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Research Article
Flowering Biology and Phenology of Aonla (*Emblica officinalis* Gaertn.) in the Semi-arid Environment of North-West India

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Abstract

Background and Objective: Aonla (*Emblica officinalis* Gaertn.) is a new introduction in the semi-arid environment of North-west India. This study is conducted for gaining knowledge about the factors affecting the floral biology and flowering phenology of this fruit plant under such environments. **Material and Methods:** The floral parameters like inflorescence and flower structure; months and time of anthesis, anther dehiscence and nectar production and floral longevity of Aonla were recorded. The stigma receptivity was determined by pollinating the female flowers at different intervals. **Results:** Inflorescences of Aonla bore unisexual flowers; sex ratio was male-biased. The flowering period of Aonla lasted for about 30 days. Anthesis started at about 1500 h and continued till 1800 h. Dehiscence of anthers started with the opening of the flowers and this too continued till 1800 h. The female flowers opened gradually in different stages and took about 72 h to open completely. Stigma was receptive from the second day of anthesis until the fifth day (for about 85 h); maximal stigma receptivity was recorded on the 3rd day of anthesis. The longevity of a male flower was about 2.5 days (about 60 h) and that of a female flower it was about 5 days (120 h). **Conclusion:** Aonla carried unisexual flowers with male-biased sex ratio, peak flower anthesis and anther dehiscence took place in the evening in March-April. The longevity of a male flower was about 60 h and of a female flower, it was 120 h. Pollination by the biotic pollen vectors seemed to be an essential requirement for the successful fruit set in the flowers of this plant.

Key words: Aonla, anthesis, dehiscence, *Emblica officinalis*, longevity, phenology

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Aonla (*Emblica officinalis* Gaertn.) is an important fruit plant. The fruit is highly nutritious and has tremendous medicinal value. It contains 500-1500 mg vitamin C, 0.2 mg nicotinic acid, 81.2% moisture, 14% carbohydrates, 3.4% fiber, 1.2% iron, 0.5% protein, 0.1% minerals and 0.02% phosphorus[1-3]. Fresh fruit is used in the preparation of products like pickle and preserves[4] and serves as an important ingredient in the preparation of Chyawanprash and Triphala, the well known Ayurvedic food and medicine[5-7]. Being the richest source of vitamin C, it helps cure scurvy, problems of teeth, gums, eye and stomach. Besides this, it is also used as remedies for dysentery, jaundice, anemia, bronchitis, cough, indigestion, urinary problems, septic fever, dyspepsia, etc. Owing to its property to strengthen the hair roots and maintain the color and luster of hairs; it is used in a wide variety of hair products. It is bestowed with spasmolytic, purgative, expectorant, hypoglycemic, hepatoprotective, hypolipidemic, antibacterial and astringent attributes and also is a powerful antioxidant[8-14].

Aonla (*Emblica officinalis*), originally a native of Southeastern Asia, thrives well under various agro-climatic and agro-edaphic situations. It is geographically distributed in Bangladesh, China, India, Malaysia, Pakistan and Sri Lanka[15]. Due to its high production potential with low maintenance cost and its immense nutritive and therapeutic value[7,16], this plant has fascinated the farmers for its cultivation. In India, the Aonla is cultivated in many states including Uttar Pradesh, Gujarat, Rajasthan, Maharashtra and Haryana[17]. Now the cultivation of this plant is rapidly spreading in other states like Tamil Nadu, Himachal Pradesh, Punjab and Andhra Pradesh[17].

Many factors influence the flowering phenology of plants; among these factors, the timing, frequency and duration of the flowering period are obviously of great importance[18-20]. Aonla is being promoted as an important horticultural plant in the semi-arid environments of India. However, detailed knowledge about the factors influencing the flowering phenology of this plant under such conditions is lacking. To accomplish this objective, the present study was carried out.

MATERIALS AND METHODS

The present study was carried out in 2009-2010 at the Research Farm of Department of Horticulture and in the Apidology Laboratory of the Department of Zoology and Aquaculture of Chaudhary Charan Singh Haryana Agricultural University, Hisar. Three varieties of Aonla (*Emblica officinalis* Gaertn.) (viz., Chakaiya, NA-7 and NA-10), selected for this study, were grown in the adjacent plots (Fig. 1). Following methods of Wadhwa and Sihag[20] were used for this study.

