



Research status of bael (*Aegle marmelos*) in India: A review

A K SINGH¹, SANJAY SINGH², P L SAROJ³, HARE KRISHNA⁴, R S SINGH⁵ and R K SINGH⁶

ICAR-CIAH-Central Horticultural Experiment Station, Godhra, Gujarat 386 340, India

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ABSTRACT

Bael [*Aegle marmelos* (L.) Correa ex Roxb., Family Rutaceae] is one of the oldest known fruit tree species native to India. Wide distribution of bael in Indian subcontinent and other parts of the world reflects its adaptation to a range of agro-climatic conditions. In addition to well-known nutritional and traditional medicinal benefits, the bael fruits have considerable processing and industrial values. In order to better utilize and improve the existing genetic resource, there is a need scrutinizing the studies related to genetic diversity, characterization, evaluation and conservation, taxonomy, phenology, floral biology and pollination. In addition, survey of literature for better understanding of various agro-techniques, propagation methods, canopy management, biotic and abiotic stresses and their management is equally important for improving the fruit productivity and quality. Accordingly, this review paper intends to critically examine and systematically arrange the voluminous literature available on aforementioned aspects of bael tree.

Key words: Arid and semi arid-zone, Bael, Genetic diversity, Morphology, Rutaceae

Bael (*Aegle marmelos* Correa) is an underutilized fruit indigenous to India. It belongs to the citrus family Rutaceae, and it is also known as Bengal quince, *bilva*, Indian quince, golden apple, holy fruit, *bel*, *belwa*, *sripthal*, stone apple and *maredo* in India. It was introduced to Europe from India in 1759. It is sacred tree in Hinduism, and is offered in prayers of Hindu deities Lord Shiva and Parvati and thus, the tree is also known by the name 'Shivaduma' (The Tree of Shiva). Its medicinal properties have been described in the ancient treatise like *Charaka Samhita*, *Upvana Vinod* and *Yajur Veda*, and it has also been portrayed in the paintings of Ajanta Caves.

It is widely distributed in South and Southeast Asia including India, China, Nepal, Myanmar, Pakistan, Bangladesh, Nepal, Vietnam, Laos, Cambodia, Thailand, Indonesia, Malaysia, Tibet, Sri Lanka, Java, Philippines and Fiji (Saroj *et al.* 2006). It is a subtropical plant and grows up to an altitude of 1200 msl and tolerates sub-zero temperature (-7°C). In India, bael tree are commonly found in the Indo-Gangetic Plains, Sub-Himalayan tracts, North-Eastern region, and dry and deciduous forests of central and southern Peninsula (Singh *et al.* 2011a).

Though a tree of subtropical origin, bael shows a wide

adaptability and performs equally well in tropical, arid and semi-arid regions (Singh *et al.* 2018a). Although fertile and well-drained soils are best suited for its commercial production, trees grow well and produce fruits on lands, unsuitable for other crops, viz. soils rich in stones and limestone as well as those suffering from swampy conditions and extremes of the soil pH ranging from 5 to 10 (Saroj *et al.* 2006), salinity and sodicity (Singh *et al.* 2016). Conventionally, bael trees of seedling origin, but in the last one decade, the ensured availability of elite planting stock of several high yielding bael cultivars has given impetus to commercial bael production in many parts of India; especially the marginal areas of North-Western India suffering from soil salinity and in western India from high temperature and moisture stress (Singh *et al.* 2011b, 2016c). At present, commercial cultivation of high yielding bael variety Goma Yashi has recently gained momentum in Rajasthan, Uttar Pradesh, Madhya Pradesh, Punjab, Tamil Nadu and Gujarat states in the form of orchard or as boundary plantation (Fig 1), and has been planted more than 150 ha in different parts of country (Singh *et al.* 2018c). As an estimate, about 1000 ha area is under plantation of improved varieties of bael in country, producing about 10,000 tonnes fruits (Singh *et al.* 2018a).

Importance, uses and medicinal significance

The fruits are valued much in *Ayurvedic* medicines. Over the past few years, researchers are increasingly identifying and validating the plant derived substances for the treatment of various human diseases. Different parts of the plant have been used in the ethnno-medicine as astringent, antidiarrhoeal, antidysenteric, antipyretic, antiulcer,

Present address: ¹Principal Scientist (aksbicar@gmail.com), ²Head (sanjaysinghcar@gmail.com), Central Horticultural Experiment Station, ICAR-CIAH, Gujarat; ³Director (plsaroj@yahoo.co.in); ⁵Principal Scientist (rssinghl@yahoo.com), ICAR-CIAH, Bikaner; ⁴Principal Scientist (kishun@rediffmail.com), ICAR-IIVR, Varanasi; ⁶Head (rjan-1971@yahoo.co.in) Division of Seed Technology, ICAR-CPRI, Shimla.

