

The Role of Epidemiology Data in Developing Integrated Management of Anthracnose in Olives - a Review

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Abstract

Colletotrichum species have the capacity to produce asymptomatic latent (quiescent) infections on various olive tree tissues: during this symptomless biotrophic phase, the pathogen invades the host without killing them and feeds on living cells. Re-infection of the tree by the repeating conidial stage is then responsible for increased anthracnose symptoms during summer, leading to new growths. Normally developed fruit and fruit damaged by abiotic factors, leaves and stems may have asymptomatic infections of *Colletotrichum acutatum* and *C. gloeosporioides* in susceptible cultivars 'Barnea', 'Manzanillo' and 'Kalamata'. Anthracnose under favourable conditions can also infect less susceptible cultivars. The infection can persist from season to season, depending on olive cultivar, environment, crop management, and pathogen virulence. Brown lesions with anthracnose fungal spores were observed in young green stems and leaves and dieback of young shoot tips of olive susceptible cultivars in orchards in early spring and summer. Flowering, fruit set and immature fruits can be observed during fruit development on a single peduncle; both flowers and fruit set late in the season, in summer rather than spring, and carry fungal infection. Immature rotten fruits are mummified. *Colletotrichum* fungi overwinter in mummified fruits on the tree, woody tissue and leaves; the fungus has long saprophytic survival ability on dead peduncle and pedicels. Fungal inoculum present year-round throughout the canopy. Hemibiotrophic anthracnose fungal pathogens grow first on living tissue and then cause host death in later, necrotrophic growth. The ability to survive and multiply in the absence of symptoms may explain why anthracnose fungi often cause unexpected crop losses in olives. Successful management of anthracnose relies on understanding the conditions that promote disease development. The complexities of anthracnose epidemiology, including the presence of different species, point to the need for continued research around disease management, particularly regarding new control strategies for *Colletotrichum* in olives.

INTRODUCTION

Anthracnose is one of the most common and serious diseases in horticulture and *Colletotrichum* spp. are devastating pathogens of many crops. Anthracnose, caused by the fungi *Colletotrichum acutatum* and *C. gloeosporioides*, is widespread and a severe disease in most olive-growing countries, causing significant yield losses, poor fruit and oil quality. Warm, rainy, misty and humid conditions or heavy dews have been observed to be associated with severe anthracnose epidemics. The disease may affect up to 80% of olives in susceptible cultivars such as 'Barnea', 'Manzanillo' and 'Kalamata' in Australia (Sergeeva, 2011d). Anthracnose is difficult to control once the plant is infected on highly susceptible cultivars.

The first record of *C. gloeosporioides* on olive fruit in Australia was in 1969 and for *C. acutatum* in 1989 both from New South Wales. In 2007 a leaf spot disease on olives, was recorded for the first time on 'Barnea' and 'Manzanillo'. Brown spots carrying heavily sporulating colonies of the fungus were observed on the surface of leaves. The infected spots were observed mostly on the edge of the leaves but they also occurred near the midrib. The spots were light to dark brown in colour and the necrotic areas had

irregular shapes and were 1-3 cm in size (Sergeeva et al., 2008b).

Asymptomatic infection of olive flowers (from the early stage of flowering until fruit set) by *C. acutatum* and *C. gloeosporioides* were also recorded for the first time in 2007. The first external symptoms occurred after fruit set on immature fruits at peppercorn (2-4 mm) and pea (5-10 mm) sizes. Fruit infected at these stages can drop; and those that remain on the trees can exhibit sporulating colonies. Flower buds and flowers are more critical for anthracnose infection (Sergeeva et al., 2008a) and even a small number of infected flower buds on susceptible cultivars such as 'Barnea', 'Kalamata' and 'Manzanillo' may be an inoculum source, however, different olive cultivars have varying responses to flower infection (Sergeeva, 2011d). Infected fruit are shown in Figure 1. The pathogen can infect immature and mature fruits. The first symptoms of anthracnose fruit rot are light brown sunken lesions or infected areas that may shrivel with time. Under humid conditions before harvest, salmon-colored spore masses cover the lesions. Spore production, spore germination, and infection of olive fruit are favoured by warm, humid weather. Mateo-Sagasta (1968) indicated that the fungus might survive in mummified fruit on the soil surface. Other researches suggest that mummified fruits on the soil surface are not an important inoculum reservoir for olive anthracnose (Talhinhas et al., 2010; Graniti et al., 1993).

