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Review Article

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Floral biology, pollination behaviour and pollinators in bael (*Aegle marmelos*) in rainfed semi-arid conditions - A review

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ABSTRACT

Bael a cross-pollinated fruit crop, relies heavily on effective pollinizers to enhance fruit set, yield, and quality, particularly in commercial cultivars and self-incompatible varieties. Pollinizers play a pivotal role in supporting reproductive success by providing abundant, viable, and compatible pollen that synchronizes with the flowering period of commercial varieties. This synchrony not only ensures successful pollination but also enables pollen storage for future use. The phenomenon of herkogamy further facilitates cross-pollination in bael, emphasizing the need for optimal pollinizer arrangements in orchards. Despite their importance, the role of pollinizers is often underestimated by fruit growers due to limited awareness and insufficient scientific information. This review consolidates existing knowledge on pollination biology, the ecological role of pollinizers, and the management practices required to optimize pollinator services in bael cultivation, particularly in rainfed semi-arid conditions. By addressing critical knowledge gaps, this study underscores the necessity of maintaining recommended pollinizer ratios and highlights strategies for enhancing pollination efficiency to achieve sustainable productivity in bael orchards.

Introduction

Bael (*Aegle marmelos*), a subtropical tree belonging to the Rutaceae family, is an integral part of Indian culture and agriculture. Commonly referred to as bilva, golden apple, Bengal quince, and Maredu, this species holds deep religious significance in Hindu traditions, where it is often called the "tree of Shiva" (*Shivaduma*) (Neeraj *et al.*, 2017). Its trifoliate leaves are symbolic in Hindu philosophy, representing sacred triads such as the Trimurtis (Brahma, Vishnu, Shiva) and the three Gunas (Satva, Rajo, Tamo). Bael demonstrates remarkable ecological adaptability, thriving in drought-prone regions, nutrient-deficient soils, and saline or sodic conditions. It also shows resilience to various pests, diseases, and climatic extremes, making it a crucial species for semi-arid and rainfed ecosystems. The tree flourishes in dry forests and semi-arid plains at elevations of up to 1200 m above sea level and can withstand both arid environments and high rainfall, underscoring its potential as a sustainable crop for challenging agricultural landscapes (Bobade *et al.*, 2020; Singh *et al.*, 2021). Bael (*Aegle marmelos*), a versatile subtropical tree, is renowned for its ability to thrive under extreme and varied conditions. It grows robustly and bears fruit even on challenging soils, such as the limestone soils of southern Florida and swampy, alkaline, or stony soils with a

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pH range of 5 to 10 (Singh *et al.*, 2019e). The tree requires a distinct dry season for fruit production, showcasing its resilience in environments unsuitable for other fruit crops. Beyond its adaptability, bael contributes significantly to environmental health by acting as a natural air purifier, releasing higher oxygen levels than many other tree species (Mali *et al.*, 2020).

Bael holds immense medicinal value, with nearly every part of the tree-roots, flowers, leaves, fruits, and bark-utilized in traditional herbal medicine systems, including Siddha (Rajasekaran *et al.*, 2009). Indian medicinal plants, including bael, are recognized as rich reservoirs of pharmacologically active compounds widely used to treat various ailments (Tiwari *et al.*, 2018). Moreover, through advanced post-harvest technologies, bael fruits are transformed into diverse value-added products such as toffees, jams, ice creams, candies, and juices. These innovations minimize post-harvest losses and enhance shelf life and market value, providing a sustainable source of income for farmers (Singh *et al.*, 2019e).This combination of ecological resilience, medicinal significance, and economic potential underscores bael's vital role in sustainable agriculture, health, and livelihoods.

Approximately 80% of cultivated crops worldwide rely on cross-pollination for the production of fruits, seeds, and vegetables. This critical process not only enhances crop yield and quality but also reduces the time between flowering and fruit setting, while protecting developing fruits from pests, diseases, and agro-chemicals. The present study examines pollinator abundance and pollination dynamics in bael (*Aegle marmelos*), a predominantly cross-pollinated crop where only 5% of flowers are self-pollinated, and 95% depend on cross-pollination. Bael flowers are entomophilous, with pollination primarily facilitated by insect pollinators, including honey bees (*Apis dorsata*, *Apis mellifera*), hoverflies, yellow wasps, beetles, weevils, carpenter bees, black ants, and butterflies. Among these, bees are recognized as the most efficient and legitimate pollinators, while other organisms contribute incidentally by feeding on nectar and transferring pollen between flowers (Satapathy and Chandra, 2017).Pollinizers and pollinators play a pivotal role in various floral biological activities of bael, such as pollination, fruit set, fruit retention, quality, shelf life, and harvesting period. These activities are directly or indirectly influenced by the interaction of pollinators, pollinizers, and environmental factors, which collectively determine the yield and quality of the crop (Saroj *et al.*, 2021). Like many other cross-pollinated horticultural crops in semi-arid regions, bael requires effective pollinizers (pollen sources) to achieve commercially viable fruit production and high-quality yields.

Characteristics of ideal pollinizer variety

Not all male plants that produce pollen qualify as effective pollinizers. For a pollinizer variety to be considered ideal, it must meet specific criteria:

Flowering Synchrony: The flowering period of the pollinizer must align with that of the commercial variety, with an extended bloom period to ensure maximum overlap.

Pollen Viability and Compatibility: It should produce an abundant quantity of viable pollen grains that are compatible with the commercial variety, maintaining consistent pollen production throughout the flowering period.

Presence of Pollinators: The orchard should support an active population of bees and other insect pollinators during the bloom period to facilitate effective pollen transfer.

Proximity: The pollinizer trees must be strategically placed in proximity to the commercial variety to maximize pollination efficiency.

Pollen Storage: The pollen from the pollinizer should be suitable for storage, allowing its use for future pollination of specific flowers.

Marketable Yield: The pollinizer variety should also produce fruit of marketable quality, adding value to its inclusion in the orchard.

These characteristics ensure that the pollinizer contributes effectively to fruit set, yield, and quality, supporting the commercial success of cross-pollinated crop systems.

Essential Conditions for Effective Pollinizers in Orchard Development

The effectiveness of a pollinizer in ensuring successful orchard development depends on fulfilling specific conditions. These include synchrony in flowering with the main crop variety, production of viable and compatible pollen, strategic placement within the orchard, and the presence of active pollinators during the bloom period. Adherence to these conditions is crucial for optimizing fruit set, yield, and overall orchard productivity.

Role of Pollinizers in Self-Incompatible Cultivars: For self-incompatible cultivars or species, pollen is typically sourced from closely related, compatible species to facilitate fruit production. In such cases, the presence of effective pollinizers plays a critical role in significantly enhancing yield.

Impact on Pollination and Fertilization: Pollinizers improve the efficiency of the pollination and fertilization processes, leading to increased yields with larger, well-formed, and higher-quality fruits.

Contribution to Yield: By increasing the number of fruits per tree, pollinizers contribute directly to higher overall yields in orchards.

Genotypic Influence on Fruit Quality: Research highlights that fruit size, shape, and quality attributes are directly influenced by the genotype of the pollen, underscoring the importance of effective pollination in achieving superior fruit characteristics.

Economic Benefits of Pollinizers: Pollinizer varieties consistently produce high-value commercial crops, offering growers a reliable source of income year after year.

Pollinizers in Hybridization Programs: Hybridization, involving cross-pollination between flowers of different species or various breeding lines and genotypes, requires a dependable donor pollinizer. This is essential for the success of breeding programs aimed at varietal improvement.

Floral biology: Anthesis and Dehiscence time

Bud Emergence Across Varieties: Bud emergence in bael (*Aegle marmelos*) varieties initiates at different times, extending overall from April to late July (Singh *et al.*, 2006a). This variability underscores the genetic diversity among cultivars.

Extended Flowering Period and Pollinator Stability: Varieties with prolonged flowering periods serve as long-term floral resources, while the flowering patterns and phenology of different cultivars significantly influence ep roductive success and help sustain stable pollinator populations (Singh *et al.*, 2010b; Singh *et al.*, 2016b).

Petal in Genotypes: Variations in petal morphology, including an abnormal number of petals, are commonly observed across nearly all bael genotypes, reflecting underlying genetic or environmental influences. Usually 4 to five petals are common in almost all genotypess, sometimes abnormal petals may be seen in very few genotypes (Singh *et al.*, 2018a; Singh *et al.*, 2019b).

Anthesis and Anther Dehiscence Timing: Anthesis in bael begins at 6:00 AM and continues until 2:00 PM, with peak flower opening occurring between 8:00 and 12:00 PM. Observations reveal that anthesis and anther dehiscence occur early in the morning (5:30-8:30 AM) under conditions of low temperature and high humidity (Singh *et al.*, 2019b).

Flower Opening Dynamics: During anthesis, flowers exhibit variations in petal opening patterns. Some flowers open all petals simultaneously, while others open sequentially, taking 45-60 minutes to fully open. The duration of this process can vary among flowers within the same genotype, highlighting phenotypic diversity (Singh *et al.*, 2019a).

Post-Anthesis Changes in Floral Organs: Within 30 minutes of anthesis, the anthers and floral organs began to shrink and gradually turned brick red, a process that progressed as dehiscence occurred (Singh *et al.*, 2011b; Singh *et al.*, 2016i).

Bud Opening Patterns in Inflorescences: The sequence of bud opening within the inflorescence varied among varieties. In most cases, buds located on the lower side of the inflorescence opened earlier than centrally positioned buds. However, some varieties exhibited a reversed pattern, with central buds opening before lateral buds (Singh *et al.*, 2011c; Singh *et al.*, 2014d).

Synchrony of Anthesis and Anther Dehiscence: Anther dehiscence occurred in precise synchrony with anthesis, with all anthers within a flower dehiscing simultaneously and releasing pollen in cohesive masses.

Mechanism of Anther Dehiscence: The dehiscence process involved longitudinal slits that initiated near the basal end of the anther lobe and extended toward the apex, facilitating efficient pollen release.

Pollen viability and stigma receptivity

Pollen Viability in Newly Opened Flowers: In all varieties of bael (*Aegle marmelos*), newly opened flowers exhibited high pollen viability, consistently exceeding 95%.

Stigmatic Receptivity and Anthesis: The stigma, initially non-receptive during the bud stage, became receptive immediately upon flower opening. Stigmatic receptivity coincided with anthesis and anther dehiscence and persisted for approximately 48 hours.

Variation in Stigma Receptivity Across Varieties: The highest stigma receptivity was recorded on the day of anthesis, ranging from 45.27% to 68.53% across all varieties. Among these, the maximum receptivity was observed in the Pant Urvashi variety, followed by Goma Yashi, with NB-7 showing the lowest values.

Temporal Dynamics of Stigma Receptivity: Receptivity was significantly lower on the day before anthesis (7.95% to 15.52%) and the day after (3.62% to 14.37%), highlighting the critical window for effective pollination during peak receptivity on the day of anthesis (Singh *et al.*, 2014a; Singh *et al.*, 2019b).

Inflorescence morphology

Floral morphology

Bisexual flowers in bael (*Aegle marmelos*) are borne in clusters, appearing as greenish-white axillary or terminal cymes.

Calyx Structure: The calyx is shallow and comprises 4 or 5 short sepals, which are either tetramerous or pentamerous, featuring broad teeth and a pubescent exterior.

Petal Characteristics: The petals are oblong-oval, typically numbering 4 or 5, with occasional occurrences of 6 or 7. They are pale greenish-white in color.

Stamen Features: The stamens are numerous and hypogynous, characterized by short filaments.

Variations in Floral Phenology: Key floral traits such as bud emergence, flowering duration, anthesis timing, anther dehiscence, stigma receptivity, and pollen viability exhibit significant variability across different varieties and locations (Singh *et al.*, 2011; Singh *et al.*, 2014a).

Evaluation of Floral Organ Dimensions:

The size and shape of floral organs, including bud size, flower size, and petal size, were assessed for multiple bael varieties under the rainfed conditions of the semi-arid ecosystem at CHES, Godhra (Singh *et al.*, 2016).

Variability in Floral Organ Dimensions: Significant variation was observed in the dimensions of floral organs across bael (*Aegle marmelos*) varieties. Measurements ranged as follows: bud length (10.00–13.5 mm), bud width (7.25–9.80 mm), flower length (12.25–19.5 mm), flower width (22.00–35.75 mm), pedicel length (4.25–10.75 mm), pedicel width (2.00–2.75 mm), petal length (11.50–19.25 mm), petal width (7.25–10.50 mm), stamen length (6.25–9.50 mm), filament length (2.75–5.50 mm), filament width (0.45–0.85 mm), anther length (3.25–4.75 mm), anther width (0.50–0.75 mm), pollen diameter (41.25–45.50 microns), ovary length (4.25–8.50 mm), ovary diameter (2.25–5.25 mm), style length (1.00–1.75 mm), style width (1.50–2.75 mm), stigma length (2.25–3.50 mm), and stigma width (2.25–3.00 mm).

Bud Dimensions: The maximum bud length and width were recorded in NB 17 and CISH-B 2, respectively. The shortest bud length was observed in Pant Aparna, followed by NB 9 and NB 16. The smallest bud width was found in CISH-B 1, followed by Pant Shivani and Pant Sujata (Singh *et al.*, 2014).

Flower Size: Flower size, measured in terms of length and width, was largest in CISH-B 2 and NB 7, respectively. The smallest flower dimensions were noted in Goma Yashi, followed by NB 9 and NB 16 (Singh *et al.*, 2014).

Pedicel Dimensions: Maximum pedicel length and width were observed in NB 5, followed by Pant Aparna and Pant Sujata. The shortest pedicel length and width were recorded in NB 9 and NB 16 under rainfed conditions (Singh *et al.*, 2014).

Petal Dimensions: The maximum petal length was found in NB 7, while the widest petals were observed in Pant Aparna. The shortest petal length and width were recorded in NB 9, followed by NB 16 and CISH-B 2 (Singh *et al.*, 2014).

Superior Floral Traits in NB-7: Overall, NB-7 exhibited larger floral organs compared to other varieties, suggesting its potential advantage in reproductive success.

Stability of Floral Traits: Floral traits, being among the most conserved characteristics, were minimally influenced by environmental factors, underscoring their reliability for

Variation in flower colour and size

Pollination

Pollination's Role in Fruit Set: The significance of pollination in fruit sets varies considerably among different cultivars and is influenced by factors such as the availability and quality of functional pollen, the characteristics of the pollen, the relationship between pollen availability and seed set, and the capacity of certain cultivars to produce parthenocarpy fruits, with or without pollination (Neeraj *et al.*, 2017).

Self-pollination and Cross-pollination in Bael: In *Aegle marmelos* (bael), approximately 5% of flowers undergo self-pollination, while 95% depend on insect-mediated cross-pollination. As a primarily cross-pollinated species, bael requires a compatible pollinizer variety to enhance the fruit set, which varies significantly among cultivars based on the quantity of functional pollen and its relationship with fruit setting (Singh *et al.*, 2014a, 2018b).

Clonal Variation in Flower Morphology: Singh *et al.* (2014a, 2018b) reported clonal variation in the morphology of bael flowers and inflorescences, indicating the impact of genetic differences on reproductive success. The fragrant flowers, typically arranged in clusters of 4 to 7 along young branchlets, feature 4 or 5 fleshy petals with a green exterior and yellowish interior, alongside 50 or more greenish-yellow stamens.

Pollinators in Bael's Flowering Period: During the flowering period (May-June), bael flowers attract a variety of insect pollinators, including honey bees (*Apis dorsata*, *Apis mellifera*), beetles, house flies, ants, and butterflies, which forage between 6 AM and 1 PM. These pollinators access the central portions of flowers, whether fully open or in the early stages of opening, and carry significant amounts of pollen on their bodies, primarily on their abdomens and legs (Singh *et al.*, 2019a).

Monitoring Insect Activity for Pollination Study: Insect activity was monitored at one-hour intervals to study insect pollination. Honey bees were found to be the most effective pollinators, visiting each flower 5 to 23 times per hour and carrying an average of 29.65 pollen grains per visit, surpassing other pollinators in both frequency and pollen load (Singh *et al.*, 2014a).

Role of Honey Bees as Primary Pollinators: Honey bees have been established as the primary and most efficient pollinators for bael, contributing significantly to the reproductive success of the crop. Their foraging behavior and high pollen-carrying capacity make them the most legitimate pollinators for bael and many other tropical fruit trees (Singh *et al.*, 2019c, 2019b, 2021a).

Controlled Pollination and Pollination Methods: The pollination mechanism in *Aegle marmelos* (bael) was examined through controlled pollination experiments. Unopened flowers and panicles were bagged with butter paper bags to isolate them from external pollination. To assess the extent of self-pollination (autogamy), flowers were bagged before anthesis. Manual crosses were performed to investigate the occurrence of geitonogamy and xenogamy, while emasculated flower buds were bagged to explore the potential for apomixis. The fruits and seeds produced from these crosses were subsequently counted to evaluate reproductive success.

Bael as a Cauliflorous Fruit Tree: Bael is a prime example of a cauliflorous fruit tree, where flowers and fruit can emerge directly from the main trunk and old branches (Singh *et al.*, 2018b). This characteristic allows the tree to adapt to various environmental conditions. In bael, flowering and fruiting can occur not only on the current season's shoots but also on shoots up to 10 years old, including those on the main trunk, providing a unique reproductive advantage (Singh *et al.*, 2019f).

Metaxenia in Bael: The phenomenon of metaxenia, which refers to the direct influence of pollen grains on the external parts of the fruit (such as size and shape) outside the embryo and endosperm, was observed in bael. Metaxenia has been found to shorten the fruit development period and increase yield, especially in mixed cultivar plantings. A metaxenia effect, ranging from 2-5%, was observed in the fruit shape and ripening period across various genotypes of bael (Singh *et al.,* 2014, 2015, 2018).

Different pollinators in bael

Mechanism behind metaxenia

The most plausible explanation for metaxenia is the secretion of hormones or soluble substances by the embryo, endosperm, or both, which directly influence the external fruit characteristics. Although this phenomenon has been noted in bael, it has not been previously documented in detail. The pollen source plays a significant role in determining the size, shape, fruit set, stylar cavity, and fruit development rate in bael, thereby affecting the ripening time and quality of bael fruits (Singh *et al.*, 2018b, 2018a, 2019a, 2021a).

Conclusion

There are significant gaps in the available knowledge of pollination and pollinators in bael fruit tree. To bridge these gaps, it is essential to analyze and compare pollinator diversity and effectiveness across species, assessing their contributions to bael crop productivity and economic value. This review explores the diversity and efficiency of pollinator species, offering insights into their economic impact on bael cultivation. Insect pollination, particularly by bees, plays a crucial role in bael production, emphasizing the importance of conserving bee populations to enhance pollination and increase yields. Among all pollinators, the giant honeybee (*Apis dorsata*) stands out as the most effective and legitimate pollinator for bael, significantly improving fruit set and boosting overall yield. Further research is needed to elucidate the influence of pollinators on the internal and external physiological traits of bael fruits. Unfortunately, many fruit growers fail to recognize the importance of maintaining sufficient pollinizers and pollinators in their orchards due to a lack of awareness about their critical role in pollinating commercial varieties. Enhancing honeybee colony presence in cropping areas offers a practical solution, with the potential to substantially improve both the quality and quantity of bael fruits.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Anthranilicdiamide insecticide, Cyantraniliprole 10.26 OD for the control of pest complex in pomegranate

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ABSTRACT

The experiment was conducted to evaluate the bio-efficacy of a new anthranilic amide insecticide, Cyantraniliprole 10.26 OD, against aphids and thrips infesting pomegranate under the AICRP on Arid Zone Fruits at the Department of Horticulture, MPKV, Rahuri, during the *Ambe bahar* seasons from 2020-21 to 2022-23 on the Bhagwa variety of pomegranate. The four-year pooled data demonstrated that the application of Cyantraniliprole 10.26 OD at 0.75 to 0.9 ml per liter of water (75–90 g a.i./ha) was consistently effective in controlling aphids and thrips throughout the study period. The treatment resulted in significantly lower mean populations of aphids and thrips (2.1 to 6.18 and 1.74 to 3.65 per twig, respectively) compared to untreated control populations (24.9 and 14.47 per twig, respectively) on the 5th, 10th, and 15th days after two consecutive sprays. Cyantraniliprole 10.26 OD performed better than Lambda-cyhalothrin 5% EC, while Fipronil 5% EC and Spinosad 45 SC were the least effective treatments. Pooled yield and economic analysis revealed that Cyantraniliprole 10.26 OD at 0.9 ml per liter of water recorded the highest marketable fruit yield (15.26 t/ha) with a maximum cost-benefit ratio of 1:2.33 and an incremental cost-benefit ratio (ICBR) of 12.74. Based on these findings, it is recommended to apply two sprays of Cyantraniliprole 10.26 OD at 0.9 ml per liter of water at 15-day intervals during pest incidence for effective management of aphids and thrips on pomegranate.

Introduction

The pomegranate, *Punica granatum* L. belonging to family Punicaceae is a native of Iran and it is an ancient favorite table fruits of tropical and sub-tropical regions of the world. Pomegranate is rich in tannins and possess anti-atherosclerotic properties due to its potential anti-oxidative nature and also reduces blood pressure (Aviram and Dornfeld, 2001). India ranks first in area (2,57,000 ha), production (3097.72 MT) and productivity 12.01 MT/ha of pomegranate. Maharashtra state is leading state in country growing first in area(137.85 thousand ha), production (1554.25 thousand MT) and productivity 11.28 MT/ha (Anonymous, 2023).Future demand for export quality pomegranate may certainly show increasing trend.Such an important fruit crop is attacked by several insect and non-insect pests as well as diseases. About 91 insects, 6 mites and a snail pest found damaging pomegranate crop in India. The major pests observed during different fruiting season in pomegranate area are thrips (*Scirtthrips dorsalis* H.) and

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aphids (*Aphis punicae* P.) which cause serious damage by desapping and scaring the fruit rind that has resulted into threatened export quality of fruits. Moreover, the fruit borer (*Virachola isocrates* F.) recorded throughout the year in most part of India and causes 50 per cent loss in marketable yield (Balikai *et al.*, 2011). In past several insecticide have been proved effective and recommended for the pest control on pomegranate by university through State Agriculture recommendation committee. However, there was no specific label claim in pomegranate. Therefore, present investigation has been conducted tostudy the efficacy of novel additional chemistry of Anthranilicdiamide molecule, which is recently registered label claim under CIBRC for the control of pests of pomegranate as a sustainable approach in pest management.

Material and Methods

The present investigation was carried out during the year of 2020-21 to 2022-23 at experimental farm of AICRP on Arid Zone Fruits, Department of Horticulture, MPKV, Rahuri, Distt.-Ahmednagar (MS). The experiment was laid out in Randomized Block Design consisting seven treatments *viz.*, Cyantraniliprole 10.26 OD at 0.7 & 0.9, Lambdacyhalothrin 5%EC at 0.5 & 1.0, Fipronil 5%SC at 1.0 and Spinosad 45 SC at 0.2 ml per litre of water including untreated control and each treatment replicated thrice on variety 'Bhagwa' of pomegranate (fours-year-old) with spacing of 4.5 x 3.0 m. For eachtreatment 4 L spray fluid was prepared by taking into account spray fluid @ 1000 Lha^{-1}. With hand operated knapsack sprayer equipped with hollow cone nozzle was used to carry out spray operation. Among total two spray withinterval at 15 days interval, first spray was taken at the flowering and fruit settingstage on incidence of the pest noticed.

The observations on pest's *viz.,* aphids and thrips was recorded at vegetative/ fruiting stage of the crop. The observations on survival population of aphid and thrips (both nymphs and adults) per five twig/ shoot were taken on 0 day as pre-count and 5th, 10th and 15th days after each spray as post count. Mean survival population of pest complex *i.e.* aphids and thrips (nymphs and adults) per twig was worked out in various treatments. The natural enemies (defenders: predators) were also recorded while taking the post count of the pests. The values of survival populations were subjected to statistical analysis by converting to angular transformed values (T) using formula, $T= \sqrt{n+0.5}$, where n = natural count of survived population of aphids and thrips. Fruit damage caused by borers was assessed at the time of harvest by categorizing fruits as healthy or infested. The percentage of damaged fruits was calculated and statistically analyzed using arc-sine transformation for normalization. The pomegranate fruit yield from each treatment was recorded per plant during each picking, conducted at 15-day intervals starting 150 days after the '*Bahar*' treatment and continuing until the conclusion of the harvesting period. The yield was measured in kilograms per plant and subsequently converted and expressed as tonnes per hectare. Additionally, economic data were analyzed, and the benefit-cost (B:C) ratio and incremental cost-benefit ratio (ICBR) were calculated to evaluate the profitability of each treatment.

Results and Discussion

Aphids (*Aphis punicae* P.): It is revealed from the three years pooled data presented in Table1 that the pre-count was found to be non-significant and recorded average survived aphids population in the range of 13.54 to 15.20 per twig. On 5th day, all the insecticide treatments were found effective against aphids as compared to untreated control. The treatment (T_2) Cyantraniliprole 10.26%OD @ 0.9 ml/litre was found most effective against aphids in recording least survival of aphids *i.e.* 4.10 per twig was found on par with the treatment of Fipronil 5%SC @ 1.0 ml/litre and recorded the average survived aphids in the range of 3.4 per twig as against 19.01 in untreated control. The next best promising treatment of Lambda-cyhalothrin 5% EC @ 1.0 per litre were also found effective against aphids. Significant difference were not noticed on 10th day after spray. The treatment of Cyantraniliprole 10.26%OD @ 0.9 ml litre of water, was found significantly effective and recorded least average survived aphids in the range of 1.92 as against 19.87 per twig in untreated control. The next best promising treatment of Cyantraniliprole 10.26%OD @ 0.75 ml was also found on par with the treatment dose of 0.9 ml per litre for the effective control of aphids. On 15th days after spray treatment, it was the evident that among the treatments the treatment of Cyantraniliprole 10.26%OD @ 0.9,0.75 ml, Lambda-cyhalothrin 5% EC @ 0.5 were found equally effective significantly superior over rest of the treatments and recorded least survival of aphids in the range of (2.78 to 4.27 per twig/shoot) as against 14.85 per twig in untreated control. However, the treatment of Cyantraniliprole 10.26%OD @ 0.9 ml per litre was found most effective treatment for the control of aphids.

Thrips (*Scirtothrips dorsalis* H.): It is revealed from the three years pooled data presented inTable1 that all the treatment were found effective for the control of thrips as against untreated control.The data on pre-count was found non-significant and recorded average survived thrips population in the range of 11.48 to 12.99 per twig /shoot.

Significant difference were not noticed on 5th day after spray. The data on 5th day observation presented in Table 2 revealed that, all the insecticide treatments were found effective against thrips as compared to untreated control. The treatment of Cyantraniliprole1 0.26%OD @ 0.9 ml/ litre was found most effective against thrips in registering average survival of aphids *i.e.* 4.90 per twig and on par with the Cyantraniliprole 10.26%OD @ 0.75, Lambdacyhalothrin 5%EC @0.5 & 1.0, Fipronil @1.0 and Spinosad 2.5 SC @1.0 ml/litre of water and recorded least average survived population of thrips *i.e.* 6.60 to 7.43 per twigs as against 12.56 in untreated control. On 10th day after spray, the treatment of Cyantraniliprole10.26%OD @ 0.9 ml per litre found superior and recorded least average survivedthrips *i.e.*1.19 as against 19.70 /twig in untreated control. Which was found on par with Cyantraniliprole 10.26%OD @ 0.75 and Spinosad 0.25 ml per litre and recorded least survived thrip population *i.e.*1.3 &1.52 respectively for the control of thrips on pomegranate. On 15th days after spray, the treatment of Cyantraniliprole10.26% OD @ 0.9 ml per litre were found significantly superior for the control of thrip population and recorded average survived thrips*i.e.* 2.60 as against 6.6 per twig. However, the treatment of Cyantraniliprole10.26% OD @ 0.75ml, Lambda-cyhalothrin @ 1.0 and Spinosad 2.5 SC @1.0 ml/litre of water was found equally effective treatment for the control of thrips.

Anar butterfly (*Deudorix (=Virachola) Isocrates)*: The data on fruit borer damage revealed that, after last spray application, the treatment of Cyantraniliprole 10.26%OD @ 0.75 was found significantly effective in controlling fruit borer damage *i.e.* 3.28 per cent as against 16.32 in untreated control. The treatment of Lambda-cyhalothrin @ 1.0 ml/ litre found next best effective treatment for the control of fruit borer and recorded percent fruit damage due to Anar butterfly *i.e.* 5.24% as against (16.32%) untreated control. (Table 3)

Natural Enemies: As regards the influence of different treatments on natural enemies Lady birdbeelte (grubs) and pollinators, it was the evident that the natural enemies survival of coccinellids (LBB) was found in the range of 0.9 to 1.3 per 5 cm twigs/ plant as against 2.6 in untreated control. The pollinators (honey bees) survival after spray at 24 & 48 hrs, the treatments were found safe and effective in average surviving better population of pollinators (2.4 to 3.3 and 4.3 to 5.3 bees/ tree) as against 9.3 to 11.23 in control, respectively and found safe to these treatments at the time of flowering to fruiting stage on pomegranate (Table 3).