Fig. 1: Trees of Aonla (*Emblica officinalis*) in full bloom

Fig. 2: Inflorescences of Aonla (*Emblica officinalis*)

Floral biology of Aonla: These studies were conducted during the flowering season of Aonla (i.e., March and April) for 2 consecutive years (viz. 2009 and 2010) on three selected varieties. Freshly opened flowers of Aonla were brought to the laboratory and it was confirmed whether these were unisexual or hermaphrodite. Their distribution on the branchlets was recorded. To find out the ratio of male to female flowers, 10 branchlets were selected at random on the Aonla trees under observation (Fig. 2-3). The flowers on each branchlet were counted daily from the time they began to

Fig. 3: Male and female flowers in the inflorescences of Aonla (*Emblica officinalis*)
Male flowers are at the base and the female flowers are on the distal part (in the red marked areas) of the inflorescences

open till the completion of blossoming. Each day the flowers were removed after counting to avoid confusion in recording the observations.

Flowering phenology of Aonla in the semi-arid environments

Commencement and cessation of flowering: The day of appearance of first fresh flower on the trees was considered as the beginning and complete disappearance as the cessation of the flowering season. The number of flowers/m^2 were counted at 6 feet height once a week and on this basis the flowering intensity was designated as scanty (when number of flowers was 1-3 flowers/m^2), mediocre (when number was 4-6 flowers/m^2) and peak (when the number was more than 7 flowers/m^2). The period between the emergence of the first and the last flower was considered as the duration of flowering. The observations were also recorded on the ambient temperature and relative humidity prevailed during the flowering period of this plant.

Time of anthesis: For recording the time of anthesis in Aonla, floral buds expected to open the next day were tagged on the previous evening. Starting from 0500 h to the next morning, the number of fully opened flowers was noted at hourly interval till 1800 h in the evening during the flowering season of Aonla in 2009 and 2010. The observations were recorded at weekly intervals on 350 flowers for each variety and year.

Time of anther dehiscence: The dehiscence of anther was determined by observing the presence of a yellow powdery mass of pollen on the anthers with the help of a hand lens. The time during which maximum anthers dehisced was observed. Anthers' dehiscence was also noticed in both the years. For each parameter, observations were recorded on 350 flowers.

Stigma receptivity: The stigma receptivity was determined by pollinating 350 female flowers for each variety and the year after their opening till these were shed at different time intervals. The pollen grains germinated on the stigmatic surface confirmed the stigma receptivity. This was further ascertained by the visual observations with the help of a magnifying glass showing the shining surface of stigma during the period of stigma receptivity.

Flower longevity: The longevity of the flower was determined by recording the time of opening of the flower until the latter was shed. Individual flower buds due to open on next day were tagged on a preceding day and were monitored subsequently on the next days. The observations were repeated on 350 flowers/variety each year.

Statistical analysis: Statistical analysis was used wherever required in one way completely randomized design and paired t-test following Snedecor and Cochran[21] and comparisons were made at 5% level of significance.

RESULTS

Floral biology of Aonla: The basic flower morphology of Aonla was similar in the 3 varieties. This plant carried racemose type inflorescences. Flowers were ebracteolate, minute, unisexual, monoecious, actinomorphic, trimerous and hypogynous and were born in clusters. The male flowers were present at the lower end of a growing branchlet and the female flowers were above them (Fig. 3). Male flowers appeared first in a cluster and were numerous. The sex ratio of the flowers was highly variable in the different varieties. It was observed that NA-7 had the highest male-biased sex ratio followed by Chakaiya and NA-10. The numbers of male flowers/branchlet were 554.10 in NA-7, 398.20 in Chakaiya and 414.60 in NA-10, whereas, the numbers of female flowers/branchlet were 9.40 in NA-7, 6.60 in Chakaiya and 4.70 in NA-10 and the differences in the 3 varieties were significant (F-test, $p \leq 0.05$, ANOVA, Table 1). The sex ratio of male to female flowers per branchlet was 58.95:1 in NA-7, 60.33:1 in Chakaiya and 88.08:1 in NA-10.

