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Flowering behaviour, yield dynamics and fruit quality of Indian gooseberry (*Emblica officinalis*) in eastern tropical region of India

KUNDAN KISHORE[1], DEEPA SAMANT[2], H S SINGH[3] and P SRINIVAS[4]

Central Horticultural Experiment Station, ICAR- Indian Institute of Horticultural Research, Aiginia, Bhubaneswar, Odisha 751 019

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ABSTRACT

Performance of aonla (*Emblica Officinalis* Gaerten.) varieties was evaluated with respect to their flowering behaviour, yield and fruit quality at Central Horticultural Experiment Station (ICAR-IIHR), Bhubaneswar during 2011-14. Flower initiated in November and continued till February with the perceptibly long flowering duration (51-85 days). December-January was considered as a critical period for bloom. Post-fertilization fruit dormancy was relatively short (45 days) and fruits took about six months to get matured. Aonla genotypes showed low alternate bearing index (ABI) by exhibiting minimal temporal variation in yield. NA 7 exhibited maximum flowering intensity (82.5%), number of productive branchlets (80.93) and pistillate flowers/branchlet (6.15). It was the most promising variety in eastern tropics due to high yield (42.34 kg/tree), yield efficiency (0.86 kg/m^3) and crop density (6.37 fruits/cm^2), whereas, Krishna was found to the second most productive variety in the region. It was observed that fruit yield was not significantly related with flowering intensity, number of productive branchlets and sex ratio. NA 7 had maximum TSS (10.38 °B), whereas NA-10 had maximum vitamin C content (365.67 mg/100g). In comparison to subtropical regions, aonla genotypes had low TSS and vitamin C content.

Key words: Aonla, Crop density, Flower initiation, Productive branchlets, Yield efficiency

Indian gooseberry (*Emblica Officinalis* Gaertn.), commonly known as aonla, is an important subtropical fruit of Indian origin. It is well recognized for its nutritive, neutraceutical and therapeutic values. It has also been identified as an important component of crop diversification due to its wider adaptability under different land use systems and agro-climatic zones (Pathak and Pathak 2001, Maholiya *et al*. 2014). Flowering behaviour and yield potential of aonla varied with genotype, region and climatic conditions. The variation in flowering and yield may be attributed to the interaction between environment and genotype affecting sex ratio, flowering intensity and fruit set. However, some of the varieties are consistent in their yield performance (Singh *et al*. 2012). Under subtropical condition, flowering occurs only during February-March, whereas under tropical condition flowering occurs twice during February-March and June-July. The variation in the flowering behavior in aonla seems to be influenced by climate (Rao and Singh 2007). In addition to flowering pattern and yield, fruit quality attributes like fruit weight, fruit maturity period, pulp content, TSS, acidity and vitamin content are also influenced by climatic conditions. In aonla, majority of research work has been conducted under arid and semi-arid conditions, but its production potential has seldom been investigated in eastern tropical regions. The present study was aimed for critical assessment of vegetative morphomatrix, flowering behaviour, yield and quality attributes of aonla under tropical eastern region of India to evaluate its performance.

[1]Senior Scientist (e mail: kkhort12@gmail.com), [2]Scientist (e mail: horti.deepa@gmail.com), [3]Principal Scientist (e mail: singhhs21@rediffmail.com), [4]Senior Scientist (e mail: sripost@gmail.com).

MATERIALS AND METHODS

The investigation was carried out during 2011 to 2014 at the research farm of Central Horticultural Experiment Station, Bhubaneswar on 10 aonla varieties, viz. Kanchan, Krishna, Francis, Chakaiya, Banarasi, NA 6, NA 7, NA 9, NA 10 and Anand 2 maintained under uniform cultural practices. Varieties were planted at the distance of 5 × 5m during 2006-07. They were evaluated for their growth behavior, flowering behaviour, yield potential and fruit quality under eastern coastal region of India. The experimental site lies between 20° 15' N latitude and 85° 15' E longitude at an altitude of 45 m above mean sea level. The climate of the location is tropical hot and humid and the mean minimum and maximum temperature varies 22.0 and 33.7°C, respectively. December and January were relatively colder with the minimum temperature of 16°C. Temperature starts rising from March onwards and reaches to maximum in May. Bhubaneswar receives about 1 600 mm rainfall annually and most of the rain occurs during June-September,

however sporadic rain also occurs during October and summer (March - May). The experimental site is quite humid throughout the year due to the prevalence of high relative humidity (>60%). The soil of the experimental site was red lateritic, highly acidic (4.8-5.2) with low organic matter (0.42%). Soils of aonla block had low N (<200kg/ha), medium P (10-15 kg/ha) and K content (150-20kg/ha). Experiment was laid out in randomized block design with three replications each with three plant units and each variety was considered as a treatment.