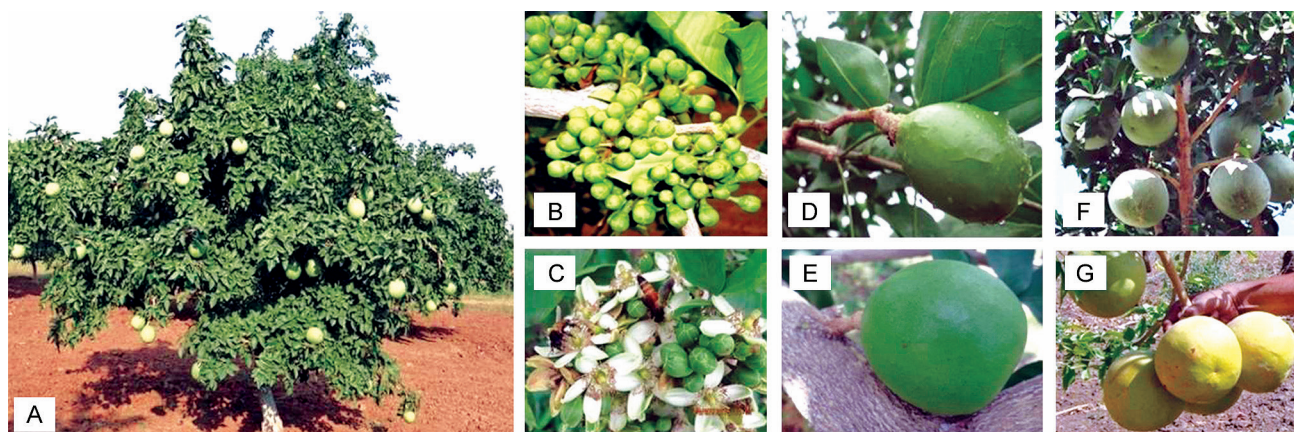


Fig 1 Bael variety Goma Yashi. (A) Plant bearing habit, (B) Flower bud, (C) Flower anthesis and pollination, (D) Young developing fruit, (E) Developed fruit, (F) Mature fruit, (G) Ripened fruit.

antidiabetes, antibacterial, antiviral antifungal, anticancer, analgesic, radioprotective, antiviral, antimicrobial and anti-helminthic. Compounds purified from different parts of bael tree have also shown repressive effects against several diseases (Maity *et al.* 2009, Patkar *et al.* 2012). The root is also used as major ingredient of ‘*dasmula*’ (10 roots): an *Ayurvedic* formulation known to be a panacea for stomach ailments. Poulitice made of leaves is used for ophthalmia and ulcers. Fresh leaves are also used as remedy for dropsy, beriberi, catarrh and asthma (Maity *et al.* 2009).

Bael fruit is highly nutritious. Analysis of the fruit reflects the following values: 61.5g moisture, 1.8 g protein, 0.39 g fat, 31.8 g carbohydrates, 1.7 g minerals, 55 mg carotene, 0.13 mg thiamine, 1.19 mg riboflavin, 1.1mg niacin and 8.0 mg vitamin C per 100 g of edible portion (Gopalan *et al.* 1985). Several bioactive compounds, viz. skimmianine, cineole, citral, citronellol, aegelin, lupeol and marmesinin, marmelosin, luvangetin, psoralen, marmelidefagarine, marmin, umbelliferone, aegelin, lupeolauoptin, marmin, umbelliferone, lupeol, xanthotoxin, scopoletin, tembamide, dictamnine, marmesin have also been isolated from the different parts of the bael tree (Maity *et al.* 2009). The nutritional and antioxidant potential of the bael varieties in terms of phenolic content, total antioxidants capacity, ascorbic acid content and carotene content has been studied. The total phenolics (mg/g FW) ranged between 18.90-48.58, whereas total flavonoids (mg/g FW) and antioxidant activity (CUPRAC (micro mol TE/g) ranged between 14.86-38.83 and 98.75-160.81, respectively among the varieties under dryland conditions (Sarkar *et al.* 2015, Singh *et al.* 2018a).

The gummy substance surrounding the seeds serves as a good adhesive and is added to water-paints to improve the strength and brilliancy, and the shell of the hard fruits is fashioned into pill and snuff boxes, sometimes decorated with gold and silver (Saroj *et al.* 2006). Gum obtained from stem and seed locules is used for the stabilization of drilling fluids, preparation of adhesive and in water proofing and oil emulsion coating, whereas the wood is used for making small agricultural implements and pulp for manufacturing wrapping paper (Singh *et al.* 2018a).

RESEARCH AND DEVELOPMENT

Morphology, flower biology, cytogenetic, pollination and pollinators

Bael is a slow-growing, medium sized tree attaining 25-30 feet height. The stem is short, thick, soft, flaking bark, and spreading, sometimes spiny branches (2-5cm long), the lower ones drooping (Singh *et al.* 2011a, Singh *et al.* 2015). The bark is furrowed and corky yellowish-brown in colour. In different varieties, variation in bark colour (light yellow, grey and dark grey) and bark splitting pattern (rectangular, cylindrical, triangular and irregular) were observed by Singh *et al.* (2009).

