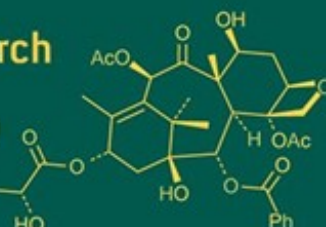
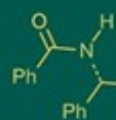


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Evaluation of sensory diversity among wild, seedling-origin bael (*Aegle marmelos* Correa) accessions from Chhattisgarh and Madhya Pradesh

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ABSTRACT

Bael (*Aegle marmelos* Correa) is an underutilized fruit species of central India with considerable variation in fruit characteristics. Sensory attributes are important in determining the eating quality and consumer value of fruits, but information on sensory diversity among wild, seedling-origin bael accessions from Chhattisgarh and Madhya Pradesh remains limited. The present study was undertaken to document sensory variation among these accessions and identify accessions with better organoleptic characteristics. Sixty-four wild, seedling-origin accessions collected from nine districts were evaluated, including 33 accessions from Chhattisgarh (CGB 1–CGB 33) and 31 from Madhya Pradesh (MPB 1–MPB 31). The accessions were identified during surveys conducted in 2023-24 and 2024-25. A panel of five judges evaluated the fruits using a nine-point hedonic scale for pulp colour, pulp texture, pulp aroma, pulp taste, fruit appearance and overall sensory score. Principal component analysis was performed using the five individual sensory attributes to examine the major sources of variation, while Spearman's rank correlation was used to assess their association with overall score. Pulp colour, texture and taste scores ranged from 6 to 9, while pulp aroma and fruit appearance ranged from 5 to 9. Overall sensory scores ranged from 6.6 to 8.8. The highest overall score of 8.80 was recorded for CGB 11, CGB 12, CGB 20, MPB 6 and MPB 23, whereas MPB 18 recorded the lowest score of 6.60. CGB 11, MPB 6 and MPB 23 each received a score of 9 for pulp colour, texture, aroma and taste. High scores for pulp attributes did not always correspond with fruit appearance, as observed in MPB 26, which scored 9 for the four pulp attributes but 5 for fruit appearance and 8.20 for overall score. The first three principal components accounted for 81.11% of the total variation. PC_1 had an eigenvalue of 2.033 and explained 40.66% of the variation, while PC_2 had an eigenvalue of 1.014 and explained 20.28%. PC_3 had an eigenvalue of 1.009 and explained a further 20.17%. Pulp texture (0.651), pulp taste (0.567) and pulp aroma (0.479) contributed most to PC_1 , whereas fruit appearance (0.858) and pulp colour (0.488) were the main contributors to PC_2 . Accessions from Chhattisgarh and Madhya Pradesh were intermixed in the PCA, with no clear separation by state. Pulp texture showed the strongest association with overall score ($\rho = 0.84$), followed by pulp taste (0.66) and pulp aroma (0.65). The findings demonstrate substantial sensory variation among the evaluated bael accessions and provide a basis for further characterization of promising accessions.

Keywords: *Aegle marmelos*, Wild germplasm, Sensory evaluation, Nine-point hedonic scale, Principal component analysis

1. Introduction

Bael (*Aegle marmelos* Correa) is an important underutilized fruit species distributed widely across central India. Seedling-origin trees show substantial variability in fruit and other morphological characteristics, providing opportunities for identifying superior accessions (Nath *et al.*, 2003; Kumar and Nath, 2010; Pandey *et al.*, 2008a, 2008b; Chaturvedi *et al.*, 2023) [1, 2, 3, 4]. Many such trees are maintained by farmers and villagers without standardized varietal names, resulting in considerable differences among trees and locations. The consumer value of bael fruit is strongly influenced by its sensory characteristics. Pulp colour, aroma, texture and taste, together with external fruit appearance, contribute to overall acceptability. Variation in these characters has been reported among bael accessions and genotypes from different regions, indicating considerable diversity in consumer-relevant fruit traits (Islam *et al.*, 2012; Mani *et al.*, 2017; Pale *et al.*, 2019; Pathirana *et al.*, 2020) [5, 6, 7, 8].

Bael fruit is also widely utilized for the preparation of processed products. Sensory evaluation has been reported for pulp powder (Bhanot, 2018) [9], value-added products prepared from pulp and powder (Bhanot *et al.*, 2019) [10], RTS beverages (Kumar *et al.*, 2022a) [11], fermented wine (Pandaa *et al.*, 2014) [12], herbal

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tea prepared from leaves (Garg *et al.*, 2023) [13], and flavoured bael fruit juice (Reema *et al.*, 2026) [14]. These studies demonstrate the importance of sensory quality in determining the acceptability and utilization of bael. Organoleptic evaluation provides a practical approach for converting perceptions of colour, aroma, taste and texture into quantitative scores for comparison among samples. Such evaluations have been used for bael products as well as directly among fruit accessions. Pale *et al.*, (2019) [7] evaluated bael accessions from Meghalaya using sensory attributes including pulp colour, aroma or flavour, taste and acidity, while Pathirana *et al.*, (2020) [8] assessed ripe fruits for aroma, flesh colour, sweetness, texture, external appearance and overall preference. These studies indicate that sensory assessment can also assist in distinguishing accessions based on consumer-relevant characteristics.

However, most available sensory studies on bael have focused on processed products rather than direct evaluation of fresh fruits from diverse, undocumented germplasm. Studies on fruit accessions have also differed in their geographical origin, panel size and sensory scales (Pale *et al.*, 2019; Pathirana *et al.*, 2020) [7, 8], making direct comparison among accessions difficult. Furthermore, the available literature provides limited information on the sensory diversity of wild, seedling-origin bael accessions from Chhattisgarh and Madhya Pradesh. The present study therefore evaluated the sensory quality of 64 wild, seedling-origin bael accessions collected from nine districts of Chhattisgarh (33 accessions, CGB 1 to CGB 33) and Madhya Pradesh (31 accessions, MPB 1 to MPB 31). A five-member panel scored the fruits on a nine-point hedonic scale for pulp colour, pulp texture, pulp aroma, pulp taste, fruit appearance and overall sensory score. The objective was to document variation in these sensory attributes within and between the two state groups and to identify accessions with superior organoleptic quality.