Vegetative growth parameters in terms of trunk cross sectional area (TCSA) and tree volume were recorded. TCSA was worked out by using the formula πr^2 considering the cross sectional area of trunk as a circle and expressed in cm^2. Canopy volume (V) was computed by following formula assuming tree shape as half prolate spheroid (Zekri 2000).

$$V = (1/6) \times H \times Dl \times Dr$$

where, Dl = canopy width in parallel, Dr = canopy width in perpendicular, H = tree height (m).

To ascertain flowering duration and peak flowering, 15 branches were tagged in three different plants (five each) in each variety and date of first cyme (inflorescence) initiation was considered when 5% flower buds were opened, whereas the cessation of cyme initiation was considered as completion of flowering. The duration between initiation and cessation of cyme was considered as flowering duration. The peak flowering was considered when more than 75% cyme were in bloom. Flowering intensity in different aonla varieties was worked out by diving the number of floriferous branches and total number of tagged branches and expressed in percentage. Productive branchlet percentage was calculated by using following formula.

$$P = (F/T) \times 100,$$

where, F = number of branchlets with both forms of sex, T = total number of branchlets.

Intensity of female (pistillate) flower in productive branchlet was worked out by counting the number of female flowers in 100 branchlets and mean was computed. Sex ratio was calculated by counting the number of pistillate and staminate flowers in 100 branchlets and expressed as the number of pistillate flowers per 100 staminate flowers. Fruit set was calculated by diving the number of fruits (pea stage) and number of pistillate flowers in 100 tagged floriferous branchlets and expressed in percentage. Whereas fruit maturity period was the days between fruit set and fruit harvesting. Fruits were harvested separately in each replicates and mean was worked out to express the yield in kg/tree, whereas yield efficiency was computed by dividing the yield and tree volume and expressed in kg/m^3. Crop density was worked out by dividing the number of fruits and TCSA (Lombard *et al.* 1988). The yearly fluctuation in yield was expressed in terms of alternate bearing index (ABI) using the following expression $ABI = 1/(n\text{-}_1) \times \{|a_2\text{-}a_1|/(a_2+a_1) + |a_3\text{-}a_2|/ (a_3+a_2)/ + |an\text{-}an\text{-}_1|/(an+an\text{-}_1)\}$, where n = number of years and $a_1, a_2, \ldots, an\text{-}_1$, an = yield of the corresponding years (Stenzel *et al.* 2003). The value of ABI varies between 0 to 1. Zero indicates no alternate bearing whereas, 1 indicates complete alternate bearing.

Physicochemical parameters, viz. fruit weight, moisture content, TSS, titratable acidity, pH and vitamin C content were estimated at fruit maturity. Fruit weight was computed by dividing the yield and number of fruits per tree. For estimation of moisture content in aonla, the difference between fresh weight and oven dry weight (60°C for 36 hr) of 20 fruits was taken into account and expressed in percentage. TSS was determined using hand held digital refractometer (0-85 °Brix, Hanna) and pH of fruit juice was estimated by digital pH meter. Acidity (% citric acid) and vitamin C (mg/100g pulp) were determined by following standard technique as described by AOAC (1990). The data on various parameters were statistically analyzed by performing one way ANOVA and *F*-test, wherever relevant, to determine the significance of differences among treatments. Relation between parameters was worked out through simple linear regression equation following least squares method.

RESULTS AND DISCUSSION

Vegetative growth in terms of TCSA and tree volume varied significantly with genotypes. Kanchan had the maximum TCSA and tree volume, whereas NA 6 had the minimum (Table 1). It was also observed that Kanchan and NA 9 had relatively high vegetative growth in comparison to other varieties. Aonla exhibited typical asynchronous flowering behaviour under tropical eastern coastal region. Flower initiated in November and continued till February. However, genotypic variation was observed. Flowering in NA 7 and Francis started in November and continued till January, whereas in other varieties, flowering started in December and continued till February. December was considered as a critical period for bloom in NA 7 and Francis, whereas other varieties exhibited peak flowering in January. In contrary, under subtropical condition, flowering starts in March and continues till April (Shukla *et al.* 2009) and lasts for a month. The phenological response of aonla in terms of flowering advancement is considered among the prominent biological indicators of climate influence. Since winter is not intense in tropics, flowering event in aonla seems to be influenced by the age of shoots rather than low temperature. On the other hand, low temperature could be the critical component for flower induction in subtropics as flowering takes place when winter is over (Davenport 2003). Moreover the advancement in flowering in tropics may be attributed to the prevalence of mild winter (minimum temperature 16 °C) during flowering which is not prevalent in the subtropics. Under tropical eastern coastal region, aonla exhibited perceptibly long flowering duration (Table 1). The longest duration was exhibited by NA 10 and Anand 2 (> 80 days), whereas Francis had the shortest duration. Long flowering spell in aonla under tropics may be attributed to the prevalence of mild temperature between November to February.

