Bael (*Aegle marmelos* Correa.) 12

Abstract

Bael (*Aegle marmelos* Correa) is an important indigenous fruit of India. Like many other species of Rutaceae family, bael also has fragrant flowers. They are also highly valued in *Ayurvedic* medicines. All the parts of the tree, whether it is stem, bark, root, leaf, flower, seed oil, or fruits of any stage of maturity and ripening, are used in various *Ayurvedic* medicines. There is lot of variability as the stray plants are of seed origin. There are no regular orchards of bael. It can tolerate salinity to some extent and can be grown successfully once the orchard is established under semiarid rainfed conditions. In situ softwood budding/grafting can be used to establish an orchard. The gestation period is reduced by adopting vegetative propagation. Varieties NB-5 and NB-9 are performing better in semiarid areas, and a yield of 40–50 kg can be obtained per plant.

It is the most suitable crop for value addition. The pulp is diluted with water and add the requisite amount of sugar to tamarind juice to prepare a delicious cooling drink. The bael pulp is used as a base of various fruit products like squash, jam, slab, toffee, powder, nectar, RTS, etc. Green bael fruits are used for preparing *Murabba* (preserve).

12.1 Introduction

India is the second largest producer of fruit (63.50 million tons) obtained from 5.78 million ha area accounting for 10.00 % of the world production of fruits. Bael (*Aegle marmelos* Correa) is an important indigenous fruit of India. It is grown in various parts of South Asian countries including India, Sri Lanka, Pakistan, and Bangladesh and most of the Southeast Asian countries including Myanmar and Thailand. In India, bael is being grown throughout the country and is also known by other vernacular names like bael, bili, bilva, belo, sriphal, and Bengal quince (Johns and Stevenson 1979). The bael tree has found mention in mythological treatises. It is grown near the temple of the Lord Shiva in India. According to Hindu customs, the leaves of the tree are considered sacred and offered to the Lord Shiva. In history, the mention of bael tree has been traced to Vedic times (C 2,000 B.C.–C 800 B.C.) in the Yajurveda. Om Prakesh (1961) recorded mentions of bael in early Buddhist and Jain literature (C 800 B.C.–C 325 B.C.) describ-

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ing various methods of ripening of the bael fruit along with some other fruits. In the "Ramayana" period, the bael fruit was known and its trees were reported to be growing in "Chitrakuta" hills and "Panchavati." In the "Upavana Vinod," a Sanskrit treatise on silviculture (Majumdar 1935), and in the "Brihat Samhita," mention had been made of bael fruit (Aiyer 1956); as the legend goes, in the forest, Lord Rama performed religious rites by offering various fruits including bael (Aiyer 1956). The bael fruit has been portrayed in the painting of Ajanta Caves along with other fruits (Om Prakesh 1961). Like many other species of the Rutaceae family, bael also has fragrant flowers. It is believed that this tree acts as an indicator plant for tracing of underground water (Singh and Roy 1984).

12.2 Importance

The fruits are official in the Indian Pharmacopoeia. They are also highly valued in *Ayurvedic* medicines. The peripheral part just within the rind is fleshy and thick, has a pleasant resinous odor. The walls separating the chambers have a light yellow tint which becomes yellowish brown on exposure and have slightly acrid bitter taste. The chambers are full of amber- or honey-colored viscous very sticky or glutinous, translucent pulp, which is slightly sweet and feebly aromatic. The gummy substance surrounding the seeds serves as a good adhesive and is added to water paints to improve strength and brilliancy. It is more abundant in young fruits. The gum has been used for the stabilization of drilling fluids. The stem also contains a gum similar to gum arabic.

The importance of bael fruit lies in its curative properties, which make the tree one of the most useful medicinal plants of India (Kirtikar and Basu 1935). Its medicinal properties have been dealt with in the "Charaka Samhita," an early medical treatise in Sanskrit (Aiyer 1956). All the parts of the tree, whether it is stem, bark, root, leaf, flower, seed oil, or fruits of any stage of maturity and ripening, are used in various *Ayurvedic* medicines.

The demand of bael fruit is not much higher as other major fruits like mango, banana, guava, apple, etc. The ripe fruit is eaten as fresh and has a more demand among those who wants it for therapeutic use. Sometimes the pulps are diluted with water, and the requisite amount of sugar and tamarind was added to prepare a delicious cooling drink. The bael pulp is used as a base of various fruit products like squash, jam, slab, toffee, powder, nectar, RTS, etc. Green bael fruits are used for preparing *Murabba* (preserve), which is generally taken for stomach ailments. The green bael fruit slices often are dried and stored for future use. The unripe or half ripe fruit is regarded as astringent, digestive stomachic, and good for heart and brain (Kirtikar and Basu 1935). The fruit is used in chronic diarrhea and dysentery and to act as tonic for the heart and brain. It is a useful adjuvant, as it helps to remove constipation which hinders the healing ulcerated surfaces of the intestine. Besides the fruits, the root is an ingredient of *dasamula* (ten roots) used as Ayurvedic medicine. The roots as well as bark are used in the form of a decoction as a remedy in melancholia, intermittent fever, and palpitation of the heart. The root has anti-amoebic and hypoglycemic properties. The young leaves and shoots are used as fodder for cattle, sheep, and goats. The leaves are bitter and used as febrifuge; poultice made of leaves is used for ophthalmia and ulcers. Fresh leaves are also used as remedy for dropsy and beriberi associated with weakness of the heart. The astringent rind of ripe fruits and bark are employed in dyeing and tanning. The timber is commonly used for making pestles of oil and sugar mills and for posts, shafts, axles, and naves of cart. The shells of smaller fruits are used as snuff boxes. A yellow dye is extracted from the rind of unripe fruit. The diluted leaf juice is used for catarrh. The alkaloid aegelin present in the leaves is efficacious in asthma. Utilization of bael fruit has been reported by Roy and Singh (1979b).

