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Evaluation of Bael (*Aegle marmelos* corr.) germplasm under acidic soil conditions

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Abstract

Bael is adaptable to a wide range of soils, but soil and land characteristics are key factors that influence its growth, yield, and overall productivity. Acidic soils are those which have a pH level below 7, indicating a higher concentration of hydrogen ions. The present study was conducted at Citrus Research Station, BARI, Jaitapur, Sylhet for evaluation of bael germplasm under acidic soil. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The treatments comprised four types of germplasm like AM Jai-001, AM Jai-002, AM Jai-003 and AM Jai-004. Among the tested germplasm, the germplasm of AM Jai-001 consistently exhibited outstanding performance in terms of growth, yield attributes and desirable physic-chemical traits and closely followed by AM Jai-004. From the above study the germplasm AM Jai-001 and AM Jai-004 are found to perform well under the acidic soil conditions, when compared to the other germplasm.

Keywords: Bael; Skull; Acidic Soil; Soil pH; Yield; Physic-Chemical

1. Introduction

Bael (*Aegle marmelos* Correa) is the sole species in the monotypic genus *Aegle* and is a member of the Rutaceae family, which also includes citrus fruits [1]. It is a hardy and underutilized fruit species native to Southeast Asia and widely distributed across the tropical and subtropical regions of the Indian subcontinent, including India, Nepal, Bangladesh, Sri Lanka, and Thailand. It commonly grows wild in dry forests and hilly plains of South and Southeast Asia [2]. Bael is a highly nutritious fruit with all plant parts (fruit, seeds, bark, leaves, and roots) used in traditional Ayurvedic and Unani medicine to treat various health issues, particularly digestive problems such as diarrhea and dysentery [3]. Bael fruit holds great medicinal and nutritional importance in daily life, as it is a rich source of vitamins, minerals, dietary fiber, and antioxidants. [4]. Ripe fruits are generally used for fresh consumption and preparation of making value added products like sherbet, squash, murabba, nectar and candy, offering both nutritional security and income generation [5]. The bael exhibits significant variation in morphological traits like plant height, canopy spread, fruit size and shape along with in its physico-chemical properties, including total soluble solids, acidity, and sugar content within the germplasm cultivated in Bangladesh [6].

Bael is well-adapted to diverse soil conditions with a pH range of 5.5 to 8 [5], and exhibits resilience to waterlogging, drought, and extreme temperatures ranging from -7 °C to 48 °C [7]. Soil and land parameters are one of the important requirements deciding the production and productivity of the crop. Acidic soils are characterized by excess level of hydrogen ion (H+) in the soil solution phase, which leads to a pH value below 7. Acidic soils hinder nutrient availability and microbial activity, resulting in poor plant growth and reduced yields [8]. The growth performance of bael trees in acidic soils may differ based on the germplasm. To determine which germplasm, perform best under such conditions, four germplasm were selected and observed for their suitability in acidic soil environments. Considering the effect of

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the soil properties in the plant growth and establishment depending upon the germplasm, the present investigation has been undertaken with the following objectives.

- To assess the variations in growth, yield and fruit quality of bael germplasm.
- To evaluate the physico-chemical attributes of bael germplasm.
- To identify promising bael germplasm that performs best in acidic soils.

2. Materials and Methods

2.1. Experimental site and germplasm

The experiment was conducted at the Citrus Research Station, Bangladesh Agricultural Research Institute, Jaintapur, Sylhet, during 2019-20. Five germplasm of bael were initially included in this study. These were AM Jai-001, AM Jai-002, AM Jai-003, AM Jai-004 and AM Jai-005. Among the germplasm, But AM Jai-005 dropped due to unsatisfactory growth and non-bearing habit.

2.2. Experimental Plan

The experiment was laid out in a Randomized Complete Block Design (RCRD) with three replications. The plants were of variable age range from 7-10 years. A single plant of each germplasm constituted the unit of replication. The plants were fertilized with recommended manure and fertilizers [9] at the beginning and end of the rainy season. Each plant was fertilized with 20 kg rotten cowdung, 750 g urea, 500 g TSP, 250 g MoP, 250 g gypsum and 15 g zinc sulphate in two split doses of manure and fertilizers (recommended dose for 8-10 years old plants) at the beginning and the end of the rainy season. Two full cover spray of carbendazim (Bavistin 50WP @ 2 g/L of water) was applied before spring in the month of February. As bael requires a pronounced dry season to give flowers and fruits therefore no irrigation was applied in winter. Weeding was done in rainy season before applying fertilizer. Necessary actions were taken against other pests and diseases as and when needed.

