CHAPTER 1

Mango popularly known as “Aam” is a national fruit of India. Scientifically it is called as *Mangifera indica* L., which belongs to Anacardiaceae family. It is designated as ‘King of Fruits’. It is extensively cultivated in tropical, sub-tropical countries of the biosphere and admired for its delicious taste, flavour, aroma and high source of amino acids, various fatty acids, important minerals, organic acids, carbohydrates, proteins and vitamins (Bally, 2006; Mukherjee and Litz, 2009; Banerjee, 2011). Mango pulp is one of the important sources of vitamins particularly “Vitamin-C” and free sugars (glucose, fructose, and sucrose), increasing 3-4-fold with the fruit ripening (Mukharjee and Litz, 2009). A review of the literature indicates that mango fruits also possess various properties like cardiotonic, anti-diabetic, hypotensive, anti-oxidant, anti-viral, and anti-inflammatory (Shah *et al*., 2010). Therefore, is used in Ayurvedic and indigenous medicinal systems since time immemorable.

Taxonomically, mango plants are erect and tall trees, reaching up to 10 to 65 feet in height, canopy dome-shaped, symmetrical, evergreen, stem woody, profusely branched with a dense canopy. In contrast, grafted trees are relatively small (dwarf) with variously spreading branches. The size of the tree and shape of the canopy of trees depend on variety of the mango and space available for their growth and development. Available literature indicates that some of the mango varieties are surviving for the last 300 years, and still, these trees are fruiting, while the age of grafted trees 80 years or less (FAOSTAT, 2002).

In India, a giant mango tree is reported to grow at Chandigarh (Punjab, India), which has a main stem nearly 350 cm and limbs are 75 cm in diameter, having colossal crown and producing nearly 16,000 fruits during the peak years, though the tree is more than 100 years of age (Singh, 1960). Another giant mango tree is recorded from Brazil by Popenoe (1920). This tree is occupying nearly 38.1 meter and a circumference of nearly 8 meter. A fully grown tree has a long, vigorous taproots with several branches of surface feeder roots reaching a depth of 20 ft. Depending on the variety, leaf morphology is highly variable; they are simple, alternate, petiolate, may be lanceolate, oblong-lanceolate, ovate, or intermediate type, linear and brownish (copper colour) when young and gradually turn green with maturity.

The inflorescence is a panicle that bears several white, pinkish flowers with reddish lines. The flower size varies from 5.5 to 8.5 mm and depends on the variety.

The drupe type of fruits is irregularly egg-shaped, rounded to ovate-oblong and have a slight conical beak at the apex. Depending on the variety, fruit flavour, taste and size varies. The fruit skin is leathery, waxy, smooth, thick, and aromatic. The skin colour is a combination of green to dark-green, red and yellow pigments when unripe or immature, while ripen fruit turns yellow, orange, reddish, pink and purple-red depending on the genotype (Mukharjee and Litz, 2009; Knight *et al*., 2009).

1.1 *Varieties*:

It is believed that cultivated mango varieties/germplasms are produced from the natural hybridization between *M. indica* and *M. sylvatica* Roxb. After several years of selection and breeding programs, high-quality germplasms were developed (Litz, 2009). India has a large number of mango varieties as compared to other parts of the world. The number of varieties/germplasms is estimated to be more than 1000, and each variety differs from others in size, shape, colour, texture & taste of the fruit and tree size (Litz, 2009; Singh, 2019).

Every variety has different names based on their quality and characters depending on the locality. The same variety may be known by another name in a different location/ biogeographical zone of India. For example, Himsagar of South Bengal is known as Khirsapati in Malda (Sammadar, 2001). The most preferable and famous varieties like *Alphanso*, *Bombay Green*, *Banganpalli*, *Bangalora*, *Chausa*, *Dashehari*, *Gulab Khas*, *Himsagar*, *Kesar*, *Kishan Bhog*, *Langra*, *Neelam*, *Rumani*, *Rajapuri*, *Suvarna Rekha* and *Vanraj* are under cultivation in different states depending on the suitability of the climate. State-wise cultivation of these varieties are provided in the following Table 1.

Table 1. State-wise cultivation of some of the important varieties of Mango (*Mangifera indica*) Source: NHB, 2018; Yadav and Pandey, 2016.