2. Materials and Methods

2.1 Study area and plant material

The study, entitled "Studies on genetic variability in Bael (*Aegle marmelos* Correa) available in central-India", was carried out at Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, and the Central Institute of Sub-tropical Horticulture (CISH), Lucknow. Fruit-related measurements and biochemical characterization were carried out in the laboratory of CISH, Lucknow. A random survey was conducted in districts of Chhattisgarh and Madhya Pradesh during 2023-24 and 2024-25 to identify promising accessions and assess diversity in physiological and morphological traits. The experiment was descriptive in design (descriptive statistics). Chhattisgarh lies between latitudes 17°46' and 24°05' N and longitudes 80°15' and 84°24' E. Accessions from this state were collected from Sakti (22.024° N, 82.960° E; 294.4 m above mean sea level [MSL]), Sarangarh-Bilaigarh (21.54° N, 83.13° E; about 223 m), Raigarh (21°20'–22°47' N, 82°57'–83°47' E; 244 m above MSL) and Bilaspur (21.47°–23.80° N, 81.14°–83.15° E; about 244 m above MSL). Madhya Pradesh lies between approximately 21°17' and 26°52' N and 74°08' and 82°49' E. Material from this state, representing its central and northeastern regions, was collected from Jabalpur (23.17° N, 79.95° E; about 411 m above MSL), Rewa (24.32° N, 81.15° E; about 316 m), Satna (24.58° N, 80.83° E; about 317 m MSL), Panna (24.72° N, 80.19° E; approximately 427 m) and Maihar (24.27° N, 80.75° E; approximately 367 m above MSL).

The climate of both states is mainly tropical to subtropical monsoonal, with hot summers, a southwest monsoon season extending

from June to September, and moderately dry and cool winters. According to the Indian Meteorological Department (IMD) database, annual rainfall in eastern Madhya Pradesh was 999.3 mm in 2023, 1297.4 mm in 2024 and 1333.2 mm in 2025, while in Chhattisgarh it was 1061.3, 1364.1 and 1388.0 mm in the respective years. Trees were selected based on field observation and inspection, along with information obtained from local farmers, villagers and agriculture officials. These individuals were consulted regarding seedling-grown bael plants with distinct quality characteristics. In total, 64 healthy, seedling-origin genotypes, at least 20 to 30 years old, were selected based on initial visual heterogeneity. The material was based on biased seedling selection or voluntary contribution by farmers. The genotypes differed in location and originated from a broad range of soil and climatic conditions. Since they had no standardized names, each was assigned a treatment code, CGB 1 to CGB 33 for the 33 accessions from Chhattisgarh and MPB 1 to MPB 31 for the 31 accessions from Madhya Pradesh.

2.2 Sensory evaluation

The organoleptic evaluation was conducted by a panel of five judges, including skilled field workers and experts on bael germplasm and cultivation practices. The judges were briefed about the scoring method before the fruits were presented. Fruits of the different accessions were served to the panelists at room temperature in daylight and were scored using the nine-point hedonic scale of Amerine *et al.*, (1965) [15], 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; and 2 = dislike extremely. Each panelist scored the fruits for the individual traits. An average score for each accession was calculated from the scores given by the different panelists, and the total points were tabulated.

2.3 Sensory parameters

Fruits and pulp were evaluated for pulp colour, pulp texture, pulp aroma, pulp taste and fruit appearance, and an overall score was calculated for each of the 64 accessions. Pulp colour was evaluated visually, with deep colour considered attractive and preferable. Scores were assigned according to the sequence of pulp colours, dark green, light green, yellowish green, yellowish green with few black spots, blackish green and black. The internal colour of the fruits was also recorded through visual observation as white, creamy white, dull white, dull creamy white or blackish white. For pulp texture, the pulp was tasted and scored according to its tongue feel, with smoothness, grittiness and fibre level taken into account. Pulp aroma was assessed by smelling the fruit after cutting and was scored as excellent, good or satisfactory. Pulp taste was judged by eating the pulp, and scores were recorded for the degree of sweetness, sourness and acidity. Fruit appearance was scored based on attractiveness, considering fruit shape and colour at ripening.

3. Results and Discussion

Sensory evaluation of the 64 bael accessions (33 from Chhattisgarh, coded CGB, and 31 from Madhya Pradesh, coded MPB) showed considerable variation in pulp colour, pulp texture, pulp aroma, pulp taste, fruit appearance and overall score (Table 1). Scores were awarded by a panel of five judges using the nine-point hedonic scale (Amerine *et al.*, 1965) [15]. Across all accessions, the minimum and maximum scores were 6 and 9 for pulp colour, 6 and 9 for pulp texture, 5 and 9 for pulp aroma, 6 and 9 for pulp taste, 5 and 9 for fruit appearance, and 6.6 and 8.8 for overall score.

Table 1. Sensory evaluation scores of 64 bael accessions from Chhattisgarh and Madhya Pradesh

Accession No.	Pulp Colour	Pulp Texture	Pulp Aroma	Pulp Taste	Appearance of Fruit	Overall Score
CGB 1	7	7	5	9	9	7.40
CGB 2	8	8	6	9	9	8.00

(continued on next page)

Accession No.	Pulp Colour	Pulp Texture	Pulp Aroma	Pulp Taste	Appearance of Fruit	Overall Score
CGB 3	9	8	8	8	9	8.40
CGB 4	9	7	6	7	8	7.40
CGB 5	9	9	7	8	9	8.40
CGB 6	7	7	8	7	8	7.40
CGB 7	8	6	7	7	9	7.40
CGB 8	9	7	6	6	9	7.40
CGB 9	9	7	8	7	9	8.00
CGB 10	8	9	9	9	8	8.60
CGB 11	9	9	9	9	8	8.80
CGB 12	8	9	9	9	9	8.80
CGB 13	9	9	9	8	8	8.60
CGB 14	8	9	9	9	8	8.60
CGB 15	9	8	8	8	8	8.20
CGB 16	9	7	6	7	6	7.00
CGB 17	9	9	9	8	6	8.20
CGB 18	8	6	5	7	8	6.80
CGB 19	6	6	8	8	6	6.80
CGB 20	9	9	9	8	9	8.80
CGB 21	7	9	9	8	9	8.40
CGB 22	8	8	9	8	8	8.20
CGB 23	7	8	8	7	9	7.80
CGB 24	8	8	9	8	7	8.00
CGB 25	9	8	8	7	9	8.20
CGB 26	6	7	8	7	8	7.20
CGB 27	9	8	8	7	9	8.20
CGB 28	7	7	7	7	7	7.00
CGB 29	8	9	9	9	8	8.60
CGB 30	9	7	6	7	8	7.40
CGB 31	8	9	9	8	6	8.00
CGB 32	9	6	7	7	5	6.80
CGB 33	9	9	8	9	7	8.40
MPB 1	9	7	7	9	8	8.00
MPB 2	9	7	8	7	7	7.60
MPB 3	9	6	7	6	9	7.40
MPB 4	8	8	7	8	9	8.00
MPB 5	8	9	8	9	6	8.00
MPB 6	9	9	9	9	8	8.80
MPB 7	7	7	8	6	9	7.40
MPB 8	9	7	9	6	8	7.80
MPB 9	9	6	8	6	7	7.20
MPB 10	9	6	6	7	8	7.20
MPB 11	7	6	9	6	8	7.20
MPB 12	8	7	7	7	7	7.20
MPB 13	7	9	9	7	8	8.00
MPB 14	8	8	9	8	9	8.40
MPB 15	7	6	7	7	7	6.80
MPB 16	8	8	8	8	6	7.60
MPB 17	8	7	7	6	7	7.00
MPB 18	7	7	7	6	6	6.60
MPB 19	9	8	7	8	6	7.60
MPB 20	7	7	8	7	5	6.80
MPB 21	8	8	8	8	6	7.60
MPB 22	9	8	7	7	6	7.40
MPB 23	9	9	9	9	8	8.80
MPB 24	9	8	7	7	6	7.40
MPB 25	9	8	9	9	7	8.40

