Report

Anthracnose of mango:
Management of the most important pre- and post-harvest disease

Randy C. Ploetz, Professor
University of Florida, TREC-Homestead
Department of Plant Pathology
18905 SW 280th Street, Homestead, FL 33031-3314 USA
Phone: 305 246-7001, x321
Fax: 305 246-7003
Email: kelly12@ufl.edu

Executive Summary

The successful management of anthracnose relies on understanding the conditions that promote disease development, and the economics, efficacy and market acceptability of the various control measures. Depending on the mango cultivar that is grown, the production area, and the intended final market, an integration of two or more tactics may be needed. Key considerations are:

1) Rainfall and high humidity are required for infection and disease development. As a consequence, flowering should be initiated such that fruit set and development occurs during the driest portion of the year.
2) Where significant rainfall exists and altered flowering is not possible (i.e. the subtropics and with some cultivars in the tropics), export production is usually not possible.
3) Latent infections that accumulate during fruit development are responsible for postharvest anthracnose. Postharvest treatments focus on these infections as the most significant source of postharvest decay.
4) Diverse preharvest and postharvest treatments are available, but none that are available for the US market are highly effective under high disease pressure. Unless new, highly effective treatments are developed in the future, the production of export-quality fruit destined for the US will be possible only where disease pressure is low (low rainfall areas).

Abstract

Anthracnose is a major pre- and post-harvest disease on mango, causing direct yield loss in the field and packing plant, and quality and marketing issues thereafter. A review of the etiology and epidemiology of the disease is provided below as background for the various approaches that have been used to manage the disease.

Introduction

Anthracnose is the most important disease of mango in humid production areas (Arauz, 2000; Dodd *et al*., 1997; Lim and Khoo, 1985; Ploetz and Freeman, 2009; Ploetz and Prakash, 1997; Ploetz, 2003). Although losses occur in the field, postharvest losses to this disease are most significant. Anthracnose presents great challenges for those who are involved in the international commerce of this fruit.

Etiology

Anthracnose is caused by two related species of fungi. *Colletotrichum gloeosporioides* (teleomorph: *Glomerella cingulata*) is responsible in most situations (Dodd *et al*., 1997), and *C. acutatum* (teleomorph: *G. acutata*) plays a minor role in a few locations (Fitzell, 1979; Ploetz and Prakash, 1997; Tarnowski and Ploetz, 2008). Another taxon, *C. gloeosporioides* var. *minor*, is no longer recognized. Information below refers only to *C. gloeosporioides.*

Epidemiology

Moist conditions and high humidity are primary factors in the spread and development of anthracnose (Fig. 1). Conidia produced on branch terminals, mummified inflorescences, flower bracts and leaves (most important) are significant

