INDUSTRY BIOSECURITY PLAN
FOR THE GRAINS INDUSTRY

Threat Specific Contingency Plan

Philippine downy mildew of maize (*Perenosclerospora philippensis*)
and
Downy mildew of sorghum (*P. sorghi*)

Prepared by Gordon M. Murray

and Plant Health Australia

November 2009

Plant Health AUSTRALIA

GRDC Grains Research & Development Corporation

CRC PLANT biosecurity

Disclaimer

The scientific and technical content of this document is current to the date published and all efforts were made to obtain relevant and published information on the pest. New information will be included as it becomes available, or when the document is reviewed. The material contained in this publication is produced for general information only. It is not intended as professional advice on any particular matter. No person should act or fail to act on the basis of any material contained in this publication without first obtaining specific, independent professional advice. Plant Health Australia and all persons acting for Plant Health Australia in preparing this publication, expressly disclaim all and any liability to any persons in respect of anything done by any such person in reliance, whether in whole or in part, on this publication. The views expressed in this publication are not necessarily those of Plant Health Australia.

Further information

For further information regarding this contingency plan, contact Plant Health Australia through the details below.

Address:	Suite 5, FECCA House 4 Phipps Close DEAKIN ACT 2600
Phone:	+61 2 6215 7700
Fax:	+61 2 6260 4321
Email:	**admin@phau.com.au**
Website:	**www.planthealthaustralia.com.au**

1 Purpose of this Contingency Plan

This Contingency Plan provides background information on the pest biology and available control measures to assist with preparedness for incursions into Australia of downy mildews of maize and sorghum. It provides guidelines for steps to be undertaken and considered when developing a Response Plan to these pests. Any Response Plan developed using information in whole or in part from this Contingency Plan must follow procedures as set out in PLANTPLAN and be endorsed by the National Management Group prior to implementation.

2 Pest information/status

2.1 Pest details

Scientific name	Other Scientific Names	Common Names
Peronosclerospora philippinensis (W. Weston) C.G. Shaw, 1978	*Sclerospora philippinensis*	Philippine downy mildew of maize, downy mildew of maize, downy mildew of sorghum, downy mildew of sugarcane
Peronosclerospora sorghi (W. Weston & Uppal) C.G. Shaw 1978	*Sclerospora sorghi-vulgaris* (Kulk.) Mundk., *Protomyces graminicola* (auct. non Schroeter, 1876), *Sclerospora graminicola* (auct. non Schroeter, 1879), *Sclerospora sorghi*	Sorghum downy mildew, mildew of maize and sorghum

2.1.1 General information

Taxonomic position — Phylum: Oomycota; Class: Oomycetes; Order: Sclerosporales; Family: Sclerosporaceae

2.1.1.1 PHILIPPINE DOWNY MILDEW OF MAIZE

Philippine downy mildew (PDM) is caused by the oomycete *Peronosclerospora philippinensis*. Although brief mentions of the disease had been made in 1916 and 1918, the first comprehensive description of the disease and its pathogen was provided by Weston (1920), and this paper is still considered to be one of the most comprehensive studies on the disease.

Peronosclerospora philippinensis is considered the most virulent of the maize downy mildew pathogens (Bonde, 1982). If infection rates are high PDM may cause significant losses to maize production, by causing malformed and/or sterile ears with few grains. Yield losses in individual fields are frequently 40–60%, but under favourable conditions, may be as high as 80–100% (Exconde & Raymundo, 1974; Bonde, 1982). In the 1974-5 season national yield losses in the Philippines were estimated at 8%, with a dollar value of US $23,000,000 (Exconde, 1976). In general, yield losses correlate with percentage of plants infected (Exconde, 1975; Bonde, 1982), but further losses may occur through secondary attack by stem borers and other secondary parasites and pathogens (Exconde & Raymundo, 1974).

Transmission occurs through the release of airborne conidia and is highly dependent on dew or a thin film of moisture on the surface of the infected surfaces (Dalmacio & Raymundo, 1972). *P. philippinensis* penetrates the stomata of maize leaves by means of germ tubes from germinating conidia (Weston, 1920). Penetration is followed by invasion of the mesophyll. Abundant mycelium and two types of hyphae were present. One type was long, slender and sparsely branched; the other was irregularly branched, crooked and varied in size.

Seed transmission of *P. philippinensis* to seedlings occurred at the rate of 11% in sterilised soil from seeds harvested at 36-38% moisture content; no transmission occurred from seeds with a moisture content of 14% (McGee, 1988).

Significant differences in virulence between isolates of *P. philippinensis* indicate physiological specialisation (Exconde, 1976).

2.1.1.2 DOWNY MILDEW OF SORGHUM

Sorghum downy mildew (SDM; *Peronosclerospora sorghi*) is a soil borne oomycete that infects sorghum and maize plants. The fungus invades the plant through the root system, and results in plant leaves becoming chlorotic, usually appearing within 2 weeks of sowing. Heavily infected plants can be dwarfed and a white downy growth may appear on both surfaces of infected leaves.

Transmission occurs mainly through oospores which survive in the soil (Broyles, 1956), while it can also be transmitted from plant to plant by airborne conidia or through the seeds (Rao *et al.,* 1985), except when stored under low moisture conditions (Sommartaya *et al.,* 1975). Soil temperature (Schuh *et al.,* 1987) and composition (Bigirwa *et al.,* 1998) play important roles in determining disease spread, with sandy soils at about 25°C being the optimum temperature for SDM spread.

Susceptible plants can be used to assess spatial patterns of *P. sorghi* oospores instead of direct sampling by soil cores; this was demonstrated by studying the pattern of sorghum systemically infected with downy mildew and oospores residing in the soil (Schuh *et al.,* 1988). In addition, high humidity is required by *P. sorghi* for transmission via both conidia (airborne) and oospores (soil borne).

The taxonomy of *P. sorghi* is confused and therefore identification of the downy mildew species in different parts of the world is in doubt (Perumal *et al*., 2008). *P. sorghi* from sorghum infects sorghum and maize, producing oospores in sorghum but not readily producing oospores in maize. However, a ~~"~~*P. sorghi*", which is prevalent in the Nigerian Guinea savanna, does not readily form oospores in maize or in sorghum, although oospores have been detected in maize seed from some areas (Adenle & Cardwell, 2000). It is, therefore, unlikely that this Nigerian pathogen over seasons as soil-borne oospores. A number of grasses were artificially inoculated with the Nigerian fungus but none of the grasses were susceptible to infection. It has been reported that *P. sorghi* may perpetuate itself by conidial infection in maize plants in view of three virtually overlapping maize crops in the Guinea savannah area of Nigeria (Anaso, 1989) but seed borne infection emanating from farmer-saved seed is also an important consideration (Adenle & Cardwell, 2000). Nonetheless, the species identity of this Nigerian *P. sorghi* remains in doubt (Perumal *et al*., 2008) so the significance of its failure to produce oospores remains unknown.

Pathotypes of *P. sorghi* have been identified. A total of 16 worldwide isolates of *P. sorghi* were tested for virulence on 75 sorghum cultivars previously identified as resistant to three pathotypes from Texas, USA, and to some regional populations of *P. sorghi*, in an ICRISAT multilocational screening programme. All isolates were identified as distinct pathotypes on the basis of differential sporulation on host cultivars. Host-pathogen interactions were consistent with the gene-for-gene hypothesis (Pawar *et al.,* 1985). The relationship between the genes for resistance to *P. sorghi* pathotypes 1, 2

and 3 in the sorghum lines QL3-India and SC414-12 were investigated by making reciprocal crosses between them and susceptible lines. A pathotype confined to maize also occurs in some areas such as the southern humid zone of Nigeria where it causes substantial damage through systemic infection (Payak, 1973; Olanya & Fajemisin, 1993).

2.1.1.3 OTHER DOWNY MILDEWS OF MAIZE

Worldwide there are at least ten species of downy mildews that affect maize and sorghum, with at least two, *Peronosclerospora maydis* and *Sclerophthora macrospore*, known to be present in Australia. Identification to the species level is difficult and involves morphological, host range and potentially molecular studies.

2.1.2 Disease cycle

2.1.2.1 PHILIPPINE DOWNY MILDEW OF MAIZE

P. philippinensis produces conidia from infected plant material, which can be cultivated on crops, such as corn, sorghum or oats, or weed species, which are then transmitted between plants through an air borne mechanism. Temperature has a minor effect on PDM transmission, with larger conidia produced at higher temperatures, while infection rates were significantly lower when temperatures were between 10 and 16°C (Bonde *et al.,* 1992). Field experiments on maize indicate that dew or a thin film of moisture over the surfaces of infected leaves were the determining factors in spore production. Sporulation always occurred at, or above, 90% relative humidity (Dalmacio and Raymundo, 1972).

P. philippinensis spores germinate on the leaves of the host, with the germ tube penetrating the stomata to enter the leaf (Weston, 1920), followed by the invasion of the mesophyll cells. Hyphae are produced in two forms long, slender and sparsely branched or irregularly branched, crooked and varied in size.

P. philippinensis produces oospores in plant tissue but their role in the disease cycle has not been demonstrated. The disease is seed borne in moist seed but is not seed borne in seed that has been dried to less than 14% moisture content.

