Genetic Resources of Mango: Status, Threats, and Future Prospects

Shailendra Rajan and Umesh Hudedamani

Abstract Mango (*Mangifera indica* L.) is an important fruit crop cultivated throughout the tropical and subtropical regions of the world. The importance of conservation of wild species is very much essential to avoid the genetic erosion as many species of mango are already threatened by loss of their habitat. Recent reports have indicated that four species of the common mango, viz., *M. pajang*, *M. zeylanica*, *M. lalijiwa*, and *M. odorata*, have been listed as endangered, while another species *Mangifera casturi* has been listed as extinct even in its wild habitat. The collection and conservation of tree species like mango needs to be given a special attention due to its varied ecosystems, high level of extinction threats, socioeconomic, cultural, and nutritive value. The mango germplasm is being conserved through various in situ and ex situ approaches. The custodian farmers of the mango are adding to conservation efforts through their on-farm conservation of valuable germplasm. The availability of the draft genome of the mango is serving as a valuable tool for molecular characterization studies focused on the identification of candidate genes governing color and ripening of the fruit. The tropical fruit genetic resources are being documented as hardcopy in books, journals, and other print and electronic media making information readily available to the end users of the germplasm. Identification of the diverse germplasm for higher yield to develop broad-based cultivars suited for changing climate can help achieve food and nutritional security demands of the increasing global population.

Keywords Mango · Conservation · Germplasm · Gene bank · Biodiversity

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1 Introduction

Mango (*Mangifera indica* L.) belonging to Family *Anacardiaceae* is the most important commercially grown fruit crop of the world. It is called the king of fruits. Mango is generally eaten raw, either cut into pieces for fruit salads or blended for juice and yogurt smoothies. It is also used in desserts, chutneys, preserves, and pickled dishes. In traditional medicine, some parts of the mango tree and the unripe fruit are used for their antibiotic properties. Fruits are rich in vitamin C and folate (Budhwar 2002). Different parts of mango plant exhibit different pharmaceutical properties, viz., dentifrice, antiseptic, astringent, diaphoretic, stomachic, vermifuge, and diuretic. It is utilized in treatment for diarrhea, dysentery, anemia, asthma, bronchitis, cough, hypertension, rheumatism, toothache, leucorrhoea, hemorrhage, and piles (Shah et al. 2010). The raw fruit is used in making chutney, tambuli, and pickles. The tender fruits are used for extracting resin used as flavoring agent (Vasudeva et al. 2015). Mango has a long history of cultivation and has been mentioned in many ancient Vedic texts as well as in notes of foreign travelers. The mango is cultivated throughout the tropics and in many subtropical areas of the world (Popenoe 1920). Many of the commercial mango varieties emerged as chance seedlings during Mughal rule. The Mughal emperors promoted cultivation of the best mango varieties and planted many large orchards indicating its tremendous value in Indian society and culture. Available records indicate that Indian people had accumulated substantial knowledge on mango cultivation by sixteenth century AD or even earlier (Mukherjee 1953).

It is widely distributed across the globe and is grown from equator to latitudes of 35–37° N in Southern Spain. Mango is the eight most produced fruit in the world with a production of over 45 million tonnes. The production saw a steep rise in recent years with rise of around 75% between 2000 and 2015 (FAOSTAT 2016). The mango production is widespread in the intertropical zones but is concentrated in certain countries with the top ten countries accounting for nearly 75% of the world production. Region-wise, Asia is the top producer followed by Africa and Latin America. India, China, Thailand, Indonesia, Mexico, Pakistan, Brazil, Bangladesh, Nigeria, and Egypt are the major mango-producing countries in the world (FAOSTAT 2016). The consumption of the fruit is fairly uniform across the world with major consumption from North America, European Union, Asia, and Persian Gulf countries. Around 80% of the export is contributed by ten exporting countries (Unctad 2016). India is one of the major countries exporting mango to the UAE, Bangladesh, the UK, and Saudi Arabia (Horticultural Statistics at a Glance 2015).

2 History

Earliest in-depth description about mango is found in *Ain-I-Akbari*, an encyclopedia written during 1590 AD. The Mughal emperor Akbar who ruled northern India from 1556 to 1605 planted an orchard of hundred thousand mango trees near *Darbhanga* the Lakh Bagh (Chadha 1996), and noteworthy is that many of these trees were found to be vigorous even after 300 years by English horticulturist Charles Maries. De Candolle, a Swiss botanist who established scientific structural criteria for determining natural relations among plant genera, is of the view that the mango is being cultivated by man for more than 4000 years. The mango known in Sanskrit *Amra*, *Chuta*, and *Sahakasa* is said to be a transformation of Prajapati, a lord of creatures, an epithet in Veda originally applied to Savitri, Soma, Tvastri, Hiranyagarbha, Indra, and Agni, but afterward the name of a separate god presiding over procreation (Manu xii 121). The Persians called this fruit as *Naghzak* as glorified by famous Urdu poets Amir Khusro and Ghalib. In the travels of Buddhist pilgrims Fa-Hien and Sung-Yun, a mango grove (Amravana) is mentioned and was presented by Amradarika to Buddha in order that he might use it as a place of repose (Singh 1960). The Chinese traveler Hiuen Tsang, who visited India between 632 and 645 AD, was the first to bring mango to the notice of the outside world. Several centuries later in 1328, Friar Jordanus visited Konkan and appreciated the progenitors of Goa and Bombay mangos. Ibn Battuta, John de Marignolli, Var therma, and Swatan Baber all have mentioned mango in their scriptures. First and successful attempt for the cultivation of mango was made by late Earl of Powis, in his garden at Walcot. In the USA the species was first introduced into former state by Henry Perrine, who sent plants from Mexico to his grant land below Miami in 1833. Second and successful attempt was in 1861 by Fletcher of Miami (Popenoe 1920).

3 Botany

Mango belongs to family *Anacardiaceae* which contains 73 genera and about 600–850 species. The plants are distinguished by their resinous bark and caustic oils in leaves, bark, and fruits (Whitmore 1975). Kostermans and Bompard (1993) proposed the most recent classification of the genus (Table 1) which includes the results of collections and surveys carried out from 1986 to 1988 in Borneo and Peninsular Malaysia. They used various important morphological characters for identification. The genus *Mangifera* contains approximately 69 species. The *Mangifera* is divided into two subgenera: *Mangifera* and *Limus*. Subgenus *Mangifera* contains most of the species and is characterized by its cushion-shaped papillose disc which is four or five lobed, partly or completely surrounding the ovary and with free stamen filaments. *Mangifera* is divided into sections, viz., *Marchandora* Pierre, *Euantherae* Pierre, *Rawa* Kosterm, and *Mangifera* Ding Hou. Subgenus *Limus* consists of 11 species and is characterized by the cylindrical disc which is located at the base of

Table 1 Classification of *Mangifera* species (Kostermans and Bompard 1993)

Genus *Mangifera*		
Subgenus *Limus* (Marchand) Kosterm		
Species	*M. blommesteinnii* Kosterm	*M. leschenaultia* Merchand
	M. caesia Jack	*M. macrocarpa* Blume
	M. decandra Ding Hou	*M. odorata* Griff.
	M. foetida Lour	*M. pajang* Kosterm
	M. kemanga Blume	*M. superb* Hook. f.
	M. lagenifera Griff	
Subgenus *Mangifera*		
Section Marchandora Pierre		
Species	*M. gedebe* Mig	
Section *Eutherae* Pierre		
Species	*M. caloneaura* Kurz	*M. pentandra* Hook. f.
	M. cochinchinensis Engl	
Section *Rawa* Kosterm		
Species	*M. andamanica* King	*M. minutifolia* Evard
	M. gracilipes Hook. f.	*M. nicobarica* Kosterm
	M. griffithii Hook. f.	*M. paludosa* Kosterm
	M. merrillii Mukh	*M. parvifolia* Boerl. & Koord
	M. microphylla Griff. Ex. Hook.f.	
Section *Mangifera*		
Species	*M. altissima* Blanco	*M. mucronulata* Blume
	M. applanata Kosterm	*M. oblongifolia* Hook.f.
	M. astroindica Kosterm	*M. orophila* Kosterm
	M. astroyunnanensis Hu	*M. pedicellata* Kosterm
	M. casturi Kosterm	*M. pseudoindica* Kosterm
	M. collina Kosterm	*M. quadrifida* Jack ex Wall
	M. dewildei Kosterm	*M. rigida* Blume
	M. dongnaiensis Pierre	*M. rubropetala* Kosterm
	M. flava Evrard	*M. rufocostata* Kosterm
	M. indica L	*M. similis* Blume
	M. lalijiwa Kosterm	*M. sulauesiana* Kosterm
	M. laurina Blume	*M. sumbawaensis* Kosterm
	M. linearifolia (Mukh.) Kosterm	*M. sylvatica* Roxb
	M. longipetiolata King	*M. swintonioides* kosterm
	M. M. Kochummen	*M. timorensis* Blume
	M. minor Blume	*M. torguendra* Kosterm
	M. monandra Merr	*M. zeylanica* (Blume) Hook. f.

