Indian Journal of Agricultural Sciences **89** (11): 1773–81, November 2019/Review Article
https://doi.org/10.56093/ijas.v89i11.95288

Aonla (*Emblica officinalis*) in India: A review of its improvement, production and diversified uses

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Received: 20 March 2019; Accepted: 06 May 2019

ABSTRACT

Aonla (*Emblica officinalis* Gaertn), commonly called Indian gooseberry, belonging to family Euphorbiaceae, is one of the oldest known indigenous fruit tree species with wide distribution, reflecting its adaptation to wide range of edaphoclimatic conditions. It is an important fruit owing to its nutritional, therapeutical, and postharvest and industrial value. Various pharmaceutical attributes of aonla have been described in ancient treatise either in combined formulation or alone. In a bid to better utilize and improve the present genetic resource, there is a need to apprehend and appreciate the studies related to use, centre of origin and diversity, as well as the characterization, evaluation and conservation, taxonomy and systematics, phenology, floral biology and pollination. In addition to basic biology of plant, agro-techniques, propagation, canopy architecture, physiological disorders, insect-pests and diseases and their management practices, etc. have been used to conserve aonla germplasm as well as improve its production. An attempt has been made to cover aforementioned aspects with respect to aonla in this review article.

Key words: Agronomy, Crop improvement, *Emblica officinalis*, Indian gooseberry

Aonla (*Emblica officinalis* Gaertn), also known as Indian gooseberry, is an important fruit crop of Indian origin grown in all parts of country in diverse agro-climatic conditions. It has been regarded as sacred tree and known as *Amritphal* in ancient literature. Besides India, aonla trees are also found in the natural forests of Cuba, USA, Pakistan, Sri Lanka, Malayasia, China, Java and West Indies. It is used in *Ayurvedic* medicine for making *Triphala* and *Chyavanprash*. Owing to its hardy nature, high productivity, nutritive and therapeutic values, and its suitability for various kinds of value added products, aonla has now become an important fruit of 21st century (Pathak 2003). The fruit is useful against several ailments, and can be made into various value added products. Fruit is also used to prepare aonla powder, which is superior to synthetic vitamin C in treating deficiencies. It is grown at an estimated area of 50,000 ha with an annual production of 1.5 lakh tonnes (Pathak *et al.* 2003).

Origin and distribution, soil and climate, area and production

In India, domestication of aonla was first started in Varanasi, Uttar Pradesh with the initiative of Maharaja of Kashi. Banarasi, a superior genotype was selected from the wild aonla trees available in large number in the nearby Vindhyan hills. Authentic information regarding its cultivation dates back to 1881-82 in the Pratapgarh district of Uttar Pradesh. The ailing state owner of the district (King) was advised for regular consumption of aonla fruits. Those brought from Varanasi were named as 'Banarasi' and those brought from Gujarat were known as Francis and later on as *Hathijhool* because of its drooping branches. A seedling of Banarasi having flat fruits was named as *Chakla* and now it is known as Chakaiya. Such diverse introductions, which later on played important role in the development of present day high yielding cultivars from Pratapgarh, Uttar Pradesh.

It is commercially cultivated in Uttar Pradesh, Uttarakhand, Gujarat, Maharashtra, Rajastan Tamil nadu, Andhra Pradesh, Karnataka, Bihar, Haryana, Madhya Pradesh, Rajasthan and West Bengal (Pathak 2003). In Uttar Pradesh, its cultivation is more common in Pratapgarh, Varanasi, Sultanpur, Azamgarh, Jaunpur, Rai Bareily, Agra and Bareilly. Of which, Pratapgarh is a leading district of aonla cultivation on commercial scale throughout the country (Pathak *et al.* 1993). In last two decades, there has been tremendous increase in the area under aonla cultivation across the country, utilizing the wasteland. This has resulted in efficient utilization of resources leading to better income to farmers, nutritional security coupled with enhanced employment and rehabilitation of wastelands (Singh *et al.* 2014c).