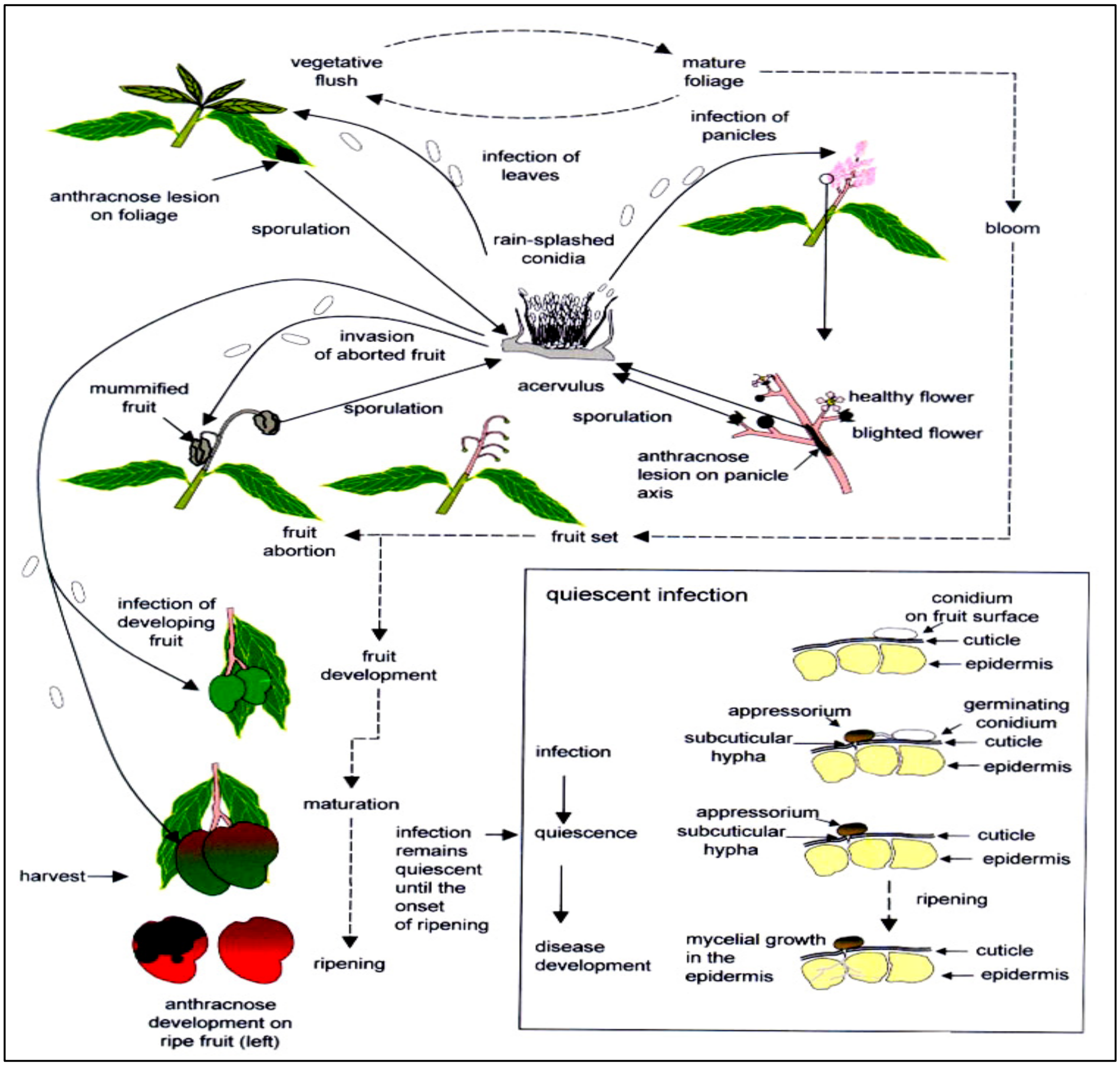

Fig. 1. Anthracnose disease cycle (Arauz, 2000).

sources of inoculum (Dodd *et al*., 1991; Fitzell and Peak, 1984). They are produced most abundantly when free moisture is available, but also at relative humidities as low as 95%. Conidia are dispersed by rainsplash and infection requires free moisture (Jeffries *et al*., 1990). As appressoria age, they become melanized. Melanization strengthens the appressorium and facilitates penetration of the cuticle by infection pegs that the appressoria produce. The presence and prevalence of melanized appressoria have been used to predict when infection is possible and anthracnose control measures are needed (Dodd *et al*., 1991; Fitzell and Peak, 1984).

Small fruit can develop minute brown spots and abort if infected early in their development. Once an appressorium is formed and fruit exceed 4 – 5 cm in diameter, infections cease development. Quiescent infections renew develop once concentrations of preformed fungal inhibitors in fruit decline during the ripening process. On larger (especially ripening) fruit, lesions can form anywhere, but linear smears that radiate from the stem end to the apex are common (Fig. 2). Lesions on fruit are superficial and extend into the flesh only after large portions of the fruit surface are affected. Nonetheless, even superficial disease development results in serious aesthetic damage and rejection of fruit along the marketing chain.

Disease management

Anthracnose is one of several fruit diseases that affect pre- and post-harvest quality (Ploetz, 2003). Stem-end rots (caused by several different fungi, in particular *Lasiodiplodia theobromae*) can be serious where anthracnose is prevalent but well controlled (Fig. 3). Alternaria black spot (*Alternaria alternata*) is important in dry regions where anthracnose is not significant (Fig. 4). Management of these and other, less common diseases, is needed to produce high quality fruit.

Anthracnose affects leaves, flowers and fruit, and inoculum is present year-round throughout the canopy. Management requires an awareness of this ever-present threat and the weather conditions that promote infection and disease development. Optimum disease control relies on

Fig. 2. Anthracnose on 'Edward'

An integrated approach that holistically combines the best measures, depending on the cultivar, production location and final market. The efficacy and pros and cons of the different approaches that have been used to manage this disease on fruit are summarized below with an emphasis on mangos that are grown in or destined for the US market.