2.1.2.2 DOWNY MILDEW OF SORGHUM

P. sorghi produces oospores in infected host tissue. Oospores are produced less frequently and abundantly on maize than on sorghum, and appear in both hosts only in systemically infected plants (Bigirwa *et al*., 1998). Oospore populations in soil of 8–95 oospores per gram have been reported following sorghum crops (Pratt & Janke, 1978). Oospores are thought to survive for at least three years under a variety of conditions (Frederiksen, 1980), and can also be dispersed by wind. Oospores germinate in soil by germ tubes that infect underground parts of susceptible seedlings, which then become systemically infected. Infection by oospores does not occur if seedlings emerge in cool soils below 20°C. In arid areas, where soil temperature is higher, oospores initiate infection of seedlings, whereas in areas where a perennial host such as Johnson grass is present, infection can be initiated from conidia (Bigirwa *et al*., 1998).

Conidia are produced from systemically infected plants at temperatures between 17 and 29°C from midnight to about 8 am (Bock *et al*., 1998), with an optimum temperature of 24 to 26°C, depending on

the geographic isolate (Bonde *et al*., 1985). Conidial germination requires a saturated atmosphere, and moderate temperatures of 15 to 25°C, depending on the isolate. High levels of systemic infection can occur between 11 and 32°C, with a wet period of 4 hours or longer. Conidia are well adapted to wind dispersal (Bock *et al*., 1998), but lose their viability after 3 to 4 hours so probably only play a role in short distance spread of the fungus.

The fungus can infect corn seed but is confined in mature seeds to the pericarp and pedicel. Jones *et al.* (1972) found that seed transmission of the disease occurs when infected seeds at the soft dough stage are planted in sterile soil. In contrast, seed transmission of the disease is prevented by reducing the moisture content to 9% and by storage for 40 days prior to planting. These results should be treated with caution, since the findings are based on a total of only 75 seeds per treatment. When 400 seeds harvested from systemically infected maize plants were planted in sterile soil in a greenhouse, 256 plants showed systemic infection at and after the fifth leaf stage (Rao *et al*., 1984). These findings suggest that the presence of oospores within the seed resulted in the transmission of the fungus, regardless of seed moisture content (Rao *et al*., 1984).

2.2 Affected Hosts

2.2.1 Host range

2.2.1.1 PHILIPPINE DOWNY MILDEW OF MAIZE

P. philippinensis primarily infects monocot species. The hosts of this fungus are:

- Major hosts: *Zea mays* (corn)
- Minor hosts: *Avena sativa* (oats), *Saccharum officinarum* (sugarcane), *Saccharum spontaneum* (wild sugarcane), *Sorghum bicolor* (sorghum), *Sorghum halepense* (Johnson grass), *Zea mexicana* (teosinte)

2.2.1.2 DOWNY MILDEW OF SORGHUM

P. sorghi primarily infects the following species:

- Major hosts: *Sorghum bicolor* (sorghum), *Sorghum caffrorum*, *Sorghum sudanese* (sudan grass), *Zea diploperennis*, *Zea mays* (corn)
- Minor hosts: *Andropogon sorghi*, *Panicum trypheron*, *Pennisetum glaucum* (pearl millet), *Sorghum halepense* (Johnson grass), *Zea mexicana* (teosinte)

2.2.2 Geographic distribution

2.2.2.1 PHILIPPINE DOWNY MILDEW OF MAIZE

P. philippinensis is present throughout Asia with limited distribution outside this area. Countries known to have this oomycete are:

- Asia: China, India, Indonesia, Japan, Nepal, Pakistan, Philippines, Thailand
- Africa: Mauritius

2.2.2.2 DOWNY MILDEW OF SORGHUM

P. sorghi is widely distributed as follows:

- Asia: Bangladesh, China, India, Iran, Israel, Japan, Nepal, Pakistan, Philippines, Thailand and Yemen (CMI, 1988; Jeger *et al.,* 1998)
- Africa: Benin, Botswana, Burundi, Egypt, Ethiopia, Ghana, Kenya, Malawi, Mauritania, Mozambique, Nigeria, Rwanda, Somalia, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe (CMI, 1988; Jeger *et al.,* 1998)
- North America: Mexico and USA (Alabama, Alaska, Arkansas, Georgia, Illinois, Indiana, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New Mexico, Oklahoma, Tennessee and Texas (Bonde, 1982; CMI, 1988; Jeger *et al*., 1998)
- Central America and Caribbean: El Salvador, Guatemala, Honduras, Nicaragua, Panama and Puerto Rico (CMI, 1988; EPPO 1998; Jeger *et al,* 1998)
- South America: Argentina, Bolivia, Brazil, Colombia, Uruguay and Venezuela (CMI, 1988; EPPO 1998; Jeger *et al,* 1998)

2.2.3 Symptoms

2.2.3.1 PHILIPPINE DOWNY MILDEW OF MAIZE

Symptoms of PDM occur on the leaves and stems of maize plants. However, it is the effects of the disease on the production of viable cobs that is most detrimental to the commercial value of the crop. The severity of the disease in individual corn plants varies with environmental conditions and developmental stage of plants at the time of infection (Weston, 1920). When the disease infects young seedlings, there is usually a complete failure of the plant to develop and produce fertile ears. When infection attacks older plants, the plant may mature and produce stunted, malformed cobs with fewer grains (Weston, 1920).

Downy mildew on maize leaves is characterised by elongated chlorotic streaks with a downy growth of conidia and conidiophores (Figure 1). Symptoms first appear 3–6 days after infection as pale yellow to whitish discolourations on the leaf blade. Tassels may be deformed, and ears may be aborted. When the disease is severe, the infected plants are stunted and weakened, and may die within a month. When the attack is moderate, infected plants usually reach maturity but produce small, deformed ears (Weston, 1920; Dalmacio & Raymundo, 1972).

By contrast, infection of corn leaves by *P. sacchari* produces irregular, discontinuous discolourations which do not tend to develop into the long streaks characteristic of *P. philippinensis*. Symptoms and sporulation take longer to appear than in infections with *P. philippinensis*. Although called downy mildew, infection by *Sclerophthora macrospora* causes excessive tillering, dwarfing and replacement of the tassel by a mass of leaf-like growth. *S. macrospore* produces large numbers of oospores in the thickened leaves.

Symptoms by affected plant parts are as follows:

- Inflorescence: abnormal forms
- Leaves: abnormal colours and fungal growth
- Whole plant: dwarfing

Figure 1: *Young maize plant showing typical symptoms of Philippines downy mildew (CABI Plant Compendium).*

2.2.3.2 DOWNY MILDEW OF SORGHUM

There are two types of symptom produced by *P. sorghi* in both sorghum and maize: systemic infection which occurs by oospores or conidia during the first four weeks of germination of the seed; and local lesions resulting from conidial infection of older plants, which may also give rise to systemic infection (Schuh *et al*., 1986).

Systemic infection in maize seedlings is characterised by chlorosis that normally appears after seedling emergence. The first leaf is invariably free from infection; this may be caused by the first leaf outgrowing the pathogen, which requires time to invade the root and stem tissue, or the existence of a passive defence mechanism in the first leaf which prevents entry of the pathogen. If no infection is observed within 2 weeks, the second leaf escapes infection while the younger leaves may subsequently develop symptoms.

Infected maize plants are sometimes stunted and occasionally have white-striped leaves and abnormal seed set. Leaf chlorosis always includes the base of the blade, with the transverse margin usually sharply defined between the diseased and healthy tissue. This symptom appears further up the blade in successively formed leaves (half-leaf symptom). The leaves of infected plants tend to be narrower and more erect than those on healthy plants. In maize, most systemically infected plants are sterile, but occasionally some will set seed.

Symptoms by affected plant parts are as follows:

- Fruits/pods: abnormal shape
- Inflorescence: abnormal leaves and abnormal forms
- Leaves: abnormal colours, abnormal forms, fungal growth and shredding
- Stems: internal discolouration
- Whole plant: dwarfing

2.3 Entry, establishment and spread

2.3.1 Philippine downy mildew of maize

Entry potential: Rating = Low

The entry potential of *P. philippinensis* is Low for the following reasons:

- Because of the short lived nature of conidia of *P. philippinensis*, the only feasible pathways for introduction of the fungus are introduction of infected vegetative material, or introduction on seed. Advincula & Exconde (1975) have shown that the fungus can be transmitted by seed produced on systemically infected plants but that transmission was possible only if hard dough kernels were sown as fresh seeds immediately after harvest. Transmission in seeds was possible only if the seeds had moisture contents of more than 30% and less than 43%.
- The pathogen is widespread in Indonesia. Because airborne spread is short range, it is highly unlikely to enter northern Australia directly. However, if it is spread into Papua New Guinea, there is an increased risk of entry to northern Australia.

Establishment potential: Rating = High

The establishment potential of *P. philippinensis* in Australia is High for the following reasons:

- Maize and alternative weed hosts occur across maize growing areas of Australia.
- Temperature and night time dews in maize growing areas are favourable for sporulation of and infection by conidia.

Spread potential: Rating = Medium

The spread potential of *P. philippinensis* in Australia is Low to Medium for the following reasons:

- The dissemination of PDM via seed is unlikely provided certain precautions are exercised, including harvest of seed from healthy plants only, drying seed to less than 10% moisture and holding seed for several months before planting (Frederiksen & Renfro, 1977).
- Fungal hyphae of *P. philippinensis* are associated with the pericarp of infected seeds, and have not been reported in the endosperm or embryo; hence a reduction in seed moisture to 14-30% completely prevents transmission (Bonde *et al.,* 1992).
- Local spread is by airborne conidia (Bock *et al*., 1998) so it would readily spread between adjacent crops and to neighbouring grass hosts.

