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Mango Diseases: Impact of Fungicides

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Abstract

Mango, *Mangifera indica* L., is known to be the king of all fruits due to its delicious taste, marvelous fragrance, and beautiful appearance. However, several infectious diseases caused by many phytopathogens are deteriorating mango quality and quantity. Mango tree and fruit have been affected by about 83 diseases reported worldwide, and in Pakistan, 27 diseases are recognized as more important. Disease control always remains a challenge for the farmers to get optimum production especially due to pesticide resistance. Resistance to fungicide in current days is a major threat to plant disease management. In many cases, plant pathogen resistance could develop naturally; thus, several newly developed chemistries of fungicides remain at high risk. However, research toward an increase of resistance and delay in disease development has been undertaken. Existing fungicide chemistry, sometimes, renamed with new trade name does not satisfy the farmer to apply such fungicides for disease management. However, chemical fungicides are believed to be a significant way to control fungal pathogens or sometimes to inhibit and prevent the development of pathogens. However, due to pathogen resistance development, it is hard to manage plant diseases. Therefore, the impacts of such fungicide management in some important mango diseases are discussed in this chapter.

Keywords: mango diseases, cause, management, fungicides, resistance development

1. Introduction

Mango, *Mangifera indica* L., the king of all fruits, belongs to the family Anacardiaceae and order Sapindales [1]. Generally, it is grown in tropical and subtropical regions of Southeast Asia [2]. The native home of mango is considered as India to Burma (Myanmar) or maybe from the Malay region. Since the sixteenth century, it traveled to other parts of the world [3]. Mango was introduced from India to other countries of the tropical and subtropical world mainly by the Muslim missionaries, Spanish voyagers, and Portuguese [4–6]. The great Mughal Emperors, especially Akbar, made the preliminary contribution by establishing the Lakh Bagh through the selection and subsequent cloning. In other reports, mango seed traveling begin around 300 or 400 AD from Asia to the Middle East, East Africa, and South America [7, 8]. Some mango growers believed that Malaysian region is the original home of mango, due to a maximum number of species grown over there, whereas the recorded numbers of grown species are about 20. However, in Eastern India and Burma, the cultivation of mango reported in history is certainly for more than 4000 years [9–11]. The highest number of mango species takes place

in the Malay Peninsula, the Indonesian archipelago, Thailand, Indo-China, and the Philippines [12, 13]. Many researchers have reported that Southeast Asia is currently recognized as the center of origin due to the diversity of mango species. Thus, the origin of mango has remained controversial for many years. However, it is now grown in many tropical and subtropical regions worldwide [14, 15]. The cultivation of mango is now being distributed in about 85 countries. The important mango growing countries are Pakistan, India, China, the Philippines, Sri Lanka, Bangladesh, Indonesia, Thailand, Burma, Malaysia, Israel, Egypt, South Africa, Australia, Brazil, Cuba, and the USA [8, 16–18]. Nevertheless, the top 10 mango growing countries of the world and production scenario of 2014 are illustrated in **Figure 1**. It is shown that India is on the top followed by China, Thailand, Indonesia, Pakistan, Mexico, Brazil, Bangladesh, Nigeria, and the Philippines [19].

The mature tree of many can survive for several hundred years and attain a height of 40 meters or more [20]. The mango fruits from Pakistan are well reputed due to its delicious taste, excellent flavor, and high nutritive values [21]. Mango is providing seasonal job opportunities to most common illiterate and less literate villagers of the countryside; thus it is considered a major foreign currency earning fruit crops of Pakistan. The people from the countryside are mostly engaged in various jobs such as growing and managing the orchards, picking, packing, shipment, and processing of mango fruits. The unripe (green) mango fruits are also processed as powder form or in solar-dried slices, which is used in curries as well as in other cookies. Therefore, in the mango growing areas of Tando Qaisar, District Hyderabad, Sindh, Pakistan, it is believed to be one of the best sources of earning for local people [22].

Mango is a nutritionally rich fruit with a unique flavor, fragrance, and taste. It is an excellent source of vitamin A with flavonoids like beta-carotene, alpha-carotene, and beta-cryptoxanthin. The research reports revealed that the consumption of natural fruits rich in carotenes is known to protect against oral cavity and lung cancers. In addition, mango fruit is also a rich source of vitamins, minerals, fiber, prebiotic dietary, and antioxidant compounds, thus promoting the benefits for human health. Recent research revealed that the consumption of mango fruit protects against colon, breast leukemia, and prostate cancer [23, 24].

It is also believed that almost every part of the mango plant is used for different purposes. The mango is delighted and liked by everyone for its marvelous flavor