S. No	States	Germplasms/Varieties
1.	Andhra Pradesh	*Survarnarekha, Banganpalli, Neelam, Totapuri*
2.	Bihar	*Bombay Green, Chausa, Dashehari, Fazli, Langra, Gulab Khas, Kishan bhog, Himsagar, Zardalu*

3.	Gujarat	*Alphanso, Dashehari, Jamadar, Kesar, Langra, Neelam, Rajapuri, Totapuri, Vanraj,*
4.	Haryana	*Chausa, Dashehari, Fajri, Langra,*
5.	Himachal Pradesh	*Chausa, Dashehari* and *Langra*
6.	Karnataka	*Alphanso, Banganpalli, Mulgoa, Neelam, Pairi, Totapuri*
7.	Maharashtra	*Alphanso, Kesar, Neelam, Pairi, Totapuri*
8.	Punjab	*Chausa, Dashehari, Malda*
9.	Rajasthan	*Bombay Green, Chausa, Dashehari, Langra*
10.	Tamil Nadu	*Alphonso, Bangalora, Banganpalli, Neelam*
11.	Uttar Pradesh	*Bombay Green, Chausa, Dashehari, Langra, Totapuri*
12.	West Bengal	*Bombay Green, Fajri, Gulab khas, Himsagar, Kishan bhog, Langra,*

1.2 *History of Mango cultivation*:

Available literature indicates that mangoes are cultivated in India since time immemorable, and records can be found in various sacred *Granths* (Sanskrit literature) like *Ramayana* and *Mahabharat* mentioning the mango forest and gardens (Das *et al*., 2019), including *Ashok Vatika* in Shri Lanka. Their inflorescences are used for the worship of the goddess, while leaves are strung in the form of garland over doorways on auspicious occasions. The mango is not only national fruit, but is also one of the commercially important and ancient fruit yielding crops of India, Pakistan, the Philippines and the national tree of Bangladesh (Mehta, 2017).

According to Singh *et al.* (2016) and Mehta (2017), mango is cultivated for many years in the Indian sub-continent, estimated to be more than 4000 to 6000 years ago. The mango has been described as "Kalpakavruksha" or wish giving tree. The Mughal Emperor Babar called it is the choicest fruit of Hindustan whereas, the son of Babar, Akbar (1556-1605), established an orchard in Darbhanga (Bihar) with 1,00,000 trees. This was the first mango orchard in India which shows the record of grafted Mango (Singh, 2019). The second orchard of grafted mangoes was established by

Jahangir in Lahore (now in Pakistan). Similarly, the most favourite, expensive and internationally recognised variety from Gujarat called '*Kesar'* was first cultivated by Nawab of Junagadh in 1931.

Sculptures of the mango tree and its fruit are found in the Buddhist stupa at Sanchi, which dates back about 150 BC. The invading armies of Alexander, found it established in the Indus Valley in 327 BC. The travel notes written by Fahien and Sung–Yun on the Buddhist pilgrims has mentioned about the mango sacred groves that have been presented by *Amaradharika* to Lord Buddha so that the Great Master might use them as a place of repose. Mango as an important fruit of India is also recorded in the notes of the early foreigners who travelled in India. These travellers include Hsiian – Tsang (632-645), ibe-Haukul (902-968), ibn-Batuta Hsiian (1325-1349) and Ludovici de Varthama (1503- 1508). It appears, however, that Hsiian – Tsang was the first person to bring the mango to the notice of the people outside India (Singh *et al.*, 2016; Mehta, 2017). The mango cultivator Haji Kalimullah developed a variety by crossing between Kolkata's Husn–e –Aara and Lucknow's *Dashehari* and named the variety as "Modi Mango" (Mehta, 2017).

1.3 *Origin and Geographical Distribution of Mango*:

The origin of mango is highly debatable matter from several years. According to De Candolle (1884), mango is native to South Asia or Malay, while Hooker (1876) believe that it has been naturalized in India. Seward (1912) reported that mango is originated in Assam based on some fossil records. Similarly, available literature from the Birbal Sahni Institute of Palaeobotany, Lucknow, indicates that the genus *Mangifera* originated from Meghalaya and named *Eomangiferophyllum damalgiriensis* (Mehrotra *et al*., 1998). In 4-5th centuries BC, it was believed that mango was carried from India to North East countries such as Malays, Peninsula and China by the Buddhist monks (Singh *et al*., 2016). The spread of mango started in the 7th century AD when Chinese traveler Hwen Tsang took Mango from India to China (Litz, 2009; Gao *et al*., 2011; Mehta, 2017).