(continued on next page)

Accession No.	Pulp Colour	Pulp Texture	Pulp Aroma	Pulp Taste	Appearance of Fruit	Overall Score
MPB 26	9	9	9	9	5	8.20
MPB 27	8	8	7	9	6	7.60
MPB 28	8	9	8	9	7	8.20
MPB 29	9	7	9	7	5	7.40
MPB 30	8	8	6	9	5	7.20
MPB 31	8	8	9	9	6	8.00

Note: Scores were awarded on a nine-point hedonic scale by a panel of five judges. CGB = Chhattisgarh bael accessions; MPB = Madhya Pradesh bael accessions.

3.1 Pulp colour

Pulp colour scores varied from 6 to 9 among the Chhattisgarh accessions and from 7 to 9 among the Madhya Pradesh accessions. In Chhattisgarh, the maximum score of 9 was recorded for CGB 3, CGB 4, CGB 5, CGB 8, CGB 9, CGB 11, CGB 13, CGB 15, CGB 16, CGB 17, CGB 20, CGB 25, CGB 27, CGB 30, CGB 32 and CGB 33, whereas CGB 19 and CGB 26 recorded the minimum score of 6. The remaining accessions scored 7 or 8. In Madhya Pradesh, a score of 9 was recorded for MPB 1, MPB 2, MPB 3, MPB 6, MPB 8, MPB 9, MPB 10, MPB 19, MPB 22, MPB 23, MPB 24, MPB 25, MPB 26 and MPB 29, while MPB 7, MPB 11, MPB 13, MPB 15, MPB 18 and MPB 20 recorded the minimum score of 7; the remaining accessions scored 8. Overall, 30 of the 64 accessions received the maximum score of 9, and no Madhya Pradesh accession scored below 7.

Variation in pulp colour among bael accessions has also been reported in earlier studies. *Pale et al.*, (2019) [7] included pulp colour among the sensory traits used for characterization of bael accessions from Meghalaya, while *Pathirana et al.*, (2020) [8] evaluated flesh colour along with other morphometric and organoleptic characters in elite bael accessions. Colour has also been assessed in processed bael products, including bael powder and value-added products (*Bhanot, 2018; Bhanot et al.*, 2019) [9, 10]. These studies used different materials and scoring scales, so their values are not directly comparable with the present hedonic scores. The variation observed here may be associated with differences in pigment accumulation during fruit development, although this remains an interpretation of the observed

sensory variation. Pulp colour scores were generally high in both groups, with the lowest score of 6 occurring only in the Chhattisgarh accessions.

3.2 Pulp texture

Pulp texture scores ranged from 6 to 9 in both groups. In Chhattisgarh, the maximum score of 9 was recorded for CGB 5, CGB 10, CGB 11, CGB 12, CGB 13, CGB 14, CGB 17, CGB 20, CGB 21, CGB 29, CGB 31 and CGB 33, whereas CGB 7, CGB 18, CGB 19 and CGB 32 recorded the minimum score of 6. In Madhya Pradesh, a score of 9 was recorded for MPB 5, MPB 6, MPB 13, MPB 23, MPB 26 and MPB 28, while MPB 3, MPB 9, MPB 10, MPB 11 and MPB 15 recorded a score of 6. Thus, 12 Chhattisgarh and 6 Madhya Pradesh accessions received the maximum texture score.

Texture has been used as an important organoleptic character in the evaluation of bael germplasm and products. *Pathirana et al.*, (2020) [8] assessed fruit texture together with other sensory attributes for characterization of elite bael accessions, while *Bhanot (2018)* [9] and *Bhanot et al.*, (2019) [10] evaluated texture-related acceptability in bael powder and value-added products. The present variation indicates differences in pulp eating quality among accessions. The observed differences may be related to variation in pulp fibre and pectin characteristics during fruit maturation, as suggested in the manuscript. Pulp texture showed a similar range of 6 to 9 in both Chhattisgarh and Madhya Pradesh, with accessions at both ends of the scale in each group.