The casual agent of olive anthracnose, originally described in Portugal as *Gloeosporium olivarum*, was subsequently reclassified as *Colletotrichum gloeosporioides*. The sexual stage, *Glomerella cingulata*, has been observed both in axenic cultures and on artificially inoculated olive tree (Cacciola et al., 1996).

Disease management was made more difficult by the presence of different species of *Colletotrichum* most important pathogens (*C. acutatum*, *C. gloeosporioides*, *C. simmondsii*, *C. fioriniae*, *C. clavatum* and *C. theobromicola*). Affected groves may have one or both species of the pathogen present (Sergeeva, 2011d). *C. acutatum* was more virulent than *C. simmondsii* at temperatures <25°C (Moral et al., 2012). Variability exists within each of the species with different isolates displaying different appearance, color (pigment production), growth rates in different temperatures and different tolerance to copper fungicides in vitro. Copper-based fungicides are the main method of disease control but they are not effective in suppressing anthracnose disease in olives under high disease pressure (Sergeeva, 2011d).

The epidemic progressed fastest in the densest plantings and that important anthracnose epidemics may develop in dense planting even with a moderately resistant cultivar such as 'Arbequina' (Moral and Trapero, 2009).

DISEASE CHARACTERISTICS

The anthracnose in olives 'Barnea', 'Manzanillo', 'Kalamata' is a serious problem particularly in the summer-dominant rainfall regions. The anthracnose pathogen infects many parts of the olive tree (*Olea europaea*) including buds, flowers, flower buds, leaves, stems, fruit, fruit set, sepals, pedicels, peduncles, receptacles, petioles, green shoots, twigs, suckers and waterspouts. The symptoms often develop on entire branch and cause branch dieback. The anthracnose fungal conidia were observed on bark of the olive tree.

The pathogen developed conidiomata (acervuli) or conidial masses on infected tissue. Anthracnose fungi overwinter in mummified fruits on the trees and also in infected woody tissue and leaves infected the previous year still attached to the tree; the fungus has long saprophytic survival ability on dead peduncle and pedicels. Fungal inoculum to start the disease cycle comes primarily from infected twigs, mummified fruits, buds, peduncles, leaf scars, leaves; fungus produces conidia from the overwintering fungal structures or in acervuli that develop on infected tissues and exude sticky orange masses of conidia. These fungal conidia can spread to infect healthy tissue in the spring, increasing inoculum pressure in the tree canopy.

Colletotrichum may infect olive fruits at any time after commencement of flowering, but infections do not usually become visible until they begin to ripen. The fungi may affect developing shoots and expanding leaves. If weather conditions

conductive to anthracnose prevail during flowering, the disease can build up, causing severe flower infection and reducing fruit set. Brown spots carrying sporulating colonies of the fungus were observed on the surface of leaves (Sergeeva et al., 2008b).

Fungus produces conidia in acervuli that develop on infected tissues and exude sticky orange spore masses; however, the pathogen can also be isolated from symptomless in olive tissue conidial masses without acervuli (Sergeeva, 2011d). In strawberry leaves, it has been demonstrated that *C. acutatum* can produce appressoria and secondary conidia without causing any symptoms (Leandro et al., 2001).