Economic impact: Rating = High

The economic rating is High because:

- Philippine downy mildew is potentially the most destructive disease of maize in Asia, being able to stop maize production.

Environmental impact: Rating = Negligible

There is no potential to degrade the environment or otherwise alter the ecosystem by affecting species composition or reducing the longevity or competitiveness of wild hosts.

Overall risk: Rating = Medium

2.3.2 Downy mildew of sorghum

Entry potential: Rating = High

P. sorghi is seed-borne, either as mycelium in immature seeds, or oospores in the pericarp and pedicel of the seed, so the entry potential is high. While there is evidence that seed transmission can be prevented by reducing the moisture content of the seed to 9% and by storage for 40 days prior to planting, other experiments suggest that the presence of oospores within the seed results in the transmission of the fungus, regardless of seed moisture content (Rao *et al*., 1984). The oomycete could also be introduced in bulk maize shipments as oospores in trash and soil.

Establishment potential: Rating = High

The establishment potential of the pathogen is high in some parts of the maize and sorghum growing areas of Australia: Wang *et al*. (2000) found that areas of coastal Queensland were suitable for infection, but the main inland growing areas of Queensland and NSW were much less suitable. Oospores in or on seed, trash or soil are the likely primary inoculum. These spores require soil temperatures above 20°C for germination, and these temperatures occur in Australia in summer where maize crops are grown. Suitable temperatures for conidial production and germination also occur during this period but the moisture requirements are only met in coastal areas of Queensland.

The close proximity of maize and sorghum crops to many of the feed lots where imported maize would be used in Australia increases the risk of establishment should spillage of grain, trash or soil occur. The wide distribution of Johnson grass in northern Australia, especially along roadways, also provides a perennial source of susceptible host material.

Spread potential: Rating = High

The spread potential of the pathogen is high, as oospores can be spread long distances by wind, in seed and crop residues, and in soil on farm machinery. Conidia can also spread the disease locally within crops and between adjacent crops and weed hosts.

Economic impact: Rating = High (on sorghum) and Medium (on maize)

The economic impact is likely to vary depending on location. Conditions are more likely to be favourable for disease development in coastal Queensland, where losses would be potentially high and less favourable in inland growing areas where the losses are likely to be low. The disease is more likely to affect breeding programs, which are in the more conducive coastal areas. One response may be to relocate these programs to less conducive areas.

Sorghum downy mildew is a serious disease of both maize and sorghum in the tropics and subtropics, and is the most widely distributed of the major downy mildew diseases of these crops. Severe

outbreaks have occurred in India, Israel, Mexico, Thailand, Texas and Venezuela. In Nigeria, grain yield losses in maize from this disease range from 10 to 90%. In Texas, the disease incidence can be 30% or higher given favourable environmental conditions.

Environmental impact: Rating = Negligible

There is no potential to degrade the environment or otherwise alter the ecosystem by affecting species composition or reducing the longevity or competitiveness of wild hosts.

Overall risk: Rating = High (for sorghum) and Medium (for maize)

2.4 Diagnostic information

2.4.1 Diagnostic protocol

At least ten species of downy mildews affect maize worldwide, but the identification of these based on morphology and host range is difficult so that the precise distribution of species is not known (Perumal *et al*., 2008). Molecular techniques are improving knowledge of the relationships between these pathogens (Spencer and Dick, 2002) and recent studies of microsatellite sequences shows promise for improved identification methods for this group (Perumal *et al*, 2008). However, current identification is based on symptoms and morphology.

It must be emphasised that morphological characters are subtle and have been controversial – for this reason it is essential that a team of taxonomists confer on the identification. The identification will need to be based on combination of all available symptoms with all available morphological characters and comparison with published data from a number of sources. The pattern of leaf symptoms is regarded as marginally more reliable than the characters of conidia and conidiophores. Any downy mildew found on maize with elongate chlorotic streaks must be regarded as suspect PDM.

2.4.1.1 PHILIPPINE DOWNY MILDEW OF MAIZE

The mycelium, growing intercellularly in all parts of the plant except the roots, is 8 μm in diameter, but irregularly inflated and constricted, with simple haustoria, vesiculiform to sub-digitate, 8 μm long by 2 μm diameter (Holliday, 1975). Conidiophores develop through stomata during the night dew or times of high relative humidity, they are 150–400 μm long by 15–26 μm wide, the stalk cell branches 2–4 times at the apex, and each of these sub-branches may also branch twice, each terminating in two or more conoid to subulate sterigmata; these are 10 μm long and slightly curved (Holliday, 1975). Conidia, borne on the sterigmata, are elongate ellipsoid or ovoid, varying in size from 27–39 μm long by 17–21 μm wide; they are hyaline, smooth with a minute apiculus at the base. Germination is by germ tube (Holliday, 1975).

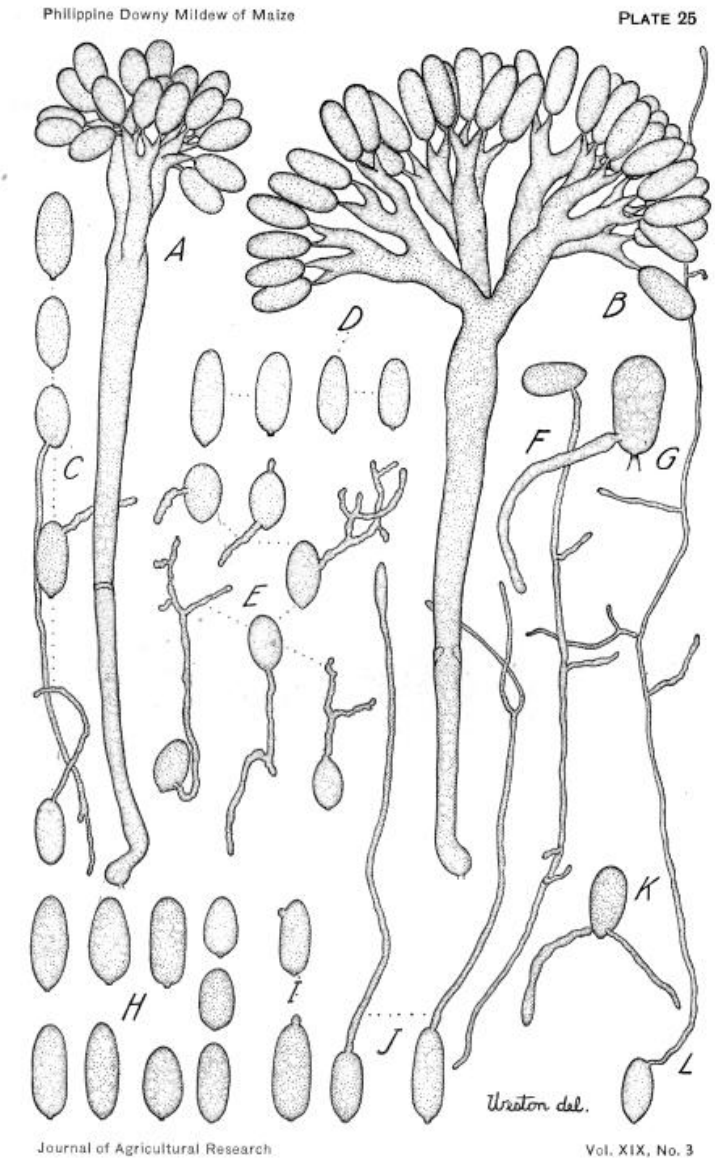

Figure 2: *Morphology of P. philippinensis (from Weston, 1920): A, conidiophore from sorghum; B, conidiophore from teosinte; C, conidia from sorghum; D, conidia from teosinte; E, germinating conidia; F, extending germ tubes and hyphae in dew at 7°C; G, germinating conidium still attached to its sterigma; H, conidia from maize; I, conidia from maize germinating in rain water; J, conidia from maize germinating in brook water at 8°C; K, conidium from maize germinating in dew; L, conidium from maize germinating in dilute decoction of young maize kernels.*

The oogonia are smooth walled with fragments of oogonial stalk or antheridial cell frequently adhering, and average 22.9 μm (Holliday, 1975). Oospores are regularly spherical, central to eccentric, 15.3–22.6 μm in size. The oospore wall is 2–3.9 μm thick with a homogenous, finely granular content with masses of oil reserves (Napi-Acedo & Exconde, 1967; Holliday, 1975). Napi-Acedo & Exconde (1967) reported oospore production from the early stages of infection until

disintegration of the leaf tissues. The oospores were smaller in *P. philippinensis* compared to other species of *Peronosclerospora*, and were scattered in the leaf tissues with no shredding of leaves observed.

P. philippinensis is readily distinguished from the other downy mildews that infect maize by conidial morphology, except for *P. sacchari,* which it most resembles.

