Tar spot of corn-*Phyllachora maydis*

Phyllachora maydis, a perithecial ascomycete, causes a tar spot disease of maize that is usually a minor problem. More significant damage to leaves and yield is caused by the fungus *Monographella maydis* whose infection follows that of the tar-spot fungus, at least where studied in Mexico. The source of initial inoculum for both fungi is not determined. The disease they cause is occurs in the cooler and higher elevations of Mexico and Central and South America, and the West Indies, so their ability to spread over land through other climatic zones may be limited. Not known to be seedborne or to infect other species, *Phyllachora maydis* could be transported on fresh or dry maize leaves or husks, or products made from them, from which ascospores would have to be produced and carried by wind or rain splash to maize.

Phyllachora maydis Maubl. 1904

Clypeus amphigenous, developing in epidermis, generally circular, 0.5-2 mm diam, dark brown to black, glossy.

Perithecia subglobose, ostiolate, aggregated or scattered, subepidermal beneath clypeus, 170-350 µm diam. Paraphyses numerous, filiform, longer than asci, to 125 µm.

Asci narrowly cylindrical, 8-10 x 80-100 µm, pedicel short.

Ascospores uniseriate in ascus, hyaline, aseptate, broadly ellipsoid, 5.5-8.5 x (8-)10-14 µm, often 13-14 µm.

Anamorph: Pycnidia subepidermal beneath clypeus, often in younger lesions. Conidiophores branched at two or three levels, branches tapering, 11-16 x 1-1.5 µm. Conidia filiform, hyaline, 10-15 - 0.5 µm, gradually tapering to apex.

Initial symptoms are small yellow-brown spots on either side of the leaf. The raised glossy black clypeus covering the ascomata, surrounded by a narrow chlorotic border, develops in the spot. Spots are circular, oval, sometimes angular or irregular, and may coalesce to form stripes up to 10 mm long (Liu, 1973).

Some spots enlarge around the ascomata, with an initially water-soaked area becoming necrotic, to form circular-ova,l brown lesions 3-8 mm diam with a dark outer edge (Bajet et al., 1994); this is called the 'fish-eye' symptom (Hock et al.,1992). These larger lesions coalesce after 7-14 days; areas between spots become water-soaked and dry out. When conditions favor disease, leaves may be fully dead in 21-30 days. The fungus spreads from the lowest leaves to upper leaves, leaf sheathes and the husks of developing ears (Bajet et al., 1994).

As many as 4000 lesions may form on a leaf, and, in susceptible genotypes, 80% or more of the leaf area is affected, leaving little green tissue or killing the plant (Ceballos and Deutsch, 1992). Affected ears have reduced weight and loose kernels, and kernels at the ear tip may germinate prematurely (CIMMYT, 2003).

For additional descriptions see Dalby 1917, Orton 1944, Parbery 1967, and Liu 1973.

Host range: *Zea mays* L.

Geographic distribution: Mexico, Central and South America

NOTES

Phyllachora maydis Maubl. is a member of a large genus of fungi causing 'tarspot' on grasses and other plants. It is the only species reported on *Zea* and is restricted to *Zea* (Parbery, 1967, 1971). Like other species of *Phyllachora*, it has a pycnidial anamorph in the genus *Linochora* (Parbery, 1967; Muller and Samuels, 1984). Parbery (1967) confirmed Petrak's determination that the anamorph of *Phyllachora graminis*, the type species, is not in the genus *Leptostromella*. Characters of the anamorph are useful in distinguishing species within the genus (Parbery and Langdon, 1964).

DISTRIBUTION

This fungus is reported from parts of Mexico, Central and South America and the West Indies (Hock et al., 1995; Cline 2005). Known primarily from the cooler and higher elevations (Malaguti and Subero, 1972; Bajet et al., 1994), it may be unable to spread by its own ability through the drier or hotter tropics. Watson (1971) lists it as present in Brazil, but Hock et al. (1995) state that there are no reports of it there, or farther south in the continent.

RISK OF INTRODUCTION

Not known to be seedborne, the two pathogenic fungi of the 'tar spot complex' could be transported beyond their known distribution on fresh or dry maize leaves or husks, or products made from them. Ascospores of *Phyllachora maydis* and conidia of *Monographella maydis* would then have to be carried by wind or rain splash to maize. To cause the serious damage that occurs in the native range, the two fungi would need to be introduced together in order to threaten the crop, unless *M. maydis* were already present or other species will interact with *P. maydis* as *M. maydis* does. Suitable environmental conditions of temperature, relative humidity and/or rainfall are required for the sequence of infections that results in the blight on maize. *Phyllachora maydis* by itself usually causes a low level of necrosis (Hock et al., 1995), although this level might be economically significant in some areas.