Marketable yield: All the insecticidal treatments exhibited good protection against pomegranate pests (Table 5). The treatment of Cyantraniliprole10.26% OD @ 0.9 ml/litre recorded significantly highest marketable yield of 19.68 kg/ plant (14.56 t/ha) followed by Lambda-cyhalothrin @ 1.0 ml/litre with 18.5 kg/plant (13.69 t/ha) as compared with the lowest yield was recorded in untreated control 14.60 kg/ plant (10.80 t/ha). It is revealed from the data presented on treatment economics and additional yield of pomegranate over untreated control and cost benefit ratio presented in Table 6 that the treatment of Cyantraniliprole 10.26% OD @ 0.9 ml/litre gave additional increase in yield (3.76 t/ha) with maximum cost benefit ratio and ICBR of 1:2.15 followed by with treatment Lambda-cyhalothrin @ 1.0 ml/litre (13.69 t/ha) with cost benefit ratio (1:2.07). Keeping in view to above results,it is recommended that the two sprays of Cyantraniliprole 10.26 OD @ 9 ml per 10 litre of water at an interval of 15 days is recommended for the control of aphids, and 0.75ml thrips and life for fruit borer in pomegranate as soon as incidence is noticed.

As regards the influence of different treatments on natural enemies Lady bird beelte (grubs) and pollinators, it was the evident that the natural enemies survival of coccinellids (LBB) was found in the range of 0.9 to 1.3 per 5 cm twigs/plant as against 2.6 in untreated control. The pollinators (honey bees) survival after spray at 24 & 48 hrs, the treatments were found safe and effective in average surviving better population of pollinators (2.4 to 3.3 and 4.3 to 5.3) as against 9.3 to 11.23 bees/tree in control, respectively and found safe to these biological treatments at the time of flowering to fruiting stage on pomegranate (Table 3)Several workers reported the organophosphate, Synthetic pyrethriods and neoniconoids as most effective for the control of sucking pests as well as lepidopteran borers of pomegranate. Earlier Balikai *et al.* (2011) and Walunj *et al.* (2015) reported effective control of thrips on pomegranate with Tolfenpyrad.

The observed findings are consistent with those of Anonymous (2020), who reported that two applications of Cyantraniliprole 10.2% OD at a dosage of 90 g a.i./ha were highly effective and recommended for the control of aphids and thrips infesting pomegranate. Patel *et al.* (2014) proved Cyantraniliprole @ 90-100 g a.i./ha for control of sucking pests on cotton. Patil *et al.* (2017) reported effective control of thrips in watermelon. Rath *et al.* (2013) showed effectiveness of Cyzpyre against stem borer and gall midge on rice, Savitha *et al.*(2018) and Kumar *et al.* (2019) showed effective control of thrips in watermelon.

Table 1. Efficacy of new molecules against aphids on pomegranate

S. No.	Treatment	Dose (ml/ litre water)	Pooled Mean on number of aphids (Nymphs and adults/ twig/ plant) (2020-21 to 2022-23)			
			Pre-Count	5 DAS	10 DAS	15 DAS
1.	Cyantraniliprole1 0.26OD	0.75	13.54 (3.75)	6.05 (2.44)	3.40 (1.76)	3.88 (1.92)

2.	Cyantraniliprole10.26OD	0.9	13.63 (3.71)	4.10 (1.97)	1.92 (1.40)	2.78 (1.64)
3.	Lambda-cyhalothrin 5 EC	0.5	14.37 (4.21)	7.16 (2.52)	5.79 (3.38)	5.07 (2.13)
4.	Lambda-cyhalothrin 5 EC	1.0	14.50 (4.22)	4.51 (2.21)	4.69 (5.16)	4.27 (2.08)
5.	Fipronil 5 SC	1.0	14.85 (4.17)	3.4 (1.97)	3.2 (2.15)	5.27 (2.23)
6.	Spinosad 45 SC	0.2	14.72 (3.97)	5.90 (2.73)	5.69 (2.65)	7.33 (2.89)
7.	Untreated control	-	15.20 (4.23)	19.01 (4.23)	19.87 (4.41)	14.85 (3.74)
	SEm+		0.185	0.26	1.47	0.36
	CD at 5%		NS	0.82	0.47	1.11
	CV (%)		5.7	17.6	31.1	25.96

Figures in parenthesis are transformed value √x+0.5

NS=Non-significant

Table 2. Efficacy of new molecules against thrips on pomegranate

S. No.	Treatment	Dose (ml/ litre water)	Pooled Mean on number of thrips (Nymphs and adults/ twig/ plant) (2020-21 to 2022-23)			
			Pre-Count	5 DAS	10 DAS	15 DAS
1.	Cyantraniliprole10.26OD	0.75	11.58 (3.24)	6.85 (2.66)	1.52 (1.52)	3.1 (1.85)
2.	Cyantraniliprole10.26OD	0.9	11.48 (3.17)	4.90 (2.25)	1.19 (1.19)	2.6 (1.51)
3.	Lambda-cyhalothrin 5 EC	0.5	11.89 (3.2)	6.60 (2.49)	1.93 (1.93)	4.3 (2.16)
4.	Lambda-cyhalothrin 5 EC	1.0	11.85 (3.28)	7.42 (2.56)	2.07 (2.07)	3.8 (2.16)
5.	Fipronil 5 SC	1.0	12.88 (3.29)	6.80 (2.62)	2.02 (2.02)	3.3 (2.32)
6.	Spinosad 45 SC	0.2	12.99 (3.46)	7.43 (2.47)	1.3 (1.5)	3.1 (1.7)
7.	Untreated control	-	12.12 (3.33)	12.56 (5.10)	19.7 (4.18)	6.6 (3.26)
	SEm+		0.10	0.29	0.23	0.28
	CD at 5%		NS	0.91	0.71	0.88
	CV (%)		5.4	17.63	19.34	22.73

Figures in parenthesis are transformed value √x+0.5

NS=Non-significant

Table 3. Effect of insecticide on activities of natural enemies on pomegranate

S. No.	Treatment	Dose (ml/litre water)	Pooled mean on survived natural enemies/ pollinators (bees)		
			Natural enemies LBB/ twig	Bees visit 24 hrs after spray	Bees visit 48 hrs after spray
1.	Cyantraniliprole10.26OD	0.75	2.0	2.3	4.0
2.	Cyantraniliprole10.26OD	0.9	1.3	2.0	3.3
3.	Lambda-cyhalothrin 5 EC	0.5	1.0	2.0	4.3
4.	Lambda-cyhalothrin 5 EC	1.0	0.6	1.6	2.9
5.	Fipronil 5 SC	1.0	2.0	3.6	4.6
6.	Spinosad 45 SC	0.2	2.3	3.0	4.3
7.	Untreated control	-	2.6	3.6	4.9

Table 4. Efficacy of treatments on per cent fruit borer damage on pomegranate

S. No.	Treatment	Dose		Pooled % fruit borer damage			Pooled Av. fruit damage (%)
		g a.i./ ha	ml / litre	2020-2021	2021-22	2022-23	
1.	Cyantraniliprole 10.26%OD	75	0.75	9.18 (17.60)	3.55 (10.85)	5.57 (13.67)	6.10 (14.23)
2.	Cyantraniliprole 10.26%OD	90	0.9	4.24 (9.73)	2.16 (8.32)	3.45 (10.65)	3.28 (9.03)
3.	Lambdacyhalothrin 5% EC	15	0.5	7.78 (16.20)	4.80 (12.66)	5.84 (14.11)	6.14 (14.43)
4.	Lambdacyhalothrin 5% EC	30	1.0	5.25 (10.77)	3.21 (10.32)	7.26 (15.62)	5.24 (10.547)
5.	Fipronil 5% SC	50	1.0	11.21 (19.4)	4.27 (11.88)	5.57 (13.54)	7.02 (15.64)
6.	Spinosad 45% SC	75	0.25	8.61 (17.1)	4.51 (12.23)	10.18 (18.61)	7.77 (14.67)
7.	Untreated control	-	-	18.31 (25.30)	12.21 (20.44)	18.43 (25.46)	16.32 (22.87)
SEm±				2.50	0.64	0.98	2.342
CD at 5%				7.73	1.98	3.03	0.752
CV 5%				26.21	8.99	10.69	8.988

Figures in parenthesis are arcsine transformed value

Table 5. Effect of treatments on yield of pomegranate

S. No.	Treatment	Dose		Three years pooled mean yield of pomegranate (kg/plant)			Pooled mean yield (kg/ plant)	Yield (t/ha)
		g a. i.	g/ ml/ litre	2020-21	2021-22	2022-23		
1.	Cyantraniliprole 10.26 %OD	75	0.75	19.27	17.17	18.00	18.15	13.43
2.	Cyantraniliprole 10.26 %OD	90	0.9	19.70	19.17	20.17	19.68	14.56
3.	Lambdacyhalothrin 5% EC	15	0.5	17.67	17.33	17.83	17.61	13.03
4.	Lambdacyhalothrin 5% EC	30	1.0	18.17	18.33	19.00	18.50	13.69
5.	Fipronil 5% SC	50	1.0	18.0	17.0	17.0	17.33	12.83
6.	Spinosad 45% SC	75	0.25	17.3	16.7	16.3	16.77	12.41
7.	Untreated control	-	-	14.4	14.5	14.9	14.60	10.80
	SEm±				0.47	0.49		0.21
	CD at 5 %				1.45	1.52		0.67

Table 6. Effect of treatments on economics on pomegranate

Treatment	Yield (t/ha)	Gross income (Rs/ ha)	Cost of insecticide treatment	Total expenditure (Rs/ ha)	Add. yield over control (t/ ha)	Net monetary return (Rs/ ha)	B:C ratio	ICBR
Cyantraniliprole 10.26%OD	13.43	671500	24525	333509	2.63	131500	5.36	2.01
Cyantraniliprole 10.26%OD	14.56	728000	28530	337514	3.76	188000	6.58	2.15
Lambdacyhalothrin 5% EC	13.03	651500	4500	313484	2.23	115000	2.55	2.07
Lambdacyhalothrin 5% EC	13.69	684500	9000	317984	2.89	144500	16.05	2.05
Fipronil 5% SC	12.83	641500	5253	314237	2.03	1.01500	19.32	2.04
Spinosad 45% SC	12.41	620500	18750	327734	1.61	80500	4.22	1.89
Untreated control	10.80	540000	-	-	-	-	-	-

* Total expenditure= Cost of cultivation Cost C (308984/-ha)
Cost of treatment = Cyantraniliprole @ Rs 8900/-litre (2250 ml* Rs 20025), Lambda-cyhalothrion @ Rs 1110/-litre, Fipronil @ Rs 502/-litre, Spinosad 45 SC @ Rs 18000/-litre
Cost of labour cost spraying Rs @ 300/- per day per labour (Rs 1500/- ha)

Market price rate of pomegranate fruit A grade @ 50000/ t.

Conclusion

Based on the four-year pooled data, it is concluded that the treatment Cyantraniliprole 10.26 OD at 0.75 to 0.9 ml/litre water (75- 90 g a.i./ha) showed equally effective for the control of aphids and thrips on variety Bhagwa of pomegranate. Spray of Cyantraniliprole 10.26 OD registered least survived pooled mean population of aphids and thrips *i.e.*2.1 to 6.18 and 1.74 to 3.65 as against 24.9 and 14.47 per twigs in untreated control respectively on 5th, 10th and 15th days after two consecutive sprays. This treatment also outperformed Lambda-cyhalothrin 5% EC. Therefore, it is recommended to apply two sprays of Cyantraniliprole 10.26 OD at a concentration of 0.9 ml per liter of water at 15-day intervals during the *Ambe Bahar* season to effectively manage aphids and thrips in pomegranate.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Climatic influence on initiation and opening of spathe in date palm (*Phoenix dactylifera* L.) under arid conditions of North Western India

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ABSTRACT

Khadrawy, *Saidy* and *Shamran* are three significant date palm cultivars grown in Jaisalmer, Rajasthan, located in the North Western part of India. These cultivars are primarily consumed in their dried form, known as *Chhuhara*, during the *Doka* stage of fruit maturity. Climatic factors, including temperature, relative humidity, and sunshine hours, play a critical role in spathe initiation and opening in both male and female palms. The data on date to first spathe and its opening in the palm was recorded in the three cultivars consecutively for 6 years from 2008-2013 from 25 Years old plantation located at Chandan Experimental farm of ICAR-Central Arid Zone Research Zone, Regional Research Station, Jaisalmer and correlation was studied with three climatic parameter i.e. temperature, relative humidity and sunshine hours. The investigation revealed that significant effect of temperature (male-3.99e-07**, female-2.05e-08***), relative humidity (male-0.000236***, female-0.00237**) and sunshine hours (male-0.015550*, female-0.01649*) on days taken to first opening of spathe in both the sexes of the palm. Higher relative humidity extends the time required for male spathes to open, while lower humidity levels accelerate the process. This observation highlights the need to investigate the underlying mechanisms and potential interactions between these environmental factors to better understand their influence on spathe development.

Introduction

The date palm (*Phoenix dactylifera* L.), commonly known as *Khajur*, is a dioecious palm native to the Persian Gulf region. Renowned for their nutritional value and high caloric content, dates are a staple crop in many regions. Rich in essential nutrients like iron, potassium, calcium, and fair amounts of protein, copper, magnesium, chlorine, sulfur, and vitamins A, B, and B_2, dates are a valuable dietary addition.

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India, once a leading importer of date fruit, has significantly reduced its reliance on foreign imports as the introduction of commercial date palm cultivars from the Middle East, coupled with advanced tissue culture techniques, has facilitated successful cultivation in arid regions like Gujarat, Rajasthan, Haryana, Punjab, and parts of Tamil Nadu.
Date palm cultivars are categorized based on their ripening season (early, mid, or late) and nature of astringency in the "doka" stage, a crucial period when the fruit begins to ripen and develop its characteristic sweetness. Astringent dates have a high tannin content, which gives them a astringent taste, rendering them inedible as fresh fruit so they are often harvested early and dried to reduce the astringency like in Khadrawy which is typically processed into dried fruits, while non-astringent dates have a low tannin content and a sweet, soft texture, they are often consumed fresh and are popular for their dessert-like quality such as Barhee, Khunezi, Shamran, and Saidy. In India, due to the monsoon season coinciding with the dang stage (when half the dates start ripening), it is a common practice to harvest date fruits at the doka stage (early ripening stage). These harvested fruits are then processed into a dried product known as chhuhara.
Climatic factors, such as temperature, relative humidity, and sunshine hours, significantly influence the initiation and opening of spathes in both male and female date palm cultivars. These factors also affect pollen and stigma receptivity, which, in turn, impacts fruit set and yield. The reproductive floral organs and local climatic conditions play a crucial role in fruit setting and maturation. Flowering initiation and maturity can vary across different cultivation regions, particularly between traditional and non-traditional areas, due to varying climatic factors. Additionally, the physiological characteristics of date fruits and the consistency of abiotic climatic conditions are critical determinants of yield and quality. Understanding the relationship between climatic parameters and spathe initiation and opening is crucial for predicting their impact on fruit set and subsequent yield. Research on flowering behaviour in relation to climate and other environmental factors across various cultivation areas is essential. Synchronous flowering, where both male and female flowers open simultaneously, is ideal for manual pollination. Asynchronous flowering, with a significant time gap between male and female flower opening, requires pollen storage for later pollination if male flowers open earlier. This can impact pollen viability (Sharma *et al.*, 2023; Osman and Soliman, 2002; Khalil, 2015; Kadri *et al.*, 2022; Helail and El-Kholey, 2000; Iqbal *et al.*, 2004; Botes *et al.*, 2009; El-Shafey *et al.*, 2011; Al-Shoaibi *et al.*, 2011; Hachef *et al.*, 2023).
This study focuses on the flowering behaviour of three date palm cultivars: *Khadrawy* (astringent), *Saidy* (non-astringent), and *Shamran* (non-astringent) to understand how climatic factors influence flowering patterns in arid conditions of North Western region of India.

Material and Methods

To investigate the spathe and flowering patterns of the *Khadrawy, Saidy* and *Shamran* date palm cultivars, data was collected from a 25-year-old plantation at the Chandan Farm of the ICAR-Central Arid Zone Research Institute (CAZRI) Regional Research Station (RRS) Jaisalmer. This farm is located at 26.9970277° N latitude, 71.3350833° E longitude, and an altitude of 224 meters. Data on spathe initiation and opening in both sexes of the palm was recorded for six consecutive years, from 2008 to 2013. The dates of spathe initiation and spathe opening were recorded for both male and female flowers. The number of days between these two events was calculated to derive the days to male spathe opening (DMSO) and days to female spathe opening (DFSO). Weather data, including average temperature, humidity, and sunshine hours, was collected from January to March each year using a PAN evaporimeter, thermometer, hygrometer and sunshine recorder installed at the ICAR-CAZRI RRS Jaisalmer. Data analysis was performed using R software (R Core Team, 2024) with packages from the tidyverse ecosystem (Wickham *et al.*, 2023), including readxl for data import, ggplot2 (ggplot2 Team, 2023) for data visualization, and car (Fox, 2008) for ANOVA and post-hoc comparisons. A factorial two way ANOVA model was employed to assess the main and interaction effects of cultivar, average temperature, year, relative humidity, and bright sunshine hours on days to male spathe opening (DMSO) and days to female spathe opening (DFSO).
A mixed-effects linear model was employed to analyze the effects of Cultivar, Year, Avg Temp, RH, and SSH on DMSO. The model was fitted using the lmer function from the lme4 package in R. The random effects included in the model were: Random intercept for Year to account for year-to-year variation, Random intercept for Cultivar to account for variation among cultivars. Fixed effects included Year, Cultivar, average Temperature, RH, and SSH. Model assumptions were checked, including normality of residuals and homogeneity of variance. Post-hoc pairwise comparisons were conducted using the emmeans package to identify significant differences between cultivars.

Result and Discussion

Climatic factors such as temperature, relative humidity, and sunshine hours significantly influence the timing of spathe initiation and opening in both male and female date palms. This study examined the trends in spathe initiation and flowering for the *Khadrawy*, *Saidy* and *Shamran* date palm cultivar over six consecutive years (2008-2013) in the arid North Western region of India. The goal was to understand how these climatic factors affect the pattern of spathe initiation and opening.

Table 1. Mean climatic parameter of the experimental farm at Chandan, ICAR-CAZRI, RRS, Jaisalmer

Year	Temperature January			RH (%)	SSH	Temperature February			RH (%)	SSH	Temperature March			RH (%)	SSH
	Max	Min	Average			Max	Min	Average			Max	Min	Average		
2008	22.5	4.2	13.4	48.1	6.7	27.1	6.0	16.5	41.7	8.5	37.2	16.8	27.0	37.4	8.6
2009	23.0	4.5	15.9	52.5	7.0	28.0	12.8	20.4	49.5	7.8	33.5	17.7	25.6	46.0	7.7
2010	25.4	5.2	15.3	61.3	8.2	30.0	8.5	19.3	58.3	7.7	38.7	17.3	28.0	49.0	9.5
2011	25.1	3.1	14.1	62.0	8.0	27.9	7.9	17.9	58.0	7.4	37.6	9.7	23.6	48.0	8.6
2012	25.1	3.9	14.4	60.2	7.5	27.7	4.7	16.2	55.7	8.2	35.0	12.0	23.5	38.1	8.4
2013	26.3	4.2	15.2	62.9	7.8	30.6	10.0	20.3	50.4	7.5	35.7	13.2	24.4	45.1	8.5
Mean	24.6	6.6	14.7	57.8	7.5	28.6	8.3	18.4	52.3	7.8	36.3	14.5	25.4	43.9	8.6
Std. Dev.	1.5	6.1	0.9	6.1	0.6	1.4	2.9	1.9	6.4	0.4	1.9	3.3	1.9	5.0	0.6
CV (%)	6.0	16.7	6.2	10.5	7.7	4.9	34.7	10.0	12.2	5.2	5.3	22.8	7.3	11.4	6.7

A comprehensive analysis of the correlation matrix reveals a strong negative correlation between temperature and the time taken for both male and female spathes to open. As temperature increases, the time required for spathe opening decreases. The correlation matrix (Fig. 1) indicates a strong negative correlation of -0.87 between temperature and DMSO (days to male spathe opening). This implies that with rising temperatures, the duration for male spathe opening diminishes. In other words, higher temperatures promote a faster opening of male spathes. Similarly, a significant negative correlation of -0.90 (Fig. 2) is observed between temperature and DFSO (days to female spathe opening), indicating that increased temperatures also accelerate the opening of female spathes. These findings align with previous research by Khalil (2015) and Munier (1963, 1980), which demonstrated phenomenal changes on number of days taken to open in both sexes of the palm in the cultivars of this species *Phoenix dactylifera* due to the temperature and its role as a primary factor in controlling on the reproductive phenology behaviour in dates.

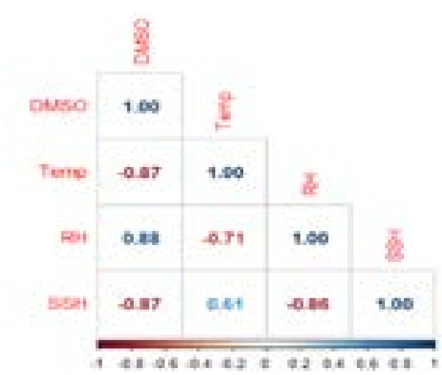

Fig.1. Correlation between DMSO and climatic factors

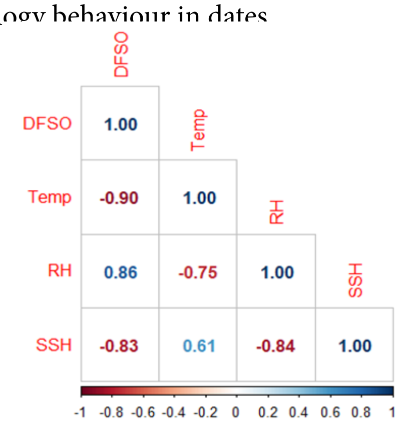

Fig. 2. Correlation between DFSO and climatic factors

Correlation of Relative Humidity (RH) with spathe initiation and opening in date palm

The analysis reveals a significant positive association between relative humidity (RH) and the time taken for male and female spathes to open in all three cultivars studied i.e. *Khadrawy*, *Saidy* and *Shamran*. Higher relative humidity is associated with a longer time frame for male spathe opening, conversely, lower humidity levels can accelerate the opening process. This is supported by a strong positive correlation of 0.88 between RH and Days to Male Spathe

Opening (DMSO), as shown in Fig. 1. For female spathes, the correlation is slightly weaker at 0.86, but still indicates a positive relationship between RH and Days to Female Spathe Opening (DFSO), as depicted in Fig 2. This suggests that increased humidity can also delay the opening of female spathes. Possible explanations for this include slower growth rates in humid conditions, indicating that drier conditions are more favourable for rapid flowering in both male and female plants. Our finding is in conformity to the study carried out by Al-Shuaibi (2012). The finding of a significant correlation between lower humidity and the initiation of flowering in date palms is consistent with studies by Afifa *et al*. (2023). However, relative humidity may not be the sole factor influencing the phenological behaviour of date palms. Its interaction with other climatic factors, such as temperature, may also contribute to the reproductive phase of date palms. The combined interaction effect of temperature and relative humidity is known to trigger the second reproductive cycle in date palms, as reported by Peñuela *et al*. (2019).

Correlation of sunshine hours (SSH) with spathe initiation and opening in date palm

The correlation analysis reveals a significant negative correlation between sunshine hours (SSH) and the time it takes for male and female spathes to open in the cultivars studied i.e. *Khadrawy*, *Saidy* and *Shamran*. A strong negative correlation of -0.83 is observed between SSH and the days to male spathe opening (DFSO), as illustrated in Fig. 1. This indicates that more sunshine hours are typically associated with a shorter duration for male spathe opening. The increase in sunlight may provide the necessary energy and favourable conditions for more rapid development. Similarly, a strong negative correlation of -0.83 is found between SSH and DFSO for female spathes, as shown in Fig. 2. Thus, enhanced sunlight exposure tends to accelerate the spathe opening process for both male and female spathes. The finding in our study is in alignment to the study conducted by Al-Mssallem (2018).

Analysis of Variance (ANOVA) of climatic factors on spathe initiation and opening in date palm

There is no significant effect of cultivars on days taken to spathe initiation and its opening in both male (0.233039) and female palm (0.84035) as depicted in the ANOVA Table 2 and 3. However there is significant effect of temperature (male-3.99e-07**, female-2.05e-08***), RH (male-0.000236***, female-0.00237**) and sunshine hours (male-0.015550*, female-0.01649*) on days taken to first opening of spathe in both the sexes of the palm in all the three cultivars studied. Significant effect of mean temperatures with flower initiation in both sexes of the palm may be due to the recording of fluctuations and the advance shown in the timing of floral initiation from one year to another Afifa *et al.* (2023).

Table 2. Analysis of Variance on date of male spathe opening and climatic parameters

Particular	df	SS	Mean SS	F-value	Pr (>F)
Year	1	4.6	4.6	1.635	0.233039
Cultivar	2	22.3	11.2	3.989	0.057493
AT	1	470.2	470.2	167.966	3.99e-07 ***
RH	1	96.7	96.7	34.544	0.000236 ***
SH	1	24.8	24.8	8.857	0.015550 *
Residual	9	25.2	2.8	-	-

Significant level ‘***’p≤ 0;
‘**’ p≤0.01; ‘*’ p≤0.05

df-degree of freedom, SS-Sum of Square, Mean SS-Mean Sum of Square, AT- Average Temperature; RH-Relative Humidity; SSH-Sunshine Hours

Table 3. Analysis of Variance on date of Female Spathe opening (FMSO) and climatic parameters

Particular	df	SS	Mean SS	F-value	Pr(>F)
Cultivars	2	1.0	0.5	0.177	0.84035
AT	1	472.7	472.7	201.189	2.05e-08 ***
Year	1	3.7	3.7	1.313	0.27625
RH	1	43.6	43.6	15.411	0.00237 **
SH	1	22.6	22.6	7.987	0.01649 *
Residual	11	31.1	2.8		
Significance level '***'p≤ 0; '**' p≤0.01; '*' p≤0.05					

df-degree of freedom, SS-Sum of Square, Mean SS-Mean Sum of Square, AT- Average Temperature; RH-Relative Humidity; SSH-Sunshine Hours

Conclusion

The findings of the present investigation suggest that temperature and sunshine hours are significant factors influencing the duration of spathe opening in both male and female date palms of the *Khadrawy*, *Saidy*, and *Shamran* cultivars in the North Western part of India. Higher temperatures and increased sunlight appear to accelerate the spathe opening process, while higher relative humidity may delay it. Further research is needed to explore the underlying mechanisms and potential interactions between these environmental factors, which could provide deeper insights into their influence on spathe development.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Influence of organic amendments on growth and yield attributes in poly-house grown tomato

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ABSTRACT

The research findings indicated that diverse combinations of biodynamic, silica and *Dashparni* have remarkable influence on the growth and yield characteristics of the tomato Ajeet variety cultivated under protected conditions. From a range of treatments and combinations of treatments, treatment T_{10} (BD 500 @7 5g/ha + BD 501 @ 2.5g/ha + Silica @ 1% + *Dashparni* @10%) produced the highest plant height at 30 DAT, 60 DAT and at final harvest (44.23, 88.56 and 244.90 cm, respectively), leaf area (254.8 cm^2), minimum day to flowering (42.66) and least day to harvest (89.00%), maximum number of branches (25). The maximum fruit length of 6.66 cm, maximum fruit diameter of 5.20 cm, maximum fruit volume of 115.33 cc, maximum fruit weight of 109.26 g, number of fruits per plant (46.46), yield per plant of 5.05 kg, yield per square metre of 11.23 kg and yield per acre of 44.94 t were attained in T_{10} (BD 500 @ 75 g/ha + BD 501 @ 2.5 g/ha + Silica @ 1% + *Dashparni* @ 10%) compared to the control.

Introduction

Tomato (*Solanum lycopersicum* L.) is the most commonly and widely grown in the world, next to potato (Bertin and Genard, 2018). It has the chromosomal number 2n=24 and belongs to the family Solanaceae, which embraces more than 3000 species, including significant food, spice and drug plants. It was domesticated from a wild ancestor of *Lycopersion esculentum* sub. species *cerasifoeme* in the Andean area of South America and in Mexico (Bai and Lindhout, 2007) and the tomato originated in Peru in South America while the name of the crop came from the Aztec word "tomato." It contains a significant amount of lycopene, minerals, essential amino acids, sugars, dietary fibres, vitamin B and C, iron and phosphorus (Agarwal and Rao, 2000); hence, due to its nutritive properties tomato is also known as a protective food. From Europe, the Portuguese introduced the tomato crop to India in the 17th century.

Production of vegetables under protected conditions involves protection of various stages of vegetables mainly from adverse environmental conditions such as temperature, high rainfall, hail storms, scorching sun light etc. In greenhouses, the management of soil fertility is of utmost importance for optimizing crop nutrition on both a short-term and a long-term basis to achieve sustainable crop production. It is related to the greenhouse climate and the complex interaction involving the many factors contributing to the biological, chemical and physical properties of the soil. Biological factors

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can be beneficial (microbial population, mycorrhizal fungi, Rhizobium bacteria) and physical properties importance for greenhouse production is soil texture and structures the soil volume that can be explored by the roots, and its water-holding capacity. Chemical factors contributing to soil fertility include nutrient status and soil organic matter, soil pH and cation exchange capacity.

