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Research Article

Floral biology and physico-morphological characteristics of 10 bael (*Aegle marmelos*) germplasm grown at Chapainawabganj, Bangladesh

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A B S T R A C T

The experiment was carried out in the research field and laboratory of Regional Horticulture Research Station (RHRS), BARI, Chapainawabganj during 2018 to 2019 to know the floral biology and post-harvest physical parameters of ten bael germplasm viz., AM-01, AM-02, AM-03, AM-04, AM-05, AM-06, AM-07, AM-08, AM-09 and AM-10 which were grown at Chapainawabganj. The maximum number of pollinations occurred in selected germplasm at 6:00-10:00am when temperature was 27–33°C and relative humidity was 79–83°F. The earliest flowering was observed at 7 April 2019 in AM-02 germplasm. The flowering duration was noted in between 51 to 60 days. The maximum anthesis was occurred at 7:00-8:00 am. Estimates for the maximum fruit weight, fruit length, fruit diameter, pulp weight, and skull pulp percentage in the AM-04 were 2900g, 28.90cm, 55.0cm, 2305g, and 79.48%, respectively and lowest fruit weight was recorded 750g in AM-07 compared to the others germplasm. The AM-06 germplasm had the highest recorded number of seeds (170), whereas the AM-02 and AM-08 genotypes had the lowest calculated number of seeds per axil (76). The superior germplasm of Bael is indicated by the lowest seed number.

INTRODUCTION

The tropical fruit bael (*Aegle marmelos* L.) is indigenous to Southeast Asia and is a member of the Rutaceae family and a significant native fruit found in Bangladesh as well. Bael is a crop grown on dry terrain. The fruit is classified as medium-sized, round, oval, or oblong, with a diameter that ranges from 5 to 20 cm. It has a thin, rigid, woody shell that becomes yellowish when ripe and gray-green when unripe. The fruit has tiny, fragrant oil glands scattered throughout it. The fruit has compound leaf. The tree grows abundantly in arid forests on the hills and plains of Bangladesh, India, Burma, Pakistan, Sri Lanka, Northern Malaya, Java, and Philippine Islands (Singh and Roy, 1984). Although it can be found in almost every part of Bangladesh, the east-west and northern regions are where it is most common, particularly in

the districts of Chapainawabganj, Rajshahi, Rangpur, Dinajpur, Gazipur, Jamalpur, Sherpur, Chadpur, Faridpur, Tangail, Mymensingh, Cumilla, Sylhet, and Chattogram. Bael owing to its environment-friendly nature, is placed among plant species group called “climate purifiers” as it emits a greater percentage of oxygen in sunlight as compared to other plants (Anurag *et al*., 2014) Bael is self-pollinating and exhibits a substantial (Jindal *et al*., 1993) initial fruit set; however, eventual retention is minimal due to significant fruit drop, perhaps attributable to climatic conditions (Sharma *et al*., 1996). Bisexual, bael blooms are about 2 cm in diameter, born in bunches, have a pleasant sweet perfume, and are greenish-white. Within seven to ten days of the new leaves appearing, the trees begin to produce flower embryos, or clumps, which bloom fully in April and May when the days are longer and the temperature is greater. Because of its extreme hardiness, the fruit can thrive in unfavorable agro climatic conditions with four months of availability in a year. Most tropical and subtropical fruits exhibit low shelf life; however, this particular fruit may be stored for an extended duration because to its robust outer shell, enabling it to endure transportation and marketing challenges effectively (Pandey *et al*., 2008). Flowers possess five sepals, and 3- 5 petals within same accession. Number of anthers varied from 26.46 to 61.40. Length and width of flower buds varied from 4.03 to 9.53 mm and 3.73 to 6.40 mm respectively. Pistil height varied from 7.63 to 12.43 mm. Different germplasm has different floral biology. Some set fruit earlier, some are later. Flowering duration also depend on germplasm. Therefore, an attempt has been made in this review to critically analyze the important aspects of flowering time, flowering duration flowering habit, and fruit set etc. which have been identified and found useful for commercial cultivation by bael cultivars. It can be consumed fresh, but usually converted into processing products (Morton, 1987). Fruit that is ripe has a hard core inside and 8 to 20 hardly noticeable triangular segments with thin, dark-orange walls that are loaded with pulp that is sticky, delicious, resinous, sallow orange, and somewhat astringent. Ripe fruit can be stored for up to a week. Therefore, following experiments were conducted to study the floral biology, flowering behavior and reproduction biology of the crop using existing genetic variation of bael.