2.3. Key Soil Features

The experimental site features sandy loam soil with a strongly acidic nature, exhibiting a very low (4.4) pH [10]. This site is situated in agro-ecological zone 22, known as the Northern and Eastern Piedmont Plains. The chemical and physical characteristics of the soil profile are presented in Table 1.

Table 1 Initial soil physical and chemical properties at the experimental sites

Texture	pH	OM	Ca	Mg	K	Total N	P	S	B	Zn	Cu	Fe	Mn
		%	(MEQ/100g soil)			%	(ug/g soil)						
Sandy loam	4.4	1.12	2.8	0.91	0.28	0.071	28	18	0.11	1.13	0.07	12.2	2.2
Critical level	-	-	2.0	0.8	0.20	-	14	14	0.2	2.0	0.2	10	5

2.4. Field Observations and Measurements

Plant height was recorded by measuring from the base to the tip of the tallest leaves and expressed in meters. The base girth was measured 15 centimeters above the soil surface and reported in centimeters. Similarly, canopy spread was determined by measuring the extent of the canopy in both the north-south and east-west directions and expressed in meters. Plant volume was calculated by using the formula of Castle [11]. Plant Volume = $\frac{1}{6}\pi \times$ plant height $\times (2r)^2$, where 2r = (East-West spread + North-South spread)/2 and expressed in cubic meter. The number of fruits per plant was counted, and yield (kg per plant) was recorded during each commercial harvest. Fruit size was determined by measuring the length and diameter of individual fruits using a vernier caliper. The pulp, fibre, and seeds were separated and weighed separately, and their edible portions were calculated as a percentage of the total fresh fruit weight. The fruit was split horizontally, and the number of seed sacs was counted manually. The average count was calculated and expressed in numbers. Similarly, seeds within each seed sac were manually counted, and the average number was recorded. The total number of seeds per fruit was also counted manually, with the average expressed in numbers. Total soluble solids (TSS) were measured using a refractometer and adjusted with temperature. Titratable acidity (TA) was calculated as the percentage of citric acid in the juice was determined as per the method suggested by AOAC [12]. The maturation index (MI) was derived from the ratio of TSS to TA. Total sugars, as well as reducing and non-reducing

sugars, were estimated according to the protocols outlined by AOAC [12]. Fruit shape and color were determined through visual assessment.

2.5. Data Analysis and Interpretation

All collected data for various parameters were statistically analyzed using Statix10 software, and Fisher's LSD test was applied for mean separation and result interpretation [13].

3. Results and Discussion

All growth characteristics showed significant differences among the germplasm tested (Table 2). The tallest tree was obtained from AM Jai-003 (6.77m), while the lowest plant height was recorded (4.80m) in AM Jai-001. In case of base girth, AM Jai-002 produced maximum (82.98cm) and minimum (45.78cm) in AM Jai-003. The highest tree volume (80.82 m3) was recorded in AM Jai-002, while the lowest (43.46 m3) was noted in AM Jai-004 which was statistically similar AM Jai-003 (50.28 m3). The highest canopy spread (5.62 m) in the north-south direction was found in AM Jai-002 and lowest (4.23 m) was found in AM Jai-003. The highest canopy spread in the east-west direction (5.30 m) was noted in AM Jai-001 followed by AM Jai-002 and AM Jai-004 and lowest (3.30 m) in AM Jai-003.

Table 2 Growth characteristics of different Bael germplasm

Genotypes	Plant height (m)	Base girth (cm)	Plant volume (m^3)	Canopy Spread (m)	
				N-S	E-W
AM Jai-001	4.80c	67.90b	66.31b	5.00b	5.30a
AM Jai-002	5.95b	82.98a	80.82a	5.62a	4.57a
AM Jai-003	6.77a	45.78d	50.28c	4.23c	3.30b
AM Jai-004	3.95d	59.19c	43.46c	4.67bc	4.50a
LSD $_{(0.05)}$	0.74	5.81	9.05	0.60	0.92
CV (%)	6.92	4.55	7.52	6.14	10.44
SE	0.30	2.37	3.69	0.24	0.38