The organic amendments, such as biodynamic, *Dashparni* and silicon were applied to enhance soil structure, boost fertility and act as natural pesticides and resisting both biotic and abiotic stresses. BD-500 is made by burying cow horns filled with cow dung for six months during autumn and winter in the soil. Those prepared using indigenous cow dung in indigenous cow horn are more effective. BD-500 promotes soil texture, earthworm activity, porosity, and activity of humus forming bacteria, crumb structure, nodulation and root penetration. It has been noticed that regular applications over the years provide fourfold increase in moisture-absorbing capacity that extended down the humus depth up to about 30 cm, at four-leaf stage and again at the flowering or fruit maturation stage.

BD-501 is made by filling the horns with 'mealy' silica powder and burying them in the soil during spring (March/ April) at a time when BD-500 is taken out. The preparation gets ready for use within 6 months. This aids in fungal control, nutrition, and ripening, keeping quality and drought resistance. However, by itself it can cause reduction in fruit size and burning when the weather is very dry. It is used where an extra burst of ripening is needed in the autumn or in dull seasons. Silicon is the second most abundant element in the earth's crust (Debona *et al*., 2017). Although it is not considered as an essential element for higher plants, it is beneficial for plants, especially when they are subjected to environmental stresses (Al-Aghabary *et al*., 2005; Sanglard *et al*., 2014; Adrees *et al*., 2015; Kleiber *et al*., 2015 and Debona *et al*., 2017). *Dashparni* is a natural pesticide and pest repellent which can be used on any crop, vegetable plants or fruit trees. It is made with extract of 10 leaves and Desi cow's urine. Best against insects like a mealybug, aphids, whiteflies, thrips etc.

Material and Methods

An experiment was conducted at Hi-Tech Unit, Department of Horticulture, Rajasthan College of Agriculture, MPUAT, Udaipur during June-December, 2023 to assess the influence of organic amendments on tomato [*Solanum lycopersicum* L. (Mill.)] under polyhouse condition. The ten treatments applied with three replication under completely randomized design. The treatments consisted of T_1- control, T_2- BD 500 (75g/ha), T_3- BD 501 (2.5g/ha), T_4- BD 500 (75g/ha) + BD 501 (2.5g/ha), T_5- Silica (1%), T_6- *Dashparni* (10%), T_7- Silica (1%) + *Dashparni* (10%), T_8- BD 500 (75g/ha) + Silica (1%) + *Dashparni* (10%), T_9- BD 501 (2.5g/ha) + Silica (1%) + *Dashparni* (10%), T_{10}- BD 500 (75g/ha) + BD 501 (2.5g/ ha) + Silica (1%) + *Dashparni* (10%). The raised beds of 1 meter width having 1.5 ft above from ground level along with length of polyhouse were prepared the plot size was 5 m x 1 m and spacing was followed 60 cm x 45 cm. All the cultural practices including irrigation and hoeing were carried out as per the standard commercial procedures. Plants were vertically trained with nylon ropes. Observation regarding plant height at 30 DAT, 60 DAT, final harvest (cm), leaf area (cm^2), days to first anthesis, days to first harvest, fruit weight (g), fruit volume (cc), fruit length (cm), fruit diameter (cm), number of branches (at final harvest), number of fruits per plant, yield per plant (kg), yield per square meter (kg) and yield per acre (t) were recorded on selected five tagged plants of each treatment and further analysed.

The plant height was measured at 30, 60 DAT and at final harvest from the base of stem to the highest tip of the plant with the help of measuring tape and mean value was expressed in centimeter. Leaf area was measured at full maturity stage with the help of leaf area meter and then means value was expressed in cm^2. The number of days taken for anthesis and number of days taken to first picking from the date of transplanting in each tagged plant and average value was expressed in days. Total number of branches of the individual plants was counted at the time of final harvest. Fruits were harvested when they attend horticulture maturity. Number of marketable fruits were counted at each picking and summed for all the picking. Five marketable fruits were randomly selected from each replication during the picking and weight of individual fruit was measured in grams with the help of digital balance and average was computed. Fruit length was measured with the help of meter scale, fruit diameter was measured with the help of vernier caliper from the center of each fruit and average value was expressed in cm. Fruit volume was measured by water displacement method and measured in cubic centimeter. Total yield per plant was derived by multiplying average number of fruits per plants by average weight of fruit and expressed in gram. Total yield per square meter area was derived from yield per plant and respective crop geometry. The yield per acre was calculated by multiplying yield per square meter with 4000 and expressed in t. In polyhouse approx. 40 per cent area is used in path, hence calculation was done including this area not only for effective area of planting i.e. approx. 60 per cent. The recorded observations were analysed statistically as per the procedure advocated by Panse and Sukhatme (1985) for drawing inferences.

Results and Discussion

The experimental results (Tables 1 and 2) indicated that various treatments impacted different growth and yield attributes. In general, as compared to control, various treatments enhanced tomato growth and yield. The results showed that higher plant height at 30 DAT (44.23 cm), at 60 DAT (88.56 cm), at final harvest (244.90 cm), leaf area (254.83 cm^2), number of branches (25.00), number of fruits per plant (46.46), fruit weight (109.26 g), fruit volume (115.33 cc), fruit length (6.66 cm), fruit diameter (5.20 cm), yield per plant (5.05 kg), yield per square meter (11.23 kg), yield per acre (44.94 t) and minimum days to first flowering (42.66), days to first harvest (89.00) were reported for treatment T_{10} (BD 500 @75g/ha + BD 501 @2.5g/ha + Silica @1% + *Dashparni* @10%). Best performance shown by treatment T_{10} might be due to presence of biodynamic preparations, silica and *Dashparni* as constituents of this treatment combination as BD 500 causes significant internal changes in the soil, the principal changes are a significant drop in pH, an increase in aerobic status and production of nitrate causing more plant height, similarly BD 501, enhances the photosynthesis and as such compliment the activity of the preparation BD 500, which works mostly in the root zone of the plant. It also strengthens the plants against some fungus attack, further, application of BD 500 and BD 501 also activate natural manure and humus content and *Dashparni* used for control of wide range of pests such as thrips, whiteflies, leaf folder, leafhopper, *etc*. Various bio-products as pesticides in agricultural practices and concluded that *Dashparni* ark was effective and also silicon plays a significant role in imparting both biotic and abiotic stress resistance and thereby enhances the growth of vegetables. Findings of Sharma *et al.* (2011) was in conformity with the findings of present study as they reported significantly higher plant height for the treatment having BD 500 and BD 501 while working with cumin. The findings of Soundharya *et al.* (2019) showed that maximum number of fruit per plant and maximum yield per plant in tomato is also associated due to presence of silica as silicon deposited in the walls of epidermal cells after absorption by plants which contributes considerably to stem strength. These observations were shown to be similar with that of an investigation conducted by Trivedi *et al.* (2014), Dutta *et al.* (2018), Aarya *et al.* (2023) and Nandeha *et al.* (2024).

Table 1. Effect of organic amendments on growth attributes of tomato

	Treatment details	Plant height (cm)			Days to first flowering	Days to first harvest	Leaf area (cm^2)	Number of branches per plant
		30 DAT	60 DAT	at final harvest				
T_1	Control	32.40	65.83	214.73	47.70	95.23	204.00	18.40
T_2	BD 500 (75g/ha)	35.26	73.56	218.96	46.33	93.56	215.53	19.60
T_3	BD 501 (2.5g/ha)	34.43	71.86	217.60	46.00	95.80	212.06	21.13
T_4	BD 500 (75g/ha) + BD 501 (2.5g/ha)	40.40	80.43	227.26	45.26	93.73	225.80	22.03
T_5	Silica (1%)	35.13	74.26	226.93	45.46	94.73	217.00	21.93
T_6	Dashparni (10%)	34.13	71.66	227.16	47.03	94.26	208.96	22.33
T_7	Silica (1%) + Dashparni (10%)	38.40	74.80	235.33	44.63	93.83	235.70	22.76
T_8	BD 500 (75g/ ha) +Silica (1%) + Dashparni (10 %)	41.06	83.00	244.23	44.10	90.33	245.80	24.36
T_9	BD 501 (2.5g/ha) + Silica (1%) + Dashparni (10 %)	42.76	85.70	241.46	43.06	91.93	248.46	23.93
T_{10}	BD 500 (75g/ha) + BD 501 (2.5g/ha) + Silica (1%) + Dashparni (10%)	44.23	88.56	244.90	42.66	89.00	254.83	25.00
	SEm±	0.700	0.841	2.022	0.726	0.727	2.305	0.907
	C.D. (P=0.05)	2.081	2.498	6.007	2.156	2.158	6.846	2.694

Table 2. Effect of organic amendments on yield traits and yield of tomato

	Treatment details	Fruit length (cm)	Fruit diameter (cm)	Fruit volume (cc)	Fruit weight (g)	Number of fruits per plant	Yield/ plant (kg)	Yield/ m^2 (kg)	Yield/ acre (t)
T_1	Control	5.40	4.13	95.94	90.72	38.33	3.48	7.74	30.96
T_2	BD 500 (75g/ha)	5.73	4.36	98.35	93.58	41.06	3.85	8.57	34.28
T_3	BD 501 (2.5g/ha)	5.90	4.56	100.64	95.43	42.53	4.09	9.10	36.41
T_4	BD 500 (75g/ha) + BD 501 (2.5g/ha)	6.10	4.96	108.17	102.18	43.06	4.39	9.75	39.02
T_5	Silica (1%)	5.96	4.66	102.18	96.06	42.46	4.11	9.15	36.59
T_6	Dashparni (10 %)	6.03	4.70	100.95	95.15	44.86	4.36	9.69	38.75
T_7	Silica (1%) + Dashparni (10%)	6.20	5.13	107.38	100.33	42.00	4.33	9.63	38.55
T_8	BD 500 (75g/ ha) + Silica (1%) + Dashparni (10 %)	6.43	5.13	113.33	106.70	44.96	4.65	10.33	41.33
T_9	BD 501 (2.5g/ha) + Silica (1%) + Dashparni (10 %)	6.43	5.16	112.31	105.61	46.10	4.89	10.87	43.49
T_{10}	BD 500 (75g/ha) + BD 501 (2.5g/ha) + Silica (1%) + Dashparni (10%)	6.66	5.20	115.33	109.26	46.46	5.05	11.23	44.94
	SEm±	0.139	0.083	0.922	0.991	1.197	0.126	0.280	1.119
	C.D. (P=0.05)	0.413	0.247	2.739	2.944	3.556	0.374	0.831	3.323

Conclusion

On the basis of results obtained in present investigation it is concluded that among the different treatments used, treatment T_{10} (BD 500 @ 75g/ha + BD 501 @2.5g/ha + Silica @1% + *Dashparni* @ 10%) proved the most beneficial for most of parameters studied *viz.,* plant height (at 30 DAT, 60 DAT and final harvest), days to first flowering, days to first harvest, leaf area, number of branches, fruit length, fruit diameter, fruit volume, fruit weight, number of fruits per plant, yield per plant, yield per square meter and yield per acre of tomato grown under polyhouse conditions.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Effect of NPK and boron on growth and yield of early cabbage (*Brassica oleracea L. var. capitata*)

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ABSTRACT

The thirteen treatment combinations of NPK and boron fertilizers were evaluated with three replications under randomized block design during July 2023 to December 2023. The results exhibited significant effect of various treatment combinations on growth, yield of cabbage. Maximum plant height (21.20 cm, 31.67 cm and 36.87 cm on 30, 60 DAT and at harvest, respectively), number of non-wrapped leaves per plant (10.53, 14.13 and 17.87 on 30, 60 DAT and at harvest, respectively), leaf area at harvest (288.17 cm²), leaf length (28.10 cm), leaf width (21.47 cm), plant spread at harvest (71.10 cm), with minimum days taken to head harvest (80.30 DAT) and maximum polar diameter of head (13.80 cm), equatorial diameter of head (15.80 cm), fresh weight of head (931.70 g), yield per plot (13.05 kg) and yield per hectare (230.05 q/ha) were recorded in treatment T13 (NPK 125% + boron 15 kg/ha) compared to rest of treatments, while minimum days taken to head formation (47.83 DAT) was found in T12 (NPK 125% + boron 10 kg/ha). Lowest values for these parameters were recorded under treatment T1 (Control), in which no fertilizers had been applied.

Introduction

Cabbage is the most important cole crop which belongs to the family Brassicaceae and originated in Western Europe and the Mediterranean region. India stands as the world's second-largest producer of cabbage. It can grow easily under wide range of environmental conditions, both temperate and tropical, but cool moist climate is most suitable (Muzimal *et al*., 2011).

It is rich source of vitamins and minerals. It contains, vitamin A (2000 IU), thiamine (0.06 mg), riboflavin (0.03 mg), vitamin C (124 mg), potassium (114 mg), phosphorus (44 mg), calcium (39 mg), sodium (14.1 mg) and iron (0.8 mg) per 100 g edible part (Fageria *et al*., 2003). Cabbage is used for salad, boiled, cooked, cured, pickling and dehydration purposes and its juice is also used as a remedy against poisonous mushrooms has an anti-cancer property and protects against bowl cancer due to the presence of indole-3-carbinal. The leaves are used to recover from ulcers and wounds. Shredded cabbage leaves fermented under pressure (sauerkraut) in their own juice have a curative effect on scurvy disease. It neutralizes acidity and improves digestion and appetite (Katyal and Chadha, 1985).

It is a heavy feeder, especially of nitrogen, so the supply of proper nutrients must be ensured during its cultivation. The crop production system with high yield targets cannot be sustainable unless nutrient inputs to the soil are at least balanced against nutrient removal by crops (Nahar *et al*.,

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2014). Nitrogen is one of the most important nutrients for higher yields and good quality heads. Nitrogen plays an important role in the building up of protoplasm and proteins, which induce cell division and initiate meristematic activities when applied in optimum quantity (Riad *et al.*, 2009). Phosphorus is an important constituent of living and enters in the composition of phospholipids, nucleic acids, nucleoprotein and coenzymes. Phosphorus is also involved in carbohydrate metabolism, enzyme activation, nitrogen uptake and protein synthesis (Singh *et al.,* 2004). Potassium helps in the translocation of accumulations and improves the quality of cabbage head in relation to taste and keeping quality (Rutkauskiene and Poderys, 1999). Boron has a significant role in the vegetables of cruciferous plants. It mainly requires the synthesis of proteins, cell wall development, carbohydrate metabolism, translocation of sugars, hormone regulation, pollen grain germination, pollen tube growth, fruit setting and seed development (Singh, 1991).

Material and Methods

The experimental trial was conducted at open field Hi-tech unit of Horticulture, Department of Horticulture, Rajasthan College of Agriculture, Udaipur from July 2023 to December 2023 situated at 24˚34'50.0556" N latitude and 73˚42'19.8648" E longitude. The soil samples were collected and evaluated for different soil parameters. The seedlings were raised in pro trays. Transplanting of seedling was done at 4 to 5 true leaves stage and light irrigation has been given immediately after transplanting. Treatments applied before the transplanting at the time of plots preparation. Full dose of phosphorus, potassium, boron and half dose of nitrogen was applied as basal and remaining nitrogen dose has been applied 30 days after transplanting. The experiment was layout in a Randomized Block Design (RBD) with three replications. The size of each unit plot was 2.7 m × 2.1 m and R × P was 45 cm × 30 cm. A total of 13 treatments including the untreated control were selected in this investigation which were T_1 = Control, T_2 = NPK 75% + 0 kg Boron/ha, T_3 = NPK 75% + 5 Boron/ha, T_4 = NPK 75% + 10 kg Boron/ha, T_5 = NPK 75% + 15kg Boron/ha, T_6 = NPK 100% + 0 kg Boron/ha, T_7 = NPK 100% + 5 Boron/ha, T_8 = NPK 100% + 10 kg Boron/ha, T_9 = NPK 100% + 15kg Boron/ha, T_{10} = NPK 125% + 0 kg Boron/ha, T_{11} = NPK 125% + 5 Boron/ha, T_{12} = NPK 125% + 10 kg Boron/ha, T_{13} = NPK 125% + 15 kg Boron/ha. The sources of NPK and boron were urea, diammonium phosphate, muriate of potash and boric acid.

Observations were recorded for growth and yield parameters. At 30 days after transplanting (DAT), 60 DAT and at harvest, the height of the plant was measured in cm from the stem's base at ground level to the maximum length of upper leaves from the randomly selected five plants by meter scale. Total number of non-wrapped leaves per plant were counted at 30 DAT, 60 DAT and at harvest and average was worked out. Leaf area was calculated at harvest by third leaf from the top in cm^2 by leaf area meter. Plant spread and leaf length were measured in cm at harvest and the average was calculated and at harvest also, the plant's leaf width was measured in cm and the average value computed. The number of days from the transplant to head formation and head harvest calculated by randomly tagged plant basis and the average values were reported.

On tagged plant's polar diameter was determined using a scale from the stalk end to the crown of one's head, and average was calculated. The diameter between opposite sides at right angles (to the polar diameter) was measured by scale which were used from recording equatorial diameter of head. Fresh weight of head from randomly selected five plants was taken and average head weight was calculated by weight machine. Yield per plot was measured in kg by average from tagged plants of every plot. Yield per hectare was obtained by then total head yield per plot was multiplied by a factor (quintal). The recorded observations were analyzed statistically as per the procedure advocated by Panse and Sukhatme (1985) for drawing inferences.

Results and Discussion

It is evident from the results presented in Table 1 that NPK and boron had imparted significant effects on all the growth parameters. The results showed that maximum plant height at 30 DAT (21.20 cm), at 60 DAT (31.67 cm), at harvest (36.87), number of non-wrapped leaves at 30 DAT (10.53), at 60 DAT (14.13), at harvest (17.87), leaf area (288.17 cm^2), leaf length (28.10 cm), leaf width (21.47) and plant spread (71.10 cm) with minimum days taken to head harvest (80.30 days) were reported with T_{13} (NPK 125 % + boron 15 kg/ha), although treatment T_{12} (NPK 125 % + boron 10 kg/ha) were found best for minimum days taken to head formation. Best performance in almost all the growth parameters was observed by the treatment having maximum doses of fertilizers along with highest boron, which clearly indicated that the behavior of NPK and boron played a significant role on vegetative growth of cabbage. It might be due to fact that available nitrogen is a major component of chlorophyll, the pigment responsible for photosynthesis and increased production of carbohydrates, this abundance of carbohydrates stimulates cell division and elongation, resulting in larger leaf areas and large plant spreading, more leaf length and width as reported by Verma and Nawange (2015) working with cabbage. Phosphorus has significant role in energy storage, cell division and cell enlargement, which enhances the number of leaves and it is also responsible for better growth and development. Potassium plays a key role in stomata regulation, which affects leaf size, shape and thickness. Boron is a constituent of cell membrane and is essential for cell division, so boron is must for maintaining vegetative growth. These results are in agreement with the findings in broccoli has also been reported by Brahma *et al.* (2002), who observed highest plant height, number of non-wrapped leaves and plant spread by application of higher doses (200:120:80 NPK). Sharma *et al.* (2002) and Nahar *et al.* (2014) also observed maximum leaf length, leaf width, early head formation and early head harvest due to application of highest doses of NPK and boron in cabbage. The findings of Yeshiwas *et al.* (2017), Akand *et al.* (2015) in cabbage, Singh *et al.* (2015) in broccoli and Kumar *et al.* (2012) in cauliflower were in close proximity with the results of current study as they also observed the robust growth with high doses of NPK and boron.

Similarly the significant results on yield and yield attributing parameters were noticed with each increasing dose of NPK and boron up to a level of NPK 125 % +15 kg boron/ ha as compare to control (Table 2 and Fig. 1), therefore maximum values of yield and yield attributes *i.e.* polar diameter (13.80 cm), equatorial diameter of head (15.80 cm), fresh weight of head (931.70 g), yield per plot (13.05 kg) and yield per hectare (230.05 q ha^{-1}) were recorded in treatment T_{13} (NPK 125% + 15 kg boron/ha). Best performance in yield attributes due to application of treatment T_{13} certainly due to availability of major nutrients along with boron which might have accelerated anabolic and catabolic physiological process, resulting more synthesis of chlorophyll, amino acids and effective utilization of carbohydrates resulted in enlargement of head (Raid *et al.*, 2009). The increase photosynthate and food material move to sink and ultimately increased the yield, further head diameter increased with the increase in phosphorus application adequate phosphorus nutrition promotes many aspects of plant physiology fundamental process. (Arif *et al.*, 2005). Potassium also regulates water loss from the plant by maintaining the balance between anabolism, respiration, transpiration and synthesis of amino acid and the accumulation of high molecular carbohydrates necessary for fruit formation and development which leads to increase yield (Yildirim *et al.*, 2009). The beneficial effect of boron on yield might be due to enhanced supply of micronutrients during entire growing season, significant increase in yield attributes and yield as reported by Khadka *et al.* (2005). Similarly Alam and Jahan (2007) reported highest head weight, Basumatary *et al.* (2017) recorded maximum head diameter, head weight and total yield per ha while working with cabbage due to application of NPK and boron. Prasad *et al.* (2009) recorded maximum head length, head width, total head weight, yield per hectare due to application of higher doses of nitrogen and phosphorus in Chinese cabbage. Findings of Meena *et al.* (2017) and Gochar (2016) in cauliflower, Jilani *et al.* (2009) in cucumber, Haque (2006) in cabbage, Katiyar *et al.* (2011) in broccoli were also in same trend as they reported increased yield due to application of higher doses of fertilizers.

Table 1. Effect of NPK and boron on growth parameters of cabbage

	Treatment details	Plant height(cm)			Number of non-wrapped leaves per plant			Leaf area (cm^2)	Leaf length (cm)	Leaf width (cm)	Plant spread (cm)	Days taken to head formation (DAT)	Days taken to head harvest (DAT)
		30 DAT	60 DAT	at final harvest	30 DAT	60 DAT	at final harvest						
T_1	Control	17.10	25.00	32.07	6.70	9.40	11.23	243.60	20.50	14.87	52.97	54.84	92.40
T_2	NPK 75% + Boron 0 kg/ha	17.60	28.13	33.50	7.77	10.57	12.93	262.43	23.27	16.70	61.33	54.07	90.23
T_3	NPK 75% + Boron 5 kg/ha	17.73	28.40	33.83	7.97	11.23	13.43	266.93	25.20	18.10	61.17	54.33	91.43
T_4	NPK 75% + Boron 10 kg/ha	17.67	28.33	33.70	7.90	11.40	13.47	271.80	24.87	17.90	64.60	53.90	89.57

T_5	NPK 75% + Boron 15 kg/ha	18.07	28.57	34.90	8.07	12.17	14.50	273.03	25.63	18.27	65.77	53.57	87.90
T_6	NPK 100% + Boron 0 kg/ha	18.23	29.10	35.47	8.17	12.37	14.97	276.80	25.83	18.60	66.27	53.00	87.57
T_7	NPK 100% + Boron 5 kg/ha	18.63	29.63	35.80	8.43	12.73	15.03	277.23	26.37	19.17	66.73	52.20	86.37
T_8	NPK 100% + Boron 10 kg/ha	18.37	29.27	35.53	8.57	12.47	14.90	281.67	26.93	19.13	68.10	51.13	83.53
T_9	NPK 100% + Boron 15 kg/ha	19.30	30.60	35.93	8.60	13.27	16.53	279.93	27.23	19.37	68.80	52.50	84.70
T_{10}	NPK 125% + Boron 0 kg/ha	18.97	30.33	36.07	9.53	13.33	16.40	283.20	27.37	19.83	68.23	49.93	83.30
T_{11}	NPK 125% + Boron 5 kg/ha	20.30	30.50	36.30	10.33	13.53	17.33	285.07	27.43	20.34	69.50	48.90	81.93
T_{12}	NPK 125% + Boron 10 kg/ha	19.53	30.73	36.23	10.17	13.70	17.47	286.80	27.47	20.80	71.03	47.83	80.50
T_{13}	NPK 125% + Boron 15 kg/ha	21.20	31.67	36.87	10.53	14.13	17.87	288.17	28.10	21.47	71.10	48.33	80.30
	SEm±	0.765	0.632	0.603	0.561	0.505	0.604	2.097	0.677	0.450	1.086	0.604	0.811
	CD at 5%	2.247	1.855	1.771	1.646	1.483	1.773	6.158	1.988	1.321	3.188	1.772	2.381

Table 2. Effect of NPK and boron on yield parameters of cabbage

	Treatment details	Polar diameter of head (cm)	Equatorial diameter of head (cm)	Fresh weight of head (g)	Yield/ plot (kg)	Yield/ ha (q)
T_1	Control	9.00	10.43	493.23	6.90	121.79
T_2	NPK 75% + Boron 0 kg/ha	9.97	11.30	698.77	9.78	172.54
T_3	NPK 75% + Boron 5 kg/ha	9.93	11.73	720.10	10.08	177.80
T_4	NPK 75% + Boron 10 kg/ha	10.20	11.60	733.97	10.28	181.23
T_5	NPK 75% + Boron 15 kg/ha	10.53	12.13	750.83	10.51	185.39
T_6	NPK 100% + Boron 0 kg/ha	11.37	12.27	737.33	10.32	182.06
T_7	NPK 100% + Boron 5 kg/ha	11.83	12.67	786.20	11.01	194.12

T_8	NPK 100% + Boron 10 kg/ha	12.27	12.77	806.67	11.29	199.17
T_9	NPK 100% + Boron 15 kg/ha	12.57	13.60	838.63	11.74	207.07
T_{10}	NPK 125% + Boron 0 kg/ha	12.87	14.37	844.47	11.82	208.51
T_{11}	NPK 125% + Boron 5 kg/ha	12.93	15.33	894.53	12.52	220.87
T_{12}	NPK 125% + Boron 10 kg/ha	13.40	15.43	914.03	12.80	225.69
T_{13}	NPK 125% + Boron 15 kg/ha	13.80	15.80	931.70	13.05	230.05
SEm±		0.429	0.394	14.475	0.203	3.574
CD at 5%		1.260	1.158	42.501	0.597	10.495

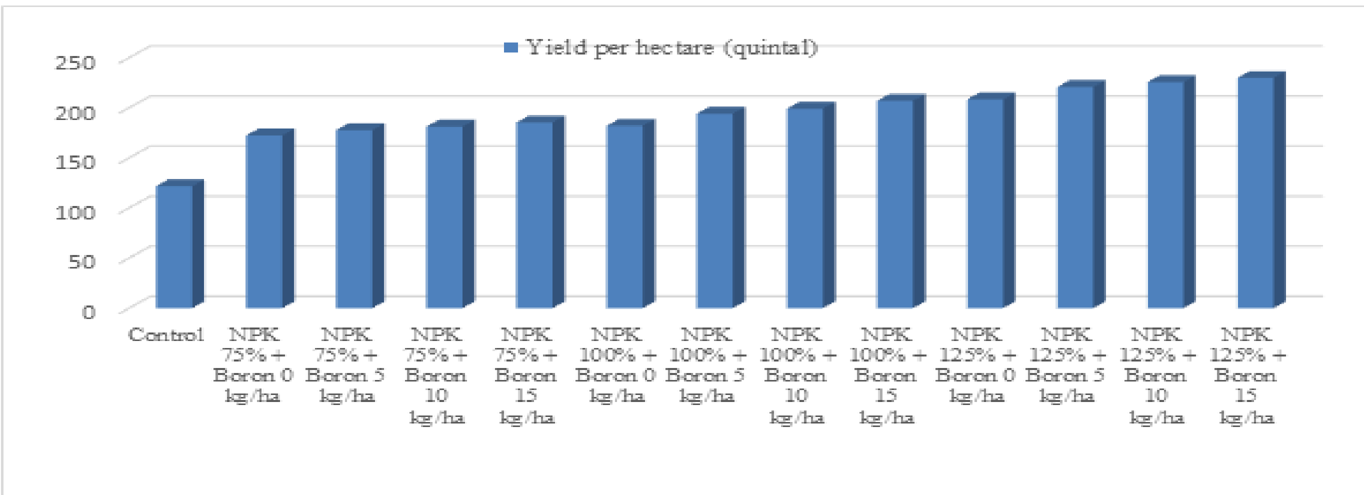

Fig. 1. Effect of NPK and boron on yield of cabbage (q/ ha)

Conclusion

The application of NPK and boron fertilizer treatment T_{13}, which consists of NPK at 125% of the recommended dose and boron at 15 kg per hectare, has been found to be superior in promoting the growth and yield of early cabbage. This treatment demonstrated the most positive impact on various growth parameters, including leaf area, leaf length, leaf width, plant spread. Additionally, the yield attributes, such as head weight and total yield per hectare, were markedly improved with this treatment. The enhanced performance of the T_{13} treatment can be attributed to the synergistic effect of balanced NPK nutrition and the essential micronutrient boron, which plays a crucial role in cell wall formation, membrane integrity, and reproductive development.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Optimizing Brussels sprout *(Brassica oleracea var. geminifera* L.*)* yield through strategic sowing dates and environmental parameters across various growth stages

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ABSTRACT

The important exotic vegetable crop in nutritive and cultivation concern had been planted on different dates to study the environmental effect on Brussels sprout growth and yield.The experiment was conducted during 2018 and 2019 at Punjab Agricultural University, Regional Research Station, Gurdaspur. The findings revealed that yield increased significantly with rising maximum, minimum, and mean temperatures. Plant height also showed a positive response to temperature increases. Temperature exhibited a strong and significant correlation with key growth parameters such as the number of leaves, ten-fruit weight, and fruit diameter. Heat use efficiency demonstrated a positive and significant relationship with yield, plant height, number of leaves, ten-fruit weight, and fruit diameter, highlighting its relevance in predicting crop performance. The highest yield was observed when planting done on October 20, while the lowest yield was recorded for the November 10 planting. Similarly, growth attributes, including plant height, number of leaves, ten-fruit weight, and fruit diameter, improved significantly with earlier planting dates. These findings underscore the importance of optimizing planting dates and understanding environmental interactions to maximize Brussels sprout productivity and growth.