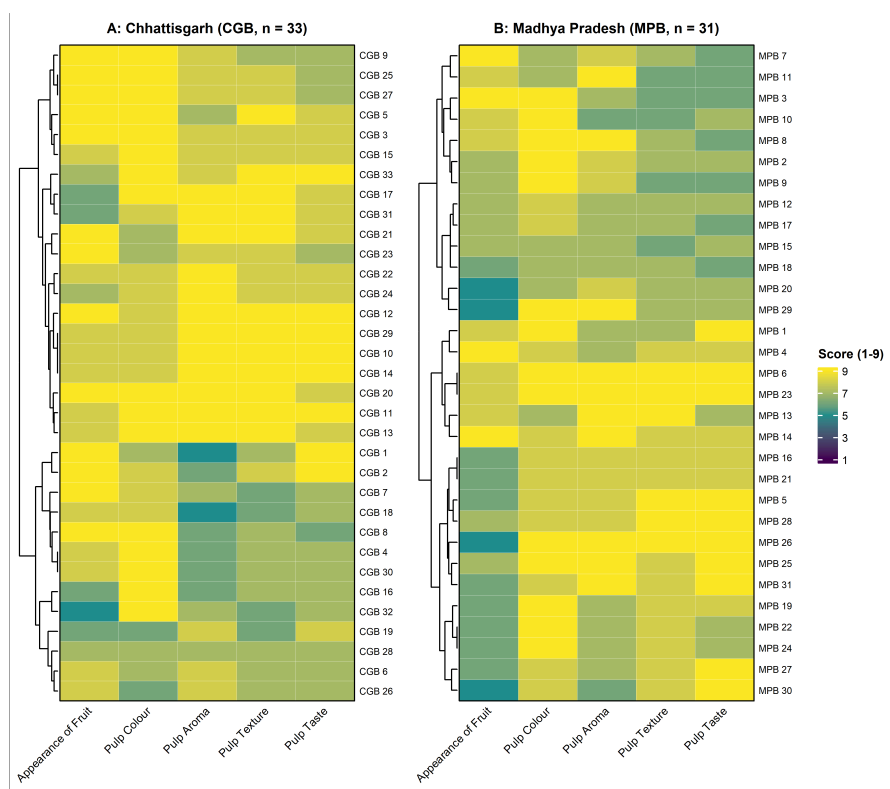


Figure 1. Heatmap showing variation in sensory scores for pulp colour, pulp texture, pulp aroma, pulp taste, fruit appearance and overall sensory score among 64 bael accessions from Chhattisgarh and Madhya Pradesh.

3.3 Pulp aroma

Pulp aroma scores ranged from 5 to 9 among the Chhattisgarh accessions and from 6 to 9 among the Madhya Pradesh accessions. In the Chhattisgarh group, the maximum score of 9 was recorded for CGB 10, CGB 11, CGB 12, CGB 13, CGB 14, CGB 17, CGB 20, CGB 21, CGB 22, CGB 24, CGB 29 and CGB 31, while the minimum score of 5 was recorded for CGB 1 and CGB 18. In the Madhya Pradesh group, a score of 9 was recorded for MPB 6, MPB 8, MPB 11, MPB 13, MPB 14, MPB 23, MPB 25, MPB 26, MPB 29 and MPB 31, and the minimum score of 6 for MPB 10 and MPB 30. Aroma was assessed after cutting the fruit and smelling the pulp. Thus, the lowest aroma score recorded in the study (5) was confined to two Chhattisgarh accessions. CGB 1 also scored 9 for both pulp taste and fruit appearance, whereas CGB 18 scored 6 for pulp texture and had an overall score of 6.80.

Aroma and flavour have been considered in earlier organoleptic evaluations of bael fruits and products. *Pale et al.*, (2019) [7] reported variation in flavour among bael materials, while *Pathirana et al.*, (2020) [8] included aroma among the organoleptic attributes used for evaluating elite bael accessions. Aroma has also been assessed in processed bael products such as wine, fruit powders and value-added products (*Pandaa et al.*, 2014; *Bhanot 2018*; *Bhanot et al.*, 2019) [9, 10, 12], as well as in bael fruit juice (*Reema et al.*, 2026) [14]. The present findings similarly indicate accession-to-accession variation in pulp aroma. Such differences may be associated with variation in volatile compounds during fruit ripening; however, this remains an interpretation because volatile compounds were not measured in the present study. Aroma scores varied from 5 to 9, with the lowest scores restricted to the Chhattisgarh group.

3.4 Pulp taste

Pulp taste, judged on sweetness, sourness and acidity, was scored from 6 to 9 in both groups. In the Chhattisgarh group, the maximum score of 9 was recorded for CGB 1, CGB 2, CGB 10, CGB 11, CGB 12, CGB 14, CGB 29 and CGB 33, whereas the minimum score of 6 was recorded only for CGB 8. In the Madhya Pradesh group, a score of 9 was recorded for MPB 1, MPB 5, MPB 6, MPB 23, MPB 25, MPB 26, MPB 27, MPB 28, MPB 30 and MPB 31, while a score of 6 was recorded for MPB 3, MPB 7, MPB 8, MPB 9, MPB 11, MPB 17 and MPB 18. Thus, eight Chhattisgarh accessions and ten Madhya Pradesh accessions received the maximum taste score. The lowest score was recorded for one accession in the Chhattisgarh group and seven accessions in the Madhya Pradesh group. The manuscript reports a single taste score per accession, and sweetness, sourness and acidity were not scored separately.

Taste has also been used as an important organoleptic attribute in earlier evaluations of bael germplasm and processed products. *Pale et al.*, (2019) [7] reported variation in pulp taste and acidity among bael accessions, while *Pathirana et al.*, (2020) [8] evaluated organoleptic properties of elite bael accessions. Organoleptic evaluation has also been reported for bael beverages and other value-added products

(*Kumar et al.*, 2022a; *Kumar, B. P. et al.*, 2022; *Bhanot 2018*; *Bhanot et al.*, 2019) [9, 10, 11, 16]. The present study likewise showed clear differences in taste among accessions from both states. These differences may be related to variation in sugars, organic acids and other fruit constituents, as reported in physico-chemical evaluations of bael fruit (*Kaur and Kalia, 2017*; *Kumar, A. et al.*, 2022) [17, 11], although these components were not separately related to the sensory scores in the present study. Pulp taste varied among accessions in both groups, with taste scores of 9 recorded for accessions from both states.

3.5 Fruit appearance

Fruit appearance, based on the attractiveness of fruit shape and colour at ripening, ranged from 5 to 9 in both groups. In the Chhattisgarh group, the maximum score of 9 was recorded for CGB 1, CGB 2, CGB 3, CGB 5, CGB 7, CGB 8, CGB 9, CGB 12, CGB 20, CGB 21, CGB 23, CGB 25 and CGB 27, whereas CGB 32 received the minimum score of 5. In the Madhya Pradesh group, MPB 3, MPB 4, MPB 7 and MPB 14 received a score of 9, while MPB 20, MPB 26, MPB 29 and MPB 30 recorded the minimum score of 5. Thus, thirteen Chhattisgarh accessions received the maximum appearance score compared with four Madhya Pradesh accessions. Some accessions showed contrasting responses among sensory attributes. For example, MPB 26 scored 9 for pulp colour, texture, aroma and taste but only 5 for appearance, with an overall score of 8.20. In contrast, MPB 3 scored 9 for appearance but 6 for texture and taste.

Variation in external fruit appearance among bael accessions has also been reported previously. *Pathirana et al.*, (2020) [8] evaluated external appearance along with morphometric and organoleptic characteristics of ripe bael fruits, while *Pale et al.*, (2019) [7] reported considerable morphological variation among bael accessions from Meghalaya. Such differences in appearance may be associated with the genetic diversity present among bael germplasm, as reported in several diversity studies (*Chaturvedi et al.*, 2023; *Debbarma and Hazarika, 2024*; *Kannaujia et al.*, 2025) [18, 19, 20]. However, the specific causes of variation in size, shape, rind smoothness and colour were not tested in the present study. Fruit appearance therefore covered the full observed range of 5 to 9 in both groups, and high pulp scores did not necessarily correspond to high appearance scores.