SIMILARITIES TO OTHER SPECIES/CONDITIONS

Orton (1944) distinguished *Phyllachora maydis* among species of *Phyllachora* on grasses on the basis of its ellipsoid, uniseriate ascospores, the intermediate length of asci, and the size and shape of the clypeus. According to his key other North American species that are similar occur on grasses in genera such as *Andropogon*, *Anthephora*, *Bouteloua*, *Panicum*, *Paspalum*, *Spartina* and *Stenotaphrum*.

According to this only monograph of the genus (Parbery, 1967, 1971), the morphogically similar species of *Phyllachora* cause tar spot on *Boutetoua*, *Cynodon*, and *Chloris*. *Phyllachora maydis* is restricted to *Zea*. Species reported on *Sorghum* were distinguished by the shape of the ascus from *P. oxyspora*, and the greater length of ascospores from both *P. oxysopora* and *P. sacchari* (Parbery, 1967).

Among other leaf spots on maize, tar spot is unique in the dark glossy clypeus, 0.5-2 mm diam, produced in the epidermis, with or without a larger brown necrotic area developing around it (Carson, 1999; CIMMYT, 2003).

DETECTION AND INSPECTION METHODS

Lower leaves should be examined for small, raised, glossy, dark, circular, or oval to irregular, spots, or for brown lesions, often with a dark border, having a dark ascomata at the centers (CIMMYT, 2003).

DIAGNOSTIC METHOD

No DNA sequences for this species are available in GenBank as of October, 2009, but sequences for the 18S and ITS2 regions of rDNA for *P. graminis* have been recorded (NCBI, 2009).

NOTES ON HABITAT

The disease is favored by cool temperatures, 16-20°C, and high relative humidity (Bajet et al., 1994). Severe disease was observed during a winter in lowland eastern Mexico when temperatures were in the range of 17-22°C, mean relative humidity was greater than 75%, more typical of mid-altitude zones, and there were more than seven hours of leaf wetness per night (Hock et al., 1995). Rainfall was not a significant factor in disease progress and severity. In Mexico, disease is most severe at elevations of 700-1600 m and in the cooler months from November to April at lower altitudes (Bajet et al., 1994).

NOTES ON CROPS/OTHER PLANTS AFFECTED

Phyllachora maydis is restricted to *Zea mays* (Parbery, 1967), and was not found on other grasses, including other*Zea* species, in Mexico (Hock et al., 1995)

BIOLOGY AND ECOLOGY

Ascospores of *Phyllachora* spp. on Australian grasses are actively discharged after rain or high relative humidity and collect in glutinous masses at the ostioles, from which they are probably dispersed by rain splash (Parbery 1963). Hock et al. (1995) trapped windborne ascospores of *P. maydis* in Mexico during periods of high humidity, with a maximum in the evening hours. Most of the spores trapped were in clusters of three or four; the fungus was able to spread up to 75 m from infected plants. In the laboratory, ascospores germinate best between 10 and 20°C, but poorly outside this range (Dittrich et al., 1991).

In eastern lowland Mexico, tar spot begins to appear about two weeks before flowering and reaches a maximum severity about six weeks later (Hock et al., 1995). Infection may also occur at the 8 to 10 leaf stage ((Hock et al., 1989).

The clypeus (stroma) of *Phyllachora* species grows separately in the epidermis on either side of the leaf and is not an extension of the perithecia (Parbery, 1963b).

The pycnidial of the *Linachora* asexual state appear early in infection (Parbery, 1967; Hock et al., 1992). Spores of the anamorphs of *Phyllachora* species tested did not germinate in water on slides or on host plants, and probably serve as spermatia in mating (Parbery and Langdon, 1963).

PHYSIOLOGY AND PHENOLOGY

Phyllachora species are generally obligate parasites, and cannot be cultured on the usual laboratory media (Parbery, 1963b). The apparent necrotrophic activity of *P. maydis* (Dalby, 1917; Liu, 1973; Bajet et al., 1994) is unusual for a fungus that should require living plant cells for its support, which suggests that the fungus is not fully adapted to its host.