MATERIALS AND METHODS

The experiment was carried out in BARI, Chapainawabganj, at the regional horticulture research station's laboratory. Ten (10) bael germplasm were analyzes using convenient selection by excess of tree no. AM-01, AM-02, AM-03, AM-04, AM-05, AM-06, AM-07, AM-08, AM-09 and AM-10. To monitor trees growth and growth habit, productivity, and maturity, the chosen germplasm was measured. Visual appearance was used to record the growth habit of trees.

Floral biology data collection Methods

Floral biology data recorded from three randomly selected panicles each from 10 trees visually with the help of digital camera (Nikon DX) when flowering initiation started and continued to fruit set, fruit dropping and fruit maturation periodically. Clipboard, tag paper, marker, pencil, tag rope etc. are used for flowering observation. The fruit set was calculated on percent basis. Basic floral biological data (flower color, flower duration, number of flower in bud, anthesis percentage etc.) were collected from the selected 10 germplasms. From 6:00am to 6:00pm, flowering time was recorded at each four hours interval.

Physico-morphological Characteristics

Fruit characteristics

Qualitative characteristics like fruit flavor, eating quality, grittiness, bitterness, sweetness etc. were measured.

Fruit size and shape: Fruit's diameter and length were measured to estimate its size. Using Vernier callipers, the fruits' maximum diameter and length were measured in centimeters, and their size was assessed visually.

Fruit weight: A digital balance was used to weigh the fruit in grams, and the average weight was determined.

Pulp Characters

Fruit pulp

The pulp content of each fruit was ascertained by measuring the edible portion of each fruit using a digital balance after the fiber, mucilage, and seeds were removed from the flesh. Additionally, the pulp content percentage was computed using the entire weigh

Color of the pulp

As recommended by Kumar *et al*. (2009), ocular observation was used to determine the pulp color.

Taste and flavor of the pulp

An expert panel consisting of five individuals conducted organoleptic investigations to establish the pulp's taste and flavor, following the recommendations of Kumar *et al*. (2009).

Skull Characters

Skull weight

Each fruit's skull was weighed individually on an electronic balance.

Skull thickness

Using Vernier Calipers, the thickness of the skull was measured and recorded in millimeters and the proportion of the skull within the entire fruit was noted as well.

Fruit mucilage

Seeds and mucilage were discarded from fruits flesh and segmented further and weighed. In following, mucilage was washed with water and remaining portion was weighed again. The mucilage portion was computed by subtracting the weight of seeds and segment membrane from weight of segments and calculated on percent basis.

Seed characters

Count of seeds in each fruit

The seeds were washed and surface dried after bring out from the fruit flesh. The seeds were tallied and as number of seeds per fruit were demonstrated.

Weight of seeds

Each fruit's seed weight was tracked using an electronic balance. To figure out the weight of the seeds, use previously done surface-dried seeds. Each fruit's seed count was determined by counting all of the pulp's seeds and weighing them in grams. To calculate the seed percentage, the weight of the seeds was divided by the total weight of the fruit.

Non-edible portion

The fruit's unpalatable center was cut out and weighed. The data was computed using a percent basis.

Statistical analysis

Microsoft Excel (Model-2013) and Statistical analysis software (SPSS version 28, IBM, Armonk, NY, USA) was used to examine the data.

RESULTS

Some general characters like growth, growth habit, productivity, maturity periods etc. were observed. Maximum trees growth happens at intermediate level. Trees growth habits are spreading but some are erect and intermediate. Higher productivity of bael germplasm were recorded in AM-01, AM-04, AM-05, AM-06, AM-07 and AM-10 and medium productivity level was found in AM-02, AM-03, AM-08 and AM-09 (Table 1). A similar result was reported by (Singh *et al.*, 2024), and, (Rai *et al.*, 1991), where they described a high yield of bael germplasm found at the early maturity period.