Pre-harvest (field) control

Pre-harvest management of anthracnose relies on: i) orchard sanitation (removing sources of inoculums); ii) altering the time of flowering to ensure that fruit set and development occur during dry conditions (this also focuses on off-season production for profitable market windows); and iii) an integration of these and other chemical and biological measures (Johnson and Hofman, 2009). Despite its potential beneficial impact, sanitation is often not practiced due to its difficulty and expense (Akem, 2006; Prusky et al., 2009). And flower manipulation is not possible in all situations (Johnson and Hofman, 2009). Floral induction is usually achieved with applications of KNO_3 (The growth retardant paclobutrazole is also used for this purpose, but it is not registered in the USA). These treatments are not effective in the subtropics or on all cultivars (e.g. ‘Kensington’). And on other cultivars (e.g. ‘Kent’), applications of KNO_3 increase flowering but do not alter its timing. Thus, pre-harvest management of anthracnose often relies only on chemical, and to a lesser extent biological, inputs.

Fig. 3. Stem-end rot, caused by by *Lasiodiplodia theobromae*.

Fig. 4. Alternaria black spot, caused *Alternaria alternata*.

In all but the most disease-conducive environments and on the most susceptible cultivars, pre-harvest anthracnose control focuses solely on protecting flowers and early fruit development. In moist environments, this entails one or two fungicide applications during flowering and early fruit set, and subsequent fungicide applications may be required before harvest (see below). In moist environments, applications are needed throughout the season. For example, monthly or more frequent applications have been used in Florida where the onset of the rainy season coincides with the maturation and harvest of most cultivars. Where dry conditions prevail, such as arid production areas along the Pacific Rim of Tropical America, pre-harvest fungicide treatment may not be needed prior to harvest (Arauz, 2000).

Disease Forecasting. Two anthracnose forecasting models have been developed to determine fungicide application schedules and reduce fungicide usage (Dodd et al., 1991; Peak et al., 1988). Akem (2006) noted differences between the time predicted for infection with the Australian and Philippine models. He indicated that caution should be used when adopting a model in an area other than the one in which it was developed. Forecasting would be most useful in seasonally dry situations where, in practice, it could be assumed that infection occurs whenever there is significant rainfall (Arauz, 2000). Once rains begin in a humid region, calendar-based application schedules are needed.

Fungicides. Fungicide use is constrained by the limited number of products that are available, the pesticide regulations that exist in the producing and destination countries, and the product's efficacy. In general, copper fungicides have the widest acceptance. There are minor differences among the different copper formulations. Retention on applied surfaces was greatest with CuO, compared to $CuCl_2$ and 3 Cu $(OH)_2 \cdot CuCl_2$ (copper oxychloride) (Johnson and Hofman, 2009).

Copper fungicides are usually not very effective unless they are applied with other fungicides. For example, monthly applications of copper oxychloride combined with mancozeb were effective for most post-harvest diseases in South Africa (Lonsdale, 1993). Most dithiocarbamate fungicides, such as mancozeb, are not labelled in the USA, although residue tolerances have been established for one of these products, ferbam

Fig. 5. Symptoms of chlorothalonil phytotoxicity

Table 1. Products labeled for anthracnose management (*) and with residue tolerances (**) in the USA

Brand name(s)	Chemical name active ingredient	Post-harvest residue (ppm)[a]
*,**Abound	azoxystrobin	2.0
Benomyl (cancelled)	methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate	3.0
**Captan (no labeled product)	cis -N-Trichloromthylthio-4-cyclohexene-1,2-dicarboximide	50.0
*,**Chlorothalonil	tetrachloroisophthalonitrile	1.0
*Serenade Max	*Bacillus subtilis*	n/a
*Kocide, others	copper	n/a
*,**Ferbam	ferric dimethyldithiocarbamate	7.0
**Thiabendazole	2-(-4'-Thiazolyl)benzimidazole	10.0

(Table 1). Another contact fungicide, chlorothalonil, is effective but phytotoxic to fruit larger than a golfball in size (Fig. 5). Its use should be restricted to early bloom and early fruit set.

