Plant Archives Vol. 25, Supplement 2, 2025 pp. e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.090

VARIABILITY STUDIES IN FRUIT PREFERENTIAL TRAITS OF BAEL (*AEGLE MARMELOS* CORREA)

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(Date of Receiving : 27-02-2025; Date of Acceptance : 17-05-2025)

ABSTRACT

The present study evaluated the morphological variability in fruit traits among 55 genotypes of bael (*Aegle marmelos* Correa) collected through an extensive field survey from a major bael growing regions of Uttar Pradesh, India. The selective genotypes were characterized using standardized DUS descriptors as developed by PPV&FRA, 2001. The evaluation focused on key fruit traits including maturity group, fruit surface, shape, rind colour, locule and seed arrangement, cavity structure, and seed shape. From the results, it was evident that there was considerable variability among the genotypes. Most of the genotypes were mid-maturing types (65.45%) and matured mostly during the first and second weeks of April. Mature fruit color showed a near-equal distribution of categories, viz. yellowish green (34.55%), greenish pale yellow (32.73%), and green (32.73%). The fruit surface was observed to be smooth for 37 (67.27%) genotypes, while the fruit shape among the 55 genotypes studied was mostly round (52.73%). The majority of genotypes showed centric locule arrangement (78.18%) and whole pulp seed distribution (90.91%) across the population. Based on the combined assessment of these fruit characters, genotypes such as BUAT-B-01, BUAT-B-12, BUAT-B-20, and BUAT-B-36 were identified as promising candidates for fresh consumption, processing, and breeding programs.
Keywords: Bael (*Aegle marmelos* Correa), Morphological variability, DUS descriptors

Introduction

Bael (*Aegle marmelos* Correa) has become a popular underutilized fruit crop in tropical and sub-tropical regions of India. It belongs to the family Rutaceae and is widely distributed in South and Southeast Asia, including countries like India, China, Nepal, Myanmar, Pakistan, Bangladesh, Nepal, Vietnam, Laos, Cambodia, Thailand and Indonesia (Saroj *et al*., 2006). Fruit is also known as the Bengal quince, this tree is held in high regard in Indian mythology for its medicinal and therapeutic values. Various bioactive compounds derived from bael such as marmelosin, citronellol, aegeline, lupeol and marmesinin have been used as traditional medicines for the treatment of various ailments like gastrointestinal disorders, diabetes, respiratory disorders and cancer (Patkar *et al*., 2012). This is a drought hardy crop since it can survive in adverse climatic conditions, as well as in marginal lands, from temperatures ranging from -7°C to 50°C, even at altitudes up to 1200m above the mean sea level, making it one of the few fruit crops possessing climate resilience (Pathirana *et al*., 2020). As per statistics 2023, the annual Bael production in India was 85,940 metric tons, making India one of the largest producers of Bael (Singh *et al*.,

2024a). Bael has also been put under the category of "near threatened species" by the International Union for Conservation of Nature and Natural Resources, since its naturally growing habitats have been on the verge of destruction by mankind (Plummer, 2020). So, characterization and conservation of Bael germplasm has become the need of the hour. Besides that, farmers are also having a hard time identifying the Bael cultivars because they don't know about various features of the cultivars (Singh *et al*., 2025). Thus, identification of suitable genotypes for the region could help farmers enhance the production, productivity and quality of fruits.

Thus, characterization of morphological traits is essential for assessing germplasm, selecting desirable characteristics, and conserving genetic resources. This process is the foundation for the identification of superior genotypes for the purposes of selection and future improvement programs (Singh *et al*., 2024a). Among morphological traits, the characteristics of fruit hold significant importance owing to their direct economic implications. Various fruit characters like fruit maturity group, average date of maturity, mature fruit colour, styler end cavity, stem end cavity, fruit surface, fruit shape, fruit skull colour, locule arrangement, arrangement of seeds in pulp and seed shape are essential for ensuring both market attractiveness and suitability for industrial applications (Singh *et al*., 2025). Keeping in view the above facts, this study entitled "Variability studies in fruit preferential traits of Bael (*Aegle marmelos* Correa)" aims to assess the morphological diversity among 55 bael seedling genotypes under different growing conditions.