A wide range of variability with respect to leaf morphology (shape, margin, base and apex) has been reported in the bael germplasm (Singh *et al.* 2012, 2015b, 2018b). Leaves are alternate, compound, trifoliate with one pair of shortly stalked opposite having pulvinus leaflet, ovate or ovate lanceolate, crenate, acuminate and membranous, and midrib prominent beneath. It has also been observed that 4-8 leaflets may also be found rarely in place of trifoliate leaflets (Singh *et al.* 2018b). Nicotra *et al.* (2011) also reported that different leaf shapes can be found in association with variation in other leaf traits due to different climatic factors. Variation in thorn orientation, number, size and shape is found in different genotypes; thorn may be small and stout in pairs in most of the genotypes; three thorns can be seen rarely at a single node in few genotypes, and it is also observed that the thorn convert into a pair of spine in very few genotypes. Goma Yashi trees are thornless under rainfed semi-arid conditions. However these attributes may vary in different agro-climatic conditions (Singh *et al.* 2018a, Nicotra *et al.* 2011). The extent of pollination depends on factors like the amount of functional pollen, stigma receptivity and relation of pollen to setting. Fragrant flowers, in clusters of 4 to 15 along the young branchlets having 4 or 5 curved, fleshy petals, green outside, yellowish inside, and 40 or more greenish-yellow stamens (Singh *et al.* 2011b).

Bud emergence in all the varieties starts at different

times, but lasts usually from April to late July (Singh *et al.* 2014c). The varieties having a longer flowering period may serve as a long-term resource which allows the presence of a constant population of pollinators (Singh *et al.* 2008). In some flowers, all the petals may open simultaneously while in others they may open one by one taking 45 to 60 minutes for the complete opening. Opening of petals in the individual flowers may also vary from flower to flower in the same genotype, and the anthers and floral organs shrunk and turn into brick red after dehiscence as the time passes on (Singh *et al.* 2018a). The findings regarding anthesis revealed that the anthesis and anther dehiscence in bael varieties coincided with relatively cool and humid microclimate of tree canopies early in the morning (5.30-8.30A.M.) (Srivastava and Singh 2000). Stigma receptivity after anthesis was recorded to be the highest on same day (45.27-68.53%), whereas it ranged between 7.95-15.52% and 3.62-14.37% one day before and after the anthesis, respectively, showing considerable difference in stigma receptivity (Singh *et al.* 2014b). Bael is a cross pollinated crop; different insects like honey bees (e.g. *Apis dorsata*), beetles, houseflies and butterflies visit the flowers for foraging in the forenoon (Singh *et al.* 2011b, 2018a) (Fig 2). Honeybees are recognized as the ultimate and legitimate pollinators in many tropical trees (Singhal *et al.* 2011) as well as in bael (Singh *et al.* 2018a). Cauliflorous and ramiflorous bearing habits have also been recorded on bael tree wherein flowering occurs on current seasons' shoot to quite old (9 years) shoots (Singh *et al.* 2018b).

Recently, two species added to the genus *Aegle* are *A. decandra* Fernvill and *A. glutinosa* (Blanco) Merr. Other members of Rutaceae are *Citrus*, *Casimiroa*, *Clausena*, *Eremocitrus*, *Limonia*, *Feroniella*, *Fortunella*, *Poncirus*, *Triphasia* etc. While generic name *Aegle* is of Greek origin,

the species name (*marmelos*) is a Portuguese word. Bael has a somatic chromosome number of $2n=18$ chromosomes with an average chromosomal size of about $1.60\mu\text{m}$. Length of individual chromosomes vary from 1.08 to $2.62\mu\text{m}$. Total chromatin length of bael is calculated to be $28.88\mu\text{m}$. Cytology, phenology, pollination, breeding system and natural regeneration of wild and cultivated trees from India revealed the existence of diploid ($2n=18$) and tetraploid trees ($2n=36$) in Pachmarhi hills and only diploid trees in Punjab plains and Shiwalik hill and trees of both the ploidy level showed normal meiosis and high pollen fertility (Singhal *et al.* 2011).

There is a considerable effort by national groups working on bael to collect, evaluate and conserve the bael germplasm from various states of India, viz. Uttar Pradesh, Bihar, Gujarat, Rajasthan, Punjab, Haryana, Madhya Pradesh, Jharkhand and West Bengal by NDUAT, Faizabad, GBPUAT, Uttarakhand, CHES, Godhra, ICAR-CIAH, Bikaner, ICAR-CISH, Lucknow, CCSHAU, Regional Research Station, Bawal, ICAR-CAZRI, Jodhpur (Jana *et al.* 2014, Singh *et al.* 2018a, Sharma *et al.* 2013).