Table 1: General characters of different Bael germplasm

Germplasm	Tree growth	Tree growth habit	Maturity period	Productivity
AM-01	Vigorous	Spreading	Early	High
AM-02	Intermediate	Spreading	Mid	Medium
AM-03	Intermediate	Erect	Early	Medium
AM-04	Vigorous	Intermediate	Medium	High
AM-05	Vigorous	Spreading	Medium	High
AM-06	Vigorous	Spreading	Medium	High
AM-07	Intermediate	Spreading	Early	High
AM-08	Intermediate	Erect	Early	Medium
AM-09	Intermediate	Erect	Medium	Medium
AM-10	Intermediate	Erect	Medium	High

***AM**=*Aegle marmelos*

The maximum number of pollination occurred in selected bael germplasm at 6:00-10:00 am. During observation, the temperature was 27-33^{0}C and relative humidity was 79-83^{0}F. First flowering was started at 7 April in AM-02. Delayed flowering was observed in AM-09 (1st May) and AM-06 (9th May). According to Mani *et al.* (2017), the earliest flowering was noticed in ACC-5 (17th April), ACC-11 (20th April) and ACC-25 (21st April), whereas delayed flowering was appeared in ACC- 17 (17th May), ACC-6 (16th May), ACC-23 (14th May), ACC-19 (14th May), ACC-1 (11th May) and ACC-7 (11th May).

Table 2: Floral Biology in Different Germplasm

Germplasm	First Flowering	Flower Duration (Day)	No. of flower per axil	Flower color
AM-01	10th April	53 ± 1	16 ± 1	Greenish white
AM-02	7th April	55± 5	14 ± 2	Greenish white
AM-03	15th April	58± 4	18 ± 4	Greenish white
AM-04	9th April	51± 2	21 ± 3	Greenish white
AM-05	21th April	56± 11	16 ± 4	Greenish white
AM-06	9th May	59± 4	12 ± 2	Greenish white
AM-07	11th April	56± 5	17 ± 4	Greenish white
AM-08	8th April	59 ± 9	11 ± 5	Greenish white
AM-09	1st May	60± 5	11 ± 4	Greenish white
AM-10	11th April	54± 4	14 ± 2	Greenish white
LSD (5%)		9.78	5.67	-

Values are expressed as Mean ± SD, LSD Test for the significance level at (5%).

Flowering period continued from the days 51 to 60 days and maximum flowering time was needed 60 days in AM-09. A similar scientific study (Singhal *et al.*, 2011), suggested that the first flowering duration in bael germplasm occurred between 51-60 days and they provide greenish white color (Uddin *et al.*, 2016). Flowering period was lasting for 1.5-2 months. The highest number of flower per axil (21) was counted from the germplasm AM-04 and the lowest number was recorded in AM-08 (11) and AM-09 (11) up to complete flowering. All the blooms of each panicle were opened within one week period. Anthers and peals turned brownish color after 10-12 hours of anthesis. Stigma also turned into light brownish color after 10-12 hours of flower was opening though a wet surface.

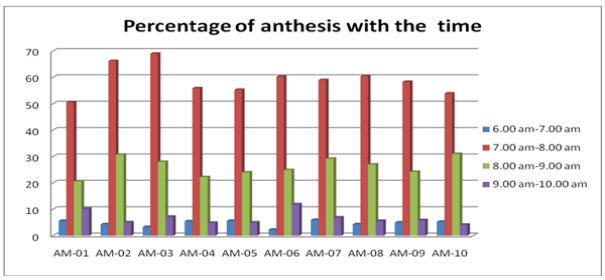

Figure 1: Percentage of anthesis with the time

The maximum anthesis was noted during 7:00 am-8:00 am (Figure-1). Flower color was greenish white (Table-2). Similar pattern of anthesis was observed in all accessions. Kumar *et al.* (2010) stated that the time of anthesis in bael varied from 3.00am to 8.00 am with a peak period between 4.00–5.00 am followed by 5.00 to 6.00 am and 6.00-7.00 am. A similar relationship between weather conditions and anthesis was also reported by Dhaliwal and Singla (2002) in guava and Srivastava and Singh (2000) in bael.