12.3 Chemical Composition

Various chemical constituents, viz., alkaloids, coumarins, steroid, etc., have been isolated and identified from the different parts of the plant. The bael fruit is one of the most nutritious fruits. Analysis of the bael fruit gave the following values: 61.5 g 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, 1.1 mg niacin, and 8.0 mg vitamin C per 100 g of edible portion (Gopalan et al. 1961). No other fruit has such a high content of riboflavin. Tannic acid is the only phenolic substance detected from bael fruits. The fruit contains allo-imperatorin, marmelosin identical with imperatorin, and β-sitosterol. Chakraborty et al. (1978) reported that marmolide, an isomer of imperatorin which exhibits tyrosinase-accelerating and tryptophan pyrolase-inhibiting furocoumarin, was isolated from ripe fruits. The fruit yields 2 % water-soluble dried gum. Hydrolysis of the gum gave galactose, 20.4 %; arabinose, 10.7 %; D-GALACTURONIC acid, 25.2 %; and traces of rhamnose (Haskar and Kendurkar 1961). Compounds like auroptin, marmin, umbelliferone, and lupeol have also been found from the bark of bael (Patra et al. 1979). Occurrence of auropotins, umbelliferone, marmin, lupeol, and skimmianine has also been reported in roots (Chatterjee and Choudhury 1960). Besides these compounds, psoralen, xanthotoxin, scopoletin, and tembamide have also been isolated from the roots of bael (Shoeb et al.1973).The presence of aegelin, an alkaloid, has been reported in the leaves of bael fruit (Chatterjee and Roy 1957). Analysis of the leaves gave the following values (dry basis): crude protein, 15.13; ether extract, 1.54; crude fiber, 16.45; N-free extract, 52.83; ash, 14.05; calcium, 5.93; and phosphorus, 0.69 %. Marmelosin is probably the most therapeutically active compound present in bael fruit (0.03–0.37 %) and varies according to variety and locality (Dixit and Dutt 1932). The mature bark contains marmin, auropotins, umbelliferone, lupeol, and skimmianine (Chatterjee and Bhattacharya 1959). The bael fruit mucilage on hydrolysis shows the presence of three reducing sugars, galactose, arabinose, and rhamnose (Parikh et al.1958). The wood contains a furoquinoline alkaloid, dictamnine, marmesin, and neutral compound. The seed yields oil 34.4 % on dry basis and the fatty acid composition of oil as follows: palmitic, 16.6; stearic, 8.8; oleic 30.5; linoleic, 30.0; and linolenic, 8.1 %. Bael seed contains 62 % protein and 3 % each carbohydrate and ash (Banerjee and Maiti 1980).

12.4 Area and Distribution

So far, there is no organized orcharding of bael in our country; hence, exact data on acreage and production is not available. However, in recent years, concerted efforts have been made for the collection of elite genotypes of bael from all over the country and the evaluation and establishment of germplasm block at ICAR Institutes/Regional Stations and State Agricultural Universities. The bael is grown in India and in neighboring countries, namely, Nepal, Sri Lanka, Pakistan, and Bangladesh and most of the Southeast Asian countries, Myanmar and Thailand. In India, it is distributed throughout the country, but concentrated area under bael is in the eastern parts of the Gangetic Plains and nearby areas particularly in Uttar Pradesh, Bihar, West Bengal, and Orissa. Its trees are also available in wild state in sub-Himalayan tract from Rajasthan to West Bengal and central and southern India. In Gujarat, bael trees are found growing naturally in the forest with great diversity (Singh et al. 2008b). Most of the genotypes available in Gujarat are having small-size fruits (Singh et al. 2008a). Apart from systematic orchards, bael trees are also planted in nutritional gardens, parks, temple gardens, and roadsides for various purposes. It was introduced into Europe from India in 1759 (Johns and Stevenson 1979).

12.5 Soil and Climate

The bael tree is very hardy and deciduous and can thrive well in swampy, alkaline, and stony soils having pH range from 5.0 to 10.0 (Jauhari and Singh 1971). Its trees are cold hardy and found to be grown up to an altitude of 1,200 m above mean sea level. It has a wide range of adaptability to adverse soil and climate. Under hot semiarid ecosystem, the extent of hardiness of bael plants has also been observed, and the plants are giving good yield in rainfed conditions. The extent of hardiness of bael plants under *Thar* desert has also been observed that the plant even after being buried under sand for 2–3 months is capable of rejuvenating itself (Anon 2001). Marked reductions in the contents of leaf NPK and Ca were observed in response to increase in salinity and sodicity level in the soil in which plants were grown. Salinity caused significant increase in leaf Mg, while sodicity decreased it. Leaf Na was at toxic levels in both saline and sodic soils (Shukla and Singh 1996b).

Bael is bestowed with a natural characteristic for being tolerant to the extremes of temperature and soil moisture stress by shedding its leaves during summer. However, young plants need to be protected from low temperature (4 °C) and desiccating hot winds. It can also be successfully grown in saline, sodic, and sandy wasteland provided the soil is treated with gypsum and pyrite before plantation.

12.6 Botany and Morphology

Aegle marmelos Corr. belongs to the family Rutaceae. Other members of the family Rutaceae are *Citrus, Casimiroa, Clausena, Eremocitrus, Limonia, Feroniella, Fortunella, Poncirus, Triphasia*, etc. The genetic name *Aegle* is of Greek origin and the species *marmelos* is of Portuguese origin. Its chromosome number is $x=9$ and $2n=36$. The tree is medium to tall, deciduous, and slow growing up to the height of 5–10 m. Its leaves are green aromatic trifoliate; often branches have spines and trunk is strong and stout. The leaves are divided into three leaflets, i.e., a pair and a terminal one; the terminal one is usually the largest. Some leaf abnormalities of *Aegle marmelos* have been noticed. The branches are unusual with long, straight spines. The bark is shallowly furrowed and corky. The bisexual flowers are nearly 2 cm wide and borne in clusters, sweet scented, and greenish white. The calyx is shallow with five short, broad teeth, pubescent outside. There are five petals which are oblong oval, blunt, thick, pale greenish white, and dotted with glands. Stamens are numerous, sometimes coherent in bundles. The ovary is oblong ovoid and slightly tapering, the axis being wide; cells are numerous 8–20, small, and arranged in a circle, with numerous ovules in each cell. The ripe fruits are woody, large, spherical, up to 23 cm in diameter, oblong, or pear shaped, with a more or less smooth or slightly tuberculate surface. The fruit is usually globose with a pericarp nearly smooth, grayish yellow, 1.6–2.7 mm thick, hard, and filled with soft, yellow and orange, very fragrant, and pleasantly flavored pulp. Botanically, the fruit is berry with hard pericarp. The number of cells in the fruit, arranged in a circle, is equal to the number of cells in ovary. Seeds are numerous, compressed, and arranged in closely packed tiers in the cell surrounded by very tenacious, slimy, transparent mucilage, which becomes hard when dry. The testa is white with wooly hairs and the embryo has large cotyledons and a short superior radical. Pollination is usually through honey bees. The nectar secreting disk found beneath the ovary is the main source of attraction for the insects (Reuther et al. 1967; Srivastava and Singh 2000; Singh 1989; Pal and Mishra 2005; Singh and Mishra 2004; Singh et al. 2007).