Further, Persians transferred it to East Africa in the 10th century AD (Purseglove, 1969). In the 16th century AD, Mango was transported to West Africa and Brazil by the Portuguese (Litz, 2009). After establishing mango plantation in Brazil, it was spread all over the area of the West Indies around 1742 AD, followed by Jamaica in 1782 AD. Subsequently, it reached the Philippines and the West Indies to Mexico in the

19th Century (Morton, 1987). During 1862-1863, it was taken from the West Indies and transferred to Miami (Litz, 2009). In 1875, more than 40 mango varieties taken from India were planted in North Queensland, Australia, after post-European colonisation (Morton, 1987). The maximum diversity of wild species of mango is found in the peninsular Malaya, Borneo and Sumatra area of Indonesia and Malaysia. The existence of *Mangifera* species naturally extends as 27°N latitude north and the Caroline Islands as the East (Bompard and Schnell, 1997).

Regarding its origin, genetic diversity studies revealed that mango is originated from the Indo-Burma region (Vavilov, 1926), while Mukherjee (195l) suggested that mango originated first during the Quaternary period. On the other hand, Mukharjee and Litz, (2009) considered that *Mangifera indica* might have originated from several closely allied species from Malaya Archipelago. Now, it is unanimously accepted that the centre of origin and diversity of the genus *Mangifera* is Southeast Asia (Mukherjee, 1997; Bompard and Schnell, 1997).

Based on recent molecular evidence supported with taxonomic characters, mango might have probably evolved in North-eastern India and adjoining large area such as North Western Myanmar and Bangladesh (Mukherjee, 1997; Bompard, 2009; Mukharjee and Litz, 2009). For cultivation purpose, mainly the dry region of the North and South equator zone of the Indian subcontinent, Southeast Asia, Central, South America, and tropical wet areas are suitable for Mango (Litz, 2009). After the evolutionary study on mango, North East India is documented as the centre of origin and spread into neighbouring areas of India like South East Asia, Malaysia and other countries (Litz, 2009; Singh *et al*., 2016; Mehta, 2017).

1.4 *Production of Mango Fruits*:

India is the major producer of mango fruits and its production is increasing year by year (Figure 1). At represent, India contributes to nearly 50% of the total production of mango fruits throughout the world (FAOSTAT, 2016). Commercially, more than 80 countries are growing mango, but India is still leading in its production, thereafter ranks China and Thailand (FAOSTAT, 2016). Major mango producing nations of the world are India, Brazil, China, Mexico, Thailand etc. In 2019, Thailand overtook other countries and became the world's largest mango exporter, followed by Mexico and Brazil, respectively. In India, mango production in 2017-18 was recorded around 21,822

MT and 2258 ha, with 9.7 MT productivity (NHB, 2018) (Figure 1). The area, production and productivity of different states are provided in Figure 2.

1.5 *Nutritional Value*:

Mango fruit has high-quality fibre, a great source of amino acids, carbohydrates, fatty acids, minerals, organic acids, proteins and vitamins like A and C), higher minerals, and nutrients. It has a delicious taste due to free sugars (glucose, fructose and sucrose), which increases 3-4-fold with the fruit ripening and gives good health benefits. Due to all these valuable components, it always remains in high demand (Mukharjee and Litz, 2009; Lemmens *et al*., 2013; Ward 2014; Maldonado-Celis *et al*., 2019). Now, its food value has been well recognised, and fruits have become an essential part of a complete or balanced diet for the maintenance of life and growth of body tissues. Mango fruits also contain essential mineral elements like potassium, phosphorus, iron, calcium and sulphur in an easily assimilable form (Lauricella *et al*., 2017; Lebaka *et al*., 2021; Maldonado-Celis *et al*., 2019). Fruits are very rich in vitamins, which directly influence the growth and development of the body.

Before ripening, fruits are initially acidic, astringent, and rich in ascorbic acid. Subsequently, they become sweet as they ripe owing to hydrolysis of starch into free sugars such as glucose, fructose, sucrose and mainly sucrose concentration increase 3-4 times (Chander *et al*., 2004; Mukharjee and Litz, 2009). Besides these components, oxalic, malonic, succinic, pyruvic, adipic, galacturonic, glucuronic, tartaric, glycolic and mucic acids are also present in it (Mukharjee and Liz, 2009; Lebaka *et al*., 2021; Maldonado-Celis *et al*., 2019). The following table gives general information about the different nutritional components of mango fruits (Table 2).

Table 2. Nutritional value of *Mangifera indica* fruits per 100 g (Source: Lauricella *et al*., 2017).