Fruit characteristics were presented in Table 3 and it showed that the harvesting period ranged from 1st week of March to 2nd week of June where AM Jai-001 was the earliest and AM Jai-003 was the latest fruit-producing germplasm. There was a significant difference among the germplasm regarding the number of fruits per plant. AM Jai-001 produced the maximum number of fruits per plant (63.21), while it was noticed minimum in AM Jai-003. There was a significant difference among the germplasm concerning fruit length, breadth, individual fruit weight, pulp weight, fiber weight, skull weight and yield. The largest fruit with respect to length (18.73 cm) and breadth (14.85 cm) in AM Jai-002 and the smallest fruit including length (11.57 cm) and breadth (9.17 cm) were observed in AM Jai-003. The same trend was also observed in fruit weight. Maximum fruit weight was recorded in AM Jai-002 (1140 g) and the minimum was recorded in AM Jai-003 (663.2 g).

Pulp weight is the most valuable part of bael for commercial and medicinal use and it showed significant variation among the germplasm studied (Table 3). AM Jai-002 had the highest pulp weight (641.67 g), while AM Jai-003 had the lowest (426 g). Higher pulp weight is desirable sharacter as it enhances fruit yield and processing efficiency. Although fibre content negatively affects pulp quality but it is valued for medicinal benefits. In the present study, AM Jai-003 gave the maximum fibre content (53.82 g), whereas AM Jai-001 gave the minimum (31.51g). This suggests that genotypes with lower fibre content may be more suitable for edible and processing purposes. Similar variations have been reported by previous researchers [14, 15, 16].

Yield is a key factor in determining the overall productivity of any genotype. In the present study, significant differences in yield were observed among the evaluated germplasm (Table 3). AM Jai-001 gave maximum fruit yield per plant (51.85kg). On the other hand, less productivity was observed in AM Jai-003 (17.30g). Similar variations in yield traits among different bael genotypes under different agro-climatic conditions were reported earlier [4, 17, 18, 19]. The differences observed in various quantitative fruit traits among varieties are primarily attributed to genetic factors, rather than edaphic (soil-related) or other environmental influences.

Table 3 Fruit characteristics of different Bael germplasm

Germplasm	Date of harvest	Fruits/ plant (No.)	Fruit size (cm)		Fruit weight (g)	Pulp weight (g)	Fiber weight (g)	Yield/ plant (kg)
			Length	Breadth				
AM Jai-001	1st WK of March	63.21a	14.77b	12.79b	820.4b	563.00b	31.51d	51.85a
AM Jai-002	2nd WK of April	38.53c	18.73a	14.85a	1140.2a	641.67a	45.16b	43.93b
AM Jai-003	2nd WK of June	26.10d	11.57d	9.17d	663.2d	426.00d	53.82a	17.30d
AM Jai-004	1st WK of May	48.77b	12.97c	10.43c	755.8c	510.25c	37.50c	36.85c
LSD (0.05)	-	5.56	1.37	0.60	22.44	15.45	4.94	4.50
CV (%)	-	6.30	4.78	2.54	1.33	1.44	5.89	6.01
SE	-	2.27	0.56	0.25	9.17	6.31	2.02	1.84

The skull (outer hard skin) of bael is an important indicator of fruit quality. A thick, brittle shell makes bael fruit harder to process and less appealing, while a thin, light shell improves ease of peeling and yields more edible pulp, enhancing its suitability for consumption and processing (Table 4). In this study, AM Jai-002 showed maximum skull thickness (0.48cm) as well as skull weight (266.32g), whereas lowest skull thickness and weight was found from AM Jai-001. Uddin [15] reported that the thickest shell (0.40 cm) was found in AM 03, while thinner shells (0.20 cm) were observed in AM 04, AM 05, and AM 08. Similarly, Pareek and Nath [24]) noted that bael shell thickness ranged between 0.26 and 0.32 cm, indicating variability among genotypes.

The evaluation of bael germplasm revealed significant differences in seed related attributes, which are critical for both propagation and processing suitability (Table 4). Among the germplasm studied, AM Jai-002 demonstrated superior performance, with the highest averages for seed sacks per fruit (15.21), seeds per sack (9.80), total seeds per fruit (148.94), and seed weight (41.03 g). In contrast, AM Jai-001 exhibited the lowest seed sacks per fruit (10.72), seeds per sack (5.46), total seeds per fruit (58.57), and seed weight (29.77 g). Such variations in quantitative traits appear to align with the findings was reported earlier [7, 17, 20, 21], who also observed significant diversity in seed-related characteristics among different bael genotypes. These differences suggest a strong genetic influence on trait expression, consistent with earlier studies on bael germplasm.

