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The Bael
(Production Technology)

A. K. SINGH | SANJAY SINGH | P. L. SAROJ

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Authors
A. K. Singh
Sanjay Singh
P. L. Saroj

Technical Assistance
Bhoj Raj Khatri
M. K. Jain

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1. Introduction

Bael (*Aegle marmelos* Correa) is an important indigenous fruit of India and known since ancient times. It is grown in various parts of South East Asia including India, Sri Lanka, Pakistan, Burma, Bangladesh, Thailand etc. In India, bael is being grown throughout the country and is also known by other vernacular names like *bela, bili, bilva, belo, maredu, vilwam, sriphal*, golden apple, Indian quince and Bengal quince (John and Stevenson, 1979). Often, it is grown near temple of the Lord Shiva in India. As per Hindu customs, the leaves of the tree are considered sacred and offered to the Lord Shiva. The fruits form an essential ingredient of holy offering to the God and Goddess through holy pyre (*havan*). In the *Yajur Veda,* the mention of bael tree has been traced to Vedic times (C 2000 B.C.–C 800 B.C.). Mention of bael in *Yajur Veda* and also in early Buddhist and Jain literature (C 800 B.C. – C 325 B.C.), describing various methods of ripening of the bael fruit along with some other fruits was observed by Om Prakash (1961). During 'Ramayana' period, the bael fruit was known and its trees were reported to be growing in '*Chitrakuta*' hills and '*Panchvati*'. In the '*Upavana Vinod*' a Sanskrit treatise on silviculture (Majumdar, 1935) and in the '*Brihat Samhita*' mention had been made of bael fruit and as the legend goes, in the forest, the Lord Rama performed religious rites by offering various fruits including bael (Aiyer, 1956). Bael fruit has been portrayed in painting of Ajanta Caves along with other fruits (Om Prakash, 1961). Like many other species of Rutaceae family, bael also has fragrant flowers. It is believed that bael tree act as indicator plant for tracing of underground water (Singh and Roy, 1984).

It is a nutritious and medicinal fruit plant, which is most suitable to grow in water scarce areas of the country. Its fruit is rich in riboflavin, vitamin A, carbohydrate etc. Various chemical constituents' *viz*., alkaloids, coumarins and steroids have been isolated from different parts of bael plants. Bael is known as the panacea of the stomach ailments and marmelosin is probably the therapeutically bioactive compound of bael fruit (0.03-0.37%) which vary according to variety and locality (Dixit and Dutt, 1932). All parts of the tree, whether stem, bark, root, leaves, flower and fruit at different maturity stages has some use or the other. It is also used in the preparation of several *Ayurvedic* medicines since ancient times (Sharma *et al*., 2007). The pulp of ripe fruits is eaten fresh or in the form of *sharbat* and used for preparation of value added products such as jam, *murabba*, squash, powder, pickle, ice cream, slab, nectar, toffee, ice creame, etc.

The pulp diluted with water and added with requisite amount of sugar and tamarind, forms a delicious cooling drink. A firm jelly is made by combining pulp of bael with guava. The bael fruit toffee is prepared by combining the pulp with sugar, glucose, skimmed milk powder and hydrogenated fat. Green bael fruits are used for preparing *murabba* (preserve). The leaves, roots, flower, fruit and other parts are known to have medicinal properties especially for stomach disorders and improvement in digestive system. Besides an infusion of flowers as cooling drink, the fruit pulp dressed with palm sugar, eaten as breakfast, is a common practice in Indonesia. The green bael fruit slices often are dried and stored for future use (Singh and Roy, 1984). The cavity formed in fruit pulp are full of amber or honey coloured 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. The shell of the hard fruits is fashioned in to pill and snuff boxes, sometimes decorated with gold and silver. It is more abundant in young fruits. The stem also contains a gum similar to gum arabic. Being rutaceous plant, the leaves are mildly flavoured and hence chewed as mouth freshener.

Bael has enormous traditional uses against various disease and many bioactive compounds have been isolated from different part of tree. Different parts of the plant *viz.*, leaves, roots, stem, flower and fruit have been used in enthno medicine to exploit its therapeutic properties including astringent, antidiarrhoeal, antidycentric, antipyretic, antiulcer, antidiabetes, antibacterial, antiviral antifungal, anticancer, analgesic, redioprotective, because compounds purified from bael have been proven to be biologically active against several diseases. Crude extract from various parts of bael plant are used to treat various disorders in different Indian traditional systems (folklore medicine). Roots are used to cure cardiac malfunction, abdominal pain, fever, urinary trouble, hypochondriasis and melancholia; leaves are used as astringent, laxative, digestive and febrifuge while unripe fruit is helpful in curing dysentery and ripe fruit is used as astringent, appetizer, laxative, tonic, restorative and febrifuge (Kirtikar and Basu, 1935). Besides the fruits, the root is an ingredient of '*dasmula*' (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 heart. Root has also anti-amoebic and hypoglycemic properties. The leaves are bitter and used as febrifuge. Poultice made of leaves is used for ophthalimia and ulcers. Fresh leaves are also used as remedy for dropsy and beri-beri associated with weakness of heart. The astringent rind of ripe fruits and bark are employed in dyeing and tanning. The diluted leaf juice is used for catarrh. The alkaloid aegelin present in the leaves are efficacious in asthma. Utilization of bael fruit has been reported by Roy and Singh (1979 a).

Bael fruit is one of the most nutritious fruits. Analysis of the fruit gave 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). No other fruit has such a high content of riboflavin. Tannic acid is only phenolic substance detected from bael fruits. Analysis of the leaves gave the values (dry basis) like crude protein (15.13), ether extra (1.54), crude fibre (16.45), N-free extra (52.83), ash (14.05), calcium (5.93) and phosphorus (0.69) per cent. The seed yields oil 34.4% on dry basis and the fatty acid composition of oil includes; palmitic-16.6; stearic- 8.8; oleic-30.5; linoleic-30.0 and linolenic-8.1 per cent. Bael seed contains 62% protein and 3% each carbohydrate and ash. The fruit yields two per cent dried, water soluble gum. Hydrolysis of the gum gave galactose-20.4, arabinose-10.7, D-galacturonic acid-25.2 per cent and traces of rhamnose.

Several bioactive compounds have been isolated from various parts of the bael tree such as skimmianine, cineole, citral, citronellol aegelin, lupeol and marmesinin from bael leaves; marmelosin, luvangetin, aurapten psoralen marmelide from fruit; fagarine, marmin, auropotins, umbelliferone, lupeol and skimmianine from bark; auroptins, umbelliferone, marmin, lupeol and skimmianine, psoralen, xanthotoxin, scopoletin roots (Shoeb *et. al.* 1973). The bael fruit mucilage on hydrolysis shows the presence of three reducing sugars, galactose, arabinose and rhamnose.

2. Origin and Distribution

Bael is an indigenous tree of India and also found growing in neighboring countries namely Nepal, Sri Lanka, Malesia Pakistan, Bangladesh, Myanmar, Thailand and most of the South East Asian countries. Because of its status as sacred tree, it is also grown in north Malaya, the dry area of Java and to a limited extent in northern Luzol of Philippines and gardens of Egypt, Surinam and Thailand. In India, it is distributed throughout the country, but concentrated area under bael is in eastern parts of the Gangetic plains and nearby areas particularly in Uttar Pradesh, Bihar, Madhya Pradesh, Chhatisgarh, Jharkhand, and it can also be seen growing in West Bengal, Punjab and Odisha. In Gujarat, bael trees are found growing naturally in the forest with great diversity. Most of the genotypes available in forest areas of Gujarat having small size fruits (Singh *et al.,* 2008, 2012a & 2014a), but the plants growing in temple promise or in courtyard of house having big size fruits were brought by travelers, saints, pilgrims from north India (Fig.1).

Fig.1. A view of seedling bael bagh near Somnath Temple

3. Area and Production

There are no systematic plantations of bael trees in our country, now some systematic orchards of improved varieties are being established in the States of Rajasthan, Uttar Pradesh, Punjab and Gujarat; hence, exact data on acreage and production is not available. Generally, the bael plantations are made as boundary plants, premises of temples or in home gardens. Some seedling plantations are available in natural forest areas. However, in recent years, concerted efforts have been made for collection of elite genotypes of bael from all over the country and their evaluation and establishment of germplasm block at ICAR Institutes/ Regional stations and State Agricultural Universities. Some progressive farmers of Rajasthan, Uttar Pradesh, Madhya Pradesh, Punjab and Gujarat have started planting bael on large scale in the form of orchard or as boundry plantation (Fig. 2). As an estimate, about 1000 ha area is under plantation of improved variety of bael in country with about 10,000 tonnes of production.

Fig. 2 Boundary plantation of bael

4. Soil and Climate

Bael is bestowed with a natural gift to tolerate the extremes of high temperatures and during minimum soil moisture regime by shedding its leaves during summer. However, young plants need to be protected from the temperature below 4^0C and desiccating hot winds. It can thrive well in swampy, alkaline and stony soils having pH range from 5.0 to 10.00, where many other fruit trees fail to establish. It can also be successfully grown in saline, sodic and sandy wastelands provided the soil is treated with gypsum and pyrite before plantation. The extent of hardiness of bael plants under Thar desert have been observed that the plant even after being buried under sand for 2-3 months are capable of rejuvenating itself and can tolerate salinity up to 9 dsm^{-1}. However, well-drained sandy loam soil is ideally suitable for *bael* orchards. Bael plants can grow easily in wasteland and in sandy soils of arid ecosystem, having low fertility status and poor moisture holding capacity. Marked reductions in the contents of leaf NPK and Ca were observed in response to increase in salinity and sodicity levels 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. It has wide range of adaptability to adverse soil and climate. Owing to its hardy nature, it can be grown in wide range of soil *viz.*, sandy, clay, stony, acidic, alkaline, salt affected soils and wastelands *etc*.The bael tree grows successfully and produces higher yield in sub-tropical climate where summer is hot and winter is mild. In semi-arid and tropical regions, it can be successful grown under rainfed conditions. Under arid conditions of western part of Rajasthan, the leaves and tender parts of budded *bael* cultivars and young seedlings were severely affected by low temperature/frost during winter season (Saroj *et al.,* 2006).

5. Taxonomy, Botany and Morphology

5.1 Taxonomy

The genus *Aegle* belongs to the subfamily: Aurantioideae, family Rutaceae and order: Sapindale. Other members of Rutaceae are *Citrus, Casimiroa, Clausena, Eremocitrus, Limonia, Feroniella, Fortunella, Poncirus, Triphasia* etc. The generic name is of Greek origin and the species *marmelos* is of Portuguese origin. The chromosome number is x=9 and 2n=36. The tree is a medium to tall, deciduous, slow growing and 5-10 m in height. 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.

5.2 Botany

Seedling tree requires 7-8 years to produce flower while grafted one starts flowering at the age of 3 years. Bael tree flowers in April-June, fruit setting takes place by the end of May and continues till July. Time of flowering may vary according to agro-climatic condition and genetic makeup of varieties. The bisexual flowers are born in clusters and they are greenish

white, axillary or terminal cymes (Fig.3). The calyx is shallow with 4 or 5 short (tetramerous), broad teeth, pubescent outside. Petals are oblong oval, 4 or 5 in numbers and pale greenish white in colour. Stamens are numerous, hypogynous with short filaments. Ovary is oblong-ovoid, slightly tapering in to the thick, short style which is thickened upward; stigma capitate, deciduous multi celled (8-20), arranged in a circle with numerous ovules (1-5) in each cell. The style is open type having variable number of stylar canals depending on the number of carpels. The stigma is classified as wet stigma as it is covered by a sticky secretion at the time of pollination.

Goma Yashi NB-7

Fig. 3. Flower buds of Goma Yashi and NB-7

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, Singh *et. al.,* 2008 & 2011b). 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 semi-arid ecosystem (Singh *et. al.,* 2014e) which has been illustrated in table 1, 2 & 3. Floral biology of bael varieties and main pollinating agents has been reported by Singh *et al.* (2014b). The nectar secreting disc found beneath the ovary is main source of attraction for the insects (Srivastava and Singh, 2000). Singhal *et al.* (2011) reported that the diploid and tetraploid trees showed normal meiosis and high pollen fertility. Phenological events which included leaf fall, leaf emergence and floral bud break, flowering and fruiting are nearly the same in wild and cultivated trees (Singh *et al.,* 2011b & 2014d; Mishra *et al*., 1999 & 2000). Natural pollen transfer in the species was highly efficient. Levels of fruit set following open pollination were quite high and it is reduced considerably by following hand pollination probably due to injury caused to stigma during emasculation. In spite of synchronous nature of anther dehiscence and stigmatic receptivity, selfing in a flower is avoided due to herkogamy.