Variation in the size and length of conidiophores and conidia have been reported by a number of authors (Titatam & Esconde, 1974; Josue & Exconde, 1979) and has generally been attributed to host genotype and prevailing environmental conditions (especially temperature and relative humidity). The length of the conidia of *S. sacchari* (the closest relative to *P. philippinensis*) shows a positive relationship with temperature, with the width remaining unaffected and thus changing the length to width ratio. However, most authorities believe that under identical conditions, *P. philippinensis* is consistently different in its conidial shape from *P. sacchari*. In general, length to breadth ratios are 2.1 *for P. philippinensis* and 2.4 for *P. sacchari.* There are also differences in the symptoms produced in corn, with *P. philippinensis* causing chlorotic streaks, and *P. sacchari* causing discrete chlorotic blotches.

2.4.1.2 DOWNY MILDEW OF SORGHUM

Oogonia of *P. sorghi* are spherical, 40–55 µm in diameter and are embedded among mesophyll cells between fibrovascular bundles. Oospores measure 25–42.9 µm (av. 36 µm), are hyaline, spherical, with light yellow walls, and germinate by germ tube.

Conidiophores are erect, fragile, hyaline, 180–300 µm long, usually dichotomously branched 2–4 times and emerge through stomata on the lower sides of leaves. Conidia are hyaline, oval to spherical, 15–26.9 × 15–28.9 µm, and borne on elongated, tapered sterigmata. They germinate by germ tube under high humidity (APS, 1973).

The taxonomy of *P. sorghi* is difficult (Perumal *et al*., 2008). There have been two incorrect identifications of this fungus in Australia, which subsequent examination showed to be *P. maydis* (Wang *et al*., 2000).

2.5 Response checklist

2.5.1 Checklist

Guidelines for Response Checklists are still to be endorsed. The following checklist provides a summary of generic requirements to be identified and implemented within a Response Plan:

- Destruction methods for plant material, soil and disposable items
- Disposal procedures
- Quarantine restrictions and movement controls
- Decontamination and farm cleanup procedures
- Diagnostic protocols and laboratories
- Trace back and trace forward procedures
- Protocols for delimiting, intensive and ongoing surveillance

- Zoning
- Reporting and communication strategy

Additional information is provided by Merriman and McKirdy (2005) in the Technical Guidelines for Development of Pest Specific Response Plans.

2.6 Delimiting survey and epidemiology study

Delimiting surveys should comprise local surveys around the area of initial detection concentrating on areas of poor growth. The normal procedure is to collect symptomatic plants and to test them to confirm the presence of *Peronoslerospora* sp. If confirmed, plants taken at random from the same crop should be tested to enable an estimate to be made of the disease incidence. Surrounding crops would then be surveyed. The extent of the survey beyond the initial infected crop should be guided by the test results from surrounding crops.

Seed trace-back and trace-forward will indicate how many seed lots and crops will need to be tested. If the seed used has been sown at several sites, delimiting surveys should be conducted at each site.

2.6.1 Philippine downy mildew of maize

Weston (1920) described the process of sporulation of *P. philippinensis* as commencing under favourable conditions at around midnight and continuing until a few hours after dawn in rainy or misty weather. Intact conidiophores and conidia cannot be found once the morning sun has dried the leaf surface. In morphological studies of conidia, Weston insisted that conidia should be measured when freshly harvested at the period of maximum production at 2–3 am. Visarathanonth & Exconde (1976) tracked the progress of sporulation in *P. philippinensis* after artificial inoculation. Conidiophores started to emerge from stomata at 11 pm and sporulation was evident by 3:30 am, with spores mature and easily detached by 7 am.

2.6.2 Downy mildew of sorghum

Sporulation of *P. sorghi* is similar to that of *P. philippinensis*, beginning under favourable conditions of high humidity with dew or rain at around midnight and continuing until a few hours after dawn (Bonde *et al*, 1985; Bock *et al*., 1998). Sporulation can also be induced under artificial conditions (Bock *et al*., 1998).

Consequently, sampling and microscopic examination for confirmation of downy mildew occurrence on symptomatic plants and for assessment of conidial morphology should ideally be done in the early hours of the morning. It is essential that sampling and identification not be attempted more than a couple of hours after dawn. If conidia are successfully found by this, trials should be done on collected living plants to determine whether sporulation will occur under artificial conditions.

2.6.3 Sampling method

Once initial samples have been received and preliminary diagnosis made, follow up samples to confirm identification of the pathogen will be necessary. This will involve sampling directly from the infected crop, and sampling crops over a larger area to determine the extent of disease distribution. The total number of samples collected at this point may run into the hundreds or even thousands. It is vital that a system of sample identification is determined early in the procedure to allow for rapid sample processing and accurate recording of results. Follow up samples will be forwarded to the nominated diagnostic laboratories for processing.

Samples should be initially collected over a representative area of the infected crop to determine the disease distribution.

Consequently, sampling and microscopic examination for confirmation of downy mildew occurrence on symptomatic plants and for assessment of conidial morphology should be conducted in the early hours of the morning. It is essential that sampling and identification not be attempted more than a couple of hours after dawn.

If the pathogen was detected in Australia, trials should be done to determine whether the pathogen would produce conidia under artificial conditions. This would simplify surveys if plant material could be collected during the day and incubated later to produce spores.

It is important to note the distribution of disease in the initial crop, as this will indicate whether the disease has been seed-borne, carried on trash from adjacent paddocks or originated from contaminated machinery or human movement.

It is vitally important that all personnel involved in crop sampling and inspections take all precautions to minimise the risk of disease spread between crops by decontaminating between paddocks.

Any personnel collecting leaf samples for assessment should notify the diagnostic laboratory prior to submitting samples to ensure expertise is available to undertake the diagnosis. General protocols for collecting and dispatching samples are available within PLANTPLAN, Appendix 3 (Plant Health Australia, 2009).

2.6.3.1 NUMBER OF SPECIMENS TO BE COLLECTED

The initial outbreak will appear as small to larger lesions on plants in groups within the planting. These will be associated with spread from the initial seed-borne infection. If only a small area is affected, all plants with symptoms should be collected. If there are several foci of infection, collect up to 10 plants with a range of symptoms from up to 10 locations within the affected planting.

2.6.3.2 HOW TO COLLECT

Initial infections will be systemic in seedlings and young plants. Spread to nearby plants from airborne conidia will result in partially affected plants. Whole young plants with roots in soil will provide the freshest samples. Leaves and stems of larger plants should be collected.

Samples should be collected that represent a range of symptoms observed in the infected crop. Preferably enough material should be collected to allow for immediate processing and retention of a portion that can be placed into long term storage as a reference.

Samples should be wrapped in moist paper (newspaper) and placed in clearly labelled plastic bags, which are then sealed.

It is important to record the precise location of all samples collected, preferably using GPS, or if this is not available, map references including longitude and latitude and road names should be recorded. Property and owners names should also be included where possible.

Samples should be processed as quickly as possible after sampling from the field if sub cultures are to be made from infected tissue. Once removed from the field, fresh plant samples can deteriorate and become contaminated by other mould fungi and bacteria, which may prevent successful sub-culturing of the pathogen.

It is important that all diagnoses of suspected exotic and emergency pathogens are undertaken according to the following parameters:

- The laboratory diagnostician has expertise in this form of diagnosis
- The test is undertaken as described in Section 2.4
- The results are confirmed by diagnosis in another recognised laboratory or by another diagnostician
- Where possible, diagnosis is confirmed by a second method

2.6.3.3 HOW TO PRESERVE PLANT SAMPLES

At all times the samples should be treated in a manner that allows them to arrive at the laboratory in a fresh, well-preserved state. An esky with ice packs or portable fridge should be carried when sampling crops.

Samples should be processed as quickly as possible after sampling from the field. Once removed from the field, fresh plant samples can deteriorate and become contaminated by mould fungi and bacteria.

It is important that all diagnoses of suspected exotic and emergency pathogens are undertaken according to the following parameters:

- The laboratory diagnostician has expertise in this form of diagnosis
- The test is undertaken as described in Section 2.4
- The results are confirmed by diagnosis in another recognised laboratory or by another diagnostician
- Where possible, diagnosis is confirmed by a second method

2.6.3.4 HOW TO TRANSPORT PLANT SAMPLE

Laboratory diagnosis of *P. philippinensis* and *P. sorghii* requires examination of living infected plants.

Suspect samples should be marked —Plant Sample for Urgent Diagnosis" (or the system preferred by the diagnostic laboratory samples are sent to) and the diagnostic laboratory contacted prior to samples being sent. See Appendix 2 of this document for addresses and Appendices 3-5 of PLANTPLAN for collection and transport of samples (Plant Health Australia, 2009).

Green plant samples should be wrapped in moist but not wet paper and placed in a suitable plastic bag. Grain samples need to be tightly packed into a plastic container (preferably) or in a plastic bag.

Double bag the samples and wipe the outside of the bag with alcohol and allow to dry before dispatching the sample to the laboratory.

Additional information including the detail of the sample date, location and site must be recorded on an accompanying sheet, together with all relevant paperwork. This information should be placed in a plastic bag, on which is also written the summary details of the sample and the address, and included with the samples that are dispatched.

All samples should be dispatched using an overnight courier service or Express Post.

Important: Prior to dispatch, the Manager of the laboratory to which the sample is being consigned should be advised by telephone (not e-mail – a more direct advice than e-mail is required) of the expected arrival date. Special arrangements may need to be made for weekends. If the receiving laboratory is in another state, then a permit from AQIS is required for the movement of seed into that State. Check with the State or Local Pest and Disease Control Headquarters that approval has been granted.