Introduction

Brussels sprout (*Brassica oleracea var. gemmifera*) is an important exotic vegetable of brassica family. It is a highly nutritious and known for exceptional nutritive value. Among cole crops, its demand is increasingly day-by-day particularly in metropolitan cities. Brussels sprout is a leading source of protein (4.4% by weight), total carbohydrates (8.9% by weight), and calories (58 per 100 grams) (Brown and Hutchison, 1949). Helm (1963) traced the origin of Brussels sprout to Belgium, suggesting they evolved from the older variety var. ramose (thousand head kale) into var. gemmifera. The crop's stem exhibits longitudinal growth, often exceeding one meter in some cultivars. The axillary buds of the petiolate leaves develop into miniature heads, just a few centimeters in diameter, which hold commercial value. Early planting has been consistently associated with higher yields (Krieghoff, 1988; Abuzeid and Wilcockson, 1989; Gaye and Maurer, 1991; Babik, 1994).

Keeping in view, the importance of Brussels sprout the present study explores the impact of varying planting dates on the growth and marketable yield of Brussels sprout, with

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particular attention to their correlation with environmental conditions, aiming to provide insights for improved cultivation practices.

Material and Methods

The experiment was carried out during 2018 and 2019 at Punjab Agricultural University-Regional Research Station, Gurdaspur on sandy loam, using Brussels sprout cv. Hills Ideal. In each year the crop was planted at three planting dates with three replications. The experiment was laid out in 2 m x 3 m sized plots. The plot consisting of two rows at a distance of 75 cm x 50 cm from row to row and plant to plant each row consisting 6 plants where total plant per plot was 12. The planting was done on 20th October (D_1), 30th October (D_2) and 10th November (D_3) during 2018 and 2019. The marketable yield (excluding unmarketable buds due to quality defects) of the crop was determine for each planting dates at the same time number of days after planting (Table 3) by mechanical harvesting. The date of harvesting coincided with the three to four latest measurements of the total crop. At the same time each observation was also recorded like plant height (cm), number of leaves, weight per plant (g), ten sprout weight (g), fruit length (cm), fruit diameter (cm) to compare the yield quintal per acre with each character. The analysis of variance was carried out with the R statistical package.

Results and Discussion

The yield is a complex polygenic character and the improvement in yield depends on the knowledge and extent of its association with various component characters. An understanding of the association among the different pairs of component characters and their relative association with yield is necessary for improvement in the desired traits. In the present investigation also, the phenotypic correlation coefficients were worked out. The estimates of correlation coefficients among different pairs of characters at phenotypic showed a close resemblance to each other.

Yield demonstrated (Table 1) a positive and significant correlation with maximum temperature during early growth (0.69) and the overall season (0.82), indicating that as temperature increases, both vegetative and reproductive growth improve. However, being a cool-season crop, Brussels sprout exhibited a negative and non-significant correlation with fruiting (-0.44), as temperature had limited influence on this stage. Similarly, yield showed a positive and significant correlation with minimum temperature during early growth (0.88) and the overall season (0.73), but a negative and non-significant relationship with fruiting (-0.32). Mean temperature displayed the strongest positive and significant correlation with early growth (0.90) and the overall season (0.97), while also having a negative and non-significant relationship with fruiting (-0.40). The intensity, duration, and rate of temperature changes collectively influence plant development and physiology (Wahid *et al.*, 2007).

Yield comparisons with diurnal temperature range revealed a negative and significant relationship with fruiting (-0.49). Evening relative humidity showed a positive but non-significant correlation with fruiting (0.35) and negative correlations with early growth (-0.43) and the overall season (-0.50), the latter being significant. Mean relative humidity exhibited a negative and significant relationship with early growth (-0.59) and the overall season (-0.84), while showing a positive but non-significant correlation with fruiting. Rainfall displayed a negative and non-significant correlation with yield, while bright sunshine hours showed no relation. Wind speed negatively correlated with all growth stages, significantly with fruiting (-0.53). Finally, yield demonstrated a positive response to reference evapotranspiration across all stages, significantly correlating with fruiting (0.73). Most crops experience adverse effects when exposed to high temperatures during the vegetative growth period, a phenomenon well-documented for cool-season annuals such as wheat (Porter and Gawith, 1999) and *Brassica juncea* (Hayat *et al.*, 2009).

Plant height exhibited a significant and positive correlation with yield (0.63). When compared with maximum temperature, plant height showed a positive and significant correlation during early growth (0.51) and the overall season (0.58) but a negative and non-significant correlation with fruiting (-0.37). Similarly, plant height compared with minimum temperature displayed a mix of positive and negative non-significant results. In relation to mean temperature, plant height showed a positive and significant correlation with early growth (0.55) and the overall season (0.53), but a negative and non-significant correlation with fruiting (-0.37). The increase in plant height with rising temperatures highlights the significant influence of temperature on vegetative growth, while its relationship with fruiting remained non-significant. Plant height did not show a significant relationship with the diurnal temperature range. Comparisons with relative humidity in the morning showed a positive but non-significant correlation, while relative humidity in the evening exhibited a negative and significant correlation with plant height during the season (-0.50). Mean relative humidity had a negative and significant correlation with plant height during early growth (-0.51) and the overall season (-0.61), but a positive and non-significant correlation with fruiting (0.33). Rainfall, sunshine hours, wind speed, and evapotranspiration did not significantly affect plant height.

The number of leaves per plant showed a strong positive and significant correlation with yield (0.93). When compared with maximum temperature, leaves per plant exhibited a positive and significant correlation during early growth (0.68) and the overall season (0.79), but a negative and significant correlation with fruiting (-0.49). Similarly, comparisons with minimum temperature revealed a positive and significant relationship during early growth (0.79) and the overall season (0.64), while the correlation with fruiting was negative and non-significant (-0.35). When compared with mean temperature, leaves per plant displayed a positive and significant correlation during early growth (0.86) and the overall season (0.89), but a negative and non-significant correlation with fruiting (-0.45). Leaves per plant showed no significant correlations when compared with diurnal temperature range, relative humidity (morning, evening, or mean), rainfall, bright sunshine hours, wind speed, or reference evapotranspiration. These factors appeared to have no measurable impact on the number of leaves per plant.

The ten-fruit weight showed a strong positive and significant correlation with yield (0.86). When compared with maximum temperature, ten-fruit weight exhibited a positive and significant relationship during early growth (0.60) and the overall season (0.75), but a negative and non-significant relationship with fruiting (-0.34). Comparisons with minimum temperature revealed a positive and significant correlation with early growth (0.83) and the overall season (0.70), while the correlation with fruiting was negative and non-significant (-0.27). Similarly, ten-fruit weight showed a positive and significant response to mean temperature during early growth (0.82) and the overall season (0.91), but a negative and non-significant relationship with fruiting (-0.32). Factors such as diurnal temperature range, relative humidity (morning, evening, or mean), rainfall, bright sunshine hours, wind speed, and reference evapotranspiration did not have any significant effect on ten-fruit weight.

Fruit diameter showed a significant and positive correlation with yield (0.80), indicating that an increase in fruit diameter is associated with a higher yield. When compared with maximum temperature, fruit diameter exhibited a positive and significant correlation during early growth (0.58) and the overall season (0.69), but a negative and non-significant correlation with fruiting (-0.39). Comparisons with minimum temperature revealed a positive and significant relationship during early growth (0.82) and the overall season (0.67), while the correlation with fruiting was negative and non-significant (-0.29). Similarly, mean temperature showed a positive and significant correlation with fruit diameter during early growth (0.79) and the overall season (0.85), but a negative and non-significant correlation with fruiting (-0.37). Fruit diameter also demonstrated a positive and significant correlation with reference evapotranspiration during early growth (0.30), fruiting (0.77), and the overall season (0.36). Other factors, including diurnal temperature range, relative humidity (morning, evening, or mean), rainfall, bright sunshine hours, and wind speed, did not show a significant correlation with fruit diameter.

The data presented in Table 2 demonstrate the correlation between Brussels sprout and growing days, as well as thermal growing indices. Yield, when compared with crop stage duration, showed a positive and significant correlation with early growth (0.88), fruiting (0.67), and the entire season (0.93). Yield also exhibited a positive and significant relationship with both growing degree-days and photo-thermal units during early growth (0.97). The yield showed a positive and significant correlation with heliothermal units during early growth (0.69) and the overall season (0.77). Additionally, the photo-thermal index demonstrated a positive and significant correlation with yield during early growth (0.91) and the entire season (0.97). Plant height, compared with crop stage duration, showed a positive and significant correlation with the overall season (0.41), and a positive and significant relationship with growing degree-days during early growth (0.54). Plant height also exhibited a positive and significant correlation with heliothermal units during early growth (0.58) and the entire season (0.62). The photo-thermal index had a positive and significant correlation with plant height during early growth (0.56) and the overall season (0.51). Heat use efficiency showed a positive and significant correlation with yield (1.00), plant height (0.62), number of leaves (0.92), ten-fruit weight (0.86), and fruit diameter (0.82). Crop stage duration was positively and significantly correlated with the number of leaves during early growth (0.80), fruiting (0.56), and the overall season (0.83), as well as with ten-fruit weight during early growth (0.82), fruiting (0.55), and the entire season (0.84), and fruit diameter during early growth (0.78), fruiting (0.81), and the overall season (0.86).

The data presented in Table 3 highlight the significant differences in yield (quintals per acre) across different sowing dates. The maximum yield was recorded in D_1 (61.35), while the minimum yield was observed in D_3 (9.81). D_1 showed no significant difference compared to D_2, and D_2 was significantly at par with D_3; however, D_1 was significantly different from D_3. The highest recorded yield per acre was 70.2, while the lowest was 7.8. Everaarts and De Moel (1998) also reported that combinations of high plant density and late planting resulted in fewer sprouts per plant.

Table 3 also demonstrates significant differences in plant height (cm) across the three sowing dates. The tallest plants were observed in D_1 (36.4 cm), while the shortest plants were observed in D_2 (14.6 cm). Early planting led to taller plants compared to late planting. Bravo *et al.* (1986) suggested that the period from transplanting to harvest was shorter for later planting dates. The number of leaves per plant showed a significant difference among the sowing dates. The highest number of leaves was observed in D_1 (31.5), while the lowest was in D_3 (20.5). Early sown plants produced more leaves, directly impacting yield. Abuzeid and Wilcockson (1989) noted that early-sown plants produce more buds than late ones due to a longer growing season.

A significant difference in ten-sprout weight (g) was also observed across sowing dates. The maximum ten-sprout weight was recorded in D_1 (151.83 g), while the minimum was observed in D_3 (75 g), with an overall mean of 111.44 g. Early sowing showed better performance in sprout weight, positively influencing yield, as higher temperatures during early planting promote vegetative growth, while cooler temperatures are essential for bud formation. Vural *et al.* (2000) also reported that Brussels sprout require a period of low temperatures (12-17°C) for proper bud initiation. The data on sprout diameter (cm) showed significant differences across sowing dates. D_1 (3.28 cm) exhibited the largest sprout diameter, while D_3 (2.11 cm) had the smallest. The overall mean diameter was 2.83 cm. No significant effect on sprout diameter was found between D_1 and D_2, as cooler temperatures are needed for sprout formation, as reported by Grevsen and Olesen (1994).

Table 1. Correlation of yield and related characters of Brussels sprout with growing environ parameters at different growth stages

	Yield	p-Value	Plant height	p-Value	Leaves/ plant	p-Value	Ten fruits weight	p-Value	Fruit diameter	p-Value
Yield	1.00	<0.001	0.63	0.005	0.93	<0.001	0.86	<0.001	0.80	<0.001
Maximum Temperature										
Early growth	**0.69**	**0.002**	**0.51**	**0.029**	**0.68**	**0.002**	**0.60**	**0.008**	**0.58**	**0.012**
Fruiting	-0.44	0.069	-0.37	0.128	-0.49	0.037	-0.34	0.172	-0.39	0.107
Seasonal	**0.82**	**<0.001**	**0.58**	**0.011**	**0.79**	**<0.001**	**0.75**	**<0.001**	**0.69**	**0.002**
Minimum Temperature										
Early growth	**0.88**	**<0.001**	0.36	0.140	**0.79**	**<0.001**	**0.83**	**<0.001**	**0.82**	**<0.001**
Fruiting	-0.32	0.196	-0.35	0.156	-0.35	0.159	-0.27	0.280	-0.29	0.239
Seasonal	**0.73**	**<0.001**	0.27	0.288	**0.64**	**0.004**	**0.70**	**0.001**	**0.67**	**0.002**
Mean Temperature										
Early growth	**0.90**	**<0.001**	**0.55**	**0.019**	**0.86**	**<0.001**	**0.82**	**<0.001**	**0.79**	**<0.001**
Fruiting	-0.40	0.102	-0.37	0.136	-0.45	0.063	-0.32	0.201	-0.37	0.135
Seasonal	**0.97**	**<0.001**	**0.53**	**0.025**	**0.89**	**<0.001**	**0.91**	**<0.001**	**0.85**	**<0.001**
Diurnal Temperature Range										
Early growth	0.21	0.411	0.33	0.183	0.25	0.311	0.14	0.569	0.13	0.618
Fruiting	**-0.49**	**0.037**	-0.31	0.212	**-0.56**	**0.015**	-0.36	0.142	-0.43	0.076
Seasonal	0.16	0.534	0.31	0.212	0.20	0.422	0.11	0.657	0.09	0.736
Relative Humidity (Morning)										
Early growth	-0.17	0.501	0.13	0.611	-0.12	0.634	-0.15	0.540	-0.24	0.344
Fruiting	0.18	0.473	0.35	0.156	0.22	0.379	0.12	0.627	0.13	0.610
Seasonal	-0.03	0.903	0.20	0.435	0.02	0.929	-0.06	0.821	-0.07	0.783
Relative Humidity (Evening)										
Early growth	-0.43	0.073	-0.44	0.068	-0.45	0.060	-0.38	0.119	-0.34	0.174
Fruiting	0.35	0.156	0.38	0.117	0.40	0.102	0.26	0.307	0.28	0.263
Seasonal	**-0.50**	**0.035**	**-0.50**	**0.037**	**-0.49**	**0.040**	-0.46	0.055	-0.38	0.116
Relative Humidity (Mean)										
Early growth	**-0.59**	**0.011**	**-0.51**	**0.031**	**-0.58**	**0.012**	**-0.53**	**0.023**	-0.46	0.056
Fruiting	0.29	0.248	0.33	0.175	0.34	0.171	0.20	0.421	0.24	0.333
Seasonal	**-0.84**	**<0.001**	**-0.61**	**0.008**	**-0.77**	**<0.001**	**-0.81**	**<0.001**	**-0.67**	**0.003**
Rainfall										
Early growth	-0.01	0.960	-0.26	0.305	-0.05	0.835	0.01	0.960	0.06	0.813
Fruiting	-0.05	0.845	0.16	0.533	0.01	0.964	-0.09	0.714	-0.09	0.712
Seasonal	-0.32	0.196	-0.09	0.734	-0.25	0.318	-0.38	0.124	-0.26	0.293
Bright Sunshine Hours										

Early growth	0.23	0.363	0.37	0.130	0.27	0.284	0.17	0.501	0.13	0.619
Fruiting	-0.46	0.056	-0.40	0.102	**-0.52**	**0.026**	-0.29	0.237	-0.43	0.077
Seasonal	0.18	0.479	0.35	0.160	0.22	0.379	0.15	0.552	0.08	0.763
Wind Speed										
Early growth	-0.15	0.558	-0.33	0.184	-0.20	0.432	-0.10	0.685	-0.03	0.902
Fruiting	**-0.53**	**0.023**	-0.05	0.848	-0.41	0.092	**-0.49**	**0.040**	**-0.50**	**0.033**
Seasonal	-0.40	0.099	-0.41	0.091	-0.42	0.084	-0.38	0.119	-0.23	0.353
Reference Evapotranspiration										
Early growth	0.41	0.088	0.44	0.068	0.43	0.077	0.36	0.142	**0.30**	**0.219**
Fruiting	**0.73**	**<0.001**	0.42	0.086	**0.65**	**0.003**	**0.63**	**0.005**	**0.77**	**<0.001**
Seasonal	0.46	0.055	0.45	0.063	0.47	0.051	0.40	0.101	**0.36**	**0.14**

Correlation values in bold faces are significant at $p \leq 0.05$

Table 2. Correlation of yield and related characters of Brussels sprout with growing days and thermal growing indices

	Yield	p-Value	Plant height	p-Value	Leaves/ plant	p-Value	Ten fruits weight	p-Value	Fruit diameter	p-Value
Crop stage duration days										
Early growth	**0.88**	**<0.001**	0.37	0.127	**0.80**	**<0.001**	**0.82**	**<0.001**	**0.78**	**<0.001**
Fruiting	**0.67**	**0.002**	0.21	0.402	**0.56**	**0.015**	**0.55**	**0.017**	**0.81**	**<0.001**
Seasonal	**0.93**	**<0.001**	**0.41**	**0.091**	**0.83**	**<0.001**	**0.84**	**<0.001**	**0.86**	**<0.001**
Growing Degree Days (GDD)										
Early growth	**0.97**	**<0.001**	**0.54**	**0.022**	**0.91**	**<0.001**	**0.89**	**<0.001**	0.85	<0.001
Fruiting	**-0.14**	**0.579**	-0.30	0.226	**-0.25**	**0.325**	**-0.10**	**0.693**	**-0.03**	**0.910**
Seasonal	0.96	<0.001	0.49	0.041	0.88	<0.001	0.89	<0.001	0.86	<0.001
Photo-thermal unit (PTU)										
Early growth	**0.97**	**<0.001**	0.54	0.021	**0.91**	**<0.001**	**0.89**	**<0.001**	0.85	<0.001
Fruiting	**-0.20**	**0.432**	**-0.32**	**0.191**	**-0.30**	**0.233**	**-0.15**	**0.543**	**-0.09**	**0.735**
Seasonal	0.96	<0.001	0.48	0.042	0.88	<0.001	0.89	<0.001	0.85	<0.001
Helio-thermal unit (HTU)										
Early growth	**0.69**	**0.001**	**0.58**	**0.011**	**0.68**	**0.002**	**0.62**	**0.007**	0.53	0.025
Fruiting	-0.27	0.280	-0.33	0.183	-0.36	0.146	-0.16	0.517	**-0.20**	**0.421**
Seasonal	**0.77**	**<0.001**	**0.62**	**0.006**	**0.74**	**<0.001**	**0.71**	**0.001**	**0.58**	**0.011**
Photo-thermal index (PTI)										
Early growth	**0.91**	**<0.001**	**0.56**	**0.016**	**0.86**	**<0.001**	**0.82**	**<0.001**	**0.79**	**<0.001**
Fruiting	-0.35	0.157	-0.33	0.179	-0.41	0.093	-0.26	0.293	-0.31	0.213
Seasonal	**0.97**	**<0.001**	**0.51**	**0.032**	**0.89**	**<0.001**	**0.91**	**<0.001**	**0.86**	**<0.001**
Heat use efficiency (HTU)										
Seasonal	**1.00**	**<0.001**	**0.62**	**0.006**	**0.92**	**<0.001**	**0.86**	**<0.001**	**0.82**	**<0.001**

Correlation values in bold faces are significant at *p*≤0.05

Table 3. Analysis of variance

Planting Date	Yield (q/ ha)			Plant height (cm)			Leaves/ plant (no.)			Ten fruits weight (g)			Sprout diameter (cm)		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
D_1 (20th Oct.)	61.35± 7.62a	52.2	70.2	30.77± 6.81a	20.9	36.4	31.5± 2.16a	29	35	151.83± 18.65a	125	175	3.28± 0.23a	3.0	3.6
D_2 (30th Oct.)	31.80± 2.26b	28.3	34.2	22.10± 3.86b	14.6	25.4	24.66± 1.86b	22	27	107.50± 10.35b	90	120	3.11± 0.27a	2.8	3.6
D_3 (10th Nov.)	9.81± 1.43c	7.8	11.3	23.36± 3.15b	20.2	28.9	20.50± 2.25c	18	24	75.00± 18.43c	50	105	2.11± 0.19c	1.8	2.3
LSD	5.74			5.64			2.58			20.04			0.29		
Grand Mean	34.32			25.40			25.55			111.44			2.83		

Conclusion

This study reveals the intricate dynamics shaping the growth and yield of Brussels sprout in response to environmental conditions and sowing dates. The crop's yield displayed a positive correlation with maximum, minimum, and mean temperatures, demonstrating its sensitivity to temperature variations. Vegetative growth parameters such as plant height increased with rising temperatures, further highlighting temperature's role in development. Key growth attributes, including the number of leaves, ten-fruit weight, and fruit diameter, were positively influenced by temperature, reinforcing the importance of environmental factors in the plant's development. Heat use efficiency, a critical metric for evaluating plant performance, significantly correlated with traits like yield and growth parameters, validating its utility in assessing productivity.

Sowing dates emerged as a pivotal factor, with the highest yield recorded for planting on October 20. Early sowing improved critical growth characteristics, such as plant height, leaf count, fruit weight, and diameter, emphasizing the importance of optimal planting times for achieving maximum productivity. This research underscores the potential of Brussels sprout as a high-value crop with remarkable nutritional benefits. Understanding the interplay of environmental factors and cultivation practices enables growers to optimize yields, enhance nutritional value, and contribute to sustainable agricultural practices, paving the way for further advancements in this versatile crop.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Studies on genetic parameters and selection indices in eggplant (*Solanum melongena L.*) for growth and yield attributes

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ABSTRACT

The present experiment was carried out to assess the genetic variability for 60 genotypes of eggplant/ brinjal for growth and yield attributes. A degree of variation was observed for all the characters. High PCV and GCV were recorded for the plant height (22.29 and 22.13), number of primary branches (24.96 and 23.74), intra cluster distance (30.75 and 29.80), number of fruits per plant (38.76 and 37.76), length of fruits (32.07 and 31.97), girth of fruits (29.41 and 29.33), fruit weight (29.26 and 29.20), short styled flowers (31.64 and 22.51), fruit yield per plant (40.52 and 40.30), shoot infestation by shoot and fruit borer (24.34 and 23.83) and fruit infestation by shoot and fruit borer (24.92 and 24.35). High heritability (>60%) was noticed for all the characters under study except short styled flowers (50.64). High genetic advance as per cent mean was observed for fruit yield per plant (82.58%), number of fruits per plant (75.77%), length of fruit (65.67%), fruit weight (60.01%), girth of fruit (60.25%), intra cluster distance (59.50%), fruit infestation by shoot and fruit borer (49.03%), shoot infestation by shoot and fruit borer (48.06%), number of primary branches per plant (46.51%), plant height (45.24%), short styled flowers (33.01%) and inter cluster distance (24.11%). The estimates of genetic parameters revealed scope for further improvement of fruit yield by selection. Top index values for five genotypes were recorded. The genotype SM 36 (4724.25), SM 2 (4676.91), SM 9 (4471.43), SM14 (4313.06) and SM21 (4255.83) respectively and these best five high yielding genotypes were further selected for hybridization programme.

Introduction

Eggplant or brinjal (*Solanum melongena* L.) belongs to the family *Solanaceae,* has chromosome number of 2n=24.Itis an important crop in the tropical regions of world and being grown extensively in India, Bangladesh, Pakistan, China and Philippines. It is also popular in Egypt, France, Italy and United States. In India, it is one of the most common, popular and principal vegetable crop grown throughoutthe country. It is a versatile crop adapted to different agro-climatic regions and canbe grown throughout the year. It is a perennial but grown commercially as an annual crop. Brinjal has several ayurvedic medicinal properties and is good for diabetic patients. It has

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also been recommended as an excellent remedy for those suffering from liver complaints (Shukla and Naik, 1993). A number of cultivars are grown in India based on consumer preference for fruit color, size, shape and taste. However, for further improvement evaluation of available genetic variability is prerequisite for planning the crop improvement programme. Knowledge of the nature and magnitude of variation provide rationale choice of character(s) on which selection can be practiced. The observed variability is a combined estimate of genetic and environmental factors, of which the former is heritable and responds to selection. However the estimate of heritability alone does not provide an idea about the expected gain in the next generation, therefore it has to be considered in conjugation with genetic advance. Hence, the present investigation was carried out to analyze variability for growth and yield characters.

Material and Methods

The present study was carried out to assess the variability and character association in 60 diverse genotypes of eggplant at Department of Plant Breeding & Genetics, College of Agriculture (KAU), Vellayani Trivandrum-Kerala during 2016-17. The experimental site was located at 8°5' N latitude and 77°1' E longitude at an altitude of 29 m above mean sea level.

Seedlings were transplanted at a spacing of 60 cm x 70 cm. The crop received timely management practices as per package of practices recommendations of Kerala Agricultural University. The crop was maintained properly till last harvest and observations on growth, yield as well as yield contributing characters was noted on five randomly selected plants in each replication at different stages of the crop. The variance components and coefficients of variation were computed as per Burton (1952). The heritability in broad sense and expected genetic advance were determined by using the formula given by Johnson *et al.* (1955). Observations were taken for all the twenty three characters like plant height, number of primary branches per plant, days to first flower, percentage of medium styled flowers, percentage of long styled flowers, intra cluster distance, inter cluster distance, number of fruits per plant, length of fruit, girth of fruit, fruit weight, days to first harvest, days to last harvest, fruit yield per plant, SFB shoot damage, SFB fruit damage. Percentage of infested shoots and fruits per plant was calculated by number of shoots or fruits showing damage symptoms to the total number of shoots or fruits respectively which is multiply by the 100. The selection index developed by Smith (1937) using discriminate function of Fisher (1936) was used to discriminate the genotypes based on all the characters. Plant height, number of primary branches, number of fruits per plant, girth of fruit, fruit weight together with fruit yield per plant were used for constructing selection index.

Results and Discussion

The analysis of variance revealed significant variation among the 60 accessions for all the characters studied (Table 1). This indicated the presence of high degree of variation within the genotypes. One of the ways by which variability is assessed through a simple approach of examining the range of variations (Phaomei and Pereira, 2016). Range of variation observed for all the traits in the present study (Table 2).

Various genetic parameters like phenotypic and genotypic co-efficient of variability (PCV, GCV), heritability, genetic advance (GA) and genetic advance as per cent of mean (GAM) for the twenty three quantitative characters like plant height, number of primary branches per plant, days to first flower, percentage of medium styled flowers, percentage of long styled flowers, intra cluster distance, inter cluster distance, number of fruits per plant, length of fruit, girth of fruit, fruit weight, days to first harvest, days to last harvest, fruit yield per plant, SFB shoot damage, SFB fruit damage were measured and have been discussed as below (Table 2 and Fig. 1).

High PCV and GCV were recorded for the plant height (22.29 and 22.13), number of primary branches (24.96 and 23.74), intra cluster distance (30.75 and 29.80), number of fruits per plant (38.76 and 37.76), length of fruits (32.07and 31.97), girth of fruits (29.41and 29.33), fruit weight (29.26 and 29.20), short styled flowers(31.64 and 22.51),fruit yield per plant (40.52 and 40.30), shoot infestation by shoot and fruit borer (24.34 and 23.83) and fruit infestation by shoot and fruit borer (24.92 and 24.35) which indicating maximum amount of variability present in the germplasm for these characters. Similar results were reported in brinjal by Patel *et al.* (2004), Rai *et al.* (1998), Shilpa *et al.* (2018), Mohanty *et al.* (2020), Satyaprakash *et al.* (2021). Moderate PCV and GCV were recorded only for inter cluster distance (12.06 and 11.88) whereas, low PCV and GCV was recorded days to first flower (8.73 and 8.55), medium styled flowers (7.18 and 6.56), long styled flowers (5.15 and 4.33), days to first harvest (6.81 and 6.72) and days to last harvest (6.04 and 6.02) indicating the existence of limited variability or low genetic variability in the germplasm evaluated for the trait. This necessitates need for generation of new variability for these characters. The higher estimates of PCV than the GCV indicated towards the environmental influence in the expression of all the characteristics. These results are concurred with the earlier worker in brinjal by Singh and Gopalakrishnan (1999), Sharma and Swaroop (2000), Satyaprakash *et al.* (2021) and Chithra *et al.* (2022).