Flowering phenology of Aonla

Commencement and cessation of flowering: All 3 varieties of Aonla viz. Chakaiya, NA-7 and NA-10 flowered once a year in the 3rd week of March to 2nd week of April and the flowering stretched for about a month (Table 2-3). The flowering intensity seemed to be associated with ambient temperature regimes. In 2009 and 2010, the flowering started when minimum and maximum temperatures ranges were 16.3-18.8 and 35.8-37.4°C (Table 2) and 17.4-19.4 and 35.5-37.0°C, respectively (Table 3). There after the flowering was mediocre for around a week. The peak flowering was witnessed in the first week of April when the minimum and maximum temperatures ranged between 15.6-23.2 and 35.2-37.2°C in 2009 (Table 2) and 21.2-23.9 and 39.0-41.8°C in 2010, respectively (Table 3). Thereafter, the flowering started to decline in the second week of April when the minimum and maximum temperatures ranged between 14.2-24.2 and 33.6-39.2°C in 2009 (Table 2) and 21.3-24.8 and 40.2- 42.7°C in 2010, respectively (Table 3). Flowering ceased completely in the 3rd week of April when minimum and maximum temperature ranges soared at 22.2-26.0 and 39.9-44.0°C in 2009 (Table 2) and 22.8-28.0 and 43.5-45.2°C in 2010 (Table 3).

Time of anthesis: The male flowers of all the 3 varieties started to open around 1500 h which continued till 1900 h; the peak of anthesis took place between 1600-1800 h (Fig. 4a and b). The female flowers of all the 3 varieties too started opening around 1500 h, but these flowers opened gradually in different stages and took about 72 h to open completely. The patterns of anthesis of male flowers were similar in all the three varieties of Aonla of this study and so were also the patterns of anthesis of female flowers.

Time of anther dehiscence: Anther dehiscence coincided with the opening of male flowers in the 3 varieties of Aonla and occurred soon or about 10-15 min after anthesis. The dehiscence too started at around 1500 h and continued up to 1900 h in all the three varieties and the maximal numbers of flowers dehisced between 1600-1800 h in all the 3 varieties (Fig. 5a and b).

Time of stigma receptivity: The stigma became receptive on the 2nd day of anthesis of a female flower and continued

Table 1: Sex ratio among the flowers of 3 varieties of Aonla (*Emblica officinalis*)

Varieties**	Number of male flowers/branchlet*	Number of female flowers/branchlet*	Sex ratio Male:Female
Chakaiya	398.20±6.33^{c}	6.60±0.45^{b}	60.33:1
NA-7	554.10±8.54^{a}	9.40±0.51^{a}	58.95:1
NA-10	414.60±8.49^{b}	4.70±0.37^{c}	88.08
CD	22.92**	1.34**	

*Mean±SD of 10 observations, **p<0.05, F-test: Significant

Table 2: Flowering phenology of Aonla (*Emblica officinalis*) in relation to ambient temperature regimes in 2009

			Ambient temperatures (°C)			
			Ranges		Means	
Crop parameters	Time interval	Duration (days)	Minimum	Maximum	Minimum	Maximum
Commencement of flowering	18/03/2009 to 21/03/2009	4	16.3-18.8	35.8-37.4	18.0	36.6
Scanty flowering	22/3/2009 to 25/03/2009	4	16.1-19.9	34.4-35.7	18.0	35.1
Mediocre flowering	26/03/2009 to 31/03/2009	6	15.2-18.0	30.7-33.7	17.8	32.2
Peak flowering	01/04/2009 to 08/04/2009	8	15.6-23.2	35.2-37.2	19.6	36.4
Mediocre flowering	09/04/2009 to 12/04/2009	4	14.2-24.2	33.6-39.2	18.8	35.9
Scanty flowering	13/04/2009 to 17/04/2009	5	18.3-24.7	36.7-41.9	22.3	39.6
Cessation of flowering	18/04/2009 to 20/04/2009	3	22.2-26.0	39.9-44.0	23.5	42.0