Materials and Methods

Morphological characterization

During the survey 10-30 years of old plants were selected for the study. and a total of 55 genotypes were collected from major bael-growing area of Uttar Pradesh, India during the years 2022-23 and 2023-24, to select promising accession among the diverse seeding bael genotypes. The district wise collection includes 6 genotypes from Kushinagar (BUAT-B-01 to BUAT-B-06), 4 from Gorakhpur (BUAT-B-07 to BUAT-B-10), 9 from Ayodhya (BUAT-B-11 to BUAT-B-19), 14 from Sultanpur (BUAT-B-20 to BUAT-B-33), 4 genotypes from Mau (BUAT-B-34 to BUAT-B-37), 7 genotypes from Gazipur (BUAT-B-38 to BUAT-B-44), 3 genotypes from Ballia (BUAT-B-45 to BUAT-B-47), 3 genotypes Bhadohi (BUAT-B-48 to BUAT-B-50) and 5 genotypes from Banda (BUAT-B-51 to BUAT-B-55). The fruit parameters such as fruit maturity group, average maturity date, mature fruit colour, styler end cavity, stem end cavity, fruit surface, fruit shape, locule arrangement, and seed arrangement in pulp and seed shape were recorded according to the guidelines. The observations were recorded at the full maturity stage of fruits using the standardized descriptors developed by Protection of Plant Varieties and Farmers' Right Authority (PPV&FRA), Government of India.

Results and Discussion

The qualitative variation in fruit maturity group, average date of maturity, mature fruit colour, styler end cavity and stem end cavity has been shown in Table 1 and Table 2. According to the observations, a wide range of variations were observed among the fifty-five bael genotypes used in the study.

As far as fruit maturity is concerned, out of 55 genotypes, seven genotypes (12.73%) were classified as early maturing, 36 (65.45%) genotypes were classified as medium maturing and the remaining 12 (21.82%) genotypes were classified as late. The prevalence of mid-mature genotypes might be due toselection by farmers/breeders, since mid-maturing bael genotypes might have better fruit development and might have provided farmers with a stable harvest window during the peak period of market demand (April-May). Besides, this may be due to shared ancestry between the individuals studied (Bhatnagar and Meena, 2018). Average maturity for the genotypes showed a similar trend as of fruit maturity with most of the genotypes showing a clustering trend around the mid-maturity group. The average maturity, however, ranged from the early (fourth week of March) to the (late first week of May). Similar findings on early, mid and late maturing genotypes of bael have been reported by Singh *et al*. (2024a) and Uddin *et al*. (2024). Early maturing cultivars are desirable since they help farmers to gain profit by catching the market early (Krishna *et al*., 2019).

Mature fruit colours were categorized into 3 groups, viz. Green (32.73%), Greenish Pale Yellow (32.73%), and Yellowish Green (34.55%), showing a nearly equal distribution. The two categories other than green might be an apt indicator of the extent of fruit ripeness and may be associated with internal fruit quality (Debbarma and Hazarika, 2024). Similar reports of mature fruit color in bael have been studied by Parihar (2015) and Singh *et al*. (2024b).

The styler end cavity was divided into two categories i.e. Shallow (60.00%) and Depressed (40.00%). The shallow styler end cavity is generally preferred for its more usable pulp space and less

internal deformity, making it one of the important criteria for selecting fruits in the processing industry. Similar results were reported by Singh *et al*. (2025) while studying 80 wild Bael accessions.

The stem end cavity was categorized into Shallow (54.55%), Flattened (38.18%), and Depressed (7.27%), showing a considerable diversity of this trait among the genotypes. Shallow stem ends are mostly desirable since they are of a nearly uniform shape, making them suitable for processing industries as well as making mechanical handling relatively easier. Similar classification was also observed for the characterization of Bael fruit by Singh *et al*. (2024a) and Singh *et al*. (2024b).