Table 4 Skull, seed and edible portion of different bael germplasm

Genotypes	Thickness of skull (cm)	Skull weight (g)	Number of seed sacks/ fruit	Number of seeds /sacks	Number of seeds/ fruit	Seed weight/ fruit (g)	Edible portion (%)
AM Jai-001	0.30d	109.29d	10.72d	5.46d	58.57d	29.77d	68.63a
AM Jai-002	0.48a	266.32a	15.21a	9.80a	148.94a	41.03a	56.28c
AM Jai-003	0.35b	239.46b	12.54b	8.30b	104.09b	37.85b	64.27b
AM Jai-004	0.33c	126.13c	11.50c	6.34c	72.97c	34.21c	67.52a
LSD (0.05)	0.02	5.52	0.58	0.21	3.92	3.13	2.41
CV (%)	2.43	1.49	2.31	1.43	2.04	4.38	1.88
SE	7.20	2.26	0.24	0.09	1.60	1.28	0.98

The edible portion of bael fruits varied significantly across the evaluated germplasm (Table 4). The highest edible portion (68.63%) was recorded in AM Jai-001, which was statistically at par with AM Jai-004 (67.52%). whereas the lowest edible portion (56.28%) was observed in AM Jai-002. These findings are in line with previous studies. Uddin [15] reported a maximum edible portion (70.40%) in AM 04 and minimum (55.31%) in AM 03**.** Similarly, Sarker [4] observed the highest edible portion (76.78%) in Germplasm No.5 and the lowest (62.11%) in Germplasm No.3. Variation among

germplasm is primarily due to genetic factors, as different cultivars naturally differ from one another. Some germplasm produces larger fruits with thinner skulls and more pulp, leading to a higher percentage of edible parts compared to others.

The chemical composition of bael fruit is key to its nutritional, medicinal, and commercial importance, enhancing its value for both traditional uses and processed products. There was a significant difference among the germplasm concerning Total soluble solids, total sugars (reducing and non-reducing), Titratable acidity, Sugar:Acid ratio and maturation index (Table 5). TSS content showed notable variation among bael germplasm, with AM Jai-001 having the highest (39.60%) and AM Jai-003 the lowest (32.48%). Similar ranges were reported [15, 17], indicating substantial diversity in TSS levels among the germplasm. Fruits with higher TSS content are more beneficial for medicinal purposes and the processing industry.

Fruit titratable acidity was found to be significantly higher in AM Jai-002 (0.40%), which was statistically similar to AM Jai-004 (0.38%), while the lowest acidity (0.31%) was recorded in AM Jai-001. Kumar et al. (2023) reported TSS values ranging from 31.12% to 40.2% among 13 bael genotypes. Similarly, Nagar et al. (2017) observed the highest acidity (0.52%) in the Samastipur Selection and the lowest (0.30%) in the NB-9 germplasm. Variations in acidity among different bael germplasm have also been documented by various researchers [20, 22], indicating a wide range of genetic diversity in this trait.

AM Jai-001 recorded the highest total sugar content (27.79%), whereas the lowest was observed in AM Jai-002 (19.65%). Kumar [23] observed total sugar content ranging from 15.9% to 20.3% in 13 bael germplasm under semi-arid conditions of Haryana, which is lower than the values reported in the present study. In comparison, Nagar [17] recorded a wider range of total sugars, with the highest (29.65%) in NB-5 and the lowest (18.43%) in NB-9 among 12 bael germplasm.

The highest reducing sugar content was recorded in AM Jai-001 (12.94%), while the lowest was observed in AM Jai-002 (9.31%). Kumar [23] also reported a similar range of reducing sugars, varying from 8.58% to 13.34% across different bael germplasm. These results are in line with the observations made by Nagar [17] and Pandey [20], who also found considerable variation in reducing sugar content in different bael germplasm. AM Jai-001 showed a significantly higher non-reducing sugar content (14.85%), while the lowest was recorded in AM Jai-002 (10.34%). Similar results found by Kumar [23], who reported the highest non-reducing sugars in the NB-5 germplasm and the lowest in the Samastipur Selection.

