the impact of integrated pest management (IPM) technology for mango fruit fly control on food security among smallholders in Machakos County, Kenya, 91st Annual Conference, Royal Dublin Society, Dublin, Ireland.

Patel, M. M., Jhajharia, A. K., Khadda, B. S. and Patil, L. M. 2013. Frontline demonstration: an effective communication approach for dissemination of sustainable cotton production technology. *Indian Journal of Extension Education*, 21: 60-62.

Prasad, D., Prakash, V., Meena, R. S. and Bairwa, S. K. 2022. Performance of chickpea (*Cicer arietinum*, L.) front line demonstrations in North West Plain Zone of Rajasthan. *Indian Journal of Agricultural Sciences*, 92 (2):109-112.

Sagar, R. L. and Chandra, R. 2004. Front line demonstration on sesame in West Bengal. *Agriculture Extension Review*, 16(2): 7-10.

Samui, S. K., Maitra, S., Roy, D. K., Mandal, A. K. and Saha, D. 2000. Evaluation of front-line demonstration on groundnut. *Journal of the Indian Society of Coastal Agricultural Research*, 18(2): 180-183.

Singh, B. and Sharma A. K. 2018. Impact of front-line demonstrations on yield, knowledge adoption and horizontal spread of cumin crop in arid zone. *International Journal of Seed Spices*, 8(2):32-35.

Tetarwal, A. S. 2021. Impact of front-line demonstrations on productivity of cumin in arid Kutch of Gujarat. *Annals of Agricultural Research*, 42(3): 325-331.

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Evaluation of bael (*Aegle marmelos* Correa.) varieties for growth, yield and quality under semi-arid conditions of Madhya Pradesh

Bharti Choudhary[1], Rahul Dongre [2], U.K. Chendaria[3] and S. K. Pandey[4]

[1]Senior Technical Officer (Hort.), AICRP on Arid Zone Fruits, Deptt. of Hort., JNKVV, Jabalpur, M.P.
[2]Asstt. Prof. (Hort.), Deptt. of Forestry, JNKVV, Jabalpur, M.P., India
[3]Scientist (Plant Pathology), AICRP on Arid Zone Fruits, Deptt. of Hort., JNKVV, Jabalpur (M.P.)
[4]Professor & Head, Deptt. of Hort., JNKVV, Jabalpur (M.P.)

ARTICLE INFO

Received: 04 March 2025
Accepted: 07 April 2025

Keywords: Bael, *Aegle marmelos*, varietal performance, fruit quality, Madhya Pradesh

doi:10.48165/ijah.2025.7.1.10

ABSTRACT

This study aimed to evaluate the performance of various bael varieties under the Kymore Plateau and Satpura Hills agro-climatic zone of Madhya Pradesh over a three-year period (2021-22, 2022-23 and 2023-24). A total of seven bael varieties (Goma Yashi, Narendra Bael-5, Narendra Bael-7, Narendra Bael-9, Narendra Bael-17, CISH Bael-1 and CISH Bael-2) were assessed for growth, yield, and quality parameters. The results indicated that CISH Bael-2 recorded the highest number of fruits per plant (33.96), while Narendra Bael-7 exhibited the heaviest fruit weight (3.97 kg) and the highest pulp percentage (70.71%). CISH Bael-1 demonstrated the greatest plant height (6.52 m), stem girth (76.30 cm), and TSS (39.69°Brix), highlighting its potential for high-quality fruit production. The findings suggest that CISH Bael-2 and Narendra Bael-17 are ideal for high-yield cultivation, while CISH Bael-1 is best suited for superior fruit quality. This study provides valuable insights for the selection of suitable bael varieties for commercial production in semi-arid regions of Madhya Pradesh.

Introduction

Bael (*Aegle marmelos* Correa.) is an economically significant fruit crop known for its exceptional nutritional, medicinal and therapeutic properties. It is widely regarded as one of India's most underutilized indigenous medicinal fruit crops, belonging to the Rutaceae family. This impressive fruit is known by various names, including bael fruit, Indian bael, holy fruit, golden apple, elephant apple, Bengal quince, Indian quince, and stone apple in English, as well as Baelputri, Bela, Siri-phal, and Kooralam in Hindi (Kumar *et al.*, 2021). It has been valued in Ayurvedic, Siddha, and traditional medicine systems for centuries. Bael is renowned for its digestive, anti-inflammatory, and antioxidant properties, making it a valuable functional food in both traditional and modern diets.

As a native of India, it originates from the Eastern Ghats and central India, where it has been valued for its rich content of riboflavin, vitamin A, carbohydrates, and more (Gopalan *et al.,* 1989). It exhibits remarkable adaptability, allowing it to be cultivated under diverse agro-climatic conditions. The therapeutic potential of Bbel is primarily attributed to the presence of marmelocin, a bioactive compound known for its gastrointestinal benefits (Dongre and Choudhary, 2023). Madhya Pradesh ranks among the leading bael-producing states in India. In 2020-21, bael was cultivated on 1,292 hectares, yielding 15,102 metric tons of fruit (Anonymous, 2021). The districts of Chhindwara, Seoni, Jabalpur, and

Corresponding author's Email: dongre.jnau@gmail.com (Dr. Rahul Dongre)

Narsinghpur are the key production centers. Despite its nutritional and economic significance, bael remains underutilized in commercial horticulture, necessitating systematic evaluation of its genetic potential to enhance production and promote its large-scale cultivation.

This study aims to assess the performance of different bael varieties under the Kymore Plateau and Satpura Hills agro-climatic zone of Madhya Pradesh. By comparing growth, yield, and fruit quality parameters, the research seeks to identify superior varieties best suited for commercial cultivation and genetic improvement programs in semi-arid regions. The findings will provide valuable insights into bael varietal selection, enabling growers to make informed decisions for maximizing productivity and profitability.

Material and Methods

Experimental site: The study was conducted under the All India Coordinated Research Project on Arid Zone Fruits (AICRP-AZF) at the Department of Horticulture, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, Madhya Pradesh, India. Jabalpur is located in the Kymore Plateau and Satpura Hills agro-climatic zone, characterized by a semi-arid and subtropical climate. The geographical coordinates of the site are latitude 23.100°N and longitude 79.580°E, with an elevation of 411.73 meters above sea level.

Climatic conditions: The region experiences hot summers and moderately cool winters, with an annual rainfall range from 1100 to 1400 mm, with an average of 1191 mm. Approximately 99% of the total rainfall occurs between June and September, with the remaining precipitation received from October to January. The winter season extends from November to February, occasionally witnessing mild frost. The soil type at the experimental site is clay loam, of moderate fertility, which becomes sticky when wet and hard when dry, influencing plant growth and nutrient availability.

Plant material and experimental design: The experiment was conducted on a 10-year-old bael orchard, evaluating seven different bael varieties: Goma Yashi, Narendra Bael-5, Narendra Bael-7, Narendra Bael-9, Narendra Bael-17, CISH Bael-1 and CISH Bael-2. The experimental design followed a Randomized Block Design (RBD) with four replications. The trees were spaced 5m × 5m apart, and uniform agronomic practices were applied throughout the study.

Agronomic and cultural practices: Irrigation was regularly provided as per the requirement of plants. The fertilizers were applied based on soil test recommendations. Pests and diseases were managed using integrated pest management (IPM) strategies. The orchard was kept clean through regular weeding and mulching.

Observations recorded: The study evaluated growth, yield and fruit quality parameters over three consecutive years (2021-2024). The plant height (m) was measured from the ground level to the highest growing point. Number of branches were counted from the main trunk. Stem girth (cm) was measured at 30 cm above the ground level. The plant spread (m) was recorded in East-West and North-South directions. Among yield parameters, number of fruits per plant, total number of fruits per tree, fruit weight (kg) and fruit yield per plant (kg) were recorded. The fruit length (cm) and fruit width (cm) were measured using Vernier caliper. Total soluble solids (TSS) was measured in °Brix using a digital refractometer.

Data analysis: The collected data were statistically analyzed using analysis of variance (ANOVA) as per the method outlined by Fisher (1937). Significance levels were determined using the Least Significant Difference (LSD) test at a 5% probability level ($p \leq 0.05$) to compare treatment means.

Results and Discussion

Growth parameters

The performance of different bael varieties varied significantly in terms of growth attributes (Table 1). The maximum plant height (6.52 m) was recorded in CISH Bael-1, followed by Narendra Bael-7 (5.91 m), indicating their superior vertical growth potential. In contrast, Narendra Bael-5 exhibited the shortest plant height (4.85 m), suggesting a more compact growth habit. Taller plants generally indicate vigorous growth, which can contribute to higher biomass accumulation and canopy development (Kumar *et al*., 2021). The highest number of branches (41.45) was observed in Goma Yashi, suggesting its superior branching potential and canopy formation. In contrast, Narendra Bael-5 exhibited the lowest number of branches (27.30), which may be attributed to genetic factors or environmental adaptation. Increased branching often correlates with enhanced photosynthetic efficiency, leading to better fruit set and yield.

Stem girth is a crucial indicator of plant robustness and structural stability. CISH Bael-1 recorded the thickest stem (76.30 cm), whereas Narendra Bael-7 exhibited the thinnest stem (40.49 cm). A larger stem girth is often associated with improved vascular transport, which supports better nutrient and water uptake, contributing to overall plant health and productivity. In terms of plant spread, CISH Bael-2 exhibited the maximum canopy expansion in the North-South direction (5.66 m), while CISH Bael-1 had the widest spread in the East-West direction (4.92 m). Greater plant spread enhances light interception, thereby improving photosynthetic efficiency and promoting higher yields. The differences in growth parameters, such as plant height, stem girth, and branching pattern, suggest distinct genetic traits influencing canopy architecture and resource utilization. These traits play a critical role in determining productivity, especially in semi-arid regions where efficient water and nutrient use are essential (Dongre and Choudhary, 2023).

Yield and quality parameters

Significant variations were observed among the evaluated bael varieties concerning yield-related traits (Table 2 and Fig. 1-3). The highest number of fruits per plant was recorded in CISH Bael-2 (33.96), followed by Narendra Bael-17 (26.80), making them promising selections for commercial cultivation. The lowest fruit count was observed in Goma Yashi (8.77), indicating its lower productivity potential. Narendra Bael-7 produced the heaviest fruits, with an average fruit weight of 3.97 kg, followed by CISH Bael-2 (2.60 kg). In contrast, Narendra Bael-5 had the lowest fruit weight (0.93 kg), indicating genetic differences in fruit size and weight distribution. Fruit weight is a crucial determinant of market preference and consumer acceptance, with larger fruits generally being more desirable. Narendra Bael-7 also recorded the highest fruit yield per plant (67.72 kg), closely followed by Narendra Bael-17 (66.91 kg). The lowest yield was observed in Goma Yashi (11.76 kg), reinforcing its limited potential for large-scale production. These findings align with previous studies indicating that bael varieties exhibit substantial genetic variability in yield performance (Dhakar *et al*., 2019). Regarding fruit dimensions, Narendra Bael-7 had the longest and widest fruits (18.12 cm and 15.88 cm, respectively), making it an attractive cultivar for both fresh consumption and processing. Larger fruit size often enhances market appeal, contributing to higher commercial value.

Fruit quality plays a vital role in consumer preference and commercial value. Narendra Bael-7 exhibited the highest pulp percentage (70.71%), making it a preferred choice for processing industries. Pulp percentage is a key determinant of edible yield and is crucial for juice and pulp-based product development. The maximum total soluble solids (TSS) content (39.69°Brix) was recorded in CISH Bael-1, suggesting its superior sweetness and flavour profile. Higher TSS levels indicate enhanced sugar accumulation, making the fruit more palatable and suitable for processing. TSS is a critical parameter in fruit grading and directly influences consumer acceptance. Bael is a cross-pollinated crop, primarily propagated through seeds, leading to high genetic variability among genotypes. This variability affects fruit weight, rind thickness, number of seeds, TSS, and acidity, as also reported by Kumar *et al.* (2008, 2009). Identifying high-yielding, superior-quality cultivars is crucial for promoting bael as a mainstream horticultural crop and improving its marketability.

The observed variation in growth and yield parameters across different bael cultivars can be attributed to genetic diversity, environmental adaptability, and physiological responses. The superior performance of CISH Bael-2 in fruit number and Narendra Bael-7 in fruit weight and yield indicates that these varieties have significant commercial potential for large-scale cultivation.