(continued)

Table 1 (continued)

Species of uncertain position		
	M. Acutigemma Kosterm	*M. persiciforma* C. Y. Wu & T. L. Ming
	M. bompardiii Kosterm	*M. subsessilifolia* Kosterm
	M. bullata kosterm	*M. taipa* Buch Ham
	M. campospermoides Kosterm	*M. transversalis* Kosterm
	M. hiemalis J. Y. Liang	*M. utana* Buch. Ham
	M. maingayi Hook. f.	

Source: Ram and Rajan (2003)

the ovary in bisexual flowers and which is neither lobed nor papillose and contains united stamen filaments. *M. indica* belongs to subgenus *Mangifera*. Besides *M. indica*, there are number of other species of *Mangifera* which produce edible fruits: *M. caesia*, *M. odorata*, *M. pentandra*, and *M. pajang* (Hou 1978; Kostermans and Bompard 1993). The species of subgenus *Limus* are mostly confined to rainforests of Western Malaysia excepting *M. foetida* which extends to the east as far as New Guinea and is more primitive than subgenus *Mangifera* (Bompard and Schnell 1997; Ram and Rajan 2003).

3.1 Origin and Natural Distribution

Fossil leaves and wood with affinities to *Mangifera* have been found mostly from South and Southeast Asia, and the oldest *Mangifera*-like leaf fossil, *Eomangiferophyllum damalgiriense*, was recovered from the upper Paleocene of Northeastern India. This fossil is considered to be a precursor to the extant genus *Mangifera*, which hypothetically evolved within peninsular India and migrated to Asia, diversifying in the rainforests of Malaysia and Sumatra, after land connections were established between the Indian and Asian plates at the end of the Eocene or beginning of the Oligocene (Mehrotra et al. 1998). A fossil leaf impression of *Mangifera*, identified to the extant species *M. pentandra*, was reported from Assam in 1912 (Seward 1912; Bompard and Schnell 1997; Mukherjee 1997). Leaf impressions of *Mangifera* cf. *indica* and *M. tertiaria* Engelhardt are recorded from the Eocene of Germany (Edwards and Wonnacott 1935; Awasthi 1966).

Mango was reported as native of south Asia or of the Malay archipelago due to the presence of multitude of varieties cultivated in those countries, the number of ancient names particularly, Sanskrit names, its distribution in the gardens of Bengal, of Deccan peninsula, and of Ceylon (De Candolle 1884). The fossil record described by Seward (1912) provides few clues, as the only fossil bearing the imprint of a leaf of *M. pentandra* has ever been found in Assam. Mango (*Mangifera indica* L.) originated as alloploid, and its native home was suggested as Eastern India, Assam to Burma, or possibly further in the Malay region (Popenoe 1920). Vavilov (1926) also suggested Indo-Burma region as the center of origin of mango. Mukherjee (1953) provided evidence of morphology, phytogeography, and the fossil record to conclude that the origin of *Mangifera* is in the Burma-Siam-Indo-Chinese region or the Malay Peninsula. Studies of Mukherjee (1997) and Bompard and Schnell (1997) suggest that Southeast Asia is the center of origin and diversity for *Mangifera*. *Eomangiferophyllum damalgiriense* has been used to support the suggestion that the origin of *Mangifera* is in Eastern India (Mehrotra et al. 1998). The Indo-Burma region was considered by Vavilov in 1926 as the center of origin of the mango (Mukherjee 1951) and is believed to have arisen during the Quaternary period (Mukherjee 1997). It was suggested that there are three main centers of distribution, the India-Burma-Siam area, the Philippines, and the Malay Peninsula, with emphasis on the India-Burma region (Mukherjee 1967). Support for this suggestion is provided by the distribution of wild *M. indica* and its allied species, *M. sylvatica* and *M. caloneura*, the history of cultivation, introduction, the occurrence of fossils, and the species Sanskrit name. Popenoe (1974) suggested the native region of *M. indica* as Eastern India (Assam) to Burma or possibly in the Malay area, similar to the proposal by Mukherjee (1967). With the aid of recent taxonomic and molecular evidence, it seems that the mango probably evolved within an area encompassing northwestern Myanmar, Bangladesh, and Northeastern India (Mukherjee 1997).

The geographical distribution of *Mangifera* species indicates that Malaya is the center of origin of the genus, but fossil records of *M. pentandra* in Assam and of *M. duperreans* and *M. lagenifera* in Laos, Cambodia, and Vietnam indicate that it may have arisen in these places. Commercial cultivars of mango appear to have originated predominantly in India. Suitable environments have resulted in wider diversity in seedling progeny with improved types as in Florida, where such cultivars as Haden have larger and more attractive fruits than the dull-colored parent Mulgoa. The predominance of nucellar lines in Malaysia and the Philippines may be a result of genotype X environment reaction (Mukherjee 1972).

3.2 Morphology

The mango is a large, spreading evergreen tree with a dense crown. Mature trees can attain a height of 40 m or more, with a 60–120 cm trunk and grayish-brown, longitudinally-fissured bark. Mango trees grown from seeds have long straight bole with sympodial branching, while grafted trees are dwarf with spreading branches. Considerable variation can be noticed in canopy characteristics of Indian mango cultivars with compactness of the canopy, branching pattern, and leaf component showing ecogeographical dependence (Rajan et al. 1998). The tree forms a long unbranched tap root plus a dense mass of superficial feeder roots. Feeder roots develop at the base of the trunk or slightly deeper which form anchor roots, and sometimes a collection of feeder roots develop above the water table (Bojappa and Singh 1974).

The mango seeds are solitary, large and flat, ovoid oblong, and surrounded by the fibrous endocarp at maturity. The testa and tegmen are thin and papery. Embryos are dicotyledonous. The seeds are recalcitrant and cannot survive for more than a few days or weeks at ambient temperatures. The leaves are simple, exstipulate, alternatively arranged, and 15–45 cm in length. The petiole varies in length from 1 to 12 cm with swollen base. It is grooved on the upper side. The phyllotaxy is usually 3/8, but the leaves arranged very closely at the tips give the whorled appearance. Leaves are variable in shapes like oval-lanceolate, lanceolate, oblong, linear-oblong, ovate, obvovate-lanceolate, or roundish-oblong (Singh 1960). The inflorescence is pseudo-terminal, originating from a bud, together with the new leafy sprout; there are cultivars with lateral inflorescence. The inflorescence is a narrow to broadly conical panicle up to a 45 cm long depending upon cultivar and environmental conditions during its development. It is usually bracteate but may sometimes ebracteate. The bract if present is leafy, elliptical, and concave. The color of the panicle may be yellowish green or light green with crimson patches or with crimson flush on branches. It is generally pubescent but sometimes may be glabrous. The branching of the inflorescence is usually tertiary, rarely quaternary, but the ultimate branching is always cymose (Singh 1960).