Table 1: Flowering behavior of bael varieties under hot semi-arid conditions

Genotypes	Flower bud emergence			Flowering period		
	Start	Peak period	End	Start	Peak period	End
CISHB-1	20April	24-29 May	16 June	22 May	8-12June	18 June
CISHB-2	30 April	23-28 May	20 June	24 May	7-14 June	22 June
NB-5	3May	24-29 May	22 June	26 May	10-15June	24 June
NB-7	2 May	25-30 May	15 June	22 May	7-12 June	16 June
NB-9	5 May	25-30 May	23 June	15 May	10-18June	24 June
NB-16	7 May	24-29 May	26 June	14May	10-20June	25June

Genotypes	Flower bud emergence			Flowering period		
	Start	Peak period	End	Start	Peak period	End
NB-17	30April	23-28 May	20 June	24 May	7-14 June	22 June
Pant Aparna	5 May	24-29 May	16 June	15 May	9-14 June	18 June
Pant Sujata	1May	25-30 May	15 June	22 May	7-12 June	16 June
Pant Shivani	2 May	25-29 May	20 June	23 May	10-15June	17 June
Pant Urvashi	8 May	25-30 May	23 June	15 May	10-18June	24 June
Goma Yashi	21April	16-23 May	19 June	12May	9-16 June	30 June
Thar Divya	1 April	2-9 May	09 June	12May	22-29 May	04 June
Thar Neelkanth	24 April	14-21 May	14 June	22May	5-11 June	27 June

Table 2: Morphomatrics of floral organs of different bael varieties

Genotypes	Flower size (mm)		Bud size (mm)		Petal size (mm)		Pedicel size (mm)	
	Length	Width	Length	Width	Length	Width	Length	Width
CISHB-1	14.00	35.00	11.00	7.00	15.00	7.00	07.50	2.00
CISHB-2	19.00	26.00	13.00	9.50	13.00	8.00	06.50	2.00
NB-5	14.15	29.00	11.50	8.00	18.00	7.50	10.50	2.50
NB-7	18.00	35.00	13.00	9.50	19.00	9.00	05.50	2.50
NB-9	12.00	25.00	11.00	8.00	11.00	7.00	04.00	2.00
NB-16	14.00	28.00	11.00	8.00	12.00	7.00	04.50	2.00
NB-17	18.00	34.00	13.00	9.50	18.00	9.00	05.00	2.50
Pant Aparna	16.00	30.00	10.00	9.00	18.00	10.00	10.00	2.50
Pant Sujata	15.15	29.00	12.50	8.00	17.00	7.50	09.50	2.50
Pant Shivani	15.00	30.00	11.00	7.50	18.50	8.00	09.50	2.00
Pant Urvashi	15.00	26.00	11.00	8.50	16.00	9.00	7.00	2.50
Goma Yashi	12.00	22.00	12.00	8.00	15.00	9.50	6.50	2.00
Thar Divya	15.12	25.00	11.50	7.50	14.50	7.00	8.00	2.20
Thar Neelkanth	15.00	30.00	11.00	7.75	10.23	8.00	10.00	1.50

Table 3: Floral morphology of different bael varieties under rainfed conditions of western India

Varieties	Type of Inflorescences	Flower colour	Flower characters	Number of sepals		Number of petals	
				C	R	C	R
CISHB-1	Axillary biparous cyme	Whitish green	Bracteolate, actinomorphic, imbricate	4,5	6	4,5	6
CISHB-2	Axillary biparous cyme	Greenish white	Bracteate, bracteolate, actinomorphic, quincuncial aestivation	4,5	6	4,5	6
NB-5	Terminally multiparous cyme	Light green	Bracteate, bracteolate, ctinomorphic, Imbricate aestivation	4,5	6	4,5	6
NB-6	Axillary multi parous cyme	Greenish white	Bracteate, bracteolate, ctinomorphic, Imbricate aestivation	4,5	6	4,5	6
NB-7	Axillary biparous cyme	Greenish white	Bracteate, bracteolate, actinomorphic, Imbricate aestivation	4,5	6	4,5	6
NB-9	Axillary uniparous cyme,	Whitish green	Bracteate, bracteolate, ctinomorphic, quincuncial aestivation	4,5	6	4,5	6
NB-16	Terminally mutiparous cyme	Greenish white	Bracteate, bracteolate , actinomorphic, quincuncial aestivation	4,5	6	4,5	6
NB-17	Axillary multiparous cyme,	Light green	Bracteate, bracteolate, actinomorphic, quincuncial aestivation	4,5	6	4,5	6
Pant Aparna	Axillary biparous cyme	Greenish white	Bracteolate, actinomorphic, imbricate aestivation	4,5	6	4,5	6
Pant Shivani	Terminally biparous cyme	Whitish green	Bracteate, bracteolate, actinomorphic, quincuncial aestivation	4,5	6	4,5	6
Pant Sujata	Axillary multiparous cyme	Greenish white	Bracteolate, actinomorphic, Imbricate aestivation	4,5	6	4,5	6
Pant Urvashi	Axillary biparous cyme	Greenish white	Bracteolate, actinomorphic, imbricate aestivation	4,5	6	4,5	6
Goma Yashi	Axillary multiparous cyme	Whitish green	Bracteolate, actinomorphic, quincuncial aestivation	4,5	6	4,5	6
Thar Divya	Compound cyme	Whitish green	Bracteolate, actinomorphic, quincuncial aestivation	4,5	6	4,5	6
Thar Neel kanth	Axillary receme	Whitish green	Bracteolate, actinomorphic, quincuncial aestivation	4,5	6	4,5	6

5.3 Flower Anthesis and Dehiscence

Bud emergence in all the varieties started at different time, but lasted from April to late June. The peak period of it was observed during 2nd fortnight of May in all the varieties. All the buds are globose, spheroid in shape in each variety and green in colour which commenced to full bloom from 13th May to 26th June among all the varieties. An early blooming was observed in (mid May) in the varieties CISHB-1, NB-16, Pant Urvashi and in Goma Yashi, the peak period started from 6th June to 11th June whereas rest of the varieties had blooming in between 20th May to 26th June with peak period started from 7th June to 18th June (Singh and Mishra, 2004 & Singh *et al.,* 2014e). The varieties which have long flowering period may serve as a long-term resource whereas flowering phenology of different cultivar affects reproductive success which allows the presence of a constant population of pollinators. Abnormal number of petals in flower may be observed in almost all genotypes. There were deviation in the time of initiation and termination of the anthesis which was observed between 5 to 8 A.M. among all the varieties of bael. It was observed early initiation (5.00A.M.) in the variety NB-7, NB-9, Pant Shivani and Pant Sujata. No flowers of any variety opened completely before 5 .00 A.M and followed specific time under semi-arid condition of western India. During anthesis flowers starts loosening their floral organs which later on blooms completely. Some flowers opened all petals at a time while other petals start opening one by one which takes 45 to 60 minutes in complete opening and also vary flower to flower. In the inflorescence, lower side bud opened earlier as compare to rest of buds localized centrally in all varieties, whereas varieties had anthesis vice versa where centrally located buds opened first as compare to lateral buds. After anthesis within half an hour, the anthers dehiscence started which continued between 5.45- 8.30 A.M. The pollens were coming outside by bursting the anther centrally by pore (Fig. 4). The anthers and floral organs shrunk and turn into brick red after dehiscence as time passed on. The findings regarding anthesis clarified that the anthesis and anther dehiscence in bael varieties took place early in the morning (5.30 -8.30 A.M.) where low temperature and high humidity prevailed (Srivastava and Singh, 2000).

Inkling of anthesis | Opening of petals | Complete anthesis

Fig. 4. Anthesis and dehiscence in bael variety Goma Yashi

5.4 Pollen Viability and Stigma Receptivity

In newly opened flowers of all the varieties, pollen viability is about 95 % or more in the different varieties (Singh *et al.,* 2014e). Stigma receptivity after anthesis was recorded the highest on same day within hour in all the varieties being the maximum in Pant Urvashi (68.53%) followed by Goma Yashi (65.19%) and it was least in NB-7 (45.27%), whereas it was recorded between 7.95-15.52 % and 3.62-14.37% one day before and after the anthesis, respectively which showed considerable difference in their values and had lesser percentage of stigma receptivity.

5.5 Pollination and Pollinating Agents

At the time of flower opening, large number of honey bees (*Apis dorsata*) and beetles, houseflies and butterflies less in number arrive and start the visiting the flowers for the foraging purpose and they directly enter on the central portion of the flower whether it is completely opened or just started to open due to which large number of pollens stick to their abdomen and legs (Fig.5). Effective pollination occurred through the honeybees, which visited the flower 5-23 times in one hour and carried highest number of pollen grains (29.65) than the rest of pollinators (Table 4). Honeybees have been recognized as ultimate and legitimate pollinators in many tropical trees (Seghieri *et al.,* 1995). They forage on bael flower only in the forenoon and honey bee is recognized as ultimate pollinators than others, because their presence was noticed in plenty and carried large number of pollen grains but the presence of other pollinators were less in number and carried less pollen grains owing to their foraging behavior and had less contact to the pollen grains (Singh *et al.,* 2014e and Singhal *et al.*, 2011).

Fig. 5. Different pollinating agents in bael

Table 4. Pollinators visits, pollen load carried and duration to bael flowers

Insects	Visitation Time	Number of visits/ flower	Duration of stay on flower (min)	Pollen load/insect
Honey bees	6-9 pm	5-23	1-5	29.65
Houseflies	6-9 pm	1-5	1-5	16.75
Beetles	6-9 pm	1-2	1-15	15.53
Butterflies	6-9 pm	2-7	1-5	09.00
Ants	6-9 pm	1-5	2-7	05.34

5.6 Morphology

Fig. 6. Variability in number of leaflet per leaf in different bael genotypes

A wide range of genetic variability with respect to plant morphology have been observed in different bael accessions. Considerable variations with respect to shape, margin, base and apex of leaf have been reported by Singh *et al.,* (2012e, 2014k and 2015a) Leaves alternate, compound, trifoliate with one pair of shortly stalked opposite showing pulvinus leaflet, ovate or ovate lanceolate, crenate, acuminate and membranous, and midrib prominent beneath. It has also been observed that in place of the leaflets (trifoliate), 4-8 leaflets are also found rarely in bael plant (Fig. 6).

Leaf character and growth pattern of bael have been reported by Mishra *et al.,* (1999). Nicotra *et al*. (2011) have also reported that the different leaf shapes can be found in association with variation in other leaf traits due to different climatic factors. There were significant differentiations in dorsal and ventral colour of leaflet and texture. Varieties *viz*., CISHB-1, Pant Sujata, NB-9 and NB-16 had dark green color at both the sides and shiny smooth excluding CISHB-1 which had dull, rough surface. The leaf colour in CISHB-2, Pant Aparna, NB-7 and Goma Yashi was dark green at dorsal surface and light green at ventral surface; texture dull papery in CISHB-2, rough in Pant Aparna, shiny smooth in NB-7 and dull smooth in Goma Yashi. Pant Urvashi and Pant Shivani had light green at both the sides and texture was shiny smooth and dull rough, respectively.

Similarly, bark morphology of different varieties/genotypes also varied to some extent. 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) was also observed by Singh *et al.,* 2009 .

Bael tree armed with straight, sharp, axillary thorns, 2-5 cm long. Considerable variation in thorn orientation, its number, size, shape is found in different genotypes (Fig. 7). In some genotypes thorn is small and stout, whereas in few genotypes, three thorns can be seen at a node. It can also be observed that the thorn convert into spines in pair. Generally, two thorns at a node are common. Goma Yashi is thornless under rainfed dryland conditions of western India (Singh *et al.,* 2011g). In some of the genotypes, thorn may be seen on primary branches but not at secondary or tertiary branches under dry land conditions. However, it may vary in different agro-climatic conditions.

Fig. 7. Variation in thorn pattern in genotypes under dryland condition

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 and undulating and in few genotypes it is following pattern as musk melon (Singh *et al.,* 2016n). 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 (Fig. 8).

Fig. 8. Variations in styler end cavity

Variation in morphological characters of fruit has been reported by Singh *et al.* (2011c, 2014j & 2016q) in germplasm collected from Central-East India. Locule arrangement was noticed scattered, centric and highly centric (Fig.9).

Pant Aparna: Scattered Goma Yashi: Centric Pant Sujata: Periferal

Fig. 9. Variations in locule arrangement

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 colour is white to yellow, medium to high fibre content and fine to thick in different germplasm (Fig. 10).

Goma Yashi: Hairy CISH-B-2: Non hairy NB-9: Less hairy

Fig. 10. Variations in seed morphology

6. Genetic Resources and Conservation

Existing biodiversity of bael in India can be grouped into two prominent categories *i.e.* one small fruit type, having bitter pulp with more seeds, mucilage and fiber content and second of large fruit type with thin shell, less seed, fibre and mucilage and more sweet pulp. The earlier type is generally used in ayurvedic preparation because of high marmelosin and psoralen content while the second type is generally used as dessert fruit and for preparation of processed products. Diverse germplasm of bael has been widely collected from various states of India *viz.,* Uttar Pradesh, Bihar, Gujarat, Haryana, Madhya Pradesh and West Bengal by NDUAT, Faizabad, CHES, Godhra (CIAH, Bikaner), CISH, Lucknow, CCSHAU, Regional Research Station, Bawal, CAZRI, Jodhpur; Jharkhand (Pandey *et al.,* 2008a), Bihar (Rai *et al*., 1991); Uttar Pradesh and Madhya Pradesh (Pandey *et al.,* 2005&2008b); Rajasthan (Saroj *et al.,* 2008) and Gujarat (Singh *et al.*, 2014a & 2018). Growth behavior of bael varieties has been reported by Singh *et al.* (2008, 2010a & 2016j). Characterization of bael genotypes has been undertaken at CHES, Godhra under rainfed hot semi-arid environment of Gujarat (Singh *et al.*, 2011b) (Fig. 11).

Fig. 11. Fruit variability in bael germplasm (shape, size and surface texture)

Different genotypes of bael showed wide variations with respect to vegetative characters (Rai *et al.,* 1991, Singh *et al.,* 2012e, 2014b & 2015e). Singh *et al.* (2015) have also reported variability among the genotypes collected from Rajasthan. The yield and yield attributing traits of fruit of different genotypes *viz*., fruit yield (40.50- 69.29 kg), fruit weight (0.43-4.25 kg), length (10.61-19.59 cm), width (9.40-22.00 cm) and fruit girth (29.10-70.00 cm) also showed considerable variations.Physical composition of bael fruit exhibited wide variation in their shell weight (115.25- 560.05g), shell thickness (0.16-0.31cm), number of seed/fruit (90.34-212.25), total fresh seed weight (17.34-43.41 g), number of seed sacs (10.23-19.17), fibre weight (15.91-106.50g) and pulp weight/fruit (0.27-3.67 kg). The qualitative characters of fruit in terms of TSS mucilage, TSS pulp, total sugar, reducing sugar, non reducing sugar, 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 (Singh *et al.* 2011c, 2014d and 2016m and Sharma *et al.,* 2013). Bael varieties varied in their leaf characters

(Singh *et al,* 2015a). Germplasm exhibits variability in growth and maturity. Diversity of bael germplasm based on morphological characteristics of the fruit has been reported by Singh *et al.,* (2015a) and Rai and Misra (2005). 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 value was 183.69 ± 2.41 mg KOH/g, acid value was 19.05 ± 0.09 mg KOH/g and peroxide value is absent in oil analyzed. The seed oil was found to contain predominantly in the composition of unsaturated fatty acids *viz.,* linoleic acid (2452.06 ppm), oleic acid (961.52 ppm) and linolenic acid (37.55 ppm) (Bajaniya *et al*., 2015).