High heritability in broad sense is useful in identifying appropriate character for selection and enables the breeder to select superior genotypes on the basis of phenotypic expression of quantitative traits. High heritability (>60%) was noticed for all the characters under study except short styled flowers (50.64). The high heritability recorded for the traits like plant height (98.49%), number of primary branches per plant (90.45%), days to first flower (95.85%), percentage of medium styled flowers (83.48%), percentage of long styled flowers (70.43%), intra cluster distance (93.94%), inter cluster distance (97.03%), number of fruits per plant (94.88%), length of fruit (99.39%), girth of fruit (99.43%), fruit weight (98.80%), days to first harvest (97.43%), days to last harvest (99.24%), fruit yield per plant (98.93%), SFB shoot damage (95.87%) and SFB fruit damage (95.50%). It indicating that these characters are less influenced by environmental factors and are under the control of additive gene effect and selection for improvement of such characters would be rewarding (Sharma and Swaroop, 2000). Burton (1952) suggested that GCV along with heritability estimates would provide a better picture of the amount of advance expected by phenotypic selection. Heritability estimates in conjunction with genetic gains are more effective and dependable in predicting the improvement through selection (Johnson *et al.,* 1955). Since the units of measurements influence the magnitude of genetic advance (GA), the GA as per cent of mean is considered as an essential selection parameter. High genetic advance as per cent mean was observed for fruit yield per plant (82.58%), number of fruits per plant (75.77%), length of fruit (65.67%), fruit weight (60.01%), girth of fruit (60.25%), intra cluster distance (59.50%), fruit infestation by shoot and fruit borer (49.03%), shoot infestation by shoot and fruit borer (48.06%), number of primary branches per plant (46.51%), plant height (45.24%), short styled flowers (33.01%) and inter cluster distance (24.11%) indicating that these characters are controlled by additive gene action. Similar results were reported by Singh and Gopalakrishnan (1999), Sharma and Swaroop (2000). Thus, selection for these characters will improve the yield. Moderate genetic advance as per cent mean was observed for days to first flowering (16.86%), days to first harvest (14.02%) and days to last harvest (12.44%) where as low genetic advance as per cent mean was observed for medium styled flowers (4.52%) and long styled flowers (5.545%) indicating that these characters are governed by non additive gene action, selection for these characters is not useful. More or less similar results were reported by Singh and Gopalakrishnan (1999), Mohanty *et al.* (2020), Satyaprakash *et al*. (2021) and Chithra *et al.* (2022) in eggplant.

Discriminate function technique was adopted for the construction of selection index for yield using fruit yield per plant and the component characters *viz*., plant height, number of primary branches, fruits per plant, girth of fruit and fruit weight. These component characters showed relatively stronger association with yield and could form a valuable selection index for yield in this crop. The index value for each sixty genotypes were determined and they were ranked accordingly (Table 3). Top index values for five genotypes were recorded. The genotype SM 36 (4724.25), SM 2 (4676.91), SM 9 (4471.43), SM14 (4313.06) and SM21 (4255.83) respectively and these best five high yielding genotypes were further selected for hybridization programme.Thus, selection index was formulated to increase the efficiency of selection by taking into account the important characters contributing to yield. Further Hazel, (1943), suggested that selection based on suitable index was more efficient than individual selection for the characters. These results were concurred with earlier works reported by Vadivel and Bapu (1991), Chattopadhyay *et al.* (2011) and Bashar *et al.* (2015).

Table 1. Analysis of variance (mean squares) for growth and yield parameters in eggplant

S. No.	Character	Replication d.f. = 1	Genotypes d.f. = 59	Error d.f. = 59
1	Plant height (cm)	15.02	485.50**	5.99
2	No. of primary branches	0.30	3.72**	0.24
3	Days to first flower	0.14	26.60**	0.49
4	Medium styled flowers (%)	0.01	9.50**	4.94
5	Long styled flowers (%)	2.36	12.49**	4.00
6	Short styled flowers (%)	0.37	3.59**	1.08
7	Intra cluster distance (cm)	0.01	0.34**	0.02
8	Inter cluster distance (cm)	0.12	2.17**	0.03
9	No. of fruits per plant	2.44	95.98**	1.87
10	Length of fruit (cm)	0.00	21.99**	0.17
11	Girth of fruit (cm)	0.01	35.47**	0.28
12	Fruit weight (g)	0.78	2879.43**	23.18
13	Days to first harvest	0.25	39.08**	0.83

14	Days to last harvest	0.00	171.72**	0.77
15	Fruit yield per plant (g)	56325.11	1203696.12**	15162.16
16	FSB shoot damage (%)	0.07	195.92**	1.39
17	FSB fruit damage (%)	3.71	200.90**	3.56

Table 2. Range, mean, estimates of GCV, PCV, heritability and genetic advance for growth and yield parameters in egg-plant

Character	Range		Mean	GCV	PCV	Heritability	Genetic advance at 5%	Genetic advance as % mean
	Min.	Max.						
Plant height (cm)	41.40	119.90	71.80	22.13	22.29	98.49	32.48	45.24
No. of primary branches	3.00	9.30	5.64	23.74	24.96	90.45	2.62	46.51
Days to first flower	32.9000	50.50	42.90	8.55	8.73	95.85	7.40	17.25
Medium styled flowers (%)	33.50	47.85	40.39	6.56	7.18	83.48	4.99	12.34
Long styled flowers (%)	46.05	59.15	53.00	4.33	5.15	70.43	3.96	7.48
Short styled flowers (%)	3.20	11.35	6.59	22.51	31.64	50.64	2.17	33.01
Intra cluster distance (cm)	0.80	2.45	1.46	29.80	30.75	93.94	0.87	59.50
Inter cluster distance (cm)	5.05	10.37	8.44	11.88	12.06	97.03	2.03	24.11
No. of fruits per Plant	10.10	41.75	18.26	37.76	38.76	94.88	13.83	75.77
Length of fruit (cm)	4.90	22.05	10.43	31.97	32.07	99.39	6.85	65.67
Girth of fruit (cm)	8.45	26.65	14.49	29.33	29.41	99.43	8.73	60.25
Fruit weight (g)	47.25	246.50	131.00	29.20	29.26	98.80	78.61	60.01
Days to first harvest	52.70	70.35	62.50	6.72	6.81	97.43	8.54	13.67
Days to last harvest	136.50	174.60	152.56	6.02	6.04	99.24	18.85	12.35
Fruit yield per plant (g)	774.00	4388.50	2024.29	40.30	40.52	98.93	167.67	82.58
FSB shoot damage (%)	6.35	57.50	39.81	23.83	24.34	95.87	19.13	48.06
FSB fruit damage (%)	7.60	51.00	38.03	24.35	24.92	95.50	18.65	49.03

GCV- Genotypic co-efficient of variation

PCV- Phenotypic co-efficient of variation

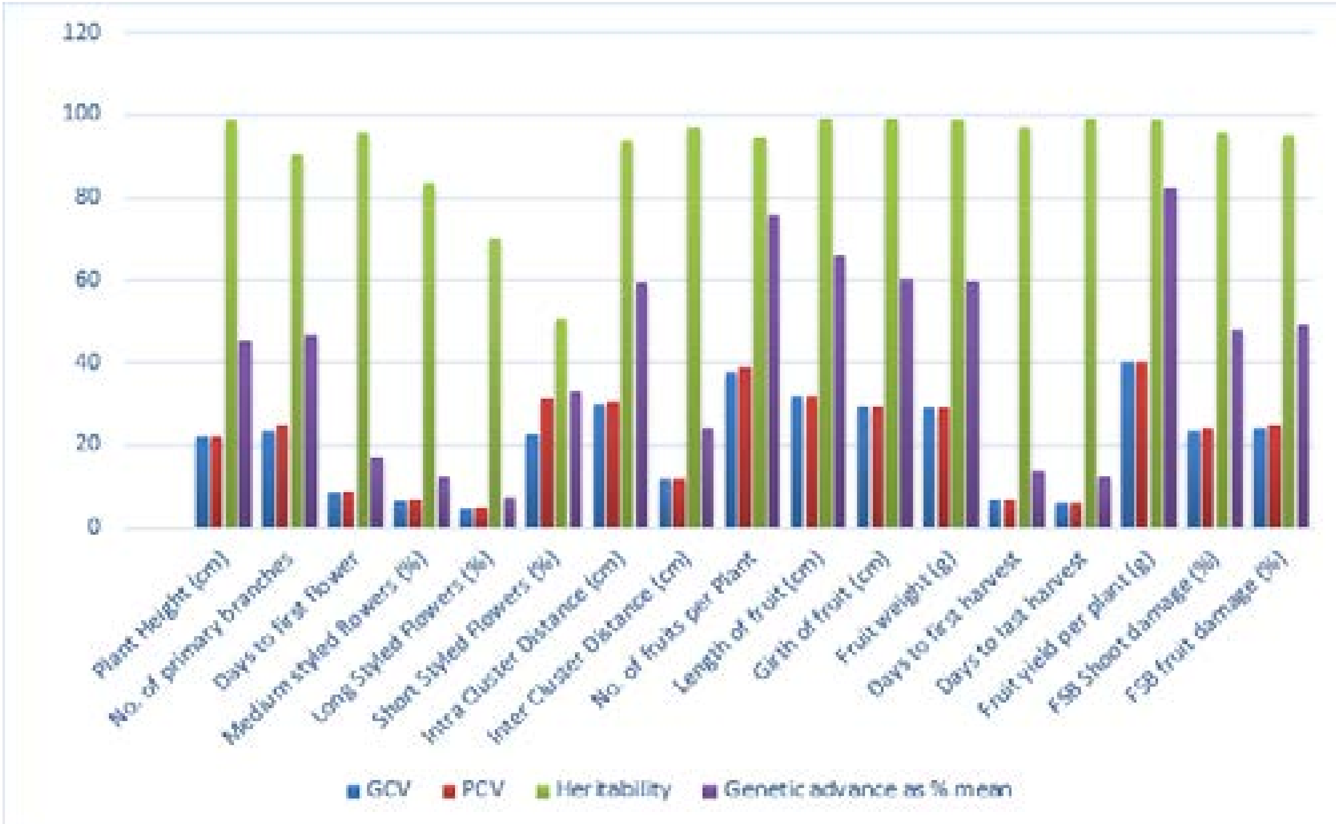

Fig. 1. Estimates of genetic parameters for various characters in eggplant

Table 3. Eggplant accessions ranked according to selection index (based on discriminate function analysis)

S.No.	Genotype	Index	Rank	S.No.	Genotype	Index	Rank
1	SM 36	4724.25	1	31	SM 58	2113.79	1
2	SM 2	4676.91	2	32	SM 52	2111.61	2
3	SM 9	4471.43	3	33	SM 20	2110.63	3
4	SM 14	4313.06	4	34	SM 28	2084.78	4
5	SM 21	4255.83	5	35	SM 51	2070.18	5
6	SM 60	3748.20	6	36	SM 6	2065.42	6
7	SM 1	3714.01	7	37	SM 56	2027.76	7
8	SM 59	3512.11	8	38	SM 42	2026.46	8
9	SM 30	3211.14	9	39	SM 4	2003.13	9
10	SM 35	2720.65	10	40	SM 26	1979.95	10
11	SM 7	2657.05	11	41	SM 5	1977.10	11
12	SM 19	2559.93	12	42	SM 8	1959.33	12
13	SM 31	2514.97	13	43	SM 48	1942.74	13
14	SM 33	2482.48	14	44	SM 53	1914.51	14
15	SM 13	2474.15	15	45	SM 38	1890.95	15

16	SM 15	2458.37	16	46	SM 39	1861.51	16
17	SM 23	2446.83	17	47	SM 24	1831.02	17
18	SM 18	2434.20	18	48	SM 55	1822.30	18
19	SM 43	2336.09	19	49	SM 32	1773.42	19
20	SM 50	2327.30	20	50	SM 46	1771.83	20
21	SM 54	2319.68	21	51	SM 49	1748.27	21
22	SM 25	2309.21	22	52	SM 27	1651.20	22
23	SM 57	2301.97	23	53	SM 10	1636.34	23
24	SM 17	2290.46	24	54	SM 34	1600.28	24
25	SM 45	2281.00	25	55	SM 40	1592.29	25
26	SM 41	2280.56	26	56	SM 11	1373.57	26
27	SM 44	2264.34	27	57	SM 29	1290.56	27
28	SM 37	2186.44	28	58	SM 12	1263.55	28
29	SM 22	2160.14	29	59	SM 3	1051.11	29
30	SM 47	2140.84	30	60	SM 16	994.70	30

Conclusion

The higher PCV and GCV was observed for plant height, number of primary branches per plant, number of fruits per plant, length of fruit, girth of fruit, fruit weight, intra cluster distance, fruit yield per plant, SFB shoot damage and SFB fruit damage indicating that a greater amount of genetic variability was present for these characters which provide greater scope for selection in eggplant. High heritability coupled with high genetic advance as per cent of mean was observed for plant height, number of primary branches plant, intra cluster distance, inter cluster distance, number of fruits per plant, length of fruit, girth of fruit, fruit weight, fruit yield per plant, SFB shoot damage, SFB fruit damage. It indicated that, these traits were under the strong influence of additive gene action and hence simple selection based on phenotypic performance of these traits would be more effective. The selection index was increases the efficiency of selection by taking into account the important characters contributing to the total yield. The index value for each sixty genotypes were determined and they were ranked accordingly.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Variability studies in bael (*Aegle marmelos*) genotypes under semi-arid conditions

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ABSTRACT

A survey of bael genotypes was conducted in the districts of Ajmer, Churu, Jaipur, and Jhunjhunu in Rajasthan during 2021-22 and 2022-23.The collected genotypes exhibited significant variability in fruit morphology and physico-chemical characteristics. The number of fruits per tree ranged from 65 to 145, with fruit yield per tree varying between 22.79 kg and 176.6 kg. Fruit weight ranged from 0.33 kg to 2.85 kg across the genotypes. The important fruit traits, such as fruit length, ranged from 9.05 cm to 18.45 cm, shell weight per fruit varied from 115.25 g to 374.74 g, shell thickness ranged from 0.16 cm to 0.32 cm, and seed weight per fruit from 0.15 g to 0.32 g. The total soluble solids (TSS) ranged from 29.15 to 39.46 °Brix among the genotypes analyzed. Based on the overall assessment, the genotypes SKN-15 and SKN-2 were identified as the most promising.

Introduction

Indian bael (*Aegle marmelos* L. Correa) is one of the most ancient and common fruit indigenous to India. It belongs to family Rutaceae. It grows throughout subtropical and arid region and is a popular crop involving lower input with higher economic return even in the most fragile eco systems. The importance of bael fruits lies in its curative, pesticidal and nutritive properties. Ripe fruits are laxative and unripe fruits are prescribed for treatment of diarrhea and dysentery and have a great demand in Ayurvedic system of medicine. Every part of the plant such as fruit, seed, bark, leaf and root are important ingredients of several traditional formulations. Apart from medicinal value, it acts as a sink for chemical pollutants as it absorbs poisonous gases from atmosphere and makes them neutral. The tree is also considered under the category of 'Fragrant' species, whose flower and volatile vapours neutralize bad smell of putrefied organic matter or decaying refuge and thus save human life from bacterial attack by making them inert and deodorizing the bad odour of the air (Agarwal *et al.*,1997).

In India, it is found in wild form in sub-Himalayan tracts and dry deciduous forests of central and southern regions from prehistoric times and therefore a large number of ecotypes are available in different regions (Pandey *et al.*, 2008). A wide range of diversity of bael trees has been noticed in dry sub-tropical belts of north India. Plains of Uttar Pradesh have wide distribution of bael land races particularly in waste and

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degraded lands. Recently, few cultivars have been identified and found useful for commercial cultivation, i.e., NB-5 and NB-9 from NDUA&T, Faizabad (Pareek and Nath, 1996); Pant Aparna, Pant Shivani, Pant Sujata and Pant Urvashi from GBPUA&T, Pantnagar (Singh *et al*., 2000) and CISH-B-1 and CISH-B-2 from CISH, Lucknow (Pathak *et al*., 2002).
Some superior genotypes known to local people are on the verge of extinction and there is an urgent need to conserve them for use in posterity (Singh *et al*., 2000). The western Rajasthan has high level of variability in bael land races. Therefore, a survey was conducted in high variability areas of western Rajasthan with a view to identify superior genotypes for various useful traits.

Material and Methods

Survey of bael trees was conducted in the districts of Ajmer, Churu, Jaipur and Jhunjhunu, of Rajasthan in the years 2021-22 and 2022-23. Both forested and farmed areas were covered throughout the survey using the technique recommended by Gupta and Rai (1996). The goal was to find only disease-free, pest-free, regularly bearing, dwarf trees with thin shells that contained less seed, fiber, and mucilage, had a pleasant scent, and produced uniformly shaped and sized fruits. A total of 15 genotypes having good fruit and tree characters were identified. Biased sampling after learning more about a certain genotype was done, in addition to random sample from the population. For each genotype, five fruits were randomly selected from every orientation in order to record the morphological and qualitative characteristics. It was noted how much the physical and qualitative characteristics of fruits from various places varied from one another. The physical attributes, viz., plant height, plant spread, stem girth, fruit weight, number of fruits per plant, number of seeds, seed weight, shell weight, shell thickness and pulp weight were calculated following standard procedures. Fruit yield per tree was calculated by counting the number of fruits per tree and multiplying by the average fruit weight. Total soluble solids were estimated in term of degrees Brix with the help of hand refractometer. The data were statistically analyzed as per method given by Gomez and Gomez (1984) using completely randomized block design.

Results and Discussion

The results of study on morphological characters and quality attributes of fruit revealed that the various germplasm of bael exhibited wide range of variation for all the characters studied under rainfed conditions of western India. The results of study on the vegetative characters of different bael germplasm revealed that the growth in terms of plant height, stem girth, plant spread, leaf and flower characters showed different variations under rainfed semi-arid environment.

Growth traits

The data on vegetative growth of different genotypes depicted in Table 1 exhibited significant differences. The differences in plant height, stem girth, plant spread ranged between 1.71-4.52m, 22.87-39.57cm, 1.39-3.57m, and 1.58-4.26m respectively. The plant height (4.52 m), stem girth (39.57 cm), plant spread (E-W-3.57 m and N-S-4.26m) were recorded the maximum in SKN-15, while the vegetative characters in terms of plant height (1.71 m), stem girth (22.87 cm) were measured minimum in SKN-9 and plant spread (E-W-1.39 m and N-S-1.58m) in SKN-3 respectively among the genotypes. The difference among SKN-1 to SKN-15do not differ at all in plant height, stem girth, plant spread (NS) but a significant difference was recorded among SKN-2 to SKN-13; SKN-13 to 14; and SKN-14 to SKN-7. The difference in vegetative growth among the genotypes may be due to inherent characters of individual genotype and their acclimatization to varied agro-climatic conditions. The dwarfness is the desirable characters for the high-density planting by accommodating a greater number of plants per unit area which ultimately enhance the productivity. Mishra *et al*. (1999) also reported that the different bael genotypes exhibited variations in their growth behavior under moist conditions of eastern India.

Table 1. Morphometrics of vegetative characters of bael germplasm under semi-arid region of Rajasthan

Genotypes	Vegetative growth				Terminal leaf size (cm)		Lateral leaf size (cm)	
	Plant height (m)	Stem girth (cm)	Plant spread (m) (NS and SW)		Length	Breadth	Length	Breadth
SKN-1	2.78	24.87	2.08	2.43	11.42	6.19	9.17	4.55
SKN-2	4.39	37.47	3.48	4.05	14.94	8.49	9.38	6.65
SKN-3	2.08	23.57	1.39	1.58	10.57	6.19	7.95	4.65
SKN-4	2.78	39.07	1.67	2.36	11.18	5.85	8.01	3.65

SKN-5	2.22	25.27	1.89	2.28	11.75	7.02	7.83	4.13
SKN-6	2.98	34.47	2.12	2.54	12.84	7.09	9.93	5.44
SKN-7	3.12	25.97	2.29	2.87	13.02	6.38	9.12	5.57
SKN-8	3.31	35.57	2.5	2.83	10.72	6.15	7.45	4.43
SKN-9	1.71	22.87	1.4	1.88	12.45	7.03	9.57	5.52
SKN-10	1.96	25.37	1.64	1.95	10.58	7.08	9.42	5.35
SKN-11	2.72	30.87	1.82	2.22	11.43	6.45	8.63	5.41
SKN-12	2.42	25.87	2.62	2.82	11.28	7.27	8.41	4.87
SKN-13	3.52	26.47	3.28	3.44	11.15	5.86	7.45	5.58
SKN-14	3.94	28.57	2.82	3.37	12.84	6.82	8.57	5.45
SKN-15	4.52	39.57	3.57	4.26	15.02	9.29	9.32	6.13
SEm±	0.16	1.67	0.16	0.13	0.47	0.21	0.54	0.33
CD at 5%	0.47	4.83	0.46	0.36	1.36	0.84	1.55	0.96

Leaf traits

It is evident from the data that the genotypes showed wide differences in their leaf characters under dry land conditions of western India (Table 1). It was noticed that the terminal leaflet size in terms of length (15.02) and breadth (9.29 cm) was found maximum in SKN-15 followed by SKN-2, SKN-7, SKN-14, SKN- 6 and SKN-9 for length andSKN-2, SKN-12, SKN-6, and SKN-5 with respect to leaflet width, while the minimum length (10.57 cm) was recorded in SKN-3 followed by SKN-9, SKN-10 and SKN-4, and minimum breadth (1.58 cm) was recorded in SKN-3 followed by SKN-10 and SKN-11. The lateral leaflet length (9.93 cm) and breadth (6.65 cm) was observed the maximum in SKN-6 and SKN-2, respectively, whereas the minimum lateral leaflet length (7.45cm) and breadth (3.65cm) was observed in SKN-8 and SKN-6 respectively followed by SKN-5 and SKN-3 for leaf length and genotypes SKN-5 and SKN-8 with respect to lateral leaflet breadth in all genotypes studied for the leaf morphological characters. The difference between lateral and terminal leaf size among genotypes do not differ at all but a significant difference was recorded among SKN-2 to SKN-12 in lateral leaf breadth and; SKN-2 to 7 in; and SKN-14 to SKN-7 in lateral leaf length. Differences in the leaf morphology in different germplasm are specific characters and adaptability to different agro-climatic conditions. More or less similar variations with respect to leaf characters in various bael genotypes have been reported by Mishra *et al.* (1999) and Singh (2000) in bael under different agro-climatic conditions.

Flower traits

The data on the morph metrics of flower of bael germplasm depicted in Table 2 and 3 showed considerable differences for all the floral characters studied. Flower characters with respect to flower length (12.39-19.84 mm), flower width (22.44-37.67 mm),bud size in terms of bud length (10.23-13.12 mm), bud width (7.17-9.24 mm), petal length (10.25-14.79 mm), petal width (7.43-9.16 mm), pedicel length (4.56-9.98 mm), pedicel width (2.02-2.88 mm), stamen length (6.7-8.5 mm), filament length (3.5-5.5 mm), width (0.40-0.80mm), anther length (40.45-45.25 mm), width (0.50-0.80 mm), pollen length (4.8-6.5mm), pollen width (1.5-2.5 mm), ovary length (1.1-1.5 mm), ovary width (1.50-2.5 mm), style length (2.4-3.5 mm), width (1.7-2.5 mm). The pollen viability was found to be significantly highest 95% in SKN-2 and SKN-15 followed by SKN-5 (94%), SKN-4 and SKN-1 (93%) and SKN-11 (92%) whereas rest of the germplasm have less than 92% pollen viability.

A significant difference was recorded between SKN-15 to SKN-3, SKN-4 to SKN-9 in stamen length; SKN-15 to SKN-1, SKN-1 to SKN-4, SKN-4 to SKN-5, SKN-6 to SKN-13 and SKN-11 to SKN-7 in stamen breadth. A significant difference was recorded between SKN-10 to SKN-13 and SKN-13 to SKN-11 in filament length; SKN-15 to SKN-10, SKN-10 to SKN-1, SKN-11 to SKN-4 and SKN-13 to SKN-3 in filament breadth. A significant difference was recorded between SKN-15 to SKN-2 and SKN-13 to SKN-4 and SKN-11 to SKN-8 in pollen length. A significant difference was recorded between SKN-12 to SKN-4, SKN-13 to SKN-3, SKN-15 to SKN-2, SKN-9 to SKN-1 in ovary length; SKN-15 to SKN-3, SKN-3 to SKN-1, SKN-11 to SKN-8, SKN-10 to SKN-12, SKN-13 to SKN-14, SKN-14 to SKN-7, and SKN-7 to SKN-5 in ovary breadth.

Variations in floral traits in different bael genotypes have been reported by Singh (1989), Srivastava and Singh (2000), Lal (2002) and Singh and Mishra (2004) under different climatic conditions of India.

Table 2. Floral biology of bael germplasm under semi-arid region of Rajasthan

Genotypes	Flower size (mm)		Bud size (mm)		Petal size (mm)		Pedicel size (mm)	
	Length	Width	Length	Width	Length	Width	Length	Width
SKN-1	14.34	28.18	10.85	7.23	10.25	7.55	7.56	2.02
SKN-2	19.32	35.56	12.39	9.18	14.23	8.93	9.58	2.88
SKN-3	14.38	27.48	10.64	8.65	12.28	7.45	8.06	2.15
SKN-4	18.74	36.22	11.23	8.55	12.59	7.46	5.57	2.19
SKN-5	12.39	23.44	10.52	8.36	10.41	6.99	4.56	2.47
SKN-6	14.4	27.64	11.46	8.11	12.22	6.87	4.59	2.09
SKN-7	14.44	29.16	10.23	7.17	13.08	8.08	5.45	2.14
SKN-8	16.84	32.11	10.96	7.22	13.28	7.76	8.88	2.08
SKN-9	15.38	31.02	12.51	8.29	10.47	7.51	7.96	2.07
SKN-10	15.46	29.13	11.58	7.59	13.25	7.43	7.66	2.03
SKN-11	15.34	30.63	11.52	8.59	12.86	7.65	7.46	2.11
SKN-12	12.65	25.43	12.33	7.89	13.45	8.11	6.56	2.12
SKN-13	14.4	28.32	11.37	8.11	12.87	7.34	7.84	2.43
SKN-14	16.44	32.43	10.54	8.39	11.65	6.65	7.64	2.13
SKN-15	19.84	37.67	13.12	9.24	14.79	9.16	9.98	2.87
SEm±	0.72	0.94	0.78	0.37	0.70	0.37	0.35	0.15
CD at 5%	2.08	2.73	2.25	1.08	2.03	1.06	1.01	0.44

Table 3. Floral biology of bael germplasm under semi-arid region of Rajasthan

Geno-types	Flower size (mm)		Filament size (mm)		Anther size (mm)		Pollen size (mm)		Ovary size (mm)		Style size (mm)		Pollen viabili-ty (%)
	Length	Breath	Width	Length	Width	Diame-ter	Length	Width	Leng th	Width	Length	Width	
SKN-1	7.5	5.1	0.6	3.5	0.8	41.25	6.1	3.1	1.1	2.1	2.5	2.1	93
SKN-2	8.5	5.5	0.8	4.5	0.7	45.25	6.5	4.2	1.2	2.5	3.5	2.5	95
SKN-3	8.2	4.4	0.4	4.5	0.8	44.35	5.5	3.2	1.3	2.2	2.5	2.5	91
SKN-4	8.1	4.8	0.5	3.5	0.6	42.45	5.9	3.3	1.4	2.1	2.8	2.2	93
SKN-5	7.5	4.5	0.6	3.5	0.8	41.25	5.4	3.5	1.5	1.5	2.7	2.1	94
SKN-6	7.5	4.3	0.6	3.5	0.8	40.25	5.6	3.5	1.5	2.1	2.5	2.1	90
SKN-7	6.7	2.7	0.5	4.5	0.7	41.25	4.9	3.2	1.2	1.6	2.4	2.3	93
SKN-8	7.4	3.5	0.4	3.5	0.5	41.25	4.8	2.5	1.3	1.9	2.9	2.2	91
SKN-9	7.7	3.7	0.6	4.5	0.7	42.55	6.1	3.6	1.2	1.5	2.8	1.9	89
SKN-10	7.5	4.5	0.7	3.5	0.7	43.57	6.5	2.5	1.5	1.9	2.5	1.8	91

SKN-11	7.3	3.5	0.6	4.6	0.6	42.55	5.5	3.5	1.5	2.1	3.1	1.7	92
SKN-12	7.5	4.5	0.5	3.5	0.7	43.45	6.5	3.6	1.5	1.8	2.5	1.9	88
SKN-13	6.9	3.8	0.5	4.8	0.7	40.46	6.4	3.5	1.4	1.8	2.4	2.1	89
SKN-14	7.4	4.5	0.4	4.6	0.8	41.48	6.5	3.7	1.3	1.7	2.9	2.3	89
SKN-15	8.5	5.5	0.8	5.5	0.8	44.27	6.5	4.5	1.3	2.5	3.5	2.5	95
SEm±	0.10	0.07	0.01	0.07	0.01	0.52	0.08	0.05	0.02	0.03	0.04	0.02	1.41
CD at 5%	0.29	0.19	0.03	0.20	0.03	1.50	0.23	0.15	0.05	0.09	0.101	0.06	4.07

Fruit characters

It is evident from the data (Table 4) that the values of quantitative characters also varied significantly in different germplasm. The maximum yield per plant was recorded in SKN-15 (535.76 kg) followed by SKN-2 (138.58 kg), SKN-1 (55.87 kg), SKN-12 (54.02 kg),SKN-7 (52.94 kg) and they were found at par for fruit yield, whereas fruit yield was recorded minimum in SKN-4 (40.52 kg) followed by SKN-9 (41.06 kg), SKN-5 (45.39 kg), SKN-13 (46.45 kg) in the genotypes studied for yield. Fruit weight was recorded the highest in SKB-15 (2.85 kg) followed by SKN-2 (0.96 kg), SKN-7 (0.67 kg) and SKN-4 (0.65 kg), whereas the lowest fruit weight was recorded in SKN-13 (0.33 kg) followed by SKN-8 (0.37 kg). The fruit length (18.45 cm) was found to be highest in SKN-15 followed by SKN-2 and SKN-11, whereas the same was recorded the lowest in SKN-10 (9.05 cm) followed by SKN-6 (9.03 cm) and SKN-5 (9.45 cm).The maximum fruit girth (67.88 cm) was exhibited by SKN-15 followed by SKN-5 (48.62 cm) and SKN-11 (12.12 cm), while the minimum fruit girth was observed in SKN-8 (29.39 cm) followed by SKN-4 (29.81 cm), SKN-13 (32.42 cm), SKN-1 (32.53 cm), SKN-10 (33.24cm), SKN-14 (35.34 cm) and SKN-3 (36.44 cm). A significant difference was recorded between SKN-15 to SKN-2 and SKN-2 to SKN-1 in number of fruits and fruit yield per plant; SKN-4 to SKN-1in fruit weight; SKN-15 to SKN-2 and SKN-2 to SKN-12 in fruit length; SKN-15 to SKN-5 in fruit girth among genotypes of bael. Variations in the physical parameters among the germplasm may be owing to individual varietal characters. However, difference in floral traits in various genotypes of bael are as just reported by earlier workers (Mazumdar, 1975; Rai *et al.,* 1991; Pathak *et al.,* 2002; Ram and Singh, 2003; Pandey *et al.,* 2005) under different agro-climatic conditions.

