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Review

Powdery mildew of mango: A review of ecology, biology, epidemiology and management

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ABSTRACT

Powdery mildew of mango, incited by the fungus *Pseudoidium anacardii* (F. Noack) U. Braun & R.T.A. Cook 2012 (formerly known as *Oidium mangiferae* Berthet), is one of the most common, widespread and serious diseases throughout the world and causes significant yield losses. Symptomatology, biology, and etiology of powdery mildew and its control through fungicides have not been widely studied, and substantial information is still required on the inoculum potential, growth models and epidemiological parameters of powdery mildew, influence of changing climate, impact of extensive use of fungicides and disease resistance. These critical factors may influence the development and emergence of diverse isolates of *O. mangiferae* including fungicide-resistant strains. Mango varieties differ slightly in their reaction to powdery mildew but a source of resistance has not been identified. In view of the increasing demands of mangoes in the world, control of powdery mildew is gaining importance. The present review treats briefly different aspects of powdery mildew disease with major emphasis on its ecology, pathology, epidemiology and management. Some new approaches such as biological control, integrated management strategies and some other aspects which have not been highlighted in former reviews, are also discussed.

1. Introduction

Mango, *Mangifera indica* L. (2n = 40), literally meaning "Indian plant bearing mango" belongs to the genus *Mangifera* which is one of 73 closely related genera within the family *Anacardiaceae*. Out of 69 recognized species of the genus *Mangifera*, 26 produce edible fruits of inferior quality. However, these species are a good source of rootstocks for common mango or may provide suitable material for hybridization. *M. indica* is the species that is most commonly, widely, extensively and commercially grown in the world. The uncultivated mango species are shrubs which are found in the South Asian countries (Mukherjee, 1953, 1997). It is generally believed that the wild and undomesticated species have been completely or partially deforested for expanding agriculture which resulted in genetic erosion and loss of disease resistance sources. Some surviving wild species on record include: *Mangifera moderata*, *Mangifera foetida*, *Mangifera caesia*, *Mangifera casturi*, *Mangifera griffitbii* and *Mangifera torquenda*, but pathogenic association of these species with the obligate parasites, such as powdery mildew, is not known. Common mango is considered as one of the most delicious, finest and important fruits in the world. In terms of production, mango ranks fifth in the world among all the fruits after banana, grapes, apples and oranges. Mango is widely consumed throughout the world and its demand is increasing due to rapid growth of population and awareness of its unique flavor and nutritive values. Fruit yields can be drastically reduced or even lost due to powdery mildew. The most serious losses occur when flowering and growth flushes are infected during cool and dry conditions (Verma and Deepraj, 1998a; Misra, 2001; Sinha et al., 2001). The disease has been described in some books on plant diseases particularly those dealing with the diseases of tropical fruits. The present review deals with different aspects of powdery mildew disease with major emphasis on its ecology, pathology, epidemiology and management. Some new approaches such as biological control, integrated management strategies, host resistance and some other aspects which have been insufficiently

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addressed in the previous reviews (Prakash and Srivastava, 1987; Joubert et al., 1993; Akhtar and Alam, 2000) are also discussed.

2. Powdery mildew

Mango is attacked by several fungal diseases including anthracnose, gummosis, root rot, decline complex, powdery mildew and some post harvest problems, and a few diseases caused by bacteria, nematodes and viruses. Malformation of mango inflorescence has remained an unsolved problem. Among all the diseases, powdery mildew is the most common, widespread and damaging disease affecting almost every cultivar irrespective of geographical and ecological differences (Prakash, 2004).

2.1. Occurrence and geographical distribution

Powdery mildew is one of the longest-known diseases on mango in the world. The disease is known to be present in India before 1874 (Nelson, 2008). It was first recorded in 1914 in Brazil, and the fungus was described by Berthet (Briton Jones, 1923). The disease was sporadic in the past and frequent epidemics were not encountered but during the years 2000–2010, it has assumed epiphytotic proportions in India, Pakistan, Sri Lanka, Israel, Egypt and South Africa (Prakash, 2004; Jiskani et al., 2007). Powdery mildew of mango occurs at latitudes of up to 40 north and south of the equator and its infections persist for longer periods at elevations of 600–1200 m (Prakash, 2004). It has wide distribution in the world, and had been reported from many countries of Asia (India, Pakistan, Sri Lanka, Nepal, Burma, Bangladesh), Middle East (Iran, Israel, Turkey, Lebanon, Palestine, Greece), Africa (Egypt, Congo, Tanzania, Ethiopia, Kenya, Rhodesia, South Africa), the Americas (Florida, California, Cuba, Peru, Brazil, Venezuela, Colombia, Mexico) and Australia (Haigh, 1931; Wager, 1937; Fields, 1945; Reichert and Palti, 1951; Hernandez et al., 1955; Ruehle and Ledin, 1956; Singh, 1960; Rodrigues and Figueroa, 1963; Brodrick, 1971; Palti et al., 1974; Padron Soroa, 1983; Prakash and Raoof, 1994; Prakash et al., 1997; Pernezney and Ploetz, 2000; Felix-Gastelum et al., 2013). According to Johnson (1994), the disease was probably present throughout the Indian Subcontinent since late 1980s. In India, it was reported by McRae (1924), Kulkarni (1924), Galloway (1935) and Uppal (1937); being serious in Maharashtra, Uttar Pradesh, Karnataka and Hyderabad states. In Pakistan, the disease was recorded by Raisinghani (1945) and Jiskani et al. (2007) in Sindh and Sattar (1946) in the Punjab where serious epidemics of powdery mildew have been occurring frequently.

