Research Article

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

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ABSTRACT

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

Introduction

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

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

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

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

Material and Methods

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

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

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

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

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

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

Results and Discussion

Growth parameters

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

Stem girth is a crucial indicator of plant robustness and structural stability. CISH Bael-1 recorded the thickest stem (76.30 cm), whereas Narendra Bael-7 exhibited the thinnest stem (40.49 cm). A larger stem girth is often associated with improved vascular transport, which supports better nutrient and water uptake, contributing to overall plant health and productivity. In terms of plant spread, CISH Bael-2 exhibited the maximum canopy expansion in the North-South direction (5.66 m), while CISH Bael-1 had the widest spread in the East-West direction (4.92 m). Greater plant spread enhances light interception, thereby improving photosynthetic efficiency and promoting higher yields. The differences in growth parameters, such as plant height, stem

girth, and branching pattern, suggest distinct genetic traits influencing canopy architecture and resource utilization. These traits play a critical role in determining productivity, especially in semi-arid regions where efficient water and nutrient use are essential (Dongre and Choudhary, 2023).

Yield and quality parameters

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

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

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

Table 1. Morphological performance of different varieties of bael cultivar

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

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

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

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

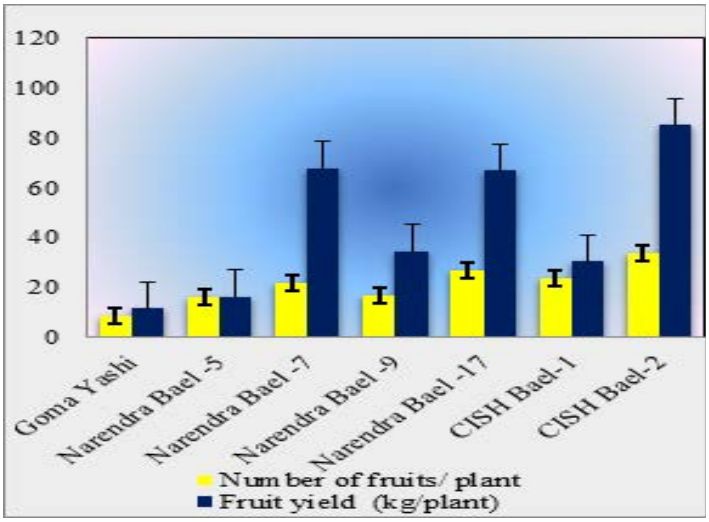

Fig. 1. Number of fruits and yield of bael varieties

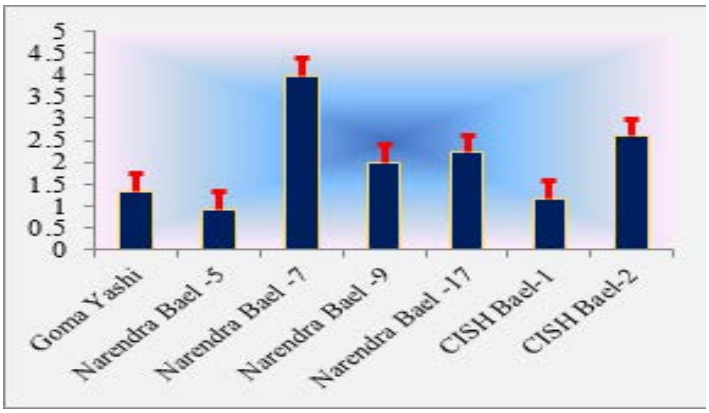

Fig. 2. Fruits weight (kg) of different bael varieties

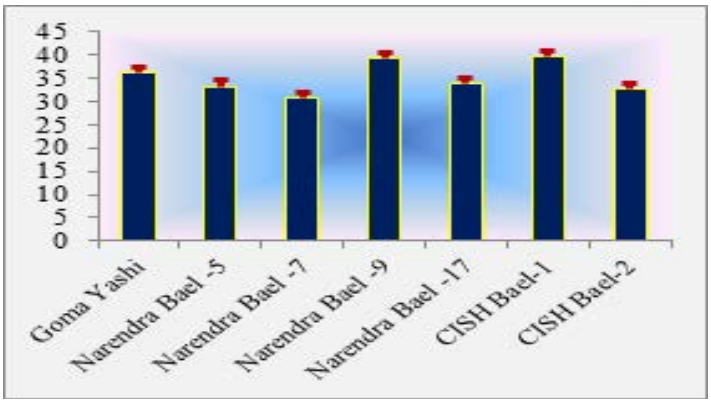

Fig. 3. TSS (°Brix) content of bael varieties

Conclusion

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

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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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