ASSOCIATIONS

Phyllochora maydis is seldom found alone in affected tissue (Bajet et al, 1994). The anamorphic form of *Monographella maydis* Muller & Samuels usually grows in the necrotic areas around the ascomata (Muller and Samuels, 1984; Bajet et al., 1994) and is the cause of the severe blighting (Hock et al, 1995). In lowland eastern Mexico, when only *P. maydis* was present on a leaf, no leaf blight occurred (Bajet et al., 1994). Leaf inoculations with *M. maydis* were not usually successful unless *P. maydis* infections were already present, and lesions caused by *M. maydis* have not been observed in the field without the tar spot fungus in the center (Hock et al., 1992). This other pathogen may be present as an endophyte (Muller and Samuels, 1984; Bajet et al., 1994) or an epiphyte (CIMMYT, 1988); in either case, its shift to pathogenicity depends primarily on infection of the plant by *P. maydis*. Hock et al. (1992) observed that *P. maydis* develops first on the leaves, and they suggest that it may provide a means of entry for the second fungus. Symptoms caused by *M. maydis* then appeared as early as two days after *P. maydis* was visible; the majority of lesions produced by *M. maydis* occurred within seven days after the tar spot was seen.

The temperature range for optimal germination of *M. maydis* conidia in water, is 25-30°C, and germination was faster in the dark (Dittrich et al., 1991). The optimal temperature range for growth in culture, 24-27 C, corresponds to that typical of the November-February period in lowland eastern Mexico (Muller and Samuels, 1984). The higher optimum for the second pathogen may be a factor in its later appearance, following *P. maydis* infection in cooler months (Hock et al., 1995). Conidia in dried leaves in the laboratory or in leaves on the ground from August to December in lowland Mexico, began losing viability after 1 month, although survival outdoors was better (Hock et al, 1995).

Another member of the fungus complex associated with tar spot is *Coniothyrium phyllachorae* Maubl., a pycnidial fungus that is considered to be a hyperparasite on *Phyllachora*. Maublanc (1904) described it as occurring in the clypeus ('stroma') and empty perithecia of *P. maydis*. Hock et al. (1995) found almost 50% of *P. maydis* lesions containing pycnidia of *Coniothyrium* two weeks before harvest. Its incidence on *P. maydis* is independent of lesion infection by *Monographella maydis* (Hock, 1991). Tar spot lesions containing *C. phyllachorae* are smaller (Hock et al., 1989, 1995).

MOVEMENT AND DISPERSAL

Natural dispersal: Windborne ascospores of *P. maydis* were trapped in Mexico during periods of high humidity with a maximum in the evening hours (Hock et al., 1995). Plants located up to 100 feet away from a source of inoculum were infected in Puerto Rico (Liu, 1973). Parbery (1963a) suggested rain splash as a dispersing agent for *Phyllachora* on grasses in Australia. Rainfall was not a major factor in severity of the disease in lowland eastern Mexico (Hock et al 1995).

Other than maize, a source of initial inoculum for a new crop is unknown (Hock et al., 1995). If maize is not in continuous cultivation locally and the fungus does not survive well in crop debris, then volunteer plants or wild species of *Zea* or other grasses are the likely sources of ascospores. The disease was not found on grasses or on wild *Zea* (teosinte) in Mexico (Hock et al., 1995). In eastern lowland Mexico, the disease is observed on maize throughout the year (Bajet et al., 1994). Tropical and subtropical maize cropping patterns may allow the pathogen to persist and multiply.

Accidental introduction: This has not been reported, but the natural means of dispersal may not be sufficient to explain spread between environmentally favorable areas of maize cultivation at higher elevations in South America or to islands in the Caribbean. Transport of ears in the husk or of items made with leaves or husks are possible means of introduction.

SEEDBORNE ASPECTS OF DISEASE

No species of *Phyllachora* are reported as seedborne (Richardson, 1990). Hock et al., (1995) considered infestation of maize seed by either *P. maydis* or *M. maydis* unlikely in that the fungi would not penetrate through the husks to the ear. They were unable to isolate *M. maydis* from seeds.