Though aonla is classified as a subtropical fruit, its cultivation in tropical, arid and in rainfed semi-arid

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conditions is quite successful. The natural growing plants can be seen on hills up to 1800 msl (Pathak 2003). In India, now it is grown near sea coast of South India as well as the foothills of North India. Mature aonla tree can tolerate freezing as well as high temperature of 48°C, but the plants are susceptible to frost in winter and sometimes heavy damage occurs owing to frost in hot arid ecosystem of western part of Rajasthan (Pathak *et al.* 2006). Warm temperature seems conducive for initiation of flower buds, whereas ample humidity is essential for initiation of fruit growth of dormant fruitlets during July-August (Pathak 2003). Abrupt changes in temperature during flowering and fruit set adversely affect the fruiting of aonla. Dry spells result in heavy fruit dropping and delay in initiation of fruit growth (Pathak *et al.* 2006). Since aonla is very hardy plant, it can be grown in light as well as heavy soil. The deep root system, reduced foliage, dormancy of fertilized fruitlets (April-June), coincidence of fruit growth and development with moisture availability period make aonla an ideal plant for arid and semi-arid regions. Aonla can be grown in marginal degraded lands. It can be grown in acidic to saline/ sodic (*p*H up to 9.5, ESP-35 and ECe-6-9 ds/m) soils (Pathak and Patkah 2001).

Importance, uses and medicinal significance

In *Ayurveda,* aonla has been extensively used, both as an edible (tonic) plant for its therapeutic potentials and fruit has been used in *Ayurveda* as a potent *Rasayana* (rejuvenator). It contains phytochemicals including fixed oils, phosphatides, essential oils, tannins, minerals, vitamins, amino acids, fatty acids, glycosides, etc. Various pharmaceutical potentials of *P. emblica* have been reported previously including antimicrobial, antioxidant, anti-inflammatory, analgesic, antipyretic, adaptogenic, hepatoprotective, antitumor and antiulcerogenic, immunomodulatory, activities either in combined formulation or Indian gooseberry alone (Bajpai and Shukla 1990, Baliga 2012, Chatterjee and Sil 2007). However, the pharmacological effect of aonla is often discussed with the *Triphala,* consisting of equal amounts of three medicinal plants, viz. *Emblica officinalis, Terminalia chebula and T. bellerica*. Antioxidant and free radical scavenging activity in aonla is due to presence of ascorbic acid, tannins and polyphenolic constituents. Different extract of aonla and phytoconstituents are reported to have antioxidant efficacies against several free radicals such as 1,1-Diphenyl-2-picrylhydrazyl radical (DPPH) free radicals, superoxide, nitric oxide, iron reduction, 5,5-dimethyl-1-pyrroline-N-oxide etc. Phytochemicals of aonla are also reported as good metal ion chelator they as they can prevent the oxidative cascades (Scartezzini *et al.* 2006). The nutraceutical and therapeutic values of fruit include great health and vitality (Pathak 2003).

Morphology, flower biology, cytogenetic, pollination and pollinators

Aonla belongs to the family Euphorbiaceae and order Euphorbiales with new genus *Emblica* (earlier *Phyllanthus*) which comprises about 350 species to 500 species, mostly shrubs, few herbs and trees. Amongst various species of aonla, *E. officinalis* is largely used for cultivation (Fig 1). However, other related species *E. acidus* Skeel, known as star gooseberry is mainly grown for ornamental purpose, *E. myrobalan* is a small or moderate sized deciduous tree, *E. fischeri* is suitable for pickle making and *Phyllanthus indofischeri* is a monoecious tree found in scrub forests of south India (Pathak 2003). Crop improvement of aonla is mainly confined to the selection of desirable types from the diverse seedling populations of the cultivated genotypes. Basic chromosome number of Indian gooseberry is reported to be 2n=26, however, somatic chromosome number in aonla to be 2n=28, while variants possessing chromosome numbers from 2n=23 to 104 have also been reported in aonla.