Table 1. Morphological performance of different varieties of bael cultivar

Treatments	Plant height (m)	Nuber of branches	Stem girth (cm)	Plant spread (East-West) (m)	Plant spread (North-South) (m)	Number of fruits/ plant
Goma Yashi	4.98	41.45	56.72	4.38	4.35	8.77
Narendra Bael-5	4.85	27.30	45.84	4.80	4.61	16.46
Narendra Bael-7	5.92	32.06	40.49	5.32	5.42	21.84
Narendra Bael-9	5.39	30.86	52.79	5.18	5.46	17.05
Narendra Bael-17	5.91	33.68	49.91	5.69	6.14	26.81
CISH, Bael-1	6.52	40.95	76.30	4.92	4.53	23.62
CISH, Bael-2	5.45	27.41	56.16	5.19	5.66	33.96
SEm+	0.056	0.877	2.508	0.198	0.067	7.709
CD at 5%	0.173	2.731	7.812	0.616	0.209	N/A

Table 2. Yield and quality performance of different varieties of bael

Treatment	Fruit weight (kg)	Fruit yield kg/ plant	Fruit length (cm)	Fruit width (cm)	Pulp (%)	TSS (°Brix)
Goma Yashi	1.330	11.757	13.613	12.810	66.770	35.967
Narendra Bael-5	0.930	16.580	12.553	11.723	63.517	33.167
Narendra Bael-7	3.977	67.720	18.120	15.887	70.713	30.613

Narendra Bael-9	2.000	34.627	15.457	12.770	62.470	39.287
Narendra Bael-17	2.233	66.910	15.370	12.653	61.210	33.747
CISH, Bael-1	1.170	30.610	16.367	11.763	66.543	39.690
CISH, Bael-2	2.600	85.007	16.517	14.263	62.937	32.513
SEm±	0.320	16.615	0.502	0.630	0.247	0.328
CD at 5%	0.998	N/A	1.563	1.961	0.770	1.022

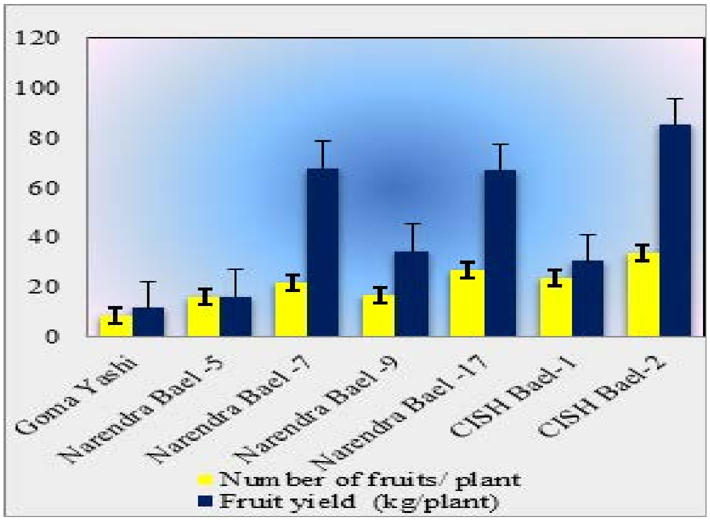


Fig. 1. Number of fruits and yield of bael varieties

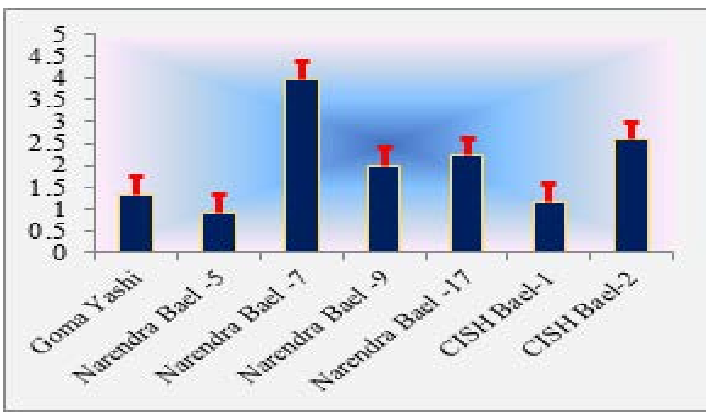


Fig. 2. Fruits weight (kg) of different bael varieties

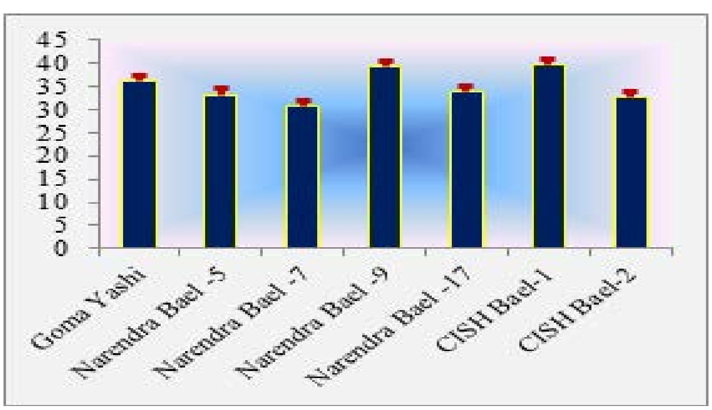


Fig. 3. TSS (°Brix) content of bael varieties

Conclusion

The study highlights CISH Bael-2 as the most productive variety in terms of fruit number, whereas Narendra Bael-7 exhibited the highest fruit weight, yield, and pulp content, making it suitable for both fresh consumption and processing. CISH Bael-1 excelled in growth attributes and TSS content, indicating its suitability for premium-quality fruit production. The findings provide valuable insights into varietal selection for commercial bael cultivation in semi-arid regions, helping farmers maximize yield and profitability.

Acknowledgements

The authors express their sincere gratitude to the All India Coordinated Research Project on Arid Zone Fruits (AICRP-AZF), ICAR-Central Institute for Arid Horticulture (CIAH), Bikaner, for providing the necessary infrastructure, research facilities and financial assistance to conduct this study. We extend our heartfelt thanks to the Department of Horticulture, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, for their continuous support and guidance throughout the research period.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Anonymous. 2021. Ministry of Agriculture Database. http://agricoop.nic.in; http://agricoop.nic.in.

Bhawna and Mishra, K.K., 2011. Variability in growth, yield and photosynthetic parameters in clones of bael (*Aegle marmelos* Correa). *Environment and Ecology*, 29(1A):254–262.

Dhakar, M.K., Das, B., Nath V., Sarkar, P.K. and Singh, A.K. 2019. Genotypic diversity for fruit characteristics in bael (*Aegle mar-*

melos Corr.) based on principal component analysis. *Genetic Resources and Crop Evolution*, 66: 951–964.

Dongre, R. and Choudhary, B. 2023. Study on the physico-chemical characteristics of bael germplasms collected from various locations of Madhya Pradesh, India. *International Journal of Theoretical and Applied Sciences*, 15(2): 11–15.

Fisher, R.A. 1937. Statistical Methods for Research Workers. 7th ed. Oliver and Boyd, Edinburgh, UK.

Gopalan, C., Rama Sastri, B.V. and Balasubramanian, S.C. 1989. Nutritive Value of Indian Foods. National Institute of Nutrition (India). Indian Council of Medical Research, P. 156.

Kumar, D. and Nath, V. 2010. Variability in bael (*Aegle marmelos* Corr.) genotypes from Odisha. *Indian Journal of Plant Genetic Resources*, 23(3): 303–305.

Kumar, S., Dongre, R. and Choudhary, Bharti. 2021. Investigating the biochemical makeup of various bael (*Aegle marmelos* Correa.) cultivars under semi-arid condition of Madhya Pradesh. *Indian Journal of Arid Horticulture*, 3(1&2): 29–32.

Kumar, V., Pal, V., Sapra, P. and Umrao, V. 2008. Variability evaluation in bael (*Aegle marmelos* Correa) accessions. *Annals of Horticulture*, 1(1): 23–26.

Nagar, S., Kumar, M., Sharma, J.R., Baloda, S. and Godara, R.K. 2018. Bael germplasm evaluation for leaf and fruits pulp variability under South Haryana conditions. *International Journal of Pure and Applied Bioscience*, 6(1): 959–964.

Nath, V., Pandey, D. and Das, B. 2003. Diversity of bael (*Aegle marmelos* Correa) in East Central India. *Indian Journal of Plant Genetic Resources*, 16: 222–225.

Pandey, D., Tandon, D.K., Hudedamani, U. and Tripathi, M. 2013. Variability in bael (*Aegle marmelos* Corr.) genotypes from Eastern Uttar Pradesh. *Indian Journal of Horticulture*, 70(2): 170–178.

Parihar, N. and Pandey, C.S. 2019. Evaluation of bael (*Aegle marmelos* Correa.) gene pool of Kymore Plateau and Satpura Hill region. *International Journal of Genetics*, 11(3): 571–574.

Singh, K.K., Bairwa, B., Mahour, R.K. and Pareek, V. 2021. *Aegle marmelos* (Bael) benefit for health: A review. *Current Research in Agriculture and Farming*, 2(1): 17–20.

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Empowering farmers through front line demonstrations on the management of shoot and fruit borer (*Leucinodes orbonalis* Guenee) in brinjal

Shakti Khajuria, Kanak Lata, Renu Godara and J.K. Jadav

ICAR-CIAH, Krishi Vigyan Kendra, Panchmahal, Vejalpur, Godhra, Gujarat

ARTICLE INFO

Received: 03 April 2025
Accepted: 24 April 2025

Keywords: Brinjal, shoot and fruit borer, emamectin benzoate 5 SG, front line demonstrations, yield and economic analysis

doi:10.48165/ijah.2025.7.1.11

ABSTRACT

This study assessed the efficacy of emamectin benzoate 5 SG (0.0025%) in managing the shoot and fruit borer of brinjal through front line demonstrations (FLDs) conducted during 2021-22, 2022-23, and 2023-24 in Kalol Taluka and Panchmahal districts of Gujarat. The study compared demonstrated practice (emamectin benzoate 5 SG @ 12.5 g a.i./ ha) with farmer's practice (inconsistent pesticide use). Results revealed significant reduction in pest damage under the recommended practice, with shoot borer infestation decreasing from 7.25% to 8.50% and fruit borer damage reducing from 13.50% to 15.50%, compared to 17.50%-18.75% and 22.75%-23.50%, respectively, under farmer's practice. Yield increased from 235.25 q/ ha (2021-22) to 249.75 q/ ha (2023-24) in the recommended practice, significantly higher than farmer's practice yields (170.50 to 198.50 q/ ha). The technology gap was 45.83 q/ ha, extension gap 55.75 q/ha, and technology index 16.37%. Economic analysis showed a B:C ratio of 3.10 for the recommended practice versus 2.56 in farmer's practice, with an additional net return of ₹ 28,400/ ha. The study confirms that emamectin benzoate 5 SG effectively manages brinjal fruit and shoot borer, enhancing productivity and profitability, making it a viable pest control strategy for sustainable brinjal cultivation.

Introduction

Brinjal (*Solanum melongena* L.) is widely cultivated in India and the second-largest producer after China. Despite its significance, brinjal cultivation faces severe challenges due to insect pests, with the fruit and shoot borer (*Leucinodes orbonalis* Guenee) being the most destructive. This pest can cause 14-43% fruit damage, leading to significant yield losses (Khajuria *et al.,* 2014a; Khajuria *et al.***,** 2014b; Khajuria *et al.***,** 2015; Khajuria *et al.***,** 2017; Khajuria, 2022). Farmers often rely on chemical pesticides for pest control, but their indiscriminate use leads to pesticide resistance, environmental pollution, and health risks. Therefore, sustainable pest management strategies are needed to improve yield and economic returns, while reducing pesticide dependence.

Front line demonstrations (FLDs) played a vital role in promoting improved agricultural practices by demonstrating scientifically tested technologies in real farm conditions. This study evaluates the effectiveness of emamectin benzoate 5 SG (0.0025%) in controlling brinjal fruit and shoot borer through FLDs. The study compares demonstrated technology with farmer's conventional practices, assessing yield performance, cost-benefit ratio, and economic gains. Additionally,

Corresponding author's Email: shaktikhajuria@gmail.com (Dr. Shakti Khajuria)

technology gap, extension gap and technology index were analyzed to understand technology dissemination. The findings aim to support brinjal production and encourage the adoption of improved pest management practices among farmers.

Material and Methods

The study was conducted during the *kharif* seasons of 2021-22, 2022-23 and 2023-24 to evaluate the effectiveness of emamectin benzoate 5 SG (0.0025%) in managing brinjal fruit and shoot borer under front line demonstrations. The demonstrations were carried out in selected farmer's fields in Kalol Taluka, Panchmahal district, Gujarat, under the supervision of ICAR-Krishi Vigyan Kendra, Panchmahal. A total of 10 farmers per year were selected based on their willingness to participate and adopt the demonstrated pest management practices.

Demonstration details

The study compared two pest management practices to evaluate the effectiveness of emamectin benzoate 5 SG in managing brinjal fruit and shoot borer. In the demonstrated practice (FLD Plots), emamectin benzoate 5 SG was applied at a rate of 5 g per 10 liters of water (12.5 g a.i./ ha) for pest management. In contrast, the farmer's practice involved the use of inconsistent pesticide applications, which varied among farmers based on their individual practices. This comparative approach helped assess the efficacy, yield impact, and economic benefits of the demonstrated technology over conventional methods.

The FLDs were conducted by adopting standard agronomic practices including land preparation, spacing, irrigation, and disease management, as per scientific recommendations.