Energy	**60 Kcal**
Fruit composition	**Quantity**
Carbohydrates	14.98 g
Protein	0.82 g
Fat	0.38 g
Fibre	1.6 g
Vitamins	

Vitamin C	36.4 mg
Vitamin E	1.12 mg
Vitamin A	1082 IU
Niacin (Vit B3)	669 µg
Pantothenic acid (vit B5)	160 µg
Pyridoxine (Vit B6)	119 µg
Riboflavin (Vit B2)	38 µg
Thiamin (Vit B1)	28 µg
Folates	43 µg
Vitamin K	4.2 µg
Minerals	
Potassium	168 mg
Phosphorus	14 mg
Calcium	11 mg
Magnesium	10 mg
Sodium	1 mg
Copper	110 µg
Iron	160 µg
Manganese	27 µg
Zinc	90 µg
Carotenoids	
β−Carotene	445 µg
α−Carotene	17 µg

Despite all these importance, economic significance and nutritional value; mango crop is suffering from numerous diseases *viz*., Powdery mildew, Anthracnose, Dieback, Phoma blight, Bacterial canker, Red rust, Sooty mold and other disorders like Mango malformation, Biennial bearing, Fruit drop, Blacktip and Clustering illness also referred as 'Jhumka' (Prakash and Srivastava, 1987). Every part of the plant, including-trunk, branch, twig, leaf, petiole, flower and fruit, are assaulted by several plant pathogens, including fungi, bacteria and viruses. These pathogens are responsible for inducing various types of illness like- rot, dieback, anthracnose, scab, necrosis, blotch, spots, mildew *etc.* (Prakash and Srivastava, 1987, Prakash, 2004; Litz, 2009).

Among different diseases of mango, powdery mildew is of great economic importance as it causes heavy losses in mango production. The powdery mildew is documented in more than 35 countries of the world and causing up to 90 % loss in India (Mishra, 2001). Anthracnose is also a destructive and widespread disease throughout India and recorded the failure in the range from 2-39 % in India (Prakash *et al*., 1996) and recorded 30-60 percent yield losses from various nations throughout the world (Akem, 2006; Chowdhury and Rahim, 2009). Bacterial canker causes fruit drop up to 10- 70 % yield loss of 10-85 % before harvesting and 5-100 % in storage rot after post-harvesting (Sarwar, 2015). However, mango malformation disease is also a major problem, which reduces yields from 50-80 % (Kumar *et al*., 2011). Among all the disease mentioned above, "**Mango burl**" is another critical disorder that earlier researchers invariably neglected. The reason for not paying attention is that it is not directly associated with fruits; instead, it is a stem disease. Burl is an uncontrolled growth like tumours or swelling, which develops on the main trunk and lower or primary branches.

In the past, burls like symptoms were reported in *Mahmud Vikarabad* variety from India by Chand and Rao (1954). White and Millington (1954) wrote that burls or gall are not only occurring on specific plants but also found to develop on other numerous plant species as single or in groups at any stage of plant development. The comparable disease symptoms were reported from various countries like Hawaii (Cook *et al*., 1971), from Mexico by Angulo and Villapudua (1982) and the USA by Ploetz and Freeman (2009). It is also reported from Pakistan with large size and of different textures (Hafiz, 1986). Jiskani *et al*. (2007) reported the same on the name of crown gall disease of Mango from Pakistan and documented that it is an overgrown ball-shaped mass that looks like a tumour or knots or galls on the main trunk/stem and branches. Such symptoms are also observed on several plant species, including Cherry, Apple, Grape and Apricot from Pakistan (Ali *et al*., 2010), which leads to significant economic loss. These tumours are smaller on the roots portion, whereas hard and woody on the collar region of the stems.

Prakash and Srivastava (1987) reported the burls of mango under woody gall in varieties like *Langra*, *Pairi*, and *Gulab Jamun* from Malda, Hessarghatta, and Uttar Pradesh. Smith (2012) reported that a gall results from hypertrophy (overgrowth) and hyperplasia (excessive cell division), usually under the influence of a parasitic organism. It is well known that gall and tumours are induced by bacteria, fungi,

nematodes, mites and insects (White and Millington, 1954; Malaguti and de Reyes, 1964; Angulo and Villapudua, 1982; Ploetz *et al.*, 1996b; Saran *et al*., 2020a, b). However, there is an erroneous use of the term by various researchers. Burl disorder differs from previously reported gall disease; burl is caused by a bacteria named *Agrobacterium tumefaciens* (Saran *et al*., 2020b), while gall is caused in response to the activity mainly by insects or nematodes (White and Millington, 1954; Harris, 1994).