The inflorescence produces both hermaphrodite and male flowers in the same panicle with comparatively large number of male flowers. The size of both male and hermaphrodite flowers varies from 6 to 8 mm in diameter. The flowers are subsessile, rarely pedicellate with sweet smell. Pedicels are very short or missing; they are articulate with a panicle branch of the same diameter, which is often mistaken for the pedicel (Barfod 1988). The calyx is five partite with ovate-oblong and concave lobes. The corolla consists of five pale yellow petals with three to five ridges on the ventral side. The petals are in bud imbricate and slightly contorted. The petals are thin and yellowish, and after expanding horizontal, the upper half is rather irregularly and not very prominently reflexed with slightly dark ridges. The upper half and the margins of the petals are white in color. On fading the petals become pinkish. Between the corolla and androecium, there is an annular, fleshy, and five-lobed disc (Singh 1960; Kostermans and Bompard 1993). The androecium consists of five stamens and staminodes of which usually one or two are fertile and rest are sterile (Juliano and Cuevas 1932). The ovary is sessile, one celled, and slightly compressed in its lateral aspect. The ovule is anatropous and pendulous and shows one-sided growth. The style arises from the edge of the ovary and ends in a simple stigma (Singh 1960). The fruit is fleshy drupe with considerable variation in size, shape, color, presence of fiber, flavor, taste, and several other characters. The beak, a small conical projection developing at the proximal end of the fruit, is prominent in many varieties. The shape of the fruit varies from rounded to ovate-oblong or oblong with maximum frequency of oblong oval-shaped fruits (Rajan et al. 1999a, b). The skin is gland dotted, and at maturity its color exhibits different mixtures of green, yellow, and red shades (Golap and Bandyopadhyay 1977; Ram and Rajan 2003).

4 Current Global Distribution

The mango is cultivated throughout the tropics and in many subtropical areas of the world. It is grown at the equator and up to the latitudes of 35–37° N in Southern Spain. The mango cultivation is widespread with unique superior germplasm being cultivated in different countries across the globe (Table 2). In Australia, mango is grown throughout the northern tropical and subtropical regions with major production areas in Queensland, Northern territory, and Western Australia (Bally et al. 2000). In Bangladesh, superior varieties of Indian origin are distributed in Rajshahi, Kushtia, Dinajpur, and new Satkhira districts (Abedin and Quddus 1990). In China several *Mangifera* species have been distributed in Guangdong, Guangxi, Hainan, Yunnan, Taiwan, Fujian, and Southwest Sichuan (Shupei and Yanqing 1996). Wild and cultivated species of *Mangifera* are distributed throughout the tropical and subtropical parts of India including hilly forests and ravines and in Andaman and Nicobar islands. Many of the Indian cultivars possess narrow adaptability and show ecogeographical preference for growth and yield (Yadav and Rajan 1993). In Indonesia, both *M. indica* and other edible mango species, viz., *M. odorata*, *M. foetida*, *M. pajang*, and *M. laurina*, are distributed in different parts of Java, Sumatra,

Table 2 Important cultivars in major mango-producing countries

S.No	Country	Cultivars
1	Australia	Kensington Pride, Banana, Earlygold, Glenn, Haden, Irwin, Keitt, Kent, Zill
2	Bangladesh	Aswina, Fazli, Gopal Bhog, Himsagar, Khirsapati, Langra, Kishan Bhog, Kohinoor, Kua Pahari, Mohan Bhog
3	China	Baiyu, Guixiang, Huangpi, Huangyu, macheco, Sannian, Yuexi No. 1
4	India	Alphonso, Amrapali, Banganapalli, Bangalora, Bombay Green, Chausa, Dashehari, Fazli, Fernandian, Gulabkhas, Himsagar, Kesar, Kishen Bhog, Langra, Mallika, Mankhurd, Mulgoa, Neelum, Pairi, Samar Behisht, Suvarnarekha, Totapuri, Vanraj, Zardalu
5	Indonesia	Arumanis, Cengkir, Dodol, Gedong, Golek, Madu, Manalagi, Wangi
6	Israel	Haden, Keitt, Kent, Maya, Nimrod, Palmer, Tommy Atkins
7	Malaysia	Apple Mango, Apple Rumani, Arumanis, Golek, Kuala Selangor 2, Maha-65, Malgoa, Tok Boon
8	Myanmar	Aug Din, Ma Chit Su, Sein Ta Lone, Shwe Hin Tha
9	Pakistan	Anwar Ratol, Banganapalli, Chausa, Dashehari, Gulab Khas, Langra, Siroli, Sindhri, Suvarnarekha, Zafran
10	Philippines	Binoboy, Carabao, Digos, Dudul, Mamplong, Manila Super, Pahutan, Pico, Senora
11	Singapore	Apple Mango, Arumanis, Golek, Kaem Yao, Mangga Dadol
12	Sri Lanka	Dapara, Hingurakgoda, Karutha Colomban, Malwana Amba, Parrot Mango, Petti Amba, Peter Pasand, Vellai Colomban, Willard
13	Thailand	Choke Anand, Kao Keaw, Keaw Sawoey, Khiew Sawoey, Klarangwun, Nam Doc Mai, Ngar Charn, Okrong, Pimsenmum, Rad, Tongdim
14	Vietnam	Cambodiana

Source: Ram and Rajan (2003)

and Kalimantan. The *M. indica* and its wild species like *M. altissima*, M. *cassia*, *M. laurina*, *M. monandra*, *and M. odorata* are distributed in primary forests, in wet tropical lowlands, as well as in areas with moderate rainfall in the Philippines (Coronel 1996). In Myanmar, Nepal, and Sri Lanka, *M. indica* and other wild species are well distributed. In Sri Lanka, *M. zeylanica* locally known as *Etamba* is mainly distributed in the forests of intermediate and wet zones. In Taiwan varieties introduced from the USA, viz., Irwin and Keitt, are popular and distributed in mango-growing areas (Shu et al. 2000; Ram and Rajan 2003).

4.1 Global Production, Supply, and Demand

Mango is the eight most produced fruit in the world with a production of over 45 mt. The production saw a steep rise in recent years which witnesses a rise of around 75% between 2000 and 2015. India, China, Thailand, Indonesia, Mexico, Pakistan, Brazil, Bangladesh, Nigeria, and Egypt are the major mango-producing countries (Table 3). The mango production is widespread in the intertropical zones but is concentrated in certain countries with the top 10 countries accounting for nearly 75% of the world production. Region-wise, Asia is the top producer followed by Africa and Latin America (FAO STAT 2016).

The export data reveals a very distinct pattern as it is not in tandem with the quantum of production by respective countries indicating varying levels of self-consumption by the producer countries. The total exports account to just 3.4% of total volume produced indicating high level of self-consumption by the producing countries with 80% of the export contributed by 10 exporting countries, viz.,

Table 3 Area, production, and yield of mango in major mango-producing countries of the world (2014–15)

Country	Area (000 ha)	Production (000 tons)	Productivity (tons/ha)	% Share in world total production
India	2515.97	18431.33	73.26	40.75
Bangladesh	56.30	992.30	176.26	2.19
Brazil	70.32	1132.46	161.05	2.50
China	571.00	4674.95	81.87	10.34
Indonesia	251.00	96.87	2431.33	0.21
Mexico	196.22	1754.61	89.42	3.88
Nigeria	130.20	875.00	67.20	1.93
Pakistan	170.71	1716.88	100.57	3.80
Philippines	196.41	899.01	45.77	1.99
Thailand	410.71	3597.59	87.60	7.95
Other countries	1073.53	11054.21	102.97	24.44
World	5642.36	45225.21	80.15	

Source: FAOSTAT (2016)

Table 4 Top exporting and importing countries of mango in the world

S.no	Country	Export (in tonners)	Country	Import (in tonnes)
1	Mexico	297,295	United States	385,861
2	India	214,640	China	190,182
3	Thailand	196,441	Netherlands	101,826
4	Brazil	127,132	United Arab Emirates	99,728
5	Pakistan	101,164	Canada	57,991
6	Peru	99,790	Saudi Arabia	57,858
7	Ecuador	60,139	Malaysia	55,000
8	Yemen	43,467	Spain	35,498
9	Philippines	24,076	Singapore	21,234
10	Egypt	19,564	Germany	15,369

Source: Unctad (2016)

Mexico, India, Thailand, Pakistan, Brazil, Peru, Ecuador, Yemen, the Philippines, and Egypt (Table 4). The demand is well covered by supply, but it is affected by seasonality and trading habits with excessive prices affecting the demand levels. The consumption of the fruit is fairly uniform across the world with major consumption from North America, European Union, Asia, and Persian Gulf countries. The Asian countries are top producers as well as consumers of the fruit (Unctad 2016).