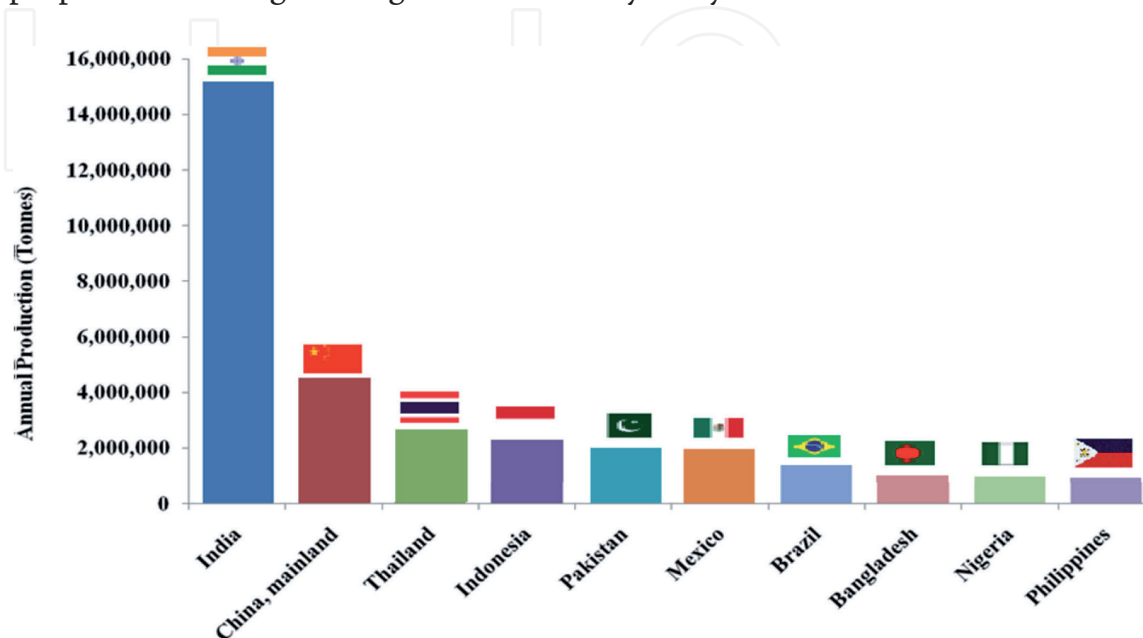


Figure 1.

Top 10 mango growing countries of the world [accessed from source: FAOSTAT database, 2014].

and delicious taste. Nutritionally as well as medicinally, mango is known to be a rich fruit. It is consumed raw as well as ripe, thus interestingly no any part is wasted. Raw fruits are sliced, dried, and floured (starch), commonly used for cooking. In addition, unripe fruit can be made into chutneys, drinks, and pickles is considered to be an effective antidote for mild forms of sunstroke, whereas ripe fruits besides being consumed as a dessert are processed into jam, squash, slices, pulp, juices, as a flavoring for baked goods, ice cream, milkshakes, jelly, marmalade, yoghurt, nectar, and mango leather. The kernel contains 8–10% fat which is used in the soap industry, while its starch can be used in the confectionary industry [6, 25].

Almost all the products and by-products made from mango are commonly used and preferred by the people in Pakistan and India. Anacardic acid is prepared from the peels (skin); although the wood quality of mango is poor, timber is used for making furniture, flooring, boats, packing cases, and other applications. Tannins mainly used for curing leather are also obtained from the bark of the tree. The twigs as well as young vegetative leaves are used for various religious purposes and for medicinal value [6, 8].

2. Major yield threats to mango production

Several pests, diseases, and disorders have been recorded on various mango varieties, ultimately resulting in severe losses to all parts of the mango around the world. Approximately 260 pest species including major and minor pests have been recorded from seedlings to mature trees at harvest and postharvest stages [26].

2.1 Mango diseases

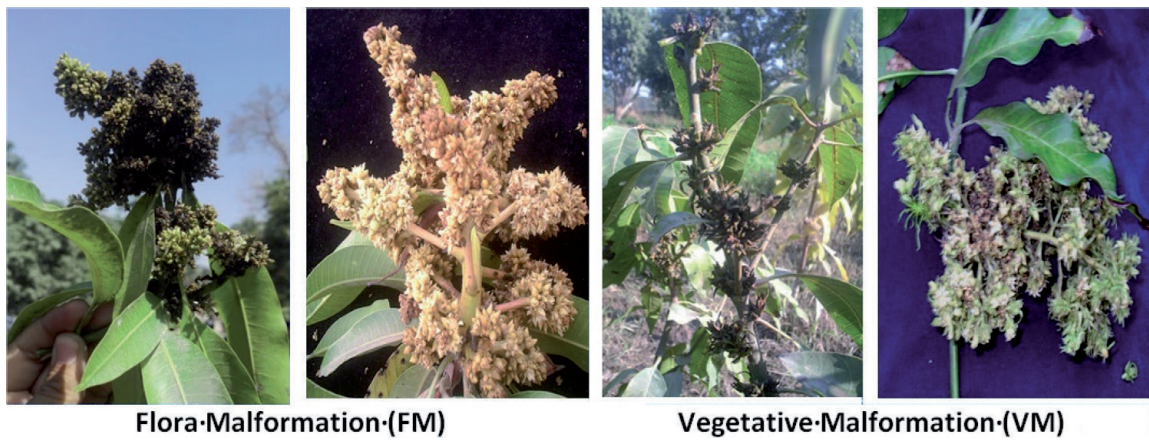
Mango suffers from several infectious diseases caused by many phytopathogens. More than 83 different diseases and disorders including 52 fungal, 3 bacterial, and 3 plant-parasitic nematodes of the mango tree and fruit have been recorded worldwide which cause losses; however, fortunately no single disease is caused by the virus till now in mango [27, 28]. Twenty-seven diseases have been reported in mango trees of Pakistan [28]. Among them the main diseases are anthracnose, *Colletotrichum gloeosporioides* (Penz.) (**Figure 2**); powdery mildew, *Oidium mangiferae* (Bert.) (**Figure 3**); malformation, *Fusarium* spp. (**Figure 4**); bacterial leaf spot, *Erwinia mangiferae* (Doidge) (**Figure 5**); crown gall, *Agrobacterium tumefaciens* (**Figure 6**); sooty mold, *Capnodium mangiferae* (**Figure 7**); fruit rot, *C. gloeosporioides* and *Aspergillus niger* (**Figure 8**); root rot, *Rhizoctonia solani* (Kuhn) and *F. oxysporum* (Schl.) (**Figure 9**);



Figure 2.
Anthracnose disease (Colletotrichum gloeosporioides Penz.).



Figure 3.
Powdery mildew disease (Oidium mangiferae Bert.).



Flora-Malformation-(FM)

Vegetative-Malformation-(VM)

Figure 4.
Mango malformation disease (Fusarium spp.).