Metroglyph grouping and association analysis on physical characters of bael fruit has been reported by Ghosh and Gayen (1990). Analysis of genetic divergence in seventeen bael germplasm using Mahalanobis D2 statistics indicated the existence of substantial genetic diversity. The genotypes were grouped into 3 clusters which included one solitary group (PB-3). The clustering pattern of genotypes was random and did not correspond to the geographic distribution (Rai and Mishra 2005). Various collections are maintained at CCSHAU, Regional Research Station, Bawal (10), NDUAT, Faizabad (22), ICAR-CIAH, Bikaner (21), ICAR-CISH, Lucknow (44), GBPUAT, Pantnagar



Fig 2 Different pollinating agents of bael flowers genetic resources and varietal wealth.

(10), ICAR-CAZRI, Jodhpur (5) and at CHES (ICAR-CIAH), Godhra (193) (Singh *et al.* 2018a). In recent past, some promising varieties of bael have been developed through clonal selection at ICAR Institutes and Agricultural Universities (Table 1).

Plant propagation

Seeds germinate in 8-15 days after sowing during summer under raifed semi-arid conditions (Singh *et al.* 2011a). Since, baelseed belongs to recalcitrant category; the seeds cannot be stored for longer periods under normal storage conditions. Sometimes seeds germinate while fruits are kept on tree for longer duration after ripening of tree (vivipary) (Singh *et al.* 2018b). Sodicity adversely affects the seed germination, seedling growth, tissue mineral composition and leaf chlorophyll content leading to a range of injury symptoms. Delayed and poor seed germination and reduced plant growth were observed in response to increased sodicity. Leaf Mg increased in saline soils but decreased with increasing sodicity. Leaf Na was at toxic levels in both saline and sodic soils. The foliar sprays of plant bio-regulators, i.e. gibberellic acid (GA_3) and IBA (both at 250, 500, 750 and 1000 ppm), and potassium nitrate (250, 500, 750 and 1000 ppm) improve seedling vigour mainly by improving the stem and root growth (Mishra and Jaiswal 2001).

Performance of bael with respect to seed germination and plant growth was observed to be satisfactory in sodic soils up to 29.0 ESP without application of any chemical amendments (Saroj *et al.* 2006). For selecting mother plants, the following basic criteria must be considered: (i) Trees should be consistently high yielding, (ii) Quality of fruit should be very good with all desired traits, (iii) Trees should be free from diseases and pests and (iv) It should be in full bearing stage (Singh *et al.* 2018b). The bael scion shoots can also be grafted on number of related species, such as *Aegle fraeglegabonensis*, *Aegle chevrier*, *Aegle paniculata*

and *Aegle glutinosa* (Singh *et al.* 2011a).

Under dryland conditions, some thumb size branches of mother plant are cut during March to put forth new shoots for budding during summer (May-June). For accelerated growth of shoot, plants should be irrigated one week after cutting the branches. For softwood grafting; one season old shoots are used when plants start putting forth new leaves (Singh *et al.* 2018a). Patch budding is the commercial method of multiplication of bael (Singh *et al.* 2014a). This method is very useful for transportation of sapling to the distant places (Singh *et al.* 2018a). Patch budding and softwood grafting were found to be successful when performed in the month of May-June (before onset of rain) under Gujarat conditions and the plants propagated through *in-situ* patch budding in the month of May and June (before onset of rain) recorded 94.14% and 90.82% success, respectively (Singh *et al.* 2014a, Singh 2018). Under arid conditions of Bikaner, Rajasthan; more than 90% success was obtained through patch budding on polybag raised rootstocks in July (Saroj *et al.* 2006).

Although bael can also be multiplied through inarching, cutting, root sucker, layering and stooling, success and survival rates are invariably lesser than those in budding and grafting (Singh *et al.* 2018a). Stooling with application of 5000 ppm IBA is suggested for producing uniform rootstocks. However, successful establishment of the stools after separation from the mother plant is less (19%) under dryland conditions (Singh *et al.* 2018a). Air layers prepared in the second week of August with IBA (1000 ppm) in lanolin paste on new shoots emerged after envigoration, gave 90% rooting and 77% survival of rooted air layers (Saroj *et al.* 2006). Micro-propagation techniques have been gainfully employed in mass multiplication of various fruit species. Multiplication of shoots is also possible by using the micro shoots. Regeneration from nucellous tissues, cotyledons, leaf, axillary shoots, zygotic embryo has been reported by Hossein *et al.* (1994) and Islam *et al.* (1994) in bael.

