DOI : 10.58993/ijh/2025.82.4.2

Indian J. Hortic. 82(4), December 2025: 395-400

Eco-physiological assessment of aonla (*Emblica officinalis*) genotypes for sustainable carbon sequestration in semiarid region

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ABSTRACT

The present investigation was conducted to assess the aonla genotypes for their growth, yield, fruit quality attributes and carbon sequestration potential under the semi-arid condition. The evaluated genotypes had significant variability for the observed parameters. CHES 1 and BSR 1 were found comparatively less vigorous amongst selected genotypes. Among the genotypes under investigation, NA 20 gave maximum yield, with higher fruit weight (54.39 g) and fruit length (3.33 cm). TSS and TSS: acid ratio was observed higher in BSR 1. Ascorbic acid content was recorded highest in Chakaiya and NA 7, respectively. The most promising genotype were NA 20 and NA 7 with the highest yield (105.9 & 94.41 kg/plant) and B:C ratio (8.9 & 7.9) respectively. A highly significant positive correlation ($r = 0.84$, $p \leq 0.01$) was observed between fruit weight and yield, suggesting that heavier fruits markedly enhance total productivity. Furthermore, ascorbic acid also correlated significantly with the benefit–cost (B:C) ratio ($r = 0.39$, $p \leq 0.05$). These interrelationships provide valuable insights for selecting genotypes with desirable traits for breeding and cultivation in semi-arid conditions. The higher R^2 value for biomass and diameter indicates that biomass increments are more closely related to increments in girth. The finding therefore implies that genotype NA 20 and NA 7 could be recommended for commercial cultivation in semi-arid regions of Haryana for upliftment of rural livelihood.

Key words: Genotype, carbon sequestration, *Embilica officinalis*, semi-arid region, B:C ratio

INTRODUCTION

Aonla (*Embilica officinalis* Gaertn.) is also known as Indian gooseberry and a member of family *Euphorbiaceae* is originated in Tropical South East Asia particularly South India. It is an important fruit crop of 21st century and it has been regarded as 'Amritphal' in ancient literature and identified as an ideal plant for various kinds of wastelands, viz moisture stress, eroded, ravines, upland, riverbed and the areas with undulated topography (Korwar *et al*., 9). It possesses some specific characters like intensive and deeper root system, summer dormancy of zygote, reduced leaf area, synchronization of fruit growth and development with maximum moisture availability period and selective absorption of ions which enable it to grow in fragile agro-climatic conditions. It has gained momentum under hot arid region of the country due of its hardy nature, prolific bearing, potential fruit crop and capacity to grow under various adversities (Pandey *et al*., 14). It is known as Amritphala due to its nutritive and energy restoring quality. The edible fruit tissue of aonla contains about three times as much protein and 160 times as much vitamin 'C' compared to apple (Vikram *et al*., 22). The fruit contains a chemical substance called leucanthocyanin which retards the oxidation of ascorbic acid. Antioxidant effect of gallic acid, present in aonla fruit is being well acknowledged.

Carbon Sequestration is known to be a cost-effective option for mitigation of global warming and global climatic change. Sequestration can be defined as the net removal of carbon dioxide from the atmosphere into long lived carbon pools. Estimates of carbon stocks and stock changes in tree biomass (above and below ground) are necessary for reporting to the United Nations Framework Convention on Climate Change (UNFCCC) and will be required for Kyoto Protocol reporting (Green *et al*., 7).

Majority of plants convert the carbon dioxide into sugar chemical compounds, oxygen etc. (Francesco, 6; Jana *et al*., 8) and thereby remove the atmospheric carbon dioxide. The release of carbon dioxide cannot be stopped easily so the only solution for CO_2 mitigation is reforestation and conservation of the already existing species and diversity.