Figure 5.
Bacterial leaf spot (Erwinia mangiferae Doidge).



Figure 6.
Crown gall (Agrobacterium tumefaciens).



Figure 7.
Sooty mold (*Capnodium mangiferae*).



Figure 8.
Fruit rot (*C. gloeosporioides* and *Aspergillus niger*).



Figure 9.
Root rot (*Rhizoctonia solani* Kuhn and *F. oxysporum* Schl.).

dieback, *Diplodia natalensis* and *Lasiodiplodia theobromae* (Pat.) Griff. and Maubl. (Syn. *Botryodiplodia theobromae* Pat.) (**Figure 10**); gummosis, *L. theobromae* (**Figure 11**); and mango sudden decline (**Figure 12**), a complex disease [28–38].

Moreover, mango decline, mango sudden decline syndrome (MSDS), mango sudden death syndrome (MSDS), and mango tree mortality (MTM) are the common terms/phrases used for mango sudden decline disease. In the last decade, MSDS remained the most common and destructive diseases throughout Pakistan. Different workers have isolated various fungi and another organism from an infected mango tree. In a recent study, 21 different species of diseases from infected mango trees have been reported. However, it is a complex problem and actually is a result of anthracnose, dieback, root rot, tip dieback, gummosis, and dying of plants, observed very commonly in the orchards of different ages in Sindh province [22].



Figure 10.
Dieback (Lasiodiplodia theobromae Pat.)



Figure 11.
Gummosis (Lasiodiplodia theobromae).



Figure 12.
Mango sudden decline.

3. Fungicide management and resistance development

Plant disease control has always been a challenge for the growers and farmers to get optimum production due to pesticide resistance. Resistance to fungicide in current days is a major threat to plant disease management. In many plant pathogens, resistance could develop naturally; thus, several newly developed chemistries of fungicide remain at high risk. However, research toward the increase of resistance and delay in disease development has been undertaken. The existing fungicide chemistry, sometimes, renamed with new trade name does not satisfy the farmer to apply such fungicides [39] for the management of diseases. It is also obvious that

even within the same fungal group the nature of resistance can be different. Fungi may develop alternative biochemical pathways around the ones that the fungicides are blocking. The blocked biochemical pathway may also be overwhelmed by the overproduction of precursors. Fungal cells may develop mechanisms to block entry of the fungicide and/or efficiently export the chemical out of cells. The result manifests itself the same way through disease control failure. An example is benzimidazole fungicides which when first introduced were more effective, and even at lower rates, than anything else on the market. The new systemic nature of the compounds and their broad spectrum of activity encouraged the wide use of these fungicides. These fungicides could control many different fungal diseases including powdery mildews, botrytis blights, leaf spots and blights, and root rots on a large variety of crops. There is even nontarget activity on other organisms including earthworms. Benzimidazole fungicides act by blocking the polymerization of tubulin preventing the nuclear division of fungal cells. The mode of action is so specific within the fungi that simple natural mutations allowed for the development of resistant fungi. The resistance is also very stable within the population. Widespread use of benzimidazole fungicides caused widespread development of resistance. Another example is dicarboximide fungicides which when first introduced were highly effective against diseases caused by *Botrytis*, *Monilinia*, *Sclerotinia*, and similar organisms. The greatest activity of these compounds is in preventing mycelial growth, but spore germination is also reduced. The resistant population is not as stable or competitive as sensitive populations and declines gradually after the selection pressure is removed. How long a break is necessary before the effective reintroduction of the dicarboximide is debatable [39].

Mango diseases as discussed earlier are sometimes hard to manage due to the pathogen cycle and perpetuation in soil and deep root. Several mango diseases are attacking from seedling to maturity; and pre-harvest to postharvest depends on the environmental conditions of the region. Chemical fungicides are believed to be a significant way to control fungal pathogens [40] or sometimes to inhibit and prevent the development and spread of pathogen [41, 42]. However, due to resistance development in pathogen or sometimes in the environment-development of new physiological races, it is hard to manage the plant diseases. The impacts of fungicide management in some importance mango diseases are discussed here.

4. Pre-harvest diseases

4.1 Anthracnose: *Colletotrichum gloeosporioides* (Penz.)

4.1.1 Cause, disease cycle, and symptoms

Anthracnose, caused by a fungal pathogen *Colletotrichum gloeosporioides*, is a severe outbreak which can cause huge economic losses at various growth stages of mango production ranging from the blossom period to postharvest. It is considered to be the most important disease of the crops in all mango producing areas worldwide [43, 44, 52]. Anthracnose is favored by high relative humidity and abundant rainfall that help in the development of the severe symptoms on leaves, flowers, fruits, and branches of all ages. The disease can cause losses varying from 50 to 100% in unmanaged orchards under a favorable environment [43, 45–46, 52]. Symptom appeared on leaves consisted of angular dark spots, about 3–5 mm long, which can coalesce, and the necrotic areas become more extended generally bordered by a yellow chlorotic halo. The leaf spots appeared due to anthracnose which serves as an important source of inoculum for the more destructive phases of infection on

blossoms and fruits [47]. The conidia of *C. gloeosporioides* are disseminated by rain and/or irrigation water. Thereafter, conidia are become attached with panicles, leaves, and branch terminals at the infection site. Conidia germinate on immature fruits and tender tissues and then penetrate through the cuticle and epidermis. The fungus grows rapidly forming elongated brown necrotic lesions, which later on get blighted and ruptured. Dark blister-like spots also appear on young twigs and leaves. The leaves dry up slowly and ultimately fall down, leaving a black scar on the twig [7]. In the inflorescence, it appears as tiny black spots, which cause extensive necrosis of flowers, and small fruits fall off easily because of wind or rain leaving only the rachis attached to the tree. Affected fruits in early development can remain mummified in necrotic panicles or be aborted altogether. In the case of fruits nearing maturity, the infections are quiescent and cause irregular dark spots that quickly rot the pulp of the fruit when it reaches senescence. In the case of mature fruits, penetration occurs through the cuticle but remain quiescent until the onset of ripening, which can cause postharvest anthracnose after harvesting. In young vegetative stems, it causes canker lesions [48, 49]. Many cycles of the disease can occur as the fungus continues to multiply during the favorable seasons. The pathogen survives between seasons on infected and defoliated branch terminals and mature leaves.