AGRONOMY CULTIVATION, PESTS AND DISEASES

Planting, planting density and planting systems

The ideal time of planting under rainfed conditions is June just after first rain in the monsoon. Bael grafts are planted at the spacing of 5 m to 8 m depending upon variety and agro-climatic conditions (Singh *et al.* 2011a). Under rainfed conditions of the hot semi-arid ecosystem, planting of vegetatively propagated plants of dwarf varieties, especially Goma Yashi, can be done at 5m × 5m spacing to maximize the productivity by accommodating 400 plants/ha (Singh *et al.* 2018a). Based on vegetative growth habit of different varieties under rainfed hot semi-arid condition, Thar Divya, NB-7, Pant Urvashi, Pant Sujata, CISHB-1, CISHB-2 should be planted at 8m × 8m; NB-9, NB-17, NB-16 and Thar Neelkanth at 8m × 6m, and Pant Aparna, and NB-5 at 6m × 6m (Singh *et al.* 2011b). However, closer spacing, growth regulation by training and pruning and the use of

Table 1 Improved high yielding bael varieties developed in India

Varieties	Organizations
Narendra Bael-5, Narendra Bael-7, Narendra Bael-9, Narendra Bael-16 and Narendra Bael-17	N. D. University of Agriculture and Technology, Kumarganj, Faizabad, Uttar Pradesh
Pant Aparna, Pant Sujata, Pant Shivani and Pant Urvashi	G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand
CISHB-1 and CISHB-2	ICAR-Central Institute for Sub-tropical Horticulture, Lucknow, Uttar Pradesh
Goma Yashi, Thar Divya and Thar Neelkanth	Central Horticultural Experiment Station (ICAR-CIAH), Vejalpur, Panchmahals (Godhra), Gujarat

Growth behaviour, flowering, fruiting, qualitative and quantitative characters of bael varieties have been studied under rainfed semi-arid conditions (Singh *et al.* 2014d, 2016c, 2018a).

mechanical devices is being tried for the successful adoption of high density planting in bael. At CHES, Godhra, work for the evaluation of high density planting (4m × 4m, 6m × 4m, 8m × 6m, 6m × 6m) has been initiated with variety Goma Yashi in 2015 (Singh *et al.* 2018a).

In the bearing orchards, trees should not be irrigated by the flooding method because heavy irrigation after long period often causes severe cracking in such dryland soils (Singh *et al.* 2018a). However bael can be grown successfully without irrigation under rainfed conditions (Singh *et al.* 2016c). Drip irrigation should be adopted for better growth, fruit and development, and for saving irrigation water. Under arid conditions, plants should be protected from the hot desiccating winds and low temperature below 0°C (Saroj *et al.* 2006).

For proper growth and development, an annual dose of about 20 kg of FYM during the pre-bearing period and 50-80 kg per tree at bearing stage is considered beneficial. It is suggested to apply 10 kg farm yard manure and 50, 25, 50 g N P K, respectively, to one year old plants. This dose should be increased every year in the same proportion up to the age of 10 years (Singh *et al.* 2011a, 2018a). Green manuring with legumes have special significance in sustaining the nutrient requirements of bael orchards established on degraded lands (Singh *et al.* 2018a). Three foliar sprays with 0.6% mixture containing zinc sulphate, borax and ferrous sulphate in equal proportion during July, October and November have been found to be beneficial for proper growth and development of plant (Singh *et al.* 2011a).

Training, pruning and canopy management

Young plants should be allowed to develop 4-6 well spaced branches in all the directions to develop into the main scaffold structure of the tree. Pruning of 25% annual growth during leafless stage is found to encourage the emergence of new shoots and development of a dense canopy to avoid the sun scald, especially under dryland conditions (Singh *et al.* 2018a). Organic mulching improves soil properties like pH and EC as well as the microbial and earthworm populations in the tree basin soil over time. Mulches should be applied in the tree basin (20 cm thick) after rainy season and un-decomposed organic mulches should be incorporated and mixed into the soil in the last week of September which is helpful in increasing the beneficial microorganism and earthworm in basin soil when applied for longer duration (Singh *et al.* 2011a).

Crop diversification

Cover cropping with *lobia*, moth bean was found to increase the water holding capacity of light soils as a result of increased organic carbon content in the soil (Saroj *et al.* 2006). Intercropping in the newly established bael orchard had no adverse effects on plant growth up to 5 years. Intercropping of guar with bael cv. Goma Yashi increased the fruit yield. Bael + cluster bean, bael + bottle gourd, bael + bhindi were found ideal crop combinations to generate extra income from bael orchards under rainfed semi-arid

conditions (Singh *et al.* 2018a). Under dryland conditions, bael based cropping model has been found beneficial to minimize the risk and enhance the productivity. Bael+ aonla + karonda+ drumstick, bael + chironji + fig + custard apple, and bael+ khirni + phalsa + wood apple multi-storey cropping models have been found to be useful in enhancing the productivity of dryland soils. Green manuring in the basin of fruit tree with sunhemp and mung is very beneficial for better growth and development of plant under rainfed semi-arid environment (Singh *et al.* 2011b, 2018a).