3.6 Overall sensory score

Overall sensory scores ranged from 6.6 to 8.8 among the 64 accessions. In the Chhattisgarh group, the maximum score of 8.80 was recorded for CGB 11, CGB 12 and CGB 20, whereas CGB 18, CGB 19 and CGB 32 recorded the minimum score of 6.80. In the Madhya Pradesh group, MPB 6 and MPB 23 recorded the maximum score of 8.80, while MPB 18 recorded the lowest overall score of 6.60. Other high scores included 8.60 for CGB 10, CGB 13, CGB 14 and CGB 29, and 8.40 for CGB 3, CGB 5, CGB 21, CGB 33, MPB 14 and MPB 25. CGB 11, MPB 6 and MPB 23 each scored 9 for pulp colour, texture, aroma and taste, whereas CGB 20 scored 9 for pulp colour, texture, aroma and fruit appearance. The same maximum overall score of 8.80 was therefore recorded in both states.

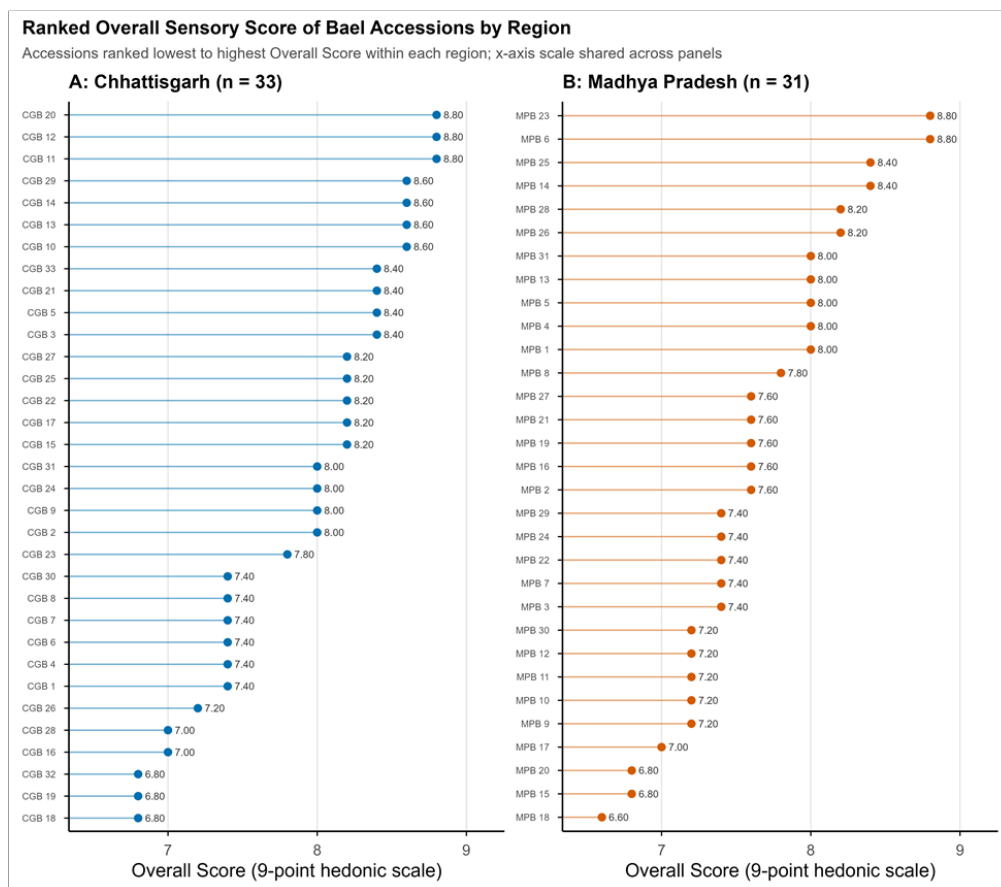


Figure 2. Ranking of 64 bael accessions based on overall sensory score evaluated using the nine-point hedonic scale.

Variation in sensory and organoleptic characteristics of bael has been reported in earlier studies (Bhanot *et al.*, 2019 [10]; Pale *et al.*, 2019 [7]; Pathirana *et al.*, 2020 [8]; Kumar *et al.*, 2022b; Garg & Sharma, 2023 [13]; Reema and Ritu, 2026) [14]. Pale *et al.*, (2019) [7] reported differences in organoleptic characteristics among bael accessions, while Pathirana *et al.*, (2020) [8] evaluated ripe fruits using morphometric and organoleptic traits. Studies on processed bael products have also documented variation in acceptability and sensory attributes (Bhanot *et al.*, 2019; Kumar *et al.*, 2022a; Reema and Ritu, 2026) [10, 11, 14]. The variation observed in the present study may be related to inherent genetic diversity among the accessions and, to some extent, environmental and agro-climatic conditions. However, these factors were not tested directly using the present sensory data.

3.7 Principal component analysis of sensory attributes

Principal component analysis (PCA) was used to summarise the variation among the 64 accessions for the five sensory attributes and to examine their relationships (Table 2). PC_1 and PC_2 had eigenvalues of 2.033 and 1.014 and explained 40.66% and 20.28% of the variance, respectively, giving a cumulative variance of 60.93%. PC_3 had an eigenvalue of 1.009 and contributed a further 20.17%, increasing

the cumulative variance to 81.11%. PC_4 and PC_5 accounted for 14.40% and 4.49%, respectively. The use of PCA to assess variation and relationships among bael accessions is consistent with earlier studies that have used multivariate approaches to characterise diversity in bael germplasm (Dhakar *et al.*, 2019; Debbarma and Hazarika, 2024) [21, 19].

PC_1 was characterised by positive loadings for Pulp Texture (0.651), Pulp Taste (0.567) and Pulp Aroma (0.479), with a smaller contribution from Pulp Colour (0.157) and a negligible loading for Appearance of Fruit (-0.022). Thus, this component mainly separated the accessions according to the three pulp attributes. PC_2 was mainly associated with Appearance of Fruit (0.858) and Pulp Colour (0.488), while Pulp Texture (0.076), Pulp Aroma (-0.104) and Pulp Taste (-0.100) had loadings close to zero. This axis therefore mainly represented fruit appearance and, to a lesser extent, pulp colour. Such variation in organoleptic and fruit quality attributes has also been reported among bael genotypes and germplasm collections (Kumar *et al.*, 2022b; Pathirana *et al.*, 2020) [16, 8]. PC_3 showed a contrast between Pulp Colour (-0.802) and Appearance of Fruit (0.486) and Pulp Aroma (0.337). Its eigenvalue was only marginally above 1, so this component was interpreted cautiously.