4.1.2 Fungicide management

The use of fungicides for the management of anthracnose disease has been widely done worldwide. Generally, such kinds of fungicides are used when especially anthracnose is out of control due to wet and humid conditions in most commercial mango production situations [50]. To produce commercial market quality fruit, chemicals such as benomyl, copper, and mancozeb have been sprayed weekly on the flowers and at 2- to 3-week intervals on fruit until harvest [51]. Although some mango cultivars are moderately tolerant, none are sufficiently resistant to be produced without fungicides in humid areas [50]. During rainy seasons numerous preventive fungicide applications in the field are necessary to obtain acceptable fruit production [52]. In extreme situations, where fruit develops completely under disease-favorable conditions, up to 25 sprays of fungicides have been reported. It is also mentioned that fungicides are highly effective for anthracnose control reducing the severity in treated fruit by over 90% [52]. Research in India showed that fungicides reduced the severity from 54% infected fruit to 5% [53]. Research has clearly shown that low postharvest decay is associated with effective protection of fruit throughout the growing season [54]. The fungicides carbendazim, prochloraz, and benomyl tested against anthracnose on 40-year-old mango trees revealed that carbendazim showed minimum disease severity when first spraying was done during the emergence of new flushes; second and third spray applications were made at 15-day intervals. Fourth and fifth spray applications were done before monsoon (June) and after the monsoon (first week of October). Reduction in disease severity with the increased average number of fruits per tree on the third year was recorded after application of fungicides [55]. In a field trial, different doses of systemic fungicide, azoxystrobin at 1, 2, and 4 ml L⁻¹ were evaluated against anthracnose disease. All doses of azoxystrobin suppressed the development of both panicle and leaf anthracnose with more production of fruits than control. The results further showed that 2 ml L⁻¹ proved effective against disease than other doses of fungicides [56]. Recently in Pakistan Nasir et al. [57] evaluated seven different organic and one inorganic fungicides for their effectiveness against anthracnose disease. Three bloom sprays were applied: first at 25% flowering and two later applications at 15-day intervals. Best results were achieved with Nativo 75% WDG (tebuconazole+ trifloxystrobin) which controlled anthracnose by 92.03% and powdery mildew by 90.19%. It was followed by Cabriotop 60% WDG

(metiram +pyraclostrobin) which reduced the incidence of these diseases by 89.08% and 88.04%, respectively, whereas Topsin-M 72% WP (thiophanate-methyl), Score 25% EC (difenoconazol), and Shincar 50% SC (carbendazim) provided less than 80% control. In general, all the fungicide treatments significantly reduced the incidence of the diseases and produced a higher yield of quality fruits than control in both years.

Fungicidal resistance/sensitivity among the six different isolates of *C. gloeosporioides* (Cg1 to Cg7) collected from Agricultural Export Zone (AEZ) of Andhra Pradesh and one from Tamil Nadu was studied using four systemic fungicides, viz. carbendazim (50 ppm), thiophanate-methyl (50 ppm), propiconazole (25 ppm), and hexaconazole (25 ppm), and two non-systemic fungicides, viz. mancozeb (1000 ppm) and copper oxychloride (1000 ppm), in poisoned food technique. All isolates were highly sensitive to sensitive for systemic fungicides except Cg3 which was moderately resistant to thiophanate-methyl. Isolates Cg1, Cg3, and Cg6 were highly sensitive, Cg5 and Cg7 were resistant, and Cg2 and Cg4 were highly resistant to mancozeb. It was also confirmed that all isolates were resistant to copper oxychloride. These results indicated the differential resistance/sensitivity to commonly used fungicides against *C. gloeosporioides* and allowed to recommend a specific fungicide on a regional basis [58].

However, in recent years growers have experienced problems controlling this disease, and they have suggested that the fungicides used are not providing acceptable levels of control. Products currently registered for pre-harvest use include mancozeb, copper hydroxide, and copper sulfate products—these are routinely used from flowering through to harvest. Prochloraz is used when weather conditions favor disease development, and a strobilurin product has recently been registered. Thus, an experiment was conducted to develop an integrated crop management (ICM) practice for controlling anthracnose (*C. gloeosporioides*) of mango with emphasis on nonchemical means and achieving higher yield. Pruning + weeding + spading + fertilizer + Dithane M-45 or garlic extract (three times) + irrigation (at 14-day intervals) resulted in the highest fruit retention, healthy fruits, and highest yield [58]. Postharvest hot-water treatments (15 minutes at 5°C (124–125°F) have been shown to reduce anthracnose development in ripe fruits of some specific cultivars such as “Larravi” in Puerto Rico [59] and with the cultivars “Zill,” “Haden,” “Sensation,” “Kent,” and “Keitt” for 5 minutes at about 55°C (131°F) and 15 minutes at 49°C (120°F) in Florida [60]. Hot water dips also reduced stem-end decay caused by several fungi [61]. Because of varietal differences in heat tolerance, tests must be conducted to determine the optimum time and temperature for each cultivar. However, fruit should be ripened before refrigerating in order to avoid chilling injury. Benomyl and thiabendazole at 500–1000 ppm heated to 52°C (126°F), in which mango fruits were dipped for 1–3 minutes, were effective in controlling postharvest decay on “Tommy Atkins” and “Keitt” [62–64]. However, within a short time, the fungus developed resistance to benomyl and had cross-resistance to the related fungicides thiabendazole and thiophanate-methyl (18). Heated iprodione [64], unheated prochloraz [62], and unheated imazalil [60] have also shown efficacy in controlling anthracnose. Anthracnose is best controlled by a combination of preventive measures, field fungicide sprays, and postharvest treatments.