Flowering intensity varied significantly among varieties (20.6 - 82.5%). Data clearly depicted that NA 7 had the

Table 1 Growth and flowering behaviour of aonla varieties*

Variety	TCSA (cm^2)	Tree volume (m^3)	Flowering period	Peak flowering	Flowering duration (days)	Flowering intensity (%)	Productive branchlets (%)	No. of pistillate flowers/ productive branchlet	Sex ratio (pistillate/ 100 staminate flowers)
Kanchan	211.63	60.95	Early December–mid February	20th–30th January	69.42	56.42	69.38	4.21	3.35
Krishna	158.64	44.01	Late November–late February	10th–20th January	80.74	75.84	17.62	1.49	0.18
NA 6	111.15	25.24	Early December–mid February	20th–30th January	70.66	65.38	45.52	5.81	1.08
NA 7	173.75	49.04	Mid November–mid January	15th–30th December	58.54	82.53	80.93	6.15	9.80
NA 9	186.43	55.13	Early December–mid February	24th–30th January	68.87	25.65	60.95	5.64	6.75
NA 10	143.22	40.34	Late November–early February	10th–20th January	85.63	32.57	66.52	3.42	16.05
Francis	129.19	32.14	Mid November–early January	20th–30th December	51.48	45.53	35.52	1.54	4.90
Chakaiya	135.32	34.96	Mid December–early February	10th–20th January	55.64	22.52	63.42	7.65	2.74
Banarasi	120.24	30.21	Late December–Late February	20th–30th January	62.63	20.64	57.82	1.23	0.29
Anand 2	149.39	38.41	Late November–Late February	10th–20th January	85.31	64.58	47.55	2.25	2.18
CD (P=0.05)	4.67	4.42			5.23	2.63	6.21	0.52	0.63
SE	1.56	1.47			1.74	0.88	2.07	0.17	0.21
CV	1.72	6.20			4.39	3.10	6.59	7.63	7.71

*Data are mean of 2011-14.

highest flowering intensity with more floriferous canopy area (>80%) followed by Krishna. Whereas, Banarasi had the minimal flowering intensity (Table 1). NA-6 and Anand 2 also had moderately high flowering intensity. When intensity of productive branchlets was studied, it was observed that NA 7 had the highest productive branchlets followed by Kanchan. The lowest intensity of productive branchlets was recorded in Krishna whereas NA 10, Chakaiya and NA 9 had moderate intensity of productive branchlets. Data indicated significant genotypic variation in the occurrence of pistillate flowers/branchlet (Table 1). The highest intensity of pistillate flowers was recorded in Chakaiya followed by NA 7, whereas Banarasi, Krishna and Francis had low intensity of occurrence of pistillate flowers. Sex ratio representing the relative occurrence of pistillate and staminate flowers, varied significantly with genotypes. The highest sex ratio was observed in NA 10 followed by NA 7, whereas Krishna and Banarasi had significantly low sex ratio (<1.0). Genotypes exhibited wide variation in the intensity of fruit set. Krishna and NA 10 had comparatively better fruit set than other genotypes whereas, NA 9 and Chakaiya had minimal fruit set. Fruit set in other aonla varieties was intermediate (Table 1). Variation in the fruit set was observed between subtropics and tropics. Shukla *et al.* (2009) reported more fruit set percentage in NA 7 under semi-arid subtropical condition, whereas in tropics Krishna exhibited better fruit set.