The highest sugar-acid ratio (89.72) was recorded in AM Jai-001, while the lowest (48.76) was found in AM Jai-002. These variations align with the findings of Kumar [23], who reported the highest sugar-acid ratio in the NB-17 germplasm and the lowest in the Samastipur Selection genotype. Maximum maturation index (127.79) was observed in AM Jai-001, with the minimum value (85.82) recorded in AM Jai-002. This variation in TSS-acid ratio is consistent with the earlier observations reported by Kumar [23].

Table 5 Physico-chemical characteristics of different Bael germplasm

Germplasm	Total Soluble Solids (%)	Titratable Acidity (%)	Total Sugars (%)	Reducing Sugars (%)	Non-Reducing Sugars (%)	Sugar: Acid ratio	Maturation Index
AM Jai-001	39.60a	0.31c	27.79a	12.94a	14.85a	89.72a	127.79a
AM Jai-002	34.59c	0.40a	19.65c	9.31d	10.34d	48.76d	85.82c
AM Jai-003	32.48d	0.34b	23.02b	10.45c	12.57b	67.10b	94.78b
AM Jai-004	36.47b	0.38a	22.68b	11.29b	11.39c	60.20c	96.85b
LSD $_{(0.05)}$	1.44	0.03	0.89	0.57	0.61	4.88	8.78
CV (%)	2.01	3.84	1.91	2.58	2.49	3.67	4.34
SE	0.59	0.01	0.36	0.23	0.25	1.99	3.59

Morphological attributes of different bael germplasm presented in table 6. Various fruit shapes were observed among the bael germplasm, including oblong, ovate, and roundish forms. Oblong fruits were found in AM Jai-001 and AM Jai-004, while AM Jai-002 showed an ovate shape and AM Jai-003 exhibited a roundish form. These observations are in line with the findings of Uddin [15], who also reported oblong, ovate, round, and roundish fruit shapes among 14 bael germplasm. The apex shape of bael fruits varied among the germplasm, with raised and flat types observed. AM Jai-001 and AM Jai-003 exhibited a raised apex, while AM Jai-002 and AM Jai-004 had a flat apex. This variation is supported by Uddin [15], who reported that out of 14 bael germplasm, six showed a flat apex and one displayed a raised apex. The skin color of mature fruits of the germplasm showed differences such as greenish yellow, grayish and yellow. The ripe fruit colour of the included germplasm varied from light yellow green to yellow colour. Sarker [14] also observed a wide range of variability regarding different physico-chemical characteristics of bael fruit, where skin and pulp color of ripe fruits varied from yellow to greenish, gray, Grayish Yellow, Whitish yellow and yellow to deep yellow and light yellow, respectively. The quality of bael fruit is assessed based on key attributes such as flavor, grittiness and the presence of mucilage. The germplasm AM Jai-001 exhibited excellent fruit flavor, while AM Jai-002 and AM Jai-004 were rated as having good flavor, and the rest showed a pleasant taste. Grittiness was present in AM Jai-002, AM Jai-003, and AM Jai-004, but absent in AM Jai-001. Mucilage content was lowest in AM Jai-001, whereas it was relatively high in most of the other genotypes studied.

Table 6 Morphological attributes of different bael germplasm

Genotypes	Fruit shape	Apex shape	Skin colour	Pulp colour	Flavor	Grittiness	Mucilage
AM Jai-001	Oblong	Raised	Greenish yellow	Light yellow	Excellent	Absent	Low
AM Jai-002	Ovate	Flat	Greenish yellow	Deep yellow	Good	Present	High
AM Jai-003	Roundish	Raised	Grayish yellow	Light yellow	Pleasant	Present	High
AM Jai-004	Oblong	Flat	Yellow	Light yellow	Good	Present	High

4. Conclusion

The results of the study conducted during the period 2019-2020 aimed to evaluate the performance of four bael germplasm under acidic soil conditions. Based on the findings, among the tested germplasm, AM Jai-001 showed the best performance, producing the highest number of fruits per plant (63.21) and the greatest yield per plant (51.85 kg). It also recorded the highest edible portion (68.63%) followed by AM Jai-004 (67.52%). In terms of fruit quality, AM Jai-001 had the highest total soluble solids (39.60%), total sugars (27.79%), and maturity index (127.79). The soil in the experimental field had a pH of 4.4, indicating strongly acidiic in nature and potential deficiencies in essential nutrients like calcium, magnesium, and phosphorus. Based on overall performance, AM Jai-001 and AM Jai-004 were identified as the most suitable germplasm for cultivation under acidic soil conditions and showed good tolerance to adverse climatic conditions.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

The authors declare no conflict of interest.

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