4.2 Powdery mildew: *Oidium mangiferae* (Bert.)

4.2.1 Cause, disease cycle, and symptoms

Mango powdery mildew disease is caused by a fungal pathogen, *Oidium mangiferae* Berthet. The disease was first recorded on mango during 1914 in Brazil, and the fungus was named by Berthet [65, 66]. The associated pathogen *O. mangiferae*

belongs to the class *Ascomycetes*, order *Erysiphales*, and family *Erysiphaceae* [67, 68]. This pathogen was previously considered minor; however, it became severe and attacked nearly all varieties throughout the mango growing countries of the world [69–74]. Powdery mildew of mango is favored by cool nights with warm humid weather conditions that support the severe disease incidence [30–31]. The disease has been reported in many countries of Asia, Africa, America, and Oceania [75]. Powdery mildew appears in foliage, fluorescence, petioles, young fruits, and tender stems as well. The fungus is ectophytic and reaches into the cell through haustoria by penetrating the epidermal layer. Generally, it exhibits superficial whitish fungal growth just like talcum powder. Initially, septate mycelium is developed and later on conidia, which fall after reaching maturity. On a whole, powdery mildew fungus produces white dense coating over the surface of the host. The incidence caused by this disease varied from 31.50 to 93.00% on different sensitive mango varieties. The pathogen develops in dry and cold environments but reaches greater severity at 90% relative humidity (RH) and 20–25°C [74–80].

4.2.2 Fungicide management

Several organic and inorganic fungicides have been evaluated for their effectiveness against powdery mildew disease. The powdery mildew was controlled by applying different fungicides such as benomyl, bitertanol, carbendazim, dinocap, oxythioquinone, thiophanate-methyl, tridemefon, tridemorph, Vigil, wettable sulfur, etc. [81–89]. However, some chemical fungicides such as benomyl, dinocap, and mancozeb were set up most operational at the time of flower cluster expansions and before the cluster opening [90–92]. The higher efficacy of carbendazim against powdery mildew was also proven when sprayed three times with the interval of 15 days [93]. Recently, Topas 100% EC (penconazole) and Vangard 25% EC (triadimenol) were found effective against powdery mildew (89.96% and 91.87%, respectively) [57]. In another experiment, three sprays of penconazole at prebloom, full bloom, and after fruit setting against powdery mildew, *O. mangiferae*, were applied on Samar Bahisht cultivar. It was found more effective than pyrazophos. Several other fungicides have also been tested against powdery mildew in tropical and subtropical regions of the world as protective and curative measures. In trials carried out in 1992, Topsin-M (thiophanate-methyl) was almost as effective as penconazole [94]. Trifloxystrobin has been mentioned as a new strobilurin fungicide, and it was highly effective in controlling powdery mildews on mango [95]. Some foliar fungicides, viz. Baytan Foliar, Calixin, Topas, and Bayleton, against mango powdery mildew (*O. mangiferae* Bert.) were also evaluated in 2000. Two spray applications at 15 days intervals were done on Sindhri, Siroli and Samar Bahisht, and Chaunsa varieties and revealed that Bayleton was found to be the most effective for control of disease followed by Calixin, Baytan Foliar, and Topas [79]. The study on different fungicides such as Topsin-M (thiophanate-methyl), Dithane M-45 (mancozeb), Antracol (propineb), Thiovit (sulfur), Topas (penconazole), Nordox (darosal, copper hydroxide), Anvil (hexaconazole), Aliette (fosetyl), and Rubigan (fenarimol) were tested. Maximum disease control with thiophanate-methyl and sulfur was observed. Two applications at 20–30% and 30–40% in flowering stage were used at fortnight intervals [96]. Another trial tested on Dusehri cultivar against the disease with Anvil (hexaconazole), Spotless (diconazole), Bayleton (triadimefon), benomyl, Score (difenoconazole), and Folicur (tebuconazole) fungicides were evaluated. Anvil, Spotless, and Bayleton gave better results than other fungicides [97], whereas Score (difenoconazole) and Anpower (hexaconazole) resulted to be most effective [98]. The in vitro efficacy of hexaconazole at 0.01% and wettable sulfur at 0.3% was highly effective in the inhibition of conidial germination [99].

Six fungicides such as carbendazim (Bavistin 50 WP) 0.05%, wettable sulfur (Sulfex 80 WP) 0.25%, triadimefon (Bayletan 25 WP) 0.05%, thiophanate-methyl (Roko 70 WP) 0.1%, penconazole (Topas 10% EC) 0.05%, and hexaconazole (Contaf 5EC) 0.05% went through a 3-year experimentation (2006–2008). All the fungicides reduced the disease significantly when applied at prebloom, 10 days after first spray, and at fruit setting stage compared to the untreated control. However, hexaconazole gave the lowest incidence of powdery mildew (21.2%) and was significant over the rest of treatments except triadimefon [100]. Fungicides mostly are of high efficiency in the management of plant diseases [101]. However, the need for reducing pesticide residues in food crops, pressures to maintain a healthy environment, and often the unavailability of commercially acceptable resistant plants intensify the need for alternative methods for disease control. One of the potential methods of reducing the severity of powdery mildew in an environmentally safe manner is the use of inorganic salts like foliar spray by potassium salts [102, 103] as biocompatible fungicides. Monopotassium phosphate and potassium dihydrogen phosphate sprayed alone or in alternation with fungicides have been successful in the control of powdery mildew diseases in apples, grapes, peaches, nectarines, greenhouse cucumbers, roses, melons, and mangoes [103].