Table 4. Physical attributes of fruits of bael germplasm under semi-arid region of Rajasthan

Genotypes	Number of fruit/ tree	Fruit yield/ tree (kg)	Fruit weight (kg)	Fruit length (cm)	Fruit girth (cm)	Shell weight (g)	Shell thick-ness (cm)	Pulp weight (g)
SKN-1	98	55.87	0.57	11.15	32.53	141.69	0.18	418.31
SKN-2	145	138.58	0.96	15.59	48.12	241.65	0.27	708.35
SKN-3	91	43.68	0.48	10.28	36.44	146.09	0.16	323.91
SKN-4	65	42.25	0.65	9.61	29.81	115.25	0.16	525.75
SKN-5	71	38.82	0.55	9.45	48.62	212.92	0.22	327.08
SKN-6	86	33.56	0.39	9.03	43.27	146.47	0.17	235.53
SKN-7	79	52.94	0.67	10.54	37.88	260.05	0.21	400.95
SKN-8	77	28.49	0.37	10.51	29.39	227.31	0.21	140.32
SKN-9	67	23.50	0.35	11.15	43.39	240.22	0.22	100.67
SKN-10	79	37.84	0.48	9.05	33.24	374.74	0.23	100.26
SKN-11	88	50.33	0.57	12.12	41.25	190.63	0.32	369.37
SKN-12	73	54.02	0.74	13.2	41.75	210.75	0.23	519.25
SKN-13	69	22.79	0.33	9.45	32.42	216.45	0.24	110.51
SKN-14	82	34.37	0.42	10.35	35.34	231.46	0.24	184.54
SKN-15	62	176.70	2.85	18.45	67.88	587.5	0.32	2096.40
SEm±	5.38	4.39	0.02	0.53	2.14	11.85	0.01	28.81
CD at 5%	15.57	12.73	0.07	1.53	6.20	34.33	0.02	83.45

Physical composition of fruits

It is evident from the data that the fruit attributes vary greatly in different germplasm (Table 4 and 5). Shell weight (374.74 g) was measured conspicuously very high in SKN-15 and the lowest in SKN-4 (115.25 g) followed by SKN-1 (141.69 g) and SKN-3 (146.09 g). Shell thickness (0.32 cm) was recorded maximum in SKN-15 & SKN-11 and the least thickness was observed in SKN-3 & SKN-4 (0.16 cm) followed by SKN-6 (0.17 cm) and SKN-1 (0.18 cm). The pulp content was maximum in SKN-15 (2096.40 g) followed by SKN-2 (708.35 g), SKN-4 (525.75 g) and the minimum pulp content was obtained in SKN-10 (100.26 g). Total number of seeds/fruits (122) was recorded maximum in SKN-11 followed by SKN-12 (113), SKN-9 (101), SKN-6 & SKN-13 (97) and the minimum numbers of seeds/fruit was observed in SKN-2 (65). Seed weight was maximum in SKN-15 (0.32 g) followed by SKN-13 (0.29 g), SKN-3 (0.28 g) and the minimum seed weight was obtained in SKN-8 (0.25 g). Total seed weight /fruit (13.5 g) was measured conspicuously very high in SKN-14 and SKN-11 and the lowest in SKN-2 (7.2 g) followed by SKN-15 (7.5 g), SKN-7 (8.6 g) and SKN-5 (8.7 g). Fiber weight/ fruit was maximum in SKN-15 (109.79 g) followed by SKN-2 (67.0 g), SKN-12 (52.46 g) and the minimum fiber weight was obtained in SKN-10 (22.7 g). A significant difference was recorded between SKN-10 to SKN-15, SKN-15 to SKN-7, SKN-11 to SKN-6 in shell weight; SKN-15 to SKN-2, SKN-2 to SKN-13 and SKN-8 to SKN-1 in shell thickness; SKN-15 to SKN-2, SKN-2 to SKN-4, SKN-12 to SKN-1 and SKN-3 to SKN-6 in pulp weight; SKN-15 to SKN-13, SKN-11 to SKN-1, SKN-9 to SKN-8 in total seed weight/fruit; SKN-15 to SKN-2, SKN-2 to SKN-12 in fiber weight among these genotypes of bael whereas a non-significant variation were recorded in number of seeds/ fruit among these genotypes of bael.

Table 5. Physical attributes and TSS content of fruits of bael germplasm under semi-arid region of Rajasthan

Genotypes	Total number of seed/ fruits	Seed weight (g)	Total seed weight/ fruit (g)	Fiber weight/ fruit (g)	TSS (°Brix)
SKN-1	90	0.22	10.2	22.70	31.20
SKN-2	65	0.20	7.2	67.00	36.45
SKN-3	81	0.28	9.6	28.50	30.16
SKN-4	92	0.25	10.2	25.91	32.23
SKN-5	79	0.27	8.7	36.50	29.15
SKN-6	97	0.21	10.7	35.24	33.17
SKN-7	78	0.27	8.6	49.30	30.57
SKN-8	90	0.15	10.4	43.80	33.46
SKN-9	101	0.18	11.2	35.60	31.49
SKN-10	94	0.19	10.4	41.50	34.56
SKN-11	122	0.25	13.5	30.77	33.25
SKN-12	113	0.22	12.2	52.46	33.98
SKN-13	97	0.29	10.6	43.21	34.23
SKN-14	122	0.21	13.5	39.46	33.18
SKN-15	71	0.32	7.5	109.79	39.46
SEm±	4.32	0.01	0.22	4.14	1.58
CD at 5%	12.52	0.03	0.64	11.98	4.58

Qualitative traits

It is quite obvious from the data (Table 5) that the different genotypes manifested considerable variation in qualitative attribute. The total soluble solids in pulp were recorded highest in SKN-15 (39.46° brix) followed by SKN-2 (36.45° brix), SKN-13 (34.23° brix) and SKN-10 (34.56° brix) and the lowest TSS of pulp was recorded in SKN-5 (29.15 brix) followed by SKN-3 (30.16° brix) and SKN-7 (30.57° brix), whereas a non-significant variation in the total soluble solids was recorded in among these genotypes of bael. Based on the observations, it may be inferred from the study that the bael can successfully be grown commercially with and without irrigation under rainfed conditions of western India. Among the genotypes the SKN-15 and SKN-9 for plant height and stem girth; SKN-15 and SKN-3 for plant spread and leaf length; SKN-15 and SKN-4 for leaf breadth; SKN-13 followed by SKN-8 and SKN-6 for lateral leaf length; SKN-4 and SKN-6 for lateral leaf breadth, SKN-15 ranked first for floral biology attributes followed by SKN-5 for flower size, SKN-7 for flower bud, SKN-1 for petal length, SKN-10 for petal breadth, SKN-5 for pedicel length and SKN-1 for pedicel breadth, SKN-7 for stamen size, SKN-14, 3, 2 for filament width, SKN-6, 2 for anther diameter, SKN-10 for pollen width, SKN-2 for ovary width, style size and pollen viability percent. The genotype SKN-15 ranked first for yield attributes, yield and quality (except SKN-14, in which total seed weight / fruit was recorded higher) followed by SKN-4 for number of fruit/ tree and yield / tree; SKN-13 for fruit weight; SKN-6 for fruit length; SKN-8 for fruit girth; SKN-4 for shell weight; SKN-3, 4 for shell thickness and SKN-10 for pulp weight; SKN-11 for total number of seed/ fruits; SKN-8 for seed weight; SKN-2 for total seed weight / fruit (g); SKN-1 for fiber weight/ fruit (g) and SKN-5 for TSS pulp ((°Brix).

Conclusion

Based on the overall performance in both qualitative and quantitative traits, including vegetative growth, fruit characteristics, and yield, the genotypes SKN-15 and SKN-2 demonstrated superior adaptability and productivity under the rainfed semi-arid conditions of western India.

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Conflict of Interest

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Data Sharing

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Research Article

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Influence of thiourea on growth parameters of jackfruit (*Artocarpus heterophyllus* L.)

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ABSTRACT

The experiment was conducted during the year 2022-23 at the Department of Fruit Science, College of Horticulture and Forestry, Jhalrapatan, Jhalawar to investigate the effect of thiourea on growth and development of jackfruit cv. Chandra. The study consisted of nine treatments, arranged in a Randomized Block Design with three replications. Among the various treatments, the application of 2.0% Thiourea (T_8) to individual plants was found to be significantly superior to the other treatments in terms of growth parameters, including plant height (17.84%), rootstock girth (21.82%), scion girth (21.34%), number of leaves per plant (26.55%), and leaf area (32.88%).

Introduction

The jackfruit (*Artocarpus heterophyllus* L.) is an important fruit tree widely cultivated in tropical and subtropical regions, particularly in South-East Asia. With a basic chromosome number of 14, jackfruit is native to the Western Ghats of India. It is often referred to as the "poor man's fruit" in the eastern and southern parts of India due to its affordability and nutritional value. The jackfruit is an evergreen tree that produces separate male and female inflorescences on the same plant, exhibiting a unique cauliflorous bearing habit where female flowers grow directly on the trunk. In eastern India, tender jackfruit is widely used as a vegetable.

The rind of jackfruit is rich in protein, with its principal protein, "jacalin," having been extracted and studied. According to the Ministry of Agriculture and Farmers Welfare (2021-22) 3rd advance estimate, jackfruit is cultivated on 1.88 lakh hectares in India, producing 19.46 lakh metric tonnes annually (Anonymous, 2021-22). Its versatility and wide range of uses make jackfruit an important species for research, particularly in enhancing nutrition and supporting income generation through agroforestry and home garden systems. Jackfruit is also suitable for diversification, thriving alongside other fruit crops like mango, litchi, and sapota. Furthermore, it can be cultivated independently in commercial orchards and has shown great adaptability when introduced to other parts of the world with suitable climates (Morton, 1965).

Thiourea, also known as Thiocarbamide, is a compound containing nitrogen (36.8%) and sulphur (42.1%). Its biologically significant functional groups make it a valuable exogenous application for promoting plant growth (Jocelyn, 1972). In the face of increasing atmospheric dryness, plant growth and development are severely affected. Thiourea has been shown to improve plant stress resistance, thereby enhancing growth and development, making its application particularly relevant and practical in current agricultural practices. Keeping in view the significance of thiourea, this investigation was undertaken to evaluate its effect on the various growth parameters of jackfruit (*Artocarpus heterophyllus* L.).

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Material and Methods

A field experiment was conducted from June 2022 to March 2023 at the Instructional Farm, Department of Fruit Science, College of Horticulture and Forestry, Jhalrapatan, Jhalawar, in a newly established plantation of Jackfruit (*Artocarpus heterophyllus* L.) cv. Chandra. One-year-old plants were selected for the study. The experiment was designed using a Randomized Block Design (RBD) with three replications. The treatments comprised of control (T_o) and eight concentrations of thiourea applied as foliar sprays viz., T_1-0.25%, T_2-0.50%, T_3-0.75%, T_4-1.00%, T_5-1.25%, T_6-1.50%, T_7-1.75% and T_8-2.00%. The foliar applications were performed during the second week of June, August, and October 2022 after recording the initial (baseline) growth and development parameters of the plants.

Observations on plant growth parameters, including plant height (cm), rootstock girth (mm), scion girth (mm), number of leaves per plant, and leaf area (cm^2), were initially recorded in June 2022. Subsequent measurements were taken at two-month intervals, continuing until March 2023. During the course of the experiment, three detailed observations were recorded in September, December, and March to evaluate the effects of thiourea on these growth parameters. This systematic approach allowed for the assessment of the progressive impact of the treatments over the experimental period.

The data collected during the experiment were statistically analyzed following the methods outlined by Panse and Sukhatme (1995). To clarify the efficacy of thiourea, percentage values were calculated based on the original recorded values across different growth periods. The percent values are provided in brackets alongside the corresponding recorded measurements, offering a clear representation of the relative changes observed during the study.

Result and Discussion

The foliar application of thiourea significantly impacted key growth parameters of jackfruit, including plant height, rootstock girth, scion girth, number of leaves per plant, and leaf area (Table 1, Fig. 1). Among the treatments, T_8 (Thiourea 2.0%) demonstrated the highest increase in plant height (17.84%; 107.46 cm), rootstock girth (21.82%; 22.05 mm), scion girth (21.34%; 21.55 mm), number of leaves per plant (26.55%; 41.33), and leaf area (32.88%; 39.35 cm^2) compared to the other treatments, including the control (T_o). The superior growth observed in treatment T_8 (Thiourea 2.0%) can be attributed to the action of thiourea, which enhances plant growth by regulating hormonal activity, promoting differentiation and morphogenesis, and supporting vital physiological processes like carbon and nutrient assimilation (Wahid *et al.*, 2017).

The notable improvement in leaf parameters under T_8 (Thiourea 2.0%) is likely due to the sulphur and nitrogen content in thiourea, which stimulates the meristematic activity of apical tissues and promotes cell division. This effect enhances shoot length and leaf area, which, in turn, improves light capture, carbohydrate synthesis, and overall plant growth (Pravin *et al.*, 2021).

Table 1. Effect of thiourea on growth parameters of jackfruit cv. Chandra during growth period

Treatments	Plant height (cm)*		Rootstock girth (mm)*		Scion girth (mm)*		No. of leaves/ plant*		Leaf area (cm^2)*	
	Initial value	Final value	Initial value	Final value	Initial value	Final value	Initial value	Final value	Initial value	Final value
T_0 (Control)	82.52	87.12 (5.57%)	16.67	18.00 (7.96%)	16.37	17.17 (4.87%)	33.33	36.33 (9.01%)	21.87	23.40 (7.03%)
T_1 (Thiourea 0.25%)	86.24	93.62 (8.55%)	18.84	20.80 (10.38%)	18.41	20.08 (9.07%)	34.33	38.00 (10.68%)	29.09	32.44 (11.53%)
T_2 (Thiourea 0.50%)	90.45	99.17 (9.64%)	16.71	18.67 (11.73%)	15.79	17.41 (10.26%)	33.00	36.66 (11.11%)	29.15	32.98 (13.13%)
T_3 (Thiourea 0.75%)	84.67	93.13 (9.99%)	18.01	20.17 (12.01%)	17.85	19.87 (11.30%)	33.33	37.66 (13.00%)	22.04	25.20 (14.32%)
T_4 (Thiourea 1.00%)	81.70	89.90 (10.03%)	17.59	19.80 (12.54%)	17.30	19.41 (12.20%)	33.00	37.33 (13.13%)	29.78	35.02 (17.58%)
T_5 (Thiourea 1.25%)	81.90	90.72 (10.65%)	17.09	19.85 (16.13%)	16.83	19.55 (15.16%)	33.67	38.33 (13.86%)	26.00	30.77 (18.36%)
T_6 (Thiourea 1.50%)	89.10	99.87 (12.08%)	17.17	19.97 (16.33%)	16.76	19.70 (17.52%)	33.66	39.50 (17.35%)	22.43	27.06 (20.67%)

T_7 (Thiourea 1.75%)	89.77	102.18 (13.83%)	16.11	19.40 (20.40%)	15.75	18.93 (20.21%)	33.00	39.66 (20.18%)	30.74	38.56 (25.46%)
T_8 (Thiourea 2.0%)	88.90	104.76 (17.84%)	18.25	22.05 (21.82%)	17.76	21.55 (21.34%)	32.66	41.33 (26.55%)	29.61	39.35 (32.88%)
SEm±	-	1.48	-	0.33	-	0.61	-	0.85	-	0.47
CD at 5%	NS	3.45	NS	1.00	NS	1.48	NS	1.80	NS	1.40

*Percent values in parentheses

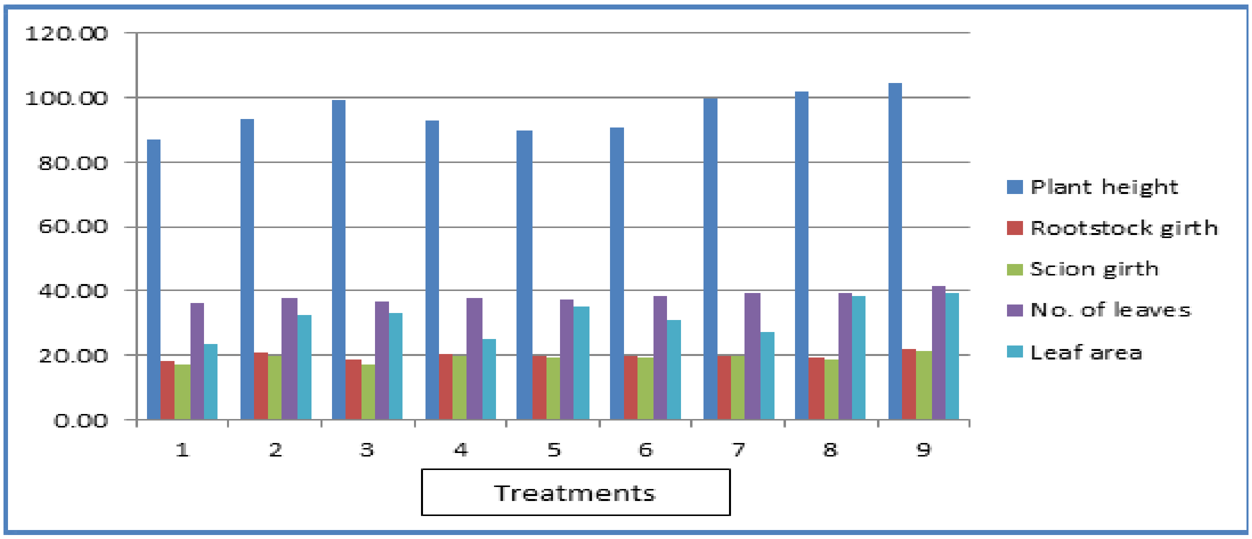

Fig.1. Effect of thiourea on growth parameters of jackfruit cv. Chandra

Conclusion

The study concluded that foliar application of thiourea significantly enhanced the growth parameters of jackfruit plants, with the 2.0% concentration (T_8) showing the best results. The application of thiourea at 2.0% resulted in the highest increases in plant height, rootstock girth, scion girth, number of leaves, and leaf area, significantly outperforming other concentrations and the control.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Studies on weather parameters, screening of cultivars and efficacy of fungicides on *Alternaria alternata* causing leaf spot in bael (*Aegle marmelos*)

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ABSTRACT

Thirteen bael cultivars were evaluated for resistance to Alternaria leaf spot disease. Three cultivars were classified as resistant, nine as moderately resistant, and one as moderately susceptible. The disease prevalence was influenced by weather conditions, particularly temperatures ranging from 27.60°C to 35.75°C, relative humidity between 58.00% and 80.40%, 7.80 hours of daily sunshine and 1.50 mm of rainfall. The disease spread rapidly after seasonal rains, peaking during the 35th meteorological week with 60.60% intensity under temperatures of 24.95°C to 31.80°C and relative humidity of 74.05% to 90.25%. Among all the treatments, Propiconazole (@ 0.1%) was the most effective, reducing disease intensity (7.78%) and 71.41% disease control followed by Difenconazole (@ 0.1%) 10.69% disease intensity and 60.35% disease control, respectively.

Introduction

Bael (*Aegle marmelos* Correa) is one of the most important indigenous fruits of the arid tropics belongs to the Rutaceae family. It is also known as 'Shriphal' and 'Bengal Quince' and is widely cultivated in various parts of Eastern Uttar Pradesh. It has been known in India since prehistoric time and holds significant mythological value. It is considered sacred, dedicated to Lord Shiva and referenced in ancient texts such as the Ramayana, Yajurveda, Buddhist and Jain scriptures. Bael leaves are also traditionally used in worship during the Vinayaka chaturthi festival, particularly for offerings to Lord Ganesha.

The bael fruit is known by various name across different regions: Bengal quince, Indian quince, golden apple, holy fruit, stone apple, Bel, Bela, Sriphal, Belger, Baelpatra, Bilva, maredu, Bilpandu, Bil, Katori, and Maredoa in India; Matum and Mapin in Thailand; Phneover Pnoi in Cambodia; Baunav in Vietnam; Oranger du Malabar in French; and Marmelos in Portuguese. Although the bael tree grows in most Indian states, it is commonly found in Uttar Pradesh, Bihar, West Bengal, Orissa, and Madhya Pradesh. The plant thrives abundantly in Eastern Uttar Pradesh, especially in the districts of Mirzapur, Varanasi, Gorakhpur, Basti, Gonda, Faizabad, Sultanpur, Etawah as well as the Sewan district of Bihar (Teaotia *et al.,* 1963). According to Jauhari and Singh (1971) varieties such as 'Kaghi Etawah,' 'Sewan Large,' 'Mirzapur,' and 'Deoria Large' were found to be superior in taste and quality.

Bael fruits contain 61.5 g of water, 1.8 g of protein, 0.39 mg of thiamine, 1.19 mg of fat, 87 mg of riboflavin, 1.1 mg of niacin, 55 mg of Vitamin A, 85 mg of calcium, 50 mg of phosphorus, 600 mg of potassium, and 8 mg of Vitamin C per 100 grams of the edible portion (Gopalan *et al.,* 1971; Kumar *et al.,* 2023). Among the several fruits containing riboflavin, bael contains highest vitamin B-2 (riboflavin). The ripe fruit serves as a tonic, restorative, astringent, laxative, and is beneficial for the heart and brain. The unripe fruit is recognized for its

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astringent, digestive, and stomachic properties and is often used to treat diarrhea and dysentery. Pitre and Srivastava (1987) studied the anti-diarrheal activity of bael root.

In India, bael trees typically flower in April and May, shortly after new leaves emerge, with fruit maturing between March and June of the following year. Bael has a rich history of ethno-medicinal uses and is recognized as a valuable source of medicine for various human and animal ailments (Kala, 2006). Different parts of the bael plant can be employed to address numerous health issues, including diabetes, liver toxicity, fungal and microbial infections, inflammation, fever, and pain relief (Sharma *et al.,* 2011; Purohit and Vyas, 2005). The fruit is utilized in pickles and sweetened preserves known as murabba when unripe, and once ripe, it is processed into jellies, shakes, and juices, providing a cooling effect, especially during summer. Bael fruit is generally resistant to pests and diseases, though it can be affected by fungi during storage (Orwa *et al.,* 2009). Observations of conidiophores showed dark structures with chains of conidia, which had both cross and longitudinal septa, characteristic of *Alternaria* species. The average size of the conidia ranged from 25-60 × 10-16 µm. The first documentation of Alternaria blight on bael occurred in the Eastern Plateau and Hill region of India (Maurya *et al.,* 2016).

Nursery plants are prone to several fungal foliar diseases, such as root rot caused by *Fusarium solani*, leaf spot caused by *Myrothecium roridum (*Kumar, S. and Singh, H.K. (2021) and *Alternaria alternata* (Maurya *et al.,* 2016 and Singh *et al.,* 2023), as well as dieback and leaf spot caused by *Fusarium pallidoroseum* (Anonymous, 2010 and Kumar *et al.* (2021). Among them, Alternaria leaf spot of bael is now becoming an important menace in Uttar Pradesh and other parts of the country. Madaan and Gupta (1985) first time reported leaf spot disease of bael, caused by *Alternaria alternata* (Fr.) Keissler from Hisar, Haryana. Hence, present study was undertaken to manage the leaf blight of bael by screening, epidemiological studies and through different contact and systemic fungicides.

Material and Methods

Field experiments were conducted on a bael cultivar at the Main Experimental Station latitude 26.55^0 N and longitude 81.84^0 E, Department of Fruit Science, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya during the year 2021-22 and 2022-23 season. The experiment was conducted in Randomized Block Design with three replications to assess the resistance in bael cultivars, along with epidemiological studies and effect of fungicides for Alternaria leaf spot. The treatments included: T_1= Copper Oxychloride 50% WP at 0.2%; T_2= Mancozeb 75% WP at 0.2%; T_3= Carbendazim 50% WP at 0.2%; T_4= Propiconazole 25 EC at 0.1%; T_5= Difenconazole 35 EC at 0.1%; T_6= Trifloxystrobin at 0.1%; T_7= Antracol at 0.2%; T_8= Iprodione at 0.2%; T_9= Fludioxonil at 0.1%; and T_{10} = Control. Each treatment was applied in 8x8m^2 distance with three replications. Fungicides were applied in three foliar sprays at 15 days interval, starting with the first spray immediately after disease onset. Disease development was assessed 20 days after the final spray, and per cent disease index (PDI) was calculated using a 0-5 rating scale.

Table 1. Scale for disease intensity

Rating	Average disease intensity in (%)	Per cent area covered with disease infection	Disease Reaction
0	0%	No infection	Immune
1	0.1-5 %	0.1-5% area covered	Resistant
2	5.1-20 %	5.1-20% area covered	Moderate Resistant
3	20.1-50 %	20.1-50% area covered	Moderately Susceptible
4	50.1- 75%	50.1-75% area covered	Susceptible
5	75.1-100%	75.1% or above	Highly Susceptible

Per cent disease intensity and per cent disease control were calculated by using the following formula (Vincent, 1947).

$$\text{Per cent disease incedence}= \frac{\text{No of infected Leaves}}{\text{Total no of examined leaves}} X100 \frac{\text{No of infected Leaves}}{\text{Total no of examined leaves}} X100$$

$$\text{Per cent disease index}= \frac{\text{Sum of all numerial rating scale}}{\text{Totl no of examined Leves x maximum grade}} X100$$

$$\frac{\text{Sum of all numerial rating scale}}{\text{Totl no of examined Leves x maximum grade}} X100$$

$$\text{Per cent disease control}= \frac{\text{\% disease of Control} - \text{\% disease of Treatent}}{\text{\% disease of Control}} X100$$

Results and Discussion

Thirteen genetically diverse genotypes of bael were tested and per cent disease incidence and severity (%) were recorded in each cultivar for resistance against Alternaria leaf spot of bael caused by *Alternaria alternata* (Table 2 and Fig. 1). Among the cultivars, ND/AH-11 exhibited the lowest average incidence and severity of Alternaria leaf spot, recording 8.99% and 2.42%, respectively. This was followed by NB-4 with 10.37% and 3.34%, ND/AH-8 with 16.59% and 4.14%, NB-9 with 21.85% and 5.17%, and NB-16 with 27.47% and 7.08%, respectively. Conversely, CISH B-2 had the highest incidence and severity, at 70.29% and 22.18%. These findings align with those reported by Singh *et al.* (2023). Among 13 cultivars, 3 were classified as resistant, 9 as moderately resistant, and 1 as moderately susceptible against Alternaria leaf spot (Table 2).