The variations in the fruit surface, fruit shape, locule arrangement, arrangement of seed in pulp, and seed shape among collected bael genotypes are shown in Table 3 and Table 4. A wide range of variations were observed among genotypes for these traits.

The fruit surface was observed to be smooth for 37 (67.27%) genotypes. This is a desirable characteristic for Bael since smooth surfaces generally tend to fetch a higher market value due to their aesthetic value as well as their easier handling. Moreover, smooth surfaces don't harbor dust and pathogens as compared to rough surfaces due to their slippery nature (Koch *et al*., 2010). The fruit shapes among the 55 genotypes studied were mostly round (52.73%), followed by Globose (16.36%), Ovate (16.36%), and Elliptical (14.55%). Round fruits might be more desirable since it may have an aesthetic value due to its uniform shape and easiness in packaging and marketing. Similar characterization has also been made by Parihar (2015) and Singh *et al*. (2024c).

Locule arrangements were classified as Centric (78.18%), which was dominant, whereas Highly Centric (14.55%) and Scattered (7.27%) type locule arrangements were less frequent. The centric locule arrangement is a desirable feature because here the seeds are distributed uniformly, paving for a relatively better fruit architecture, ideal for cutting and scooping (Sharif *et al*., 2019). As far as the arrangement of seeds in pulp is concerned, most of the bael genotypes had whole pulp seed arrangement (90.91%) while only 9.09% had seeds arranged in straight lines in the pulp. The seed arrangement in straight lines is a desirable trait since removal of seeds from the fruit is easier, leading to easier pulp extraction and processing. Similar observations for locule arrangement and arrangement of seed in pulp have been made by Singh *et al*. (2024a) and Singh *et al*. (2025).

The seed shape also showed variability among the genotypes studied, thirty-four genotypes had round seed shape while twenty-one had an oblong seed shape. Similar characterization has also been made by Sarker *et al*. (2015) and Singh *et al*. (2024 a).

Conclusion

Bael genotypes collected in the study revealed significant morphological diversity. Most of the genotypes were mid-maturing types (65.45%), revealing their natural adaptation in this maturity window. The fruit colour was majorly yellowish green and greenish pale yellow, which might be favoured by consumers as well as for industrial processing. Various fruit morphological traits like smooth surface (67.27%), round shape (52.73%), were observed genereally for most genotypes, which might be ideal for fruit processing industries as well as market acceptance. The predominance of centric locule arrangement (78.18%) and round seed shape (61.82%) of the bael fruit genotypes further enhances their functional and aesthetic value. The variation in fruit surface, seed arrangement, styler and stem end cavities, and fruit maturity period are traits of interest for processing industries as well as consumers that could be selectively bred to enhance fruit quality, marketability, and adaptability. Based on the fruit characterization studies, genotypes such as BUAT-B-01, BUAT-B-02, BUAT-B-12, BUAT-B-20, BUAT-B-33 could fetch high market value for fresh consumption due to their attractive traits like smooth surface, round shape, attractive mature fruit colour (yellowish green/greenish pale yellow) and shallow cavities. Similarly, BUAT-B-05, BUAT-B-17, BUAT-B-36, BUAT-B-44, and BUAT-B-52 can be used in processing industries for their creamish yellow/russet yellow skin colour, centric locules, straight seed line, oblong seeds which could provide for better pulp content. These genotypes, when utilized for targeted selection and hybridization, might lead to the development of improved bael cultivars with enhanced fruit quality, extended harvest periods, and higher processing potential, addressing both consumer preferences and industrial demands.

Table 1 : Variation in fruit maturity group, average date of maturity, mature fruit colour, styler end cavity and stem end cavity.