Data collection and observations

To assess the effectiveness of emamectin benzoate 5 SG in managing brinjal fruit and shoot borer, various parameters were recorded. Pest damage was evaluated by calculating the percentage of shoot and fruit infestation, determined using the ratio of infested shoots or fruits to the total number, multiplied by 100. Crop yield (q/ha) was measured separately for demonstration plots and farmer's practice plots. Economic indicators, including the cost of cultivation, gross return, net return, and benefit-cost ratio (B:C ratio), were analyzed to determine the profitability of the demonstrated technology. Additionally, the study assessed technology and extension impact by calculating the technology gap (difference between potential and demonstration yield), extension gap (difference between demonstration yield and farmer's practice yield) and technology index (%) is calculated as the difference between potential yield and demonstration yield, divided by potential yield and multiplied by 100. It reflects the extent of technology adoption.

Statistical analysis

The collected data were analyzed following the methods of Panse and Sukhatme (1989). Mean values were compared using the Least Significant Difference (LSD) test to determine treatment differences. Angular transformation was applied as per standard procedures. ANOVA was used to assess yield variations across different years, ensuring statistical reliability.

Results and Discussion

Impact of recommended practice on pest infestation and yield in brinjal

The study evaluates the impact of recommended and farmer's practices on shoot borer damage, fruit borer damage, and yield in brinjal over three consecutive years (2021-24). The results indicate a significant reduction in pest infestation and an increase in yield under the recommended practice compared to the farmer's practice.

In the recommended practice, shoot borer damage ranged from 7.25% to 8.50%, while in the farmer's practice, it was considerably higher, ranging from 17.50% to 18.75%. Similarly, fruit borer damage was significantly lower in the recommended practice (13.50%-15.50%) compared to the farmer's practice (22.75%-23.50%). These results are in accordance with the study conducted by Shamik (2019), who found that emamectin benzoate was promising insecticide to reduce brinjal fruit and shoot infestation. The transformed angular values further support these findings.

Yield data highlights the effectiveness of the recommended practice, with an increase from 235.25 q/ ha in 2021-22 to 249.75 q/ha in 2023-24, whereas the farmer's practice recorded significantly lower yields, ranging from 170.50 q/ ha to 198.50 q/ha (Table 1 and Fig. 1). Shubham et al. (2021) found that emamectin benzoate 5% SG @ 200 g a.i./ha was the most effective treatment, resulting in maximum fruit yield. Statistical parameters indicate significant differences, confirming the reliability of the findings.

Statistical analysis: ANOVA test for yield differences

The ANOVA results confirm that the recommended practice consistently produced a higher yield than the farmer's practice over three years. The low CV% (0.44, 0.06, 0.04) and significant LSD (1.34, 0.18, 0.14) indicate reliable findings. Additionally, the SEm± values (0.36, 0.05, 0.03) confirm statistical accuracy. Thus, the recommended practice is a better way to increase brinjal yield and improve farming results (Fig. 2).

Table 1. Effect of recommended and farmer's practices on shoot borer damage, fruit borer damage, and yield in brinjal (2021-2024)

Variables	Shoot borer damage (%)			Fruit borer damage (%)			Yield (q/ ha)		
	2021-22	2022-23	2023-24	2021-22	2022-23	2023-24	2021-22	2022-23	2023-24
Recommended practice	8.50 (16.96)	7.50 (15.87)	7.25 (15.63)	15.50 (23.17)	14.75 (22.59)	13.50 (21.56)	235.25	247.50	249.75
Farmer's practice	17.50 (24.75)	18.25 (25.28)	18.75 (25.67)	23.25 (28.84)	23.50 (28.98)	22.75 (28.48)	170.50	196.25	198.50
SEm±	0.24	0.04	0.05	0.20	0.22	0.26	0.36	0.05	0.03
CV (%)	3.46	0.57	0.80	1.84	2.13	2.56	0.44	0.06	0.04
LSD (5%)	0.62	0.09	0.13	0.71	0.81	0.95	1.34	0.18	0.14

Figures in parenthesis are transformed angular values

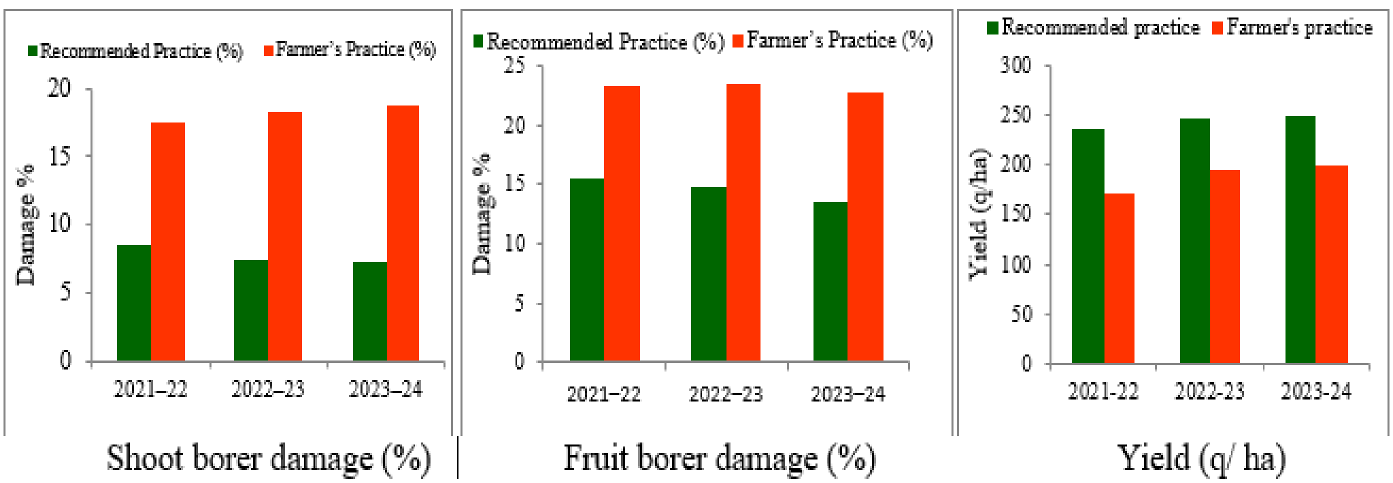


Fig. 1. Reduction in borer damage and yield enhancement in brinjal under recommended practices compared to farmer's practice

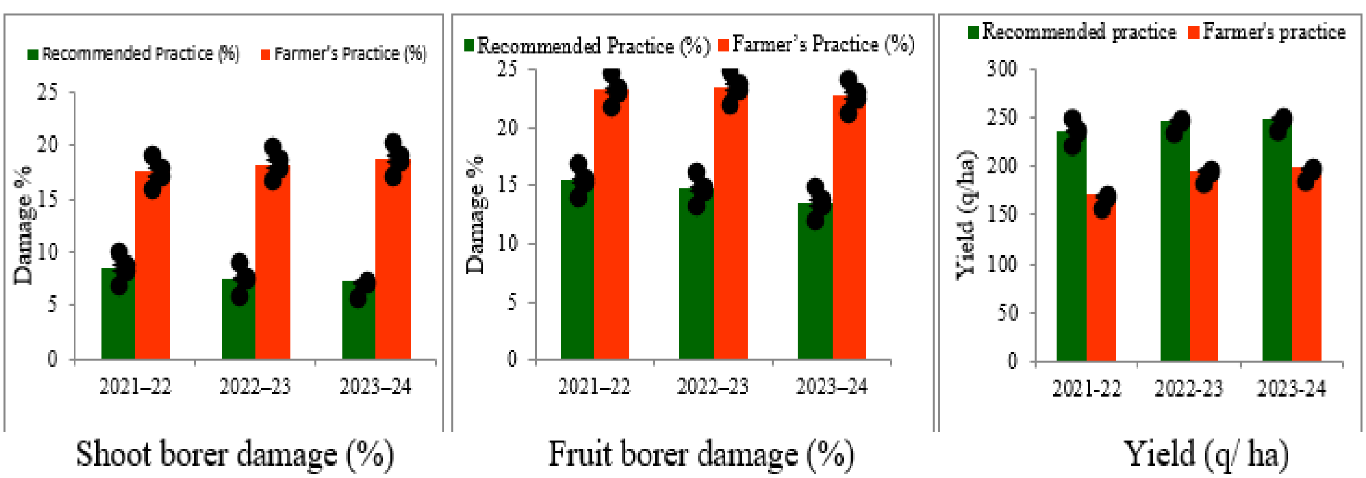


Fig. 2. Comparison of practices with standard error bars for pest damage (%) and yield of brinjal

Yield improvement and technology gap in brinjal

The impact of the recommended practice on yield, yield increase, technology gap, extension gap, and technology index in brinjal is presented in Table 2 and Fig. 3 based on pooled data over three years. The results highlight a significant improvement in yield under the recommended practice compared to the farmer's practice. The average yield obtained from the recommended practice was 244.17 q/ ha, which was notably higher than the 188.42 q/ ha recorded under the farmer's practice. This resulted in a substantial yield increase of 29.59%. These findings are similar to those of Shamik (2019), who reported that emamectin benzoate increased marketable fruit yield.

The technology gap, representing the difference between potential yield and observed yield under the recommended practice, was 45.83 q/ ha, indicating that there is still scope for further improvement. The extension gap, which reflects the difference between yields from the recommended and farmer's practices, was observed to be 55.75 q/ ha, emphasizing the need for wider adoption of improved pest management strategies. Additionally, the technology index, which quantifies the effectiveness of the recommended practice in achieving potential yield, was recorded at 16.37%. The results of the present study were in consonance with the findings of Khajuria *et al.* (2016) in case of cotton crop.

The higher yield and reduced pest infestation achieved under the recommended practice were primarily due to the application of emamectin benzoate 5 SG @ 12.5 g a.i./ ha, an effective insecticide for managing fruit and shoot borer infestations. These findings underscore the importance of adopting scientifically validated pest management practices to enhance brinjal productivity. These results emphasize the effectiveness of the recommended practice in boosting productivity and reducing pest related losses.

Table 2. Impact of recommended practice on yield, yield increase, technology gap, extension gap and technology index in brinjal (Pooled data of 3 years)

Variables	Yield (q/ ha)	% yield in-crease (q/ ha)	Tech-nology gap (q/ ha)	Exten-sion gap (q/ ha)	Technology index (%)
Farmer's practice	188.42	-	-	-	-
Recom-mended practice*	244.17	29.59%	45.83	55.75	16.37

*Foliar spray of emamectin benzoate 5 SG @ 12.5 g a.i./ ha

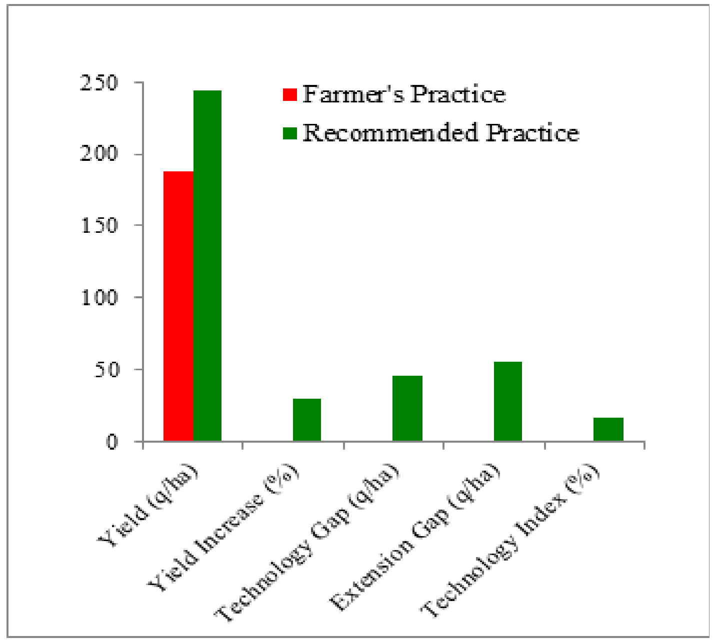


Fig. 3. Impact of recommended practice on yield and associated factors in brinjal

Economic viability of recommended practice in brinjal cultivation

The economic analysis (Table 3) highlights the financial benefits of adopting the recommended practice over the farmer's practice in brinjal cultivation, based on pooled data over three years. The cost of cultivation under the recommended practice was ₹ 44,666.67/ ha, slightly higher than the ₹ 41,833.33/ ha incurred in the farmer's practice, mainly due to the use of emamectin benzoate 5 SG (12.5 g a.i./ha). However, the gross return was significantly higher in the recommended practice (₹ 138,650.0/ ha) compared to the farmer's practice (₹ 107,416.70/ ha), resulting in a net return of ₹ 93,983.33/ ha, which was ₹ 28,400/ ha higher than the farmer's practice (₹ 65,583.33/ ha). The benefit cost ratio (BCR) improved from 2.56 in the farmer's practice to 3.10 under the recommended practice, demonstrating the profitability of adopting improved pest management strategies (Table 3 & Fig. 4).