Table 2. Identification of resistance sources against Alternaria leaf spot of bael

S. No.	Variety	Disease incidence (%)		Pooled mean	Disease severity (%)		Pooled mean	Disease reaction
		2021-22	2022-23		2021-22	2022-23		
1	CIAH B 1	57.3	70.58	63.94	11.00	16.35	13.68	MR
2	CISH B 2	63.33	77.25	70.29	21.07	23.30	22.18	MS
3	N B-5	37.65	49.27	43.46	9.73	10.48	10.11	MR
4	N B-9	17.37	26.33	21.85	3.27	7.07	5.17	MR
5	N B-16	22.33	32.6	27.47	5.83	8.33	7.08	MR
6	N B-17	42.33	53.65	47.99	9.82	11.00	10.41	MR
7	Pant Aparna	60.00	73.93	66.97	16.17	17.80	16.98	MR
8	Pant Sujata	48.17	58.55	53.36	11.37	12.17	11.77	MR
9	N B-7	53.37	65.13	59.25	11.70	14.23	12.96	MR
10	N B-4	10.41	10.33	10.37	3.10	3.57	3.34	R
11	ND/AH-8	15.35	17.83	16.59	4.36	3.93	4.14	R
12	ND/AH-17	31.83	44.13	37.98	7.91	8.34	8.13	MR
13	ND/AH-11	7.91	10.08	08.99	1.99	2.86	2.42	R

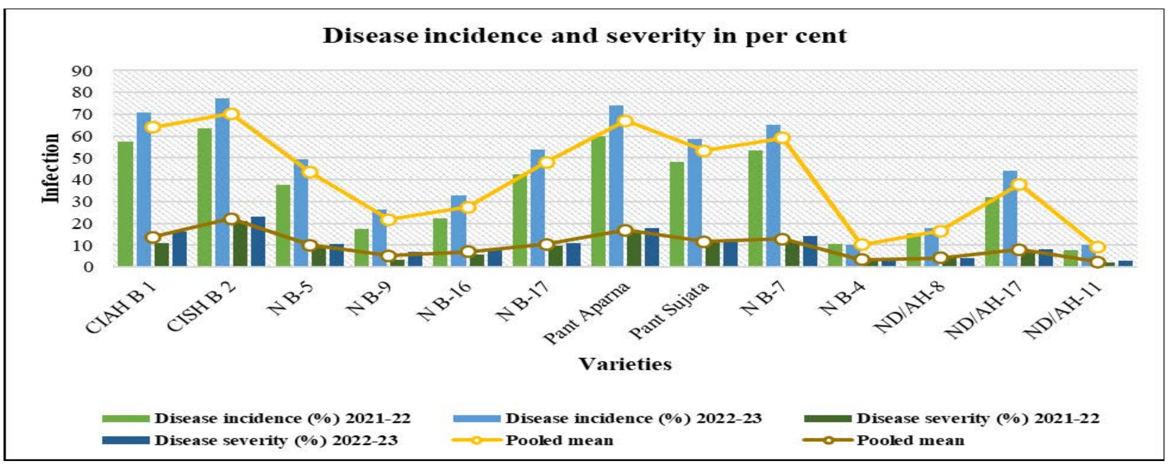

Fig. 1. Screening of bael cultivars against Alternaria leaf spot

Disease development of Alternaria leaf spot of bael in relation to weather parameters

During the first week of July (28th meteorological week), Alternaria leaf spot symptoms were observed on bael nursery plants, starting from the initial growth stage. The symptoms began at the leaf margins and tips, appearing as irregular, light brown spots that gradually darkened to brown and gray. As the disease progressed, several spots merged, forming larger necrotic areas, eventually covering significant portions of the leaves. Under severe conditions, these coalesced spots formed large patches, leading to leaf defoliation (Kumar *et al.*, 2015).

The initial onset of the disease coincided with weather conditions including temperatures ranging between 27.60°C and 35.75°C, relative humidity between 58.00% and 80.40%, daily sunshine of 7.80 hours, and 1.50 mm of rainfall. It was noted that the disease spread rapidly following seasonal rains (Table 3 and Fig. 2).

Table 3. Alternaria leaf spot of bael disease and its correlation with weather parameters

SMW	Date	Max Temp	Min Temp	Max RH	Min RH	Rf	SS	PDI
28	09July - 15July	35.75	27.60	80.40	58.00	1.50	7.85	1.21
29	16July - 22July	34.95	26.90	85.50	67.25	34.40	4.25	3.69
30	23July – 29July	33.40	26.50	89.90	73.30	60.50	2.80	7.13
31	30July – 05Aug.	33.00	25.90	89.05	70.40	12.10	4.20	9.88
32	06Aug. – 12Aug.	32.90	26.20	92.25	73.70	66.80	4.25	11.96
33	13Aug. -19Aug.	33.15	25.80	90.45	75.10	25.30	5.55	14.68
34	20Aug. - 26Aug.	32.20	25.50	92.75	77.95	44.90	5.10	16.87
35	27Aug. - 02Sep.	33.20	25.80	88.40	71.25	9.90	4.75	21.30
36	03Sep. - 09Sep.	34.05	25.45	89.30	64.25	26.90	5.90	25.05
37	10Sep. - 16Sep.	31.80	24.95	90.25	74.05	52.30	4.70	27.19

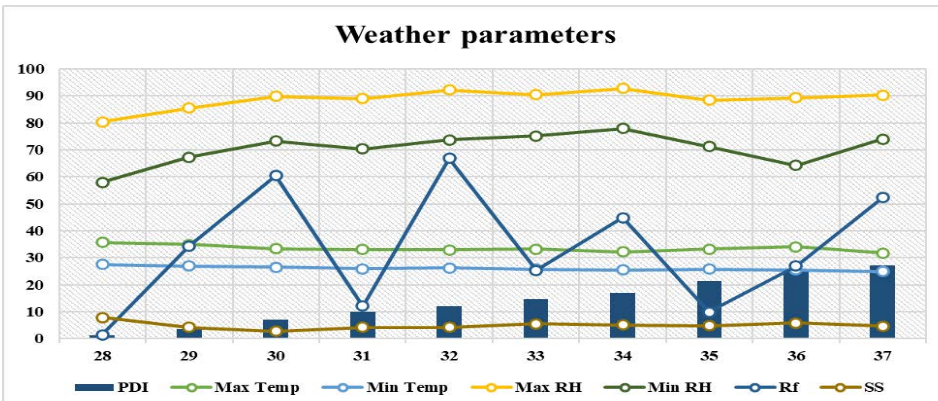

Fig. 2. Alternaria leaf spot of bael disease and its correlation with weather parameters

The highest disease intensity (60.60%) was observed during the 35th meteorological week, when weather conditions included temperatures between 24.95°C and 31.80°C, and relative humidity ranging from 74.05% to 90.25%. Additionally, there were 4.70 hours of sunshine per day and 52.30 mm of rainfall, which favored the first appearance of the disease. A negative and highly significant correlation (at the 1% level) was noted between PDI (Per cent Disease Index) and minimum temperature, while the correlation between PDI and maximum temperature was also negative but only significant. Other weather parameters showed non-significant correlations with PDI, whether positive or negative (Table 4). Similarly, Jayalakshmi *et al.* (2022) and Shivaji *et al.* (2017) recorded disease symptoms in the 29th meteorological week (2nd week of July), with weather conditions of maximum temperature (32.80°C), minimum temperature (27.00°C), morning relative humidity (84.80%), evening relative humidity (70.70%), sunshine hours/day (4.70), and rainfall (28.00 mm). Other studies, such as Ansari *et al.* (1989) and Degenhardt *et al.* (1982), also found that environmental factors, including temperatures of 15-25°C, relative humidity above 80%, and leaf wetness (rain or dew) for 4-24 hours, contributed to disease development and epidemics by supporting pathogen survival (Table 4).

Table 4. Correlation coefficient of PDI of Alternaria leaf spot of bael with weather parameters

	Max. Temp.	Min Temp	Max RH	Min RH	Rf	SS	PDI
Max Temp	1						
Min Temp	0.853**	1					
Max RH	-0.876**	-0.772**	1				
Min RH	-0.881**	-0.632*	0.885**	1			
Rf	-0.513	-0.280	0.654*	0.606	1		
SS	0.496	0.266	-0.587	-0.639*	-0.629*	1	
PDI	-0.658*	-0.917**	0.564	0.376	0.149	-0.038	1

***Correlation is significant at the 0.01 level*
**Correlation is significant at the 0.05 level*
Rf-Rainfall
SS=Sunshine hours/ day

The results of the foliar application of fungicides, presented in Table 5 and Fig. 3 that Propiconazole @ 0.1% recorded the lowest disease intensity with 7.78%. This treatment was statistically comparable to other treatments, including Difenoconazole @ 0.1%, Antracol @ 0.2%, Copper Oxychloride @ 0.2%, Trifloxystrobin @ 0.1%, Iprodione @ 0.2%, Mancozeb @ 0.2%, Carbendazim @ 0.2%, and Fludioxonil @ 0.1%. The corresponding disease intensities for these treatments were 10.69%, 13.99%, 14.79%, 15.77%, 17.88%, 21.34%, 22.33%, and 23.80%, respectively. Highest disease control was observed in Propiconazole @ 0.1% (71.41%), followed by Difenoconazole @ 0.1%, Antracol @ 0.2%, Copper Oxychloride @ 0.2%, Trifloxystrobin @ 0.1%, Iprodione @ 0.2%, Mancozeb @ 0.2%, Carbendazim @ 0.2%, and Fludioxonil @ 0.1%, with corresponding disease control of 60.35%, 48.20%, 45.23%, 41.62%, 33.78%, 21.07%, 17.50%, and 12.18%, respectively.

Similarly, Shivaji *et al.* (2017) found that Propiconazole at 0.1% was the most effective fungicide with disease severity of 7.78%, followed by Difenoconazole at 0.1% (PDI 8.34%) and Mancozeb at 0.2% (PDI 11.96%). Highest disease control (75.12%) was recorded in Propiconazole, followed by Difenoconazole (73.67%) and Mancozeb (57.71%). In another study by Maurya *et al.* (2016), successful disease management was achieved through foliar application of Chlorothalonil 75 WP @ 3g/l, followed by Carbendazim, 50 WP @1-1.5g/l at 15-day intervals. Vishwakarma *et al.* (2021), Mishra *et al.* (2017) and Kumari (2019) found that the lowest disease intensity (16.05%) was observed with Propiconazole at 0.1%, which was statistically similar to treatments with Difenoconazole at 0.1%, Copper Oxychloride at 0.2%, and Mancozeb at 0.2%, which had disease intensities of 17.10%, 18.47%, and 19.18%, respectively.

Table 5. Efficacy of fungicides against Alternaria leaf spot of bael

S No.	Treatments	Disease severity (%)		Pooled mean	Per cent disease control		Pooled mean
		2022	2023		2022	2023	
1	Copper oxychloride @ 0.2%	15.25 (22.96)	14.32 (22.22)	14.79	41.07	49.39	45.23
2	Mancozeb @ 0.2%	20.83 (27.13)	21.85 (27.85)	21.34	19.22	22.92	21.07
3	Carbendazim @ 0.2%	21.24 (27.43)	23.42 (28.92)	22.33	17.71	17.31	17.51
4	Propiconazole @ 0.1%	6.83 (15.13)	8.73 (17.17)	7.78	73.64	69.17	71.41
5	Difenconazole @ 0.1%	11.16 (19.48)	10.22 (18.62)	10.69	56.52	64.18	60.35
6	Trifloxystrobin @ 0.1%	15.91 (23.49)	15.63 (23.27)	15.77	38.21	45.02	41.62
7	Antracol @ 0.2%	14.05 (21.99)	13.94 (21.89)	13.99	45.51	50.89	48.20
8	Iprodione @ 0.2%	18.15 (25.20)	17.61 (24.79)	17.88	29.68	37.87	33.78
9	Fludioxonil @ 0.1%	22.73 (28.46)	24.87 (29.89)	23.80	11.92	12.45	12.18
10	Control	25.87 (30.54)	28.50 (32.24)	27.19	0.00	0.00	0.00
	CD at 5%	1.846	2.020	2.09			6.56
	SE(m)	0.616	0.675	0.71			2.22
	SE(d)	0.872	0.954	1.00			3.13

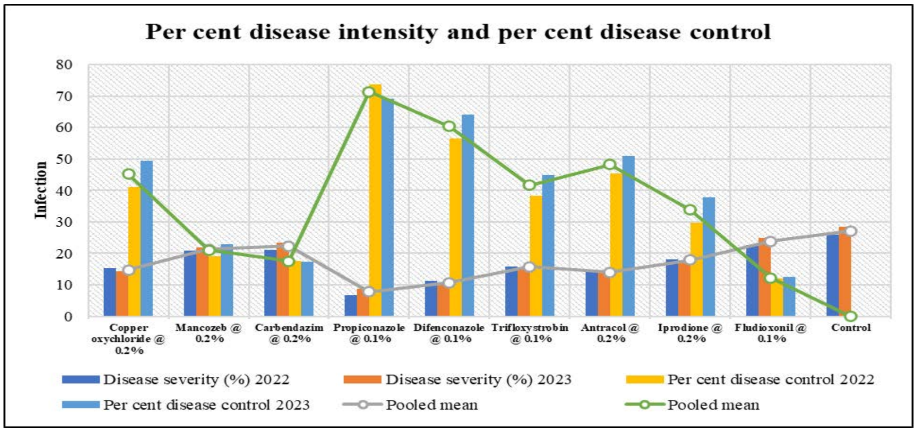

Fig. 3. Effect of fungicides on Alternaria leaf spot of bael

The fungal leaf spot disease causes significant vegetative loss in bael nurseries and is prevalent in this region. An *in vitro* study assessing the efficacy of fungicides on Alternaria leaf spot in bael nurseries showed that all treatments were significantly more effective than the control. Maximum fungal inhibition (100%) was observed with the application of Propiconazole at 0.1%, Difenoconazole at 0.1%, Antracol at 0.2%, and Copper Oxychloride at 0.2%. Similarly, Mishra *et al.* (2017) reported that Mancozeb and Carbendazim achieved 87.05% and 79.76% growth inhibition, respectively. After 72 hours, growth inhibition in Carbendazim and Mancozeb-treated plates was 69.54% and 86.00%, respectively. By 96 hours, complete (100%) growth inhibition was recorded in plates treated with Propiconazole and Difenoconazole, while Carbendazim, Mancozeb, and Copper Oxychloride treatments showed growth inhibition of 65.00%, 82.80%, and 95.32%, respectively.

Conclusion

The evaluation of bael cultivars for resistance to Alternaria leaf spot reveals significant variability in disease susceptibility among the 13 tested cultivars, with three classified as resistant and nine as moderately resistant. Weather conditions play a crucial role in disease prevalence, highlighting the importance of monitoring temperature and humidity levels, especially after seasonal rains when disease intensity peaks. The findings underscore the effectiveness of Propiconazole (0.1%) in managing Alternaria leaf spot, demonstrating a substantial reduction in disease intensity and control. These insights can inform both cultivation practices and disease management strategies, promoting the sustainable production of Bael in arid tropical regions. Further, research is recommended to explore the genetic basis of resistance in the identified cultivars and the long-term efficacy of fungicide treatments.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Effect of biofertilizers on growth of jackfruit (*Artocarpus heterophyllus* L.) and soil nutrients in South-East Rajasthan

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ABSTRACT

The soil application of different microbial consortia significantly influenced the growth, development, and soil nutrient status of jackfruit (Artocarpus heterophyllus L.) cv. Singapore Jack in South-East Rajasthan. Among the various treatments, the application of T_6 (a combination of Azospirillum, PSB, and KSB, 75g each per plant) was found to be significantly superior. The T_6 treatment resulted in notable improvements in growth and development parameters, including an 8.05% increase in rootstock girth, 15.0% in scion girth, 69.0% in plant height, 70.0% in the number of nodes per plant, 178.10% in the number of leaves per plant, a 22.92% increase in leaf area, and a chlorophyll content of 41.25 mg/100g in leaves. Additionally, T6 demonstrated superiority in enhancing soil health parameters viz., organic carbon content (0.61%), available nitrogen (326.33 kg/ha), phosphorus (36 kg/ha), and potassium (309.0 kg/ha).

Introduction

Jackfruit (*Artocarpus heterophyllus* L.) is one of the most important and widely cultivated fruit trees in tropical regions, belonging to the family Moraceae. It is native to the rainforests of the Western Ghats, a biodiversity hotspot in India. Jackfruit is also found in the wild and evergreen forests of Assam and Myanmar. Traditionally, the fruit has been a staple for the economically disadvantaged, often replacing rice as a primary meal component, earning it the title "the poor man's food" (Rahman *et al.*, 1999). Jackfruit is a powerhouse of phyto-nutrients with properties such as anti-cancer, antioxidant, antihypertensive, anti-ulcer, and anti-inflammatory effects. These attributes help combat oxidative stress, reduce the risk of chronic conditions like diabetes and heart disease, boost immune response, and promote skin and hair health. Additionally, the root of jackfruit has medicinal applications, offering relief from asthma and aiding in the treatment of diarrhoea and fever (Samaddar, 1985).

While modern intensive farming methods have increased crop yields, they are often associated with environmental pollution and health hazards, eventually leading to reduced agricultural productivity and threatening global food security. Fertilizer management plays a critical role in enhancing the growth and productivity of crops. Biofertilizers provide an eco-friendly and sustainable alternative to synthetic fertilizers. These live formulations, containing beneficial microorganisms, can be applied to roots, soil, or seeds, enhancing soil health and nutrient availability (Ismail *et al.*, 2013). Certain bacteria, such as phosphorus solubilizing bacteria (PSB) and potassium solubilizing bacteria (KSB), mobilize these essential nutrients into plant-usable forms. When used in combination, biofertilizers not only

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improve nutrient uptake but also offer additional benefits such as acting as bio-control agents against plant diseases, reclaiming degraded soils, breaking down organic waste, and remediating pesticides in the rhizosphere.

Despite its nutritional and ecological significance, jackfruit remains a neglected crop, with limited research on the role of biofertilizers in its cultivation. Hence, this study aims to evaluate the effect of biofertilizers on the growth and development of jackfruit plants, paving the way for more sustainable and productive farming practices for this underutilized crop.

Material and Methods

The study on the effect of different biofertilizers on the growth of jackfruit and soil nutrient status was carried out during 2020-2021 at the Instructional Farm, Department of Fruit Science, College of Horticulture and Forestry, Jhalarapatan, Jhalawar. The experiment was conducted on a newly established orchard of jackfruit cv. Singapore Jack. The experimental site is located between 23°4'and 24°52' N latitude and 75°29' and 76°56' E longitude. The experiment comprised seven treatments viz., T_0 (Control), T_1 (Azospirillum 25g), T_2 (PSB 25g), T_3 (KSB 25g), T_4 (Azospirillum 25g + PSB 25g + KSB 25g), T_5 (Azospirillum 50g + PSB 50g + KSB 50g) and T_6 (Azospirillum 75g + PSB 75g + KSB 75g). The experiment was arranged in a Randomized Block Design (RBD) with three replications.

Initial values for growth parameters, including rootstock girth, scion girth, plant height, number of nodes per plant, number of leaves per plant, leaf area, and chlorophyll content in leaves, were recorded in August 2020. Following the commencement of the experiment, observations on plant parameters were recorded at two-month intervals until March 2021. Soil parameters, such as available nitrogen (N), phosphorus (P), potassium (K), organic carbon percentage, bulk density, particle density, and porosity, were assessed at the beginning and end of the experiment. During the experimental period from August 2020 to March 2021, plant parameters were recorded at three intervals: October, December, and March. The data collected during the experiment were statistically analyzed using the methods outlined by Panse and Sukhatme (1995).

Results and Discussion

Growth parameters

The growth parameters of jackfruit plants, as influenced by different biofertilizers at varying levels, are presented in Table 1. Significant differences among treatments were observed across all stages of plant growth. The highest increases in rootstock girth (8.05%), scion girth (15%) and percentage increase in plant height (69%) were recorded under treatment T_6 (Azospirillum, PSB, and KSB at 75g each) during the final observations in March. Conversely, the lowest values were observed in the T_0 control treatment after the experiment. Treatment T_6 (Azospirillum, PSB, and KSB at 75g each) was significantly superior to all other treatments.

The data presented in Table 2 indicate that, at the end of the experiment in March, the maximum percentage increase in the number of nodes (70.0%) was observed under treatment T_6 (Azospirillum, PSB, and KSB at 75g each). This was closely followed by treatments T_5 and T_4 (Azospirillum, PSB, and KSB at 50g and 25g each, respectively), recording a 60.0% increase, with T_5 and T_4 being statistically at par. The minimum percentage increase in the number of nodes (37.50%) was recorded in the T_0 control treatment at the end of the experiment. These findings align with the results reported by Srivastava *et al.* (2019), Kumar *et al.* (2013), and Dheware *et al.* (2020) in guava cultivation. Better growth under this treatment over other treatments may be due to the higher effectivity of this treatment in the improvement of rhizosphere micro-environment providing all the macro and micronutrients required for the growth and development of plants. The effect of this treatment comparatively better over other treatments may also be explained in the background of better improvement of physico-chemical properties of the soil due to moderation of pH and EC, enrichment of the organic carbon, N, P, K status of the soil as reflected in the result besides probably due to better increased release of growth factors like auxins, gibberellins and cytokinin in root zone.

The data presented in Table 2 on the number of leaves per plant revealed significant differences among the various treatments. The maximum percentage increase in the number of leaves per plant (178.10%) was recorded under treatment T_6 (Azospirillum, PSB, and KSB at 75g each), followed by treatment T_5 (Azospirillum, PSB, and KSB at 50g each) with a 133.39% increase, observed during the final observations in March. In contrast, the minimum increase (63.69%) in the number of leaves per plant was recorded in the T_0 control treatment at the conclusion of the experiment. At the end of the experiment in March, the maximum percentage increase in leaf area (22.92%) was observed under treatment T_6 (Azospirillum, PSB, and KSB at 75g each), which was significantly higher than all other treatments. Additionally, the data indicated that T_6 also achieved the highest increase in chlorophyll content (41.45 mg/100g), followed closely by T_4 (39.23 mg/100g). In contrast, the minimum increase in chlorophyll content (35.24 mg/100g) was recorded in the T_0 control treatment. This may be due to the ability of phosphorous solubilizing bacteria (PSB) to produce growth-promoting substances such as IAA and gibberellins acid. It is also well known that PSB produces organic, inorganic acids and CO_2, which perhaps led to moderating soil acidity and consequently might convert the insoluble forms of phosphorus into soluble ones (Mosse *et al.*, 1981). Such an effect may also account for better results under treatment T_6 (Azospirillum, PSB, KSB) (75g each). Better improvement in proline content in the leaf may be due to water stress created during the growth period and the production of amino acid-like proline by this treatment containing different PGPR applied. These results agree with those of Mathur and Vyas (2000) as reported in *Ziziphus mauritiana* Lam. Kumar *et al.* (2013), who also a maximum increase in growth in banana plants inoculated with a combined inoculation of nitrogen fixers and PSB and Nandish *et al.* (2020) in jamun trees.

Table 1. Effect of biofertilizers on rootstock girth, scion girth and plant height of jackfruit

Treatments	Rootstock girth (mm)*				Scion girth (mm)*				Plant height (cm)*			
	Initial value (August 2020)	October 2020	December 2020	March 2021	Initial value (August 2020)	October 2020	December 2020	March 2021	Initial value (August 2020)	October 2020	December 2020	March 2021
T_0 (Control)	2.53	2.55 (1.04)	2.59 (2.36)	2.64 (2.75)	2.00	2.03 (1.56)	2.07 (3.74)	2.12 (6.07)	13.46	14.96 (11.13)	16.36 (21.53)	17.73 (31.68)
T_1 (Azospirillum 25g)	2.36	2.59 (0.55)	2.42 (2.53)	2.47 (4.95)	1.79	1.84 (2.96)	1.90 (5.93)	1.96 (99.39)	13.36	16.03 (19.95)	18.93 (41.64)	20.6 (54.11)
T_2 (PSB 25g)	2.83	2.85 (0.70)	2.87 (1.29)	2.93 (3.49)	1.66	1.71 (3.05)	1.75 (5.26)	1.87 (12.47)	11.36	13.50 (18.76)	14.50 (27.56)	15.63 (37.53)
T_3 (KSB 25g)	2.63	2.64 (0.45)	2.71 (2.98)	2.77 (5.48)	1.90	1.95 (2.58)	1.85 (4.98)	2.04 (7.19)	10.33	11.06 (7.09)	11.80 (14.19)	14.00 (35.48)
T_4 (Azospirillum 25g + PSB 25g + KSB 25g)	2.98	3.01 (0.93)	3.04 (1.94)	3.10 (3.88)	1.78	1.81 (1.53)	1.85 (4.15)	1.95 (9.50)	12.03	13.06 (8.58)	14.06 (16.89)	16.23 (34.90)
T_5 (Azospirillum 50g + PSB 50g + KSB 50g)	2.53	2.56 (1.24)	2.58 (2.03)	2.68 (5.74)	1.40	1.47 (4.71)	1.50 (7.100	1.60 (14.20)	11.76	15.00 (27.47)	18.06 (53.54)	19.66 (67.13)
T_6 (Azospirillum 75g + PSB 75g + KSB 75g)	2.89	2.92 (1.21)	2.98 (3.05)	3.12 (8.05)	1.82	1.94 (6.42)	2.00 (9.89)	2.09 (15.00)	10.43	14.36 (37.69)	16.50 (58.14)	17.63 (69.00)
CD at 5%	-	0.37	0.34	0.34	-	0.25	0.25	0.23	-	2.37	2.79	4.07
SEm±	-	0.12	0.11	0.11	-	0.08	0.08	0.07	-	0.77	0.90	1.32

*Percent values in parentheses

Table 2. Effect of biofertilizers on number of leaves, number of nodes and leaf area of jackfruit

Treatments	Number of nodes*				Number of leaves*				Leaf area (cm^2)*				Chlorophyll content (mg/100g)	
	Initial value (August 2020)	October 2020	December 2020	March 2021	Initial value (August 2020)	October 2020	December 2020	March 2021	Initial value (August 2020)	October 2020	December 2020	March 2021	Initial	Final
T_0 (Control)	5.33	5.66 (6.25)	6.00 (12.50)	7.33 (37.50)	2.10	2.22 (5.91)	2.44 (16.13)	3.44 (63.69)	3.99	4.07 (1.84)	4.14 (3.67)	4.28 (7.13)	34.24	35.24
T_1 (Azospirillum 25g)	3.66	4.00 (9.09)	4.33 (18.18)	5.33 (45.54)	0.95	1.16 (22.09)	1.34 (41.27)	2.10 (120.03)	4.40	4.56 (3.65)	4.65 (5.54)	4.86 (10.51)	35.28	37.60
T_2 (PSB 25g)	3.66	4.00 (9.09)	5.00 (36.36)	5.66 (54.54)	1.14	1.52 (32.56)	1.76 (54.00)	2.48 (116.73)	3.28	3.47 (5.66)	3.57 (8.70)	3.87 (17.87)	36.28	38.92
T_3 (KSB 25g)	3.33	3.66 (10.0)	4.60 (40.0)	5.00 (50.0)	1.37	1.67 (23.84)	1.86 (39.12)	2.86 (114.37)	2.72	2.90 (6.53)	3.09 (13.37)	3.27 (20.12)	34.14	36.20
T_4 (Azospirillum 25g + PSB 25g + KSB 25g)	3.33	3.66 (10.0)	5.00 (50.0)	5.33 (60.0)	1.14	1.51 (32.26)	1.72 (50.60)	2.29 (100.02)	3.08	3.15 (2.13)	3.18 (3.10)	3.31 (7.24)	35.26	39.23
T_5 (Azospirillum 50g + PSB 50g + KSB 50g)	3.33	3.66 (10.0)	4.00 (20.0)	5.33 (60.0)	1.14	1.64 (43.32)	1.89 (65.66)	2.67 (133.39)	3.37	3.54 (4.93)	3.70 (9.57)	4.08 (21.08)	36.33	38.39
T_6 (Azospirillum 75g + PSB 75g + KSB 75g)	3.33	4.00 (20.0)	5.33 (60.0)	5.66 (70.0)	1.72	2.83 (64.72)	3.41 (98.64)	4.78 (178.10)	4.36	4.73 (8.32)	5.09 (16.72)	5.36 (22.92)	35.45	41.45
CD at 5%	-	0.82	1.12	1.15	-	0.68	0.94	1.44	-	1.13	1.17	1.20	-	1.90
SEm±	-	0.26	0.36	0.37	-	0.22	0.30	0.46	-	0.36	0.38	0.39	-	0.61

*Percent values in parentheses

Soil parameters

The data presented in Figure 1 illustrate the variation in electrical conductivity and pH of the rhizosphere soil of jackfruit plants (cv. Singapore Jack) in response to different biofertilizer treatments, measured after the growth period from August 2020 to March 2021. Soil electrical conductivity (0.39 dS/m) and pH (7.34) were significantly lower under treatment T_6 (Azospirillum, PSB, and KSB at 75g each). In contrast, the highest soil electrical conductivity (0.65 dS/m) and pH (7.75) were observed in the control treatment. Similar findings were reported by Nandish *et al.* (2020), who observed a significant reduction in soil electrical conductivity in jamun with the application of Azospirillum, PSB, KSB, VAM and *Trichoderma harzianum* (100g).

The available nitrogen (N), phosphorus (P), and potassium (K) levels (kg/ ha) are presented in Figure 1. The highest levels of available nitrogen (326.33 kg/ ha), phosphorus (36 kg/ ha), and potassium (309.0 kg/ ha) were recorded under treatment T_6 (Azospirillum, PSB, and KSB at 75g each), which was found to be significantly superior to all other treatments. Conversely, the lowest levels of available N, P, and K were observed in the T_0 (Control) treatment. This may be due to its better effectiveness over other treatments in increased biological nitrogen fixation and phosphate solubilization. Some bacteria can solubilize inorganic P due to chelation, exchange reaction, phosphate production and excretion of organic acids that have a moderating effect on soil pH and render the insoluble phosphate into soluble form. Generally, the solubility of calcium phosphates and magnesium increases with decreasing pH. The increase in potassium content under the biofertilizer treatment T_6 (Azospirillum, PSB, KSB) (75g each) was found to be better than other treatments. This may be attributed to the comparatively higher dissolution rate of silicates and minerals, which release potassium (K), as well as the production of enzymes like chitinase and cellulase. These enzymes help break down minerals and enhance root exudation, which, in turn, accelerates microbial proliferation and respiration. This microbial activity may lead to oxygen depletion in the rhizosphere, facilitating denitrification, as reported by Mishustin *et al.* (1981) and Barker *et al.* (1997). These findings are consistent with the research work of Esitken *et al.* (2010), Manjunath *et al.* (1983), Hussain *et al.* (2017) and Singh *et al.* (2021) in custard apple cv. Raydurg.