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 (Rai *et al.,* 2002). The genotypes were grouped into 3 clusters which included one solitary group (PB-3). The clustering pattern of genotypes was random and not parallel to geographic distribution. The characters *viz;* ascorbic acid content, fruit weight, fruit length, number and weight of seed per fruit, fibre content, petiole length contributed the maximum in genetic divergence. These characters may be used in selecting diverse parents in hybridization and intercrossing between clusters to develop superior clones of bael with most desirable traits (Rai and Mishra, 2005).

Genetic resources of bael are conserved at various field gene banks of ICAR institutes and State Agricultural Universities. Various collections are maintained at CCSHAU, Regional Research Station, Bawal (10), NDUAT, Faizabad (22), CIAH, Bikaner (21), CISH, Lucknow (44), GBPUAT, Pantnagar (10), CAZRI, Jodhpur (5) and at CHES, Godhra (190) (Fig 12).

Fig. 12. Block plantation at CHES, Godhra

7. Varietal Wealth

Among local types, Ayodhya, Kagzi, Etawah, Gonda and Mirzapuri bael were popular in Uttar Pradesh due to their good yield potential and quality fruits. In recent past, some promising varieties of bael have been developed through clonal selection at ICAR Institutes and Agricultural Universities (Table 5).

Table 5: Improved bael varieties developed in India

Varieties	Organizations involved in the development
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-1and 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 (Godhra), Gujarat

The description of varieties of bael under dryland conditions of semi-arid and arid region is given below:


NB-5: Growth habit is semi-spreading, precocious and prolific in bearing but fruit size uneven. The fruits are medium in size (12.50 cm X 11.50 cm), round with smooth surface and very thin rind (0.16-0.17cm), straw yellow at maturity, low in mucilage, moderately fibrous, light yellow pulp with low seed content. Pulp is soft, excellent in taste (33^0Brix) flavour and ascorbic acid 18.63 mg/100g of edible portion (Singh *et al.,* 2012c & 2013a). The average fruit weight is 700–1300 g and average yield is 54 kg fruits/ tree during 8^{th} year under semi-arid conditions.


NB-9: The plants are semi-vigorous and spreading having compact canopy. The plants of this variety are of medium height (4-7m) having compact canopy. The variety is precocious and prolific bearer. The average fruit yield of a eight-year old plant is 69 kg. Fruits are medium to large in size (16.00 cm x 13.50cm), roundish-oblong with smooth surface and thick rind (0.24cm), light yellow at maturity, average in mucilage, moderately fibrous, slightly golden-yellow pulp with low seed content. The fruits are good to taste containing 38^0 Brix total soluble solids in pulp, 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 post harvest products. Its keeping quality for storage is very good (Singh *et al*., 2011f).

NB-7: Spreading growth habit with semi compact foliage, trunk colour grey with splitting of bark in rectangular manner, leaf medium sized, lanceolate, colour green with smooth surface, non-wavy margin. Plants are tall and semi-spreading. They are sparse in bearing with large size


fruit. The fruits are large in size (18.25cm x 22.50 cm), round and with smooth surface and very thick rind, yellow at maturity, low in mucilage and fiber, attractive yellow pulp, with low seed content. Fruits are good in taste (30^0 Brix) and flavour and having 19.78 mg/100 g ascorbic acid. The average yield of plant is 54.34 kg fruits/tree during 8^{th} year. It is highly suitable for processing. Fruit does not ripe uniformly (Singh *et al.,* 2013b & 2014c).

NB-16: The plants are erect in growth habit, precocious in bearing. The budded plants start fruiting in the 3^{th} year. The average fruit yield of eight-year old plant is 52.40 kg. The fruits are small in size (12.50 cm X 10.00 cm), round, with smooth surface and very thick rind (0.35cm), straw yellow at maturity, low in mucilage, and moderately fibrous, yellow pulp with high seed content. Fruit pulp is of excellent taste (36^0Brix) and flavor and ascorbic acid 17.61 mg/100g of edible portion. The fruit weight ranged from 750-800gand rind is very thick. It is highly suitable for powder making (Singh *et al*., 2013a & 2011f).


NB-17: The plants are erect having semi-spreading growth habit. It is moderate and sparse in bearing. The budded plants start fruiting in the 4^{th} year. The average fruit yield of eight-year old plant is 51.39 kg. The fruits are slightly large in size (20.00 cm X 15.50 cm), round, with smooth surface and very thin rind (0.24cm), straw yellow at maturity, low in mucilage, moderately fibrous and an attractive yellow pulp with low seed content. Taste of pulp is excellent (34^0Brix) and ascorbic acid 19.63 mg/100g of edible portion. The fruit weight ranged from 1.65-1.8 kg. It can be used for both table purpose and processing (Singh *et al*., 2014c).


Pant Aparna: Its trees are dwarf with drooping foliage, almost thorn-less, precocious and heavy-bearer. The leaves are large, dark green and pear shaped. Fruit has globose shape with average size of fruit 13.00 cm x 12.00 cm and weight of 0.8-1.25 kg. Flesh yellow, sweet, tasty and having good flavor rind. Fruit pulp is yellow and rind is thin. TSS 35%, titratable acidity 0.67% and ascorbic acid 17.15 mg/100 g of pulp. Mucilage, seed and fibre are low. Mucilage and seeds are enclosed in separate segments. Flavour and taste are very good. Yield during 8^{th} year is 61.06 kg/ plant (Singh *et al*., 2014c).

Pant Shivani: It is an early mid-season variety. Trees are tall, vigorous, dense, upright growth, precocious and heavy-bearer. Fruit shape is ovoid, oblong and the size being 18.50 cm x 15.00 cm. Fruit weight ranges from 1.5 to 2.0 kg. Colour of fruit is lemon-yellow and its storage quality is good. Rind is medium-thin, pulp is lemon-yellow with pleasant flavour and mucilage, seeds and fibre are low to medium. Taste is very good having 69% pulp, TSS 36^0 Brix, total titratable acidity 0.47% and ascorbic acid 19.55 mg/100 g of flesh (Singh *et al.,* 2011f). Average yield is 49.12 kg/plant during 7th year.

Pant Sujata: It is mid-season variety but has problem of fruit splitting. Trees are medium-dwarf with drooping and spreading foliage, dense, precocious and heavy bearer. Thorns are stout and bigger. Fruit is globose shaped, depressed at both ends with average size of 14.50 cm x 13.50 cm and weight varied from 1.12 to1.70 kg under rainfed condition of hot semi-arid ecosystem of western India. Fruit and pulp are light yellow. Storage life is better, thin rind, and seeds, mucilage and fibre is low. Its flavour is pleasant and taste is very good. Flesh is 72%, TSS 32^0 Brix, acidity 0.44% and ascorbic acid 17.10 mg/100 g of flesh. Average yield is 65.57 kg/plant during 8th year (Singh *et al.,* 2013a).

Pant Urvashi: It is an early mid-season variety. Trees are tall, vigorous, dense, upright growing, precocious and heavy bearer. Fruit is ovoid-oblong with average size of 14.50 cm x 17.20 cm and fruit weight ranges 1.5-2.50 kg. Fruit is yellow, rind is medium to thin and pulp is light yellow. Fruit has 62.35% pulp with pleasant flavour. Seeds and mucilage are medium, fibre content low, TSS 33^0 Brix, titratable acidity 0.49% and ascorbic acid 17.15 mg/100g pulp. Average yield is 60.15 kg/ plant during 8th year (Singh *et al*., 2017, Singh *et al.,* 2016b, 2017a&b).

CISH-B-1: It is early maturing variety. The plants are semi-tall and having spreading growth habit. The budded plants start fruiting in the 4th year. The fruits are small to medium in size (16.50 cm x 12.00 cm), oval-oblong, with smooth surface, yellow at maturity, low in mucilage and fibrous, an attractive yellow pulp with high seed content. Excellent in taste and flavour, the fruits have 30-34^0 Brix total soluble solids in pulp and 43^0 Brix in mucilage. The fruit weight varies from 0.8 to 1.40 kg with average yield 67.00kg/plant during 8th year (Pandey and Mishra, 2015 and Singh *et al.,* 2016b, 2017 a & b).


CISH-B-2: The average fruit yield of 8th year old plant is 56.78 kg. The fruits are medium in size (16.00 cm x 14.00 cm), rounded with smooth surface, yellow at maturity and the rind is thick, low in mucilage and fibrous, light yellow pulp with low seed content. Good in taste and flavour, the fruits have 31^0 Brix total soluble solids and titratable acidity (0.41%). The fruit weight ranges from 1.7 to 2.6 kg/fruit. Fruit does not ripe uniformly under natural condition. It is good for processing (Pandey and Mishra, 2015).


Goma Yashi: Yield 65.45 kg/plant during 8th year, fruit weight 1.00-1.62 kg, fruit size 13.00 cm x 12.50 cm, fruit girth 41- 45 cm, shell thickness 0.15cm, seed weight 25.37-32. 50g, fibre weight 40.24-51.20 g, shell weight 180-210g, locules in cross section 13-15, pulp 68.00-72.25%, TSS pulp $35\text{-}39^0$B, TSS mucilage $41\text{-}43^0$B, acidity (0.29-0.34%) and vitamin C 19.00-22.00 mg / 100 g pulp. This variety matures during March and belongs to early maturing group under semi-arid ecosystem (Singh *et al.,*2011a, 2011b, 2015d, 2016c, 2016d & 2016i).It possess high qualitative attributes like papery shell, very less fibre and mucilage and attractive pulp colour with pleasant aroma . It is highly suitable for *sharbet*, squash, candy and *murabba* making. Because of dwarf stature, it is highly suitable for high density planting (5mx5m).


Thar Divya: It starts ripening after 270 days of fruit setting under rainfed conditions of hot semi-arid ecosystem. Fruits of this variety are comparatively less affected (40%) by sunscald due dense canopy and luxuriant growth. The average yield/tree (kg) during 8th year, fruit weight (kg), fruit size (cm), fruit girth(cm), shell thickness (cm), number of locules in cross section (seed cavity), peel weight (g), pulp weight (kg), fibre weight (g), seed weight(g), total seed weight (g), total number of seed, TSS of pulp (°brix), TSS of mucilage (°brix), acidity (%),TSS/acidity ratio are 7.50, 1.62, 18.60x14.80, 45.80, 0.19, 14.72, 235.50, 1.30, 61.10, 0.13, 32.00, 120.75, 38.50, 51.00, 0.30 and 128.33, respectively. This variety matures during February and belongs to very early maturing group and can be grown successfully under rainfed semi-arid ecosystem (Singh *et al.,* 2015b, 2015c, 2014i, 2016c, 2016i, 2016k & 2016o).

Thar Neelkanth: It is a superior genotype having compact growth, medium height, less spiny, better yield with quality fruits having pleasant flavour and attractive colour of pulp. It started flowering and fruiting from 3rd year of budding. Average yield per plant 75.67 kg (8th year), average fruit weight 1.45 kg, fruit size 15.10 cm x 15.00 cm, fruit girth 47.30 cm, shell


thickness 0.18cm, total number of seed 73, seed weight 0.21g, total seed weight 15.46g, fibre weight 110.17 g, shell weight 265.00g, locules in cross section 13-16, pulp 71.30%, TSS pulp 40.10^{0}B, TSS mucilage 51.50^{0}B, acidity (0.30%) and vitamin C 19.90 mg / 100 g pulp were recorded. The fruit of this genotype is having good flavour and aroma. It is highly suitable in draught prone dry land conditions and also suitable for shsrbet, powder candy and squash making (Singh *et. al.,* 2012d, 2016c, 2016f, 2016g, 2016 l).

Other Promising Genotypes of Bael

CHESB-11: It is identified promising based on horticultural traits at CHES, Godhra. Average yield per plant 84.10 kg in 8th year, fruit weight 1.48 kg, fruit size 14.10 cm x 15.20 cm, fruit girth 44.21 cm, shell thickness 0.14 cm, total number of seed 75, seed weight 0.20g, total seed weight 17.58g, fibre weight 25.60 g, shell weight 200.20g, locules in cross section 14-17, TSS pulp 38.13^{0}B, TSS mucilage 49.80^{0}B, acidity (0.29%) and vitamin C 22.83 mg / 100 g pulp were recorded. It is medium maturing variety (1st week of May). It is rich in antioxidants activity. The fruits of this genotype are having good flavour and aroma. It is highly suitable for sherbet; murabba and powder making.


CHESB-16: It is identified promising based on horticultural traits, which were collected from Vidyanagar during 2011. Average yield per plant 74.20 kg in 8th year, fruit weight ranged between 0.9- 1.20 kg, fruit size 15.50 cm x 11.40 cm, fruit girth 42.20 cm, shell thickness 0.20 cm, total number of seed 98.14, seed weight 0.19g, total seed weight 19.51g, fibre weight 31.42 g, shell weight 185.20g, locules in cross section 14-16, TSS pulp 37.13^{0}B, TSS mucilage 48.75^{0}B, acidity (0.34%) and vitamin C 20.80 mg/100g pulp were recorded. Growth habit is drooping. It is late maturing variety (3rd week of May). It is rich in antioxidants activity CUPRAC (micro M TE/g) was recorded 127.87 in mucilage and 90.87 in fruit pulp. The fruits of this genotype are having good flavour and aroma. It is highly suitable for RTS, candy, murabba and powder making.