These findings align with previous studies (Patel & Radadia, 2015; Shamik, 2019), which confirm that effective pest control measures significantly reduce brinjal fruit and shoot borer infestation, leading to improved yields and higher profitability. The study shows that emamectin benzoate helps make brinjal cultivation better and more affordable.

These findings suggest that the recommended practice not only enhances productivity but also provides higher profitability to farmers, making it a financially sustainable pest management approach. This economic gain encourages wider adoption of scientifically recommended pest control methods, leading to improved income and livelihood security for brinjal growers.

Table 3. Economic analysis of farmer's practice vs. recommended practice in brinjal cultivation (Pooled data of 3 years)

Variables	Cost of cultivation (₹/ ha)	Gross return (₹/ ha)	Net return (₹/ ha)	Benefit: cost ratio
Farmer's practice	41,833.33	107,416.70	65,583.33	2.56
Recommended practice	44,666.67	138,650.00	93,983.33	3.10
Additional in recommended practice	2,833.34	31,233.30	28,400	

*Incremental benefit: cost ratio

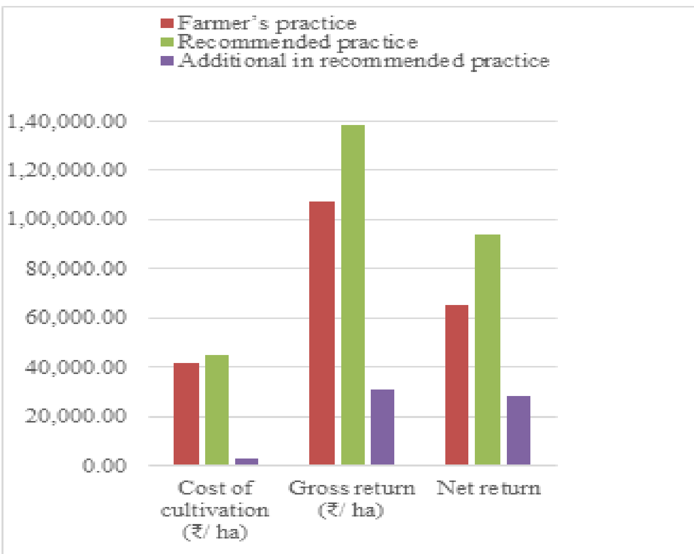


Fig. 4. Economic analysis of farmer's practice vs. recommended practice

Conclusion

The study confirms that emamectin benzoate 5 SG (12.5 g a.i./ ha) effectively manages brinjal fruit and shoot borer, significantly reducing shoot (7.25-8.50%) and fruit borer (13.50-15.50%) damage while increasing yield (244.17 q/ ha) compared to farmer's practices. The technology gap (45.83 q/ ha) and extension gap (55.75 q/ ha) highlight the need for wider adoption. Economic analysis revealed higher profitability with B:C ratio of 3.10, ensuring better returns for farmers. The front line demonstrations successfully motivated most farmers to adopt the recommended technology due to its clear advantages and effective management of brinjal shoot and fruit borer. These innovative practices contribute to improved decision making among farmers and enhance their ability to adapt and modify existing farming practices.

Acknowledgements

The authors would like to express sincere thanks and gratitude to the Director, ICAR-CIAH, Bikaner and ICAR-ATARI, Pune for financial support and providing necessary facilities throughout the study.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript

References

Khajuria, S. 2022. Reduction of little leaf disease, fruit and shoot borer by transplanting of brinjal during September. *Agriculture & Food: e-Newsletter, 4(6)*:329-331.

Khajuria, S., Rai, A. K. and Lata, K. 2014a. Occurrence and distribution of insect pests attacking solanaceous vegetables in semi-arid region of central Gujarat. *Insect Environment, 19(4): 248-249.*

Khajuria, S., Rai, A. K. and Lata, K. 2014b. Evaluation and demonstration of brinjal IPM modules for fruit and shoot borer management. In: *National Seminar on Role of Organic Farming in Climate Resilient and Sustainable Agriculture held at NAU, Navsari, Gujarat during* January 9-10, 2014. Pp. 161.

Khajuria, S., Rai, A. K. and Lata, K. 2015. Pest status of vegetable crops in semi-arid region of middle Gujarat. In: *National Seminar on Magnitude of Extension Approaches in Agricultural Development held at NAU, Navsari, Gujarat during* February 5-6, 2015.

Khajuria, S., Rai, A. K. and Lata, K. 2017. Evaluation of IPM modules for the management of brinjal fruit and shoot borer. *Gujarat Journal of Extension Education, 28(1)*:155-157.

Khajuria, S., Kumar, R. and Jadav, J. K. 2016. Frontline demonstrations: An approach for management of cotton mealybug, *Phenacoccus solenopsis* Tinsley. *Gujarat Journal of Extension Education, 27(2)*:165-168.

Panse, V. G. and Sukhatme, P. V. 1989. *Statistical Methods for Agricultural Workers.* Indian Council for Agricultural Research, New Delhi. P. 359.

Patel, H. V. and Radadia, G. G. 2015**.** Evaluation of insecticides against brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee. *Insect Environment, 20(4),* 123-125.

Shamik, D. 2019**.** Evaluation of some novel insecticides on brinjal fruit and shoot borer (BFSB) in West Bengal, India. *The Pharma Innovation Journal, 8(12):*337-341.

Shubham, Singh, R. B., Shankar, K., Upadhyay, A. and Dixit, P. S. 2021**.** Studies on the seasonal incidence of brinjal shoot and fruit borer (*Leucinodes orbonalis* Guenee) and its effective management. *The Pharma Innovation Journal (SP), 10(8):*370-374.

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Effect of harvesting stage on drying, rehydration and sensory characteristics of *khejri* (*Prosopis cineraria*) pods

P.S. Gurjar, K.L. Kumawat and D.K. Sarolia

ICAR-Central Institute for Arid Horticulture, Beechwal, Bikaner-334006, Rajasthan

ARTICLE INFO

Received: 18 March 2025
Accepted: 08 April 2025

Keywords: *Khejri*, *Thar Shobha*, maturity, dehydration, sensory properties

doi:10.48165/ijah.2025.7.1.12

ABSTRACT

Dehydrated tender green pods of *khejri* (*Prosopis cineraria*) are utilized as premium vegetable in north-west part of country. Looking into the economic importance of *khejri* pods (*sangri*), an experiment was conducted to investigate the effect of pod harvesting stage on drying, rehydration and sensory properties of dried pods during year 2021-22. The maximum dry product recovery (28.22%) was recorded in 13 days maturity closely followed by 16 days (28.08%) maturity pods. Significantly high rehydration capacity was noticed in early harvest (10, 13 and 16 day's maturity) pods as compared to late harvest (19, 22 and 25 maturity) pods. Desirable sensory properties were also observed in10 to 16 days maturity pods. Based on study, it is concluded that *khejri* variety *Thar Shobha* pods should be harvested in 2-3 pickings between 10-16 days after fruiting for getting good quality dried product.

Introduction

Khejri (*Prosopis cineraria*) is a leguminous tree grows naturally under resource poor arid edapho-climatic conditions of north-west part of country. This tree is a life-line tree of Thar Desert because it provides food, fodder, fuel, shelter to local inhabitants and also supports eco-restoration through augmenting soil fertility and checking erosion (Samadia, 2016). It is the most important component of the traditional farming systems and tolerates extreme edapho-climatic conditions with lush-green foliage and bears fruits that too during the driest period (Pareek, 2002). Its nutritious leaf (*loong*) utilized as fodder for livestock and tender pods locally known as *sangri* consume extensively for vegetable and pickle purpose. *Sangri* is sold in fresh and dehydrated form at premium prices, and it is the main constituent of *Panchkutta* vegetable culinary. *Sangri* is high valued and sold at remunerative prices *i.e.*, Rs. 100-150 and 500-800 per kg both in fresh and dehydrated form, respectively. *Sangri* is rich in minerals such as potassium, magnesium, calcium, zinc, iron and in addition a good source of protein and dietary fiber. It also contains high antioxidants, phenols, flavonoids and saponins, which help in boosting the immunity and reduce bad cholesterol in the blood.

ICAR-CIAH, Bikaner has developed an improved variety of *khejri* named as *Thar Shobha* which has many ideal horticultural attributes such as dwarf plant stature, thornlessness, regular bearer, uniform quality pods and high yield of good quality fodder. In recent times, farmers are showing much interest in commercial orcharding of *Thar Shobha* and cultivation area of this variety is rapidly increasing in arid and semi-arid regions of Rajasthan, Gujarat and Haryana state. Farmers are cultivating it for nutritious tender fresh green pods and leaf-fodder. Fresh green pods are

Corresponding Author's Email: pawan09996@gmail.com (Dr. P.S. Gurjar)

available for very short period *i.e.* 10-15 days during second fortnight of April. Farmers and rural women process these green pods into dry pods locally known as *sangri*, which is the high value product of *khejri*. A single spike of *khejri* bears variable maturity pods due to asynchronous bearing habit. In traditional practice, farmers usually harvest whole produce in single picking which includes immature and over mature pods too. Further dehydration of these pods yields non-uniform quality *sangri* that fetch lesser price in the market. To obtain uniform premium quality dried *sangri*, green pods required to be harvest at specific maturity. So far, maturity indices for harvesting of green pods for dehydration purpose have not been standardized. Therefore, the present study was carried to determine the right maturity stage for getting premium quality dried product and also to know the pod maturity level effect on drying rehydration and sensory attributes.

Material and Methods

The experiment was carried out in *Thar Shobha* variety in year 2021-22. Panicles were tagged and pod setting date was mentioned in tag during March month. First harvest was conducted after 10 days of pod setting. Later on, harvesting was carried out at 13, 16, 19, 22 and 25 days after pod setting. Immediately after harvesting pods were brought to post harvest laboratory, washed, blanched for 5 minutes, dried in tunnel type solar dryer and packed in food grade plastic boxes for further observations.

Drying yield (%): Drying yield was determined by the following formula

$$\text{Drying yield} = \frac{\text{Weight of dried pods}}{\text{Weight of fresh pods}}$$

Determination of drying ratio: The drying ratio was calculated by the following formula:

$$\text{Drying ratio} = \frac{\text{Weight of fresh pods before drying}}{\text{Weight of dried pods } (sangri)}$$

Rehydration ratio: Rehydration means refreshing the dehydrated or dried products in water. Fifteen beakers (three for each maturity stage) of each 500 ml capacity were taken and 300 ml of boiling water and 20 g of dried sample were poured into each beaker and kept for 60 minutes for rehydration. Weight of rehydrated samples was measured at 10 minutes interval for 60 minutes period. Surface moisture from rehydrated samples was removed properly by applying tissue paper before measuring weight. The rehydration ratio was calculated by following formula-

$$\text{Rehydration ratio} = \frac{\text{Weight of rehydrated pods}}{\text{Weight of dried pods}}$$

Rehydration kinetics: Drying kinetics was determined by measuring sample weight by digital balance at regular interval (1 hr) during drying and plotting graph of weight loss against time. Same way rehydration kinetics was determined by plotting curve of weight gain against time period (10 minutes interval) during rehydration process (Ismail *et al.*, 2016).

Sensory evaluation: Sensory evaluation of rehydrated *sangri* of different maturity stages was carried out on the basis of hedonic scale by group of scientists, experts and SRFs at ICAR-CIAH, Bikaner.

Statistical analysis: Data was collected in triplicate; the mean values with standard deviations were reported. Significant mean difference at 95% confidence level (α=0.05) was identified through use of WASP 2.0 software developed by ICAR-Central Coastal Agricultural Research Institute, Goa.

Results and Discussion

Effect of harvesting stage on dry product yield (%):

Dry product yield was significantly affected by the harvesting stage of green pods. Pods harvested after 10 days of setting demonstrated minimum dry product yield *i.e.* 25.86%, however as the maturity progressed yield was considerably enhanced and observed 28.19 and 28.05% in pod harvested after 13 and 16 days of setting, respectively. In later maturity stages, dry product yield was continuously decreased significantly and found 27.37, 26.99 and 26.34% of fresh weight in pods harvested after 19, 22 and 25 days after pod setting (Fig. 1). Low dry product yield in early harvested pods is may be due to presence of high moisture content during initial stage of development. The rationale behind the maximum dry product yield in pods harvested after 13 and 16 days of setting is increase in dry matter content due to deposition of fiber, cellulose and lignin in pods during later stages of development.

At the stage of 19, 22 and 25 days of harvest significant reduction in dry product recovery (%) were observed. It may be due to initiation of seed development in pods which augment the fresh weight but dry matter content do not enhanced because seed is having high water content during early developmental stage. Similar results were obtained in vegetable type cluster bean pods dehydration where dry product yield from beans were reduced at the inception of seed development stage (Gurjar *et al.*, 2023). These observations were also in an agreement with the results previously reported by Ismail *et al.* (2016) in green bean (*Phaseolus vulgaris*) during open sun drying.