Different olive cultivars had varying responses to flower and fruit infection. Infection that occurs on the pedicels after flowering can also move into the fruit, causing them to rot in immature fruits or before harvest. The peduncle and flowers are the most destructive phase of the disease, as it affects fruit set and ultimately the yield. Flowers and flower buds are very susceptible to anthracnose. Infected flowers dry quickly. Infection of flowers, leading to fruit rot, is of economic importance as anthracnose results in significant losses in yield and reduced oil quality.

Developing fruit that are infected may show symptoms soon after infection, when they are at peppercorn and pea size. Infected fruit at both stages can drop; however, they may also remain on the tree, carrying the sporulating pathogen. The first symptoms of anthracnose fruit rot are brown tiny spots or brown sunken lesions rapidly expanding; or infected areas that may shrivel with time. These expand, leading to the partial or total rot of any part of the fruit. However, the lesions are more often seen in the apex, as this remains wet longer after rain and dew. The spots grow and coalesce to become a single spot that can cover half the fruit. Infection of olive fruits by pedicel causes end rots infecting fruits by invasion from fungal mycelium growing down the pedicel. The dark decay with a well-defined margin develops and as immature fruit ripens, decay spreads and rots the entire fruit, which becomes dark and shriveled. Infected fruits eventually dry up and mummify and can become a source of inoculum for the following season. Additional spores, which also are splash-dispersed, are produced upon new infections and these can rapidly spread the disease through multiple repeating cycles of new infection and additional spore production. Under favourable conditions, *Colletotrichum* species produce salmon-orange or cream-colored slimy masses of spores on the fruit. The infection can be present and survive from season to season. The disease incidence depends on olive cultivar, environment and virulence of the pathogen among other factors.

Anthracnose has previously been recorded on olive leaves in Mediterranean countries such as Portugal, Spain, Italy (Tjamos et al., 1993) and in Australia (Sergeeva et al., 2008b). The necrotic areas had irregular shapes, developing sporulating colonies of the fungus with visible conidiomata (acervuli) as small black dots. Heavy infections of anthracnose cause massive defoliation (Graniti et al., 1993). The symptoms of anthracnose are enlarged infected shoots, suckers and water spouts which carry the fungal infection. Spores from these sucker fungal colonies can be sources of secondary infection (Sergeeva et al., 2011c). The infection can persist from season to season and its incidence depends on factors including olive cultivar, environment and pathogen virulence. Weather conditions are very important for disease development: in particular, high rainfall or irrigation combined with summer heat can create a steamy, warm environment conducive to fungal growth. Warm, rainy, misty and humid conditions or heavy dews have all been associated with severe anthracnose epidemics (Sergeeva, 2011a).

Soil conditions may also help provide ideal conditions for the disease. Susceptibility of olive fruit to anthracnose increases with maturity, although immature fruit of susceptible cultivars may be severely affected in favorable environmental conditions. *Colletotrichum* survive in varying environments and spores on fruit permit survival of the anthracnose pathogen even during a hot, dry summer. This occurs because disease is the result of interaction between host and pathogen. *Colletotrichum* species have the capacity to produce asymptomatic latent (quiescent) infections on various olive tree tissues, including unripe fruit. The species produces two types of colonizations – biotrophic and necrotrophic. During the asymptomatic biotrophic phase, the pathogen

invades host cells without killing them and feeds on living cells, while necrotrophic life kills plant tissue. The transition from biotrophy to a destructive necrotrophic phase, called the biotrophy-necrotrophy switch, is critical in symptom development (Bhadauria et al., 2011) and has been known to result in drying of flowers. The asymptomatic infection of flowers is of economic importance to the industry, resulting in significant losses in yield.