Systemic fungicides, that would provide superior control compared to the above contact fungicides, are also limited. The benzimidazoles, primarily benomyl and carbendazim, provided excellent anthracnose control before resistance to them developed in the field (Akem, 2006). Two imidazoles, prochloraz and imazilil, are used in some countries for, respectively, pre- and post-harvest anthracnose control (they are not labelled in the US). To a lesser extent, prochloraz has also been tested as a post-harvest treatment.

Although the imidazoles are moderately effective against anthracnose, they are ineffective against stem-end rot, which is managed by TBZ. Lastly, stobilurins are effective against anthracnose and several other post-harvest diseases of mango. However, they are susceptible to the development of resistance and must be used sparingly. General guidelines that have been devised for the strobilurins by the fungicide resistance action committee (FRAC) indicate that no more than three applications should be made per season, preferably alternating or combined with fungicides with a different mode of action (Brent and Hollomon, 2007). For anthracnose on mango, Johnson and Hofman (2009) suggested that one or two applications should be made during flowering and early fruit set, with two additional applications at 21 and 7 days prior to harvest.

Induced resistance. Recent research has investigated increasing the natural defense responses of plants to disease (Terry and Joyce, 2004; Dann *et al.*, 2007; Karunanayake, 2007). Anthracnose on mango fruit has been reduced by salicylic acid, an analog benzothiadiazole (BTH) (= acibenzolar-S-methyl = Bion®), and ultraviolet (UV-C) irradiation. Results have been variable and include phytotoxicity (Zainuri *et al.*, 2001; Zeng and Waibo, 2005; Zainuri, 2006; Zeng *et al.*, 2006; Karunanayake, 2007).

TABLE 2. Susceptibility of fruit of different mango cultivars to anthracnose			
Highly susceptible	**Susceptible**	**Moderately resistant**	**Resistant**
Irwin	Brooks	Carrie	Zebda
Kent	Bullock's Heart	Earlygold	
	Fascell	Edward	
	Haden	Florigon	
	Lippens	Glenn	
	Palmer	Julie	
	Sensation	Keitt	
	Zill	Tommy Atkins	
		Van Dyke	

Resistance. Table 2 summarizes information for cultivars that are important in Florida or elsewhere. Although several have moderate resistance to anthracnose, no commercial cultivar is sufficiently resistant to be produced in humid areas without fungicide application (Dodd *et al.*, 1997). Zebda, a flavorful Egyptian cultivar, is aesthetically unacceptable since it is green at maturity. Understanding why it is resistant may eventually provide useful information for the management of this disease.

Susceptible cultivars (e.g. Kent and Haden) are important in international trade but are produced for these markets only in arid production areas. Unexpected rainfall in these areas (e.g. in northwestern Peru in 2008) can cause serious problems on susceptible and relatively resistant cultivars, such as Tommy Atkins.

Post-harvest control

Diseases are primary causes of post-harvest loss. Although anthracnose is most important (Fig. 2), stem-end rots (caused by several different fungi) (Fig. 3), alternaria black spot (Fig. 4), and other post-harvest diseases can also be significant. The relative importance of each disease depends on the production area, cultivar, and pre- and post-harvest disease management tactics. Different approaches that have been used to directly affect disease development during the post-harvest handling of this fruit are discussed below.

Fungicides. The benzimidazoles are still effective as post-harvest treatments, although benomyl's registration has been cancelled. Thiabendazole (TBZ) is almost as effective as benomyl (benomyl's formulation enables superior host penetration, a greater spectrum of acitivity, and great efficacy), and it has a post-harvest residue tolerance in the USA (Table 1).

As mentioned above, prochloraz and imazilil have been used as post-harvest treatments in others countries but are not labelled for the US market. Although a nonspecified strobilurin was tested in combination with a biocontrol agent for post-harvest anthracnose control in South Africa, it was not tested alone (Govender and Korten, 2006).

Non-fungicidal measures. Since there is a close relationship between ripening and the development of post-harvest disease, post-harvest disease development can be managed indirectly by delaying the onset, and reducing the rate, of ripening (Prusky and Keen, 1993). As a climacteric fruit, mango undergoes profound biochemical changes as it ripens. Ripening is a process in fruit senescence that is associated with and enhanced by increased ethylene production (Brecht and Yahia, 2009; Snowdon, 1990). Mature fruit can be stored in the nonripe state as long as the climacteric initiation of ethylene production is prevented. Ethylene levels in mango fruit increase naturally from <0.1μl $kg^{-1} \cdot h^{-1}$ to 1 to 3 $\mu l kg^{-1} \cdot h^{-1}$ during the ripening process, and ripening can be initiated in nonripe fruit by very low concentrations of exogenous ethylene (≥0.005μl l^{-1}).