Table 2. Principal component loadings, eigenvalues and percentage variance explained for sensory attributes of bael accessions

Sensory attribute	PC1	PC2	PC3	PC4	PC5
Pulp Colour	0.157	0.488	-0.802	0.279	-0.126
Pulp Texture	0.651	0.076	0.028	-0.080	0.750
Pulp Aroma	0.479	-0.104	0.337	0.728	-0.340
Pulp Taste	0.567	-0.100	-0.076	-0.606	-0.544
Appearance of Fruit	-0.022	0.858	0.486	-0.134	-0.100
Eigenvalue	2.033	1.014	1.009	0.720	0.225
Variance explained (%)	40.66	20.28	20.17	14.40	4.49
Cumulative variance (%)	40.66	60.93	81.11	95.51	100.00

Note: PC = principal component. PCA was performed using the five sensory attributes. PC_1 and PC_2 together explained 60.93% of the total variance.

In the biplot (Figure 3), the vectors for Pulp Taste and Pulp Aroma pointed in nearly the same direction, while Pulp Texture also pointed to the right. These three attributes were therefore positioned together along PC_1 . Appearance of Fruit extended almost vertically along PC_2 , whereas Pulp Colour was positioned between the two axes and closer to PC_2 . The near right angle between the appearance vector and the texture, taste and aroma vectors suggests little linear association between appearance and these attributes in this plane, which accounts for 60.93% of the variance. Similar multivariate approaches have been used to distinguish bael accessions based on fruit and quality characteristics (Dhakar *et al.*, 2019; Chaturvedi *et al.*, 2023) [21, 18]. Accessions from Chhattisgarh and Madhya Pradesh were intermixed, with no clear separation by state. CGB 10, CGB 11, CGB 12, CGB 14, CGB 29, MPB 6 and MPB 23 were positioned towards the right, in the direction of the texture, taste and aroma vectors. CGB 11, MPB

6 and MPB 23 are among the accessions that scored 9 for all four pulp attributes (Section 3.6). CGB 3, CGB 5, CGB 20, CGB 25 and CGB 27 were located in the upper part of the plot, along the appearance vector. MPB 26 was positioned at the lower right, with high PC_1 and low PC_2 values, consistent with its scores of 9 for pulp colour, texture, aroma and taste and 5 for appearance (Section 3.5). CGB 8 and MPB 3, located at the upper left, combined a score of 9 for appearance with a score of 6 for pulp taste. These positions are in agreement with the earlier observation that accessions with the highest pulp scores did not necessarily have the highest appearance scores. Variation in sensory and organoleptic characteristics among bael materials has likewise been documented in earlier evaluations of bael germplasm and value-added products (Bhanot *et al.*, 2019; Pathirana *et al.*, 2020) [10, 8].

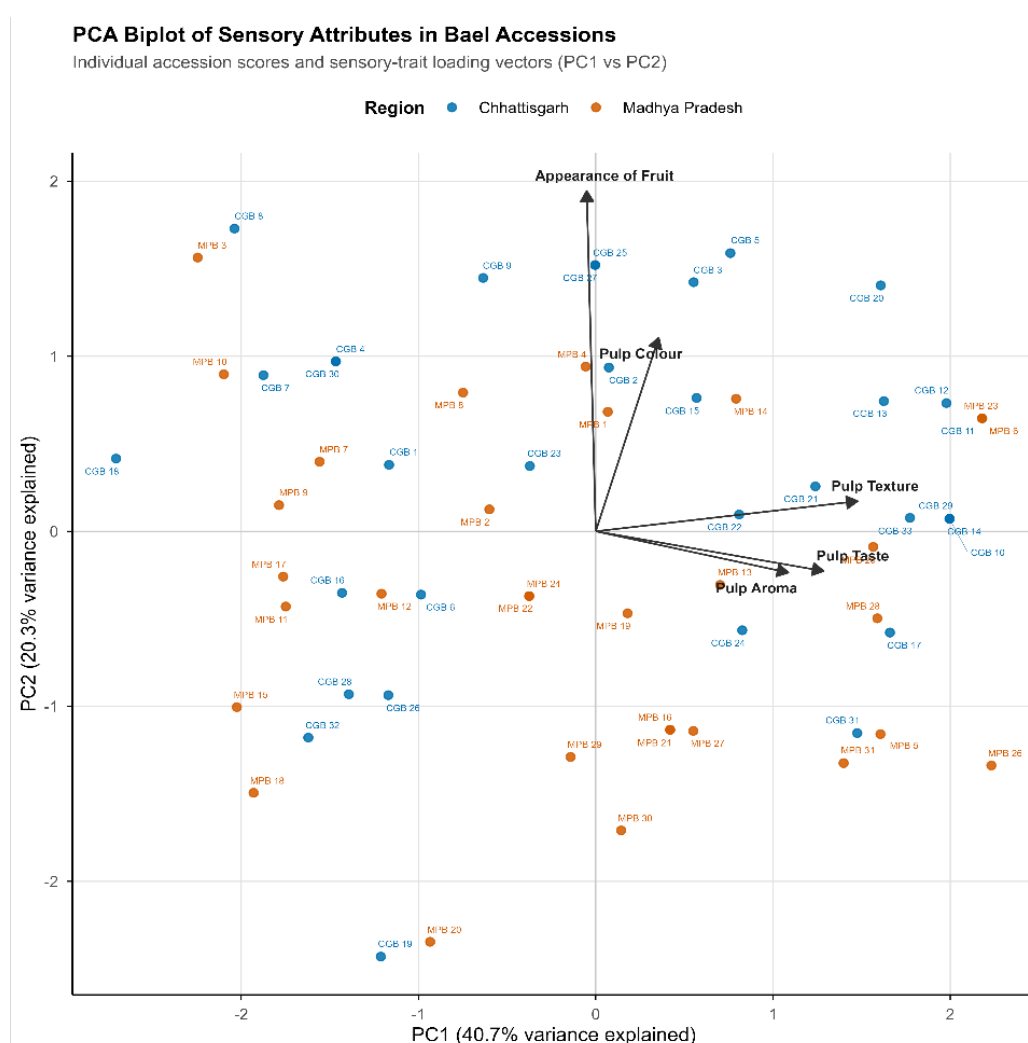


Figure 3. Principal component analysis (PCA) biplot showing the distribution of bael accessions and relationships among sensory attributes based on pulp colour, pulp texture, pulp aroma, pulp taste and fruit appearance.

