PBY 409 – PLANT PATHOLOGY I AND II

OUTLINE

- Introduction

- Methods of isolation of pathogens in pure state and their classification
.
- Viruses, bacteria, nematodes and Fungi as agents of plant diseases.

- The structure, reproduction/life cycles and classification of plant pathogenic fungi, bacteria and viruses.

- Infection and host parasite relationships.

- Koch's postulate

- Diseases of some economic plants (particularly food crops) in Nigeria.

- Symptoms, etiology, cultural characteristics and control measures

THE STRUCTURE REPRODUCTION/LIFE CYCLES AND CLASSIFICATION OF PLANT PATHOGENIC FUNGI.

Introduction

Fungi are of great economic importance to man and plays an important role in the disintegration of organic matter. They affect us directly by destroying our food, fabric, leather, and other commercial goods. They are responsible for a large number of diseases of man, animals and plants.

Fungal cell structures

Fungal cells may be minute and a single, uninucleate cell may constitute an entire organism e. g a single cell of *Olpidium* or yeast cell. On the other hand, fungal cells may be elongated and strand like and several may be joined to form a thread of cells (hypha). A large number of hyphae form a mycelium. Their cell wall is generally made up of chitin and cellulose. One cell hyphae may be separated from another by a cross wall or septum. Septa in different groups of fungi have impt diff in structure ie. The septa in the lower fungi are pseudosepta (septa perforated by so many pores that they are sieve like). In the Ascomycota, and some Fungi Imperfecti, the septum is perforated by a single pore. In the Basidiomycota and some members of the Fungi Imperfecti, the septum is more complex than found in the Ascomycota. This type of septum is called dolipore septum.

Classification of Fungi

Whittaker 1969 broke the tradition of a three kingdom system of class. Of all living organisms. Through this, he recognized that the classfn of all living organisms as prokaryotes, Animals and plants including Fungi did not reflect their relationship. He added two more kingdoms viz. Fungi and Protista.

In an attempt to recognize monophyletic groups the organisms once classified as Fungi are now considered in three different groups,

The monophyletic kingdom Fungi, Straminopila or Chromista, and four protist phyla. The kingdom Fungi includes four phyla –Chytridiomycota, Zygomycota, Ascomycota and Basidiomycota.

Kingdom Straminopila or Chromista includes the phylum Oomycota, Hyphochytridiomycota, and Labyrinthulomycota.

The four phyla of the Kingdom Protista or Protictista are Plasmodiophoromycota, Dictyosteliomycota, Acrasiomycota and Myxomycota.

The table below gives an outline of the classification of fungus and fungus-like organisms.
Glomeromycota (160 species)

KINGDOM PROTISTA

Phylum: Plasmodiophoromycota

The phylum Plasmodiophoromycota contains one Class Plasmodiophoromycetes, with a single Order Plasmodiophorales and single Family Plasmodiophoraceae.
There are about 10 genera and a total of 29 recognized species.

Plasmodiophoroids produce multinucleate unwalled protoplaststypically referred to as plasmodia, which are significantly different from the *Myxomycota* as thjey are incapable of translocational movt, lack the ability to phagocytize food materials and exist wholly within the cells or hyphae of their hosts. Their life cycle involves the production of two different plasmodial phases. Mitotic div of nuclei is called cruciform div.

The two most impt genera in plant pathology are *Plasmodiophora* and *Spongospora. In Plasmodiophora,* the cysts lie free in d cells of d host, in *Spongospora ,*the cysts are in d form of spore balls.
Plasmodiophora brassicae causes club root disease of crucifers (cabbage, cauliflower, brocolli) also known as finger and toe disease of crucifers. *Spongospora subterranea* causes powdery scab of potatoes.

FUNGUS LIKE ORGANISMS		TRUE FUNGI
KINGDOM PROTISTA	KINGDOM CHROMISTA STRAMINOPILA	KINGDOM FUNGI
Phylum Plasmodiophoromycota	Phylum Oomycota	Phylum Chytridiomycota
Phylum Dictyosteliomycota	Hyphochytridiomycota	Phylum Zygomycota
Phylum Acrasiomycota	Labyrinthulomycota	Phylum Ascomycota
Phylum Myxomycota		Phylum Basidiomycota

Classification of P. brassicae

Kingdom: Protista
Phylum: Plasmodiophoromycota
Class: Plasmodiophoromycetes
Order: Plasmodiophorales
Family: Plasmodiophoraceae
Genus: *Plasmodiophora*
Species*: brassicae*

Phylum: Dictyosteliomycota (dictyostelid cellular slime moulds)

These are distinguished from most other organisms by the aggregation of their somatic amoebae to form a pseudoplasmodium also designated as grex or slug. The component amoebae never fuse but retain their individuality while cooperating as members of a well organized community until d formation of a sorocarp. An impt member of ds group is *Dictyostelium discoideum*

Phylum: Acrasiomycota (acrasid cellular slime moulds)

Acrasids are characterized by cylindrical amoebae exhibiting phagotrophic(nutrition.