Aonla has vast scope of growing in wastelands like salt affected marginal arid and semi-arid edaphological situations. It is moderately tolerant to salt even up to 30-40 ESP and 9-12 dsm^{-1} EC. Owing to its hardiness, high productivity, suitability for growing under varied agro-climatic conditions

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and its utilization in cosmetic, pharmaceutical and processing industry, attracts the growers for its cultivation under rainfed condition. Now its cultivation is becoming popular in rainfed areas of the country. (Shukla *et al*., 18) reported varietal diversity as an important ingredient in agriculture system which fulfills the varied needs of the farmers according to their physical environments. However, there is scanty of scientific information regarding distinct traits of aonla varieties and also for visualizing the prospects of this fruit under rainfed conditions. The objective of the study was to assess the diversity of aonla genotype/varieties in terms of growth, yield and quality and to estimate the sequestrated carbon by them, contributing in reducing CO_2 concentration in the atmosphere. so that these distinct characters could be used for further improvement of the crop under hot semi-arid region of Haryana.

MATERIALS AND METHODS

The present study was carried out at experimental orchard at Regional Research Station, Bawal (Rewari), situated at an altitude of 266 m above mean sea level with coordinates of 28º10´N latitude and 76º50´E longitudes in South-West zone of Haryana having typical semi-arid climatic zone with hot and dry summer and extremely cold winter. It shows a wide range of fluctuations in temperature (maximum and minimum) and rainfall. During May to June, the temperature reaches to maximum of around 44°C, while during December and January it remains as low as freezing point accompanied by frost is also quite common. The rainfall is highly erratic with 20-30 per cent annual and 30-50 per cent seasonal variations. Large variations occur for total rainfall and its distribution, about 80-85 per cent received during monsoon season, while during winter and spring seasons some rains occurs due to the western disturbances.

A long-term field experiment was conducted on aonla plants planted during 2007 at 7 × 7 m spacing in a randomized block design with three replications and two plants per replications in a loamy sand soil having low level of organic carbon and available phosphorus. The observations on all the genotypes were recorded during 2018, 2019, 2020, 2021 and 2022.

The TSS of fresh fruits were determined at room temperature using hand refractometer having a range of 0 to 32 °Brix (ERMA made) by putting a drop of fresh fruit juice on the screen and recorded the readings. The refractrometer was calibrated with distilled water after every use and the values were expressed in degree Brix (°B). The method suggested by (AOAC, 1) was followed for estimation of titratable acidity. Diluted aonla extract was titrated against 0.1 N sodium hydroxide using phenolphathlein indicator. Fresh aonla juice was diluted with equal amount of meta-phosphoric acid and titrated rapidly with indo-phenol dye to estimate the ascorbic acid content. Similarly standard ascorbic acid solution and meta-phosphoric acid (blank) solution titrated against the indo-phenol dye (AOAC, 1). To calculate total fruit yield, the harvested fruits were weighed on the digital electric balance for each replication and the value was expressed in kilograms (kg/plant). Total yield per plant was divided by area or volume of the plant to calculate the yield per unit canopy area or volume. The data presented in this manuscript are the average values of different parameters.

For estimation of carbon sequestration, the height and diameter at breast height (DBH) are two main biophysical measurements which measured for each tree sample. Plant height was measured with the help of a graduated measuring pole from ground level to the tip of the highest shoot and expressed in meters. The tree diameter was measured at breast height (1.3m above the ground) (DBH) by using diameter measuring tape. Estimation of Above ground biomass Above-ground biomass includes all living biomass above the soil. The above ground biomass (AGB) has been calculated by multiplying volume of biomass and wood density (Ravindranath and Ostwald, 16). The volume was calculated based on diameter and height.

The wood density value for the fruit tree species obtained from web (www.worldagroforestry.org). AGB (g) = Volume of biomass (cm^3) × wood density (g/cm^3), Volume of biomass = DBH × H (diameter at breast height × height)

$$DBH = GBH/\pi \ (3.14)$$

The Below Ground Biomass (BGB) includes all bio mass includes all biomass of live roots excluding fine roots having trees. (Chavan and Rasal, 4).