Sr. No	Genotypes	Fruit Maturity Group	Average Date of maturity	Mature Fruit colour	Styler end Cavity	Stem end cavity
1	**BUAT-B-01**	Early	4th Week of March	Greenish pale yellow	Shallow	Shallow
2	**BUAT-B-02**	Mid	1st Week of April	Greenish pale yellow	Depressed	Shallow
3	**BUAT-B-03**	Mid	2nd Week of April	Green	Depressed	Flattened
4	**BUAT-B-04**	Late	3rd Week of April	Yellowish Green	Shallow	Shallow
5	**BUAT-B-05**	Mid	2nd Week of April	Yellowish Green	Depressed	Shallow
6	**BUAT-B-06**	Late	1st Week of May	Yellowish Green	Depressed	Shallow
7	**BUAT-B-07**	Mid	1st Week of April	Green	Depressed	Flattened
8	**BUAT-B-08**	Mid	1st Week of April	Yellowish Green	Depressed	Shallow
9	**BUAT-B-09**	Mid	2nd Week of April	Greenish pale yellow	Shallow	Flattened
10	**BUAT-B-10**	Early	4th Week of March	Greenish pale yellow	Depressed	Flattened
11	**BUAT-B-11**	Mid	2nd Week of April	Greenish pale yellow	Depressed	Flattened
12	**BUAT-B-12**	Mid	2nd Week of April	Greenish pale yellow	Depressed	Flattened
13	**BUAT-B-13**	Mid	1st Week of April	Yellowish Green	Depressed	Depressed
14	**BUAT-B-14**	Late	3rd Week of April	Green	Shallow	Flattened
15	**BUAT-B-15**	Late	1st Week of May	Yellowish Green	Shallow	Shallow
16	**BUAT-B-16**	Mid	2nd Week of April	Yellowish Green	Shallow	Shallow
17	**BUAT-B-17**	Mid	1st Week of April	Yellowish Green	Shallow	Shallow
18	**BUAT-B-18**	Mid	2nd Week of April	Yellowish Green	Shallow	Shallow
19	**BUAT-B-19**	Late	3rd Week of April	Yellowish Green	Shallow	Shallow
20	**BUAT-B-20**	Mid	2nd Week of April	Greenish pale yellow	Shallow	Flattened
21	**BUAT-B-21**	Mid	2nd Week of April	Green	Shallow	Shallow
22	**BUAT-B-22**	Late	1st Week of May	Greenish pale yellow	Shallow	Flattened
23	**BUAT-B-23**	Mid	1st Week of April	Green	Depressed	Shallow
24	**BUAT-B-24**	Mid	1st Week of April	Green	Depressed	Shallow
25	**BUAT-B-25**	Mid	2nd Week of April	Greenish pale yellow	Shallow	Flattened
26	**BUAT-B-26**	Late	3rd Week of April	Green	Shallow	Depressed
27	**BUAT-B-27**	Late	1st Week of May	Green	Depressed	Shallow
28	**BUAT-B-28**	Early	4th Week of March	Green	Shallow	Flattened
29	**BUAT-B-29**	Mid	2nd Week of April	Green	Shallow	Flattened
30	**BUAT-B-30**	Mid	2nd Week of April	Yellowish Green	Depressed	Flattened
31	**BUAT-B-31**	Late	3rd Week of April	Yellowish Green	Depressed	Flattened
32	**BUAT-B-32**	Mid	2nd Week of April	Green	Shallow	Depressed
33	**BUAT-B-33**	Mid	2nd Week of April	Yellowish Green	Shallow	Shallow
34	**BUAT-B-34**	Mid	1st Week of April	Green	Shallow	Flattened
35	**BUAT-B-35**	Early	4th Week of March	Yellowish Green	Depressed	Flattened
36	**BUAT-B-36**	Mid	2nd Week of April	Greenish pale yellow	Depressed	Shallow
37	**BUAT-B-37**	Mid	2nd Week of April	Green	Depressed	Flattened
38	**BUAT-B-38**	Mid	1st Week of April	Greenish pale yellow	Shallow	Shallow
39	**BUAT-B-39**	Mid	2nd Week of April	Green	Shallow	Shallow
40	**BUAT-B-40**	Mid	2nd Week of April	Greenish pale yellow	Shallow	Shallow
41	**BUAT-B-41**	Late	1st Week of April	Yellowish Green	Depressed	Flattened
42	**BUAT-B-42**	Mid	2nd Week of April	Green	Shallow	Shallow
43	**BUAT-B-43**	Mid	2nd Week of April	Green	Shallow	Shallow
44	**BUAT-B-44**	Early	4th Week of March	Greenish pale yellow	Shallow	Flattened
45	**BUAT-B-45**	Mid	2nd Week of April	Yellowish Green	Shallow	Shallow
46	**BUAT-B-46**	Mid	1st Week of April	Green	Shallow	Shallow
47	**BUAT-B-47**	Late	1st Week of May	Greenish pale yellow	Shallow	Shallow
48	**BUAT-B-48**	Mid	2nd Week of April	Greenish pale yellow	Shallow	Flattened
49	**BUAT-B-49**	Mid	2nd Week of April	Green	Shallow	Shallow
50	**BUAT-B-50**	Mid	1st Week of April	Greenish pale yellow	Depressed	Shallow
51	**BUAT-B-51**	Mid	1st Week of April	Greenish pale yellow	Depressed	Flattened
52	**BUAT-B-52**	Early	4th Week of March	Yellowish Green	Shallow	Depressed
53	**BUAT-B-53**	Mid	2nd Week of April	Yellowish Green	Depressed	Shallow
54	**BUAT-B-54**	Early	4th Week of March	Yellowish Green	Shallow	Shallow
55	**BUAT-B-55**	Late	3rd Week of April	Greenish pale yellow	Shallow	Shallow