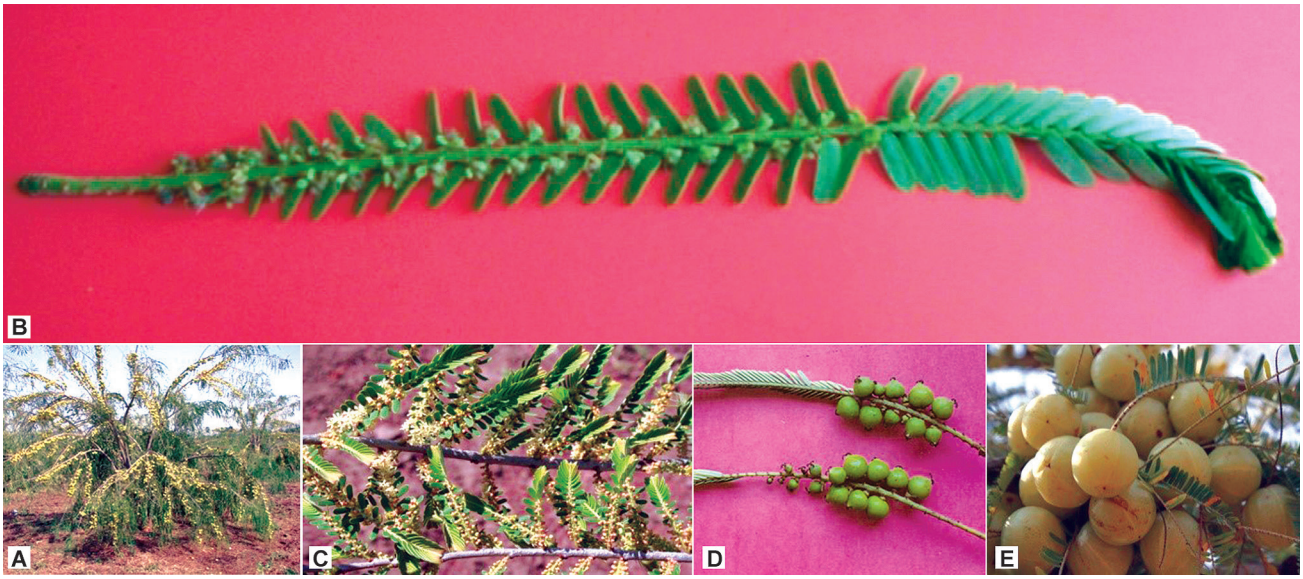

Fig 1 A, Fruit bearing tree of aonla NA-7; B, Flower bearing determinate shoot; C, Indeterminate shoots having determinate shoots with flowers; D, Developing fruits and E, Fully mature fruits ready for harvesting.

Aonla tree is characterized by phyllanthoid branching habit with two types of shoots; determinate (short shoots) and indeterminate (long shoots), and the indeterminate shoots are longer and continue to put new growth in the season. Determinate shoots appear on the nodes of indeterminate shoots and their number at each node may vary from 3 to 5 in different cultivars (Bajpai and Shukla 1990, Pathak 2003) on which flowering takes place in February to March. However, in south India, flowering occurs twice, in February-March and June-July. Flowers are borne in the axils of the leaves on determinate shoots as axillary cymules. Basal cymules are of male flowers followed by each nodes with a cymules of one central female flower (rarely two) and several lateral males (Pathak *et al.* 2006).A typical flower consists of parianth and androecium or gynoecium. Number of parianth segments vary from 5-7 but generally 6 are common. Bajpai and Shukla (1990) reported male to female ratio of 307.9:1 and 197:1 in two successive years indicating marked variation in the expression of sex. The female flowers open in stages and take 72 h to open completely and the stigma becomes receptive on the third day of anthesis and remains receptive for another 48 h synchronizing with maturity of the embryo sac (Pathak and Pathak 1993). Anthesis of male flower occurs between 16.00-17.00 h in Banarasi and in Chakaiya both in morning (08.30-11.00 h) and afternoon (15.30-18.30 h) while dehiscence of pollen grains coincides with the anthesis of male flower in different cultivar and majority of pollen grains are fertile (Pathak *et al.* 2006). Failure of pollination and low sex ratio are thus cause of low fruit set and retention (Alleemullah and Ram 1990). Pathak (2003) observed self incompatibility in initial studies in flowering and fruit set in aonla. Number of female flowers varied from 2 to 8. NA-6 had the lower sex ratio followed by NA-7, Kanchan and Chakaiya while NA-9, Banarasi and Krishna showed higher sex ratio. Aonla genotypes, viz. Chakaiya × Francis, NA-7 × Krishna, Banarasi × NA-6 and Kanchan × NA-6 showed better fruit retention and are being recommended for commercial exploitation and also indicated that the cause of poor fruit set may be due to prevalence of self-incompatibility in some of the cultivars (Pathak and Srivastava, 1994, Singh *et al.* 1998). The cause of poor fruit set may be attributed to a high percentage of staminate flowers. The initial fruit set may vary between 12 to 18 %, which can be enhanced through hand pollination (Bajpai and Shukla 1990). Although fertilization completed within 36 h after pollination, the embryo lies dormant through summer and start swelling with the onset of monsoon. The flowering period is affected less by temperature and more by day length.