Aonla exhibited post-fertilization fruit dormancy for about 45 days as fruits ceased to develop during this period. However, there was no significant genotypic variation in fruit dormancy period (Table 2). Under subtropical conditions, fruit dormancy is relatively longer as fruits remain dormant for more than 90 days of fruit set (April-May) and resume growth with the onset of rainfall, i.e. during July (Shukla *et al*. 2011). Short fruit dormancy in tropical coastal region may be attributed to the variation in climatic conditions (temperature and humidity) and hormonal activity. Studies indicate that interplay between auxin and gibberellin is essential for fruit development (McAtee *et al.* 2013). As per 'seed control' hypothesis, seed communicate through hormone to the surrounding tissue (pericarp) to promote fruit growth through firstly cell division and later on cell expansion (Ozga *et al.* 2002). After fertilization auxin levels increases in seed, while gibberellin levels increases in the ovaries. Fruit development is induced by auxin, present in the ovule, through activation of gibberellin signaling to initiate gibberellin biosynthesis in the pericarp region to initiate the process of fruit development (Zhao 2010). The fruit dormancy in aonla may be attributed to low auxin level in ovule after fertilization which could have affected

Table 2 Fruiting behavior, yield and quality attributes of aonla varieties*

Variety	Fruit set (%)	Fruit dormancy (days)	Fruit maturity (days)	Yield (kg/tree)	Yield efficiency (kg/m^3)	Crop density (fruits/cm^2)	ABI	Fruit weight (g)	Moisture (%)	TSS (°Brix)	Acidity (%)	pH	Vitamin C (mg/100g)
Kanchan	23.84	44.51	182.84	11.54	0.19	1.21	0.08	25.59	83.82	7.88	2.11	2.69	194.28
Krishna	53.69	46.77	181.42	19.72	0.40	1.30	0.07	51.91	82.42	9.08	2.65	2.54	193.32
NA-6	37.14	45.82	178.64	3.50	0.14	1.13	0.02	27.84	84.31	7.17	2.52	2.41	226.65
NA-7	31.98	45.18	177.77	42.34	0.86	6.37	0.08	38.24	84.11	10.38	2.24	2.62	228.57
NA-9	7.09	46.95	185.42	6.35	0.12	1.28	0.14	26.69	84.47	8.61	1.92	2.89	297.11
NA-10	49.92	44.23	187.47	7.62	0.19	1.69	0.14	31.43	82.87	10.06	2.30	2.65	365.67
Francis	32.46	46.64	183.41	6.35	0.20	1.86	0.09	26.45	88.68	9.02	1.89	2.95	186.67
Chakaiya	17.37	46.29	188.72	2.92	0.08	0.87	0.06	24.87	82.74	8.01	1.98	2.91	245.63
Banarasi	23.53	46.68	181.34	1.21	0.04	0.38	0.02	26.16	84.62	7.20	2.08	2.85	197.54
Anand 2	44.42	44.86	186.18	7.23	0.19	1.88	0.12	25.74	81.07	9.95	1.92	2.94	259.89
CD (P=0.05)	2.26	NS	3.36	3.53	0.14	0.49	0.04	1.02	0.90	0.37	0.31	0.27	4.58
SE(m)	0.76	0.23	1.12	1.18	0.05	0.16	0.01	0.34	0.30	0.12	0.10	0.09	1.53
CV	4.24	2.84	1.82	21.56	37.19	15.63	24.52	1.93	0.62	2.49	8.49	5.74	1.10

*Data are mean of 2011-14.

gibberellin biosynthesis in the pericarp region. Low auxin level in ovule during dormancy may be due to insufficient biosynthesis and translocation of auxin from shoot tip. On the other hand, high translocation of auxin, from vegetatively active shoots might have helped in breaking the dormancy and facilitated resumption of fruit growth. Ram (2009) corroborated the role of auxin in the dormancy mechanism of aonla. He reported that level of auxin increased in the fruit with the onset of dormancy and decreased to a low level prior to dormancy break.

Under tropical eastern coastal region, aonla required about 6 months for fruit maturity, however genotypic variation was observed. Chakaiya took maximum days to attain maturity whereas NA 7 took the minimal days (Table 2). In most of the varieties August-September was the harvesting period, though harvesting continued till October. On the other hand, under subtropical conditions aonla takes about 7 months to attain maturity (Shukla *et al*. 2009). Short maturity period of aonla in the tropics may be attributed to short period of fruit dormancy and high frequency of rainfall. Long spell of rainfall (June - October) helps in maintaining the soil moisture tension for longer period which might have played important role in fruit growth and development. Yield, the determinant of production potential of crop, varied significantly with genotypes. NA 7 was the most productive variety followed by Krishna, whereas other varieties had poor yield potential (Table 2). It may be interpreted that high flowering intensity, more number of productive branchletes and pistillate flowers contributed significantly in fruit yield of NA 7. Under subtropical arid region, dry and sub-humid region of West Bengal and Vidharbha region of Maharashtra, NA 7 was also reported to be the most productive variety of aonla (Shukla *et al*. 2009, Patil *et al.* 2010, Ghosh *et al.* 2013). The variation in yield efficiency and crop density followed the pattern of genotypic response on yield. The highest yield efficiency and crop density was recorded in NA 7 followed by Krishna. In other varieties, yield efficiency and crop density were significantly low (Table 2). Studies on alternate bearing index (ABI) indicated that all varieties of aonla had low ABI by exhibiting minimal year-wise yield variation (data not shown). NA 9, NA 10 and Anand 2 had relatively high ABI; however value was not high enough to indicate the prevalence of alternate bearing.