Table 2 : Frequency percentage in maturity group, average date of maturity, mature fruit colour, styler end cavity and stem end cavity.

Fruit Characteristic	Category	Number of genotypes	Percentage (%)
Fruit Maturity Group	Early	7	12.73
	Mid	36	65.45
	Late	12	21.82
Mature Fruit colour	Green	18	32.73
	Greenish pale yellow	18	32.73
	Yellowish green	19	34.55
Styler end cavity	Shallow	33	60.00
	Depressed	22	40.00
	Highly Depressed	0	0.00
Stem end cavity	Shallow	30	54.55
	Depressed	04	7.27
	Flattened	21	38.18

Table 3 : Variations in fruit surface, fruit shape, locule arrangement, arrangement of seed in pulp, seed shape

Sr. no	Genotypes	Fruit Surface	Fruit shape	Locule Arrangement	Arrangement of seed in pulp	Seed shape
1	**BUAT-B-01**	Smooth	Round	Centric	Straight Line	Oblong
2	**BUAT-B-02**	Smooth	Round	Centric	Straight Line	Round
3	**BUAT-B-03**	Smooth	Globose	Centric	Straight Line	Round
4	**BUAT-B-04**	Smooth	Globose	Centric	Straight Line	Round
5	**BUAT-B-05**	Rough	Ovate	Highly centric	Straight line	Oblong
6	**BUAT-B-06**	Rough	Ovate	centric	Straight line	Oblong
7	**BUAT-B-07**	Rough	Elliptical	Highly centric	Straight line	oblong
8	**BUAT-B-08**	Rough	Globose	Highly centric	Straight line	Round
9	**BUAT-B-09**	Smooth	Round	centric	Straight line	oblong
10	**BUAT-B-10**	Rough	Globose	Scattered	Straight line	Round
11	**BUAT-B-11**	Smooth	Round	centric	Straight line	Oblong
12	**BUAT-B-12**	Smooth	Round	centric	Straight line	Oblong
13	**BUAT-B-13**	Smooth	Elliptical	Centric	Straight line	Oblong
14	**BUAT-B-14**	Smooth	Round	Centric	Straight line	Round
15	**BUAT-B-15**	Smooth	Globose	Scattered	Whole pulp	Round
16	**BUAT-B-16**	Smooth	Elliptical	Highly centric	Straight line	Round
17	**BUAT-B-17**	Rough	Ovate	Centric	Straight line	Round
18	**BUAT-B-18**	Smooth	Ovate	Centric	Straight line	Oblong
19	**BUAT-B-19**	Smooth	Elliptical	Highly centric	Straight line	Round
20	**BUAT-B-20**	Rough	Round	Centric	Straight line	Round
21	**BUAT-B-21**	Rough	Globose	Centric	Straight line	Round
22	**BUAT-B-22**	Rough	Round	Centric	Straight line	Round
23	**BUAT-B-23**	Rough	Round	Scattered	Whole pulp	Round
24	**BUAT-B-24**	Smooth	Round	Centric	Straight line	Round
25	**BUAT-B-25**	Smooth	Round	Centric	Straight line	Round
26	**BUAT-B-26**	Rough	Round	Centric	Straight line	Round