2.2. The causal organism

The disease is caused by an obligate fungus recently named as *Pseudoidium anacardii* (F. Noack) U. Braun & R.T.A. Cook 2012. The fungus was formerly known as *Oidium mangiferae* Berthet which was established after long controversies. Wagle (1928) and Uppal (1937) initially named it as *Erysiphe cichoracearum* belonging to the *Erysiphe polygoni* group on the basis of production of globular haustoria and the mode of conidial germination. *Oidium* sp. attacking mango was suspected to infect oak tree (*Microspaera alphitoides*) in New Zealand (Boesewinkel, 1980), European oak and some other hosts in South Africa (Gorter, 1984; Joubert et al., 1993) because the characters of the two species were identical but the evidence was quite weak. It was realized that the oak trees were overtaken by another powdery mildew of the *Erysiphe* group and lacked a perithecial stage (Johnson, 1994). Joubert et al. (1993) differentiated two fungi on the basis of production and size of conidiophores. Ultimately, the anamorph name of the conidial stage of the fungus "*O. mangiferae*" was preferred, accepted and established throughout the world (Uppal et al., 1941) and mango is the only known host (Palti et al., 1974). The fungus was recently renamed as *P. anacardii* (F. Noack) U. Braun & R.T.A. Cook 2012. The characteristics and distinguishing morphological features of *O. mangiferae* (*P. anacardii*) have been described in detail by several workers (Uppal et al., 1941; Palti et al., 1974; Gorter, 1988a, 1988b; Akhtar et al., 1999). The mycelium of *O. mangiferae* is composed of septate, hyaline, ectotype hyphae measuring 4.1–8.2 μm; the conidiogenous cells are of moderate length (27.4–40.0 μm), conidiophores emerge from the superficial mycelium, are simple with superficial septation, short, erect, hyaline, 60–165 μm long and unbranched; conidia (oidia) are elliptical to barrel or oblong shaped, thin-walled, produced singly, unicellular or aseptate, formed in chains and measure 25–48 × 16–24 μm; haustoria are lobate, the germ tubes from the conidia form hook like appressoria on the host surface from which the infection peg penetrates the epidermis to form haustoria (Singh, 2000).

Powdery mildew fungi (Erysiphales) constitute a common group of obligate plant pathogens that can be extremely difficult to identify due to rarity of diagnostic structures. Molecular studies of the ribosomal DNA Internal Transcribed Spacer (ITS) region have provided useful links between anamorphic Erysiphales and their respective teleomorphs (Cunnington et al., 2003). PCR primers for the rDNA ITS region enhanced specificity for 12 genera tested, even in the presence of contaminating fungi. Recently, herbarium specimens of both anamorphic and teleomorphic materials yielded sufficient DNA for amplification. The ITS regions from 25 anamorphic specimens were sequenced and compared with the ITS sequences of their suspected teleomorphs with 99% sequence similarity of ITS region, indicating that correct matches had been made. Although this technique will not always unambiguously identify an anamorphic specimen, it will provide valuable information to be used in conjunction with morphological and host range data to aid in the final identification (Cunnington et al., 2003). Similarly, Felix-Gastelum et al. (2013) collected powdery mildew specimens during 2011 and 2012 comprising Kent and Keith varieties from commercial orchards, and Creole materials from backyards of private residences from northern Sinaloa, Mexico. Molecular and phylogenetic analysis of the ITS rDNA (Limkaisang et al., 2006) region showed that samples were closely related to specimens of *P. anacardii* (Braun and Cook, 2012) [teleomorph: *Erysiphe quercicola* (Takamatsu et al., 2007)] collected from mango trees in diverse countries.

2.3. Disease symptoms

Powdery mildew generally starts appearing, depending on climatic conditions in the area (Prakash et al., 1997), when new flushes emerge and grow vigorously i.e. just before flowering (Gupta, 1976; Joubert et al., 1993). Young leaves and inflorescences are covered with a whitish powdery mass; flowers on the infected inflorescence remain unfertilized and drop off the plant prematurely (Wagle, 1928; Lonsdale and Kotze, 1993a, 1993b). The fungus initially attacks young tissues of all parts, leaves and their stalks, flower scales, buds of tender flowers and fruits in the early stage (Singh, 1960). Young infected leaves fall prematurely if covered on the underside, and mature infected leaves develop purplish brown spots. Infected fruits are often malformed and off-colored. Symptoms of die-back may also occur (Singh, 2000). The infected fruits do not grow in size and drop at the pea stage.

2.4. Disease perpetuation

No teleomorph of the pathogen is known, which reflects the need for studies of the survival structures of the fungus. Powdery