Fruit setting, fruit growth and development

The seedling bael tree requires 7-8 years to bear fruits while budded plants start bearing at the age of 3 years after planting. The fruits become ready for harvest after 9-12 months or so by February-June in hot semi-arid western India (Singh *et al.* 2016a). Studies on variation in fruit set, retention and yield of bael varieties revealed the maximum fruit retention in Pant Aprna followed CISH-B-1, Thardivya, Thar Neelkanth, NB-9 and Pant Shivani, whereas the minimum fruit set was recorded in NB-7 followed by NB-17 (Singh *et al.* 2011b), whereas effect of pollen on fruit set, fruit retention have been studied by Pal and Misra (2005). The growth and development of the bael fruit follow a single sigmoid curve and classified as a climacteric fruit. Changes in qualitative and quantitative attributes of bael variety Goma Yashi during growth and development have been studied at CHES, Godhra (Singh *et al.* 2018a).

Maturity, ripening, aroma content

Ripening of fruit can be judged by separation of stalk from the fruit, but it is not applicable to all the varieties and genotypes. Ripening of bael fruit can be accelerated by a combination of high temperature and exogenous application of ethylene; however, ethylene induced ripening is not effective at the low temperature. However fruit ripening period may vary in different climatic conditions (Singh *et al.* 2018a). In bael, no climacteric rise in respiration is noticed till the fruits are attached with the plants. However upsurge increase in respiration is noticed after harvest, but the respiration during early stage of development is very fast. Considerable decline in specific gravity is noticed during ripening. Under hot semi-arid conditions of Gujarat, different varieties start ripening from February (Thar Divya), March (Goma Yashi, CISHB-1 and Pant Shivani), April (Thar Neelkanth, NB-9, NB-16, NB-17 and Pant Aprna) and in May (NB-7, Pant Urvashi, CISHB-2 and NB-5) (Saroj *et al.* 2006, Singh *et al.* 2018a).

Fruit treated with 1000-1500 ppm ethrel and kept at 30°C after harvesting can be made available 2-3 months in advance of normal ripening. It takes 18-24 days for the fruits to be artificially ripened. The composition of bael fruit, whether ripened artificially or naturally, does not vary considerably; the sugar accumulation in naturally ripened fruits is slightly more than the artificially ripened ones (Singh *et al.* 2011a). The attractive and characteristically sweet aroma components of bael fruit were investigated,

terpene alcohols and β -ionone were considered to contribute to the aroma of bael fruit (Saroj *et al.* 2006).

Harvesting, yield and quality attributes

Mature bael fruits are harvested individually from the tree along with a portion of fruit stalk (2-3 cm) to avoid the infection, as it also helps to judge the ripening (Singh *et al.* 2018a). To prevent fruit from falling on ground, fruit picker is used for harvesting. For preserve making, fruit should be harvested from November to December, whereas for fresh consumption, the optimum harvesting time is from second fortnight of February to June under rainfed semi-arid conditions (Singh *et al.* 2018b).

At CHES, Godhra, a full grown tree gives 80-120 kg fruit yield/tree under rainfed conditions (10 year onwards) (Singh *et al.* 2018a). However, a seedling tree at the 20-30 years age can yield 500-800 small sized fruits (Saroj *et al.* 2006). The morphological features of fruit of different varieties, viz. fruit yield (40.50-69.29 kg/plant), fruit weight (0.43-4.25 kg), fruit length (10.61-19.59 cm), fruit width (9.40-22.00 cm) and fruit girth (29.10-70.00 cm) also showed variations (Jana *et al.* 2014, Singh *et al.* 2008). Physical composition of bael fruit exhibited wide variation in the shell weight (115.25-560.05g), shell thickness (0.16-0.31 cm), number of seeds/fruit (90.34-212.25), total fresh seed weight/fruit (17.34-43.41g), number of seed sacs (10.23-19.17), fibre weight (15.91-106.50g) and pulp weight/fruit (0.27-3.67 kg), whereas the qualitative characters of fruit in terms of TSS of the mucilage, TSS of pulp, total sugar, reducing sugars, non-reducing sugars, vitamin C, total phenols, acidity and TSS to acid ratio ranged between 37.00-49.50°brix, 30.57-37.45°brix, 16.15-19.98%, 3.30-4.95%, 12.85-15.13%, 17.13-21.03 mg/100g, 2.34-2.75%, 0.30-0.49% and 68.88-124.83, respectively, in different bael germplasm (Singh *et al.* 2011a, 2011b, 2014d; Singh *et al.* 2009). Wide variation in physico-chemical composition in bael germplasm has been reported by earlier workers (Singh *et al.* 2014b, Singh *et al.* 2015). Effect of pollen on ripening and fruit quality has been reported by Singh *et al.* (2018a) and Pal and Misra (2005) in bael. Physico-chemical characteristics of bael seed oil showed that the light yellow oil had refractive index of 1.468. The iodine value was 114.81 ± 0.07 mg iodine/g, saponification 183.69 ± 2.41 mg KOH/g, acid value 19.05 ± 0.09 mg KOH/g and peroxide value not detected in the oil analyzed. The seed oil was found to be rich in unsaturated fatty acids, viz. linoleic acid (2452.06 ppm), oleic acid (961.52 ppm) and linolenic acid (37.55 ppm) (Bajaniya *et al.* 2015).