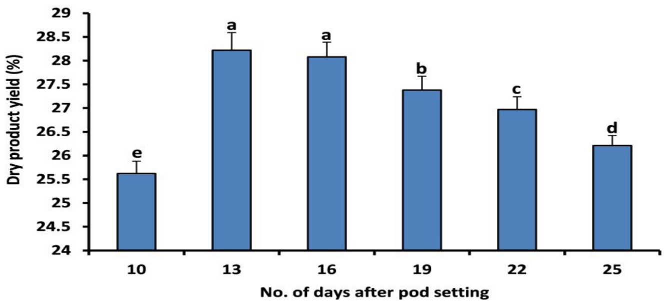


Fig. 1. Effect of pod harvesting stage on dry product yield (%) of *sangri*

Effect of harvesting stage on rehydration ratio of dried pods: Rehydration ratio (RR) is the ratio of the mass of rehydrated and drained food to the mass of the original material (dried product). Rehydration capacity is one of the important properties used to measure the quality of dried food materials (Lewicki, 1998). A high value of rehydration ratio means the dried product has ability to convert near to original color, texture and shape through absorption of water after soaking. In present study, significant variation was noticed in rehydration ratio of *sangri* harvested at different maturity stages.

The maximum rehydration ratio (2.95) was recorded in pods harvested after 10 days of setting while significant diminish in RR was observed in 13 and 16 days maturity pods. However, difference in rehydration value was non-significant between 13 and 16 days maturity pods (Fig. 2). As the pod maturity progressed, continuous significant decline in RR was observed and minimum (1.94) was found in pods harvested after 25 days of setting. According to results presented above RR is inversely proportional to the number days after pod setting. The high RR in early maturity stage (10, 13 and 16 days maturity) pods was due to porous structure of cell wall owing to less deposition of fiber, cellulose and lignin which allow water to enter unhindered in dried product. In case of later stages of pods maturity (19, 22 and 25 day's maturity), porosity and elasticity of cell wall was declined because of more concentration of fiber and lignin in peel. The similar results were reported in okra during rehydration of dried flakes harvested at different fruit maturity stages (Tufekci and Ozkal, 2017).

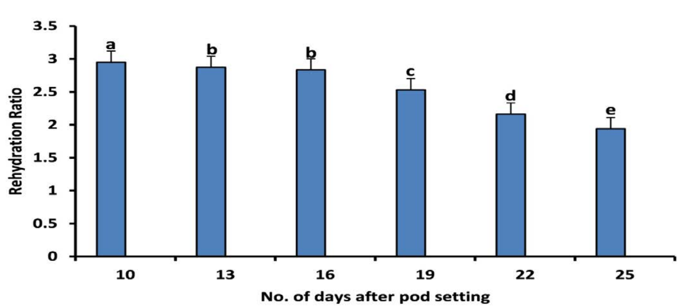


Fig. 2. Rehydration ratio of dried pods harvested at different maturity stages

Effect of harvesting stage on rehydration kinetics of dried sangri: Rehydration rate is considered as one of the important parameters for assessing dried product quality. Rehydration curves of the dried *sangri* of different maturity stages versus rehydration time were plotted in Fig. 3. It was witnessed that high rehydration rates were noticed in all samples for the first 30 minutes and then rehydration rates start to slow down. However, in case of late harvest *i.e.* 19, 22 and 25 days maturity pods rehydration rate was comparatively sluggish as compared to the early harvest pods right throughout the rehydration period. It might be due to the fact that early harvest pods possess higher porosity that facilitates quicker diffusion of water into the material.

The rapid rehydration rate in the initial period in all samples was because of high water activity gradient between the sample and surrounding media (water) and as time passes, this difference reduced with consequent lower rate of rehydration. The decline in rehydration rates at later stages is related to the lower water absorption presumably because of the filling of water in free capillaries and intercellular spaces present in tissues of dehydrated pods. Similar rehydration patterns for a variety of legumes have been reported previously (Berrios *et al*., 1999; Ulloa *et al*., 2013).

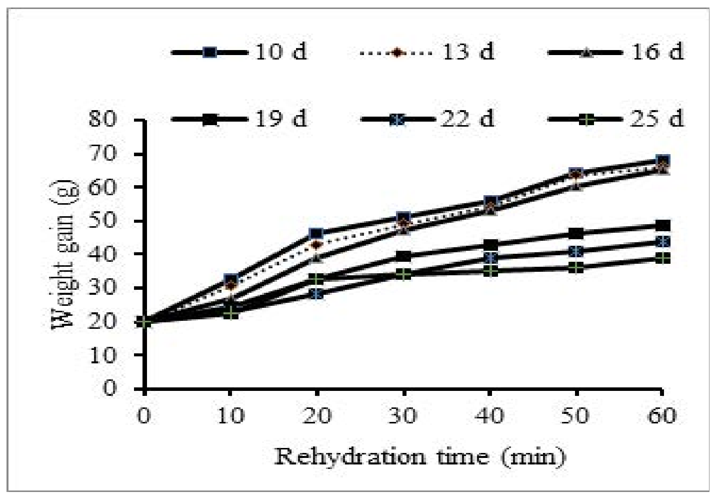


Fig. 3. Rehydration kinetics dried pods harvested at different maturity stages

Sensory evaluation of rehydrated pods: Sensory evaluation revealed that early harvest pods showed higher sensory score as compared to late harvest pods (Fig. 4). The pods harvested after 10, 13 and 16 days of setting received more than 8 score for taste, texture and color from the experts while late harvested pods showed significantly lower score. No significant difference was observed for sensory score between 10, 13 and 16 days maturity pods. Initiation of seed development, color change and peel hardness are responsible for decline in sensory score of 19, 22 and 25 days maturity pods.

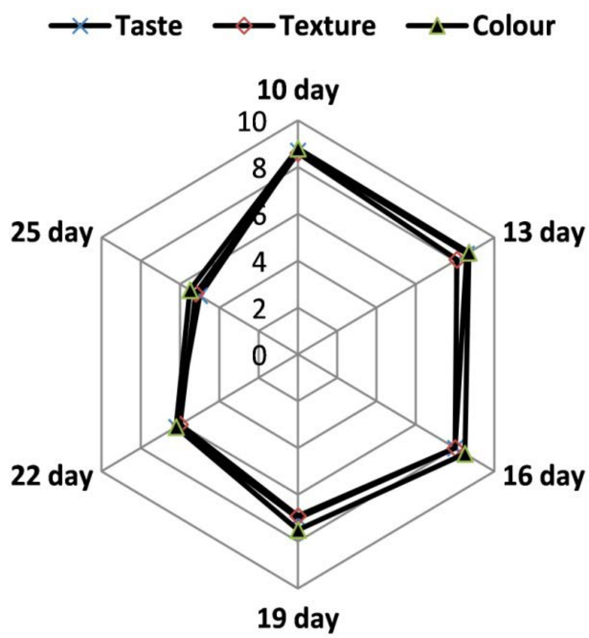


Fig. 4. Evaluation of sensory attributes of dried pods harvested at different maturity stages

Conclusion

It is concluded from the study that harvesting stage of green pods is significantly influence the drying, rehydration and sensory properties of dried pods. Pods harvested between 10 and 16 days of fruiting showed desirable drying, rehydration and sensory attributes. Late harvest, 19, 22 and 25 days maturity pods showed significant decline in all desirable attributes. Therefore, *khejri* variety *Thar Shobha* pods should be harvested in 2-3 pickings between 10-16 days of fruiting for getting good quality dried product.

Acknowledgements

The authors are grateful to the ICAR, New Delhi and Director, ICAR-CIAH, Bikaner for providing the necessary facilities to conduct this research.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Berrios, J. D. J., Barry, G.S. and Cheong, W.A. 1999. Physicochemical characterization of stored black beans (*Phaseolus vulgaris* L.). *Food Research International*, 32: 669–676.

Gurjar, P.S., Verma, A.K., Ram, H., Meena, R.K. and Samadia, D.K. 2023. Standardization of dehydration techniques for vegetable type cluster bean. *Current Horticulture*, 11(2): 16-20.

Ismail, O., Figen, A.K. and Piskin, S. 2016. Open sun drying of green bean: influence of pretreatments on drying kinetics, colour and rehydration capacity. *Heat Mass Transfer*, 55: 456-461.

Lewicki, P.P. 1998. Some remarks on rehydration of dried foods. *Journal of Food Engineering*, 36(1): 81-87.

Pareek, O.P. 2001. Vegetative propagation of khejri. *ICAR News*, 7(4): 12.

Samadia, D.K. 2016. Horticulture based crop production site management approach (HBCPSMA) - an innovative concept for doubling farm income under dry-lands. *Journal of Agriculture and Ecology*, 1: 1–9.

Tufekci, S. and Ozkal, S.G. 2017. Enhancement of drying and rehydration characteristics of okra by ultrasound pretreatment application. *Heat Mass Transfer*, 53: 2279–2286.

Ulloa, J.A., Bonilla-Sánchez, C.R., Ortíz-Jiménez, M.A., Rosas-Ulloa P, J.C. Ramírez-Ramírez and Ulloa-Rangel, B.E. 2013. Rehydration properties of precooked whole beans (*Phaseolus vulgaris*) dehydrated at room temperature. *CyTA - Journal of Food*, 11 (1): 94-99.

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Studies on comparative economic analysis of beverages and preserves of arid fruits

Mukesh Kumar[1], Pooja[2], Amarjeet Nibhoria[1], Anuradha[1] and Parveen Kumar Nimbrayan[2]

[1]CCS Haryana Agricultural University, Regional Research Station, Bawal (Rewari), Haryana
[2]CCS Haryana Agricultural University, College of Agriculture, Bawal (Rewari), Haryana

ARTICLE INFO

Received: 19 February 2025
Accepted: 08 April 2025

Keywords: B: C ratio, doubling income, fruit processing, juice, *murabba*, squash, syrup

doi:10.48165/ijah.2025.7.1.13

ABSTRACT

This study presents a comparative economic analysis of beverages and preserves made from arid fruits, aiming to enhance the profitability of underutilized and lesser-known fruit varieties. It is evident from the results that the benefit: cost ratio from beverages was 3.93 in bael juice, 2.11 in bael squash, 2.07 in bael syrup, 2.21 ber while preserves of ber, aonla and bael have 2.76, 2.94 and 2.67, respectively. The value addition of fruits resulted in generation of income, employment as well as eliminate/ minimize malnutrition problem and post-harvest losses.

Introduction

Processed fruit products are delicious, acceptable to consumer with more shelf life without losses in taste and quality. The increased fruit production needs to be supplemented by proper utilization that would be achieved through processing (Kumar *et al*., 2020). Fruits and vegetables are rich source of vitamins, minerals and dietary fibre, but there are highly perishable. They need to be preserved and processed into various value-added products. It is estimated that about 22 percent of fruits and vegetables lost or get wasted in the chain from grower to consumer, whereas 76 per cent of fruits and vegetables are consumed fresh (Acharya, 2007 and Kumar *et al*., 2013).

In the present scenario, the dietary habit of human being is drastically changing from cereals to delicious nutritive food. Hence the demand of fruits and vegetable based nutritive food is increasing all over the globe and in India as well (Kumar *et al.,* 2015). The fluctuation in fruits and vegetable prices in the market can also ease out by value added products and farmers may get more profit (Kumar *et al.,* 2017). These also contribute in nutritional security by supplying quality products for human consumption (Baloda *et al*., 2018).

As per Assocham study, "India incurs post-harvest fruits and vegetable losses worth over Rs. 2 lakh crore each year largely owing to the lack of modern cold storage facilities food processing units and a callous attitude towards tackling the grave issue of post-harvest losses" (Anonymous, 2020). ICAR-Central Institute of Post-Harvest Engineering and Technology (CIPHET) reported that the wastage of fruits and vegetable in India varied from 4.6% to 15.9% annually (Anonymous, 2017), due to lack of awareness, modern harvesting practices

Corresponding author's Email: sabharwalmk@gmail.com (Dr. Mukesh Kumar)

and inadequate cold chain infrastructure. The processing of fruits and vegetables in Indian was about 2% and export share in the global market was 1.3% during 2015 according to CIPHET report (Anonymous, 2019). This programme was structured with the aim to avoid the outbreak of food borne illness due to contaminated food.

Bael (*Aegle marmelos* Corr.) belongs to family Rutaceae is one of the arid, minor, underutilized, medicinal, indigenous fruit crops of India. The fruits of bael are rich in minerals, vitamins (specially riboflavin), anti-oxidants and with importance in medicinal remedies. It contains 61.5 g moisture, 1.8 g protein, 0.3 g fat, 209g fibre, 31.8 g carbohydrate, 12.7 to 19.0 g mucilage, 1.7 g mineral, 55 mg carotenes, 0.13 mg thiamine, 0.03 mg riboflavin, 1.1 mg niacin, 186 IU vitamin A and 8-19 mg vitamin C per 100 g of pulp (Pal *et al.,* 1993 and Singh *et al.,* 2016). The plant parts of bael tree (root, bark, leaves, branches and fruits) are consumed in the form of '*Panchang*' for curing various diseases like ulcer, dysentery, and diarrhea, etc. It has marmelosin content in fruits which protects our stomach from various stomach diseases (Nagar *et al.,* 2017). The ripe fruits are aromatic, sweet and astringent, which helps in regeneration of skin, coolant, laxative, febrifuge and good source for the heart, brain and in dyspepsia (Raju *et al.,* 2014 and Nagar *et al.,* 2018). Bael fruits can be processed into squash, jam, nectar, RTS, fruit slice and toffee. Bael squash is a poplar drink for its refreshing and cooling effect (Kumar *et al*., 2013).