CHESB-21: It was collected from bael bagh near Somnath temple Gujarat during the year 1012. Average yield per plant 62.57 kg in 7th year, fruit weight ranged between 1.25-1.50 kg, fruit size 21.200 cm x 13.40 cm, fruit girth 43.78 cm, shell thickness 0.21 cm, total number of seed 104.15, seed weight 0.20g, total seed weight 20.51g, fibre weight 40.42 g, shell weight

205.10g, locules in cross section 14-16, TSS pulp 39.15^{0}B, TSS mucilage 50.50^{0}B, acidity (0.37%) and vitamin C20.80 mg/100g pulp were recorded. It is late maturing variety (1st week of May).The fruits of this genotype are having good flavour and aroma. It is highly suitable for pickle, sherbet; candy, jam and powder making.

8. Plant Propagation

Traditionally bael was propagated by seeds. However, there is an inherent limitation associated with the seedling progenies and generally they are not true to type and hence, seed propagation is limited for the raising of rootstock only. True to type planting materials can be produced through vegetative means only. Among the vegetative propagation techniques; budding, grafting, layering and root suckers were common methods of multiplication of bael. Now-a-days, patch budding and soft wood grafting is being adopted commercially for multiplication of bael.

8.1 Seed Propagation

The bael seed has no dormancy; hence fresh seeds can be sown 2-3 cm deep in the nursery within 10-15 days after extraction. The fresh bael seeds germinate in 8-15 days after sowing during summer. Since, bael belongs to recalcitrant category; the seeds cannot be stored for longer periods under normal storage conditions. The seedlings become ready for transplanting in spring or next Monsoon. If the seeds are sown too deep, seedling emergence is delayed and there may be chance of rotting due to poor aeration. The orchard raised by seedlings is not true to type and exhibits variability. Sometimes seeds germinate while fruits are kept on tree for longer duration after ripening of tree (vivipary). To prevent the losses due to 'damping off' at nursery stage, seed treatment is essential. Seed treatment with Thiram or Captan (1:400) can be done effectively. Seed germination and seedling growth were influenced by sodic soils. Delayed and poor seed germination and reduced plant growth were observed in response to increased sodicity. Sodicity adversely affects the seed germination and seedling growth.

8.1.1 Raising of Rootstocks in Nursery

Generally, the freshly extracted seeds are used for sowing, however, if required these can be stored up to 132 days with proper treatment. For storage, three days after extraction, the seeds should be treated with fungicides such as Thiram or Captan (1: 400) and stored in alkathene bags at room temperature. For better germination, higher survival and establishment, well rotten FYM should be mixed with the soil before sowing of seeds in polythene bags (Fig. 13). For

Fig. 13. Raising of rootstocks in polythene bags

nursery raising after fungicidal treatment seeds can be sown in 2 cm depth in the nursery within 10-15 days of extraction in raised beds. Seeds may also be sown in polythene bags with ratio of soil, FYM and sand (2:1:1) as it facilitates an easy handling of rootstocks and grafted plants. Young seedlings should be protected from frost during winter under arid ecosystem and from intense radiation in rainfed semi-arid condition. Performance of bael with respect to seed germination and plant growth was observed satisfactory in sodic soils up to 29.0 ESP without application of any chemical amendments. The foliar sprays of plant biological 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) improves seedling vigour by means of improved growth of stem and roots (Mishra and Jaiswal, 2001).

8.2 Vegetative Propagation

8.2.1 Selection of Mother Plant

Utmost care should be taken while selection of the elite mother plants of bael cultivars. For selecting mother plants of *bael*, following basic characteristics needs to be considered – (i) Plants should be consistently high yielding (ii) Quality of fruit should be very good with all desired traits (iii) Plant should be free from diseases and pests (iv) It should be in full bearing stage.

8.2.2 Detopping and Promotion of Scion Shoot in Mother Plant

Under dryland condition, leaf senescence initiated from January and leaf fall starts from March in early varieties while March–April in late varieties. Leaf initiation starts after 15-25 days after leaf fall which varied in different varieties (Fig. 14). It is very difficult to get scion shoot during May-June under dryland conditions, some thumb size branches of mother plant are cut during March. Number of new shoots emerges below the cut portion. These shoots are used for budding purposes. For accelerated growth of shoot, plants should be irrigated after one week after cutting of branches, whereas for softwood grafting one season old shoots are used when plant starts putting forth new leaves (Singh *et al.,* 2014h). Under dryland condition, mother plant should be irrigated one day before separation of scion shoots for budding for better success and survival.

Fig. 14. Promotion of scion shoots

8.2.3 Selection of Bud Wood

Bud wood becomes available during the active growth period in rainy season. The buds stick (1months old) with well swollen and recently matured buds (but still not open) are collected. Immature and undeveloped buds from the upper part of the new shoots are not suitable. Similarly, over mature and inactive buds should not be used. The active growth period is indicated by easy and clear separation of the bark

Fig. 15. Selected scion shoots

from the wood of scion sticks (Fig.15).After collection, the bud wood is often stored for some period or takes same time in transportation. During this period, considerable loss of survivability may take place. Bud woods retain good survival when kept under ventilated shade and wrapped in moist jute cloth.

8.2.4 Patch Budding

In this method, a healthy bud is selected from the axils of leaf. Leaf blade is removed with the help of a sharp knife leaving petiole intact. The upper cut is given about 1-1.5 cm above bud which goes downwards up to 1.0-1.5 cm below the bud without wood portion and then lower cut is given about 1.0 cm below the bud. The similar rectangle incision is made on the rootstock by placing the bud on the root stocks to mark the exact size of the bud on them and after removing the bark of root stock, the bud is placed at the juncture. The bud is pressed by hand to remove open space if any and tied tightly except the place of bud 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 to sprout. After union, the top of the rootstock is cut a little above the bud union and polythene strips are removed carefully. Time of budding influences the survival of plant in the different varieties. Kumar *et al*. (1994) reported the effect of duration and method of budding in bael. For faster multiplication, seed shown in the month of March (1stweek) can be used for budding, but it requires skill because both scion and rootstocks are delicate. This method is very useful for transportation of sapling to distant places (Singh *et al.*, 2012d & 2014h). Patch budding and softwood grafting was found successful when performed in the month of May- June (before onset of rain) under rainfed semi-arid conditions of Gujarat. In India, patch, forkert and shield methods of budding are generally employed for multiplication of bael. 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%, respectively. For getting better success and survival of plant, patch budding may be practised in the month of May-June for multiplication of bael genotypes for establishment of orchards under dryland conditions. Budding in bael in June-Budding in July from one month old scion gave 80 per cent success and patch budding is an ideal method of bael multiplication (Singh *et al.*, 2014h and Kumar *et al*., 1994).

Precaution in budding

- The contact between stock and scion should be very fine and there should not be any gap between them as it adversely affects the budding success.
- The bud union should be properly tied with polythene band, so that the rain water could not enter in the gap. Rain plays a negative role and creates hindrance for perfect union, through seeping the water in between stock and scion.

- Avoid splitting of bark during separation of bud from scion shoots to ensure better success.
- Scion shoots should be selected from healthy plants having better fruiting record so as to evade the infestation of pests and diseases during the establishment of orchard and also ensure the better productivity.
- Sprouts emerging from the rootstock should be removed except the budded one at periodical interval to promote the scion shoots growth.
- Size of bark of patch containing bud should properly be matched with the cut portion of the bark on the root stocks for perfect and quick union.
- Polythene strip should not be removed unless it is ensured that scion shoots has started growing.
- *In-situ* grafting, mulching of basin soil should be done regularly to avoid moisture loss through evaporation and also to fill up the cracks developed in basin by spading under dryland condition for better survival.
- Weeding should be done regularly for better growth of saplings in nursery.
- Newly emerging shoots are often damaged by leaf eating caterpillars and hence, the management of the pest should be done using sprays of dimethoate @1.5 ml/l twice at 15 days interval.

8.2.5 Soft Wood Grafting

About 15-20 cm long mature shoots (4-6 months old) when plants are completely shed their leaves or new shoots (2-3 months old) which are are defoliated 10-12 days prior to grafting operation, used for soft wood grafting. These shoots are detached from the mother plant with the help of secateurs or sharp grafting knife for grafting by cleft method. For this, seedling rootstock is cut at 20-25 cm height and the top portion is removed. With the help of knife, 5 cm long vertical downward incision is made in the center of the rootstock. A sharp cut of 5 cm is made on both the sides on the base of the scion shoot to make wedge shape. Thereafter, prepared scion is carefully inserted in vertical slit of the rootstock and tightly secured with the help of 200 gauge thick and 2 cm wide polythene strips. The polythene strips should be removed carefully after completion of the union. Under dryland condition of Godhra, softwood grafting during May- June has been found successful with more than 85 per cent success in bael under semi-arid ecosystem of western India.

8.2.6 Other methods of vegetative propagation

Bael can be multiplied through inarching, cutting, root sucker (Fig. 40) layering and stooling, but the success and survival is comparatively less than budding and grafting. For uniform production of rootstocks, stooling with application of 5000 ppm IBA can be applied for better success (Fig.41). However, success after separation with mother plant is less (30%) under dryland conditions.

8.2.7 Micro Propagation

Recently, micro-propagation techniques have also been found successful in bael. True to type and disease free plants can be generated from very small piece of plant in aseptic condition in artificial growing medium rapidly throughout the year. Regeneration from nucellus (Hossein *et. al.,* 1993), leaf (Islam *et al.,* 1993) and excised cotyledon (Islam *et. al*., 1994,) has been reported. Multiplication of shoots can be done by using micro shoots. Arumugam and Rao (1996) reported that cotyledonary node explants excised from 15-days old seedlings of bael were placed in MS medium supplemented with BAP [benzyladenine], IBA IAA or NAA. BAP induced the best production of multiple shoots and subsequent plant regeneration. The highest number of shoots (75.2/explants) was observed on MS medium supplemented with BAP at 3mg/l. The number of shoots was further enhanced by i) using nodal explants of in-vitro regenerated shoots as micro-cutting, and ii) repeated subculture of original explants on the same medium after excising the shoots. Several shoots were obtained from single explants within 5 months. Regenerated shoots produced roots in 30 per cent subcultures and transferred to a medium containing IBA at 4 mg. Plantlets were transferred to soil, acclimatized and transplanted to field. Callus of *Aegle marmelos* was initiated from the stem explants on MS medium supplemented with different concentrations of kinetin, 2, 4-D and NAA. Meristemoids developed in the callus when subcultured on medium supplemented with 1 mg kinetin+ 5mg NAA l^{-1}. In presence of IBA, alone or in combination with NAA, this callus showed shoot development. Multiple shoot induction from nodal explants was achieved on MS medium augmented with different concentrations of BA, kinetin and NAA. The shoot bud that developed from nodal explants was most numerous in medium supplemented with kinetin and NAA. 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 0.1mg IBA $litre^{-1}$ (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, the 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). Kumar and Seeni (1988) reported that clonal propagation through *in-vitro* axillary shoot proliferation of *Aegle marmelos*. A protocol for organogenesis from nucellar explants excised from fertilized ovules of immature fruits was developed. Adventitious buds were initiated on MS medium containing various combinations BA, NAA, IAA and gibberellic acid. Medium containing 4.4µM BA and 2.7 µM NAA produced the greatest number of adventitious roots per explants. Shoots were elongated by transferring explants with shoot buds to medium with low concentration of BA (0.44 µM).

8.3 Care of Nursery Plants

Bael plants at nursery stage are likely to be damaged by frost under north Indian conditions and by scorching sun and hot desiccating wind under hot semi-arid ecosystem of western India. So, the nursery beds should be covered with thatches made of *sarkanda*, shaded net etc. The beds

should be irrigated whenever frost is expected. During summer, the irrigation should be given at 4-5 day intervals depending upon agro-climatic condition. In western India, plants should be irrigated in the morning and evening and should be protected from shaded net to protect the plants from direct sunlight and wind. A light application of Calcium Ammonium Nitrate or Ammonium sulphate is also recommended to encourage the growth of plants.Weeding should be done properly and timely so that plant could not compete of nutrient during active growth period. The beds/ poly bags should be kept free from weeds by regular weeding/hoeing.

Proper care is needed to protect the nursery plants from insect pest and disease also. Spraying with dimethoate 1.5ml/ l should be applied as and when required. After grafting or budding proper care should be taken, bud union should not be dipped in water at any cost; otherwise success percentage will be affected. During rainy season, polythene bag should be shifted so that plant could establish properly owing to breakage of roots penetrated beyond the polythene bags while shifting. If rain is delayed after shifting, plant should be irrigated for better survival.

8.4 Top Working

The old and uneconomic bael tree can be turned into an economic and vigorous one by top working. In this method, bael trees should be cut back to 3-4 feet from the ground in month of March and new healthy shoots arising from the stump should be allowed for further growth. Patch budding on these shoots should be performed with scion of improved varieties in the end of May. Such trees come in fruiting within three to four years after budding.

9. Agro-techniques

9.1 Orchard Establishment

The land should be prepared by usual ploughing, harrowing and leveling. There should be gentle slope to facilitate 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 wind breaks around the orchard should be planted to 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.

9.2 Planting

The pits of 1m x 1m x 1m are dug and exposed for solarization to kill harmful soil organisms, providing better aeration in the future rooting zone and making provision for the nutritional

requirement for healthy development of plants. The pits are filled with top soil mixed with 20-25 kg FYM after drenching with chlorpyriphos @ 3ml/ litre to avoid the attack of termite during early phase of the plant growth. In black cotton soil, sand should be mixed with FYM and top soil to provide proper aeration. The ideal time of planting under rainfed condition is June just after first rain in monsoon. The planting of bael is done at spacing of 5m to 8m depending upon the variety and agro-climatic conditions. Under rainfed condition of hot semi-arid ecosystem, planting of vegetatively propagated plants of dwarf varieties especially Goma Yashi can be done at 5m x 5m spacing to maximize the productivity. Based on vegetative growth habit of different varieties under rainfed hot semi-arid conditions, Thar Divya, NB-7, Pant Urvashi, Pant Sujata, CISHB-1, CISHB-2 should be planted at 8mx8m; NB-9, NB-17, NB-16 at 8m x 6m: Pant Aparna, Thar Neelkanth at 6mx6m (Fig. 16).