Table 3: General fruit characteristics in Different Germplasm

Germplasm	Fruit shape	Fruit flavour	Eating quality	Grittiness	Bitterness	Sweetness
AM-01	Ovate	Good	Good	Absent	Absent	Medium sweet
AM-02	Oblong	Good	Good	Absent	Absent	Medium sweet
AM-03	Oblong	Good	Excellent	Absent	Absent	Medium sweet
AM-04	Roundish	Excellent	Excellent	Absent	Absent	Very sweet
AM-05	Roundish	Excellent	Excellent	Absent	Absent	Medium sweet
AM-06	Roundish	Good	Good	Present	Absent	Medium sweet
AM-07	Roundish	Good	Poor	Absent	Absent	Less sweet
AM-08	Roundish	Excellent	Good	Present	Absent	Medium sweet
AM-09	Roundish	Good	Excellent	Present	Absent	Medium sweet
AM-10	Roundish	Excellent	Excellent	Present	Absent	Very sweet

From the selected germplasm, bael from AM-01 was ovate shaped, AM-02 and AM-03 was oblong shaped and the other remaining germplasms fruits were roundish. Maximum fruits flavor were good and some were excellent. Except the germplasm AM-07, eating quality of the rest germplasms were excellent. Some relevant studies conducted by Singh *et al.*, (2024) and Rai *et al.*, (1991) evaluated that round or oblate-shaped bael had amazing flavor, sweetness, and a pleasant aroma. Grittiness was found in germplasms AM-06, AM-08, AM-09 and AM-10. There was no bitterness in selected germplasms. Germplasms AM-04 and AM-10 were very sweet in taste, only AM-07 was found less sweet and the rest germplasms were medium sweet (Table 3).

Table 4: Vital fruit characteristics of various bael germplasm

Germplasm	Weight of Fruit (g)	Length of Fruit (cm)	Diameter of Fruit (cm)	Pulp-Weight(g)	% Pulp
AM-01	900.00 ± 5.00	12.13 ± 0.40	11.10 ± 0.60	638.00 ± 17.00	70.88 ± 1.89
AM-02	1900.00 ± 5.00	19.10 ± 0.60	48.00 ± 2.65	1412.00 ± 15.00	73.31 ± 0.78
AM-03	750.00 ± 10.00	10.50 ± 0.95	11.43 ± 0.84	415.00 ± 15.00	55.33 ± 2.00
AM-04	2900.00 ± 7.00	27.23 ± 1.76	55.00 ± 8.00	2305.00 ± 13.00	79.48 ± 0.45
AM-05	850.00 ± 5.00	10.10 ± 1.23	12.43 ± 1.23	661.33 ± 23.18	77.80 ± 2.73
AM-06	900.00 ± 5.00	6.23 ± 0.60	10.93 ± 0.84	553.00 ± 21.00	61.36 ± 2.22
AM-07	750.00 ± 8.00	12.30 ± 1.05	9.83 ± 0.84	504.00 ± 10.00	67.20 ± 1.34
AM-08	900.00 ± 5.00	12.00 ± 1.00	11.20 ± 1.40	587.33 ± 35.12	65.25 ± 3.90
AM-09	1000.00 ± 12.00	12.43 ± 0.80	13.17 ± 1.04	737.33 ± 27.15	73.73 ± 2.72
AM-10	1900.00 ± 5.00	25.70 ± 1.25	51.00 ± 3.00	1410.00 ± 10.00	74.21 ± 0.53
LSD (5%)	12.13	1.76	5.02	34.31	3.63

Values are expressed as Mean ± SD, LSD Test for the significance level at (5%).

Fruit weight is regarded as one of the most desirable traits for bael selection. The highest weight of fruit was observed AM- 04 (2900g), while the lowest value found in AM-03 and AM-07 (700g in both cases). There were notable differences in fruit length between specific germplasms (Table 4).

Table 5: Skull Characters of different bael Germplasm

Germplasm	Skull weight(g) (Mean ± SD)	Thickness of skull (mm) (Mean ± SD)	% Skull (Mean ± SD)
AM-01	210 ± 15	2.67 ± 0.76	23.96 ± 0.57
AM-02	390 ± 15	2.50 ± 0.00	19.93 ± 0.51
AM-03	260± 10	4.00 ± 2.00	33.44 ± 1.13
AM-04	450 ± 20	2.00 ± 0.50	15.92 ± 0.37
AM-05	142 ± 2	2.00 ± 0.50	16.08 ± 0.78
AM-06	270± 15	3.00 ± 1.00	28.67 ± 1.26
AM-07	180 ± 20	2.50 ± 1.00	22.65 ± 1.22
AM-08	260 ± 20	3.13 ± 2.10	28.63 ± 1.12
AM-09	205± 5	2.13 ± 0.90	19.80 ± 0.89
AM-10	380 ± 10	2.50 ± 1.00	19.33 ± 2.08
LSD (5%)	24.71	1.96	1.87