Fruit quality was evaluated with respect to fruit weight, moisture content, TSS, acidity, pH and vitamin C content (Table 2). Fruit weight varied significantly with the genotypes. Krishna had the maximum fruit weight followed by NA 7, whereas other genotypes had intermediate range of fruit weight. Genotypic variation in fruit weight was also reported in subtropics (Shukla *et al.* 2009). Aonla exhibited variation in the moisture content. The highest moisture content was recorded in Francis and lowest in Anand-2. However, all the varieties had more than 80 per cent moisture content. Aonla genotypes showed significant variation in TSS content (Table 2). NA 7 (10.36 °B) and NA 10 (10.06 °B) had relatively high TSS whereas NA 6, Banarasi and Kanchan had low TSS. On the other hand, Shukla *et al.* (2009) reported relatively high TSS (15–18 °B) in aonla varieties under subtropical condition. The low TSS content in aonla in eastern tropical region may be due to the occurrence of rainfall during fruit maturity (August - September) which might have increased the moisture content in the fruit and dilution of carbohydrates. Significant varietal variation was observed in acidity and pH of fruit. Most of the varieties were highly acidic (>2%) and consequently had low pH (<3.0) range. Krishna was the most acidic, whereas Francis was the least. Like other fruit quality parameters, vitamin C also exhibited significant variation among genotypes. NA-10 was relatively rich in

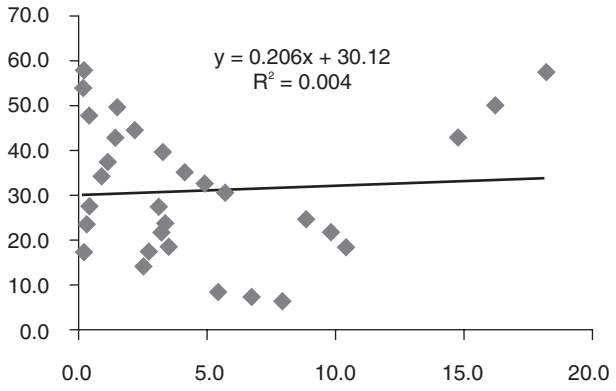

Fig 1 Linear relation between sex ratio and fruit set

vitamin C content (365.6 mg/100g), whereas Francis, Krishna, Kanchan and Banarasi had low vitamin C content (Table 2). Shukla *et al.* (2009) reported maximum vitamin C content in NA-10 (678 mg/100g) and minimum in Krishna (542 mg/100g) under subtropical regions. It is evident that the vitamin C content in aonla was relatively low in tropics which could be due to the prevalence of relatively higher temperature and moisture content at the time of fruit maturation that might have affected enzymatic biosynthesis of ascorbic acid in fruits (Njoku *et al*. 2011, Singh and Dhaliwal 2004).

Linear regression analysis indicated that the yield of aonla was not significantly related with flowering intensity ($R^2 = 0.409$), number of productive branchlets ($R^2 = 0.160$) and sex ratio ($R^2 = 0.066$). It may be interpreted from data that variables, viz. flowering intensity, number of productive branchlets and sex ratio were individually unable to influence the yield parameter, rather they influenced the yield together as the most productive variety (NA 7) had high flowering intensity, number of productive branchlets and sex ratio. On the other hand, the genotypes either with more flowering intensity or sex ratio had relatively low yield potential. Poor linear relation was also observed between sex ratio and fruit set ($R^2 = 0.004$) in aonla (Fig 1) which indicated that former may not be considered as an indicator of fruit set.

Present study indicates significant advancement in flowering and increase in flowering spell in aonla in comparison to subtropical regions. Aonla genotype exhibited low post-fertilization fruit dormancy period and fruit maturity period. NA 7 was the most productive aonla variety with respect to yield, yield efficiency and crop density followed by Krishna, whereas other genotypes exhibited low yield potential. There was no indication of alternate bearing in aonla genotypes. Fruit quality of aonla in the eastern tropical regions was relatively poor as it was evident from its low TSS and vitamin C content.

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