The BGB has been calculated by multiplying above-ground biomass taking 0.26 as the root to shoot ratio (Ravindranath and Ostwald, 16).

$$\text{Belowground biomass } (t\ ha^{-1}) = 0.26 \times \text{above ground biomass } (t\ ha^{-1})$$

Total biomass is the sum of the above and below ground biomass. (Chavan and Rasal, 4)

$$\text{Total biomass} = AGB + BGB$$

The statistical analysis of the data obtained in the experiment was conducted using software (Sheoran,17), and treatment means were compared at a 5% level of significance. Correlation analysis was performed to determine the relationship between Girth at breast height and Carbon sequestration potential, and evaluated using MS Excel. The correlation analysis among different morphological, yield, and quality parameters of aonla genotypes were done in software R-studio. Pearson correlation coefficients (r-values) were computed, and associations with $p \leq 0.05$ and $p \leq 0.01$ levels of significance.

RESULTS AND DISCUSSION

The present experiment comprising of nine genotypes (NA 6, NA 7, NA 10, NA 20, Krishna, BSR 1, G 1, Chakaiya and CHES 1) was carried out for assessing the comparative performance of growth and physico-chemical characters under semi-arid conditions. It is evident from the data in Table 1, that the maximum plant height (9.18 m), plant spread EW (9.5 m) and NS (9.93 m) and trunk girth (109.27 cm) were recorded in Gujrat-1. Plant height was found minimum in BSR 1 (5.47 m). Minimum plant spread EW (5.13 m) in NA 7 whereas plant spread NS (5.67 m) and trunk girth (54.5 cm) were found minimum in BSR1. However, variation in plant growth characters in different cultivars may be attributed to genetic features of the individual variety and soil condition (Dhandar and Shukla, 5).

Table 1: Growth parameters of different genotypes of aonla in the year 2022.

Genotype	Plant height (m)	Trunk girth (cm)	Plant spread (m)	
			N-S	E-W
CHES 1	5.90	56.25	6.72	5.40
Chakaiya	6.17	85.2	7.97	7.43
Krishna	6.05	74.2	7.23	6.77
NA 6	6.70	83.5	7.62	7.62
NA 7	6.00	57.67	5.67	5.13
NA 10	6.25	70.3	6.06	6.58
NA 20	7.09	82.33	6.87	6.12
G 1	9.18	109.27	9.93	9.50
BSR 1	5.47	54.5	6.71	6.92
CD (p≤ 0.05)	0.46	19.39	0.86	0.68

Fruit size is an important component of yield. The maximum fruit length was reported in NA 20 (3.33 cm), which was at par with NA 7 (3.31) and Chakaiya (3.28) followed by Krishna (3.18 cm)) whereas minimum was found in BSR 1 (1.87 cm). The maximum fruit diameter was observed in Chakaiya (3.70) which was closely followed by NA 20 (3.51 cm) and Krishna (3.47 cm) whereas minimum was reported in BSR 1. Fruit weight is major component of yield contributing factors. Fruit weight was varied from 7.22 to 54.39 g depending on cultivars. Similar kind of results were also recorded in chironji by (Singh *et al.,* 21).

The maximum fruit weight was reported in cultivar NA 20 (54.39 g) where as it was minimum in BSR1 (7.2 g). The fruit yield per tree was recorded maximum in NA 20 (105 kg) this may be due to a greater number of fruits per shoot. TSS was found maximum in BSR 1 (18.10 °Brix) and minimum in NA 7 (9.29 °Brix). Aonla growing in arid region with limited water tended to more accumulation of dry matter and lower moisture may result in higher TSS in fruits (Meghwal and Azam, 11). Acidity in fruit was recorded highest in NA 10 (2.56%) and minimum was observed in NA-6 (1.88 %). However, vitamin-C was found maximum in Chakaiya (569.3 mg/100g) and minimum in BSR1 (331.6 mg/100 g) (Table 2). The variation in the chemical constituent might be associated with the varietal characters and pre vailing soil and climatic conditions in that locality. These results are in agreement with the findings as reported by (Pathak *et al*., 15; Mishra *et al*., 13) in aonla, (Singh *et al*., 19) in Morinda and (Mahajan and Dhillon 10) have reported variation in quality attributes of aonla varieties which may be due to genotypic dissimilarity.

Table 2: Performance of different genotypes of aonla on the basis of yield and yield attributing characters.