It is apparent that several studies have been conducted and workers used different fungicides successfully in order to control powdery mildew disease of mango accompanied by a high yield/tree [104]. However, fungicide resistant races of powdery mildew pathogens have been reported on several crops like as cucumber, grape vines, etc. [105–108]. The fungicide Punch was the most effective on mango and mustard when tested to managing powdery mildew disease in India [109]. However, once resistant strains appeared, most of them survived for several years, therefore the risk of re-enhancing a resistant population with further applications of ineffective [110].

4.3 Malformation: *Fusarium* spp.

4.3.1 Cause, disease cycle, and symptoms

Mango malformation disease (MMD) is a serious threat and is significantly increasing because of the great demand for mango in the international market and expansion of mango production worldwide for export [111]. It occurs in almost all mango growing countries of the world and causes severe economic losses every year [112, 113]. Much more studies are carried out on physiological, viral, fungal, acarological, and nutritional causes [114]. Mango malformation is of two distinct types, vegetative malformation (VM) and floral malformation (FM). The floral malformation is more prevalent in bearing mango trees, whereas vegetative malformation mostly appears on seedlings [115]. MMD causes shortened inflorescence, sterility, and aborted hermaphrodite flowers, and the male flowers increase in number and size [116–119]. MMD was first reported in India in 1891 [120]. It is found elsewhere in Asia (Israel, Malaysia, and Pakistan) [120], Africa (Egypt, South Africa, Sudan, Swaziland, and Uganda) [121], and Americas [Brazil, El Salvador, Mexico, Nicaragua, the USA, and Venezuela [122, 123]. In Pakistan, Khaskheli et al. [38] confirmed pathogenicity of *Fusarium nivale* (Fr.) Ces., as the first record in Pakistan and also the first report of its association with mango malformation disease in Sindh, Pakistan. In another study, Iqbal et al. [119] isolated four fungi, viz. *F. mangiferae*, *F. pallidoroseum*, *F. oxysporum*, and *Alternaria alternata*, from malformed mango parts. Akhtar et al., [117] verified the association of *F. moniliforme* and *G. fujikuroi* with the disease. Various research lines have explained the etiology and control measures of MMD; however, nature and management of this disease is still a big challenge for the researcher.

4.3.2 Fungicide management

Several attempts were made to manage the MMD; however, differences in the reported species sometimes make it difficult to control the extent of MMD. Some research lines indicate that broad-spectrum systemic fungicides are beneficial for the control of the disease [124]. Kumar et al. [125] found that mangiferin metabolites of mango induced changes in isolates of *F. moniliforme* (*Gibberella fujikuroi*). In a study on management of mango malformation through physical alteration and chemical spray, the treatment with clipping at 45 cm distance followed by a spray of benomyl results in 70.37% decrease over previous years count [113]. The best management of MMD was obtained through the treatment with clipping at 45 cm distance followed by a spray of benomyl 50 WP. Eight different fungicides (Benlate, carbendazim, Score, Daconil, captan, Topsin-M, copper oxychloride, and minimum inhibitory concentration of MICs) were applied in vitro against *F. mangiferae* of MMD. As a result, Benlate and carbendazim suppressed 100% colony growth of fungus than all other fungicides [113, 126]. In Keitt tree trunk, fosetyl-Al was injected and found to reduce the floral malformation from 96 to 48% but no effect on fruit yield [127]. The spray of Benlate and biological antagonists *Trichoderma harzianum* and *Aspergillus flavus* were also applied. The results showed that Benlate alone and in combination with antagonists gave better results in a reduction of malformation intensity [128]. Moreover, the use of insecticides, fungicides, and plant growth regulators in combination with pruning has been reported an effective integrated management measure of reducing the intensity of inoculum of MMD in the orchard [120, 128]. It is recommended that once the disease is reported in the orchard, symptomatic parts should be removed to limit the occurrence of disease [21, 130, 131]. This sanitation practice leads to a reduction in mango malformation by limiting the inoculums. However, it is difficult to impose on the large trees with panicles that are difficult to access [127, 129, 132]. In most of the mango orchards, the general practice followed to control the severity of the disease is by removal of malformed (FM and VM) parts from trees and burning them outside the orchards. Usually, pruning involves the removal and burning of infected parts. The disease occurrence could almost be reduced by following this practice at least for 2–3 consecutive years. More recently, in vitro and in vivo attempts were made with commercial fungicides to reduce the severity of *Fusarium nivale* (Fr.) Ces., a predominant and virulent fungus in mango orchards of Sindh, Pakistan, which was first isolated from mango MMD [38, 133]. Mycelial growth of *F. nivale* was significantly inhibited at low doses of thiophanate-methyl and fosetyl-Aluminum. Metalaxyl+mancozeb and mancozeb alone also reduced the growth of fungus at their high doses, respectively, as compared to copper oxychloride. Thiophanate-methyl and fosetyl-Aluminum significantly reduced infection in Desi (local), Almas, and Dusheri after the first spray. The second spray of thiophanate-methyl and fosetyl-Aluminum fungicides completely inhibited infection of *F. nivale* and 100.0% reduction in vegetative malformation disease in Desi, Almas, and Dusheri, as compared to metalaxyl+mancozeb, copper oxychloride, and in control. The application of thiophanate-methyl and fosetyl-Aluminum would be useful in integrated management of MMD [133].