Flower buds

Flower bud emergence, flowering duration, time of anthesis, dehiscence of anther, stigma receptivity, and pollen viability vary according to variety and locality (Srivastava and Singh 2000).

12.7 Flowering and Fruiting

Generally, flower bud emerges in the month of April and full bloom in the month of May under hot semiarid ecosystem of western India. The seedling tree requires 7–8 years to bear fruits, while budded plants start bearing fruits at the age of 3–4 years after planting, and fruits are ready for harvest after 10–11 months by March–April. However, this varies according to genotypes and agroclimatic conditions.

12.8 Improvement

In popularization of bael, improvement in terms of higher productivity per unit area and quality of fruits in terms of percentage of edible portion, color, shape, taste, and flavor are important. Generally, bael is raised through seeds leading to great variability in morphological characteristics; bearing behavior, size, and shape of fruit; physical composition of fruit, viz., pulp, mucilage, fiber, and peel; and chemical composition in terms of TSS, total sugar, phenolics, and vitamin C, etc. There is a wide genetic diversity in the existing population. This provides ample scope for selection of genotypes for improvement.

In view of the limitations of the conventional breeding techniques, biotechnological approaches for bael improvement hold great potential. Strategies emanating out of advances made in plant biotechnology include embryo rescue, soma clonal variation, haploidy, protoplast fusion, in vitro conservation of germplasm, and recombinant DNA technology (genetic engineering). Genetic maps of species may be prepared with the use of molecular markers.

12.9 Varietal Wealth

Flowers are in clusters, sweet scented, and greenish white. The calyx is shallow with five short, broad teeth, pubescent outside. There are five petals which are oblong oval, blunt, thick, pale greenish white, and dotted with glands. Stamens are numerous, sometimes coherent in bundles. The ovary is oblong ovoid, slightly tapering, the axis being wide; cells are numerous 8–20, small, and arranged in a circle, with numerous ovules in each cell. The ripe fruits are woody, large, spherical, up to 23 cm in diameter, oblong, or pear shaped, with a more or less smooth or slightly tuberculate surface. The fruit is usually globose with a pericarp nearly smooth, grayish yellow, 1.6–2.7 mm thick, hard, and filled with soft, yellow and orange, very fragrant, and pleasantly flavored pulp. Botanically, the fruit is berry with hard pericarp. The number of cells in the fruit, arranged in a circle, is equal to the number of cells in ovary. Seeds are numerous, compressed, and arranged in closely packed tiers in the cell surrounded by very tenacious, slimy, transparent mucilage, which becomes hard when dry. The testa is white with wooly hairs, and the embryo has large cotyledons and a short superior radical. Pollination is through entomophily usually by honeybee. The nectar secreting disk found beneath the ovary is the main source of attraction for the insects (Reuther et al. 1967; Srivastava and Singh 2000; Singh 1989; Pal and Mishra 2005; Singh and Misra 2004; Singh et al. 2007).

Flower bud emergence, flowering duration, time of anthesis, dehiscence of anther, stigma receptivity, and pollen viability vary according to variety and locality (Srivastava and Singh 2000). Size and shape of floral organs in terms of bud size, flower size, petal size, etc. of the varieties evaluated at CHES, Godhra, under rainfed condition of semiarid ecosystem by Singh et al. (2008c).

12.9.1 Narendra Bael-5

The plants are small with a semi-spreading growth habit and precocious and prolific in bearing. The budded plants start fruiting in the 4th year. The average fruit yield of a 6-year-old plant is 28.78 kg. The fruits are medium in size (12.50 cm × 11.50 cm), round with a smooth surface and very thin rind (0.16–0.17 cm), straw yellow at maturity, low in mucilage, and moderately fibrous, having an attractive yellow pulp, with low seed content. Excellent in taste and flavor, the fruits have a total soluble solid of 33° Brix in pulp and 48° Brix in mucilage and ascorbic acid 18.63 mg/100 g of edible portion. The fruit weight ranged from 0.8 to 1.0 kg under rainfed conditions of semiarid ecosystem during the sixth year of orchard life. Its taste is good and can be used as fresh as well as processed into various value-added products.

12.9.2 Narendra Bael-7

Plants are tall and semi-spreading. They are sparse in bearing with large size fruit. The budded plants start fruiting in the 4th year. The average fruit yield of a 6-year-old plant is 32.10 kg (6th year). The fruits are medium in size (18.25 cm × 22.50 cm), round with smooth surface and very thick rind, yellow at maturity, low in mucilage, and fibrous, having an attractive yellow pulp, with low seed content. Fruits are good in taste and flavor, having a total soluble solid of 30° Brix in pulp and 42° Brix in mucilage, slight acidity, and 19.78 mg/100 g ascorbic acid. It is highly suitable for processing.

12.9.3 Narendra Bael-9

The plants are semi-vigorous and semi-spreading, having compact canopy. The variety is precocious and prolific bearer. The average fruit yield of a 6-year-old plant is 56 kg. Fruits are medium to large in size (16.00 cm × 13.50 cm), roundish oblong with smooth surface and thick rind (0.31 cm), light yellow at maturity, average in mucilage, and moderately fibrous, slightly golden yellow pulp with low seed content. The fruits are good in taste, containing a total soluble solid of 38° Brix in pulp and 41° Brix in mucilage, slightly acidic and ascorbic acid 19.20 mg/100 g of edible portion. It can be used as fresh as well as processed into various value-added products. Its keeping quality for storage is very good.

12.9.4 Pant Aparna

Its trees are dwarf with drooping foliage, almost thornless, precocious, and heavy bearers. The leaves are large, dark green, and pear shaped. The fruit has a globose shape with an average size of 13.00 cm × 12.00 cm and weight of 0.8–1.25 kg. The fruit pulp is yellow and rind is thin. TSS is 34° Brix in pulp and 47° Brix in mucilage, titratable acidity 0.67 %, and ascorbic acid 17.15 mg/100 g of pulp. Mucilage, seed, and fiber are low. Mucilage and seeds are enclosed in separate segments. Flavor and taste are very good. Yield during the 6th year is 40.25 kg/plant.