Latent infection of *Colletotrichum* on pedicels after flowering can spread into the fruit, causing rot and drop in fruit set and immature olive fruits. Fungal spores can still remain on pedicels after fruit drop and fruit remaining on the trees can exhibit sporulating colonies of anthracnose fungus, while quiescent infection of fungus can also spread into the fruit causing internal rotting without visible external symptoms. Nevertheless, flowering, fruit set and immature fruits can be observed during fruit development on a single peduncle; both flowers and fruit set late in the season, in summer rather than spring, and carry fungal infection. During favorable conditions heavy infections cause rapid rotting, and sometimes shriveled and mummified fruits. Immature fruits of susceptible olive cultivars may be infected at all phenological stages, providing an additional inoculum source for new infections. Re-infection of the tree by the repeating spore stage is responsible for increased anthracnose symptoms during summer on new growth suckers, waterspouts and fruits. The ability to survive and multiply in the absence of symptoms may explain why anthracnose fungi often causes unexpected crop losses in olives, and is an important factor for exploration in future work on disease management. The disease cycle can play a major role in developing strategies for effective and timely management of anthracnose, and also in reducing unnecessary fungicides applications.

The mechanisms by which species of *Colletotrichum* penetrate their hosts have been debated for last years. Several modes of penetration are possible: through natural openings like stomata, through wounds and by direct penetration of the cuticle. Of these, direct penetration is the most common means of tissue penetration (Bailey et al., 1992). In Australia Queensland fruit fly (*Bactrocera tryoni*) and Green vegetable bug (*Nazara viridula*) can increase anthracnose severity by carrying fungal conidia, and provide entry points for fungal rots. Infection spread by fungus from adjacent diseased fruit. When pathogens are present on susceptible cultivars in conducive environmental conditions an epidemic can occur.

Moist environmental conditions in general favor the spread of disease, and make anthracnose difficult to control after symptoms appear. Greater attention should be paid to sap (tree sap flows through sapwood, peduncles, leaves) and guttation (the exudation of drops of xylem sap on the tips or edges of leaves) are a physiological disorder seen after the use of automatic irrigation, heavy rains following a dry period or fluctuations in temperature. The fluid may contain a variety of organic and inorganic compounds, mainly sugars, mineral nutrients, potassium and calcium. In some soil types, nutrients can also be washed out by rain or excessive irrigation.

Pest and disease resistance in general is strongly related to the fertility of soil in which plants grow. Healthy soils contain huge numbers of diverse living organisms which help protect crops from pest and disease outbreaks through biological control. Nutrition also influences the health of plants and therefore their susceptibility to disease and plants suffering nutrient stress will be more susceptible to anthracnose. Nutrients like calcium play a major role in the ability of the plant to develop stronger cell walls and tissues, therefore adequate crop nutrition increases tolerance of or resistance to disease. Further study is needed on the impact of soil nutrient and organic amendments on the development of anthracnose, and also on the interaction between irrigation and disease.

Cultural methods can significantly contribute to controlling or reducing pest and disease damage. Sanitation in particular is very important, and involves procedures that prevent the spread of disease to new plants, plant products and new areas, or reduce the amount of inoculum in an affected area. Only disease-free propagating material is introduced to new areas (Sergeeva, 2011b).

Pruning can assist with the natural control of anthracnose and reduce fungicide use by preventing or interrupting the fungal cycle. Removal can prevent disease spread from

infected shoots, twigs and mummified fruits before spores are dispersed.

CONCLUSIONS

Hemibiotrophic infection of the *Colletotrichum* pathogens incorporate aspects of both biotrophic and necrotrophic infection strategies. It shows initial symptomless intracellular growth, where the colonized host cells remain viable (biotrophy), and then switches to necrotrophic growth, killing the colonized olive plant tissues. During the necrotrophic phase the *Colletotrichum* pathogens actively kill plant tissue as they colonize and feed on the contents of dead or dying cells. This activity contrasts with that of biotrophic pathogens which derive nutrients from living cells and therefore maintain host viability. Explanation of life style of this phenomenon and current research approaches in future developments leading to the disease management strategies.

Successful management of anthracnose relies on understanding the conditions that promote disease development. Knowledge of disease cycle is essential for developing strategies for effective and timely control of the disease and also in reducing the number of fungicide applications.

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Figures



Fig. 1. Fruit set later in the season can carry fungal infection.