Genotype	Fruit weight (g)	Fruit length (cm)	Fruit breadth (cm)	Yield (kg/ plant)	TSS (°Brix)	Acidity (%)	Ascorbic acid (mg/100g pulp)	B:C ratio
CHES 1	18.82	2.43	2.94	52.19	14.95	2.02	438.7	4.4
Chakaiya	34.69	3.28	3.70	74.39	10.58	2.27	569.3	6.2
Krishna	28.42	3.18	3.47	63.44	10.59	2.17	493.7	5.3
NA 6	29.91	3.12	3.40	84.28	11.16	1.88	381.4	7.1
NA 7	28.70	3.31	3.43	94.41	9.29	2.23	510.4	7.9
NA 10	24.86	2.95	3.24	80.92	14.34	2.56	472.1	6.8
NA 20	54.39	3.33	3.51	105.98	12.85	2.25	446.2	8.9
G 1	15.61	2.46	2.84	68.09	16.88	2.41	422.4	5.7
BSR 1	7.22	1.87	2.28	39.12	18.10	2.29	331.6	3.3
CD (p≤ 0.05)	4.75	0.06	0.09	8.31	0.48	0.07	12.1	

For estimation of carbon sequestration, the plants in the study were grouped into two classes 15-25 cm and 25-35 cm based on the girth at breast height (cm). It was observed that carbon content and carbon dioxide sequestrated increase with the increase in girth at breast height (Table 3). The carbon sequestration potential depends on various factors, i.e., wood density, GBH, height, soil depth, and the number of individuals. In addition, climatic factors such as precipitation, temperature, humidity also play an essential role. (Bung *et al*., 3).

There is strong correlation between GBH and Carbon sequestrated per year. Fig. 1 shows the regression model's plots for biomass and diameter, along with their R^2 values (regression coefficient goodness of fit) for all genotypes. The higher R^2 value for biomass and diameter indicates that biomass increments are more closely related to increments in girth. Similar findings were reported by (Bung *et al*., 3).

The correlation analysis among different morphological, yield, and quality parameters of aonla genotypes revealed several statistically significant relationships (Fig. 2). Pearson correlation coefficients (r-values) were computed, and associations with $p \leq 0.05$ and $p \leq 0.01$ levels of significance were considered meaningful.

A highly significant positive correlation ($r = 0.84$, $p \leq 0.01$) was observed between fruit weight and yield, suggesting that heavier fruits markedly enhance total productivity. Similarly, fruit length ($r = 0.83$, $p \leq 0.01$) and fruit breadth ($r = 0.84$, $p \leq 0.01$) were also significantly associated with fruit weight, indicating that fruit size attributes are closely interrelated and jointly contribute to yield. These findings are in agreement with earlier studies by (Singh *et al*., 20; Mehta *et al*., 12) who reported that fruit size parameters are key determinants of yield in aonla. Vegetative traits such as plant height and trunk girth ($r = 0.89$, $p \leq 0.01$), and N–S and E–W canopy spread ($r = 0.91$, $p \leq 0.01$) showed strong positive correlations, reflecting uniformity in canopy development. This suggests that robust vegetative growth contributes to better light interception and photosynthetic efficiency, thereby supporting enhanced fruit development, as supported by findings in other perennial fruit crops (Awasthi and More, 2).

In terms of quality parameters, TSS and acidity exhibited a moderate but significant negative correlation ($r = –0.50$, $p \leq 0.05$), indicating that fruits with higher sweetness tend to be less acidic. Ascorbic acid content was positively correlated with TSS ($r = 0.44$, $p \leq 0.05$) and yield ($r = 0.43$, $p \leq 0.05$), suggesting that genotypes rich in vitamin C not only offer better nutritional value but also superior productivity. Furthermore, ascorbic acid also

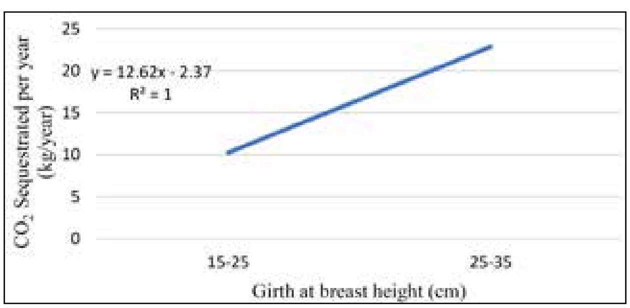

Fig. 1. Correlation between GBH and CO_2 sequestrated per year (Kg/year).