Genetic resources and varietal wealth

Wide range of variability in aonla has been reported particularly from Uttar Pradesh, Uttarakhand, Bihar, Chhatishgarh, Gujarat, Jharkhand, Madhya Pradesh, Maharashtra, Rajasthan, Himanchal Pradesh and North Eastern region of India (Pandey *et al.* 2013, Singh *et al.* 2014c, 2016, Shukla *et al.* 2005, Pathak 2003). Due to predominance of seedling propagation, India holds rich genetic diversity in cultivated and wild relatives of aonla particularly in north east region which can be utilized in aonla breeding programme to infuse hardiness into the offspring for adverse habitat (Singh *et al.* 2014c).The desirable traits for which germplasm needs to be collected include large fruit size, low fiber content, and resistance to frost, rust, internal fruit necrosis and insect-pests (Pathak, 2003). In systematic germplasm characterization studies, aonla descriptors developed at Narendra Dev University of Agriculture & Technolgy, Faizabad revealed a wide range of variation for different characters (Pathak *et al.* 1993). Similar results have been reported by Singh *et al.* (2014a), Hiwale (2015) and Bakshi *et al.* (2015) in aonla germplasm. Conservation of aonla germplasm has been taken up in the field gene banks at various ICAR Institutes and SAUs.

Systematic efforts for improvement of aonla have been done through selection (Pathak *et al.* 2006). After stabilization of yield data and fruit quality, one genotype named BSR-1 showed higher yield potential (43.05 t/ha). This genotype was recommended for commercial cultivation under irrigated and rainfed conditions of Tamil Nadu. From Anand Agricultural University, Anand developed the varieties, viz. Anand 1, Anand 2 and Anand 3 which were selected from the seedling variability available in the Gujarat (Singh *et al.* 2014c). From diverse collections made at NDUAT, Faizabad, NA-4 (Kanchan), NA-5 (Krishna), NA-6, NA-7 (Neelam), NA-9 and NA-10 showed promising results and were later released for commercial cultivation (Pathak 2003). Laxmi-52 having bold fruit has been released at CISH, Lucknow. Clonal selection made from the plus tree found in collections done at CHES, Godhra was named as Goma Aishwarya (Hiwale 2015). Among them, NA-7 is a leading cultivar and occupied maximum area under aonla cultivation in the country (Pathak 2003, Singh *et al.* 2014c, 2015).

Biotechnology

Unfortunately, conventional breeding tools could not address the problems (leaf rust, wilt, anthracnose and pests) due to various factors such as tiny flower size, variations in chromosome number and complex taxonomy in addition to highly heterozygous nature of plant. Thus, genetic improvement for such traits is possible through genetic engineering. In this regard, Thilaga *et al.* (2013) have developed a simple and one step reproducible protocol for induction of high frequency somatic embryogenesis from *in vitro* derived juvenile leaf tissues of aonla, which can be utilized for development of transgenic population of aonla. Warude *et al.* (2006) developed the markers for identification of aonla germplasm.

Plant propagation

Seed propagation and raising of seedlings: Aonla seeds germinate within two weeks. Six months to one year old seedling is used as rootstock, and scion of desired varieties are patch budded on to them during the period from May

to September for optimum success. Generally, the seed sown in first week of March in perforated polythene bag size (40×15cm) becomes ready for budding in July, which saves about six months, and also helps in effective nursery management than conventional methods, and for better germination and healthy seedling, seeds should be soaked in 500 ppm GA_3 over night (Saroj *et. al*. 2001).

Vegetative propagation: Among the different methods of vegetative propagation, patch budding showed better response followed by modified ring budding. Budding operation should be performed from mid May to mid August for better success, which may be continued up to September with appreciable success (Pathak *et al.* 2006). However, Saroj *et al.* (2001) reported more than 90% success through patch budding in perforated polythene bag under irrigated hot arid ecosystem. Softwood grafting at terminal shoot of rootstock raised *in situ* for a year or more has been found sucessful. *In situ* patch budding is the best method of multiplication of aonla under dryland condition (Singh *et al.* 2014c, Singh and Singh 2014). The minimum size of rootstocks should be 0.5 cm at the time of budding and grafting (Saroj *et al.* 2001). Effect of gypsum and distillery effluent on chemical composition of shoots and growth of aonla budlings in pot condition have been studied under north Indian condition (Singh and Gaur 2002, Singh 2007). However, in south India, aonla propagation is being done almost 8–10 months in a year, with the aid of green and net house facilities (Pathak 2003).