See PLANTPLAN for further details of sampling and transport (Plant Health Australia, 2009).

2.6.4 Epidemiological study

The number of infected plants within a crop will depend on the amount of inoculum available and whether conditions have been favourable for the disease to spread from initial foci.

Sampling of crops within a district and beyond will be based upon the origins of the initial suspect sample(s). Factors to consider will be:

- The source of seed used and how long that seed has been used by the grower
- If any other crops have been sown from the same source seed
- The proximity of other susceptible crops to the initial infected crop, both in the current growing season and previous season. This will include the growers own crops and those on neighbouring properties
- What machinery or vehicles have been into the infected crop
- The proximity to feed lots where imported grain has been fed
- The extent of human movements into the infected crop. A possible link to recent overseas travel or visitors from other regions should also be considered

2.6.5 Models of spread potential

Some general comments about possible mechanisms of spread are:

- Movement of infected seed. The pathogens have the potential to be transmitted as infected seed and as oospores in soil. Small infected fragments can also be carried within infested seed lots. Initial infections will be in small patches around the seed carrying the fungus, and these will be random within the planting
- Mechanical transmission through movement on contaminated vehicles and machinery. The initial infections may be associated with the first point of entry into the field
- Small fragments of plant debris and spores released from infested plant debris can be blown into surrounding paddocks during harvesting and allow the pathogen to move considerable

distances away from the infected crop. The initial infections will usually show a gradient with highest incidence along the side of the planting closest to the source of inoculum

- Fungal spores that adhere to clothing, machinery or animals can be carried large distances into other crops. The initial infections may be associated with the first point of entry into the field

2.6.6 Pest Free Area guidelines

Points to consider for Pest Free Area (PFA) guidelines relevant to this pest are:

- Design of a statistical delimiting field survey for symptoms on host plants (see Sections 2.6.1 and 2.6.2 for points to consider in the design)
- Plant and soil sampling using appropriate diagnostic tests
- Surveys should also consider alternative hosts (see Section 2.2.1) and not be limited to the primary infected host
- Survey around irrigation systems or waterways that may have transported oospores or conidia
- Aerial inspection or remote sensing should also be used where possible, with suspect patches inspected and sampled to confirm or deny the presence of the pathogen

Additional information is provided by the IPPC (1995) in Requirements for the Establishment of PFAs. This standard describes the requirements for the establishment and use of PFA as a risk management option for phytosanitary certification of plants and plant products. Establishment and maintenance of a PFA can vary according to the biology of the pest, pest survival potential, means of dispersal, availability of host plants, restrictions on movement of produce, as well as PFA characteristics (size, degree of isolation and ecological conditions).

2.7 Availability of control methods

2.7.1 General procedures for control

- Keep traffic out of affected areas and minimise movement in adjacent areas
- Stop irrigating affected (irrigated crops) areas and use bunding to divert overland flood flows around them (both irrigated and dryland crops)
- Adopt best-practice farm hygiene procedures to retard the spread of the pest between fields and adjacent farms
- After surveys are completed, destruction of the infected crop is an effective control
- On-going surveillance of infected paddocks to ensure downy mildew is eradicated
- Ensure that planting seed production does not take place on affected farms and do not use seed from these farms to plant next crop as downy mildew can be seed borne

2.7.2 Control if small areas are affected

Collect and destroy all plants by incineration.

2.7.3 Control if large areas are affected

If containment of the pathogen is deemed possible, destroy all plants in the infested area with knock-down herbicides.

Implementation of large area controls will depend on the ability to determine the original source and track/trace the spread. It will also depend on whether the source is infected seed or another source (e.g., contaminated clothing or machinery). If the disease is found to be confined to a single seed lot and only found in a specific crop species, it may be possible to eradicate the disease by destroying all crops of that type in the region.

If eradication was attempted, there would need to be ongoing monitoring of infected paddocks to ensure there was no opportunity for the pathogen to re-establish on self sown plants.

2.7.4 Cultural control

2.7.4.1 PHILIPPINE DOWNY MILDEW OF MAIZE

Application of high levels of nitrogen increases the susceptibility of plants to attack, however this effect is not observed in resistant cultivars (Yamada & Aday, 1977).

2.7.4.2 DOWNY MILDEW OF SORGHUM

The following practices have been shown to be beneficial in reducing SDM impact on crops:

- Short-term crop rotations, where growing crops for 15–17 days significantly reduced soil inoculum potential
- Time of planting: Delaying planting until April (Tuleen *et al.,* 1980; northern hemisphere) or until the onset of the monsoon season (Siradhana *et al.,* 1980) reduced infection rates
- Deep tillage of infected plant material, where spores were buried under at least 20 cm of soil
- Selective removal of symptomatic plants from crops
- Drying or storing of infected seeds prevents transmission of the pathogen (Jones *et al.,* 1972; Sommartaya *et al.,* 1975)

2.7.5 Host plant resistance

2.7.5.1 PHILIPPINE DOWNY MILDEW OF MAIZE

Resistance to PDM is under polygenic control and is governed mainly by additive gene effects (Leon *et al.,* 1993). Using these resistance genes, a number of resistant corn varieties have been developed (Exconde, 1976; Raymundo & Exconde, 1976; Schmitt & Freytag, 1977). Most of the developed inbred lines showed slowed systemic infections rates, maintaining infection to local areas for longer periods of time and reducing overall detrimental effects usually associated with PDM infection.

2.7.5.2 DOWNY MILDEW OF SORGHUM

Host-plant resistance is an effective method for the control of SDM (Frederiksen & Renfro, 1977). Numerous inbred resistant lines have now been developed for sorghum (Miller *et al.,* 1992) and corn (Issa *et al.,* 1977; Sreeramasetty *et al.,* 2001; Yen *et al.,* 2004). One mechanism of action is the reduction in pathogen sporulation (Adipala *et al.,* 1999). A number of genes have been identified which confer resistance (Sifuentes & Frederiksen, 1988); however, there are a large number of additional resistance elements that have yet to be identified.

2.7.6 Chemical control

The use of the chemicals listed in this section may be considered in a response to an incursion of these pests into Australia. However, any chemicals used for the eradication or control of these pests in Australia must be registered for use through the Australian Pesticides and Veterinary Medicines Authority (APVMA). For information regarding this process visit the APVMA website (**www.apvma.gov.au**).

2.7.6.1 PHILIPPINE DOWNY MILDEW OF MAIZE

The fungicides fentin hydroxide, maneb (Exconde, 1975; Exconde, 1976; Raymundo & Exconde, 1976) and metalaxyl (Cordero & Tangonan, 1988) have proven effective in controlling PDM.

2.7.6.2 DOWNY MILDEW OF SORGHUM

Foliar sprays with metalaxyl provide effective control of *P. sorghi* on maize (Odvody & Frederiksen, 1984). Several waxes and plastic polymers, sprayed onto seedlings before inoculation with the pathogen, reduced infection (Ziv & Frederiksen, 1983). Metalaxyl, applied as a seed treatment and sprayed after planting, completely controlled both systemic infection and local lesions of *P. sorghi* on sorghum. Infected plants sprayed with metalaxyl after planting recovered and produced normal heads. Seed treatment with metalaxyl alone did not provide protection against late systemic infection on main shoots or nodal tillers, or against local lesions on leaves (Anahosur & Patil, 1980).

Panicker & Gangadharan (1999) controlled downy mildew of maize by foliar sprays of phosphonic acid formulations including Aliette and Akom and at a lower cost than using metalaxyl.

The disease was effectively controlled (84%) by three or four sprays with mancozeb, the first after emergence and then at weekly intervals, in field experiments using a susceptible sorghum line (Balasubramanian, 1976).

Metalaxyl can be effective as a seed treatment against *P. sorghi* in maize. Plants grown from seeds treated with metalaxyl, or any mixture containing metalaxyl, remained free from the disease and had significantly higher grain yield than plants grown from seeds treated with thiram-based fungicides or from untreated seeds. Low rates of metalaxyl completely controlled downy mildew (Anaso *et al.,* 1989). However, metalaxyl only slightly reduced seed transmission in maize in Nigeria (Adenle & Cardwell, 2000), an indication of deep seated internal infection. Metalaxyl also reduced stands of maize and sorghum at higher rates (Odvody & Frederiksen, 1984).

Resistance to metalaxyl has developed in *P. sorghi* in Texas, where seed treatment with metalaxyl no longer controls the pathogen (Isakeit *et al*, 2003).

2.7.7 Mechanical control

Drying seed to less than 14% moisture content reduces or eliminates seed-borne transmission.

Rotations with more than three years between sorghum or maize crops and control of alternative grass hosts within the paddock will reduce soil-borne infection.

2.7.8 Biological control

There are no known biological controls for the downy mildews of maize and sorghum.

3 Course of Action – Eradication Methods

Additional information is provided by the IPPC (1998) in Guidelines for Pest Eradication Programmes. This standard describes the components of a pest eradication programme which can lead to the establishment or re-establishment of pest absence in an area. A pest eradication programme may be developed as an emergency measure to prevent establishment and/or spread of a pest following its recent entry (re-establish a pest free area) or a measure to eliminate an established pest (establish a pest free area). The eradication process involves three main activities: surveillance, containment, and treatment and/or control measures.