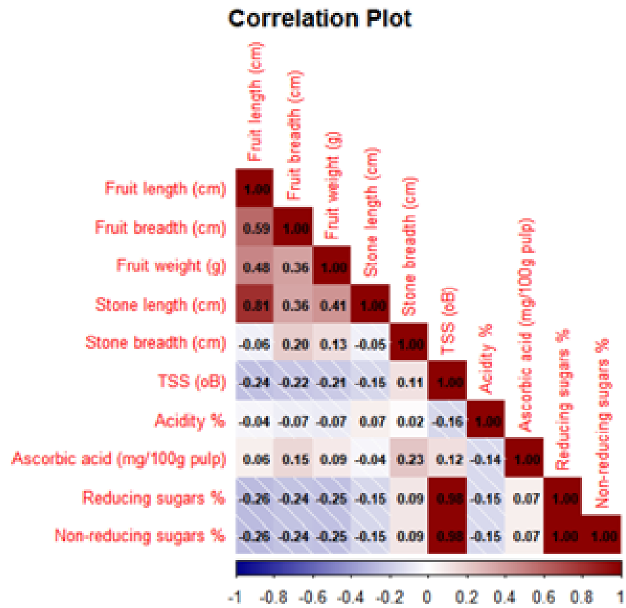

Fig. 2. Correlation coefficient analysis between aonla growth, yield and quality traits..

Note: The coloured bar revealing the positive correlation while moving towards dark red colour and negative correlation when moving towards dark blue colour.

Table 3: Annual accumulation and carbon sequestration potential of aonla.

GBH (cm)	Fresh wt. (kg)	Dry wt. (kg)	Carbon content (kg)	CO_2 sequestered (kg)	CO_2 Sequestrated (kg/year)
15-25	170	90	45	164	10.25
25-35	390	200	100	366	22.87

correlated significantly with the benefit–cost (B:C) ratio (r = 0.39, $p \leq 0.05$), suggesting that genotypes with higher vitamin C content are economically more profitable indicating its role in enhancing economic returns from aonla cultivation.

The present investigation deciphered significant variability among the aonla genotypes for their growth, and fruit-related parameters under the semi-arid conditions of Indian state Haryana. The aonla genotypes NA 20, NA 7 and Chakaiya found comparatively superior to other studied genotypes for yield and fruit biochemical attributes. Thus, these selected genotypes have the potential for commercial cultivation in the semi-arid region of India to achieve the higher yield and high-quality aonla production. Overall, the correlation matrix indicates that fruit size, ascorbic acid content, and yield are key contributors to both fruit quality and economic returns. These interrelationships provide valuable insights for selecting genotypes with desirable traits for breeding and cultivation in semi-arid conditions. The study shows that trees act as a significant CO_2 sink that captures carbon from the atmosphere and acts as a sink, stores the same in the form of fixed biomass during the growth process. Aonla is the dominant species in the semi-arid region, and this is also one of the reasons for higher carbon storage potential.

AUTHORS CONTRIBUTION

Experiment analysis, Record of data, drafting of original manuscript (AB); Formulations of research framework, research material (MK); Manuscript review and editing of manuscript (MN); Data analysis and drafting of graphs (AM).

DECLARATION

The authors declare that they do not have any conflict of interest.

ACKNOWLEDGMENT

The Authors are thankful to CCSHAU Regional Research Station Bawal (Rewari) and AICRP Arid Zone Fruit Crops, Central Institute of Arid Horticulture, Bikaner, for their technical and financial support. Authors also thankful to who directly and indirectly help during the study.

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(Received : July, 2025; Revised : December, 2025; Accepted : December, 2025)