ECONOMIC IMPACT

The disease can cause an estimated yield loss for farmers of up to 30% in Mexico, with an average loss of 8% (Hock et al., 1995); the crop area affected could be as much as 500,000 hectares (Hock et al., 1989). A yield loss of 46% due to the disease occurred in unsprayed test plots in Veracruz, Mexico (Bajet et al., 1994); some portion of the damage was due to Fusarium stalk rot to which tar spot apparently predisposes the plant. Greater losses were suggested to be possible where environmental conditions are more favorable or cultivars grown are more susceptible. Other types of losses may include reductions in quality of grain, plants used for feed, or husks used for food wrapping (Bajet et al., 1994).

Estimated yield losses of up to 75% in the 2008/2009 season were reported to have occurred in the northern provinces of Guatemala (ProMED-mail, 2009).

PREVENTION

Phyllachora maydis has been intercepted at ports in the USA coming from Mexico and Guatemala (Cline, 2005).

CONTROL

Measures to reduce the initial inoculum for a new crop would depend on the source of that inoculum and cultivation practices. Where maize is grown continuously in the vicinity, efforts at sanitation are not likely to be effective. Elsewhere, removal of volunteer plants or wild maize relatives may be appropriate. Ascospores of *Phyllachora maydis* survived in crop debris for 3 months or longer (Hock et al., 1995); the removal or destruction of the debris may be useful if a new crop will be planted in that interval.

BIOLOGICAL CONTROL

Reduction in size of *P. maydis* lesions due to hyperparasitism soon after infection suggests that *Coniothyrium phyllochorae* may be suitable for use as a control (Hock et al., 1995).

CHEMICAL CONTROL

Fenpropimorph (one or two treatments) and mancozeb applied every 10 days were found to be the most effective fungicides in field plot tests in Mexico (Bajet et al., 1994).

HOST RESISTANCE

Incorporation of resistance into maize cultivars is the preferred method of control due to the cost of chemicals, and, in Mexico, CIMMYT has developed resistant breeding lines and varieties for different ecological niches (Bajet et al., 1994). Resistance to *P. maydis* appears to be due primarily to a single dominant gene but additive effects were also detected (Ceballos and Deutsch, 1992). Although progress was difficult and slow, because the tar spot problem involves the two fungi, CIMMYT obtained 14 inbred lines that were 'almost immune' (Vasal et al.,1999).

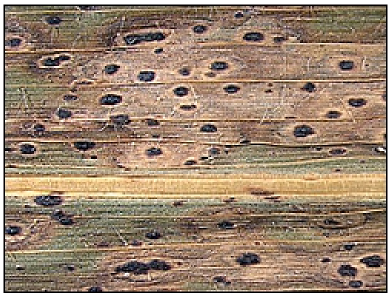
GAPS IN KNOWLEDGE/RESEARCH NEEDS

The means of persistence and sources of initial inoculum other than maize need to be determined. In addition, important questions concern whether *M. maydis* or a related species, an endophyte, or epiphyte of maize elsewhere, introduced with *P. maydis* could result in high disease severity. In addition, it should be determined how susceptible to either pathogen are maize cultivars grown elsewhere in environments favorable for tar spot.

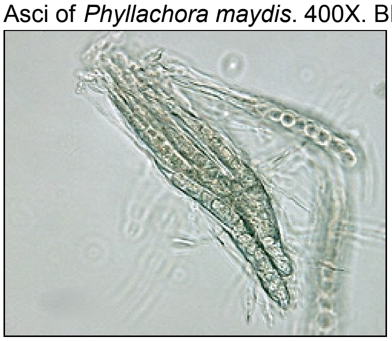
References

Tar spots on *Zea mays*. BPI 638562

Blight developing between 'fisheye' spots on *Zea mays*. 7.5X. BPI 638568

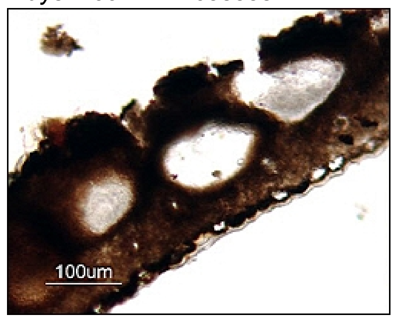


Asci of *Phyllachora maydis*. 400X. BPI 638548



'Fisheye' spots developed around tarspots on *Zea mays*. 7.5X. BPI 638568. BPI 638568

Perithecia in cross section of tarspot lesion on *Zea mays*. 100X. BPI 638558



Ascospores of *Phyllachora maydis*. 1000X. BPI 638558