Micropropagation: For quick multiplication, micropropagation is an alternative tool for production of planting materials in bulk. *In vitro* oxidative browning and contamination are two major problems in establishing the cultures of aonla through shoot bud culture. Through explants waxing around 80% success in establishment of cultures has been noticed, but, this technique delays *in vitro* bud induction and subsequent proliferation. For maximum bud induction, August to November months have been found to be the best season under north Indian condition in which maximum bud induction (76.4%) was achieved followed by in April-June. Slightly green and moderately hard (10–15th nodes) shoots gave the highest *in vitro* bud induction and proliferated profusely than soft or very hard brown nodal segments as resported by Mishra and Pathak (2001). After *in vitro* bud induction, determinate shoots appear with leaf. However, indeterminate shoots are mandatory for further multiplication. High frequency shoot proliferation (13.33 shoots/culture) was observed under the influence of 4.33 µM GA_3 + 13.9 µM Kinetin + 342.11 µM Glutamine. Incorporation of glutamin (342.11 µM) could solve this problem of *in vitro* leaf fall. From the study it can be concluded that ½ MS (49.20 µM IBA + 10.74 NAA µM) proved to be better for *in vitro* rooting of Indian gooseberry (Mishra *et al.* 2006). Callus from mature embryo explants of aonla was raised on BMS medium supplemented with 2, 4-D (1–4 mg/l + kn (0.05 mg/1) and BMS + NAA (1–4 mg/l) + kn (0.05 mg/l). In some cases the mature explants directly gave rise to embryos from the cotyledons of embryo. Secondary embryos from the culture raised embryos were also formed on BMS + BAP/or 2 iP (1–4 mg/l) + sucrose 5%. Plantlets when transferred on BMS + NAA/or IBA (2–4 mg/l) induced roots from the cut ends. These rooted plants were placed for hardening but the mortality rate was high. A few protocols for *in vitro* regeneration of aonla from various explants such as endosperm, nodal explants, epicotyls and hypocotyls (Hai-Tao *et al.* 2006) have already been reported. Previously, low frequency embryogenesis has been reported in this species but reproducibility of such protocols was not mentioned (Menka and Usha 2006).

Agronomy, cultivation, pests and diseases

Planting and orchard establishment: For better establishment of orchard, the pits of 1 m^3(1 m × 1 m × 1m size) are dug during May months at 8–10 m distance and exposed to hot sun for about a month and then each pit is filled with soil thoroughly mixed with 20-25 kg Farm Yard Manure and drenched with chlorpyriphos (Singh *et al.* 2014c). Healthy budded plants are planted during rainy season, preferably soon after occurrence of first rain. Rootstock can also be raised *in situ* at appropriate distance (8 m × 8 m or 10 × 10 m) for budding with superior clone at pencil thickness stage to get maximum success particularly in semi-arid regions. For *in situ* budding, rootstock should be planted in the already prepared pit in June and after 30-45 days budding may be carried out on them in the field itself (Singh *et al.* 2014c). For avoiding problem of self incompatibility, planting of more than two varieties is needed for proper fruit setting (Pathak *et al.* 2006).

High density planting: Results of the study on high density planting systems revealed that the mean yield/plant (121.20 kg) was recorded the highest in square, but the yield/ha were recorded the maximum in double hedgerow (284.02 q) and it was the lowest in square system (121.20 q). An increase in yield/ha in double hedgerow system over square, paired, cluster, hedgerow system ranged between 25.62–134.34% under semi-arid conditions, whereas an increase in yield in double hedgerow, hedgerow, cluster and paired over square systems was recorded 134.34, 121.10, 97.51 and 53.77% purely under rainfed conditions (Singh *et al.* 2013b, 2014d). Among the different planting systems, the square system exhibited better values for physical qualities, whereas chemical attributes like TSS, total sugar, vitamin C and total phenols were observed to be highest in double hedgerow planting systems (Singh and Singh 2007, Singh *et al.* 2007c, 2011, 2014c, 2014d).

Irrigation management: Generally, well established aonla orchards do not require irrigation in the normal rainfall and soil moisture conditions. Irrigation should be avoided during flowering period (February and March), but irrigation is required after application of manures and fertilizers, if sufficient moisture is not available in the soil. Under rainfed conditions, plants irrigated through drip at alternate day with 60% wetted area recorded better growth, yield and quality of aonla, however it can be grown successfully under rainfed semi-arid condition without irrigation (Singh *et al.* 2014c).

Low cast earthen dam and construction of series of check dams had tremendous effect on soil moisture conservation and productivity of fruit crops under semi-arid conditions of Gujarat (Meshram *et al.* 2009). The work done at NDUAT, Faizabad revealed that the alternate irrigation through drip at 0.6 CPE and mulching with paddy straw has been found effective for establishment of aonla orchard in sodic soil (Pathak *et al.* 2006).

Training, pruning and canopy management: For proper training in aonla, the main branches should be allowed to appear at a height of 0.70 m above the ground level. The unwanted branches are pinched off during March-April. In the subsequent years, 4–6 branches should be allowed to develop. Subsequent pruning consists of removal of dead, infested, broken, weak or overlapping branches after the harvest of the crop. The limb breakage in aonla cultivar NA-7 has been observed at several places owing to over bearing and narrow angle of branches with main stem, hence, balanced canopy should be ensured for this variety (Pathak *et al.* 2006, Singh *at al*. 2014c).