Improvement in physico-chemical characters in the bael genotypes by application of growth regulators and micronutrients have been reported in bael by Kundu and Ghosh (2017) and Saini *et al.* (2004). Fruit is berry usually globose, round, flat conical, elliptical, obvate; pericarp (shell) thick to thin, smooth or rough surface, light green to green (immature stage), greenish yellow to yellowish green (mature fruit), whereas fruit surface texture may be plain or undulating (Singh *et al.* 2014b). The styler end cavity was

observed smooth, narrow, depressed, highly depressed and extremely depressed, while stem end cavity was observed smooth, shallow, sunken, depressed and highly depressed (Singh *et al.* 2009). Seeds numerous, oblong and round, compressed arrange in closely packed tiers in the cell and surrounded by a very tenacious, slimy transparent which become hard when dry. The testa is white with woolly hairs and embryo has large cotyledons and a short superior radicle, while fibre may be thick to thin, colour—white to yellow, fibre content—thin to thick in different germplasm (Singh *et al.* 2018a).

Postharvest handling and value addition

Fruits harvested at full maturity for preserve making can be stored up to 21 days and fruits harvested at ripe stage can be stored up to 7-10 days at room temperature (Singh *et al.* 2018a). Fruit can be stored up to three months at about 9°C and 85-90% humidity under cool storage (Saroj *et al.* 2006). At low temperature, spoilage is caused mainly due to chilling injury, i.e. appearance of brown spots on the fruit surface during storage below 8-9°C. The effect of some chemicals like NAA (100, 200 ppm), GA₃ (50, 100), ascorbic acid (200 ppm) and wrapping materials (liquid paraffin coating, perforated polythene bags, butter paper or blue cellophane) prolonging the storage life of fruits of bael cv. Kalyani Selection-1, harvested in February, were investigated in which paraffin coating increased the storage life (Saroj *et al.* 2006).

Bael fruits have different shapes and sizes; hence they should be graded accordingly to fetch better price. At present, the fruits are packed in gunny bags, baskets or wooden crates and sometimes they are transported without any packing (Saroj *et al.* 2006). It is highly essential that some cushioning material namely, straw paper, saw dust, newspaper liner etc. should be used while packing bael fruits (Saroj *et al.* 2006). The fruit should not develop any crack or damage during packing, transportation, marketing and storage; otherwise it may get spoiled due to fungal infection (Singh *et al.* 2018a). Among the varieties, the maximum organoleptic scoring was recorded in Goma Yashi (Singh *et al.* 2016b). The preserve made from mature fruits is a most common processed bael product, while from the ripe fruit a popular drink *sharbat* is made by beating the seeded pulp together with milk and sugar. A beverage is also made by combining bael pulp with that of tamarind. Beside these, a number of value added products such as squash, fruit slab, toffee, candy, powder, jam, icecream, pickle etc. are prepared (Singh *et al.* 2011a, 2018a).

PHYSIOLOGICAL DISORDERS, INSECT PESTS AND DISEASES, AND THEIR MANAGEMENT

Physiological disorders

Fruit drop is a natural phenomenon, but the extent of damage is a matter of concern. The extent of fruit drop varies with genotypes/variety and location. Immature fruit drop (marble size) has also been observed. Sometimes

cricket ball sized fruits also fall down during August (Singh *et al.* 2018a) and mature fruits in January- February under Lucknow conditions. The extent of fruit drop in bael can be reduced effectively by adopting better orchard practices which include mulching with organic materials and proper soil nutrient management (macro-micro) and application of growth hormones like NAA (15-20 ppm/litre) at pea size stage during August-September (Singh *et al.* 2011a). Shweta and Misra (2015) reported that all the growth substances sprayed, proved beneficial in minimizing drop and enhancing quality characters of bael fruits, while the maximum fruit set (78.48%) was recorded with NAA 30 ppm, and the minimum fruit drop (90.64%) and the maximum fruit retention (9.36%) were recorded with NAA 20 ppm. Saini *et al.* (2004) suggested that the fruit drop and fruit cracking can be minimized by spraying borax 0.1% or by soil application of 100 kg farm yard manure/tree as the basal dose in monsoon.

Sun scald is manifested by turning of normal green shell into dark brown at the fruit surface where it is exposed to the hot sun for maximum period during day hours. Sometimes, the pulps of fruit beneath the shell also get affected due to moisture loss and irradiation (Singh *et al.* 2011a). The main reasons of sun scald may be ascribed to intense solar radiation affecting the shell for long time during the day coupled with unavailability of sufficient soil moisture and the temperature of sun scalded portion is increased by 8–10°C as compared to unexposed portion of the fruit. Mulching and canopy management are useful in reducing this disorder up to some extent under dryland conditions (Singh *et al.* 2018a).