12.9.5 Pant Shivani

It is an early midseason variety. Trees are tall, vigorous, dense, upright growing, precocious, and heavy bearer. The fruit shape is ovoid and oblong and the size is 18.50 cm × 15.00 cm. The fruit weight ranges from 2 to 2.4 kg. The color of the fruit is lemon yellow and its storage quality is good. Rind is medium thin, pulp is lemon yellow with pleasant flavor, and mucilage, seeds, and fiber are low to medium. The taste is very good. It has 69 % pulp, TSS 36° Brix in pulp, mucilage TSS 48° Brix, total titratable acidity 0.47 %, and ascorbic acid 19.55 mg/100 g of flesh.

12.9.6 Pant Sujata

It is an early midseason variety but has problem of fruit splitting. So far, it has not been reported under rainfed conditions of hot semiarid ecosystem of western India. Trees are medium dwarf

with drooping and spreading foliage, dense, precocious, and heavy bearers. Thorns are stout and bigger. The fruit is globose shaped and depressed at both ends with average size of 14.50 cm × 13.50 cm, and weight varied from 1.12 to 1.40 kg under rainfed condition of hot semiarid ecosystem of western India. The fruit and pulp are light yellow. The storage life is better, rind is thin, and seeds, mucilage, and fiber are low. Its flavor is pleasant and taste is very good. The flesh is 72 %, TSS 32° Brix in pulp and 42° Brix in mucilage, acidity 0.44 %, and ascorbic acid 17.10 mg/100 g of flesh.

12.9.7 Pant Urvashi

It is a midseason variety. Trees are tall, vigorous, dense, upright growing, precocious, and heavy bearers. The fruit is ovoid oblong with average size of 14.50 cm × 17.20 cm, and the fruit weight ranges from 1.5 to 2.50 kg. The fruit is yellow, rind is medium to thin, and pulp is light yellow. The fruit has 62.35 % pulp with pleasant flavor. Seeds and mucilage are medium, fiber content low, TSS 33° Brix in pulp and 41° Brix in mucilage, titratable acidity 0.49 %, and ascorbic acid 17.15 mg/100 g pulp.

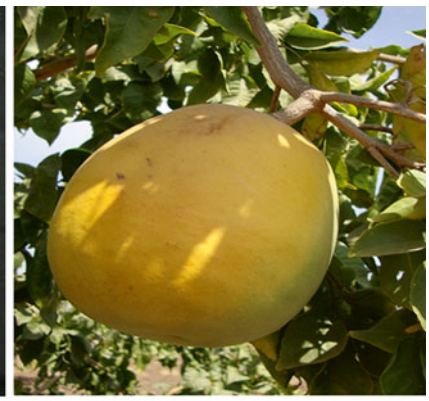
12.9.8 CISHB-1

It is an early maturing variety. The plants are semi-tall and have a spreading growth habit. The budded plants start fruiting in the 4th year. The average fruit yield of a 6-year-old plant is 42.64 kg. The fruits are medium in size (16.50 cm × 12.00 cm), oval oblong with smooth surface, yellow at maturity, low in mucilage, and fibrous, having an attractive yellow pulp, with high seed content. Excellent in taste and flavor, the fruits have a total soluble solid of 32° Brix in pulp and 43° Brix in mucilage. The fruit weight varies from 0.8 to 1.40 kg.

12.9.9 CISHB-2

The plants are dwarf and spreading. The average fruit yield of a 6-year-old plant is 38.45 kg. The fruits are medium in size (16.00 cm × 14.00 cm), round with smooth surface and thick rind, yellow at maturity, low in mucilage, and fibrous, having an attractive yellow pulp, with low seed content. It is good in taste and flavor and the fruits have a total soluble solid of 31° Brix in pulp and 38° Brix in titratable acidity (0.41 %). The fruit weight ranges from 1.7 to 2.6 kg/fruit.

Bael Pant Sujata


Bael Pant Shivani

Bael NB-5

Bael Pant Urvashi

Bael NB-7

CISH Bael-1

12.10 Plant Propagation

With the standardization of vegetative propagation method for bael, the commercial nursery has got a boost. Traditionally, bael was propagated by seeds; however, seed propagation is limited for the raising of rootstocks only. True-to-type planting materials can be produced through vegetative means only. Methods of vegetative propagation have been reported by Singh (1954). The bael fruit can be grafted on a number of related species, such as *Aegle fraegle-gabonensis, A. chevalieri, A. paniculata*, *and Swinglea glutinosa* (Hays 1957).

12.10.1 Seed

Seed propagation is the most common method of propagating bael. Bael seeds have no dormancy; hence, fresh seeds can be sown 2–3 cm deep in the nursery within 10–15 days. The fresh bael seeds germinate in 8–15 days after sowing. The seedlings become ready for transplanting in spring or the next monsoon. The orchard raised by seedlings is not true to type and exhibits variability. Therefore, vegetative propagation techniques are recommended for commercial orcharding of bael.

12.10.1.1 Raising Rootstock Seedlings

For raising of seedlings in the nursery, beds are thoroughly cleaned and plowed. For better germination, higher survival, and establishment, well-rotten FYM should be mixed with the soil before sowing of seedlings. Fresh seeds can directly be sown because of no dormancy. Young seedlings should be protected from frost during winter under arid ecosystem. Polyethylene tubes can also be used to raise the seedlings. FYM, sand, and soil (1:1:1) should be mixed before filling in the polythene tubes. Seeds are sown in the polythene tubes or bags during rainy season for better germination and survival. Delayed and poor seed germination and reduced plant growth were observed in response to increased sodicity (Shukla and Singh 1996a). Performance of bael with respect to seed germination and plant growth was observed satisfactorily in sodic soils up to 29.0 ESP without application of any chemical amendments. The media requirement for seed germination and seedling establishment has also been suggested by Chattopadhyay and Mahanta (1989).

The foliar sprays of plant growth regulators, i.e., gibberellic acid (GA_3) and IBA (both at 250, 500, 750, and 1,000 ppm) and potassium nitrate (250, 500, 750, and 1,000 ppm), improve seedling vigor by means of improved growth of stem and roots.