3.1 Destruction strategy

3.1.1 Destruction protocols

- Infected crops should be destroyed by burning and ploughing. This will prevent aerial dispersal of the pathogen via infected crop residues
- Herbicides can be used to destroy the infected crops. Knockdown herbicides will not prevent some additional development of *Peronoslerospora* spp. on killed tissue since the fungus probably has good saprophytic ability. Dessication herbicides, while not reducing the fungus, would prepare the crop residues for burning
- Infested fields should not be resown to the host crop for a minimum of two years. The first and second host crops sown after this time should be monitored for *Peronoslerospora* spp.
- Disposable equipment, infected plant material or soil should be disposed of by autoclaving, high temperature incineration or deep burial
- Any equipment removed from the site for disposal should be double-bagged

3.1.2 Decontamination protocols

If containment, eradication and/or best practice hygiene measures are implemented, machinery, equipment, vehicles in contact with infected plant material or soil or present within the Quarantine

Area, should be washed to remove soil and plant material using high pressure water or scrubbing with products such as a farm degreaser or a 1% bleach (available chlorine) solution in a designated wash down. General guidelines for wash down areas are as follows:

- Located away from crops or sensitive vegetation
- Readily accessible with clear signage
- Access to fresh water and power
- Mud free, including entry and exit points (e.g. gravel, concrete or rubber matting)
- Gently sloped to drain effluent away
- Effluent must not enter water courses or water bodies
- Allow adequate space to move larger vehicles
- Away from hazards such as power lines
- Waste water, soil or plant residues should be contained (PLANTPLAN 2008 Appendix 18)
- Disposable overalls and rubber boots should be worn when handling infected soil or plant material in the field. Boots, clothes and shoes in contact with infected soil or plant material should be disinfected at the site or double-bagged to remove for cleaning.
- Skin and hair in contact with infested plant material or soil should be washed.
- Decon 90 is a suitable detergent for using to decontaminate equipment and personnel.

3.1.3 Priorities

Specific priorities for eradication:

- Confirm the presence of the pathogen
- Prevent movement of vehicles and equipment through affected areas
- Priority of eradication/decontamination of infected host material
- Determine the extent of infection through survey and seed trace back
- Stop the movement of any seed that may be infected with the pathogen

3.1.4 Plants, by-products and waste processing

- Infected plant material should be destroyed by (enclosed) high temperature incineration, autoclaving or deep burial (in a non-cropping area)
- As the fungus can be mechanically transmitted, killed crops should be ploughed in
- Infested paddocks should remain free of susceptible host plants until soil has been shown to be free from the pathogen

3.1.5 Disposal issues

- Seeds harvested from infected plants and any soil or infected plant material removed from the infected site should be destroyed by (enclosed) high temperature incineration, autoclaving or deep burial (in a non-cropping area)
- As the pathogen can be mechanically transmitted, killed crops should be ploughed in or burnt
- Infested paddocks should remain free of susceptible host plants until soil has been shown to be free from the pathogen
- No particular issues with resistance of disease to chemicals or physical treatments are known to exist for general biocides. Resistance to metalaxyl has developed in *P. sorghi* in Texas.

3.2 Quarantine and movement controls

3.2.1 Quarantine priorities

- Plant material and soil at the site of infection to be subject to movement restrictions.
- Machinery, equipment, vehicles and disposable equipment in contact with infected plant material or soil to be subject to movement restrictions.
- Harvesting of infected crops should be prevented as the dust created during harvesting can spread the disease to neighbouring areas

3.2.2 Movement control for people, plant material and machinery

Movement of people, vehicle and machinery, from and to affected farms, must be controlled to ensure that infected soil and plant debris are not moved off-farm on clothing, footwear, vehicles or machinery. This can be achieved through:

- Signage to indicate quarantine area and/or restricted movement in these zones.
- Fenced, barricaded or locked entry to quarantine areas.
- Movement of equipment, machinery, plant material or soil by permit only.
- Clothing and footwear worn at the infected site should either be double-bagged prior to removal for decontamination or should not leave the farm until thoroughly disinfected, washed and cleaned.
- Hay, stubble or trash must not be removed from the site.
- All machinery and equipment should be thoroughly cleaned down with a pressure cleaner prior to leaving the affected farm. The clean down procedure should be carried out on a hard surface, preferably a designated wash-down area, to avoid mud being re-collected from the affected site onto the machine.
- Seed from the affected site should not be used for planting new crops, feeding stock or for human consumption.

3.3 Zoning

The size of each quarantine area will be determined by a number of factors, including the location of the incursion, biology of the pest, climatic conditions and the proximity of the infected property to other infected properties.

3.3.1 Destruction zone

The size of the destruction zone (i.e. zone in which the pest and all host material is destroyed) will depend on the ability of the pest to spread, distribution of the pest (as determined by delimiting surveys), time of season (and part of the pest life cycle being targeted) and factors which may contribute to the pest spreading.

The entire crop or pasture should be destroyed after the level of infection has been established. The delimiting survey will determine whether or not neighbouring host crops are infected and need to be destroyed. The Destruction Zone may be defined as contiguous areas associated with the same management practices as the infected area (i.e. the entire trial, paddock or farm if spread could have occurred prior to the infection being identified).

Particular care needs to be taken to ensure that soils and plant material are not moved into surrounding areas not showing symptoms of disease, as eggs or larvae can remain on seedlings and pupae can sometimes remain in the soil.

3.3.2 Quarantine zone

The Quarantine Zone is defined as the area where voluntary or compulsory restraints are in place for the affected property(ies). These restraints may include restrictions or movement control for removal of plants, people, soil or contaminated equipment from an infected property.

3.3.3 Buffer zone

A Buffer Zone may or may not be required depending on the incident. It is defined as the area in which the pest does not occur but where movement controls or restrictions for removal of plants, people, soil or equipment from this area are still deemed necessary. The Buffer Zone may enclose an infested area (and is therefore part of the Control Area) or may be adjacent to an infested area.

3.3.4 Restricted Area

The Restricted Area is defined as the zone immediately around the infected premises and suspected infected premises. The Restricted Area is established following initial surveys that confirm the presence of the pest. The Restricted Area will be subject to intense surveillance and movement control with movement out of the Restricted Area to be prohibited and movement into the Restricted Area to occur by permit only. Multiple Restricted Areas may be required within a Control Area.

3.3.5 Control Area

The Control Area is defined as all areas affected within the incursion. The Control Area comprises the Restricted Area, all infected premises and all suspected infected premises and will be defined as the minimum area necessary to prevent spread of the pest from the Quarantine Zone. The Control Area will also be used to regulate movement of all susceptible plant species to allow trace back, trace forward and epidemiological studies to be completed.

3.4 Decontamination and farm clean up

Decontaminant practices are aimed at eliminating the pest thus preventing its spread to other areas.

3.4.1 Decontamination procedures

General guidelines for decontamination and clean up:

- Refer to PLANTPLAN (Plant Health Australia, 2009) for further information
- Keep traffic out of affected area and minimise it in adjacent areas
- Adopt best-practice farm hygiene procedures to retard the spread of the pest between fields and adjacent farms
- Machinery, equipment, vehicles in contact with infected plant material or soil or present within the Quarantine Area, should be washed to remove soil and plant material using high pressure water or scrubbing with products such as Decon 90 detergent, a farm degreaser or a 1% bleach solution in a designated wash down area as described in 3.1.2
- Plant material should be destroyed using herbicide. Only recommended materials are to be used when conducting decontamination procedures, and should be applied according to the product label

3.4.2 Decontamination if pest is identified in small or large areas

Destruction of plant material by herbicide is described. The infected area would need to be monitored for a few years for self sown plants which should be tested for downy mildew and then destroyed.

3.4.3 General safety precautions

For any chemicals used in the decontamination, follow all safety procedures listed within each MSDS.

3.5 Surveillance and tracing

3.5.1 Surveillance

Detection and delimiting surveys are required to delimit the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established.

Initial surveillance priorities include the following:

- Surveying all host growing properties in the pest quarantine area.
- Surveying all properties identified in trace-forward or trace-back analysis as being at risk.
- Surveying all host growing properties that are reliant on trade with interstate or international markets which may be sensitive to downy mildew presence.
- Surveying commercial nurseries selling at risk host plants.
- Surveying other host growing properties and backyards.

3.5.2 Survey regions

Establish survey regions around the surveillance priorities identified above. These regions will be generated based on the zoning requirements (see Section 3.3), and prioritised based on their potential likelihood to currently have or receive an incursion of this pest. Surveillance activities within these regions will either allow for the area to be declared pest free and maintain market access requirements or establish the impact and spread of the incursion to allow for effective control and containment measures to be carried out.

Steps outlined in Table 2 form a basis for a survey plan. Although categorised in stages, some stages may be undertaken concurrently based on available skill sets, resources and priorities.