Table 3: Flowering phenology of Aonla (*Emblica officinalis*) in relation to ambient temperature regimes in 2010

			Ambient temperatures (°C)			
			Ranges		Means	
Crop parameters	Time interval	Duration (days)	Minimum	Maximum	Minimum	Maximum
Commencement of flowering	14/03/2010 to 18/03/2010	5	17.4-19.4	34.5-37.0	18.3	35.7
Scanty flowering	19-03-2010 to 23/03/2010	5	19.8-22.8	36.8-41.8	21.4	40.0
Mediocre flowering	24/03/2010 to 29-03-2010	6	21.8-24.9	39.5-42.0	22.9	40.3
Peak flowering	30/03/2010 to 05/04/2010	7	21.2-23.9	39.0-41.8	22.4	40.1
Mediocre flowering	06-04-2010 to 10/04/2010	5	21.3-24.8	40.2-42.7	23.3	41.6
Scanty flowering	11/04/2010 to 14/04/2010	4	25.3-27.8	41.2-43.5	24.8	42.5
Cessation of flowering	15/04/2010 to 18/04/2010	4	22.8-28.0	43.5-45.2	24.3	44.5

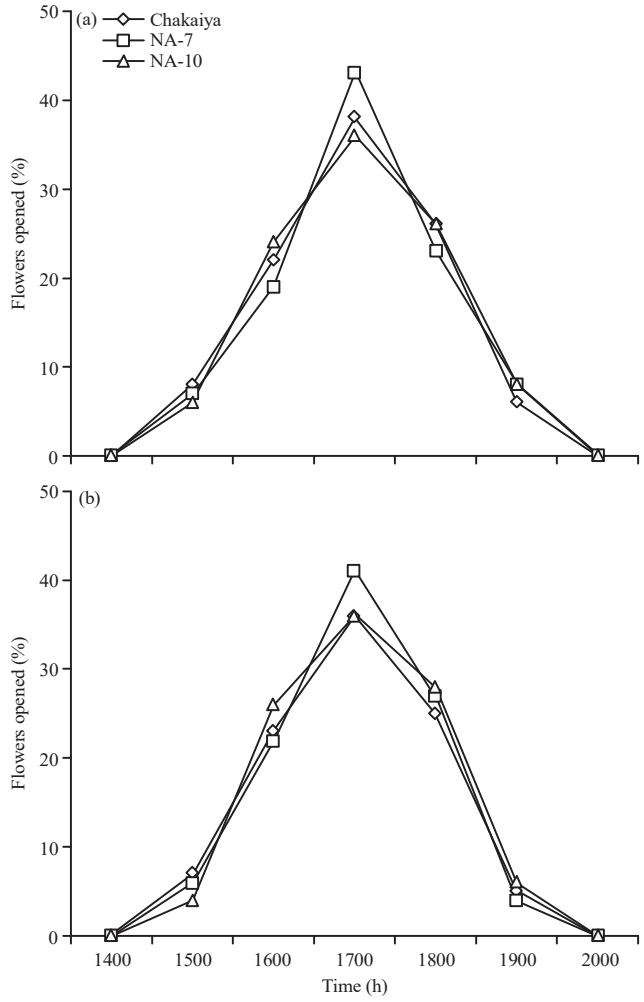

Fig. 4(a-b): Time of anthesis of male flowers in the 3 varieties of Aonla (*Emblica officinalis*) in (a) 2009 and (b) 2010