12.10.1.2 Raising Rootstocks in Polyethylene Bags

Deshi rootstock seeds are collected in April–May are extracted from fruit was dried and sown in polythene bags. The seeds germinate after 10–15 days. To reduce the time for raising rootstock and to avoid damage during handling and transportation, polyethylene tubes and polyethylene bags may be used on commercial scale. Generally, polyethylene bags (25 cm × 10 cm) are used for raising the rootstocks. Small holes are made in the bottom and sides of polythene bags for drainage and aeration and filled with porous rooting medium or pot mixture for raising rootstocks. Generally, 1–2 seeds are sown in each polythene bags and then placed in trench bed, so that it can be irrigated easily. Sometimes coiling of root becomes a problem; hence, root pruner is also used for trimming of roots. Growth of the rootstocks can be improved with the application of 1 g/L urea solution. About 8–12-month-old seedling of uniform size having stem of pencil thickness are used as rootstock for budding and grafting. Plants raised in the polythene bags can easily be transported to distant places with higher planting success.

12.10.1.3 Rootstock

Rootstock selection for vegetative propagation of bael is important, as it controls the vigor and equilibrium between yield and quality. Dwarfing rootstocks induce dwarfness and facilitate easy management of the orchard. Generally, seeds of *deshi* plants are used for raising rootstocks in nursery, but it can also be grafted on the *Aegle fraegle-gabonensis, Aeglopsis chevalieri*, and *Aegle paniculatum.* However, it is not commonly used for raising of bael plant.

12.10.2 Vegetative Propagation

12.10.2.1 Patch Budding

Rectangle incision is made on the rootstock by placing the bud on the rootstocks to mark the exact size of the bud on them and after removing the bark of the rootstock and tying with white polythene strip (200 gauge thickness and 2 cm wide). In case the cuts on rootstock are wider, at least one side bark of scion and stock must be matched properly. The rootstock is cut about 10 cm above the bud to facilitate bud sprouting. The time of budding influences the survival of plant in different varieties. Singh et al. (1976) reported 100 % bud take during the month of June or July. Effect of scion genotypes on patch budding in bael has been reported by Mishra and Jaiswal (2001).

12.10.3 In Situ Patch Budding

In arid and semiarid regions, in situ budding is the most successful method for establishing a bael orchard. This is done by sowing 2–3 seeds directly in the field or by planting seedlings. After 1 year, budding is done in the field. In bael, the tap root system is very vigorous. The root system is, therefore, disturbed during the process of planting of grafts, which ultimately affects growth and establishment adversely in the field conditions. The plants propagated by in situ patch budding in the months of June–July recorded maximum success (94.14 % and 90.82 %, respectively). Budding in bael in June–July from a 1-month-old scion gave 80 % success, and patch budding is an ideal method of bael multiplication (Singh 1954; Moti and Chaturvedi 1976; Singh et al. 1976; Kumar et al. 1994; Chadha 2001).

12.10.3.1 Softwood Grafting

Shoots of 3–4 months old are defoliated 10–12 days prior to grafting operation. For this, seedling rootstock is cut at 10–15 cm height. With the help of a knife, a 5 cm long vertical downward incision is made in the center of the rootstock. A sharp cut of 5 cm is made on both sides on the base of the scion shoot to make wedge shape, and the graft is tightly securedusing a 200 gauge thick and 2 cm wide polythene strip. Maiti et al. (1999) reported that bael can be propagated successfully, and among different grafting methods tried, whip grafting had given good response (70 % success).

Soft wood grafted plant

12.10.3.2 In Situ Softwood Grafting

The deshi rootstock is raised at desired spacing directly in the field; the seeds should be sown directly in the field during rainy season under rainfed condition.

In situ softwood grafting through wedge method is done in the months of June–July on a 1-year-old seedling. The growth below the graft union is removed regularly to encourage sprouting and subsequent growth of the scion shoots. The bud sprouts within 15–20 days of grafting. The polythene strips are carefully removed after completion of the union. The plants are given support with the help of stakes to protect them from stormy winds. High temperature and relative humidity during June–July have helped in early sprouting and better graft success, because of fast establishment of vascular connection with rootstock.

12.10.3.3 Root Cuttings

Bael can be propagated successfully by root cutting. Separation and planting of root suckers can be done during monsoon. To ensure establishment, suckers are planted in nursery beds for about 2 years after uprooting and are then shifted to the main field. Some root suckers, which arise from the roots of the bael trees having profuse roots, can be separated during monsoon and directly planted into the field. But, the success percentage is very low. It is not recommended for arid and semiarid conditions.

12.10.3.4 Stem Cutting

Bael can also be propagated through cutting. Ray and Chatterjee (1996) reported that growth regulator and etiolation treatments were significantly effective in inducing roots in ringed stem cuttings of *A. marmelos*. An invigoration treatment (the production of water shoots following removal of large branches) accompanied by growth regulator and etiolation treatment significantly increased the root quality of cuttings. The highest rooting rates of 75–80 % were achieved by using 5,000 ppm IBA etiolation and invigoration treatments. Rooting rates of 45 and 40 % can be obtained with the application of 100 ppm IBA and 100 ppm IAA, respectively. It was observed that tip cuttings of bael rooted well under intermittent

mist and treatment with IBA at 5,000 ppm produced 100 % rooting.

12.10.3.5 Layering

Air layering is very successful in bael provided that mother trees are given invigoration treatment by heading back to few of the thick branches during April. Air layers are prepared in the second week of August by bark ringing and application of IBA at 10,000 ppm in lanolin paste.

12.10.3.6 Micropropagation

Recently, micropropagation techniques have also been found successful in bael. True-to-type and disease-free plants can be generated from a very small piece of plant in aseptic condition in artificial growing medium rapidly throughout the year. Regeration can be done from explant nucellus (Hossain et al. 1993) and cotyledons leaf (Islam et al. 1993). Multiplication of shoots can be done by using micro shoots. Arumugam and Rao (1996) reported that cotyledonary node explants excised from 15-day-old seedlings of bael were placed in MS medium supplemented with BAP [benzyl adenine], IBA, IAA, or NAA. BAP induced the best production of multiple shoots and subsequent plant regeneration. Rhizogenesis of shoots was achieved in the presence of IAA (Varghese et al. 1993). Elongated shoots were rooted on half strength MS medium supplemented with 0.1 mg IBA liter^{-1} (Islam et al. 1993). The maximum survival (90 %) was recorded when medium was supplemented with 0.5 mg/l BAP and 0.5–1.0 mg/L kinetin from the plantlet regeneration from axillary bud. Similarly, maximum number of shoots (4.70) was developed in culture flask containing MS medium supplemented with 2.0 mg/L BAP and 1–0 mg/L kinetin (Bhargava et al. 2008).