5 Domestication and Dispersal

Mango trees produced small fruits with thin flesh, abundant fibers, and inferior quality during initial stages of domestication. Present-day superior varieties are the result of conscious selection process over hundreds of years. The domestication and cultivation of the mango during ancient times has been documented elaborately in the Vedic scriptures (Singh 1960). The cultivation of mango originated in India for more than 4000 years (De Candolle 1884). Huien T'sang (632–45 BC) was probably the first writer who brought the fruit to the notice of people beyond India. In India the fruit had royal patronage during Mughal rule. Akbar the Great (1556–1605) planted an orchard of 100,000 mango trees near *Darbhanga* known as Lakh Babh. During the Mughal period, emphasis was given on the selection of mango, and even today several varieties in India are based on Mughal names. Portuguese introduced approach grafting to India, and after the introduction of propagation method, Mughal rulers popularized it by propagating large-scale seedlings using the grafting technique. Superior seedlings were introduced in Southeast Asia by traders and Buddhist monks in fourth and fifth century BC. Most important varieties of Thailand, Cambodia, Vietnam, Malaysia, Indonesia, and the Philippines have polyembryonic origin and hence are easily maintained through seeds. Mango was believed to be introduced to Malaya and Eastern Asia from mainland as indicated by the Sanskrit and Tamil words for mango in Malaysia and Indonesia. Dr. Fletcher introduced mango into Miami from West Indies in 1868–1869 which became common by name peach or turpentine. United States Department of Agriculture introduced trees from Bombay in 1889. Popenoe, the explorer of US Department of Agriculture, introduced outstanding mango varieties from India and East Indies. Later on, the US Department of Agriculture introduced several cultivars from India, the Philippines, West Indies, and other sources. During the twentieth century, introductions from Southeast Asia, India, and other parts created important secondary center of diversity of *M. indica*. Floridan mango cultivars have been found to be highly adaptive and with moderate resistance to anthracnose as compared to Indian cultivars (Popenoe 1920; Ram and Rajan 2003).

6 Genetic Resources

6.1 Collection

Germplasm collections serve as an important source for the crop improvement, more so in fruit tree species like mango with long duration of juvenile period. The crop genetic resources play a key role in crop development and are considered as the basic materials for germplasm innovations and crop breeding. The efforts have to be made to collect the germplasm and make utilize the total diversity existing for the species. Mango germplasm collections in India with an objective of searching for cultivars with better fruits started from the sixteenth century (Singh 1968); however, the collection efforts got momentum with the adaption of more scientific approach after the establishment of Indian Institute of Horticultural Research at Bengaluru and Fruit Research Stations under All India Coordinated Project on Subtropical Fruits at Sabour, Kodur, Saharanpur, Sangareddy, and Vengurla (Yadav and Rajan 1993; Chadha 1996). The explorations from south and Central India (Burns and Prayag 1921) and Northeastern India as well as from the states of West Bengal (Saha 1972; Mukherjee et al. 1983), Orissa (Das and Hota 1977; Parida and Rao 1988), Bihar (Singh and Sigh 1956a, b), and Uttar Pradesh (Teotia and Srivastava 1961) led to the collection of large variability of mango germplasm (Table 5).

In Bangladesh germplasm collection was initiated under coordinated project, and germplasm collection was maintained at the Central Horticulture Station, Dhaka; later on, the collection and maintenance of germplasm was taken over by Horticulture Section in the erstwhile Agricultural Research Laboratory of the Directorate of Agriculture in 1951. Between 1960 and 1980, many varieties of local and exotic commercial cultivars were collected and maintained at the Bangladesh Agricultural Research Institute (BARI), Dhaka; Central Horticultural Station, Jaydebpur; and Regional Horticultural Research Station, Nawabganj (Hossain and Amzad 1996; Ram and Rajan 2003). In China, many surveys were conducted, and mango genetic resources were collected in between 1959 and 1967. Many exotic

Table 5 Genetic resources of mango at different field gene banks in India

S. No.	Name of the institute/FGB	Number of accessions
1	ICAR-IIHR, Bengaluru, Karnataka	447
2	ICAR-IARI, N. Delhi	71
3	Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal	135
4	ICAR-CISH, Lucknow, Uttar Pradesh	772
5	Horticulture College and Research Institute, Periyakulam, Tamil Nadu	118
6	G B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand	171
7	Agriculture Experiment Station, Paria, Gujarat	170
8	Horticulture and Agroforestry Research Programme, ICAR Research Complex for Eastern Region, Plandu, Ranchi, Jharkhand	189
9	Fruit Research Station, Rewa, M.P.	124
10	Bihar Agricultural College, Sabour, Bhagalpur, Bihar	97
11	Fruit Research Station, Sangareddy, Telangana	414
12	Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan	21
13	Regional Fruit Research Station, Venegurle, Maharashtra	308

Source: http://www.mangifera.org./station.php

commercial cultivars were introduced from Sri Lanka, Cuba, Indonesia, and Thailand. In Taiwan, varieties were introduced mainly from the USA and Costa Rica (Zhen 1989). The introduction of Indian varieties into the Philippines started as early as 1900s, and later on many important varieties were collected and introduced from Thailand, Malaysia, Indonesia, Vietnam, Sri Lanka, Hawaii, Florida, Australia, and Israel (Coronel 1996). In Thailand, wild relatives of *Mangifera* and other species have been collected at Chanthaburi Horticultural Research Centre and Trang Horticultural Research Station and Germplasm Research Centre Khao Chong, Trang Province (Vangnai 1996). In Sri Lanka the collection and conservation work has started with establishment of Plant Genetic Resource Centre in 1989 (Medagoda and Jayawardena 1997; Ram and Rajan 2003).

6.1.1 Genetic Resources of Wild Relatives: Habitat, Ecology, and Status

There are several wild species of mango found in and around the place of origin of mango. The scientific studies on the *Mangifera* genepool were conducted by several researchers; Kostermans and Bompard (1993) and Mukherjee (1985a, b) generated a lot of information on wild relatives of *Mangifera indica* (Ram and Rajan 2003). *Mangifera* genus is known to contain around 60 species that bear edible fruits, and these species are mostly spread on the islands of Borneo, Java, and Sumatra besides their abundance in and around peninsular region of Malaysia (Kostermans and Bompard 1993). *M. khasiana* Pierre, *M. sylvatica* Roxb, *M. camptosperma* Pierre, *M. andamanica* King, and several other species have been recorded in various parts of Northeastern India, sub-Himalayan tracts, Gonda hill of Uttar Pradesh, and outer hills of Kumaon and Garhwal in Uttarakhand of India (Brandis 1874, Kanjilal et al. 1937). *M. sylvatica* is known to occur in Eastern Sikkim, West Bengal, Meghalaya, Assam, and Andaman islands (Mukherjee 1949; Agharkar and Roy 1951).

The changing climate is leading to loss of genetic diversity in the wild relatives. The importance of conservation of wild species and their genetic potential has been recognized by many workers. Many species of mango are threatened by loss of their habitat (Table 6). Recent reports have indicated that four species of the common mango, viz., *M. pajang*, *M. zeylanica*, *M. lalijiwa*, and *M. odorata*, have been listed as endangered, while, the kalimantan mango (*Mangifera casturi*) has been listed as extinct even in its wild habitat (IUCN 1998a, b, c, d, e; Rhodes and Maxted 2016; IUCN 2017).