Saran *et al*. (2011) reported that *Langra* variety was found to be highly infected with burl disease and causes the highest incidence (80.3 %) with burl size (31.8 cm in diam.) subsequently in *Chausa* (17.5 %; 16.4 cm) respectively. In contrast, the *Gulab Jamun* variety was found relatively less infected (7.5 %; 4.0 cm) than *Langra* and *Chausa* (Saran *et al*., 2011). They also observed the correlation between the fruit yield losses in all three varieties, burl disease and age, and further noticed that burl size increase with the increase in age of the tree. The above observable fact was seen in 12 to 60 years old plants, mainly of *Langra* and *Chausa* varieties.

In 1675, Malpighi defined galls as "an abnormal growth of plant", which is caused by micro-organisms. After that, several reports have been published for gall disease with different names and definitions (Stubbs, 1987; Spooner, 1990; Redfern, 1992). These studies described an abnormal growth on any part of the plant body formed due to active mitosis and morphogenesis of affected cells (Williams, 1994). Furthermore, it was also described as pathologically developed cells, tissues or organs of plants. Garrett (1987) documented that crown gall had no influence on the growth of cherry trees, while others have reported that the disease causes mortality of peaches and cherries (Kainski, 1964), stunting of peaches (Kerr and Htay, 1974) and pecans (Bouzar *et al*., 1983). These species include *Prunus dulcis* (almond), *Malus domestica* (apple), Prunus sp. (apricot), *Rubus plicatus* (blackberry), *Prunus avium* (cherry), *Populus deltoides* (cottonwood), *Euonymus* sp., *Ficus carica* (fig), *Vitis vinifera* (grape), *Lonicera caprifolium* (honeysuckle), *Prunus persica* (nectarine), *Carya illinoinensis* (pecan), *Pyrus* sp. (pear), *Prunus* sp. (plum), different species of *Pyracantha* (pyracanth), *Rubus ideaus* (raspberry), *Rosa* sp. (rose), *Beta vulgaris* (sugar-beet), *Brassica rapa* var. *rapa* (turnip), *Juglans regia* (walnut), and different species of *Salix* (willow). Plants affected by crown gall frequently grow poorly due to the interference of the disease in the regular transport of water and transport of photosynthate (Horst and Raymond, 2007), leading to becoming underdeveloped, weak, and more vulnerable to winter injury.

A perusal of literature indicates the general description about the occurrence, disease symptoms and related disorder is available, but other information like the effect of disease on plant morphology, anatomy, incidence on different varieties, causal organism and yield loss is yet to be investigated. There is no unanimous opinion about the causal organism of burl disease, and it is ambiguous because several reports that mention bacteria and fungi are causal organisms. Malaguti and de Reyes, (1964) from Florida (USA), Angulo and Villapudua, (1982) from Mexico and Ploetz *et al.* (1996b) from Venezuela reported that the burl formation in mango is caused by *Fusarium decemcellulare* C. Brick (synonym: *Fusarium rigidiuscula* (Brick) Snyd. and Hans.).

In contrast, Hafiz (1986) and Jiskani *et al*. (2007) reported that it causes the infection of *Agrobacterium tumefaciens*. In Hawaii, a similar pathogen was isolated by Cook (1975), but after re-inoculating in host species, they failed to recover from affected plants. A similar experiment was carried out in Miami by using the *Agrobacterium tumefaciens*, and they were able to induce the burl. Still, they failed to isolate it from the affected parts (*cited from* R. McGuire, Miami, 1993, Ploetz and Freeman, 2009). According to Raman (2007), the modern explanation for the galls excludes abnormal growth that is caused by bacteria and fungi because their action would generally result in amorphous developments. Therefore, it should be called tumours, whereas insect induced galls result in the symmetrical structures that should be called as galls. Thus, there is an urgent need to understand the difference between galls and burls to understand the loss of yield in mango caused by burl formation in well-known varieties of *Mangifera indica*.

Therefore, the main aim of the present study was to confirm causal organism, disease development, histological alterations in the normal and burl wood, its impact on yield loss, alterations in the nutritional value of the fruits produced by affected trees and its comparison with healthy individuals of different varieties of *Mangifera indica*. The present study also intends to study the changes in morphology, the biochemical composition of fruits and structural alterations induced in the infected portions of the stem, in transition and a healthy part of the stem.