3.8 Spearman correlation among sensory attributes and overall score

Spearman's rank correlation coefficients (ρ) among the five sensory attributes and Overall Score are presented in Figure 4. Blank cells indicate $p \geq 0.05$, uncorrected for multiple comparisons, and all displayed coefficients were positive. In this study, coefficients of about 0.3 to 0.4 were considered weak, 0.5 to 0.7 moderate and values above 0.8 strong. Correlation analysis has been used previously to assess relationships among traits in bael genotypes (Amulya *et al.*, 2022) [22]. Pulp Texture showed the strongest association with Overall Score ($\rho = 0.84$). Pulp Taste (0.66) and Pulp Aroma (0.65) were moderately correlated with Overall Score, while Appearance of Fruit (0.39) and Pulp Colour (0.32) showed weak correlations. Sensory and organoleptic traits are important in the evaluation of bael fruit and its products (Bhanot 2018; Bhanot *et al.*, 2019) [9, 10]. Since Overall Score was calculated for each accession alongside the attribute scores (Section 2.3), some positive association with the attributes is expected. Therefore, the relative size of the coefficients is more informative than their direction.

Among the sensory attributes themselves, only the pulp attributes were interrelated. Pulp Texture was correlated with Pulp Taste (0.70) and Pulp Aroma (0.56), while Pulp Taste was correlated with Pulp Aroma (0.32). Pulp Colour and Appearance of Fruit showed no corre-

lation at $p < 0.05$ with any other individual attribute and were related only to Overall Score. Thus, pulp colour and appearance scores varied largely independently of the other attributes, which is consistent with the earlier observation that accessions with high pulp attribute scores did not necessarily have high appearance scores. For example, MPB 26 had an appearance score of 5 and an overall score of 8.20.

These results were consistent with the PCA. Texture, taste and aroma, which loaded together on PC_1 , were also the attributes most strongly correlated with one another and with Overall Score. Pulp Texture, which had the highest PC_1 loading (0.651), also showed the highest coefficient with Overall Score. Appearance of Fruit and Pulp Colour, which had the main loadings on PC_2 (0.858 and 0.488), showed weaker coefficients with Overall Score and no correlation at $p < 0.05$ with the other attributes. Similar PCA-based approaches have been used to characterize variation among bael accessions and fruit characteristics (Dhakar *et al.*, 2019; Debbarma and Hazarika 2024) [21, 19]. The low coefficient between Pulp Taste and Pulp Aroma (0.32), despite their similar biplot vectors, is compatible with their opposite-signed PC_4 loadings (-0.606 and 0.728), although PC_4 explained only 14.40% of the variance. Both analyses indicate that texture, taste and aroma were the attributes most closely associated with Overall Score in these accessions. These findings represent associations only and do not establish that any attribute determines the overall score.

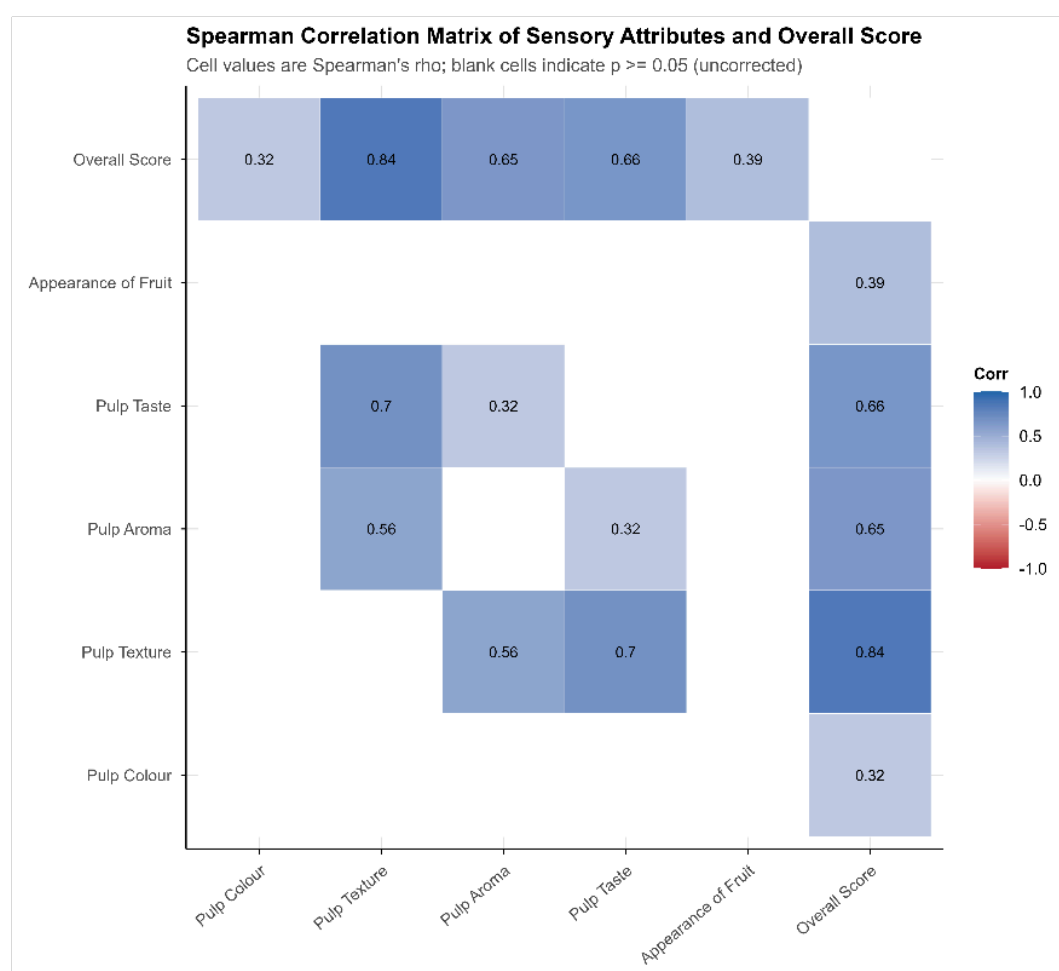


Figure 4. Spearman correlation matrix showing the relationships among sensory attributes and overall sensory score of the 64 bael accessions.