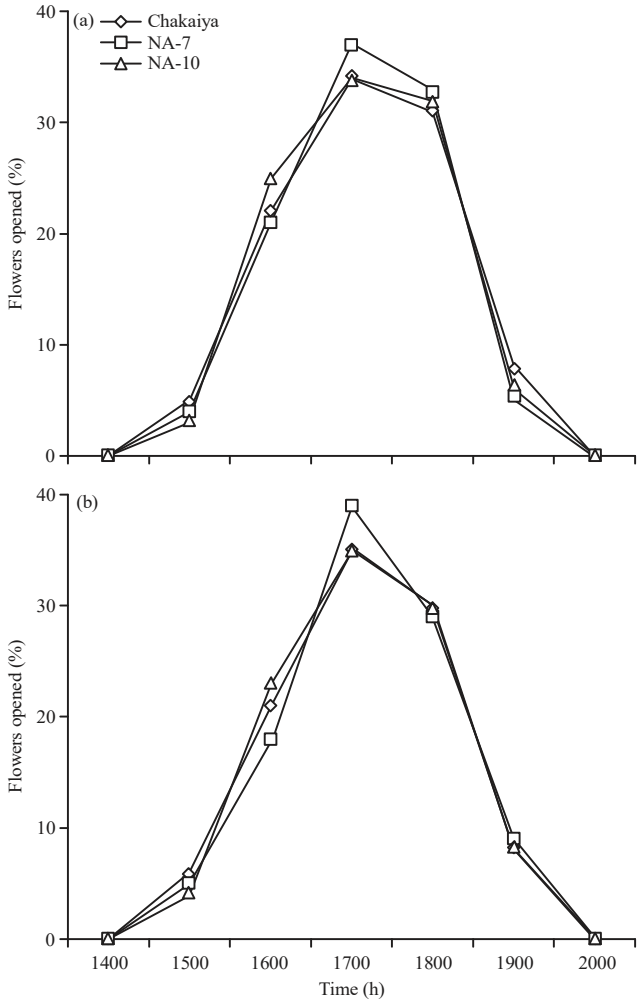

Fig. 5(a-b): Time of anther dehiscence in the male flowers of 3 varieties of Aonla (*Emblica officinalis*) in (a) 2009 and (b) 2010

Table 4: Stigma receptivity of female flowers in the 3 varieties of Aonla (*Emblica officinalis*)

	Stigma receptivity (h)	
Varieties*	2009**	2010**
Chakaiya	86.17±1.56	84.91±1.42
NA-7	85.29±1.43	84.99±1.47
NA-10	84.81±1.31	85.25±1.53

Mean±SD of 350 observations, *p>0.05, F-test: Non-significant, **p>0.05, t-test: Non-significant

Table 5: Longevity of male flowers in the 3 varieties of Aonla (*Emblica officinalis*)

	Longevity (h)	
Varieties*	2009**	2010**
Chakaiya	62.24±1.29	62.91±1.31
NA-7	63.29±1.33	63.79±1.38
NA-10	61.81±1.22	62.15±1.29

Mean±SD of 350 observations, *p>0.05, F-test: Non-significant, **p>0.05, t-test: Non-significant

until the fifth day, thus stretching for about 85 h (Table 4). The differences were non-significant between varieties (F-test, $p \geq 0.05$, Table 4) as well as the years (t-test, $p \geq 0.05$, Table 4). The pollen germination started only after a day (24 h) of female flower anthesis and continued up to 5th day of flower opening; after this, the stigmatic cells appeared brownish and the stigma became non-receptive. The highest percentage of stigma receptivity was recorded on the 3rd day of female flower anthesis.

Floral longevity: The male flowers of Aonla lasted for about 2.5 days (little over 60 h) in all the three varieties during 2009 and 2010 and the non-significant differences existed between the varieties (F-test, $p \geq 0.05$, Table 5) as well as the years (t-test, $p \geq 0.05$, Table 5). On the other hand, female flower lasted for about 5 days (about 120 h, Table 6) and here too, the

Table 6: Longevity of female flowers in the 3 varieties of Aonla (*Emblica officinalis*)

	Longevity (h)	
Varieties*	2009**	2010**
Chakaiya	121.15±2.43	120.85±2.32
NA-7	120.75±2.18	121.25±2.43
NA-10	119.85±2.27	120.05±2.38

Mean±SD of 350 observations, *p>0.05, F-test: Non-significant, **p>0.05, t-test: Non-significant

differences were non-significant between years (t-test, $p \geq 0.05$, Table 5) as well as varieties (F-test, $p \geq 0.05$, Table 6). The longevity of female flowers was significantly higher than the male flowers for each variety (paired t-test, $p \leq 0.05$, $n = 350$, $df = 348$, Table 5, 6).