M. pajang Kostermans is a species which is believed to have originated from Borneo Island (Malaysia-Sabah and Sarawak, Brunei and Indonesia-Kalimantan). Fruits are oval in shape and have a characteristic rough and brown skin. In Malaysia, the tree is scattered throughout the Borneo rainforest (Lim 2012). The species has ethno-cultural significance and has attained an iconic fruit status among the kadagon – Dusun people of Malaysia. It is favorite in local dish preparation due to the aromatic smell of its peel. The higher content of vitamin C and beta-carotene in its pulp has made it as one of the potential functional food (Mayne 1996). A clinical study at Universiti Putra Malaysia (UPM) has demonstrated its health benefits (Tangah et al. 2017).

M. zeylanica is an endemic species to Sri Lanka and is commonly known as *Etamba*. Even though the tree produces tasty fruits, it has not been cultivated on a wide scale. It is mainly found in intermediate and wet as well as dry zones of forest and conserved in situ under management of the forest department. Its natural population is declining in unreserved areas due to habitat loss and destruction of forests (Weerarathne et al. 2005). It has been traditionally used for cancer therapy. Its bark is known to mediate cytotoxic activities through induction of apoptosis cancer cell lines (Ediriweera et al. 2015). It exhibits a normal vigor, flavor, and fruiting when grafted on *M. indica* (Campbell 2007). *M. lalijiwa* is an evergreen tree that can grow up to 40 m tall. The species is highly valued for its fruits known to grow in Bali and Java regions of Indonesia. In Indonesia this species is threatened due to encroaching agriculture and water logging in lowland forest (Kostermans and Bompard 1993).

M. odorata is a fruit trees species commonly found in Southeast Asia. It is believed to be originated as a hybrid between *M. indica* and *M. foetida*. The species *odorata* has been originated from a fragrant resinous smell emitted by trees of the species including the flowers that are scented with the same fragrance. It is commonly cultivated in Borneo, Sumatra, and Java and is also known to be cultivated in Thailand, Vietnam, and Guam Islands. The fruit is popular and cultivated in Eastern Asia in areas of high rainfall, especially where *M. indica* cannot be grown. Due to its ability to sustain excessive rainfall, it can be easily popularized and grown in areas outside Southeast Asia (IUCN 1998c). The fruits must be peeled thick because of the presence of an acrid juice in the skin which can be reduced by steeping in diluted lime water before eating. Used for making chutney and for pickles with salt (Orwa et al. 2009).

Table 6 Threatened *Mangifera* sp. in IUCN Red List

S.No	Scientific name	Species authority	Red list category	Year published	Population	Geographic range	Countries of occurrence	Habitat and ecology	Conservation action	Reference
1	*M. pajang*	Kosterm	Vulnerable	1998	Rare	Restricted to Borneo	Brunei Darussalam, Indonesia (Kalimantan), Malaysia (Sabah, Sarawak), and Singapore	Primary low and dipterans forests Terrestrial	Wild and cultivated form in Dayak gardens in the northeast and west of Kalimantan	Bompard and Kostermans (1985), Fah (1987), Mukherjee (1985a, b), Ng and Wee (1994), Oldfield et al. (1998)
2	*M. zeylanica*	(Blume) Hook.f.	Vulnerable	1998	Very rare	Endemic to Sri Lanka	Sri Lanka	Scattered in both the wet and dry zones Terrestrial	As a designated reserves, in situ under management of the forest department of Sri Lanka	Gunatilleke and Gunatilleke (1991), Hamilton (1990), Kostermans and bompards (1993), Mukherjee (1985a, b), Oldfield et al. (1998)
3	*M. lalijiwa*	Kosterm	Data deficient	1998	Endangered	Semarang and Yogyakarta in Central Java. Madura, Java, Bali, and Sumatra of Indonesia	Indonesia (Bali, Java)	In Java lowland forests Terrestrial	Highly valued and conserved for its fruits	Kostermans and Bompard (1993), Oldfield et al. (1998), Whitten et al. (1996)

4	*M. odorata*	Griffith	Data deficient	1998	Endangered	Eastern Asia	Guam, Philippines, Thailand, Vietnam	Areas of high rainfall in Eastern Asia	Eastern Asian regions in areas devoid of *M. indica*	Bompard (1988), Erfurth and Rusche (1976), Kostermans, and Bompard (1993), Loc (1992), Mukherjee (1985a, b), Ng and Wee (1994), Oldfield et al. (1998), Whitmore (1990)
5	*M. casturi*	Kosterm	Extinct in the wild	2016	Extinct	Endemic to South Kalimantan Indonesia	Indonesia (Kalimantan)	It is only known from cultivation but occurred in tropical forest habitat that are thought to have been converted into agricultural lands Terrestrial	Not subject to any in situ and ex situ conservation for the species	Bompard (1988), Rhodes and Maxted (2016), Kostermans and Bompard (1993), Kostermans (1986), USDA (2014)

M. casturi Kosterm, a common species in South Kalimantan and East and Central Kalimantan, has typical dark-colored fruits which are deep orange from the inside. It has unique flavor and aroma and very tasty as rated by many connoisseurs. The fresh fruits are very popular among the people of South Borneo and neighboring regions. The species bears excellent fruits and is known to be resistant to anthracnose and attack by beetles. The species is locally known by kastooree, asem pelipisan, kasturi, peleepeesan, and many other names. It is suited to ever wet climates (Ram and Rajan 2003). There are three recorded varieties of the species, viz., *kasturi*, *manga* Cuban, and *pelipesan*. The most popular is *kasturi* due to its characteristic flavor (Orwa et al. 2009).

6.2 Characterization

Morphological characterization is the easiest and simple characterization process that allows for the study of plant variation using visual attributes. Morphological characterization mainly reveals variability for growth, leaf, flower, fruit, and quality parameters. The morphological characters mainly help in identifying elite varieties as well as superior donor parents for different horticultural traits. The earliest evidence for evaluation and characterization of mango are available in Ain-i-Akbari (Singh 1960). The fruit characters were used for grouping the cultivars based on their performance and their region of adaption (Rajan et al. 2013a, b). The fruit characters further helped in selecting the promising parents using group constellation (Rajan et al. 2009) as well as for evaluation of cultivars for their per se performance (Maries 1902). The fruit characters combined with several other traits were used in the classification of varieties (Burns and Prayag 1921). Even primary, secondary, and tertiary characters were utilized for characterization (Singh and Singh 1956a, b; Pandey 1984; Rajan et al. 1999a, b).

IPGRI descriptors (IPGRI 2006; Pinto et al. 2006) were used for visual assessment of mango accession until the development of standard DUS test guidelines (PPV& FRA 2008) by task force constituted by the PPV&FR authority. The biochemical markers using isozymes profile and cluster analysis based on allele frequencies were used to reveal genetic variation and show relationships among farmers varieties (Subedi et al. 2004). The combined morphological and molecular techniques were used for delimiting native and exotic varieties (Ramessur and Ranghoo-Sanmukhiya 2011), clustering varieties based on geographical origin within country and from outside country (Mussane et al. 2011), and confirming the phylogenetic relationship and geographic distribution of different *Mangifera* sp. (Eiadthong et al. 1999). Principal component analysis of qualitative traits and quantitative traits of fruits revealed the existence of continuum of mango diversity with no ecogeographic differentiation. Quantitative traits were also found important in determining the groupings and working out the relationships among the various cultivars (Subedi et al. 2004).