Table 1. *Phases to be covered in a survey plan*

Phase 1	• Identify properties that fall within the buffer zone around the infested premise • Complete preliminary surveillance to determine ownership, property details, production dynamics and tracings information (this may be an ongoing action)
Phase 2	• Preliminary survey of host crops in properties in buffer zone establishing points of pest detection
Phase 3	• Surveillance of an intensive nature, to support control and containment activities around points of pest detection

Phase 4	• Surveillance of contact premises. A contact premise is a property containing susceptible host plants, which are known to have been in direct or indirect contact with an infested premises or infected plants. Contact premises may be determined through tracking movement of materials from the property that may provide a viable pathway for spread of the disease. Pathways to be considered are: ○ Items of equipment and machinery which have been shared between properties including bins, containers, irrigation lines, vehicles and equipment ○ The producer and retailer of infected material if this is suspected to be the source of the outbreak ○ Labour and other personnel that have moved from infected, contact and suspect premises to unaffected properties (other growers, tradesmen, visitors, salesmen, crop scouts, harvesters and possibly beekeepers) ○ Movement of plant material and soil from controlled and restricted areas ○ Storm and rain events and the direction of prevailing winds that result in air-born dispersal of the pathogen during these weather events
Phase 5	• Surveillance of nurseries, gardens and public land where plants known to be hosts of pathogen are being grown
Phase 6	• Agreed area freedom maintenance, pest control and containment

3.5.3 Post-eradication surveillance

The period of pest freedom sufficient to indicate that eradication of the pest has been achieved will be determined by a number of factors, including cropping conditions, the previous level of infection and the control measures applied. As a guide, the following activities should be carried out following the eradication of the pest:

- Establishment of sentinel plants at the site of infection (see Section 2.6.4).
- Maintain good sanitation and hygiene practices throughout the year.
- Sentinel plants should remain in place and be inspected on a fortnightly basis for a further 6 weeks and then on a monthly basis.
- Surveys comprising plant sampling for and testing for downy mildew to be undertaken for a minimum of 12 months after eradication has been achieved.

4 References

Adenle VO, Cardwell KF (2000) Seed transmission of maize downy mildew (*Peronosclerospora sorghi*) in Nigeria. *Plant Pathology*, 49: 628–634.

Adipala E, Bigirwa G, Esele JP, Cardwell KF (1999) Development of sorghum downy mildew on sequential plantings of maize in Uganda. *International Journal of Pest Management*, 45: 147–153.

Advincula BA, Exconde OR (1975) Seed transmission of *Sclerospora philippinensis* Weston in maize. *Philippine Agriculturist,* 59: 244–255.

Anahosur KH, Patil SH (1980) Chemical control of sorghum downy mildew in India. *Plant Disease*, 64: 1004–1006.

Anaso AB (1989) Survival of downy mildew pathogen of maize in Nigerian Guinea Savanna. *Applied Agricultural Research*, 4: 258–263.

Anaso AB, Tyagi PD, Emechebe AM, Manzo SK (1989) Control of sorghum downy mildew (*Peronosclerospora sorghi*) of maize by seed treatment in Nigeria. *Crop Protection*, 8: 82–85.

APS (1973) *A Compendium of Corn Diseases*. American Phytopathological Society, St Paul, Minnesota, USA.

Balasubramanian KA (1976) Chemical control of downy mildew of sorghum. *Current Science*, 45: 416–417.

Bigirwa G, Adipala E, Esele JP (1998) Occurrence of *Peronosclerospora sorghi* in Uganda. *Plant Disease*, 82: 757–760.

Bock CH, Jeger MJ, Mughogho LK, Mtisi E, Cardwell KF (1998) Production of conidia by *Peronosclerospora sorghi* on sorghum crops in Zimbabwe. *Plant Pathology*, 47: 243–251.

Bonde MR (1982) Epidemiology of downy mildew diseases of maize, sorghum and pearl millet. *Tropical Pest Management,* 28: 49–60.

Bonde MR, Peterson GL, Duck NB (1985) Effects of temperature on sporulation, conidial germination, and infection of maize by *Peronosclerospora sorghi* from different geographical areas. *Phytopathology*, 75: 122–126.

Bonde MR, Peterson GL, Kenneth RG, Vermeulen HD, Sumartini, Bustaman M (1992) Effect of temperature on conidial germination and systemic infection of maize by *Peronosclerospora* species. *Phytopathology*, 82: 104–109.

Broyles JW (1956) Observations on time and location of penetration in relation to amount of damage and chemical control of *Physoderma maydis*. *Phytopathology,* 46: 8.

CMI (1988) *Peronosclerospora sorghi* (Weston & Uppal) C.G. Shaw. Commonwealth Mycological Institute Distribution Maps of Plant Diseases No. 179.

Cordero FS, Tangonan NG (1988) Metalaxyl (Ridomil MZ 58) as foliar spray to control downy mildew of corn. *SMARC Monitor, Southern Mindanao Agricultural Research Centre*, 8: 13–17.

Dalmacio SC, Raymundo AD (1972) Spore density of *Sclerospora philippinensis* in relation to field temperature, relative humidity and downy mildew incidence. *Philippine Phytopathology*, 8: 72–77.

Exconde OR (1975) Chemical control of maize downy mildew. Tropical Agriculture Research Series No. 8, 157–163.

Exconde OR (1976) Philippine corn downy mildew: assessment of present knowledge and future research needs. *Kasetsart Journal*, 10: 94–100.

Exconde OR, Raymundo AD (1974) Yield loss caused by Philippine corn downy mildew. *Philippine Agriculturist,* 58: 115–120.

Frederiksen RA (1980) Sorghum downy mildew in the United States: Overview and outlook. *Plant Disease,* 64: 903-908.

Frederiksen RA, Renfro BL (1977) Global status of maize downy mildew. *Annual Review of Phytopathology,* 15: 249–275.

Holliday P (1975) *Sclerospora philippinensis*. CMI Descriptions of Pathogenic Fungi and Bacteria No. 454.

Isakeit T, Odvody G, Jahn R, Deconini L (2003) *Peronosclerospora sorghi* resistant to metalaxyl treatment of sorghum seed in Texas. *Phytopathology*, 93: S39.

Issa E, Matallo MRV, Abrahao J (1977) Resistance of maize (*Zea mays* L.) cultivars to mildew due to *Sclerospora sorghi* ((Kulk) Weston & Uppal). *Biologico*, 43: 62–64.

Jeger MJ, Gilijamse E, Bock CH, Frinking HD, 1998. The epidemiology, variability and control of the downy mildews of pearl millet and sorghum, with particular reference to Africa. Plant Pathology, 47(5):544-569.

Jones BL, Leeper JC, Frederiksen RA (1972) *Sclerospora sorghi* in corn: its location in carpellate flowers and mature seeds. *Phytopathology*, 62: 817–819.

Josue AR, Exconde OR (1979) Virulence pattern, aggressiveness and sporulation of *Sclerospora philippinensis* isolates from Bukidnon on maize. *Philippine Agriculturist,* 62: 96–105.

Leon C de, Ahuja VP, Capio ER, Mukherjee BK (1993) Genetics of resistance to Philippine downy mildew in three maize populations. *Indian Journal of Genetics & Plant Breeding*, 53: 406–410.

McGee DC (1988) Maize diseases. A reference source for seed technologists. St. Paul, Minnesota, USA: APS Press.

Merriman P, McKirdy S (2005) Technical guidelines for the development of pest specific response plans, Plant Health Australia.

Miller FR, Dusek TF, Prihoda KL, Rooney LW (1992) Registration of RT436 sorghum parental line. *Crop Science*, 32: 1518.

Napi-Acedo G, Exconde OR (1967) Note: Oospores of *Sclerospora philippinensis* Weston from corn leaf tissue. *Philippine Agriculturist,* 51: 279–282.

Odvody GN, Frederiksen RA (1984) Use of systemic fungicides metalaxyl and fosetyl-Al for control of sorghum downy mildew in corn and sorghum in South Texas. I: seed treatment. *Plant Disease*, 68: 604–607.

Olanya OM, Fajemisin JM (1993) Host-range and survival studies of *Peronosclerospora sorghi* at two locations in Nigeria. *International Journal of Pest Management*, 39: 13–18.

Panicker S, Gangadharan K (1999) Controlling downy mildew of maize caused by *Peronosclerospora sorghi* by foliar sprays of phosphonic acid compounds. *Crop Protection*, 18: 115–118.

Pawar MN, Frederiksen RA, Mughogho LK, Bonde MR (1985) Survey of virulence in *Peronosclerospora sorghi* isolates from India, Ethiopia, Nigeria, Texas (USA), Honduras, Brazil, and Argentina. *Phytopathology*, 75: 1374.

Payak MM (1973) Progress in the Control of Downy Mildew Diseases of Maize - an inventory of resistant sources. *Proc. 1st IACP Planning Session*, Kuala Lumpur.

Perumal R, Nimmakayala P, Erattaimuthu SR, No E-G, Reddy UK, Prom LK, Odvody GN, Luster DG, Magill CW (2008) Simple sequence repeat markers useful for sorghum downy mildew (*Peronosclerospora sorghi*) and related species. *BMC Genetics*, 9. doi: 10.1186/1471-2156-9-77. **www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2620352**

Plant Health Australia (2009). PLANTPLAN Australian Emergency Plant Pest Response Plan. Version 1. Plant Health Australia, Canberra, ACT. **www.planthealthaustralia.com.au/plantplan**

Pratt RK, Janke GD (1978) Oospores of *Sclerospora sorghi* in soils of south Texas and their relationships to the incidence of downy mildew in grain sorghum. *Phytopathology,* 68: 1600–1605.