In practice, the climacteric rise in ethylene production is delayed with refrigeration. However, mango is sensitive to chilling injury and most cultivars must be stored at >10-13^{o}C. External sources of ethylene must also be removed from the storage environment (e.g. ripening fruit, smoke, engine exhaust fumes, etc.). Ripening can also be inhibited by modified atmosphere (MA) storage (usually reductions in O_2 levels and increased CO_2) (Brecht and Yahia, 2009). Some work has been conducted on the impact of MA on post-harvest disease. For example, when fruit were exposed to an atmosphere containing 30% CO_2 for 24 h, Prusky and colleagues reported an increase in the concentrations of antifungal compounds in fruit and consequently less disease when these fruit ripened (Prusky, 1988; Kobiler *et al*., 1998). However, MA is usually not used to manage anthracnose since mango fruit flavor is affected in atmospheres with <1% O_2 or >15% CO_2 and much more extreme concentrations of O_2 and CO_2 are needed to impact plant pathogens (Burg 2004).

Hypobaric storage is superior to MA for extending the nonripe, postharvest life of mango fruit, and has been shown to suppress the postharvest development of anthracnose of papaya (Burg, 2004). Its use for the long-distance shipment of mango is constrained by technical criteria that have not been addressed successfully in prior attempts to commercialize the process.

Heat. Hot water, vapour heat or forced hot air are post-harvest treatments for fruit flies, which are quarantine pests for mango fruit in much of the world (Jacobi et al., 2001). The Mediterranean fruit fly, *Ceratitis capitata*, and the Mexican fruit fly and related species, *Anastrepha* spp., must be controlled in mangos produced in tropical America that will be sold in the US (McGuire, 1991). Hot water, the most common of these treatments, is economical, reliable and can be used with other commodities (Jacobi et al., 2001).

The times and temperatures that are needed to achieve prescribed kill levels depends of the size and shape of the fruit that are treated. And, much the same as for cold sensitivity, there is variation among different cultivars for heat tolerance. Jacobi et al. (2001) reviewed the requirements and heat tolerances of different cultivars and the symptoms that are associated with heat damage. An added benefit of heat treatment to satisfy insect quarantines is its reduction of anthracnose and other post-harvest decays (McGuire, 1991).

Biological control. Relatively little research has been conducted on the biological control of anthracnose. Lise Korsten's group has the longest history in this area, and they have focussed on using a Gram positive bacterium, *Bacillus licheniformis*, that resists desiccation and is foodsafe. In general, minor reductions in disease occur at 10^{o}C and 25^{o}C, either alone or in combination with fungicides (Govender and Korsten, 2006). Although less publicized, significant reductions have also occurred with Gram negative bacteria and other amendments (Vivekananthana et al., 2004). To date, no biocontrol measure has been as effective as the most effective fungicides.

Summary.

- Rainfall and high humidity are required for infection and disease development. Thus, flowering should be initiated such that fruit set and development occurs during the driest portion of the year
- Where significant rainfall exists and altered flowering is not possible (the subtropics and with some cultivars in the tropics), export production is usually not possible
- Latent infections that accumulate during fruit development are responsible for postharvest anthracnose. Postharvest treatments focus on these infections as the most significant source of postharvest decay
- Diverse preharvest and postharvest treatments are available, but none that are available for the US market are highly effective under high disease pressure
- Without new, highly effective treatments, production of fruit destined for USA will be possible only in low rainfall areas

Recommendations.

Are the most important problems accurately identified and understood?

Although production situations may be generally similar, significant differences could be present in the different production countries. Each area needs to be better understood. In Mexico, cultivars are often polyembryonic clones quite different from the Florida (monoembryonic Indian) hybrids e.g. Ataulfo and anthracnose may not be primary problem on these cultivars in Mexico. In Brazil, malformation is also a serious problem.

Under normal conditions anthracnose will not be significant in arid regions. Stem-end rots become increasingly important when anthracnose is well managed or it is not important.

The identity and relative importance of the different problems needs to be assessed. Without these data, it will not be possible to develop a rational and effective approach to manage these problems**.**

References

Akem, C.N. 2006. Mango anthracnose disease: Present status and future research priorities. *Plant Pathology Journal* 5:266-273.