RAPD analysis of wild mango species (*M. zeylanica* Etamba) revealed intraspecies variation in the population of same climatic zones (Weerarathne et al. 2005). RAPD markers also aided in genetic diversity analysis and discrimination of cultivars based on geographical regions (Bajpai et al. 2008). SSR markers were used for diversity analysis, dividing the accessions into different modes representing their geographical origins, unambiguous identification of mango genotypes, and separation of cultivars originating from different countries. These markers revealed that the diversity observed within a geographic region is derived from the varieties that are being grown in that region (Dillion et al. 2013; Eiadthong et al. 1999; Shamili et al. 2012; Gonzalez et al. 2002; Dinesh et al. 2015). SSR markers served as an important tool in the estimation of genetic relatedness among polyembryonic and monoembryonic cultivars (Kumar et al. 2001). Another group of molecular markers known as variable number tandem repeats (VNTRs) were used for DNA finger printing and genetic analysis of genotypes and hybrids (Adato et al. 1995). Three different PCR methods, viz., RAPD, ISSR, and directed amplification of minisatellite DNA (DAMD), were used to analyze genetic diversity and parentage among mango cultivars and grouping of cultivars on a regional basis (Srivastava et al. 2007). Both morphological and molecular characterization studies revealed that they both follow almost the same pattern suggesting the genetic control of these fruit characters (Dinesh et al. 2015).

With the arrival of sequencing technology, the use of various sequence-based molecular tools began, and they were used for characterization of mango germplasm for different objectives. Gene cloning was used for isolation of novel ripening-specific cDNA clones (Lycett et al. 1997), while isolation and characterization of mRNAs was used for identification of differentially expressed genes during ripening of mango fruits (Saiprasad et al. 2004). Recent molecular characterization studies are mainly focused on the identification of candidate genes governing color and ripening of the fruit, genes involved in phenylpropanoid/anthocyanin biosynthesis and identification of different isoforms of several genes including chalcone synthase, chalcone isomerase, and flavonol synthase. These genes are found to be directly involved in pigment accumulation as indicated by their differential expression in different fruit peel colors (CISH 2015). The draft genome of mango already published (Singh et al. 2016) is further expected to serve as valuable resource for mango genetic improvement.

6.3 Conservation

6.3.1 On Farm Conservation

Convention on biological diversity (CBD) recognized two ways of conserving genetic resources, in situ, in place of origin, and ex situ, outside place of origin. In situ conservation is a conservation of genetic resources in the native habitat in the wild and on-farm management of genetic resources in agricultural systems. The objective of on-farm conservation is to allow natural genetic introgression between domesticated crop and its wild relatives (Harlan 1992) and to maintain crop evolution in farmer's fields, farms, home gardens, and landscapes (Bellon and Etten 2014). The conservation of genetic resources is faced with multitude of challenges. Bioversity International and its national partners launched an international research effort, 'Strengthening the scientific basis of on-farm conservation of agricultural biodiversity on-farm' in eight countries of the world (Jarvis et al. 2004, 2007). International Plant Genetic Resources Institute (IPGRI) made concerted efforts through Asian Development Bank (ADB)-funded project for conservation of fruit genetic resources under the project "Conservation and Use of Native Tropical Fruit Species Biodiversity in Asia" which was operational from 2010 in ten countries, viz., India, China, Bangladesh, Indonesia, Malaysia, Nepal, the Philippines, Sri Lanka, Thailand, and Vietnam (Mal et al. 2011). Under this project collection, characterization, conservation, documentation, training, and public awareness of different identified species of mango were carried out. During the project period, approximately 3000 accessions of 6 major fruit tree species, viz., mango, citrus, jack fruit, litchi, rambutan, and mangosteen, have been collected from different parts of the world. The geographical information system (GIS) was used for managing accessions data, locating diversity areas, and planning collection missions for different fruit genetic resources including mango. An ecogeographic survey was carried out to measure the extent of distribution and diversity of mango under Nepal component of the project. The data generated from study were analyzed and interpreted by GIS software. Customized GIS software DIVA-GIS was used for mapping collection sites and analyzing the diversity richness as well as other factors influencing the mango diversity. The Eastern *terai* (lowlands) and Western mid-hill regions were identified as regions with rich diversity in farmers named mango varieties. The old orchards with many indigenous genotypes were recorded and suggested for conservation under the project (Subedi et al. 2005).1992

In situ and on farm conservation of Tropical Fruit Tree Genetic Resources (TFTGR) is necessary. In India Indian Council of Agricultural Research (ICAR) along with Biodiversity International executed United Nations Environment Programme (UNEP) funded by Global Environment Facility (GEF) in five states viz., Amravati (Maharashtra), Chittoor (Seemandhra/Andhra), Malihabad (U.P.), Pusa (Bihar) and Sirsi (Karnataka) on three fruit crops viz., Mango, Citrus and Garcinia and collected and conserved a sizeable number of accessions of aforementioned fruit trees both at farmers fields (in situ) as well as in different gene banks of Indian Council of Agricultural Research (ICAR) institutes. On a similar lines of UPOV, in India, Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) is coordinating the registration of unique mango varieties for the benefit of farmers and giving them legal ownership of the varieties that they are conserving since time immemorial (Dinesh et al. 2014).

Community Biodiversity Management, a participatory approach toward the conservation or utilization of local genetic diversity aimed at community development, envisages empowering farmers and local institutions for local wealth of biological diversity capitalization for the benefit of local community. Global community biodiversity management study trainings were held in India, Brazil, and Nepal for imparting the working knowledge and sensitizing the scientific personnel under UNEP-GEP project. The on farm conservation of rich genetic diversity by custodian farmers is an important component of in situ conservation of germplasm. Custodian farmers are those farmers who actively maintain, adopt, and promote agricultural biodiversity and related knowledge over time and space, at farm and community levels, and are recognized by community members for doing this. Often custodian farmers are actively supported in their efforts by family or household members. They are involved in maintaining, promoting, and adopting a wide range of indigenous fruit tree variation in their farm. Identification and documentation of custodian farmers of tropical fruit tree genetic resources has been an integral part of traditional knowledge documentation of UNEP/GEP project on "Conservation and Sustainable use of Cultivated and Wild tropical Fruit Tree Diversity: Promoting Sustainable Livelihoods, Food Security and Ecosystem Services," implemented in 36 rural communities in India, Indonesia, Malaysia, and Thailand. Identification of custodian farmers (Table 8) is one of the strategies of conserving diversity that the custodian farmers are identified and supported through institutionalized support for continuing their conservation efforts (Sthapit et al. 2013). The custodian farmers are driven by variety of motives to conserve the biodiversity. The study conducted in India, Indonesia, Malaysia, and Thailand to know the motive of the farmers in conserving the genetic diversity revealed that quite a few farmers maintain rich diversity with few rare unique fruit tree species or varieties and are mainly driven by conservation ideology (Sthapit et al. 2015; Hugo et al. 2015). Personal, social, cultural/religious, natural, and biological traits also played important role in motivating the farmers for conserving the mango diversity apart from economic factor (Gajanana et al. 2015a) The identification of unique varieties along with details of custodian farmers has been documented in the form of a catalogue "National Fruit Catalogue of Tropical Fruit Diversity Catalogue" which has list of 121 mango varieties (Dinesh et al. 2014). The creation of public awareness about the fruit tree diversity and its management is necessary for on farm conservation of native and wild germplasm. The public awareness about the fruit tree diversity was created through a fruit tree diversity fairs organized in India with the aim of creating public awareness about tropical fruit tree (TFT) diversity, and this was also used as a participatory tool for locating trait-specific indigenous varieties and to enable marketing the diversity. The diversity fairs were also succeeded in recognizing the custodian farmers (Gajanana et al. 2015b). The heirloom varieties share a considerable diversity, and the survey carried out under UNEP-GEF TFT project in India resulted in the identification and documentation of the heirloom varieties with desirable traits in them. These heirloom varieties can be directly adapted for commercial cultivation as well as used as parents for introgression of desirable traits through breeding (Rajan et al. 2014; Dinesh et al. 2015).