4. Conclusion

The 64 wild, seedling-origin bael accessions from Chhattisgarh and Madhya Pradesh showed considerable variation in sensory characteristics. Scores ranged from 6 to 9 for pulp colour, texture and taste, from 5 to 9 for pulp aroma and fruit appearance, and from 6.6 to 8.8 for overall score. The highest overall score of 8.80 was recorded in both states. High scores for pulp attributes did not always correspond to high fruit-appearance scores. PCA showed that pulp texture, taste

and aroma contributed mainly to PC_1 , while fruit appearance contributed mainly to PC_2 . Accessions from Chhattisgarh and Madhya Pradesh were intermixed, with no clear separation between the two groups. These results represent the judgements of a five-member panel and do not establish genetic superiority or consumer acceptance. However, the observed sensory diversity provides a useful basis for identifying promising accessions for further evaluation and for documenting the sensory characteristics of bael germplasm from central India.

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Declarations

Conflict of interest: The authors declare that they have no conflict of interest.

Data availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Consent to Publish declaration: not applicable.

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References

- Kumar D, Nath V. Variability in bael (*Aegle marmelos Correa*) genotypes from Orissa. *Indian Journal of Plant Genetic Resources*. 2010;23(3):303–305.
- Nath V, Pandey D, Das B. Diversity of bael (*Aegle marmelos* Corr.) in east central India. *Indian Journal of Plant Genetic Resources*. 2003;16(3):222–225.
- Pandey D, Shukla SK, Kumar A. Variability in bael (*Aegle marmelos* Corr.) germplasm collected from Uttar Pradesh and Madhya Pradesh. *Journal of Tropical Forestry*. 2008a;24(1/2):31–36.
- Pandey D, Shukla SK, Kumar A. Variability in bael accessions from Bihar and Jharkhand. *Indian Journal of Horticulture*. 2008b;65:226–229.
- Islam MS, Ibrahim M, Hossain MM, Kamal AM. Studies on morphological and fruit characters of bael. *International Journal of Sustainable Agricultural Technology*. 2012;8(7):24–27.
- Mani A, Singh AK, Jain N, Misra S. Flowering, fruiting and physio-chemical characteristics of bael (*Aegle marmelos Correa*) grown in northern districts of West Bengal. *Current Journal of Applied Science and Technology*. 2017;23(3):1–8.
- Pale JL, Chetri S, Suresh CP, Singh YS, Chaurasiya A, Barman A. Morphological and bio-chemical characterization of bael (*Aegle marmelos Correa*) in West Garo Hills, Meghalaya, India. *International Journal of Current Microbiology and Applied Sciences*. 2019;8(10):2414–2420.
- Pathirana CK, Ranaweera LT, Madhujith T, Ketippearachchi KW, Gamlath KL, Eeswara JP, Sooriyapathirana SS. Assessment of the elite accessions of bael [*Aegle marmelos* (L.) Corr.] in Sri Lanka based on morphometric, organoleptic, and elemental properties of the fruits and phylogenetic relationships. *PLOS ONE*. 2020;15(5):e0233609.
- Bhanot M. Development and sensory evaluation of unripe and ripe bael fruit powder (*Aegle marmelos*). *Journal of Pharmacognosy and Phytochemistry*. 2018;7(4):2894–2897.
- Bhanot M, Dunkwal V, Goyal M, Bhanot R. Organoleptic acceptability of value added products using unripe and ripe bael fruit pulp and its powder (*Aegle marmelos*). *Journal of Pharmacognosy and Phytochemistry*. 2019;8(5):1708–1711.
- Kumar A, Ram D, Verma AK. Comparative physico-chemical evaluation of bael (*Aegle marmelos Correa*) genotypes. *The Pharma Innovation Journal*. 2022;11(7):698–700.
- Pandaa SK, Sahu UC, Behera SK, Ray RC. Bio-processing of bael [*Aegle marmelos* L.] fruits into wine with antioxidants. *Food Bioscience*. 2014;5:34–41.
- Garg V, Sharma P. A study on nutritional and organoleptic properties of herbal tea developed using dry bael leaves and its powder. *Journal of Emerging Technologies and Innovative Research*. 2023;10(9).
- Reema K, Ritu D. Sensory evaluation of bael (*Aegle marmelos*) fruit juice incorporated with selected herbal flavoring agents. *International Journal of Home Science*. 2026;12(2):42–45.
- Amerine MA, Pangborn RM, Roessler EB. Principles of Sensory Evaluation of Food. New York: Academic Press; 1965.
- Kumar BP, Kumar TS, Harshitha DN, Kumar BN. Studies on organoleptic evaluation and benefit cost ratio of bael (*Aegle marmelos Correa*) RTS beverage blended with other fruits. *The Pharma Innovation Journal*. 2022;11(12):238–242.
- Kaur A, Kalia M. Physico-chemical analysis of bael (*Aegle marmelos*) fruit pulp, seed and pericarp. *Chemical Science Review and Letters*. 2017;6(22):1213–1218.
- Chaturvedi K, Kumara U, Sane AP, Kumar P, Tripathi PC. Exploring the genetic diversity of *Aegle marmelos* (L.) *Correa* populations in India. *Plant Genetic Resources: Characterization and Utilization*. 2023;21(2):107–114.
- Debbarma P, Hazarika TK. Genetic diversity of bael (*Aegle marmelos* Corr.) accessions from north-east India based on principal component and cluster analysis. *Genetic Resources and Crop Evolution*. 2024;71(1):253–277.
- Kannaujia PK, Gomashe S, Kushawaha A, Bhardwaj R, Varghese E, Kale S, Pamarthi RK, Bhatt KC, Ahlawat SP, Malav PK, Singh PK. Diversity in morphological and some chemical traits of *Aegle marmelos* (L.) *Correa* germplasm explored from Achanakmar-Amkantak Biosphere Reserve, Chhattisgarh, India. *Genetic Resources and Crop Evolution*. 2025;72(3):2767–2780.
- Dhakar MK, Das B, Nath V, Sarkar PK, Singh AK. Genotypic diversity for fruit characteristics in bael [*Aegle marmelos* (L.) Corr.] based on principal component analysis. *Genetic Resources and Crop Evolution*. 2019;66(4):951–964.
- Amulya RN, Adivappar N, Shivakumar BS, Mallikarjuna HB. Studies on variability and correlation in bael (*Aegle marmelos* (L.) *Correa*). *Indian Journal of Plant Genetic Resources*. 2022;35(2):185–188.

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