Fig. 16. Organized orchard of bael under dryland conditions

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 wind break. Planting of the bael at 6 m x 6 m in square system and at 5m x7 m in rectangle system has been recommended by Singh and Nath (1999). The main objective to follow particular 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 but not properly tried in case of bael.

9.3 High density planting

Fig 17. High density plantation of Goma Yash: (5mx5m) at CHES, Godhra, Gujarat

The land area under cultivation is shrinking due to urbanization, fragmentation of land holding and industrialization. In such circumstances, the concept of high density planting has become the need of hour to fulfil the fruit requirement to the people of the country. High density planting not only provide high production during initial stage of bearing but also ensures better utilization of resources like land, labour, fertilizers, solar radiation, pesticides and management of weed, which ultimately leads to higher net returns. High density planting by adopting suitable planting systems has been viewed as successful in many fruit trees. Considering the soil condition, planting geometry and manipulation in the spacing are the important approaches in obtaining higher productivity per unit area.

Basic approaches of high density planting are the availability of dwarfing rootstocks/ inter tocks, cultivar and with the use of growth regulators. However, closer spacing, growth regulation by training and pruning, use of mechanical device may be tried for successful adoption of the concept of high density planting in bael. At CHES Godhra, work for the evaluation of high density planting (4mx4m, 6mx4m, 8mx6m, 6mx6m) has been initiated with variety Goma Yashi which is released by the Station recently. However, this variety has been recommended for commercial cultivation at the spacing of 5m x 5m under dryland conditions (Singh *et al.,* 2017b) (Fig. 17).

9.4 Training

Basically, training is a potential tool to manage the canopy architecture of the plant particularly in high density orcharding. In order to avoid difficulty in intercultural operation, and to develop proper framework, the branches are not allowed to develop below 0.6 m from the ground level. Young plants should be allowed with 4 - 6 well spaced branches in all direction to develop into the main scaffold structure of the tree. Young plants are trained with the help of stake, if needed so that they can grow erect. Suckers appearing from root stocks should be removed. In order to provide good frame work of individual tree, it is essential not to allow lateral branches near to the ground on trunk.

9.5 Pruning

Generally, bael plant is not pruned once 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. During early stage of orchard life, pruning of growing branches becomes necessary particularly when orchard has been established under high density planting system. Pruning of 75 per cent annual growth during leafless stage is found to beneficial to encourage the emergence of new shoots to develop dense canopy to avoid sun scald especially under dryland conditions. However, dried, criss-cross, weak and diseased branches should be removed as and when required. It will facilitate easy harvesting of the fruits.

9.6 Canopy Management

Canopy management of the crop deals with the development and maintenance of their structure in relation to the size and shape for maximization of 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 fact, as how best we manipulate the tree vigour and maximum use of available sunlight and temperature to increase the productivity and minimize the adverse effect of weather. Pruning in bael is done to improve and regulate tree size and shape to achieve desired architecture of the canopy and also to reduce foliage density by removing branches of the tree. Bael is a cauliflorous and ramiflorous fruit tree and flowering may be seen on newly emerged shoots after prunning.

9.7 Irrigation Management

In general, irrigation is not practised in bael cultivation under rainfed condition but 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 at regular intervals. However, heavy irrigation at irregular interval at a time may cause fruit cracking. In dry areas, the use of water harvesting techniques during the rainy season will be useful to ensure better moisture for subsequent growth and yield. In dry areas, the use of water harvesting techniques and mulches (organic and inorganic) should be adopted as it encourages subsequent growth, flowering and fruiting of the plant. Drip system of irrigation can be adopted to supply the optimum quantity of water to the plant and save the valuable water from wastage thereby increasing the water use efficiency. Drip irrigation or fertigation increases the productivity of optimization of moisture content in the root zone in addition to water saving. Nevertheless, bael can successfully be grown with proper orchard management under rainfed conditions of hot semi-arid and arid region without irrigation (Singh *et al*., 2016 d).

9.8 Integrated Nutrient Management

Integrated nutrient management refers to maintain soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrient in integrated manner. Therefore, it is a holistic approach, where the first things to know what exactly is required by the plant for an optimum level of production, in what different forms these nutrients should be applied in the soil and at what different timings in the best possible method and how best these forms should be integrated to obtain the productive efficiency of the economically acceptable limits in an environment friendly manner. In soil application method, fertilizers should be applied in active root zone. However, with the advent of drip irrigation system and availability of liquid fertilizers, the nutrient application technology is considered to be the most efficient. Bael, being minor fruit crop, no systematic work has yet taken up on manuring and fertilization. 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 Farm Yard Manure and 50, 25, 50 g N P K, in one year old plant, respectively. This dose should be increased every year in the same proportion up to the age of ten years. Sometimes in rich soils, the trees have a tendency to put on more vegetative growth with the result that the fruiting is delayed. Provision of green manuring has special significant for bael plantation established under degraded lands. 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 beneficial

9.9 Mulching

Mulches not only conserve soil moisture but also impart manifold beneficial effect, like suppression of extreme fluctuation of soil temperature, reduced water loss through evaporation, resulting more stored soil moisture, maintenance of soil fertility, suppression of weed growth and improvement in growth and yield. Under rainfed condition, application of organic mulch

(paddy straw) in tree basin is very beneficial for successful cultivation of bael (Fig 18). It reduces the loss of moisture from the soil, enhances the rate of penetration of rainwater in the soil and controls the growth of weed. Mulching with paddy straw, maize straw, grasses and rice husk reduces the weed population and conserves the moisture in the soil. An organic mulching material improves soil properties like pH and EC. Microbial and earthworm population in the basin soil increases with the use of organic mulch over long period (Singh *et al.,* 2012d). 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 forthcoming monsoon. Leaf litter of bael under the canopy is not only effective to retain soil moisture during summer but also improve the soil properties.

Fig. 18. Bael variety Goma Yashi: Paddy straw mulching

9.10 Weed Management

Productivity can be increased when all the aspects of production technology including weed management, intercultural operation and inter cropping are given due consideration. In general weeds affect plant growth and yield adversely very slowly in a subtle way. Most of the 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 ploughing of the land 2-3 times a year are done to suppress the weed growth. Regular spading of basin soil is required to check the moisture loss through cracks developed in summer nearby plant particularly in black cotton soil. In rainfed condition, vegetable crops grown in rainy season can be taken as intercrops in bael plantation. Intercropping and mulching also help in controlling weeds in tree basin.

10. Bael Based Cropping Systems

Intercropping in interspaces of bael plantation can be done by selecting compatible crops. Leguminous and short duration high yielding vegetable crops such as cluster bean, okra, bottle gourd etc. can be grown as intercrops in bael orchard. Under arid and semi-arid conditions, intercropping is only advisable during Kharif while in irrigated conditions vegetable crop can be grown during Rabi season also. Cover cropping with lobia, moth bean was found to increase water holding capacity of light soils as a result of increased organic carbon content in the soil. Intercropping in newly developed 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 (Fig. 19). Bael +cluster bean, bael +bottle gourd, bael + Bhindi were found ideal to generate extra income from bael orchard under rainfed semi-arid conditions.

Fig. 19. Bael +Guar intercropping

Under dryland conditions, various fruit crop models can be adopted to minimize the risk and enhance the productivity. Bael+ aonla + karonda+ drumstick, bael+ chironji + fig + custard apple, bael+ khirni + phalsa + wood apple cropping models are useful to enhance the productivity of dryland tracts of the country. Lay out and plantation of these crops should be done at proper spacing with good management of canopy so that more income can be generated.

Green manuring in the basin of fruit tree is very beneficial for better growth and development of plant under rainfed semi-arid environment. At Godhra, Gujarat, sunhemp (*Crotalaria juncea*) and mung (*Vigna radiata*) was sown in the basin of bael tree after first shower and were incorporated in the basin in the first week of September which not only improve the physical and chemical properties of soil but also enhances the growth and development of tree (Fig. 20).

Fig. 20. Green manuring with blackgram in bael

11. Flowering and Fruit Setting

The seedling bael tree requires 7-8 years to bear fruits while budded plants start bearing at the age of 3-4 years after planting. In bael, flower bud emergence takes place in the month of April and flowering in full bloom stage appeared in the month of May under hot semi-arid ecosystem of western India (Singh *et al.,* 2008c). Time of fruit setting depends up on the dehiscence and anthesis. The fruits become ready for harvest after 9-12 months or so by February-May in hot semi-arid ecosystem of western India (Fig 49). However, this may vary according to the genotypes and agro-climatic conditions. Studies on variation in fruit set, retention and yield of bael varieties revealed maximum fruit retention was observed in Pant Aprna followed CISH-B-1, Thar divya, Thar Neelkanth, NB-9 and Pant Shivani, whereas the minimum fruit set was recorded in NB-7 followed by NB-17. Pant Shivani produced the maximum fruit weight per unit volume followed by Pant Sujata whereas Pant Shivani produced the highest yield in terms of fruit weight per tree followed by Pant Sujata.

11.1 Fruit Growth and Development

The growth and development of the bael fruit follow a single sigmoid curve. Changes in composition of bael variety Goma Yash during growth and development have been studied under dryland condition at CHES, Godhra. The results of study revealed that the growth rate of bael has three distinct phases; the initial slow increase for one month followed by rapid increase for three months and then more or less a stationary phase until the fruits are harvested

(Fig. A). Fruit attains maximum size up to 15th October followed by nominal growth in size of fruit till harvesting (Fig. B). Specific gravity decreases during initial period up to August thereafter it increases gradually and sudden increase in specific gravity was observed in December (Fig. C).Total phenolic content of bael fruit decreased during the development and ripening (Fig.D). The inherent low acidity of the fruit shows decreasing trend during development and ripening (Fig. E). 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 (Fig. F). The total sugars and non reducing sugars of the fruit show a rising trend during development (Fig. G). The rate of respiration in bael fruit at early stage of development is rapid and it declines with growth (Fig. H). 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. Similar trend in the changes of bael qualitative and quantitative attributes have been reported by Roy and Singh (1980). Monthly changes in physic-chemical attributes of Goma Yashi under rainfed hot semi-arid conditions are given in table 6.

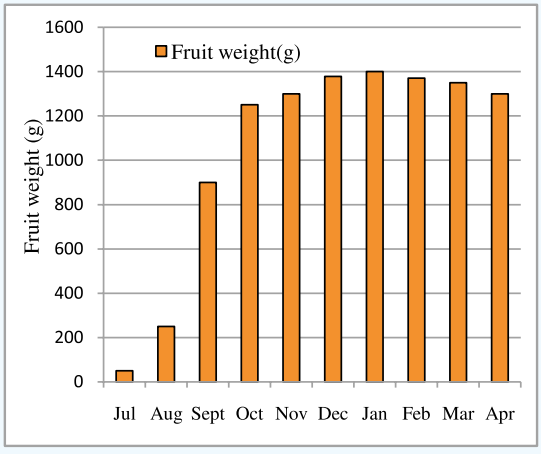

Fig A. Changes in fruit weight during growth and development

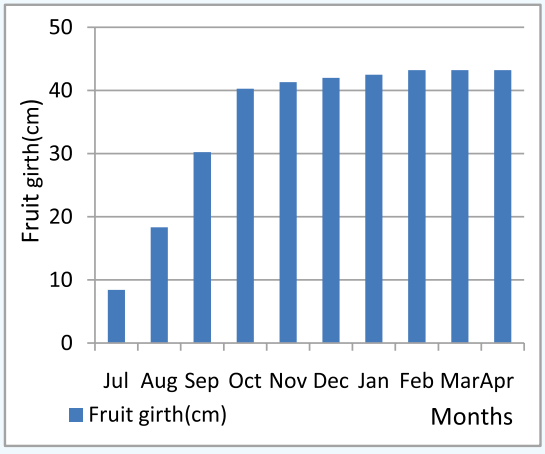

Fig. B. Changes in fruit girth during development

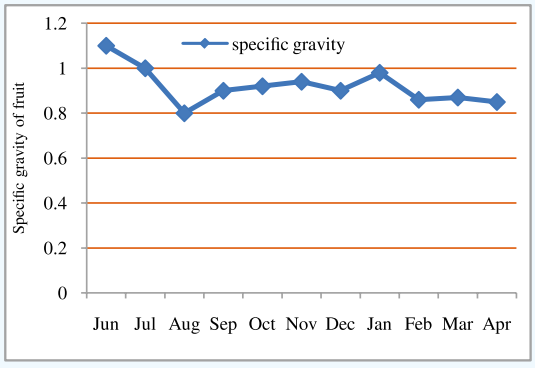

Fig C. Changes in specific gravity during growth and development

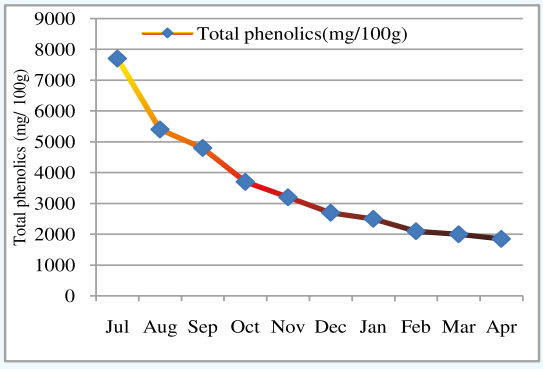

Fig. D. Changes in total phenolics during fruit growth and development under dryland condition