Integrated nutrient management: The dose of manures and fertilizers depend upon soil fertility, age of plant and production. A dose of 15 kg FYM, 100 g N, 50 g P and 100 g K should be given to one-year old aonla plants and this dose of manures and fertilizers should gradually be increased every year up to ten years and thereafter, constant dose should be given (Singh *et al.* 2014c). Various sources of nutrients like biofertilizers (*Azotobactor, Azospirillum,* PSB, VAM,), FYM and Cakes (neem, mahua, and castor and groundnut cake) have also been found useful for sustainable production of quality fruits (Singh *et al.* 2012a, 2012b). Among the different organic sources of nutrient FYM + Neem cake + CPP and FYM + *Azotobactor* + VAM were found to be better in terms of increasing the soil fertility, soil microbial and earthworm population, yield and quality of aonla fruits under semi-arid ecosystem of Western India (Singh *et al.* 2014c, 2014b). Every full grown tree should be fertilized with 1 kg N, 500 g P and 500 g K (Pathak *et al.* 2006). Spray of micronutrients, viz. B, Zn and Cu (0.4%) along with lime is helpful in reducing fruit drop and improving fruit quality (Pathak *et al.* 2006)

Soil moisture conservation: Locally available and easily decomposable organic materials like paddy straw, maize straw, grasses, husk, etc. were applied with 20 cm thickness after rainy season which were found beneficial for improving the soil quality, growth and yield of NA-7 aonla (Singh *et al.* 2007a). Mulches not only conserve soil moisture and moderate soil temperature, but also impart manifold beneficial effect on earthworm and microbial population, soil fertility and growth and yield of plant (Singh *et al.* 2007b). Leaf litter of aonla under the canopy is not only an effective mulch to retain soil moisture during summer but also improve the soil properties (Singh *et al.* 2014c). Organic mulches are quite effective in improving the physical soil properties i.e. porocity, hydraulic conductivity and reduce ECe and ESP in tree basin (Pathak *et al.* 2006). Average yield per plant (87.48 kg) was recorded to be maximum in paddy straw mulch and it was recorded lowest in control (76.29 kg) under rainfed conditions of hot semi-arid ecosystem during 10th year of orchard life (Singh *et al.* 2008). Yield in paddy straw mulch was recorded 14.66% more than control (Singh *et al.* 2014e). The quality in terms of TSS (9.50°brix), total sugar (6.00%) and vitamin C (510 mg/g) were recorded highest with paddy straw mulch and the lowest in control (Singh *et al.* 2010).

Crop diversification: Growing of cucurbitaceous vegetable crops such as bottlegourd, spongegourd, bitter gourd, cucumber and pumpkin can be grown successfully in association with plantation under rainfed condition of Gujarat. Economic analysis of aonla based cropping system revealed that the maximum net return of ₹ 147312.80/and ₹ 1000525.00/ may be obtained from aonla + bottlegourd and aonla + pumpkin respectively, under rainfed conditions of semi-arid ecosystem (Singh *et al.* 2013a, 2014c). Hiwale *et al.* (2014) reported that the aonla + okra had given net returns of ₹ 72505/ha without any adverse effect on aonla crop. Different intercrops such as okra, bottlegourd, cauliflower, coriander, matricaria, gladiolous and marigold can be grown in association with aonla plantation (Pathak *et al.* 2006, Singh *et al.* 2014c, Krishna *et al.* 2018). Among the fruit crops, guava and karonda can be used successfully as filler crops in aonla orchard (Pathak *et al.* 2006).

Fruit setting, fruit growth and development: In North India, aonla trees begin to shed their determinate shoots during February to mid- March, and new determinate shoots emerge at node from the margins of scars formed after abscission of determinate shoot in previous season, these begin to appear by end of the February and continue to appear till the first week of April on which blossom bud emerge, whereas after mid April bearing occurs (Pathak *et al.* 2006). Fruit, however, grows rapidly during rainy season between second fortnights of August to last week of September and completes almost 70% of growth during this period. Thus, fruit growth in aonla follows double sigmoid. After fertilization, embryo remains dormant for about 3-4 months and growth development starts in the end of July to first week of August after onset of monsoon depending upon agroclimatic conditions (Pathak *et al.* 2006 and Singh *et al.* 2014c)

Maturity, harvesting, yield and quality attributes: Maturity of aonla fruits can be judged externally by change in the fruit colour from greenish to whitish green or yellowish green and change in seed colour from creamy white to brown. Apart from it physiological maturity, mafurity can be determined on the basis of specific gravity (1.07 to 1.24), fibre content, and TSS/acid ratio (5 to 6), appearance of fibre on seed cover and turning of seed colour into brown (Pathak *et al.* 2006, Singh *et al.* 2006). Fruits of NA-7, Banarasi and Agra Bold mature by last week of October, while that of Kanchan and Chakaiya are ready for harvest by last week of November. Further, Anand-1 and Anand-2 mature by last week of November under semi-arid ecosystem of Gujarat (Singh *et al.* 2003, 2005, Singh *et al.* 2008b).