Aonla also called as Indian gooseberry (*Phyllanthus emblica* L syn. *Emblica officinalis* Gaertn) belongs to family Phyllanthaceae, it is native to India, Malaya and China. It is rich source of vitamin C and fair source of source of minerals, carbohydrates, carotene and thiamin. Vitamin C content in aonla is not degraded in the processed fruits. It has medicinal and therapeutic properties which encourage the farmers' towards cultivation of aonla in wasteland (Singh *et al*., 2017). Aonla can be processed into various processed products *viz*., dried fruits or powder have been reported to be useful in anaemia, cough, diarrhea, dysentery, jaundice and haemorrhages. *Chavanprash* and *trifla* are well known indigenous products prepared from aonla fruits. A number of other products namely chuntey, candy, *murabba*, pickle, sauce, dried chips and shampoo can be prepared from aonla fruits (Kumar *et al*., 2013).

Ber (*Ziziphus mauritiana* Lamk.) is a king of arid zone fruits. It can be grown easily in the area where other crops cannot survive easily. It is rich in nutritive value, popular and cheap, hence is often called as a poor man's fruit. It is rich source of vitamin C (90-120 mg/100g) (Kumar *et al*., 2009). In fact, its vitamin C content is higher than apple, citrus and mango. Ber fruits are very rich in protein and minerals such as phosphorus and calcium. Consumption of one ber fruit in a day would meet the diet requirements of vitamin C and vitamin B complex of an adult man as recommended by WHO (Kumar *et al*., 2016). Ber fruits are used to prepare processed products *viz*., preserve, dehydrated fruit, canned fruit, juice, pulp, squash and wine (Kumar *et al*., 2009a). These products having acceptability in the consumers and one can fetch good price in the market. This helps to ease out fluctuation in the market price and farmers may get better returns and consumers get value added products (Kumar *et al*., 2021).

Material and Methods

The ripe fruits were collected from local market and orchard CCS Haryana Agricultural University, Regional Research Station, Bawal, Haryana. The products were prepared during ELP and training on fruits and vegetable preservation conducted at COA, Bawal during 2022 to 2024. The objective of the training was to improve the livelihood of the rural people. The fruits were processed for demonstration with the aim earning while learning and understanding about the preparation of products. The participants were awaked about value addition and income generation from different fruits. It is very difficult to get good quality/ unadulterated products from the local market. This programme was organized to make the rural people self-reliance, improve their livelihood, living standard and live better life by good earning with more benefit.

Flow chart for bael squash/ syrup

Ripe fruits → grading →washing →peeling /cutting → extract pulp → put in hot water (temp. 68°C) →remove seeds and fibre →filter or separation of juice → prepare sugar syrup (add water+ sugar+ citric acid) → cool syrup → add juice → add preservative* → add colour if needed→ filtering →bottling → sealing → labeling (Srivastava and Kumar, 2017).

*No preservative required in syrup

Select the ripe fruits of bael, harvest after completion of litter fall. Keep them in a bag or covered with paper for proper ripening, the detached stem portion during storage was considered that the fruits are ready for processing.

Flow chart for bael juice

Ripe fruits → grading →washing →peeling /cutting → extract pulp → remove seeds and fibre →filter or separation of juice → prepare sugar syrup (add water+ sugar+ citric acid) → cool syrup → add juice → add preservative* → add colour if needed→ filtering →bottling → sealing → labeling (Srivastava and Kumar, 2017).

*Preservative was not required for fresh consumption.

Flow chart for ber murabba/ candy

Ripe fruits → grading →washing →pricking → blanching → make sugar syrup (add water + sugar+ citric acid) → cool it →add blanched fruits →increase concentration of syrup to 66°B by adding sugars 3-4 times at 2 to 4 days interval →always add fruits in cold syrup (never boil the syrup with fruits) → (dehydrate for candy) canning → sealing → labeling (Srivastava and Kumar, 2017).

The ber fruit were collected when fruit starts turning yellowish with brownish ting, avoid fully ripe and immature fruits.

Flow chart for aonla murabba

Ripe fruits → grading →washing →pricking (removing astringency by adding fruits in 2, 4, 6 and 8 % salt solution at 24 hr interval) → washing→ blanching → make sugar syrup (add water + sugar+ citric acid) → cool it →add blanched fruits →increase concentration of syrup to 66°B by adding sugars 3-4 times at 2 to 4 days interval →always add fruits in cold syrup (never boil the syrup with fruits) →canning → sealing → labeling (Srivastava and Kumar, 2017).

Aonla fruits were harvested after attaining maturity when the skin colour changed from light green to dull green yellow and seed colour changed from creamy white to blackish.

Flow chart for bael murabba

Mature fruits → grading →pealing/ cutting → remove pulp → slicing pulp →remove seeds and gum in seed sac →washing →pricking → blanching → make sugar syrup (add water + sugar+ citric acid) → cool it →add blanched fruits →increase concentration of syrup to 66°B by adding sugars 3-4 times at 2 to 4 days interval →always add fruits in cold syrup (never boil the syrup with fruits) →canning → sealing → labeling (Srivastava and Kumar, 2017).

For preparation of bael *murabba* fruit should be harvested at maturity when fruits attained full size or it takes about 150 to 180 days after fruit set or shed its leaves.

Results and Discussion

The products prepared from different fruits were bael juice, bael squash, bael syrup, bael *murabba*, aonla *murabba* and ber *murabba*. The processed products were analysed for B:C ratio. The major cost involved in the products was fresh fruits (bael, ber, aonla), sugar, preservative, citric acid, cooking gas, packaging and labeling charges. The total cost incurred during the processing of one-kilogram fruit/ pulp preparation of different beverages was Rs. 61 inbael juice, Rs. 141 in bael squash, Rs. 155 in bael squash (Fig. 1; Table 1) while the preserves of ber, aonla and bael had Rs. 145 in ber *murabba*, Rs. 136 in aonla *murabba* and Rs. 150 aonla *murabba* each (Fig. 2, Table 2).

The market rate of the bael fruits was Rs. 30/ kg, ber and aonla Rs. 20 each. Gross income from the products was Rs. 240 in bael juice, 298 in bael squash, Rs. 321 in bael syrup, whereas Rs. 400 in *murabba* of bael, ber and aonla each. Net profit per kilogram of raw fruits was Rs. 180 in bael juice, Rs. 157 in bael squash, 166 in bael syrup while Rs. 255, 264 and 250 were received from *murabba* of ber, aonla and ber, respectively. It shows form the results that the benefit: cost ratio from the processed products varied as 3.93 in bael juice, 2.11 in bael squash, 2.07 in bael syrup, while preserves of ber, aonla and ber had 2.76, 2.94 and 2.67, respectively.

The trainees who made these products have earned good income for their livelihood. The glut of the fruits in the market can be managed/ avoided by utilization in processed supplemented products (Kumar *et al*., 2009b).

The processing could not save only the post-harvest losses of the fruits but also helpful in increasing the availability of quality food, good earning and save Indian economy of about Rs. 2 lakh crore per annum. For better earning the products should be made during the main season of the fruits to be used as raw material. The trainees have started to prepare the products at the home scale. The home scale production of these products not only save the pocket money but provide the quality food which helps to avoid malnutrition. Improvement in processing industry require study of consumers interest in the product, required quantity/ container or packaging and how the products compete with existing local market products and need unfulfilled demands of consumers, strong local or regional demand at premium price.

The products prepared were judged by the jury of local consumers and modify the recipes as per their demand for community support. For successful entrepreneurship a product cycle from grower to the last consumer is required. It will not only provide quality input or raw materials (fruits and vegetable), but also ensure the availability of quality products at cheaper rate all over the year. This approach may be a way to good returns from special recipes from organically grown produce. The registration under FPO can be done onhttp://www.trademarkregistrationindia.com/ for trademark, patent, copyright, company registration, IPR services, brand registration, logo registration, LLP registration and other services are also available online. It is concluded from the study that the processed fruits not only avoid market glut and post-harvest losses but also give higher income and taste of fruits and vegetables during off season. This will help to strengthen business, reduce your risk, and support local farmers.

Table 1. Cost of product, net profit and B: C ratio of preparation of bael beverages

Products	Juice	Squash	Syrup
Fruit pulp	1 kg	1 kg	1 kg
Fruit price (Rs.)	34 (15% more for to remove peal)	34	34
Sugar + preservative + citric acid + cooking charge (Rs.) + packaging	27	107	121
Input cost (Rs.)	61	141	155
Product quantity (ml)	2400	2100	1500
Product rate/ litre (Rs.)	100	142	214
Gross income (Rs.)	240	298	321
Net profit (Rs.)	180	157	166
B: C ratio	3.93	2.11	2.07

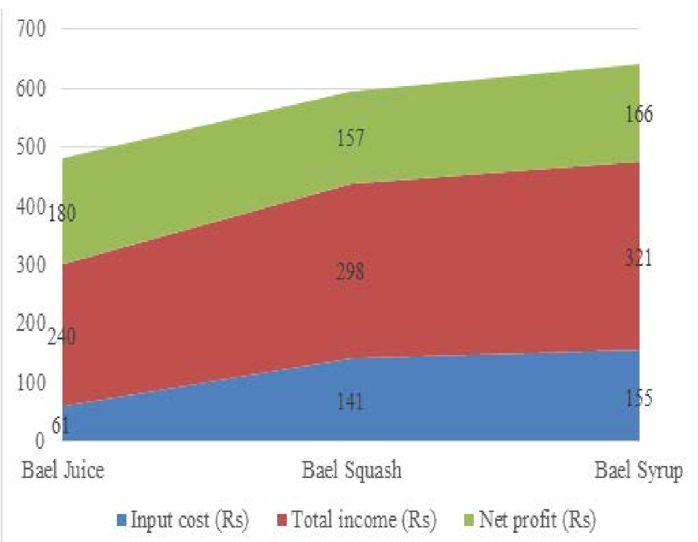


Fig. 1. Net profit (INR) from value added products of bael

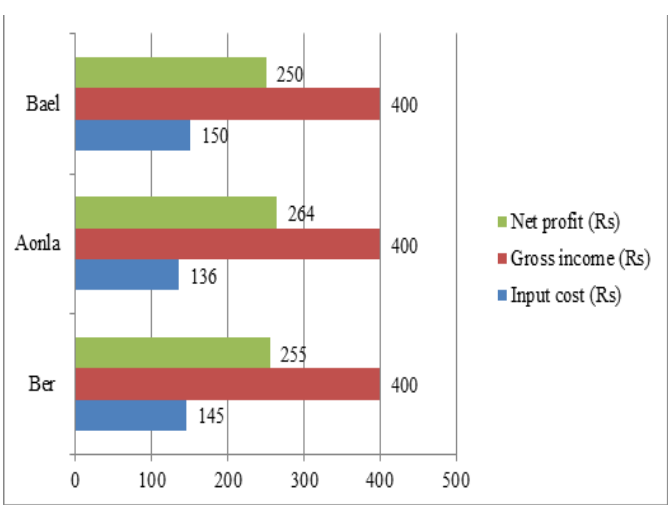


Fig. 2. Net profit from *murabba* of different fruits

Table 2. Cost of product, net profit and B: C ratio of ber, aonla and bael *murabba*/ preserves

Products	Ber	Aonla	Bael
Fresh Fruit	1 kg	1 kg	1 kg
Fruit price (Rs.)	20	20	34
Sugar + citric acid + cooking charge + packaging (Rs.)	125	116	116
Input cost (Rs.)	145	136	150
Product quantity (ml)	2.0	2.0	2.0
Product rate/ kg (Rs.)	200	200	200
Gross income (Rs.)	400	400	400
Net profit (Rs.)	255	264	250
B:C ratio	2.76	2.94	2.67

Conclusion

It is concluded from the study that the processed value-added preserves of arid fruits had 11.25, 11.25 and 6.67 times more value whereas beverages of juice, syrup and squash get 5.29, 4.62 and 4.88 times more value, respectively as compared to fresh fruits. At the same time the processed fruits may be kept for longer period or atleast 6 months however, fresh fruit can be kept only for 5 to 10 days.

Acknowledgements

The authors acknowledge CCS HAU, Hisar and ICAR-CIAH Bikaner for guidance and financial support. Authors are also thankful to the persons who helped directly or indirectly in research work and preparation of manuscript.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Acharya, S.S. 2007. India's current agrarian distress intensity and cause. NAAS News, July-Sept., 2007. P. 7.

Anonymous. 2017. Working Paper No. 61. International trade in processed foods: An Indian perspective. Export-Import Bank of India.

Anonymous. 2019. Indian food processing sector: trends and opportunities. August 2019.