6.3.2 Ex Situ Conservation

6.3.2.1 Cryopreservation and In Vitro Conservation

Conservation of tree species like mango required special attention due to their varied ecosystems, high level of extinction threats, and socioeconomic, cultural, and nutritive value. IPGRI project entitled “Development of advances technologies for germplasm conservation of tropical fruit species” funded by Australian Centre for International Agricultural Research started in 2013. The Plant Biotechnology and Conservation Group at Griffith University, Australia, with partners from Malaysia, Vietnam, the Philippines, and Thailand started with targets to develop the conservation technologies including cryostorage of seed, micropropagation, cryoprotection of in vitro short tips, and the development of somatic embryogenesis system for long-term storage by cryopreservation. Cryopreservation techniques for mango along with citrus, papaya, and Davidson’s plum were developed at Queensland, Australia (Drew and Ashmore 2003).

Success of cryopreservation of embryonic cultures was found to depend on the dehydration treatment and defined growth conditions during culture but not on the origins as revealed in the studies on direct somatic embryogenesis from both immature cotyledon cuts and nucellus in the mango variety zihua (Zhu et al. 2007). Among the different techniques used for cryopreservation of embryonic masses sampled from *M. indica cv*., Zihua vitrification technique yielded maximum recovery after treatment of embryonic masses in comparison with limited recovery in pre-growth/dehydration technique, while cryopreservation using encapsulation/dehydration resulted in no recovery after treatment of embryonic masses (Ling et al. 2003). The excised embryonic axes were found to be more tolerant to desiccation than whole seeds (Feng and Rui 1994). Nonsynchronous flowering and nonavailability of pollen are major hindrances for carrying out the desirable crossing program to address this problem, and improved method for pollen collection from freshly dehiscing anthers of mango using the organic solvent cyclohexane has been devised. Using this method, pollen quantity sufficient for large-scale pollinations could be collected and stored for future use (Chaudhury et al. 2010). Pollen storage of important varieties followed by dehydration and freezing has been demonstrated by Iyer and Subramanian (1989), and this method has utility in gene pool conservation in hybridization programs (Karihaloo et al. 2005).

6.4 Documentation

Documentation of status of plant genetic resources is essential in order to manage and conserve it. Documentation is also essential requirement in germplasm exchange and sharing of benefits. In fact it is an essential component of tropical fruit genetic resources (TFTGR) management. The information can be compiled from data obtained from exploration, gene bank documentation systems, published articles, directories, traditional orchardists, and indigenous people. In addition to information published as hardcopy in books, journals, and a variety of prints, informal publications as in departmental reports also play as important sources of information. The electronic medium is making information more readily available enabling countries to know what they have. The information in field gene banks can tell us what more need to be conserved and the help devise appropriate management needs of the germplasm conserved. The availability of data for exchange is a measure of the success of the gene bank's documentation system. IPGRI, with its mandate to advance the conservation and use of plant genetic resources, has been advocating documenting the genetic resources information in a standard manner. Its documenting scheme, even if not adopted as such, could form the basis for a standardized scheme. IPGRI has published descriptor lists in respect of many crops (Ram and Rajan 2003). IPGRI is a global body involved in maintaining the databases with summary information on ex situ germplasm collections. The data include address information on organizations holding germplasm and summary information on the type of germplasm that is maintained including species names, number of accessions per species, type of accessions, etc. Currently, summary information on more than five million accessions is available with the institution. The updating as well as collation of ex situ germplasm holding data is done in collaboration with Food and Agriculture Organization of the United Nations (FAO) that provides a similar type of data as part of its World Information and Early Warning System (WIEWS). The directory of germplasm collections of tropical and subtropical fruits and tree nuts contained information on 64,269 accessions representing 191 genera and 879 species that were divided into 14 different crop sections. The collections documented are being maintained by 242 institutes spread across 69 countries (Bettencourt and Perry 1992).

The second report on the state of the world's PGR for food and agriculture has listed 25,659 accessions of mango that are being held by different institutes across the globe. The mango collection center, Department of Primary Industries, Australia, is the largest public sector organization that holds 18,606 mango accessions (Table 7) accounting for 73% of the total world mango germplasm accessions (FAO 2010). The ICAR-Central Institute for Subtropical Horticulture (ICAR-CISH), Lucknow, India is the second largest organization in the world with 772 mango accession in its field gene bank (CISH 2015). The Royal Botanical Garden, Kew; Mekarsari Fruit Garden Indonesia (MFGI), Bogor, West Java, Indonesia; and Fairchild Tropical Botanical Garden (FTBG), Florida, USA, are the other different organizations that are known to be involved in ex situ conservation of fruit trees. Recently the genetic diversity of the crop is being documented and disseminated in the form of catalogues. A brief description of 794 mango varieties from various published sources was documented under the title "International checklist of mango cultivars" (Pandey 1984). Several catalogues including a catalogue on mango with details on 225 mango cultivars grown under subtropical conditions using 56 descriptors (Rajan et al. 1999a, b), catalogue on mango germplasm with details on 252 accession (Rajan et al. 2002), and 2 mango catalogues with the information on 404 accessions (Dinesh et al. 2014) were released, while the Philippines released cata-

Table 7 Global mango (*Mangifera indica*) germplasm collections at major field gene banks (FGBs)

S. No	Field gene bank		Accessions		Type of accession (%)				
	Name	Institute code	No.	%	Wild sps.	Land races	Breeding lines	Advanced cultivars	Others
1	Department of Primary Industries, Australia	AUS088	18,606	73	<1		99	1	
2	Central Institute for Subtropical Horticulture, India	IND045	726	3		100			
3	Horticultural Research Institute, Dept. of Agriculture, Thailand	THA056	252	1			100		
4	Subtropical Horticultural Research Unit, National Germplasm Repository-Miami, US Dept. of Agri.	USA047	240	1			1	48	51
5	Indonesian Legume and Tuber Crops Research Institute	IDN177	239	1				100	
6	Njala University College (Sierra Leone)	SLE015	200	1				100	
7	Others (109)		5396	21	<1	27	6	31	37
8	Total		25,659	100	<1	8	74	10	8

Source: FAO (2010)

logue with information on 265 accessions (IPB 2003). Similarly, electronic catalogue of mango germplasm was released by Indian and Thailand (Rajan 2003; Somsri 2003). In India, a Mango Resources Information System developed for management of phenotypic, genetic, molecular, chemical, and other available information on indigenous and exotic mango cultivars contains the information on 682 accessions with the details of fruit, leaf, and other characteristics besides a collection of 26 expressed sequence tag (EST) and 285 nucleotide sequences present in mango varieties. This provides quick access to information and serves as a quick method for extracting information from a massive data set (Rajan et al. 2013a, b). The fruit tree genetic resource documentation is important because the information on collection and exploration are needed for planning of future explorations, avoiding duplication and providing an early warning to the threat of genetic erosion besides helping in linking together information on genetic resources in a country with traditional and indigenous knowledge. The proper documentation of an accession helps to establish how that accession was developed and maintained and makes it difficult for others to try to take out inappropriate patents or other intellectual property rights (IPRs). The availability of information from all these sources determines the state of plant genetic resources in a country and reflects the state of information documentation (Ram and Rajan 2003).

7 Cultivation

The mango can be cultivated in an area with annual mean temperature of 24–30 °C. It can tolerate air temperature up to 48 °C for a short period in a day. The trees are adversely affected by frost and long cold spells leading to death of leaves, shoots, and their branches killing the tree from top to thick trunks at 0 °C. The minimum temperature of 0.6–0 °C for couple of hours on two consecutive days can cause appreciable damage, and all 1-year-old trees will be killed. Hence younger trees are easily damaged by low temperatures. The differential tolerance is observed between monoembryonic and polyembryonic cultivars with monoembryonic cultivars being more successful when the minimum temperatures fall below 12 °C during the flowering. Tropical cultivars grown in subtropical produced low percentage of perfect flowers when exposed to lower temperatures (Singh et al. 1965). The soil temperature also plays an important role and has considerable role on the photosynthates that a tree produces. Decrease in soil temperature to 12 °C is known to reduce net photosynthesis and stomatal conductance of plant at air temperature of 30/20 °C, but at the same time, there had no effect on plants at air temperature of 15/10 °C indicating air temperature below that is required for shoot growth is also a limiting factor for physiological process such as leaf gas exchange of mango (Pongsomboon et al. 1991). The chilling temperature is also known to decrease the rate of photosynthesis. The polyembryonic cultivars which originated in tropical climates showed greater chilling sensitivity than monoembryonic cultivars (Whiley and Schaffer 1997).