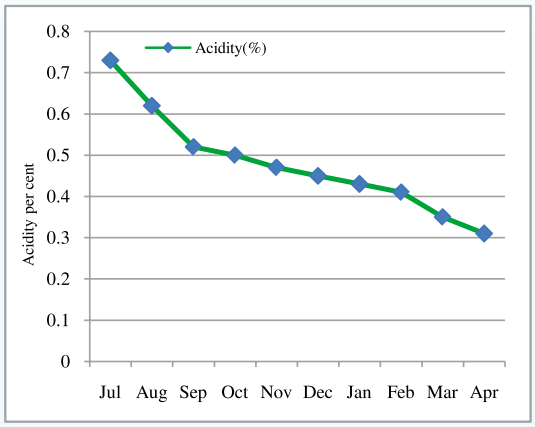

Fig. E. Changes in acidity during fruit growth and development

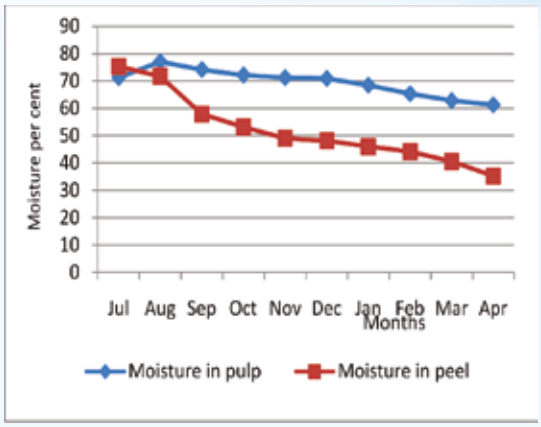

Fig. F. Changes in moisture in pulp and peel during fruit growth and development

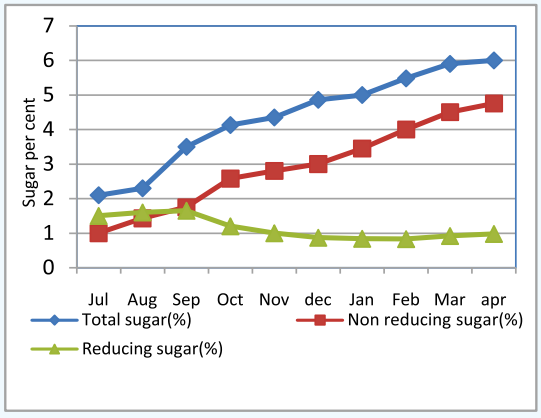

Fig. G. Changes in total sugar, reducing sugar and non reducing sugar

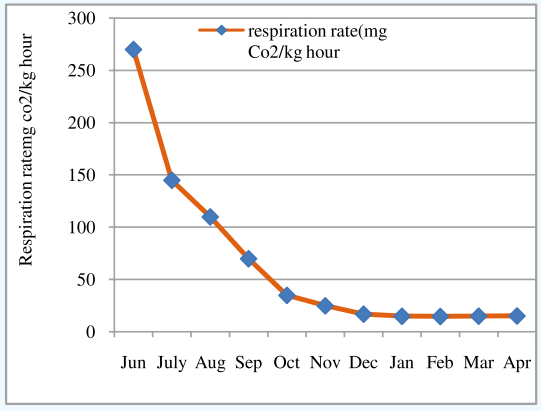

Fig. H. Changes in moisture in pulp and peel during fruit growth and development

Table 6: Monthly morphological characters of bael cv. Goma Yashi fruits during growth and development under rainfed conditions of hot semi-arid ecosystem.

Period after fruit set	Characteristics of the fruit
June	Rind deep green and soft, no seeds, flesh become brown rapidly after exposure
July	Rind deep green, soft and easily peeled, flesh slightly light yellow, turns brown on exposure, small soft seeds and very thin mucilage noticed.
August	Rind deep green, hard, difficult to peel, flesh light yellow; seed soft, size increased, mucilage thin
September	Rind deep green, very hard, impossible to peel, flesh light yellow; seed little hard, kernel formation noticed, mucilage fairly thin and cavity is full of seeds and mucilage.

October	Rind green, very hard and woody, flesh yellow, seeds hard and hairy, mucilage fairly thick, kernel prominent
November	Rind green. Very hard and woody, flesh yellow, seeds very hard and hairy on surface, mucilage thick, kernel prominent
December	Rind slightly light green, very hard and woody, flesh deep yellow, seeds very hard and hairy on surface with complete formation of kernel, mucilage thick
January	Rind light green, very hard and woody, flesh deep yellow, seeds very hard and hairy on surface with complete formation of kernel, mucilage thick.
February	Rind greenish yellow**,** very hard and woody, flesh deep yellow, seeds very hard and hairy and mucilage thick.
March and April (Fruit harvested)	Rind yellowish green, hard and brittle, flesh texture soft, prominent flavour of ripeness appeared, seeds very hard and hairy on surface with complete formation of kernel, mucilage thick.
Fully ripe stage (8-15 days)	Rind (pericarp) yellowish, pronounced ripe fruit flavour, pulp sweet and soft, fruit detaches easily from the stem end. Fruit easily broken by gentle press of thumb on fruit surface

12. Phenological Changes

Fig. 21. Leaf fall April

Phenologically, all the varieties had long leaf shedding period of 20-30 days (Fig. 21), starting from2nd week of March in Thar Divya, 2nd week of April in Pant Aparna, Pant Sujata and Goma Yashi which completes in 3rd, 4th and 2nd week of May, respectively. Variety Pant Shivani had 2nd week of April to 3rd week of April, Pant Urvashi had 3rd week of April to 2 nd week of May, whereas, NB-5, NB-7, NB-9 had leaf fall from 3rd, 2 nd, 1st week of May, respectively which completes in the 4th week of May. Variety CISHB-1 had 4 th week of March to 2nd week of April; CISHB-2 had 1stweek of June to 3rd week of June. NB-16 had 1st week of June to 2nd week of May. Leaf initiation started from 4th week of April in CISHB-1, Pant Shivani; 2nd week of May in NB-9; 3 rd week of May in Goma Yashi, 4th week of May in NB -16, NB-17 and Pant Urvashi; 1st week of June in NB-5, NB-7, Pant Aparna, Pant Sujata, which proceeded from the top of the tree towards the lower branches (Singhal *et al*., 2010). Leaf initiation starts after 15-25 days of leaf fall under rainfed hot semi-arid conditions (Singh *et al.,* 2006 a, 2014d, 2014e, Seghieri *et al*., 1995). Leaf fall depends upon the moisture content of soil and prevailing temperature of particular area.

13. Plant Protection

Bacterial shot hole, fruit canker and gummosis are some of the serious diseases. More than a dozen insect pests have been found feeding on bael. *Phyllocnistis citrella, Aonidiella aurantii* and *Papilio demoleus* are the important insects, which can easily be controlled by the use of suitable insecticides. Fruit cracking, fruit drop and sunscald are the physiological disorders which affect the productivity as well as quality of bael.

13.1 Diseases

Bael tree is not affected by serious diseases. However, powdery mildew, shot hole and fruit canker have been reported, which can be controlled by removing affected portion or by chemical sprays. Some of the diseases affect the growth and development of plant is discussed below:

Leaf Spots

***Alternaria* leaf spot** [*Alternaria alternata* (Fr.) Keissler.]

Initially brown or dark brown coloured spots of indefinite size appear on leaves with light brown or dark brown rings. Affected leaves blighten and fall. The disease is incited by *Alternaria alternata* (Fr.) Keissler. Spraying trees with 0.2 per cent copper oxychloride at 15 days interval helps in controlling this disease (Fig. 22).

Fig. 22. Alternaria leaf spot

Black Leaf Spot (*Isaropsis* sp.)

The disease is caused by fungus *Isaropsis* sp., which develops on both the surfaces of leaves as 2-3 mm black spot. For management of the disease, spraying of difolitan (0.2%) is recommended.

Bacterial Shot Hole and Fruit Canker

It is caused by *Xanthomonas bilvae* and it is characterized by minute, circular, brown, water soaked spots on susceptible leaf surface which initially measure less than 1 mm in size but later increase in size to 3-5 mm, turn brown and become concave with somewhat raised oily margin. Sometimes the area affected from necrosis blows away and results in shot holes on lamina. The pathogen also causes infection on fruit twigs and thorns. On fruits, minute roundish, water soaked (oily) grayish spots are seen on pericarp surface which shows raised margin and gradually increase in size and turn cankerous in look. Removal of more affected twigs followed by spray with Bordeaux mixture has been suggested to manage it. 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.,* (2014d) (Fig. 23).

Fig. 23. Bacterial fruit spots

Fruit Rot

During summer months, May-June, a severe post-harvest rot caused by *Aspergillus awamori* Nakazawa is observed on *bael*.The disease is somewhat serious during storage period of fruits. The disease is evident by large discoloured lesion on the fruit surface at the point where it touches the container and receives bruises from bottom or walls of the storage container. The disease result into 100 per cent loss of fruit in store house. In such fruit, *Aspergillus* develops and pulp becomes soft and emits foul smell (Fig. 24).

Microscopic view *Aspergillus nidulans*

Rotted fruits of Bael

Fig. 24. Bael fruit rot during storage

In severe cases, the outer skin of the shell become soft and rots. To avoid the disease, proper care should be taken during harvesting handling and transportation. Cracking in fallen fruit during harvesting is common. However, fallen fruit may not show damage from outside but damaged internally and cause severe problem during storage. Inner pulp produces black growth of the fungus. Pre harvest spray of Carbendazim (0.05%) and avoiding bruises to the pericarp during picking, storage and transport are suggested to manage the disease. It is better to wrap the fruits with phenol paper/newspaper and to line the containers with newspaper. Bamboo stick baskets and plastic crates are better for transport purpose. It is also suggested to ensure proper ventilation and daily inspection of the storage container (Singh *et. al*., 2014f).

Stalk End Rot [*Fusarium solani* (Mart.) Sacc., *F semitectum* var. *majus*]

Stalk end rot of *bael* is caused by *Fusarium solani* (Mart.) Sacc. It was reported by Bhargava *et al.* (1977). Dropping of immature young fruits is the main symptom of this disease. The fungal attack on the peduncle ends of the fruit forms a dark brown lesion (Fig. 25). Later, the fungus weakens the peduncle of the fruits resulting into fruit drop (Pandey and Misra, 2015). The disease is characterized by softening of rind near stalk end and underlying pulp. The affected rind turns dark brown at a later stage. Fruits neither shrivel nor deformed in their shape. Infected fruits

Reproduction symptom

Stalk end rot

Stalk end rot

Fig. 25 View of affected fruit with stalk end rot

fall when there is strong wind or heavy rain. For effective control of the disease, two sprays of Thiophanate methyle or Benomyl (0.1%) at fortnightly interval are recommended during early stage of fruit development.

Fusarium Rot (*Fusarium moniliformae* Shelden)

During rainy season particularly in the months of June-July, along with *Aspergillus* rot, other rot caused by *Fusarium moniliformae* Shelden is also observed. Cottony growth of fungal mycelium is observed just beneath the hard shell.Later the fungus covers the whole fruit and makes it soft and pulpy. Two sprays of Thiophanate methyler Benomyl (0.1%) at fortnightly interval are recommended to manage the disease (Fig. 26).

Fig. 26. *Fusarium* rot

Shell Softrot of bael (*Syncephalastrum racemosum*)

Shell soft rot is observed on matured fruits. The affected fruits rot quickly and are not fit for consumption as entire fruit pulp become unpalatable. Lesions develop as rapidly expanding water-soaked light brown rot patches with dark brown margins and a gelatinous texture. Lesions measure approximately 6-8 cm in diameter. The rot develops quickly and on the affected portion, the gelatinous layer is easily removable. Internally, the rot progress into the pulp and is colonized by white to black fungal mycelium.The affected fruit produce an unpleasant odour typically associated with decay (Misra, *et al.,* 2016) (Fig. 27).

Fig. 27. Shell soft rot

On Czapek yeast extract agar, fungus grows rapidly, covering a 90 mm Petridish in 2-3 days. Fungal colonies are composed of dense a septate blackish gray mycelium and grow quickly at 27±l^0 C. The sporangia are 30 to 50 µrn in diameter with sporangiospores found linearly within cylindrical sacs (merosporangia) borne on spicules around the columella. Sporangiospores, spherical to cylindrical in shape and borne in chains, measured 3.0 to 5.0 µm long. Fruits should be harvested carefully so that it is not damaged during harvesting and transportation. The fruit may be dipped after harvest in hot water at 52±l^0 C and then shade dried or it may be dipped in 0.05 per cent Thiophanate Methyl for 2 minutes and dried in shade (Mishra *et al.,* 2016).

Powdery Mildew

The disease is characterized by appearance of white floury patches on leaflets, especially on younger leaves which increase in size and cover entire lamina soon within 7-10 days (during November–December under Godhra condition). Later the colour of the colony turns slightly pinkish or grayish. Tender shoots are also found infected with the mildew. The disease is caused by *Oidium* sp. No perfect stage

Fig. 28. Powdery mildew

was recorded at Godhra (Fig. 28). Spray with Carbendazim 50 w p (Bavistin 0.1%) or wettable sulphur (0.2%) is found to be useful. However, during warm weather and flowering period, the application of sulphur should be avoided (Singh *et al.* 2014f).

Gummosis


Fig. 29. Gummosis in branches

Like other rutaceous plants of citrus family, oozing of gum is common in bael orchards. The disease is characterized by oozing out of pale or amber coloured gummy substance initially from bark of lower portion of trunk and later on other branches also. The gum oozing takes place from vertical splits in bark which turns dark from outside at the point of oozing but from inside other surrounding bark tissues turn light brown or white and very soft and sticky when touched with fingers (Fig. 29). Because of gummosis, the vigour of tree is severely affected and in severely affected twigs defoliation and dieback occurs. 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%) are also suggested to be applied at monthly interval during and after 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.,* 2014f).