Arauz, L.F. 2000. Mango anthracnose: Economic impact and current options for integrated management. *Plant Disease* 84:600-611.

Brecht, J.K., and Yahia, E.M. 2009. Postharvest physiology. In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. 2nd edition. CABI. (In press).

Brent, K.J., and Hollomon, D.W. 2007. *Fungicide Resistance: The Assessment of Risk*. Fungicide Resistance Action Committee. Croplife International. Brussels, Belgium.

Burg, S.P. 2004. *Postharvest Physiology and Hypobaric Storage of Fresh Produce*. CAB International. Wallingford, Oxon UK.

Davenport, T.L., Burg, S.P., and White, T.L. 2006. Optimal low-pressure conditions for long-term storage of fresh commodities kill Caribbean fruit fly larvae and eggs. *HortTechnology* 16:98-104.

Dodd, J.C., Estrada, A.B., Matcham, J., Jeffries, P. and Jeger, M.J. 1991. The effect of climatic factors on *Colletotrichum gloeosporioides*, causal agent of mango anthracnose, in the Philippines. *Plant Pathology* 40:568-575.

Dodd, J.C., Prusky, D., and Jeffries, P. 1997. Fruit diseases. In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. CABI., pp. 257-280.

Fitzell, R.D. 1979. *Colletotrichum acutatum* as a cause of anthracnose of mango in New South Wales. *Plant Disease Reporter* 63:1067-1070.

Fitzell, R.D. and Peak, C.M. 1984. The epidemiology of anthracnose disease of mango: inoculum sources, spore production and dispersal. *Annals of Applied Biology* 104:53-59.

Govender, V., and Korsten, L. 2006. Evaluation of different formulations of *Bacillus licheniformis* in mango pack house trials. *Biological Control* 37:237-242.

Jacobi, K.K., MacRae, E.A., and Hetherington, S.E. 2001. Postharvest heat disinfestations treatments of mango fruit. *Scientia Horticulturae* 89:171-193.

Jeffries, P., Dodd, J.C., Jeger, M.J. and Plumbley, R.A. 1990. The biology and control of *Colletotrichum* species on tropical fruit crops. *Plant Pathology* 39:343-366.

Johnson, G.I., Sharp, J.L., Milne, D.L., and Oosthuyse, S.A. 1997. Postharvest technology and quarantine treatments.In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. CABI., pp. 447-508.

Johnson, G.I., and Hofman, P.J. 2009. Postharvest technology and quarantine treatments. In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. 2nd edition. CABI. (In press).

Lim, T.K. and Khoo, K.C. 1985. *Diseases and Disorders of Mango in Malaysia*. Tropical Press, Kuala Lumpur.

Ploetz, R.C. 2003. Diseases of Mango. pp. 327-363. In: R.C. Ploetz (ed.) *Diseases of Tropical Fruit Crops*. CABI Publishing. Wallingford, UK. 544 pp.

Ploetz, R.C., Benscher, D., Vazquez, A., Colls, A., Nagel, J. and Schaffer, B. 1996. A re-evaluation of mango decline in Florida. *Plant Disease* 80:664-668.

Ploetz, R.C. and Freeman, S. 2009. Foliar, floral and soilborne diseases. In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. 2nd edition. CABI. (In press).

Ploetz, R.C. and Prakash, O. 1997. Foliar, floral and soilborne diseases. In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. CABI. pp. 281-326.

Prusky, D., and Keen, N. T. 1993. Involvement of preformed antifungal compounds in the resistance of subtropical fruits to fungal decay. *Plant Disease* 77:114–119.

Prusky, D., Kobiler, I., Miyara, I., and Alkan, N. 2009. Fruit diseases. In: Litz, R.E. (ed.) *The Mango:Botany, Production and Uses*. 2nd edition. CABI. (In press).

Tara L.B. Tarnowski and Randy Ploetz. 2008. Assessing the role of *Colletotrichum gloeosporioides* and *C. acutatum* in mango anthracnose in south Florida. *Phytopathology* S.

Vivekananthana,R., Ravia, M., Saravanakumara, D., Kumar, N., Prakasama, V., and Samiyappana, R. 2004. Microbially induced defense related proteins against postharvest anthracnose infection in mango. Crop Protection 23:1061–1067.