27	**BUAT-B-27**	Smooth	Round	Scattered	Whole pulp	Oblong
28	**BUAT-B-28**	Smooth	Round	Centric	Straight line	Oblong
29	**BUAT-B-29**	Smooth	Round	Centric	Straight line	Round
30	**BUAT-B-30**	Smooth	Round	Centric	Straight line	Round
31	**BUAT-B-31**	Rough	Ovate	Centric	Straight line	Round
32	**BUAT-B-32**	Smooth	Ovate	Centric	Straight line	Round
33	**BUAT-B-33**	Smooth	Round	centric	Straight line	Oblong
34	**BUAT-B-34**	Smooth	Round	centric	Straight line	Round
35	**BUAT-B-35**	Smooth	Round	Highly centric	Straight line	Round
36	**BUAT-B-36**	Rough	Round	Centric	Straight line	Round

37	**BUAT-B-37**	Smooth	Round	centric	Straight line	Oblong
38	**BUAT-B-38**	Smooth	Globose	Centric	Straight line	Oblong
39	**BUAT-B-39**	Rough	Globose	Centric	Whole pulp	Oblong
40	**BUAT-B-40**	Smooth	Elliptical	Centric	Straight line	Round
41	**BUAT-B-41**	Rough	Round	Centric	Whole pulp	Round
42	**BUAT-B-42**	Smooth	Ovate	Centric	Straight line	Round
43	**BUAT-B-43**	Smooth	Elliptical	Centric	Straight line	Round
44	**BUAT-B-44**	Smooth	Round	centric	Straight line	Oblong
45	**BUAT-B-45**	Rough	Elliptical	Highly centric	Straight line	Oblong
46	**BUAT-B-46**	Smooth	Round	centric	Straight line	Round
47	**BUAT-B-47**	Smooth	Globose	centric	Straight line	Oblong
48	**BUAT-B-48**	Smooth	Round	centric	Straight line	Round
49	**BUAT-B-49**	Rough	Ovate	Centric	Straight line	Round
50	**BUAT-B-50**	Smooth	Round	Centric	Straight line	Round
51	**BUAT-B-51**	Smooth	Round	Centric	Straight line	Round
52	**BUAT-B-52**	Smooth	Round	centric	Straight line	Oblong
53	**BUAT-B-53**	Rough	Elliptical	Highly centric	Straight line	Oblong
54	**BUAT-B-54**	Smooth	Ovate	Centric	Straight line	Round
55	**BUAT-B-55**	Smooth	Round	centric	Straight line	Oblong

Table 4 : Frequency percentage in fruit surface, fruit shape, locule arrangement, arrangement of seed in pulp, seed shape

Fruit Characteristic	Category	Number of genotypes	Percentage (%)
Fruit surface	Smooth	37	67.27
	Rough	18	32.73
Fruit shape	Globose	09	16.36
	Ovate	09	16.36
	Elliptical	08	14.55
	Round	29	52.73
Locule arrangement	Scattered	04	7.27
	Centric	43	78.18
	Highly centric	08	14.55
Arrangement of seed in pulp	Straight line	05	9.09
	Whole pulp	50	90.91
Seed shape	Round	34	61.82
	Oblong	21	38.18

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