Mango can be grown with a little irrigation in areas with annual rainfall to areas receiving above 250 mm annual rainfall. The absence of rain during flowering is essential factor for good crop as moist and humid atmosphere washes pollen and encourages insect pests and diseases apart from interfering with pollinator's activity. An excessive rain during fruit maturity is known to be condusive for disease and insect pests attack (Ram and Rajan 2003). The light interception and its utilization within tree canopy are also known to affect the growth and yield of the crop. The mango productivity by increasing photosynthetic efficiency is possible by selective pruning to increase the percentage of leaves exposed to more than 60% of full sunlight resulting in higher chlorophyll concentration in leaves of pruned canopies (Ram and Rajan 2003). The longevity of mango leaves and dense canopy is an adaptive mechanism to offset the extended seasonal period of subtropical photo assimilation. Growth of large, thick sclerophyllous leaves has a high carbon cost to trees which is accelerated by a potentially low annual carbon returns. The sink to source transition of mango leaves is around 6 weeks which is longer than deciduous trees that have transition period of 2–4 weeks. The cultivars recording more diffuse non-interception (DNI) values produced fruits with better color (Rajan et al. 2001; Chako and Ananthnarayanan 1993). The mango can be cultivated in a wide variety of soils, even though it performs well on deep well-drained soils of loamy texture. Sandy loam is better suited than loam. Heavy-textured soils like clay or clay loam are unsuitable because of their drainage. Sandy soils with low fertility can be improved to high-quality soils with the supply of humus to soil. The structure of soil in different horizons should be open, crumb, or granular. Compact soils with impermeable hard pans of clay can be used after hard pans are broken before planting (Singh 1960; Ram and Rajan 2003) (Table 8).

7.1 Uses

Mango is cultivated for the fruits which can be eaten in three ways, depending on the cultivar: unripe, ripe, and processed. The green fruit is also used to flavor fish and meat dishes in the same way as tamarind and other sour fruits. Each part of the tree has uses; seed kernels from a by-product of processing can be used to feed cattle and poultry. In India the kernels are also important as a famine food, but the astringency has to be removed by boiling, roasting, or soaking the kernels for a long time. Young leaves are eaten fresh or cooked as a vegetable or used in folk festivals (Vasudeva et al. 2015). The tender leaves of the plant are used to prevent and control early symptoms of diabetes. The smoke of burning leaves is believed to be efficient against hiccups and severe throat troubles. The mixture of leaf ash, mustard oil, and common salt is used as tooth powder for good dental hygiene. The seed kernel is used to cure various ailments like asthma, nose bleeding, piles, intestinal worms, diarrhea, dysentery, and spleen enlargement. The tree bark is known to cure diphtheria, menstrual disorders, and eczema and heal wounds. The gum of the tree and resinous substance are used curing cutaneous infections and scabies apart from their use in healing cracks in the skin of the feet. The sap or juice that oozes at the time of plucking fruit is known to give immediate relief from pain resulting from scorpion or bee sting. The raw fruit drink with salt is known to prevent excessive loss of electrolytes from the body, thereby preventing from heat stroke during summer. Because of high vitamin C contents, it is found to be useful in treating blood disorders. The raw mango powder known as Amchur or dried unripe mango slices are rich in citric acid and ease the digestion apart from helping cure digestive disorders like dysentery, piles, chronic dyspepsia, and constipation. The raw fruit is used in making chutney, tambuli, and pickles. The tender fruits of special mango variety *Appe* are used for pickle as well as extracting resin used as a flavoring agent. The consumption of ripe mango is known to cure bacterial infections, body weakness, and spleen enlargement (Budhwar 2002; Vasudeva et al. 2015). Mango is the most significant species identified through cultural importance values as well as use

Table 8 Profile of documented custodian farmers of mango from South and Southeast Asian countries

S. No.	Farmers	Varieties	Title	Country
1	Mr. Dattatreya Hegde	12 *appe* mango	The custodian of the unique *Appe* mango of the Western Ghats, India	India
2	Mr. Vishweswar Ganapathi Hegde 'Eshanna'	25 mango including 14 *appe* mango	Master grafting expert and barefoot breeder of local mango varieties	India
3	Mr. K Ravindranath	24 including 4 *naati* (local) varieties	Custodian of indigenous mango diversity	India
4	Mr. P. Laxminarayana Reddy	14 mango	Custodian of indigenous mango diversity	India
5	Mr. M Gunashekar Reddy	15 mango including 4 *naati* (local) varieties	Custodian of indigenous mango diversity	India
6	Mr. Chote Lal Kashyap	135 varieties including seedling types	Limited resources led farmers to create and conserve mango varieties	India
7	Mr. Nawab Hasan	51 varieties	Conserving century old mango varieties	
8	Mr. Kailash Prasad Rai	13 varieties of seedling mango	The custodian of high yielding diversity of *Bathua* mango	India
9	Mr. Maiku lal	42 varieties	Finding the balance between commercial and seedling trees	India
10	Mr. Ahmad Kusasi	6 *Mangifera* spp. with *Kasturi*, *Rawa-rawa*, *Kuini*, and *Hambawang* (3)	Mango custodian farmer	Indonesia
11	Mr. Suradech Tapuan	21 varieties of mango and 4 wild relatives	A champion of side grafting and custodian of unique mango diversity	Thailand
12	Mr. Vinod Rai	35 mango varieties	The custodian of richest diversity of seedling mangoes	India

Source: Sthapit et al. (2013)

categories across south and Southeast Asian countries. In India mango showed higher number of uses and cultural important value suggesting its deep cultural value. In other South and Southeastern countries like Indonesia, Malaysia, and Thailand, *M. odorata*, *M. pajang*, and *M. foetida*, respectively, were found superior in terms of cultural importance values besides *M. indica* (Vasudeva et al. 2015).

8 Conclusions with Recommendations for Future

Genetic resources play an important role in crop improvement. Majority of the mango germplasm plantations are old and traditional, planted at wider spacing and as a result of neglect, dense canopy, the yields have reduced considerably. Hence there is a need to evaluate available germplasm and find out a suitable scientific canopy management practices along with recommendations on nutrient and water management of different varieties grown under different agroclimatic conditions. The germplasm that can serve as base material for developing insect-resistant varieties needs to be collected and employed in varietal development programs to manage the mango crop from attack of large number of pests and diseases causing serious damage to fruit yield and quality due to heavy pressure on control of pests through chemical management. The large mango germplasm collections conserved and characterized in the various field gene banks across the world needs to be shared with bonafide researchers for its proper utilization in crop improvement programs. There is need for concerted studies on the effect of climate change and their consequences for conservation of genetic resources and their abundance, composition, and distribution of different species and populations. There is need to review and prepare complementary conservation measures both in situ and ex situ in the context of climate change. The ill effects of climate change can be mitigated through diversification of food production and land use. The duplication of germplasm at field gene banks increases the burden on the institution maintaining it, and hence analyzing and reducing duplications is needed to streamline conservation efforts besides helping in identification of least cost conservation areas. Extensive surveys can be conducted to identify and collect trait-specific mango germplasm in diversity-rich regions.

Surveys will also help in strengthening efforts to reduce threats to wild relatives by collecting and conserving germplasm from rich genetic diversity areas. Extending the incentive mechanisms for supporting on farm conservation activities of the local custodian farmers will provide them with sustainable livelihood options. Climate change has also made cultivation of crops in areas hitherto not possible helping in exploring the idea of establishing germplasm conservation units outside the current germplasm distribution ranges. The core and mini core collections need to be developed and evaluated for identifying the diverse genetic trait-specific germplasm for higher yield to develop broad-based cultivars that can adapt environmental changes and help achieve nutritional food and nutritional security demands of the increasing global population.

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