Table 1 Physico-chemical attributes of aonla varieties under rainfed semi-arid conditions.

Variety	Fruit set (%)	Fruit retention (%)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Juice (%)	Pulp (g)	TSS (%)	Acidity (%)	Vitamin C (mg 100/g)	TSS/ Acid ratio
Banarasi	36.21	18.78	3.73	3.93	33.90	41.34	31.91	10.25	2.02	334.12	5.07
Krishna	49.50	20.78	3.70	4.37	33.56	55.12	31.51	10.90	2.07	352.45	5.26
Francis	36.56	11.43	3.07	3.40	30.4	59.52	28.33	9.70	2.02	345.34	4.04
NA-7	51.95	26.40	3.62	4.00	33.76	70.45	31.79	11.50	2.05	453.20	5.60
Chakaiya	41.24	20.67	3.35	4.00	30.66	40.52	28.64	10.63	2.10	399.76	5.06
Kanchan	39.78	19.89	3.82	3.99	25.94	66.92	23.95	10.22	2.03	427.27	5.03
NA-10	40.61	20.38	3.39	3.98	31.45	64.28	29.46	10.50	2.00	421.76	5.25
Anand-1	37.88	18.98	3.10	3.45	28.53	69.25	26.48	11.30	2.05	419.45	5.51
Anand-2	37.13	18.65	3.12	3.41	26.63	65.34	24.59	10.25	2.04	414.78	5.02
CD @ (P=0.05)	3.98	1.71	0.30	0.34	2.69	4.99	2.51	0.87	0.19	35.42	0.48

Aonla trees start bearing fruits from 3rd year after budding. However, the economic bearing (commercial yield) commences from 5th year life of grove. The physico-chemical attributes of aonla cultivars (Table 1) have been studied under rainfed semi-arid conditions of Gujarat by Singh *et al.* (2015, 2014c). Bakshi *et al.* (2015) and Bal *et al.* (2009) reported considerable variability in physico-chemical attributes in aonla germplasm under different agro-climatic conditions.

Postharvest handling, storage and value addition: Aonla fruits may be stored for up to 30 days on tree itself from the date of maturity without reduction in the quality (Singh *et al.* 2003). The variety Chakaiya and Anand-2 exhibits 7 days, whereas Francis, NA-7 and Banarasi have up to 5 days economic life at ambient temperature after harvesting. However, fruits with brine solution can be stored up to 75 days. Fruits of NA-7, Banarasi, and Agra Bold mature by last week of October, while that of Kanchan and Chakaiya are ready for harvest by last week of November. Further, Anand-1 and Anand-2 mature by last week of November under semi-arid ecosystem of Gujarat (Singh *et al.* 2003, Singh *et al.* 2005). Treatment with chemical and keeping fruits in zero energy cool chambers has tremendous effect in enhancing shelf life of aonla (Singh *et al.* 2007, 2010). Among the aonla varieties, NA-10, Krishna and Chakaiya and Krishna have better shelf life of 10 days, retained high vitamin C having glossy and green appearance and NA-7 which can be stored for 6-8 days under north Indian conditions (Singh *et al.* 2005).

The shelf life of aonla fruits can be enhanced by grading, packaging, pre and postharvest chemical and plant hormone sprays. 'A' grade fruits (more than 4.00 cm diameter and length) are large sized and these are used for *murabba* and candy making, B grade fruits are small sized, used for *chavanprash* and *trifla*, and C grade blemished fruits are used for powder and shampoo making (Singh and Singh 2005). Under hot semi-arid ecosystem of Gujarat, fruits treated with calcium nitrate 1.5% or GA_3 (50 ppm) and kept in perforated polythene bag recorded the least physiological loss in weight (2.12–16.00 and 2.15–16.34%) and spoilage loss (2.40–15 and 2.50–15.60%) and exhibit 11 days storage life (Singh and Singh 2005). For packaging, wooden crates of 20-25 kg capacity with polyethylene bags as liners and CFB boxes (10 kg capacity) along with newspaper liner are found to be most effective packing material to enhance shelf life during transportation of fruits at long distance whereas for local market it is collected and transferred in plastic crates lined with newspaper (Singh *et al.* 2008a). Singh and Kumar (1997) stored fully mature aonla fruits at room temperature, modified storage condition, zero energy chamber and zero energy + modified storage condition. It was found that decay loss was minimum (26.56%) in modified storage condition on 24th day of storage, whereas it was maximum (48.70%) in zero energy chamber. The fruits may be kept in cold storage for 7-8 days at 0-2°C and 85-90% relative humidity.