Diseases and their management

Bael tree is not affected by serious diseases. However, leaf spots, powdery mildew, shot hole and fruit canker, fruit rot, *Fusarium* rot, stalk end rot have been reported, which can be controlled by chemical sprays easily.

The bael leaf spot disease is also reported in bael. Canker is caused by *Xanthomonas bilvae* and it is characterized by minute, circular, brown, water soaked spots on susceptible leaf surface. The pathogen also causes infection on fruit twigs and thorns. Spraying once or twice with streptomycin sulphate 250 ppm or Bordeaux mixture 1% at 12–15 days interval effectively control the disease (Singh *et al.* 2015, 2018a).

During summer months, May-June, a severe post-harvest rot caused by *Aspergillus awamori* Nakazawa is also observed. The disease is somewhat serious during storage period of fruits. Pre harvest spray of Carbendazim (0.05%) and avoiding bruises to the pericarp during picking, storage and transport are suggested to manage the disease.

Stalk end rot of *bael* is caused by *Fusarium solani* (Mart.) Sacc. Dropping of immature young fruits is the main symptom of this disease. For effective control of the disease, two sprays of Thiophanatemethyle or Benomyl (0.1%) at fortnightly interval are recommended during early stage of fruit development. *Fusarium* rot caused by *Fusarium*

moniliformae Sheldon is also observed. Two sprays of Thiophanate methyl or Benomyl (0.1%) at fortnightly interval are recommended to manage the disease. Shell soft rot caused by *Syncephalast rumracemosum* is observed on mature, harvested fruits. The fruits may be dipped after harvest in hot water at 52±1°C and then shade dried or dipped into 0.05% Thiophanate Methyl for 2 minutes and dried in shade to avoid the disease. Powdery mildew disease is characterized by appearance of white floury patches on leaflets, especially on younger leaves during November–December under Godhra condition (Singh *et al.* 2015a). Tender shoots are also found infected with the mildew. The disease is caused by *Oidium* sp. Spray with Carbendazim 50 wp (Bavistin 0.1%) or wettable sulphur (0.2%) is found to be useful (Singh *et al.* 2018a).

Gummosis is common in bael orchards. The vigour of tree is severely affected and twigs defoliation and dieback are seen in case of severe incidence. To manage the disease, it is suggested to scrap off the infected portion of bark with the help of a sharp knife, which should be followed by application of Bordeaux paste. Spray with copper fungicides (Bordeaux mixture 1% or copper oxychloride 0.3%) is also suggested at monthly intervals during and after the rainy season. Removal of highly infected twigs and incorporation of *Trichoderma viridae* propagules in the soil of rhizosphere of bael were found helpful to control the disease (Singh *et al.* 2015a, 2018a).

Insect pests and their management

Lemon butterflies, the caterpillars feed on foliage and cause economic loss. Other insect-pests like *Citrus* leaf miner (*Phyllocnistis citrella* Stainton), spiralling whitefly (*Aleurodicus dispersus* Russel) and brown scale are of minor importance, as these are either sporadic in occurrence or confined to certain pockets. In case of severe infestation, spray with Quinalphos or 0.05% Chlorpyrifos or Phosalone are recommended. Spraying the entomogenous fungus, *Bacillus thuringiensis* Berliner or nematode DD-136 strain also gives very high mortality of the caterpillars. Installation of yellow sticky traps @ 20 ha⁻¹ to attract adults and fish oil resin soap 40 ml/l in the early morning hours. Predators *Axinoschymnus puttardria* and parasites, *Encarsia haitensis* proved highly effective against spiraling white fly. Scale insect can be controlled by spraying of Diomethoate (0.05%) or Imidachlorpid (0.5ml/l) at fortnightly interval. It is first report of infestation on bael by scale insect under dryland condition (Singh *et al.* 2011a, 2018a).

Bael cultivation is still not commercialized due to several reasons. The future of this fruit depends on the development of high quality trait specific cultivars having less seed, mucilage and tolerance to various abiotic stresses, and also free from sunscald, fruit drop and fruit cracking. Being a medicinal plant, there is dire need of correlating the therapeutic activity with the chemical marker of the plant as well as studying the mode of action of the marker compound and clinical trials against the diseases. The fact of that the bael is a 'hot' commodity on health product markets and

with firm evidences regarding its usefulness in combating against various diseases, despite some legal challenges to those claims, the prospect for bael research is enormous in country. There is a need to create awareness in people regarding its nutritional, therapeutic and environmental benefits for its commercialization. It is hope that the research findings related to production technology, biotechnology in improvement and health beneficial herbal value added products on this fruit crop, would increase in future.

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