The AM-04 had significantly higher fruit length (27.23 cm) and the shortest fruit length in AM-03 (11.4cm), AM-05 (11.0cm) and AM-07 (11.2cm). Significantly higher diameters were seen in AM-04 (55.0 cm) and lowest in AM-07 (9.83 cm) respectively. The lowest pulp weight was recorded (415 g) in AM-03 and the highest significant pulp weight (2305 g) in AM-04. Pulp percentage from the whole fruit varied from 55.33- 79.48 %.

Skull weight varied from 142-450 g (Table 5). Maximum skull weight was measured in AM-04 and lowest in AM-05. Lowest thickness of skull was recorded (2.0 mm) in AM-04 and AM-05 and highest (4.0 mm) in AM-04. Skull percentage varied from 15.92-33.44 in selected germplasms. Pandey *et al.* (2013) observed range of thickness of the skull from 2.00-5.8 mm and pulp weight 320-2003g/fruit, whereas skull percent from 17.15 to 32.31, which is nearly similar to our results.

The range of seed chamber was found from 12 to 15, but 12 chamber was common in maximum fruits. As mucilage causes the bitterness of fruit, no fruits were found bitter (Table 3) because there was less amount of mucilage (Table 5). When choosing the best germplasm for bael, if the lowest number of seeds is taken into account as an instinctive, AM-02 and AM-08 (76) are the best choices.

Table 6: Seed characters of different Bael Germplasm

Germplasm	Seed Chamber	Mucilage amount	Seeds no. per axil	Seeds wt. per fruit (g)	% of Seeds
AM-01	12± 2	Less	110± 10	19 ± 3	2.11 ± 0.32
AM-02	13 ± 4	Less	76± 6	18± 3	0.95 ± 0.15
AM-03	12 ± 4	Less	150± 20	45± 5	5.99 ± 0.59
AM-04	12± 3	Less	88± 8	20± 6	0.69 ± 0.21
AM-05	15± 5	Less	91± 1	20± 5	2.35 ± 0.57
AM-06	13 ± 3	Less	170± 10	27± 7	2.99 ± 0.76
AM-07	12 ±2	Less	96± 6	16± 1	2.13 ± 0.11
AM-08	13± 4	Less	76± 8	16± 2	2.11 ± 0.40
AM-09	12± 6	Less	110± 10	21± 1	2.10 ± 0.08
AM-10	12± 5	Less	82± 3	20± 7	1.05 ± 0.37
LSD (5%)	6.81	-	16.25	7.77	0.71

Values are expressed as Mean ± SD, LSD Test for knowing the significance level at (5%).

The richest quantity of seeds was observed in AM-06 (170). The lowest seed weight (16 g) was recorded in AM-07 and AM-08 and the highest seed weight (45 g) in AM-03. The lesser percent of seed was calculated 0.68 % and highest 3.30 % from AM-02 and AM-03 respectively (Table 6).

CONCLUSION

From the experimental works it can be concluded that AM-02, AM-04 and AM-09 germplasm have more floral viability and physical parameters are richer than other germplasms. The seed numbers were also less among these germplasms. Excellent physical attributes of fruit are crucial for the advancement of processing technology and the quality of the finished products in the fruit production technology. As the floral viability and physical characteristics of these germplasms are good we can suggest these germplasms for commercial and further breeding purposes. Moreover, the study will also help the cultivars and researchers.

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CRediT authorship contribution statement

Conceptualization: M.S. Uddin, MN Islam; **Methodology:** MS UDDIN, MN Islam; **Experiment management and data collection:** MS Uddin, MN Islam, Z. FERDOUS; **Data analysis:** MN Islam, MAA Noman; **Writing-original draft preparation:** MS Uddin, MN Islam ,MAA Noman; Writing-review and editing: M.M.M. Hasan, MS Islam, MAA Noman; **Supervision:** M.S. UDDIN, MN Islam. The final manuscript has been read and approved by all writers.

Data Availability

Data are contained within the article.

Conflict of interest

There are no disclosed conflicts of interest for the writers.

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