12.11 Agro-techniques

12.11.1 Orchard Establishment

The land may be prepared by usual plowing, harrowing, and leveling. There should be gentle slope to facilitate proper irrigation and proper drainage to avoid the harmful effects of water stagnation during rainy season particularly in black cotton soil. Well-decomposed organic matter is mixed with soil and pits are filled. Planting is done during rainy season when the soil in pits has already settled. While planting, one should be careful that the earth-ball does not break and graft union remains well above the ground level. Soil all around the stem should be pressed properly to avoid the formation of air pockets. The plants should be irrigated immediately after planting. In the initial 2–3 years, it is advised to protect plants against low and high temperature injury and from hot desiccating winds by covering plants with some short of cover, leaving the one side open. Shelter belt and windbreaks around the orchard protect the tree from hot desiccating wind during summer. For this, 2–3 rows of fast growing drought hardy tree species should be planted in staggered manner. In India, bael is planted at the distance either 8 m×8 m or 10 m×10 m. No systematic work has yet been taken up on nutritional requirement of bael tree.

12.11.2 Planting

The planting of bael seedling is done at 10 m×10 m or 8 m×8 m depending upon the agroclimatic conditions. Under rainfed condition of hot semiarid ecosystem, planting of vegetatively propagated saplings can be done at 5 m×5 m spacing to maximize the productivity. The pits of 1 m×1 m×1 m are dug and exposed for solarization to kill harmful soil organisms. The pits are filled with top soil mixed with 20–25 kg FYM after drenching with chlorpyriphos at 3 ml/L to avoid the attack of termite during the early phase of plant growth. The ideal time of planting under rainfed condition is July. In situ planting is found more suitable for orchard establishment under rainfed condition of semiarid ecosystem.

12.11.3 Canopy Management

Canopy management of the crop deals with the development and maintenance of their structure in relation to the size and shape for the maximum

productivity and quality. Tree vigor, light, temperature, and humidity play a vital role in production of quality fruits. The crux of canopy management lies in the fact as how best we manipulate the tree vigor and maximum use of available sunlight and temperature to increase the productivity and minimize the adverse effect of weather. Pruning is done to improve and regulate tree size and shape to achieve the desired architecture of the canopy and also to reduce the foliage density by removing unproductive branches of the tree.

12.11.4 Planting System

No proper research has been done on plant geometry of bael orchard. Generally, bael plantation is being done in square system. Seedling of bael is planted on boundary of orchard as windbreak. Planting of the bael at 6 m × 6 m in square system and at 5 m × 7 m in rectangle system has been recommended. The main objective to follow particularly in planting system is to accommodate the maximum number of trees per unit area without affecting the yield efficiency and fruit quality adversely. Some of the popular systems of planting in vogue are the square, rectangular, quincunx, hexagonal, contour, hedgerow, double hedgerow, paired, and cluster planting. In India, most of the farmers are poor and have less resource like landholding, irrigation facility, etc., and high-density planting is suitable to increase their productivity by accommodating more number of plants per unit area. The layout of square, hedgerow, double hedgerow, cluster, and paired systems is as follows:

12.11.5 Irrigation

It promotes better growth during establishment and the early stages of growth, especially during the summer. In the early age, plants require 8–10 irrigations in a year, while bearing trees require 4–5 irrigations during the time of fruit development and ripening. In dry areas, the use of water harvesting techniques during the rainy season will be useful for ensuring proper irrigation to improve subsequent growth and yield. In dry areas, the use of water harvesting techniques during rainy season and mulches should be adopted. Nevertheless, bael can successfully be grown under rainfed conditions of hot semiarid and arid region.

12.11.6 Mulching

Continuous use of organic mulches is helpful in improving the soil physicochemical properties, microbial flora, and soil aeration which ultimately resulted into better growth and yield of plant. Under rainfed condition, application of organic mulch in tree basin is very beneficial for successful cultivation of bael. It reduces the loss of moisture from the soil, enhances the rate of penetration of rainwater or irrigation in the soil, and controls the growth of weed. Mulching can be done with black polythene or any suitable organic material. Mulching with paddy straw, maize straw, grasses, and rice husk reduces the weed population and conserves the moisture in the soil. Mulches should be applied in the tree basin (20 cm thick) after rainy season, and undecomposed organic mulches should be incorporated and mixed with soil of tree basin in the forthcoming monsoon.

12.11.7 Integrated Nutrient Management

No systematic work has yet been taken up on manuring and fertilization of bael, a minor fruit crop. Generally, bael trees are not manured. However, 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 farmyard manure and 50, 25, and 50 g NPK, in a 1-year-old plant, respectively. This dose should be increased every year in the same proportion up to the age of 10 years. Sometimes in rich soils, the trees have a tendency to put on more vegetative growth with the result that the fruiting is delayed. Singh and

Mishra (2000) have reported seasonal variation in root distribution pattern of bael.

12.11.8 Training

Training helps in avoiding difficulty in intercultural operation. The plants are trained to straight central stem in which branches are not allowed up to 60 cm. Young plants should be allowed with 4–6 well-spaced branches in all direction. Young plants are trained with the help of stake, if needed, so that they can grow erect. Suckers appearing from rootstocks should be removed.

12.11.9 Pruning

Generally pruning is not recommended in bael, but pruning is a tool to regulate tree size and shape to achieve a desired architecture of the canopy and also to reduce the foliage density by removing the unproductive branches to make the tree open. Generally, bael plant is not pruned once the tree starts fruiting, because the branches of such plant are self-oriented, even though, in case of rosette growth, few branches should be removed from its place of origin to have well-spaced scaffolds. Regular pruning in bael plant is not required because fruiting takes place on new shoots as well as old shoots. However, dried, criscross, weak, and diseased branches should be removed as and when required. It will facilitate easy harvesting of the fruits. Pruning of few growing branches becomes necessary particularly when orchard has been established under high-density planting system.