DISCUSSION

In the semi-arid environment of North-west India, Aonla was found to bear the unisexual and monoecious flowers, the male flowers appeared first in the form of a cluster at the basal part of the determinate shoot. This was followed by the female flowers which appeared in the axils of leaves at the distal end of the same shoot. Earlier reports corroborate these findings[22]. Due to the presence of floral unisexuality in Aonla, pollination of its flowers by the biotic pollen vectors seemed to be an essential requirement for its successful reproduction. In this study, there was a male-biased sex ratio in the inflorescence of Aonla. This is in agreement with the earlier report revealing that male flowers of Aonla outnumbered the female flowers and there were different floral sex ratios in various cultivars[23].

Results of this study also revealed that flowering in Aonla started in mid/late March and stretched up to mid/late April depending upon the ambient temperature conditions. Some earlier reports too revealed that Aonla tree shed its determinate shoots and became devoid of foliage by the end of February to the middle of March. New shoots appeared until the first week of April and blossom buds on these shoots appeared during the middle of March till April[24]. The blooming period in Aonla was for about a month i.e., from 15th April to 15th May[25]. However, in South India, two flowering seasons of Aonla were reported, viz. February-March and June-July; the latter showed a poor crop[26,27].

In some related plant species, however, the situations were different. For example, in *Euphorbia helioscopa* L. (Euphorbiaceae) and *Ricinus communis* L. (Euphorbiaceae), the flowering period was from February-April and March-July, respectively[28].

Results of present study revealed that maximal anthesis in Aonla occurred between 1800-1900 h and dehiscence of the anthers also took place in the evening on the day of anthesis. Earlier report too revealed that maximal anthesis in Aonla occurred between 1800-1900 h that coincided with the temperature of 23-25°C[28], after 2000 h flowers did not open. Dehiscence of the anthers also took place in the evening (1600-1700 h) on the day of anthesis[29]. However, this was not the general rule in the family of this plant. In *Dalechampia stipulacea* (Euphorbiaceae), each inflorescence opened and closed between 1330-1800 h and maintained this rhythm daily for about 6 days[30]. Similarly, it was found that the flowers of *Jatropha curcas* L. (Euphorbiaceae) opened daily during 0530-0630 h and the female flowers opened in synchrony with the male flowers[31]. In *Euphorbia geniculata*, the stigmas were fully receptive by the 3rd day of anthesis and the male phase was evident from the 5th day of female anthesis, the anthers dehisced between 0800-1000 h[32]. In *Mercurialis annua* too, the anthesis of male flowers was influenced by temperature and occurred earlier at higher temperatures and later in the day at lower temperatures[33]. In *Euphorbia boetica*, the female flower was receptive for 3-8 days and remained erect during that period. At the end of the female phase, 0-4 stamens/day were issued from involucres and remained exposed for one day. The male phase lasted for 5-18 days[34]. As far as nectar secretion is concerned, male flowers secreted more nectar than the hermaphrodite flowers in the morning and in the afternoon the pattern was almost similar[34].

The foregoing account reveals that the phenology of a plant is species-specific and varies according to the variations in the local climatic conditions. The above information on the floral biology and the flowering phenology of Aonla is specific for the semi-arid environment of Northwest India; this may change according to the local ambient temperature conditions. However, the present information would be highly useful in the establishment of newly introduced Aonla as fruit and medicinal plant in the semi-arid environment of northwest India.

CONCLUSION

In the semi-arid environment of North-western region of India, Aonla was found to be a summer-flowering fruit plant and the flowering season stretched for about 30 days. This tree carried unisexual flowers where male-biased sex ratio existed. The peak anthesis and dehiscence took place in the evening. The male flower of this tree remained alive for about 2.5 days and the female flower for about 5 days. These findings are very useful in deciding the pollination management strategy of this tree and its establishment as fruit and medicinal plant in the semi-arid environments of India and elsewhere.

SIGNIFICANCE STATEMENT

Aonla is a new introduction in the semi-arid environment of North-west India. Its establishment would depend upon the availability of knowledge on the reproductive ecology of this plant under such conditions. This study is the first step and effort in this direction.

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