The application of treatments increased soil organic carbon percentage, with the highest value (0.61%) observed under treatment T_6 (Azospirillum, PSB, and KSB at 75g each), as shown in Figure 2. Treatment T_2 (0.52%) was statistically at par with treatment T_3 (0.51%). The lowest soil organic carbon content (0.41%) was recorded in the control treatment (T_0). Among the different biofertilizer treatments, the minimum bulk density (1.28 Mg/ cubic m) and particle density (2.62 Mg/ cubic m) were recorded in treatment T_6 (Azospirillum, PSB, KSB at 75g each). In contrast, the highest bulk density (1.37 Mg/ cubic m) and particle density (2.66 Mg/ cubic m) were observed in the T_0 (Control) treatment. Additionally, treatment T_6 (Azospirillum, PSB, KSB at 75g each) exhibited the highest porosity (51.27%), followed by T_1 (Azospirillum at 25g) with 50.30%. The minimum porosity (33.61%) was recorded in the T_0 (Control) treatment. The improvement in physico-chemical properties of soil in treatment T_6 (Azospirillum, PSB, KSB) (75g) might be attributed to increased organic matter status and improved soil physical structure (bulk density, porosity), as suggested by (Gogoi *et al.*, 2004). Relatively better soil pH in this treatment may be due to better production of various organic and inorganic acids produced by microorganisms. Microbial sources generally keep the soil pH neutral (Bagyaraj and Manjunath, 1980).

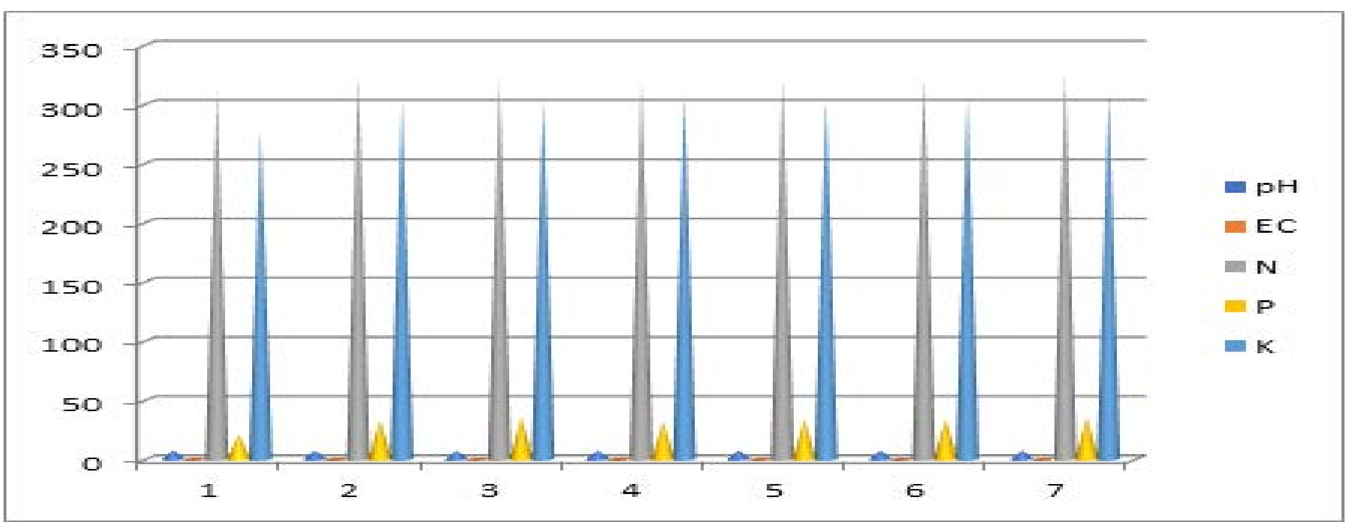
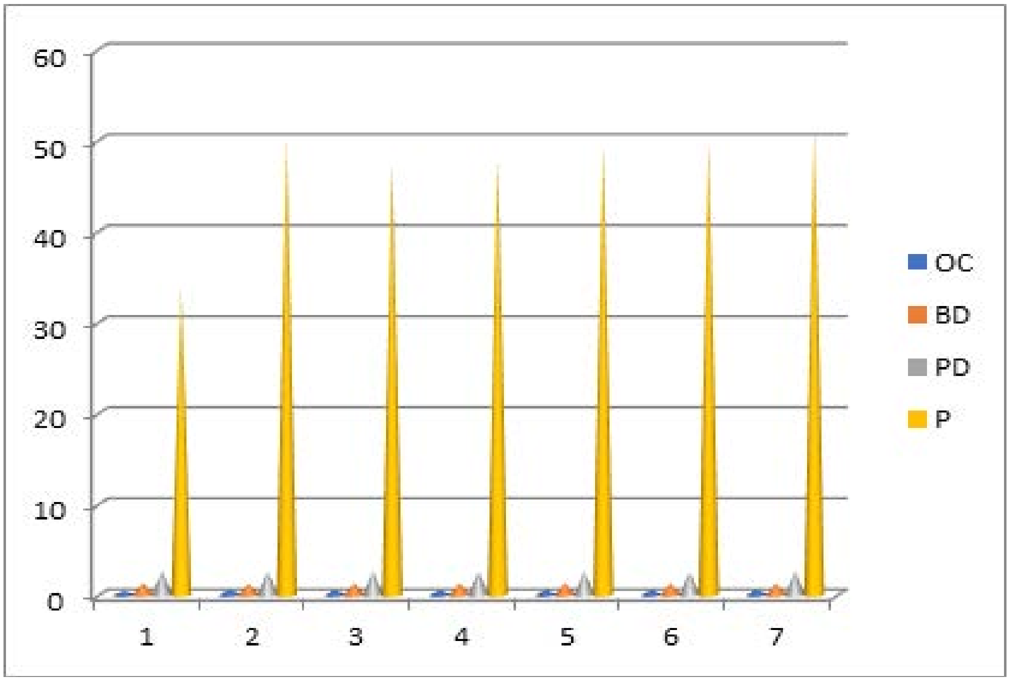


Fig. 1. Effect of biofertilizers on pH, Electrical Conductivity (EC), Nitrogen (N), Phosphorus (P) and Potassium (K) of orchard soil

Treatments



Treatments

Fig. 2. Effect of biofertilizers on Organic Carbon (OC), Bulk Density (BD), Particle Density (PD) and Porosity (P) of orchard soil

Conclusion

Based on the investigation, it can be concluded that the application of T6 (a combination of Azospirillum, PSB, and KSB, 75g each per plant) in jackfruit (*Artocarpus heterophyllus L.*) cv. Singapore Jack was significantly superior in improving both plant growth and development characteristics, as well as soil parameters. This treatment led to notable improvements in growth and development, including an 8.05% increase in rootstock girth, 15.0% in scion girth, 69.0% in plant height, 70.0% in the number of nodes per plant, a 178.10% increase in the number of leaves per plant, a 22.92% increase in leaf area, and a chlorophyll content of 41.25 mg/100g in leaves. The T_6 treatment demonstrated superiority in enhancing organic carbon content (0.61%), available nitrogen (326.33 kg/ha), phosphorus (36 kg/ha), and potassium (309.0 kg/ha). Therefore, the study concludes that T_6 (Azospirillum 75g + PSB 75g + KSB 75g) is the most effective treatment, surpassing both individual and combined microbial consortia in promoting jackfruit plant growth and improving soil quality.

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Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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Research Article

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Population dynamics of leaf gall midge, *Asphondylia phyllanthi* on aonla

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ABSTRACT

Leaf gall midge is a major pest that can significantly affect aonla production by causing leaf galls, reducing photosynthesis, and leading to overall plant stress. Population dynamics studies were carried out on gall midge (*Asphondylia phyllanthi* Felt) insect, which has been found causing galls on the leaves and shoots of *Phyllanthus emblica*. Initiation of Aonla leaf gall midge, damage was started in the month of February and it was reached at its maximum level in the month of September from 2010 to 2016. Insect population with meteorological observations showed that insect population positively correlated with the minimum and maximum temperature and negatively correlated with the relative humidity and rainfall during the study periods. It was found that 2-3 overlapping generations developed in March-May. The infestation damaged the axillary buds, inhibiting growth and normal branching.

Introduction

Aonla *(Phyllanthus emblica* Gaertn.) is nutritional and medicinal valued crop in India for its fruits and other products. Numerous galls caused by *A. phyllanthi* were observed on the leaves and shoots in orchards in Rajasthan, the infestation being particularly severe at Chomu, Jaipur and Pushkar areas of Rajasthan. Plant gall is an abnormal growth on any part of a plant formed due to active mitosis and morphogenesis of an affected cell. A galI results from hypertrophy (over growth) and hyperplasia (excessive cell division), usually under the influence of a parasitic organism (Mani, 1973). Galls may also be described as 'pathologically' developed cells, tissues or organs of plants. Galls were formed between Feb. and May, and were oval, scaly, hollow, soft, dehiscent and sessile. Larval development within them was completed in 28-34 days so that 2-3 overlapping generations developed. *Phyllanthus emblica* (*Emblica officinalis*) a euphorbiaceous tree that yields products used medicinally and in dying and tanning, and is also valued for its water-resistant timber. Asphondylia belongs to the tribe Asphondyliini, currently with 505 species, and within Asphondyliini to the sub-tribe Asphondyliina, which is diverse in the Neotropics (Gagné & Jaschhof, 2014). The subtribe contains 19 genera that share clear morphological apomorphies, but no cladistic or other phylogenetic analysis has been conducted upto 2016 to till date. All genera included in this group other than *Asphondylia* are small (with between one and 11 species), and most are restricted to South America. By contrast, *Asphondylia* is one of the largest genera in the family Cecidomyiidae, with 320 described species that feed on a great diversity of plant families worldwide (Gagné & Jaschhof, 2014), and the number of undescribed species in this genus is probably far greater. All *Asphondylia* species are gall inducers, and the galls are

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almost always associated with a fungus that lines the inside walls of the gall. Similar associations are known in other cecidomyiid genera, and although several studies suggested that the larvae of such 'ambrosia' gall midges feed on the fungus rather than on the plant tissue (Bisset & Borkent, 1988; Rohfritsch, 2008; Adair *et al*., 2009). Phytophagous insects are well-known models for studying diversification and speciation (Futuyma and Agrawal, 2009; Nosil, 2012). Numerous galls caused by the cecidomyiid, *A. phyllanthi* were observed on the leaves and shoots in orchards in different parts of the country including Rajasthan. Leaf gall midges cause extensive damage, reducing yield and quality. Studying the pest's life stages (egg, larva, pupa, and adult) to target control measures, understanding how gall midges induce gall and affect the physiology of the tree, seasonal patterns and environmental factors (temperature, humidity) influencing outbreaks, photosynthesis, nutrient uptake, yield losses and fruit quality and overall tree health. Eggs were laid in late May, which developed to the 2nd instar and remained in the undeveloped galls (less than 1 mm in diam.) until the following year, the first adults emerging in late February damaged the crop. The research on screening of aonla cultivars resistant or tolerant to leaf gall midge infestation has been limited. Early identification of pest presence and damage is crucial for timely intervention. The influence of climate change on the life cycle and distribution of the leaf gall midge has not been fully studied. The changes in temperature, humidity, and seasonal patterns could affect the pest's behaviour, population dynamics and the timing of infestations, but it requires the location specific research for developing sustainable pest management strategies. Keeping in view this study was conducted to develop the strategies for the management of leaf gall midge in aonla.

Material and Methods

The experiment was carried out during 2010 to 2016 at Experimental Station of Asalpur Farm, under SKN College of Agriculture, Jobner on fully-grown aonla trees of NA-7 cultivar. For recording observation on leaf gall midge, *Asphondylia phyllanthi,* ten aonla tree were selected from an orchard on which observation was recorded. On each tree, three branches were selected and tagged. Five twigs were selected randomly on each branch and per cent damaged and healthy twigs were counted (Fifteen twigs from each tree) at fifteen days interval throughout the year along with natural enemies. Simultaneously observations recorded on meteorological factors including temperature, RH, sunshine hrs/ day and rainfall. Correlation worked out by taking the previous fortnight data. Fortnightly observation were recorded on 10 randomly selected plants of NA-7 cultivar to find out the influence of abiotic factors on population/ infestation of leaf gall midge, *A. phyllanthi* on Indian gooseberry consecutively for seven years and percent galls/ plants worked out. The initiation of Aonla leaf gall midge, *Asphondylia phyllanthi* damage was started in the month of February and it was reached at its maximum level in the month of September in all the years.

Result and Discussion

Population dynamics study of Aonla Leaf gall midge, *Asphondylia phyllanthi* revealed that the initiation of Aonla leaf gall midge, *Asphondylia phyllanthi* damage was started in the month of February and it was reached at its maximum level in the month of September in all the years (Table 1). The population density of leaf gall midge were evaluated in every year and data showed that maximum population fluctuation was observed on 25-26, 29-30 SMW in the year 2010 (Table 2). In the year 2011 maximum population fluctuation were observed on 13-14, 15-16 & 37-38 SMW. In 2012 maximum population fluctuation were observed on 15-16 & 35-36 SMW. During the year 2013 maximum population fluctuation were observed on 25-26, 29-30 & 35-36 SMW i.e. 3.69, 8.53 & 7.27 respectively. In the year 2014 maximum population density were observed on 13-14, 23-24 & 33-34 SMW whereas the population was 6.20, 8.20 & 12.40, respectively. In 2015, the maximum population density in leaf gall midge was observed on 17-18, & 33-34 SMW where the population density was 15.98 & 9.0, respectively. In 2016 maximum population density was observed in 17-18, 21-22 &33-34 SMW where the population fluctuation was 18.49, 8.18 & 7.56, respectively. The pest population increased with the increasing September month temperature and decreased with the increasing of relative humidity in field conditions. This insect population density remained low during October- February month and active from March to September (peak). The meteorological study showed that pest population positively correlated with the minimum and maximum temperature and negatively correlated with the relative humidity and rainfall (Table 3). The finding are in close conformity to Dorchin e*t al.* (2015). Mani (1952) found that gall midge larvae feed within plant tissue, causing abnormal plant growth called galls that can damage to mango leaves, flowers, fruit and shoots. Uma and Verghese (2008) also reported that *Asphondylia phyllanthi* Felt damaged the Aonla leaves in India.

Table 1. Mean fortnightly meteorological data with peak incidence of Aonla Leaf gall midge, *Asphondylia phyllanthi* (2010-2016)

Year	Peak Time	% Infested leaves/ tree	Max. Temp. (°C)	Min.Temp.(°C)	R.H. (%) Morning	RH (%)Evening	Total Rain fall (mm)
2010	Sept	80.0	31.98	23.88	88.50	63.75	237.05
2011	Sept.	60.0	32.30	22.40	87.0	53.00	371.8
2012	Sept.	40.0	31.70	21.90	92.0	63.30	549.2
2013	Sept.	40.75	33.40	22.70	85.0	57.50	416.20
2014	Sept.	54.20	33.20	22.65	83.50	55.50	171.50
2015	Sept.	60.21	36.80	23.10	75.0	46.0	257.55
2016	Sept.	59.88	36.40	22.85	72.0	43.0	206.10

Table 2. Population fluctuation of Aonla leaf gall midge, *Asphondylia phyllanthi* at fortnightly interval under field conditions

SMW	2010	2011	2012	2013	2014	2015	2016
1-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5-6	0.0	0.0	0.0	0.48	0.0	2.91	2.28
7-8	0.0	0.0	0.0	0.24	4.00	3.33	3.29
9-10	5.5	4.00	0.0	0.0	0.0	0.13	0.13
11-12	3.50	2.80	0.0	0.25	1.00	0.0	0.02
13-14	4.50	6.00	1.40	0.07	6.20	1.54	2.09
15-16	6.00	10.40	4.40	0.14	2.20	1.11	0.09
17-18	4.50	4.20	1.40	0.23	3.80	15.98	18.49
19-20	6.50	4.20	1.80	0.22	2.40	5.00	3.57
21-22	5.50	3.40	1.10	0.90	1.60	8.00	8.18
23-24	5.00	3.80	2.30	0.0	8.20	4.00	3.17
25-26	8.50	3.20	1.20	3.69	6.80	1.00	2.01
27-28	4.50	2.60	0.20	0.45	0.20	0.0	0.0
29-30	7.50	3.20	3.20	8.53	0.60	0.0	0.0
31-32	6.50	3.40	6.80	0.58	1.80	0.0	0.0
33-34	3.50	2.80	4.80	3.37	12.40	9.00	7.56
35-36	4.50	2.00	2.20	7.27	0.80	7.00	8.02
37-38	4.00	4.00	9.20	6.31	2.20	1.00	0.44
39-40	0.0	0.0	0.0	8.02	0.0	0.0	0.0
41-42	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43-44	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45-46	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47-48	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49-50	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51-52	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. Correlation Matrix of Aonla leaf gall midge, *Asphondylia phyllanthi* population with environmental factor at field condition

Year	Temperature		Relative humidity		Rainfall
	Maximum	Minimum	Morning	Evening	
2010	0.592**	0.192	-0.773**	-0.638**	-0.407
2011	0.564**	0.386	-0.458*	-0.265	-0.086
2012	0.523*	0.452*	-0.495*	-0.272	-0.190
2013	0.247	0.163	-0.171	-0.114	-0.280
2014	0.410	0.393	-0.423	-0.150	-0.354
2015	0.500*	0.329	-0.627**	-0.422	-0.353
2016	0.322	0.224	-0.374	-0.240	-0.154

*Significant at 5% and ** significant at 1%

Conclusion

The aonla leaf gall midge damage was started in the month of February and it was reached at its maximum level in the month of September during the year 2010-2016. The meteorological study showed that pest population positively correlated with the minimum and maximum temperature and negatively correlated with the relative humidity and rainfall.

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Data Sharing

All relevant data are within the manuscript.

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Research Article

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Effect of foliar application of biofertilizers on productivity and quality of guava (*Psidium guajava* L.)

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ABSTRACT

This study examines the impact of foliar biofertilizer applications on the yield and quality parameters of guava (Psidium guajava L.) variety L-49. The results revealed significant improvements in both yield and quality parameters of guava with biofertilizer applications compared to the control. Among the treatments, T_7 (Trichoderma viride 10%) emerged as the most effective, significantly enhancing yield and quality parameters compared to the control (T_1). T_7 recorded the highest number of fruits per plant (96.50), with increases of 50% over the control, which is at par with Trichoderma viride 5%, Pseudomonas 10% and Pseudomonas 5%. Trichoderma viride at 10% exhibited the highest yield (21.95 kg/plant), with increases of 99% over the control, which is at par with Trichoderma viride 5%. It also demonstrated superior fruit dimensions, weight (226.99 g), and pulp percentage (96.29%), reflecting enhanced productivity. In terms of fruit quality, T_7 achieved the highest TSS (12.80 °Brix), TSS: acid ratio (39.03), ascorbic acid content (234.60 mg/100g), and sugar content (9.60%), while maintaining balanced acidity (0.328%).

Introduction

Guava (*Psidium guajava* L.), locally it is known by '*beehi*' and '*jaam*' is one of the important fruit crop in all over India, which belongs to the Myrtaceae family. It is not only a delicious table fruit, valued for its excellent flavor, nutritional content, and pectin, but it is also crucial for the processing industry. It is popular among the people of all social strata due to its comparative low price than some other fruits (Bhooriya *et al*., 2020). The fruit has fair source of Vitamin A and good source of Vitamin C (300mg/100g) which is highest among table fruit. It is also an excellent source of beta-carotene, lycopene, potassium and soluble fiber. Guavas are very rich in antioxidants, which can act against the free radicals that damage cells and cause cancer, diabetes and coronary diseases (Kuldeep *et al*., 2019). India is the major producer of guava fruit in the world and it shares about 45 % of total production of guava. Major guava producing states include Madhya Pradesh, Uttar Pradesh, Maharashtra, Bihar, West Bengal, Gujarat, and Karnataka. Madhya Pradesh is the second largest producer of guava after Maharashtra. With an area of 46069.6 ha and 875199.86 MT production (Anonymous, 2020).

The sole application of chemical fertilizers, even in balanced forms, may not sustain soil fertility in guava orchards. Research encourages integrating inorganic fertilizers with biofertilizers, organic manures, and crop residues to enhance soil productivity and crop yield (Singh *et al*., 2011). Biofertilizers, carrier-based microorganisms, improve soil health and nutrient uptake. Microbial inoculants such as

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Azotobacter, phosphate-solubilizing microbes (PSM), and *Trichoderma* improve nitrogen fixation, nutrient availability, plant growth, and disease resistance (Adak *et al*., 2007).

Trichoderma are considered among the main biological control agents against phytopathogenic fungi, in addition to being biostimulants. Application of Trichoderma to plants activates secondary metabolites that help to promote growth, improve nutrient availability, and induce systemic resistance against diseases, mainly phytopathogenic fungi.

Phosphate-solubilizing microbes (PSM) are a group of microorganisms, primarily bacteria and fungi that have the ability to solubilize phosphorus present in the soil. By using PSM as biofertilizers, farmers can enhance the phosphorus uptake by plants and improve their growth and productivity. Biofertisol is rich in nitrogen and are a source of several trace elements. Biofertisol is a mixed product of fish hydrolysate and sea weed (rockweed) which contain N:P:K (4:2:3), micronutrients, phytohormones (like cytokinins), betaines and work as pH controller. In light of these findings, this study was undertaken to evaluate the influence of biofertilizer foliar applications on guava productivity and quality.

Material and Methods

The experiment was conducted on 8-year-old guava variety L-49 at the Fruit Research Station, JNKVV, Jabalpur (MP) during 2020-21. The location falls on 23.9° North latitude and 79.58° East longitudes with an altitude of 411.8 m above the mean sea level. The experiment was laid out in Randomized Block Design with four replications. The treatments comprised of Control (water spray), T_2 (Trichoderma viride 5%), T_3 (Trichoderma viride 10%), T_4 (Pseudomonas 5%), T_5 (Pseudomonas 10%), T_6 (Biofertisol 5%), and T_7 (Biofertisol 10%). The treatments were imposed as foliar spray at pre-flowering and 30 days post-fruit set. The treatments were applied as foliar sprays at the pre-flowering stage and 30 days after fruit set.

The observations were recorded on various parameters of biochemical and yield attributing characters with different treatments application. In yield parameters includes number of fruits/ plant, yield/ plant (kg), fruit length (cm), fruit width (cm), fruit weight (g), and pulp percent. TSS (°Brix), acidity (%), TSS acid ratio, ascorbic acid (mg/100 g) and total sugar (%) was recorded in quality parameters.

At each picking, the number of fruits per plant was independently recorded and at the time of harvest fruit length and width of the fruit was recorded with the help of Vernier Calipers in centimeters. The pulp percent was calculated by deducting the weight of seed and peel from the total weight of fruit. Pulp percent was calculated by total weight of pulp divided by total weight of fruit. To record TSS (°Brix), using a hand refractometer, a few drops of extracted juice were put on the surface of the refractometer's prism with the assistance of a clean glass rod. The acidity (%), TSS acid ratio, ascorbic acid (mg per 100 g), total sugar (%), was determined using the AOAC (1970) technique.

Result and Discussion

The different yield attributing parameters (Table 1) of the guava show that the highest number of fruits per plant (96.50) was recorded in T_7 (*Trichoderma* viriIde 10%), significantly surpassing the control (64.36) by 50%. The yield per plant in T_7 was 21.95 kg, a 99% increase compared to the control (11.03 kg). This substantial improvement highlights the efficacy of *Trichoderma viride* 10% in enhancing guava productivity. T_7's yield was significantly superior to both T_6 (18.52 kg) and T_5 (17.43 kg), indicating its dominant performance. T_7 exhibited the maximum fruit length of 6.78 cm, fruit width (7.13 cm) and fruit weight (226.99 g,) which was higher than the control (171.22 g). The treatment T_7 achieved the highest pulp percentage of 96.29%, which was significantly higher than the control (93.47%). The investigation aligned with the hypothesis proposed by Dey *et al.* (2005), which states that biofertilizers, being microbial in origin, serve as viable alternatives due to their ability to enrich the soil with beneficial microorganisms. They facilitate the conversion of nutritionally important elements from non-usable to usable forms through biological processes, thereby enhancing the production of various fruit crops. Numerous studies on the broad spectrum of horticultural crops have shown that the use of beneficial microorganisms (e.g., the fungus *Trichoderma sp*.) may promote primary or secondary plant metabolism and boosts crop yield (Rouphael *et al*., 2017). Molla *et al*. (2012) found that the application of Trichoderma improved the quality of the tomato fruit.

The different quality attributing parameters (Table 2) of the guava show that T_7 exhibited the maximum TSS (12.80 °Brix), which was significantly higher than the control (11.27 °Brix). This higher TSS reflects improved sweetness and quality of the fruit. T_7 maintained a balanced acidity (0.328%), which is statistically at par with T_6 (0.335%) but significantly lower than the control (0.355%), contributing to enhanced fruit palatability. The TSS:acid ratio was the highest in T_7 (39.03), which was significantly superior to T_1 (29.32) and at par with T_6 (32.85). A higher TSS:acid ratio indicates better flavor and sweetness in the fruit. T_7 recorded the highest ascorbic acid content (234.60 mg/100g), which was significantly higher than the control (175.12 mg/100g). It was followed closely by T_6 (225.93 mg/100g). This suggests that *Trichoderma viride* at 10% enhances the ascorbic acid content, which is critical for nutritional quality. T_7 had the highest sugar content (9.60%), significantly superior to T_1 (8.64%) and at par with T_6 (9.36%). This increase in sugar contributes to the overall sensory quality of the fruit. The significant differences in quality parameters highlighted the efficacy of *Trichoderma viride* (10%) in improving guava quality. Treatment T_7 (*Trichoderma viride* 10%) was significantly better than T_1 (control) across all parameters and was at par with T_6 (*Trichoderma viride* 5%) and T_3 (Biofertisol 10%) in most of the attributes. These findings are closely supported by the studies of Molla *et al.* (2012), and Lal *et al.* (2017), who reported that the foliar application of *Trichoderma* enhanced total soluble solids (TSS), the ratio of TSS to titratable acidity, and ascorbic acid content. These finding is nearly supported with Molla *et al.* (2012) and Lal *et al.* (2017) found foliar application of Trichoderma increased the total soluble solids (TSS), ratio of total soluble solids to titratable acidity and ascorbic acid. In case of acidity (%) foliar application of Pseudomonas 10% (T_5) was recorded to have minimum acidity (0.311%) and maximum non reducing sugar (4.05%) which was significant among all the treatments.

Table 1. Effect of various biofertilizers on yield parameters of 8-year-old guava

Treatments		Number of fruits/ plant	Yield/ plant (kg)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Pulp (%)
T_1	Control (water spray)	64.36	11.03	5.63	6.05	171.22	93.47
T_2	Biofertisol 5%	68.50	13.08	6.25	6.89	191.97	95.40
T_3	Biofertisol 10%	75.25	15.33	6.38	6.90	204.46	95.25
T_4	Pseudomonas 5%	87.75	15.98	5.93	6.47	181.60	94.37
T_5	Pseudomonas 10%	92.25	17.43	6.10	6.43	188.63	95.11
T_6	*Trichoderma viride* 5%	89.50	18.52	6.49	7.01	206.25	95.28
T_7	*Trichoderma viride* 10%	96.50	21.95	6.78	7.13	226.99	96.29
	SEm±	4.35	1.281	0.202	0.14	9.19	0.26
	CD at 5%	12.94	3.81	0.600	0.41	27.30	0.77

Table 2. Effect of various biofertilizers on quality parameter of 8-year-old guava

Treatments		TSS (°Brix)	Acidity (%)	TSS acid ratio	Ascorbic acid (mg per 100 g)	Total sugar (%)
T_1	Control (water spray)	11.27	0.355	29.32	175.12	8.64
T_2	Biofertisol 5%	11.42	0.343	32.03	198.39	8.80
T_3	Biofertisol 10%	11.61	0.340	32.62	213.86	9.31
T_4	Pseudomonas 5%	11.40	0.350	30.73	189.37	8.72
T_5	Pseudomonas 10%	11.55	0.278	33.25	200.14	9.16
T_6	*Trichoderma viride* 5%	11.73	0.335	32.85	225.93	9.36
T_7	*Trichoderma viride* 10%	12.80	0.328	33.13	234.60	9.60
	SEm±	0.15	0.011	0.87	5.89	0.14
	CD at 5%	0.46	0.033	2.57	17.50	0.42

Conclusion

The study demonstrates the efficacy of Trichoderma viride 10% (T_7) in enhancing guava productivity and quality parameters. T_7 exhibited superior performance in yield attributes such as the number of fruits per plant, yield per plant, fruit size, and pulp percentage, and quality traits like TSS, ascorbic acid, and sugar content. Overall, Trichoderma viride 10% proves to be a highly effective and sustainable biofertilizer, supporting enhanced fruit productivity, superior quality, and nutritional quality of guava.

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