4.4 Sooty mold: *Capnodium mangiferae* (Cooke and Broome)

4.4.1 Cause, disease cycle, and symptoms

The sooty mold is a fungal disease caused by *Capnodium mangiferae* (Cooke & Broome) [134]. In actual, the sooty mold-causing fungi establish its growth

on sugary secretion by insects. Thus, occurrence, incidence, and severity of this disease depend on the infestation of insect pests. Usually, sucking insect pests infest in the beginning of disease occurrence and excrete sweet secretion upon which sooty mold develops. Later on, sooty mold appears as a black velvety growth on the leaf surface. The entire leaf surface or portion of the leaf may be covered with fungal growth, and in severe cases, the whole plants are affected. The thin layer formed on the leaf surface can be rubbed off easily [135]. When the molds attack blossoms during flowering time, the fruit set is affected, and in severe cases, small fruits also fall down [114]. Under the dry conditions, this may be blown off as small fragments by the wind. The disease-causing fungi in true sense are nonpathogenic; however, photosynthetic activity of the plant is impaired due to the covering of the leaves. The symptoms occurring due to this disease are quite obvious in diseased orchards [135].

4.4.2 Fungicide management

It has already been explained that sooty develops on the exudates of sucking insect pests such as aphids, leafhoppers, mealybugs, psyllids (including eucalyptus lerp psyllid), soft scales, and whiteflies. Both the immature and adult stages of these insects feed by sucking sap from plants, producing honeydew. Their common characteristic is that they all suck sap from plants. Therefore, these pests need serious attention and should be controlled through pesticides.

It is also pertinent to mention that sooty mold-causing fungus is a weak parasite; therefore, sometimes uses of fungicides are necessary to apply. The effectiveness of seven organic fungicides, one synthetic fungicide, bagging of fruits, and the untreated control were evaluated to control sooty mold on leaves and fruit of mango “Manila,” in Veracruz, Mexico. Results showed that the bio-fungicides Bio hcaz 3.5, Bio fyb 1.5, Fungicus ph 4 y Fungicus ph 8 provided 95% of leaves in the categories of healthy and light (less than 5% damage). Percentage of healthy fruits was 98% for bagging, 82% for benomyl, 80% for Sunset 3, and 78% for Sulfocop 4 and Bio fyb 1.5. Bio fyb 1.5 showed good control of sooty mold in leaves and fruits. The application of these organic products did not have a negative effect on the yield and fruits quality [136].

4.5 Mango sudden decline

4.5.1 Cause, disease cycle, and symptoms

Mango decline or mango sudden decline syndrome or mango sudden death syndrome or mango tree mortality are some common terms/phrases used for this disease. This remained the most common and destructive disease throughout Pakistan in the recent past years. In actual, MSDS is a complex disease of mango, and several pathogenic fungi were isolated from this complex problem [29–38]. Different investigators have isolated various fungi and another organism from an infected mango tree. Ahmed et al. [137] reported that the onset of dieback become evident by discoloration and darkening of twigs from the tip downward due to *Diplodia natalensis*. Ploetz et al. [138] observed the symptoms of decline, tip dieback, and gummosis from mango nurseries artificially inoculated with *A. alternata*, *G. cingulata*, *D. dominicana*, *L. theobromae*, and *Phomopsis* sp. According to Saleem and Akhtar [32], it is caused by root rot, anthracnose, and dieback. Jiskani [22] reported MSDS as disease complex caused by the combined attack of several different fungi and abiotic factors. Shahbaz et al. [139] pointed out disorders like twig blight, gummosis, bark splitting/cracking, and wilting as a cause. Leghari [140] isolated 10

genera with 12 species of different fungi from infected mango trees showing sudden death syndrome symptoms; however, *L. theobromae* (Prv. *B. theobromae*) was predominant with 20–83.30% incidence and 62.50–85% severity followed by *F. solani* with 56.66–73.33% incidence and 62.50–78.75% severity of mango decline. Hakro [141] isolated nine plant-parasitic nematodes and seven fungi from roots of the dead mango tree and studied the interaction of most predominant nematode with fungi (*Xiphinema index*, *F. oxysporum*, and *R. solani*). It is reported that gum is the most common symptom and *L. theobromae* was the most abundant isolated fungus, whereas it is also reported to be caused by *Ceratocystis fimbriata*. Asad et al. [144] isolated *L. theobromae*, *C. fimbriata*, and *Phomopsis* sp. as the most common fungi causing MSDS. Similar associations between *L. theobromae* and mango decline have been observed by quite a number of researchers [145–151]. Recently, the incidence of MSD was found to be 20% in Punjab and more than 60% in Sindh Provinces of Pakistan and 60 percent in Al Batinah region of Oman [152]. This phenomenon has also been reported from some other parts of the world, i.e., Brazil and Oman [152, 153]. In Brazil, Oman, and Pakistan, *C. fimbriata*, *C. omanensis*, and *L. theobromae* were the main causal organisms of MSDS were mostly isolated from diseased mango tree [152–156]. It has also been reported that fungus is mainly disseminated by the mango bark beetle, *Hypocryphalus mangiferae* (Stebbing), by infected plant material and the infested soils where it is able to survive for long periods. The best way to avoid losses due to MSD is to prevent its establishment in mango production areas [157]. *Ceratocystis manginecans* is also reported as the causal agent of a destructive mango wilt disease in Oman and Pakistan [158]. However, according to Jiskani et al., [22] it is a complex problem and actually is a result of anthracnose, dieback, root rot, tip dieback, gummosis, and dying of plants, observed very common in the orchards of different ages in Sindh. Moreover, studies also revealed that some mango varieties had more prevalence of MSDS than others, and the age-wise differences were also noticed. The findings indicate that trees of some varieties have the ability to overcome MSDS at a specific age and the severity of MSDS may be manageable till that. The variable incidence in different mango varieties at different ages can also be attributed to a possible natural tolerance against MSDS [159].