Anonymous. 2020. https://economictimes.indiatimes.com/news/economy/agriculture/indiain curs-rs-2-trillion/year-post-harvest-loss-of-fruits-veggies/articleshow /22204097.cms? utm source =content of interest & utmmedium=text & utmcampaign=cppst

Baloda, S., Sharma, J.R., Kumar, M., Singh, S. and Malik, A. 2018. Studies on performance of rejuvenated plants and fresh plants of guava cv. Hisar Safeda. *International Journal of Pure & Applied Biosciences,* 6(1): 939-941.

Kumar, M., Godara, R.K., Singh, D. and Pathak, D.V. 2015. Effect of different preservatives on the storage of ber pulp. *International Journal of Farm Sciences*, 5(4): 222-228.

Kumar, M., Nibhoria, A., Pooja. and Buswal, M. 2021. Standardization of juice concentration for preparation of phalsa nectar and changes during. *Indian Journal of Arid Horticulture,* 34(1&2): 25-28.

Kumar, M., Singh, D. and Godara, R.K. 2009. Effect of different pulp concentrations and their treatments on storage of nectar. *Beverage & Food World*, 36(2): 52-56.

Kumar, M., Singh, D., Godara, R.K.; Singh, S., Sandooja, J.K and Mehla, C.P. 2009a.Studies on the suitability of dried ber fruits for preparation of RTS beverage. *Haryana Journal of Horticultural Sciences*, 38(3&4): 216-219.

Kumar, M., Singh, D., Singh, S., Godara, R.K. and Mehla, C.P. 2009b. Studies on qualitative changes in SO_2 treated ber powder during storage. *Haryana Journal of Horticultural Sciences*, 38(3&4): 237-38.

Kumar, M., Singh, S. and Yadav, V.K. 2013. Arid fruits: post-harvest handling and processing.In: Emerging Science and technology for food, agriculture and environment. Eds. Kumar S, Yadav PK and Kumar S). Published by Agrobios (International). Pp. 435-448.

Kumar, M., Singh, S., Pathak, D.V. and Godara, R.K. 2016. Impact of natural ripening on physico-chemical characteristics of ber fruits. *AgricInternational*, 3(2): 12-18.

Kumar, M., Yadav, B.S. and Yadav, V.P.S. 2020. Effect of pulp concentration on physicochemical and organoleptic changes in RTS and juice during storage. *Indian Research Journal of Extension Education*, 20 (1): 48-50.

Kumar, M., Singh, S., Godara, R.K., Singh, D. and Pathak, D.V. 2017. Effect of pre-drying treatments, drying methods and storage of dehydrated mature and ripe ber fruits cv. Kaithali and Umran on non-enzymatic browning. *Journal of Agricultural Technologies,* 4(2): 23-30.

Nagar, S., Kumar, M., Kumatkar, R.B., Sharma, J.R. and Singh, S. 2017. Evaluation of bael (*Aegle marmelos* Corr.) germplasm for seed and qualitative characters under semi-arid conditions of Haryana. *International Journal of Pure & Applied Biosciences,* 5(3): 436-442.

Nagar, S., Kumar, M., Sharma, J.R., Baloda, S. and Godara, R.K. 2018. Bael germplasm evaluation for leaf and fruit pulp variability under south Haryana conditions. *International Journal of Pure & Applied Biosciences,* 6(1): 959-964.

Pal, P.K., Bhattacharya, D.K. and Ghosh, S. 1993. Chemical examination of the seed of *Aegle marmelos* (bael fruit) and its medicinal importance. *Journal of Oil Technologist Association of India,* 25(3): 55-59.

Raju, B., Krishna, H.C. and Chikkasubbanna, V. 2014. Assessment of stability of bael fruits (*Aegle marmelos* Corr) for processing quality. *International Journal of Science and Nature*, 5(2): 359-361.

Singh, S., Kumar, M., Saini, R.S. and Kumar, P. 2016. Studies on recipes of bael (*Aegle marmelos* Corr) beverages and their storage. *AgricINTERNATIONAL,* 3(3): 25-30.

Singh, S., Kumar, M., Sharma, J.R. and Baloda, S. 2017. Performance of aonla cultivars for growth and physicochemical attributes under semi-arid conditions. *Journal of Agricultural Technologies,* 4(1): 20-22.

Srivastava R. P. and Kumar S. 2017. Fruit and Vegetable Preservation: Principals and Practices. CBS Publishers and Distributors Pvt. Ltd.

Research Article

ISAH Indian Journal of Arid Horticulture
Year 2025, Volume-7, Issue-1 (January - June)

Standardizing propagation methods and timing in bael (*Aegle marmelos* L.) under semi-arid conditions of Uttar Pradesh

Vijay Kumar Maurya[1], Om Prakash[2], Subhash Chandra Singh[3], Vaishali Gangwar[4] and Paramanand Prajapati[5]

[1] M.Sc. Research. Scholar, Deptt. of Fruit Science, CoH, Banda University of Agriculture and Technology (BUA&T), Banda, U.P.
[2]Assistant Professor, Deptt. of Fruit Science, CoH (BUA&T), Banda, U.P.
[3]Associate Professor, Deptt. of Fruit Science, CoH (BUA&T), Banda, U.P.
[4]Assistant Professor, Deptt. of Plant Physiology, CoA (BUA&T), Banda, U.P.
[5]Ph.D. Scholar, Deptt. of Fruit Science, CoH (BUA&T), Banda, U.P.

ARTICLE INFO

Received: 04 March 2025
Accepted: 24 March 2025

Keywords: Bael, propagation, softwood grafting, chip budding, patch budding

doi:10.48165/ijah.2025.7.1.14

ABSTRACT

The study aimed to standardize the most suitable propagation method (budding and grafting) and optimal timing to achieve maximum success rates in bael under the semi-arid conditions of Uttar Pradesh, India. The findings revealed that the minimum number of days to bud sprouting (15.71 days) was observed with softwood grafting conducted on 15th April. This method and timing also resulted in the highest sprouting success rate (83.33%) and the greatest bud and graft success rate (56.67%). Furthermore, the highest survival percentage of grafted plants was recorded with softwood grafting on the same date. From this study, softwood grafting during the month of April is recommended for the successful propagation of bael in semi-arid regions of Uttar Pradesh.

Introduction

Bael (*Aegle marmelos* L.), a member of the Rutaceae family, is one of the most significant native fruit plants, known for its various therapeutic applications. It is referred to by several names, including Bengal quince, Bilva, Vilvam, and Bilpatre, and is valued for its medicinal, nutritional, and spiritual properties, as mentioned in religious scriptures. In India's tropical and subtropical climates, bael is naturally cultivated in mixed dry deciduous forests from seed. Bael seed contains 40.25% oil (Roy and Singh, 1979). The bael seed is viviparous (Singh *et al.*, 2019) and also recalcitrant in nature. Since bael is primarily propagated by seed, there is significant variability within its population. However, vegetative propagation ensures the multiplication of selected superior quality clones for commercial cultivation and conservation.

In-situ cultivation is beneficial for raising better plant stands with earlier bearing compared to nursery-raised planting material. Some information is available on the optimal time required for *in-situ* propagation of bael (Ghosh *et al.*, 2012). Chip budding is one of the primary grafting methods used for the asexual propagation of woody plants. It is the only budding system that can be performed on rootstocks with either active or dormant vascular cambium.

Bael was previously propagated by air layering (Misra, 1992; Mukherjee *et al.*, 1986), budding (Kumar *et al.*, 1994; Moti *et al.*, 1976), and grafting (Fairchild, 1930; Maiti *et al.*, 1999), with varying degrees of success. Propagation of bael through patch budding, chip budding, and softwood grafting has been reported with different success rates in various agro-climatic

Corresponding author's Email: opji.2007@rediffmail.com (Dr. Om Prakash)

regions. Among the different methods of propagation, vegetative means have proven to be the most effective technique for maintaining genetic purity and uniformity in grafts. The success of budding and grafting varies depending on the duration of the operation, the methods used, and the agro-climatic conditions (Kumar *et al*., 1994). These methods are employed to multiply plants identical to the desired parent trees, ensuring that the best-quality plants are propagated on rootstocks suitable for the region. Therefore, this study aims to standardize propagation methods and timings for nursery and field planting in bael, with a focus on the Bundelkhand region.

Material and Methods

The investigation was conducted at the main experimental nursery of the Department of Fruit Science, College of Horticulture, Banda University of Agriculture and Technology, Banda (U.P.) in 2023. The climate at the site is primarily subtropical, with long and hot summers. The average rainfall during the experiment was 77.5 cm, with 94% of it occurring between June and September. The average maximum and minimum temperatures from April to December were 33.98°C and 24.78°C, respectively, and the average relative humidity was 78.59%. The 12 to 18 months old rootstocks having 5-6 mm diameter were planted in polythene bags filled with a soil and farmyard manure mix (2:1). The rootstocks were raised from seeds for vegetative propagation. The propagation was performed on healthy and pests and diseases free rootstocks. The scion buds were collected from a healthy mother plant.

The experiment was designed using a completely randomized design with two factors: propagation methods (chip budding, patch budding, and softwood grafting) and propagation time (15th April, 15th May, 15th June, 15th July, 15th August and 15th September). A total of 18 treatments were used, each replicated three times, with 10 plants per replication. The experiment was carried out under shaded net house conditions. Observations on time taken for sprouting of bud and graft were recorded ten days after budding and grafting of the plants. The recorded data were subjected to statistical analysis and per Fisher (1925).

Results and Discussion

Sprouting in budding and grafting

The data presented in Table 1 and Fig. 1 clearly illustrate the influence of timing, method of propagation and duration required for bud sprouting. The results revealed that softwood grafted plants sprouted the earliest, requiring only 20.92 days, followed by chip-budded plants at 24.01 days, and patch-budded plants at 26.88 days. The timing of propagation also significantly affected the sprouting time. The shortest sprouting time was recorded for the 15th April propagation (18.22 days), which was significantly less than that observed on the 15th May (20.06 days) and other dates. The longest sprouting time occurred with propagation on the 15th July (29.70 days).

The interaction between propagation time and method also influenced the bud sprouting time. The quickest sprouting (15.71 days) was observed with softwood grafting on 15th April, followed by 17.45 days on 15th May, and 18.29 days with chip budding on 15th April. The minimum sprouting time for bael was reported to be 21.65 days with patch budding by Tripathi *et al.* (2004), and 23.8 days for softwood grafting in wood apple, as noted by Raghavendra *et al.* (2009).

Table 1. Effect of time on the number of days taken for bud sprouting in budding and grafting

Time (D)	Softwood grafting (M_1)	Patch budding (M_2)	Chip budding (M_3)	Mean (Time)
15th April (D_1)	15.71	20.65	18.29	18.22
15th May (D_2)	17.45	22.54	20.18	20.06
15th June (D_3)	19.32	26.35	22.46	22.71
15th July (D_4)	27.23	31.89	29.98	29.70
15th August (D_5)	21.63	28.91	25.14	25.23
15th September (D_6)	24.20	30.96	28.00	27.72
Mean (Method)	20.92	26.88	24.01	
		SEm±	CD at 5%	
Method (M)		0.12	0.35	
Time (D)		0.17	0.49	
M x D		0.30	0.85	

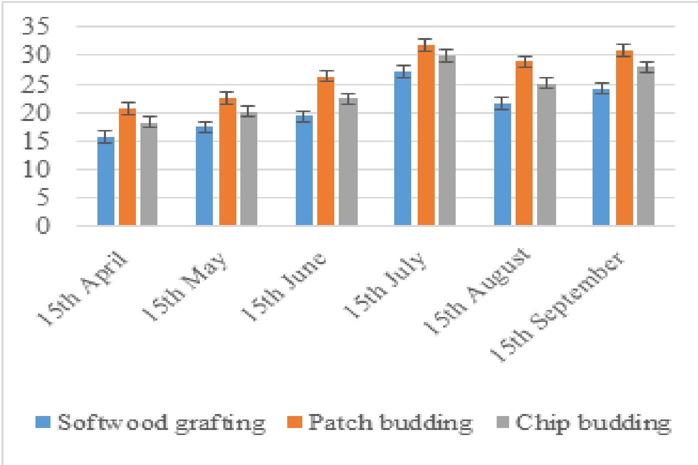


Fig. 1. Days taken to bud sprouting

Sprout percentage

A view of Table 2 and Fig. 2 indicates that the method of propagation significantly affected the bud sprout percentage. The highest sprouting rate (60.0%) was observed with softwood grafting, followed by chip budding (47.77%) and patch budding (42.22%). Regarding the timing of propagation, the 15th April was found to be the most effective, with a sprout percentage of 72.22%, followed by 15th May (64.44%), 15th June (54.44%), 15th September (53.55%), 15th August (46.66%), and 15th July (26.66%).