Rao BM, Shetty SH, Safeeulla KM (1984) Production of *Peronosclerospora sorghi* oospores in maize seeds and further studies on the seed-borne nature of the fungus. *Indian Phytopathology,* 37: 278–283.

Rao BM, Prakash HS, Shetty HS, Safeeulla KM (1985) Downy mildew inoculum in maize seeds: techniques to detect seed-borne inoculum of *Peronosclerospora sorghi* in maize. *Seed Science and Technology,* 13: 593–600.

Raymundo AD, Exconde OR (1976) Economic effectiveness of resistant varieties and duter/dithane M-45 foliar spray for the control of Philippine corn downy mildew. *Philippine Agriculturist*, 60: 52–65.

Schmitt CG, Freytag RE (1977) Response of selected resistant maize genotypes to three species of Sclerospora. *Plant Disease Reporter,* 61: 478–481.

Schuh W, Frederiksen RA, Jeger MJ (1986) Analysis of spatial patterns in sorghum downy mildew with Morisita's index of dispersion. *Phytopathology,* 76: 446–450.

Schuh W, Jeger MJ, Frederiksen RA (1987) The influence of soil temperature, soil moisture, soil texture, and inoculum density on the incidence of sorghum downy mildew. *Phytopathology*, 77: 125–128.

Schuh W, Jeger MJ, Frederiksen RA (1988) Comparisons of spatial patterns of oospores of *Peronosclerospora sorghi* in the soil and of sorghum plants with systemic downy mildew. *Phytopathology,* 78: 432–434.

Sifuentes J, Frederiksen RA (1988) Inheritance of resistance to pathotypes 1, 2, and 3 of *Peronosclerospora sorghi* in sorghum. *Plant Disease*, 72: 332–333.

Siradhana BS, Dange SRS, Rathore RS, Singh SD (1980) A new downy mildew on maize in Rajasthan, India. *Current Science*, 49: 316–317.

Sommartaya T, Pupipat U, Intrama S, Renfro BL (1975) Seed transmission of *Sclerospora sorghi* (Weston & Uppal) the downy mildew of corn in Thailand. *Kasetsart Journal*, 9: 12–25.

Spencer MA, Dick MW (2002) Aspects of graminicolous downy mildew biology: perspectives for tropical plant pathology and Peronosporomycetes phylogeny. Pp. 63–80 in Tropical Mycology, Vol. 2, Micromycetes' eds Watling R, Frankland JC, Ainsworth AM, Isaac S, Robinson CH. CAB International, Wallingford, UK.

Sreeramasetty TA, Anilkumar TB, Gowda KTP, Hattappa S, Mathapathi SS, Naik P (2001) Resistance to downy mildew in medium maturity maize genotypes. *Environment and Ecology*, 19: 213–215.

Titatarn S, Exconde OR (1974) Comparative virulence and gross morphology of isolates of *Sclerospora philippinensis* Weston on corn. *Philippines Agriculture,* 58: 90–104.

Tuleen DM, Frederiksen RA, Vudhivanich P (1980) Cultural practices and the incidence of sorghum downy mildew in grain sorghum. *Phytopathology*, 70: 905–908.

Visaranthanonth N, Exconde OR (1976) Development, morphology and cytology of sporulation in Philippine *Sclerosporas*. *Philippines Agriculture,* 59: 266–287.

Wang E, Ryley M, Meinke H (2000) Prediction of sorghum downy mildew risk in Australia using daily weather data. *Australasian Plant Pathology*, 29: 108–119.

Weston WH (1920) Philippine downy mildew of maize. *Journal Agricultural Research*, 19: 97–122.

Yamada M, Aday BA (1977) Fertilizer conditions affecting susceptibility to downy mildew disease *Sclerospora philippinensis* Weston, in resistant and susceptible materials of maize. *Annals of the Phytopathological Society of Japan (Nihon Shokubutsubyori Gakkai Ho)*, 43: 291–293.

Yen TTO, Prasanna BM, Setty TAS, Rathore RS (2004) Genetic variability for resistance to sorghum downy mildew (*Peronosclerospora sorghi*) and Rajasthan downy mildew (*P. heteropogoni*) in the tropical/sub-tropical Asian maize germplasm. *Euphytica*, 138: 23–31.

Ziv O, Frederiksen RA (1983) Control of foliar diseases with epidermal coating materials. *Plant Disease*, 67: 212–214.

4.1 Websites

CAB Compendium (**www.cabicompendium.org/cpc/home.asp**)

5 Appendices

Appendix 1. Standard diagnostic protocols

For a range of specifically designed procedures for the emergency response to a pest incursion refer to PHA's PLANTPLAN (**www.planthealthaustralia.com.au/plantplan**).

Appendix 2. Experts, resources and facilities

The following tables provide lists of experts (Table 2) and diagnostic facilities (Table 3) for use in professional diagnosis and advisory services in the case of an incursion.

Table 2. *Experts who can be contacted for professional diagnostic and advisory services*

Expert	State	Details
No experts have been identified in Australia		

Table 3. *Diagnostic service facilities in Australia*

Facility	State	Details
DPI Victoria Knoxfield Centre	Vic	621 Burwood Highway Knoxfield VIC 3684 Ph: (03) 9210 9222; Fax: (03) 9800 3521
DPI Victoria Horsham Centre	Vic	Natimuk Rd Horsham VIC 3400 Ph: (03) 5362 2111; Fax: (03) 5362 2187
Industry and Investment NSW, Elizabeth Macarthur Agricultural Institute	NSW	Woodbridge Road Menangle NSW 2568 PMB 8 Camden NSW 2570 Ph: (02) 4640 6327; Fax: (02) 4640 6428
Industry and Investment NSW, Tamworth Agricultural Institute	NSW	4 Marsden Park Road Calala NSW 2340 Ph: (02) 6763 1100; Fax: (02) 6763 1222
Industry and Investment NSW, Wagga Wagga Agricultural Institute	NSW	PMB Wagga Wagga NSW 2650 Ph: (02) 6938 1999; Fax: (02) 6938 1809
SARDI Plant Research Centre - Waite Main Building, Waite Research Precinct	SA	Hartley Grove Urrbrae SA 5064 Ph: (08) 8303 9400; Fax: (08) 8303 9403

Facility	State	Details
Grow Help Australia	QLD	Entomology Building 80 Meiers Road Indooroopilly QLD 4068 Ph: (07) 3896 9668; Fax: (07) 3896 9446
Department of Agriculture and Food, Western Australia (AGWEST) Plant Laboratories	WA	3 Baron-Hay Court South Perth WA 6151 Ph: (08) 9368 3721; Fax: (08) 9474 2658

Appendix 3. Communications strategy

A general Communications Strategy is provided in PLANTPLAN.

Appendix 4. Market access impacts

Within the AQIS PHYTO database (August 2008), the following countries require a declaration stating that "Philippine downy mildew (*Peronosclerospora philippinensis*) is not known to occur in Australia" when exporting the crops listed:

Country	Crops
Mauritius	*Avena* spp. (oats), *Panicum miliaceum* (millet, broomcorn), *Setaria italica* (foxtail millet, Japanese millet), *Zea mays* (corn, maize, popping corn)
New Caledonia	*Zea* spp. (Corn, maize, sweetcorn, popping corn), stockfeed containing maize or sorghum
New Zealand	*Sorghum bicolour* (sorghum)
Columbia	*Zea* spp. (corn, maize, sweetcorn)

Within the AQIS PHYTO database (August 2008), the following countries require a declaration stating that "Sorghum downy mildew (*Peronosclerospora sorghi*) is not known to occur in Australia" when exporting the crops listed. The exception to this is the export of sweetcorn to New Zealand, where one of the following statements are required, "The sweetcorn in this consignment has undergone appropriate pest control activities that are effective against *Peronosclerospora sorghi*" of "The sweetcorn in this consignment has been sourced from an area free (verified by official detection survey) from *Peronosclerospora sorghi*":

Country	Crops
Mauritius	*Avena* spp. (oats), *Panicum miliaceum* (millet, broomcorn), *Setaria italica* (foxtail millet, Japanese millet), *Zea mays* (corn, maize, popping corn)
Guatemala	*Sorghum* spp. (sorghum, Columbus grass, Johnson grass), *Zea mays* (corn, maize, popping corn)

Country	Crops
Honduras	*Zea* spp. (Corn, maize, sweetcorn), *Sorghum* spp. (sorghum, Columbus grass, Johnson grass)
New Caledonia	*Zea* spp. (Corn, maize, sweetcorn, popping corn), stockfeed containing maize or sorghum, *Sorghum* spp. (sorghum, Columbus grass, Johnson grass)
New Zealand	*Panicum miliaceum* (millet, broomcorn), *Sorghum bicolour* (sorghum), *Panicum* spp. (panic), *Zea mays* (corn, maize, popping corn), *Sorghum* spp. (sorghum, Columbus grass, Johnson grass)
French Polynesia	*Zea mays* (corn, maize, popping corn), *Sorghum* spp. (sorghum, Columbus grass, Johnson grass)
Vanuatu	*Zea mays* (corn, maize, popping corn)
Columbia	*Zea* spp. (corn, maize, sweetcorn), *Sorghum* spp. (sorghum, Columbus grass, Johnson grass)

Latest information can be found within PHYTO, using an Advanced search —Search all text" for ~~"~~*Peronosclerospora philippinensis*" or ~~"~~*Peronosclerospora sorghi*".