13.2 Insects and Pests

Generally, bael is free from the serious pest's problem but few insect pests are known to cause damage the crop, especially when environmental conditions are very conducive to pest attack. Major insect pests are described below:


Fig. 30. Lemon butterfly

Lemon Butterflies (*Papilio demoleus*Linnaeus) Family: Papilionidae, Order: Lepidoptera *Papilio* spp. or swallow-tail butterflies are amongst some of the most beautiful butterflies found throughout the year in gardens and orchards, visiting various flowers but causing no damage (Fig. 30). However, the caterpillars feed on foliage and cause economic loss. Eight species of these papilionids have been reported feeding on different crop leaves in India, namely, *Papilio demoleus* L. *P. helenus* L., *P. daksha* Moore, *P. polytes* L., *P. polyctor* Boisduval, *P. polymnestor* Cramer, *P. machaon asiatica* Menetries, *P. memnon* L. and *P. protenor* Cramer. Of these, only the first one i.e. *Papilio demoleus* is the major pest of Citrus and *bael*. Others are of minor importance, as these are either sporadic in occurrence or confined to certain pockets (Pandey and Mishra, 2015).

Management: To control lemon butterflies, hand-picking of various stages of the pest and their destruction has been suggested. This is very useful in mitigating the pest problem especially in nurseries and new orchards. In case of severe infestation, spray with Quinalphos or 0.05% Chlorpyriphos or Phosalone are recommended. Spraying the entomogenous fungus, *Bacillus thuringiensis* Berliner or nematode DD-136 strain also gives very high mortality of the caterpillars.

Citrus leaf miner (*Phyllocnistis citrella Stainton*)

Eggs are minute, about 0.3 mm long, broadly oval, flattened and greenish-yellow in colour. Full grown caterpillars are cylindrical, about 5 mm long, apodous and dull greenish-yellow in colour. Adults are tiny, silvery white moths with heavily fringed wings with fore wings having brown stripes and a prominent black spot near apical margin and hind wings pure white. Wing expanse is 4 to 5 mm. Eggs are laid singly and are attached to leaves and twigs. A female lays 36 to 76 eggs in 2 to 6 days. The eggs hatch in 2 to 10 days. Larval duration is 5 to 10 days. The pupae are found in white cocoons lying near the margin of the leaf, the edge of which is turned over and the inside lined with silken webbing. Pupal period is 5 to 25 days and the entire life-cycle occupies 20 to 60 days depending upon the climatic conditions. There are 9 to 13 overlapping generations in a year.

Management: As the larvae are inside the mines, these cannot be killed easily by insecticidal applications. For effective control, affected parts during winter should be pruned heavily and burnt. Fumigation with hydrocyanic acid gas is quite effective but requires great care and technical aid. Spraying with 0.2 per cent or 0.25 per cent neem cake extract keeps the infestation under check. Spray quinalphos 1 ml/litre of water at bud stage once or twice if 30 per cent leaves showing infestation is effective.

Spiralling Whitefly (*Aleurodicus dispersus Russel*)

This pest is native of Caribbean region and Central America. In India it was first reported from Kerala during 1993 and later from other parts of peninsular India and the Lakshadweep on over 253 plant species, including number of plants of economic importance. The white fly was found throughout the year. Eggs are laid on lower surface of the leaves in loose spirals. The pest has three larval instars and fourth forms pseudo-pupa. Life cycle is completed within 21 to 48 days. Adults are clear on emergence but develop a mealy covering of white powder over the next few hours and measures 4 mm in size. Nymphs and adults suck sap from leaves leading to severe defoliation and reduction in flowering and fruiting. It is generally mistaken with a mealy bug infestation. The insect produces honeydew, which facilitate the growth of sooty mould. Affected leaves dry and drop down.

Management

- Collection and destruction of fallen leaves.
- Installation of yellow sticky traps @ 20 ha^{-1} to attract adults and fish oil resin soap 40ml/lit in the early morning hours.

- Predators *Axinoschymnus puttarudria* Kapur and Munishi, *Cryptolaemus montrouzieri* Muls. and *Mallada astur* Banks are common.
- Parasites, *Encarsia haitensis* Dozier and *E. guadeloupae* Viggiani proved highly effective against spiraling white fly.

Scale insect

Under dryland condition of Godhra, brown scale can be seen occasionally during summer having waxy parchment-like upper skin. It infests foliage and young twigs and congregates on the branches. The mature female insect depositr larvae beneath her body each day for one to two months and several generation of scale develop during the year. Scale 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 (Fig.31).

Fig. 31. Infestation of scales on bael branch

13.3 Physiological Disorders

Fruit Cracking

The fruit cracking is a major physiological disorder and its degree of damage depends according to genotypes/ varieties and locality. It has not been seen till now under rainfed condition of Godhra. The fruit cracking takes place twice in a year *i.e* winter season (December-January) while developing fruits are immature ii) during summer season (March-April) when fruit are mature and in ripening phase. The cracking at later stage is more severe than former one (Fig. 32 & 33).The cracking can be minimized by maintaining optimum soil moisture regime and by creating of wind breaks against hot desiccating wind side of orchard. Organic mulches like paddy straw, maize straw, *subabul* loppings can also be effectively used in maintaining soil moisture of tree basin particularly during summer under rainfed conditions of hot semi-arid ecosystem (Singh *et al.,* 2014f).

Fig. 32.Uniform fruit cracking after irrigation in the month of February

Fig. 33. Cracking after rain (June July)

Fruit Drop

Fruit drop is a natural phenomenon, but its extent of damage is a matter of concern. The extent of fruit drop varied according to genotypes/varieties and locality. Immature fruit drop (marble size) has also been observed. Sometimes cricket ball size fruits also fall down during August (Fig. 34). 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. Shweta and Misra (2015) reported that all the growth substances sprayed, proved beneficial in minimizing drop and enhancing quality characters of *bael* fruits. The maximum fruit set (78.48%) was recorded with NAA 30 ppm, while minimum fruit drop (90.64%) and maximum fruit retention (9.36%) were recorded with NAA 20 ppm. Maintenance of proper soil moisture regime nearby rhizosphere is useful to reduce the fruit drop (Singh *et al.,* 2014f). Effect of pollen on fruit drop, fruit set and final fruitt retention in bael has been reported by Pal and Mishra (2005).

Fig. 34. Fruit drop of big size fruits in August

Sun Scald

Sun scald is major disorder of bael under dryland conditions. It is manifested by turning of normal green shell into dark brown at the fruit surface where it is expose to 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 (Fig. 35). 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. The temperature of sun scalded portion is increased by 8-10° C as compare to unexposed portion of the fruit. This malady reduces the market price of the fruit even though the pulp of fruit is not much affected below the scorched shell. Mulching and canopy management are useful to reduce down this disorder up to some extent. Under Godhra condition. It has also been observed that the variety is having thin rind are more affected by sun scaled than thick one under rainfed semi-arid conditions of western India. Initial studies revealed that covering of fruits with cotton cloth is helpful in avoiding the sun scald up to some extent.

Fig. 35. Sunscald affected fruits

14. Maturity and Ripening

14.1 Maturity indices

Bael fruits remain intact on the tree for longer duration (9-11 months) which depends up on the variety and climatic condition prevailing to locality. The fruit is categorized as climacteric fruit (Roy and Singh 1980). In general, ripening of fruit is judged by the turning of fruit shell and flesh colour, TSS and aroma of fruits. The changes in composition of bael fruit at various stages of fruit growth and development have been described in detail by Singh and Roy (1984), which

can be considered as reliable indices for judging the maturity of fruit. Ripening of fruit can be judged by separation of stalk from the fruit, but it is not applicable for almost all the germplasm of bael. Singh and Roy (1984) reported that the ripening of bael fruit can be accelerated by a combination of high temperature and exogenous application of ethylene, however ethylene induced ripening is no effective at low temperature. The stalk is easily separated while pressing the fully ripened fruit which is indication of ripening (Singh *et al.,* 2011b).

14.2 Ripening

It has been also observed that the appearance of fruit surface and fruit pulp colour is also influenced by prevailing climatic condition of particular area. Ripening of bael fruit is accelerated by combination of high temperature and soil having low moisture content. However fruit ripening period may vary in different climatic conditions.

14.2.1 Natural Ripening

Ripening of bael fruit is enhanced by combination of high temperature and production of ethylene. The bael fruit is climacteric in nature (Fig.36). 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 (Roy and Singh, 1981). Considerable decline in specific gravity is noticed during ripening. Under dryland 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 Aparna) and in May (NB-7, Pant Urvashi CISHB-2 and NB-5).

Fig. 36. Ripening on tree

14.2.2 Artificial Ripening

Fruit treated with 1000-1500 ppm with ethrel and keeping at 30^{0}C after harvesting can be made available 2-3 months ahead of schedule time of ripening. It takes 18-24 days for the fruits to be artificially ripened (Roy and Singh, 1981). 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. No climacteric rise in respiration is noticed as long as the fruit is attached to the plant. However, rapid upsurge in fruit respiration, total and reducing sugar and decline in moisture, phenolics and acidity has been observed after harvesting the fruit till complete ripening which coincides with the optimum ripening condition of fruit (Roy and Singh, 1980).

14.2.3 Aroma Content of bael fruit

The attractive and characteristically sweet aroma components of bael fruit were investigated. The aroma concentrates possessing the sweet floral and somewhat terpene-like aroma were obtained from both the pulp and peel of fresh bael fruits by means of lyophilization and ether extraction, being analyzed mainly by GC-MS. A total of 39 components were identified. Among these components, terpene alcohols and β-ionone were considered to contribute to the aroma of bael fruit. At optimum ripeness, the fruit with excellent flavour contained a large quantity of an isomeric compound of 3, 7-dimethyl-1, 5, 7-octatnen-3-ol. This compound couldn't be found in unripe fruit, and seems to be important in making the bael fruit flavor attractive (Tokitoma *et al.*, 1982).

14.2.4 Quality attributes

Results of the study on the varieties evaluated for their quality attributes revealed that the physico-chemical attributes differed considerably among the evaluated varieties. The physical composition in terms of peel, pulp, mucilage, fibre and seed per cent in fruits and chemical composition, *i.e.* pulp TSS, mucilage TSS, total sugar, reducing and non reducing sugar, acidity, phenolics, pulp TSS and acid ratio and vitamin C content varied among the varieties. Differences in physico-chemical characters in the bael genotypes have been reported by Teaotia *et al.,*(1963), Mazumdar (1975), Singh *et al.,*(2000), Sarkar *et al.,* (2015) and Singh *et al.,* (2011b, 2011c, 2013b, 2014b, 2016h). The transverse and vertical view of Goma yashi variety is given in Fig. 37 & 38. The qualitative characters are illustrated in Fig. 39.

Fig. 37. Goma Yashi: Transverse section

Fig. 38. Goma Yashi: Vertical section

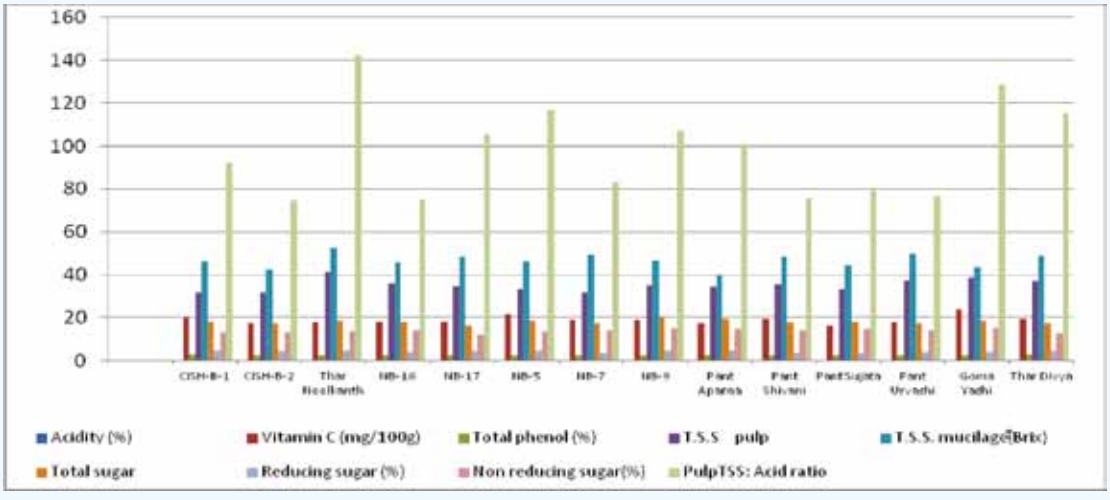

Fig. 39. Qualitative characters of bael varieties

15. Yield and Yield Attributing Characters

Bael tree shed their leaves and fruit exposed completely during ripening. The number of fruits per tree may vary from 80-150 fruits at the age of 9-10 years depending on variety, soil and climatic condition. Under Gujarat condition, a full grown tree gives 80-120 kg under rainfed conditions (10 year onwards). Number of fruit per tree is directly correlated with the size of fruit, a tree having bigger size fruit, the number of fruits is less. However, a seedling tree at the 20-30 years age can yield 500-800 fruits cooperatively smaller size. Physical characters of fruit in terms of fruit size, fruit weight, shell thickness varied in different varieties/genotypes (Fig. 40 & 41).The morphological features of different varieties in terms of fruit weight, length, width, fruit girth, shell weight, shell thickness, number of seed /fruit, total fresh seed weight, number of seed sacs, fibre weight, and pulp weight/ fruit varied considerably among the varieties. 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 (29.10-70.00cm) also showed variations. Physical composition of bael fruit exhibited wide variation in their shell weight (115.25-560.05g), shell thickness (0.16-0.31cm), number of seed/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). The qualitative characters of fruit in terms of TSS of mucilage, TSS of pulp, total sugar, reducing sugar, non reducing sugar, 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**.** The maximum fruit weight, fruit length was observed in NB-7 and the same was least in NB-16 among the varieties evaluated for physical attributes of fruit under rainfed hot semi-arid environment (Singh *et al*., 2014g & 2016p,).