12.11.10 Weed Management

Most weeds although complete their life cycle in a shorter period but compete with plants for light, water, and nutrients and thereby reduce the yield. In the orchard, hoeing, hand weeding, and plowing of the land 2–3 times a year are done to suppress the weed growth. Intercropping and mulching also help in controlling weeds in tree basin.

12.11.11 Intercropping

Intercropping is intended to maximize land and space use efficiency to generate supplemental income particularly during the initial unproductive phase of the orchard to protect the interspaces from losses through weeds, erosion, impact of radiation, temperature, wind, and water, enriching it by nitrogen-fixing legume crops. During the early phase of orchard establishment, interspaces left between tree rows can efficiently be utilized by raising suitable crops which not only enrich the soil but also generate additional income.

12.11.12 Fruit Growth and Development

The growth and development of the bael follow a single sigmoid curve. The growth rate of bael has three distinct phases: the initial slow increase for 1 month followed by rapid increase for 3 months and then more or less a stationary phase until the fruits are harvested. The moisture content of bael fruit decreases during development and ripening. With the decrease in peel moisture, the hardness of starch appears and increases steadily till harvest, but disappears with ripening. The rate of respiration in bael fruit at early stage of development is rapid and it declines with growth. However, an upsurge in respiration is noticed after picking the fruit from the plant. Based on the respiratory studies, the bael fruit can be classified as a climacteric fruit. With the fall in the rate of increase in mucilage, the starch appeared and continued to increase with fruit development but disappeared while ripening. The total and nonreducing sugars of the fruit show a rising trend during development. The total phenolic content of the bael fruit decreased during development and ripening. The inherent low acidity of the fruit shows decreasing trend during development and ripening. However, the fruit ripens normally only in April–May. Studies on biochemical changes in fruit reported an increasing trend in both reducing and nonreducing sugars. Fruit pulp contained very low acid levels which did not vary

much with fruit development. The ascorbic acid content increased with fruit maturity. A sharp increase in pectin, tannin, and marmelosin contents in the pulp was recorded until January, and thereafter, a gradual decline was noticed (Roy and Singh 1980; Pandey et al. 1986).

There is a progressive fall in crude protein content during fruit development. However, a slight increase is noticed during ripening. The pectin expressed as calcium pectate increases during development and ripening of bael fruit. It has been observed that the bael fruit matures in December–January under rainfed conditions of western India. However, the fruit starts ripening from March onward because of prevailing high temperature under rainfed conditions of hot arid ecosystem.

12.11.13 Pest and Diseases Management

12.11.13.1 Pests

Generally, bael is free from serious pests and diseases, but the insect pest damages the crop considerably, especially when environmental conditions are very conducive. Termite attack on new saplings is a major problem. Application of chlorpyriphos at 2–3 ml/L/plant has been found effective to control the termite. Chafer beetles or leaf-eating caterpillars cause damage to the plant, and it can be controlled by 2–3 sprays of dimethoate at 1.5–2.0 ml/L at 15 days interval.

12.11.13.2 Diseases

A new leaf spot disease of bael caused by *Fusarium roseum* Link has been reported by Kore and Dhande (1973). Bacterial shot hole and fruit canker of bael are caused by X*anthomonas bilvae.* The symptoms on the leaves are characterized by round, water-soaked spots (0.5 mm) surrounded by a clear halo. Gradually the spots increase in size (3–5 mm) and form brown lesions with saucer-like depression in the center surrounded by oily raised margin. The primary localized lesions all over the leaf are always followed by falling-out of the necrotic dead tissues, leaving circular or slightly irregular perforation of shot holes. The pathogens also infect the fruit, twigs, and thorns. The disease can effectively be controlled by 2–3 sprays of 500 ppm streptomycin at 15 days interval.

12.11.13.3 Fruit Rot (*Aspergillus nidulans)*

Internal rotting of fruit is a serious problem, which is mainly caused by damage to fruits during harvesting, storage, transportation, or harvesting. To avoid such, maintain proper ventilation during storage and avoid storage especially in polythene enclosures. Such disorders can be avoided by harvesting of fully mature fruits and also to avoid damage to the fruit can be wrapped/stored with newspaper or phenol papers.

12.11.13.4 Physiological Disorders

12.11.13.4.1 Fruit Cracking

Fruit cracking has been observed as a major physiological disorder, and its degree of damage depends according to genotypes/varieties and locality. Fruit cracking takes place twice in a year, i.e., winter season (December–January) while developing fruits are immature and during summer season (March–April) when the fruits are mature and in ripening phase. The cracking at later stage is more severe than the former one. The cracking can be minimized by maintaining optimum soil moisture regime and by provision of windbreaks against hot desiccating wind side of orchard. Organic mulches like paddy straw, maize straw, and *subabul* lopping can effectively be utilized in maintaining soil moisture of tree basin particularly during summer under rainfed conditions of hot semiarid ecosystem (Saini et al. 2004).

12.12 Harvesting

Bael fruits are likely to get damaged if proper care is not taken during harvesting. The tree is in leafless condition during harvesting particularly in late maturing varieties, while early maturing varieties do not shed their leaves at the time of harvesting under rainfed conditions of semiarid ecosystem of western India. Mature bael fruits

are harvested individually from the tree along with the portion of fruit stalk (2–3 cm) to avoid infection, and it also helps to judge the ripening. The stalk is easily separated while pressing the fully ripened fruit which is indication of ripening. Proper care is required for harvesting of bael fruits. Harvesting by shaking the trees should be discouraged, as the fruits are likely to develop cracks on impact because the peel of fruit is highly brittle which invites infection and can cause heavy loss during storage.

12.13 Yield and Yield Attributing Characteristics

The number of fruits per tree may vary from 30 to 45 at the age of 6–7 years depending on genotype, soil, and climatic condition. However, a seedling tree at 30–40 years age can yield 500–800 fruits. Physical characteristics of fruit in terms of fruit size, fruit weight, and shell thickness varied in different varieties/genotypes.

12.14 Ripening

Fruit setting in bael takes place in early May, and ripe fruits are available in March–June. However, this may vary in different agroclimatic zones of the country. 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 much; the sugar accumulation in natural ones is slightly more than artificially ripened. The specific gravity of the bael fruit is initially high, which falls gradually up to 3 months, and thereafter, it increases and remains more or less constant. No climacteric rise in respiration is noticed as long as the fruit is attached to the plant. However, rapid upsurge in fruit respiration, total sugar, and reducing sugar and decline in moisture, phenolics, and acidity have been observed after harvesting the fruit till complete ripening which coincides with the optimum ripening condition of fruit (Roy and Singh 1981).