Although the interaction between the method and timing was not statistically significant, the highest sprouting rate (83.33%) was recorded with softwood grafting on 15th April, while the lowest (20.0%) was observed with patch budding on 15th July. In this study, the comparatively higher percentage of scion sprouting in softwood grafting may be due to the more secure attachment of the stock and scion, while in patch and chip budding, the scion is not as firmly attached to the rootstock. Additionally, climatic factors may have adversely affected bud attachment and sprouting. Similar results were reported by Syamal *et al.* (2013), who found that patch budding in bael resulted in a maximum graft sprout percentage of 72.5%. Singh and Singh (2009) also observed a higher sprouting rate (95.16%) with patch budding compared to modified ring budding.

Table 2. Effect of time on sprout percentage in softwood grafting, patch budding and chip budding

Time (D)	Softwood grafting (M_1)	Patch budding (M_2)	Chip budding (M_3)	Mean (Time)
15th April (D_1)	83.33	63.33	70.00	72.22
15th May (D_2)	73.33	56.67	63.33	64.44
15th June (D_3)	63.67	46.67	53.33	54.44
15th July (D_4)	36.67	20.00	23.33	26.66
15th August (D_5)	56.67	40.00	44.33	46.66
15th September (D_6)	46.67	26.67	33.33	53.55
Mean (Method)	60.00	42.22	47.77	
		SEm±		CD at 5%
Method (M)		1.757		5.059
Time (D)		2.485		7.155
M x D		4.303		NS

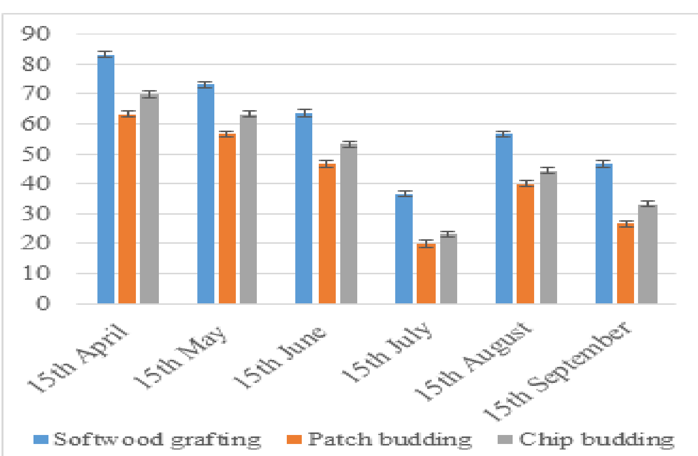


Fig. 2. Sprout % in softwood grafting, patch budding and chip budding

Budding and grafting success rate

Observations on the bud sprouting percentage of budded plants are presented in Table 3 and Fig. 3. The data indicate that the sprouting of buds was significantly influenced by the method of propagation. Softwood grafting resulted in the highest sprouting percentage (37.22%), followed by chip budding (18.89%) and patch budding (17.78%). Only the results from patch budding were on par with chip budding. The best sprouting success is typically achieved in early spring, just as the rootstock buds are beginning to swell, but before active growth has started, and callus formation occurs before the buds begin to lead out. If performed later, the leaf surface may lack sufficient moisture, leading to desiccation and death (Hartmann *et al.*, 2002).

The timing of propagation also had a significant impact on success rate of budding and grafting. The maximum success rate was observed on 15th April (37.77%), followed by 15th May and 15th June (32.22%), 15th August (23.33%), and 15th September (20.0%). The lowest success rate was recorded on 15th July (11.11%). Similar to the sprouting percentage, the interaction between propagation method and timing was not statistically significant. However, the highest success rate for budding and grafting (56.67%) was recorded with softwood grafting on 15th April, while the lowest success rate (10.0%) was observed with both chip budding and patch budding on 15th July. Singh *et al.* (2016) reported a 95% success rate with *in-situ* patch budding using one-month-old scions of bael in western India, while softwood grafting yielded more than 85% success.

Table 3. Effect of time and methods on the success percentage of budding and grafting in bael

Time (D)	Softwood grafting (M_1)	Patch budding (M_2)	Chip budding (M_3)	Mean (Time)
15th April (D_1)	56.67	26.66	30.00	37.77
15th May (D_2)	50.00	23.33	23.33	32.22
15th June (D_3)	40.00	16.67	13.33	23.33
15th July (D_4)	13.33	10.00	10.00	11.11
15th August (D_5)	33.33	16.67	20.00	23.33
15th September (D_6)	30.00	13.33	16.68	20.00
Mean (Method)	37.22	17.78	18.89	
		SEm±		CD at 5%
Method (M)		1.98		5.69
Time (D)		2.80		8.05
M x D		4.84		NS

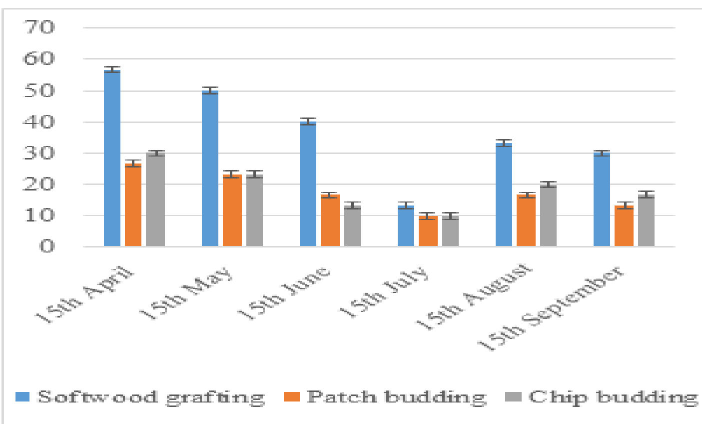


Fig. 3. Success percentage of budding and grafting in bael

Survival percentage of budded and grafted plants

The data on the survival percentage of plants propagated through softwood grafting, patch budding, and chip budding at different times are analyzed and presented in Table 4 and Fig. 4. Statistically, the method of propagation significantly influenced the survival percentage of plants. The highest survival percentage was observed with softwood grafting (35.0%), followed by chip budding (18.33%), while the lowest survival percentage was recorded with patch budding (14.44%). Propagation method and timing both had a statistically significant effect on survival rates. The highest survival percentage was recorded on April 15th (35.56%), followed by May 15th (30.0%) and June 15th (23.33%). The lowest survival percentage (7.78%) was observed on July 15th. The interaction between propagation method and timing also showed a significant effect. The highest survival percentage (53.33%) was achieved with softwood grafting conducted on April 15th, whereas the lowest survival percentage (3.33%) was recorded with chip budding on July 15th. This variation may be attributed to the use of healthy and mature bud sticks combined with favourable humid climatic conditions. Similar findings were reported by Rahman *et al.* (2011) in bael, where grafting resulted in a plant survival percentage of 56.11%.

Table 4. Effect of time and methods on survival percentage of budded and grafted plants after 90 days

Time (D)	Softwood grafting (M_1)	Patch budding (M_2)	Chip budding (M_3)	Mean (Time)
15th April (D_1)	53.33	23.33	30.00	35.56
15th May (D_2)	46.67	20.00	23.33	30.00
15th June (D_3)	40.00	16.67	13.33	23.33
15th July (D_4)	13.33	3.33	6.67	7.78

15th August (D_5)	30.00	13.33	20.00	21.11
15th September (D_6)	26.67	10.00	16.67	17.78
Mean (Method)	35.00	14.44	18.33	
		SEm±		CD at 5%
Method (M)		2.222		6.40
Time (D)		3.143		9.05
M x D		5.443		N.S.

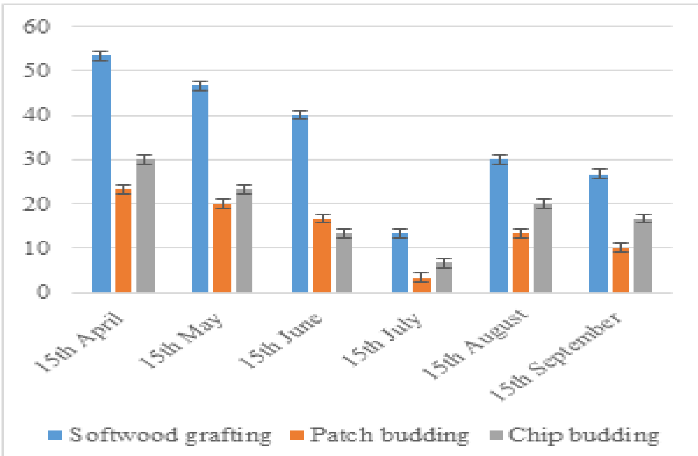


Fig. 4. Survival percentage of budded and grafted plants after 90 days

Conclusion

Based on the results of the research, it can be concluded that softwood grafting under shade net house conditions is the most effective propagation method for bael. This conclusion is supported by positive outcomes across various plant growth parameters, including days taken for bud sprouting, sprouting percentage, budding and grafting success percentage and survival percentage of the plants. Among the propagation months, April showed the best performance, followed by May, June, August, September, and July. Therefore, softwood grafting in April month is recommended for farmers, researchers, and nursery growers, particularly under the semi-arid conditions of the Banda district in Uttar Pradesh.

Acknowledgements

The authors are grateful to the Dean, College of Horticulture, Banda University of Agriculture and Technology, Banda, for the providing the essential facilities that enabled the execution of this experiment.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

References

Farchild, D. 1930. In defense of bael fruit (*Aegle marmelos* L.). In: Proceedings of the Plant, Statistic, and Horticultural Society, 165-171.

Fisher, R.A. 1925. Statistical Methods for Research Workers. Oliver and Boyd, Edinburgh, Scotland.

Ghosh, S. N., Roy, S. and Bera, B. 2012. Studies on propagation of bael (*Aegle marmelos* L.) under Jhargram conditions. *Journal of Horticultural Sciences, 7(2): 214-216.*

Hartmann, H.T., Kester, D.E., Davies, F.T. and Geneve, R.L. 2002. Hartmann and Kester's plant propagation: Principles and practices. 8th ed. Prentice Hall, Upper Saddle River, New Jersey, USA.

Kumar, D., Pathak, R.K. and Ali, W. 1994. Studies on effect of duration and method of budding in bael. *Indian Journal of Horticulture,* 51(2): 150-153.

Maiti, C.S., Nath, A. and Sen, S.K. 1999. Studies on the propagation of Bael (*Aegle marmelos* Correa.) by different grafting methods in West Bengal. *Journal of Applied Horticulture,* 1(2): 131-132.

Misra, K.K. 1992. Effect of growth regulators on rooting and root characteristics of air layers of bael. *Annals of Agricultural Research,* 13(3): 284-286.

Moti Dhar, L. and Chaturvedi, O.P. 1976. Propagation of some tropical and sub- tropical fruit by budding. *The Punjab Horticultural Journal,* 16: 33-38.

Mukharajee, S.K., Rao, D.P., Chakladhar, B.P. and Chatterjee, B.K. 1986. Effect on growth regulators, in vigoration and etiolation on rooting of air layers of bael (*Aegle marmelos* Correa). *Indian Journal of Horticulture,* 43(1-2): 9-12.

Patel, R. K., Babu, K. D. and Yadav, A. S. 2010. Softwood grafting in mandarin - A novel vegetative propagation technique. *International Journal of Fruit Science,* 10(1): 54-64.

Rahman, H., Akter, A., Rahman, M.A., Sarker, B.C. and Haque, M.A. 2011. Effect of grafting method and scion selection on the graft performance of bael. *Journal of the Bangladesh Society for Agricultural Science and Technology*, 8: 179-184.

Rghavendra, V.N., Angadi, S.G., Mokashi, A.N., Allolli, T.B., Venugopal, C.K. and Mummigatti, U.V. 2009. Studies on softwood grafting in wood apple (*Feronia limonia* L.). *Acta Horticulturae,* 890.

Roy, S. K. and Singh, R.N. 1979. Studies on utilization of bael fruit (*Aegle marmelos* Correa.) for processing II. Extraction of bael fruit pulp. *Indian Food Packer*, 33(1): 5-9.

Seletsu, S., Paul, P.K. and Thangjam, K. 2011. Effect of time and species on bud union and survivability in citrus under Allahabad condition. *Journal of Crop and Weed*, 7(1): 89-93.

Singh, A.K., Singh, S., Saroj, P. L., Hare Krishna, Singh, R.S. and Singh, R. K. 2019. Research status of bael (*Aegle marmelos* L.) in India: A review. *Indian Journal of Agricultural Sciences*, 89(10):1563-71.

Singh, A.K.; Singh, S.; Singh, R.S. and Sharma, B.D. 2016. Thar Neelkanth: a new bael variety. *Indian Horticulture,* 1:8-10.

Singh, J. K. and Singh, H. K. 2009. Studies on propagation of bael (*Aegle marmelos* Correa). *Asian Journal of Horticulture*, 4: 164-166.

Syamal, M. M., Maurya, V. K. and Joshi Mamta 2013. Effect of methods and time of propagation in Bael under different growing conditions, *Indian Journal of Horticulture,* 70(1):127-129.

Tripathi, A. and Kumar, R. 2004. Studies on the effect of method and time of budding in bael (*Aegle marmelos* L.). *Haryana Journal of Horticultural Sciences*, 33(3&4): 195-198.