4.5.2 Fungicide management

There have been several attempts to manage this severe outbreak of mango; however, the recovery of the affected tree sometimes could not succeed due to the development of fungi in the vascular system of tree. All reported fungi of MSD are soilborne and cause tree decline or wilt after several years of development. Some studies showed that Topsin-M and Daconil are the most effective fungicides, whereas copper oxychloride intermediate and mancozeb were the least effective in inhibiting the mycelial growth of *B. theobromae* under in vitro conditions [160]. In another report, Topsin-M and Aliette when applied to infected tree trunks through the injection method, three times at an interval of 10 days, are reported as the most effective fungicides.

4.6 Dieback: *Lasiodiplodia theobromae* (Pat.)

4.6.1 Cause, disease cycle, and symptoms

Mango dieback caused by *L. theobromae* is considered one of the serious diseases of mango. Previous research has already proven *L. theobromae* as the cause of dieback of mango [161–162]. *L. theobromae* is a soilborne fungus causing both field and postharvest diseases in about 2080 plant species [161, 163–166]. In Pakistan, it

has been reported on more than 50 species of plants [167]. Among several diseases responsible for low crop production in Pakistan, mango dieback is also one of them. To further complicate the issue, resistance in *L. theobromae* is emerging against different fungicides [168]. Thus, this disease has been described as one of the serious threats to mango growers [154]. The onset of dieback becomes clear by discoloration and darkening of twigs, oozing of gum, wilting of leaves, dieback, browning of vascular bundles, and death of the entire plant [147, 162, 169]. Symptoms can also be observed in reproductive structures [170]. In severe situations, branches start drying one after another in a sequence resulting in the death of the trees of the mango plantation. Commonly, once the symptoms of decline or widespread dieback are evident, it is difficult to stop or reverse the progress of the disease. The disease has also been observed on different mango varieties associated with the variation in their susceptibility toward the fungus. Reports have shown that certain varieties are highly susceptible [171–172]. In vivo studies demonstrated that *L. theobromae* becomes aggressive in colonizing host tissues when plants are under abiotic stress, such as heat, water stress, or drought stresses [173–174]. In general, dieback is one of the deadly diseases of mango, which causes serious damage to the tree and its productivity [175].

4.6.2 Fungicide management

Several attempts are made to control the mango dieback throughout the mango growing countries of the world. In Pakistan, mycelial growth of *L. theobromae* was significantly inhibited by carbendazim and thiophanate-methyl when used at 1 ppm a.i. or more. Alliete was effective at relatively high concentrations, i.e., at 1000 and 10,000 ppm a.i., whereas Copxykil, Cuprocaffaro, and Thiovit failed to inhibit the mycelial growth of *L. theobromae*. In the field experiment, carbendazim was found to be more effective than thiophanate-methyl and Alliete in reducing the fungal infection in mango plants, suppressing the gum exudation, dieback, and wilting, resulting in a significant enhancement in vegetative growth of plants [142, 143]. The efficacy of different fungicides, viz. copper oxychloride, diethofencarb, pyraclostrobin, carbendazim, difenoconazole, mancozeb, and thiophanate-methyl, was evaluated in vitro using a poison food technique. Thiophanate-methyl at all concentrations was found to be the most effective among five systemic fungicides against *L. theobromae*, followed by carbendazim, difenoconazole, and diethofencarb. The fungicides, i.e., thiophanate-methyl, difenoconazole, carbendazim, and diethofencarb, showed maximum efficacy with increasing concentration. The isolates of *L. theobromae* showed some resistance development against the tested fungicides when compared with previous work. These investigations provide new information about chemical selection for the control of holistic disease in mango growing zones of Pakistan [168]. The fungicide treatments such as cobox (copper oxychloride), precure combi (thiophanate-methyl + diethofenocarb), and Cabrio top (pyraclostrobin + metiram) at four concentrations 25, 50, 75, and 100 ppm were also evaluated in vitro against *L. theobromae*. Cobox (copper oxychloride) and precure combi (thiophanate-methyl + diethofenocarb) showed a significant reduction in colony diameter of *L. theobromae* at all concentrations compared to non-treated/control. Cabrio top (pyraclostrobin + metiram) did not significantly decrease the colony diameter of *L. theobromae*. In the field precure combi (thiophanate-methyl + diethofenocarb) and cobox (copper oxychloride) were also used as foliar fungicide and in soil drenching in addition to soil amendment with silt, NPK, and manure and pruning to manage the naturally affected mango plants with dieback, and cobox was found best where soil amendment and pruning was done with soil drenching [176]. Recently, in the UAE, some systemic chemical fungicides, Score, Cidely Top, and Penthiopyrad, significantly

inhibited the mycelial growth of *L. theobromae* both in vitro and in the greenhouse. Cidely Top proved to be a highly effective fungicide against *L. theobromae* dieback disease also under field conditions [175]. Despite efforts made to control the dieback disease using different fungicides, disease incidence is still high in some farms in Oman. Testing sensitivity of 28 randomly selected *L. theobromae* isolates to four commonly used fungicides showed that the EC50 levels of the isolates were in the range of 0.01–8.75 (avg. 0.54 mg L⁻¹) for iprodione, 0.1–242.8 (111.6 mg L⁻¹) for copper oxychloride, 40.3–738.1 (avg. 229.3 mg L⁻¹) for copper hydroxide, and 0.1 to over 1000 (avg. > 1000 mg L⁻¹) for thiophanate-methyl. The study showed the development of resistance to some fungicides, especially with thiophanate-methyl. The development of resistance to fungicides could be one of the main reasons behind the reduction in the efficacy of managing dieback in the studied farms [177].

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