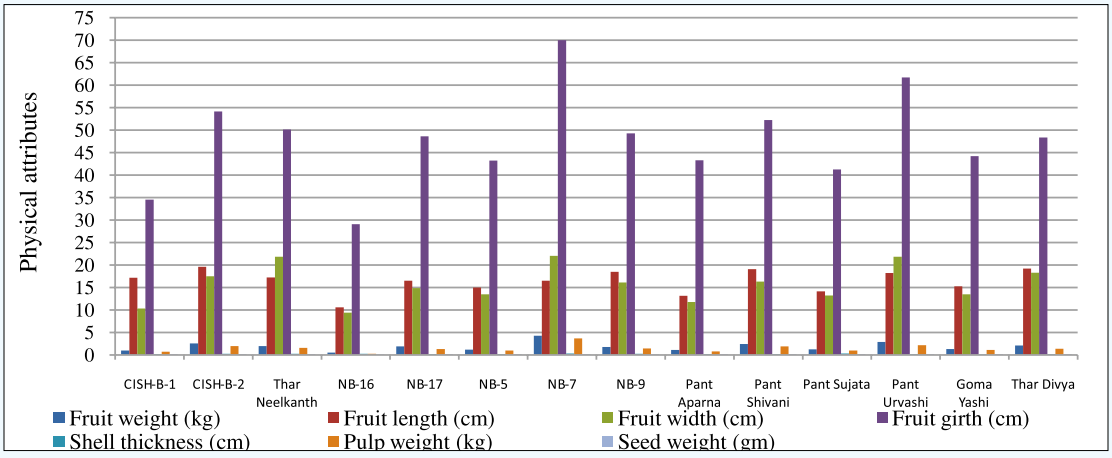

Fig 40. Physical character of fruits of different varieties of bael

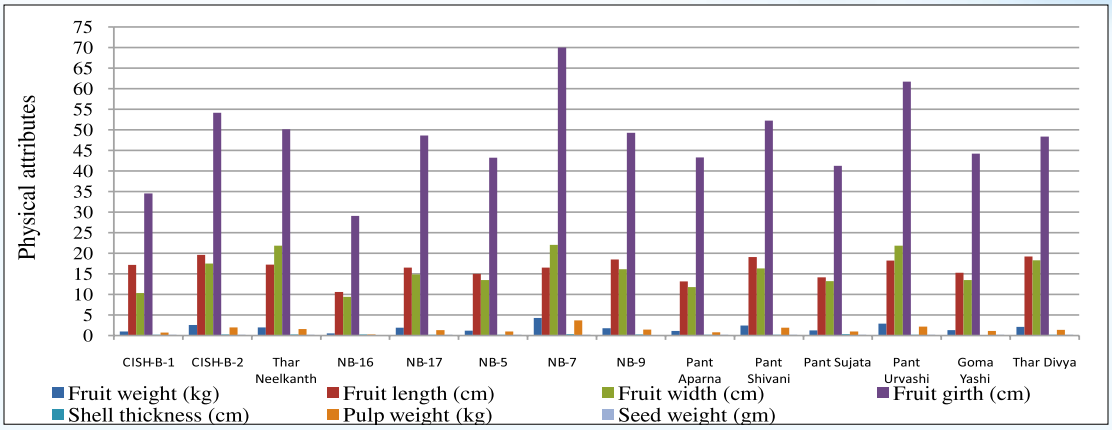

Fig. 41. Physical character of fruits of different varieties of bael

16. 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 semi-arid 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 (Fig. 42). The time of harvesting depends upon the purpose of utilization. Harvesting by shaking of trees should be discouraged, as the fruits are likely to develop cracks on impact as the peel of fruit is highly brittle which invites infection and can cause heavy loss during storage. 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 May in different climatic conditions. However, harvesting period is influenced by the temperature and moisture availability in soil. Fresh fruit harvested from late October to late December are suitable for preserve making while for fresh use as sherbet and other products from ripen fruit, harvesting time is from February to June. Singh *et al.* (2012b) have reported variation in ripening of bael varieties under dryland conditions (Fig 43).

Fig. 42 Harvesting of fruit

Fig. 43. Variability in maturity in bael varieties: Goma Yashia (left) and Thar Divya (right)

17. Post Harvest Management and Storage

Mature fruit samples of Goma Yashi variety were harvested and placed in two storage temperature (4-5°C and ambient temperature) regime and two different conditions (poly packing and without poly packing) under hot semi-arid conditions.Various parameters were observed like PLW, TSS, acidity and total sugar during storage at seven days interval. Results of study divulged that the total sugar increases gradually in poly bags during storage, but it is hastened under ambient condition. Acidity showed decreasing trend in all conditions. After 21 days of storage, the TSS decreased in various conditions whereas total sugar increases in all conditions up to 28 days excluding storage under ambient condition without poly bags and exhibited reduction in total sugar. It has been also observed that bael fruits can be stored up to 35 days under poly bags while under ambient condition up to 21 days under hot semi-arid conditions. Details are illustrated in Fig. 44, 45, 46 and 47.

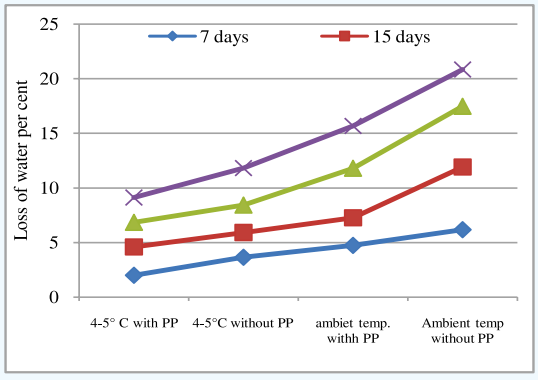

Fig. 44. Change in PLW during storage

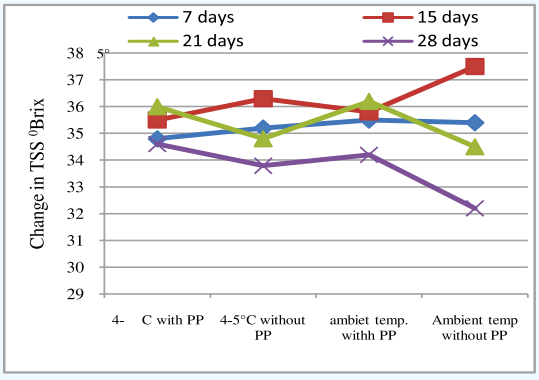

Fig 45. Changes in TSS during storage

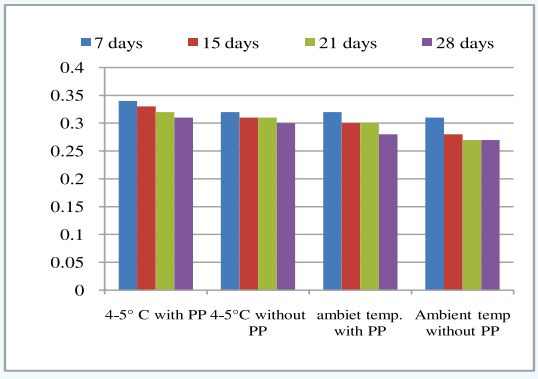

Fig. 46 Changes in acidity during Storage

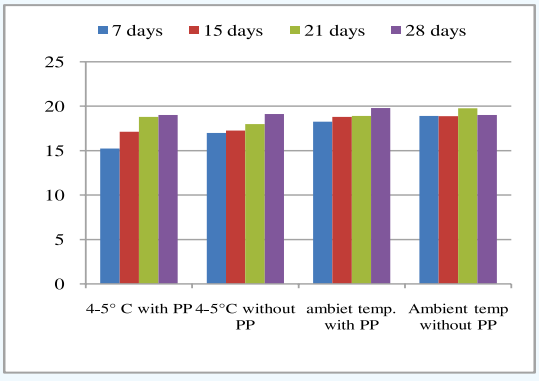

Fig. 47 Changes in total sugar during storage

17.1 Grading and Packaging

Grading is very important to avoid spoilage during storage and also to fetch better price in market. Bael fruits are likely to get damaged during harvesting due to improper care at the time of harvesting. Injured fruits are sorted out and healthy fruits are graded (Fig. 48) according to

size. Bael fruits have different shape and size; 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, saw dust, news paper 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.

Fig. 48. Graded fruits: NB-9

17.2 Post Harvest Products

Bael fruit is not popular as dessert fruit due to its hard shell, mucilaginous texture and numerous seed and fibre content. However, in recent time it is becoming popular due to its medicinal value and refreshing nature. Bael *Sharbet* is common especially in north Indian conditions in the market during summer months due to its refreshing and medicinal nature. *Bael* has been widely used since time immemorial for the processing in the mature green form to prepare preserve. 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. These drinks are consumed perhaps less as food or refreshment rather than for their medicinal value. Beside these, a number of value added products such as squash, fruit slab, toffee, powder, jam *etc*. (Fig. 49) are prepared and the recipes have been suggested by Singh and Roy (1984).

Fig. 49. Various post harvest products of bael

17.3 Storage

17.3.1 Storage of Fresh Fruit

There is no recommended practice for storage of bael. Fruits harvested at full maturity for preserve making can be stored up to 21 days and fruit harvested at ripe stage can be stored up to 7-9 days at room temperature. Fruit can be stored up to three months at about 9^0 C and 85-90 per cent humidity under cool storage (Roy and Singh, 1979b) (Fig. 50). It is sensitive to

Fig. 50. Fruit storage

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^{0}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 (Roy and Singh, 1979b). The effect of some chemicals like NAA (100, 200 ppm), GA_3 (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 of bael. Fruits treated with chemical could be stored up to 18 days. Fruits of different wrapping treatment could be stored for up to 24 days with little spoilage. Fruits treated with hot water (52± ^{0}C) could be stored for up to 21 days. Practically no change in organoleptic quality is noticed in frozen pulp after six months and in case of other products stored at 37^{o}C the organoleptic quality remained much above acceptable point (Roy and Singh, 1979a).

17.3.2 Storage of Products

During storage of fruit products, there is reduction in non-reducing sugars and increase in reducing and total sugars have been reported. Addition of SO_2 not only improves the initial quality of the fruit slab, toffee and powder, but also prevents non-enzymatic browning reaction during storage. The optimum relative humidity for the storage of fruit slab, toffee and powder is found to be 63, 58 and 5 per cent, respectively. No change in organoleptic quality is noticed in frozen pulp after six months and in case of other products stored at 37^0 C, the organoleptic quality remain up to acceptable level (Roy and Singh, 1979a).

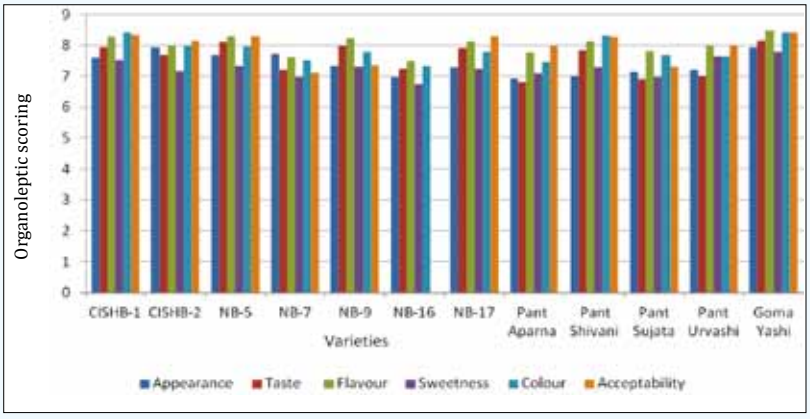

Fig. 51. Organoleptic rating of the RTS prepared from different varieties of the bael

Results of sttudy revealed that the different bael varieties varied in their organoleptic rating of the RTS prepared from the pulp of fruit, the RTS prepared from the variety Goma Yashi was found to be the best and lucrative in all the organoleptic rating parameters. However, NB-5 and CISHB-1 had also showed better rating among rest of the varieties. These varieties may be utilized commercially for RTS making and for its popularization (Singh *et al.,* 2016a). Details of organoleptic scoring are given in Fig. 51.

18. Future Thrust

Bael is gaining importance due to its suitability to various types of wastelands and the fruits having high therapeutical and nutraceutical properties. From forest confine to commercial plantation, a lot of efforts are required. A rich genetic diversity are available throughout the country especially in the states of U.P., Bihart, Haryana, Gujarat, Punjab, Rajasthan, Uttarakhand, Jharkhand, Chhatisgarh, M.P., etc. which should be exploited for selection of better genotypes. Bael based farming models should be developed for higher yield, better return and proper land utilization. Fruit drop, sun scald and fruit cracking are the major problems of bael cultivation in different parts of country. To overcome these problems, suitable genotypes should be identified with high yield potential and better fruit quality. Development of low seeded variety is necessary to lure this fruit. More emphasis on post harvest technology should be given for value added and export oriented processed products. Establishment of small scale processing units should be promoted.

Some of the research gaps identified required to be addressed in future are as under:

1. To create awareness among the people regarding its nutritional, therapeutic and environmental benefits for its commercialization in arid and semi arid regions.
2. A wide range of genetic diversity is available throughout the country especially in the states of U. P., Bihar, Uttaranchal, Jharkhand, Chhattisgarh, M.P. Gujarat etc. Existing elite genotypes needs to be exploited in crop improvement programme.
3. Fruit drop, sun scald and fruit cracking are the major physiological disorders of bael cultivation. To overcome these problems, varieties having high yield potential and better qualitative characters and free from these disorders should be identified.
4. Development of varieties which have less seed and fibre and have more TSS, minerals vitamins and antioxidants etc.
5. Development of varieties suitable for high density orcharding.
6. It is need of hour to develop herbal products useful against various ailments with scientific validation.
7. Emphasis should be given on post harvest technology to develop value added products. Small scale processing units should be established and promoted for commercialization of this fruit crop. Also, development of suitable technologies for reducing post harvest losses.
8. Development of integrated crop management strategies for sustainable fruit production of bael.
9. Bael based cropping systems/ cropping models should be developed to provide income stability to the farmers.

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