Aonla is not utilized as table fruit. Moreover, the fruits are commercially utilized in processing industries as *murraba,* candy, chatni, toffee, shreds, sauce, aonla pulp, powder, juice, *laddu*, *supari*, *sharbat* etc., *ayurvedic* medicines such as *chwanprash*, *trifla,* syrup, diabetic powder, aonla powder and in cosmetic industries for shampoo, hairoil, dyes etc. (Pathak *et al.* 2006, Singh *et al.* 2014c).

Insect-pests, diseases and physiological disorders and their management

Pests and their management: The important pests and diseases and their recommended control measures which are adopted for aonla are mentioned herewith. The suitable, effective and economical IPM strategies for boosting up the production potential of the aonla crop have been developed based on seasonality and their peak period of occurrence.

Aphids (*Cerciaphis emblica*), mealy bug (*Nipaecoccus vastator*), leaf twister (*Caloptilia acidula*), hairy caterpillar (*Euproctis flava*), shoot gall maker (*Betousa stylophora*), fruit borer (*Virochola isocrates, Meridarchis scyrodes*) and bark eating caterpillar (*Inderbela terraonis* Moore) are important insect-pests of aonla (Pathak *et al.* 2006, Singh *et al.* 2014d). Orchard sanitation is effective for bark eating

caterpillars and borers. Foliar application with Dimethoate (0.05%) in the evening at tri-weekly interval controls the overall pests effectively. However, based on the seasonality and their sequence in occurrence, insecticidal schedules involving tri-weekly application of Dimethoate (0.05%) alternatively followed by NSKE (5%) at 10 days interval commencing from fruit set to fruit development has been found significantly better in reducing the incidence of borer in aonla (Patahk *et al.* 2006, Singh *et al.* 2014c).

Diseases and their management: Rust (*Ravenaliia emblica*e), anthracnose (*Colletotrichum* state of *Glomerella cingulata*), *Penicillium* fruit rot (*Penicillium indicum, P. oxalicum, Aspergillus niger*) are important diseases which cause heavy loss to the growers (Singh *et al.* 2010c). Spray with wettable Sulphur (02%) or Mancozeb 75 w p (0.2%) manages the rust disease effectively at interval of 10-12 days in the beginning of August, while for managing anthracnose disease, spray with Mancozeb 75 wp (0.2%) or Copper oxychloride 50 wp at 0.3% concentration with practices of deep ploughing and healthy cultivation are found beneficial to control the disease. *Penicillium* fruit rot is mainly a postharvest which can be controlled by sorting out the infected fruits and destroy them. Preharvest sprays (one week before harvesting) with Blitox, Bavistin or KH_2PO_4 and postharvest treatment with 1.5% $CaCl_2$ and GA_3 (200 ppm) also controls the disease (Singh *et al.* 2009, Singh *et al.* 2014c).

Physiological disorders: Fruit necrosis, a physiological disorder, has been observed in aonla fruits, which is associated with deficiency of boron. Incidence initiates with browning of mesocarp, which extends towards the epicarp resulting into brownish black appearance of flesh. It can be controlled with three spray of borax 0.6% at 15 days interval right from the early September (Pathak *et al.* 2006, Singh *et al.* 2014c). Cultivation of necrosis resistant varieties like NA-7, NA-6 and Chakaiya etc. have been suggested (Pathak *et al.* 2006).

Aonla has tremendous potential for contributing monetarily to Indian economy and therefore, needs popularization of cultivars having desirable horticultural traits and expansion of area under arid and semi-arid ecosystem. Efforts should be made to utilize available genetic resources through survey and collection for further improvement of this crop. Attempts are required for studies related to the inheritance of specific traits. In addition to selection, other methods of crop improvement like hybridization, mutation and molecular breeding approaches have to be employed for faster development of aonla cultivars tailor-made for specific industrial demands. Intensification of research on high density planting, value addition and marketing avenues for quicker disposal of produce is need of the hour to increase area under aonla cultivation in the country.

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