12.15 Quality Attributes

Results of the study on the varieties evaluated for their quality attributes revealed that the physicochemical attributes differed significantly among the evaluated varieties. The physical composition in terms of peel, pulp, mucilage, fiber, and seed percent in fruits and chemical composition, i.e., TSS, total sugar, reducing and nonreducing sugar, acidity, phenolics, and vitamin C content, varied in different varieties. Differences in physicochemical characteristics in the bael genotypes have been reported by Teotia et al. (1963), Jauhari et al. (1969), Majumdar (1975), Pandey et al. (1986), Ram and Singh (2003), Singh et al. (2000), and Singh et al. (2008a).

12.16 Grading and Packing

Bael fruits have different shapes and sizes; hence they should be graded accordingly. At the time of harvest, generally but not always, the tree is in leafless condition at the time of harvesting, and the fruits are completely exposed particularly in late maturing cultivars/genotypes. There is no recommended practice for packing bael fruits. At present, the fruits are packed in gunny bags, baskets, or wooden crates, and sometimes, they are transported without any packing. It is highly essential that some cushioning material, namely, straw paper, sawdust, newspaper liner, etc. should be used while packing bael fruits. The fruit should not develop any crack or damage during packing, transportation, marketing, and storage; otherwise, it may cause spoilage by fungal infection.

12.17 Storage

Fruits harvested at full maturity for preserve making can be stored up to 15 days, and fruit harvested at ripe stage can be stored up to 7–9 days at room temperature. Fruit can be stored up to 3

months at about 9 °C and 85–90 % humidity under cool storage. It is sensitive to low temperature injury like other subtropical fruits. 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, while at high temperature, spoilage is mainly due to fungal attack. During storage, an increase in total sugars and greater accumulation of reducing sugars are observed.

During storage of bael fruit products, there is reduction in nonreducing sugars and increase in reducing and total sugars. Addition of SO_2 not only improves the initial quality of the bael fruit slab, toffee, and powder but also prevents nonenzymatic browning reaction during storage of all the bael fruit products. The optimum relative humidity for the storage of bael fruit slab, toffee, and powder is found to be 63, 58, and 5 %, respectively. Practically no change in organoleptic quality is noticed in frozen pulp after 6 months, and in case of other products stored at 37 °C, the organoleptic quality remained up to acceptable point (Roy and Singh 1979a).

12.18 Processing

The bael fruit is not popular as dessert fruit due to its hard shell, mucilaginous texture, and numerous seed and fiber contents. Bael fruit has been used widely from time immemorial for processing in the mature green form to prepare preserves, but recently methods have also been standardized to process the ripe fruit. Roy and Verma (1950) mentioned the process of manufacturing bael squash and bael jam. In the same year, Agnihotri (1950) published the method for preparing and preserving syrup from ripe fruits. However, an early report of Singh and Dutt (1941) stated that although the fruit is rich in pectin, it cannot form jelly due to the excess of gummy substances. Verma and Ahmed (1958) reported that bael fruit powder could also be manufactured successfully. Fruits can be processed into a number of acceptable products like slab, powder, toffee, squash, jam RTS, etc. which are briefly mentioned below in flow chart.

12.19 Flow Sheet Chart of Various Value-Added Products of Bael

12.19.1 Flow Chart of Preserve

Pulp graded + Washed mature green bael fruits → Break fruits → Scoop out pulp along with seeds and fibers → Discard seeds → Cut pulp in 2.5 cm thick slices → Wash in water → Prick with a fork → Soak overnight in cold water → Blanch → Prepare 40 % sugar solution → Impregnate with sugar by gradually raising the syrup to 78°Brix → Pour into jars and seal

12.19.2 Flow Sheet for Extraction of Bael Fruit Pulp

Ripe bael fruit → Washing → Breaking → Scooping of pulp with seed and fiber (Discarding) → Addition of water equal to the weight of pulp → Addition of citric acid (titratable acidity 0.5 %) → Kneading → Heating at 80 °C for 1 min → Passing through a pulping machine or stainless steel sieve of 20 mesh (discarding seeds and fibers) → Bael fruit

pulp → → Canning
→ Freezing
→ Preserving by SO_2

12.19.3 Flow Chart for Squash

Pulp → Dissolve citric acid (25 g/kg) in water and add → Dissolve potassium meta bisulfite (2.5 g/kg) in water and add → Filter and add → Prepare syrup by mixing 1.41 water and 1.6 kg sugar per

kg of pulp → Mix → Pour into bottles and seal → Heat pasteurize in bottles at 80–95 °C → Cool in cold water.

12.19.4 Flow Chart of Jam

Pulp → Mix 1 kg sugar and 10 g pectin per kg pulp and add → Heat mixture while stirring until the weight of pulp is reduced to half → Dissolve citric acid (5 g/kg) in water and add to pulp → Continue cooking until total sugar content is 68.50 % → Pour into jars and seal → Cool at room temperature

12.19.5 Flow Sheet RTS

Bael fruits (ripe) → Breaking of shell → Removal of pulp with seed and fiber → Addition of water (1:1) → Mixing of pulp with water → Passing through the pulper → Pulp → Mixing with syrup solution (sugar + water + acid) according to recipe → Homogenization → Addition of preservative → Bottling → Crown corking → Pasteurization → Cooling → Storage

12.20 Future Research Needs

Some of the research gaps have been identified which are as follows:

1. A wide range of genetic diversity is available throughout the country especially in the states of UP, Bihar, Uttarakhand, Jharkhand, Chhattisgarh, MP, Gujarat, etc. Existing elite genotypes need to be exploited for improvement.
2. Development of varieties which have less seed and fiber and have more TSS, vitamins, etc.
3. Emphasis should be given on postharvest technology to develop value-added and export-oriented processed products. Small-scale processing units should be established and promoted for commercialization of this fruit crop.
4. Screening of genotype for abiotic especially drought resistant and moisture stress and biotic stress is essential and characterized them for various agroclimatic conditions.
5. Development of integrated crop management strategies for sustainable fruit production of bael.
6. Development of suitable varieties for high-density orcharding.
7. Bael-based cropping systems and cropping models should be developed to provide stability in income to the farmers.

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