Phylum: Myxomycota (true slime moulds)

In the assimilative stage, the plasmodium is free living and saprobic (…….). these organisms exhibit phagotrophic nutrition and produce the following life cycle stages.

Three types of uninucleate cells, one of which is flagellate

A multinucleate somatic phase as a plasmodium dt moves and exhibits a reversible shuttle streaming of its protoplasm.

A resistant stage made up of sclerotium

•A reproductive phase dt culminates in d prdxn of stationary sporophores containing walled spores.

The phylum contains a single class Myxomycetes which is sub divided into three subclasses containing a total of six Orders. These are Liceales, Echinosteliales, Trichiales, Physarales, Stemonitales, and Ceratiomyxales

KINGDOM: CHROMISTA OR STRAMINOPILA

The kingdom Chromista is divided into three phyla namely

•Oomycota

•Hyphochytridiomycota

•Labyrinthulomycota

Phylum: Oomycota

Phylum: Oomycota

The characteristics that distinguishes the Oomycota from the true fungi are

•Asexual reproduction by means of biflagellated zoosporeswitrh a longer tinsel flagellum directed forwards and a shorter whiplash flagellum directed backwards.

•Various features of ultra-structure of zoospores

•The prdxn of diploid thallus

•Meiosis occurring at the time of gametogenesis.

•Oogamous reproduction by means of gametangial contact which results in the formation of a thick walled sexual spore called an oospore.

•Cell walls made up of β–glucans with little amounts cellulose anfd the amino acid hydroxyproline.

•Various biochemical and molecular characteristics.

•Mitochondria with tubular cristae.

The phylum contains a single Class Oomycetes, with six orders Leptomitales, Rhipidiales, Sclerosporales, Pythiales, Perenosporales and Saprolegniales.

In plant pathology, the impt ones include

a) *Aphanomyces euteiches* (Saprolegniales) which causes root rot of peas.

b) Genus *Pythium* causes damping off, seed decay, root rot and fruit rot

c) *Phytophthora* species (*P. infectans*) cause blights, fruit rot, cankers and root rot of several economic plants like potato.

<u>Classification of P. infectans</u>

Kingdom: Chromista

Phylum: Oomycota

Class: Oomycetes

Order: Pythiales

Family: Scarabaeoidea

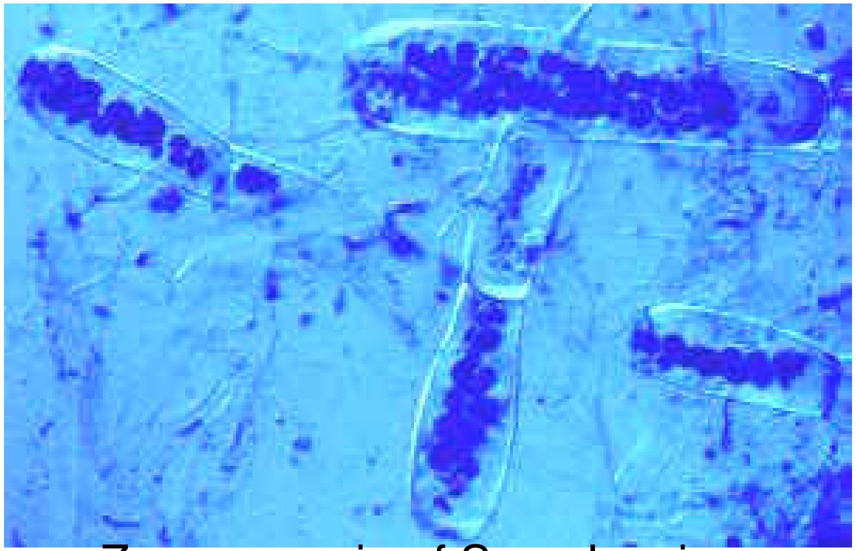
Genus: *Phytophthora*

Species*:* *infectans*

Saprolegniales - broad hyphae of *Achlya* growing from a hemp seed and producing, (1) long, white asexual zoosporangia and (2) round white sexual oogonia

Saprolegniales – zoosporangia X 400

Oogonium of Saprolegnia



Zoosporangia of Saprolegnia

Parasitic water molds damage fish and many crop plants.

Some water molds are **parasites** on other organisms; they may grow on the scales or eggs of fish, or on amphibians. The water mold *Saprolegnia* causes lesions on fish which cause problems when the water is rather stagnant, as in aquaria or fish farms, or at high population densities, such as when salmon swim upstream to spawn.

Other species of *Saprolegnia* are parasitic on aquatic invertebrates such as rotifers, nematodes, and arthropods, and on diatoms.

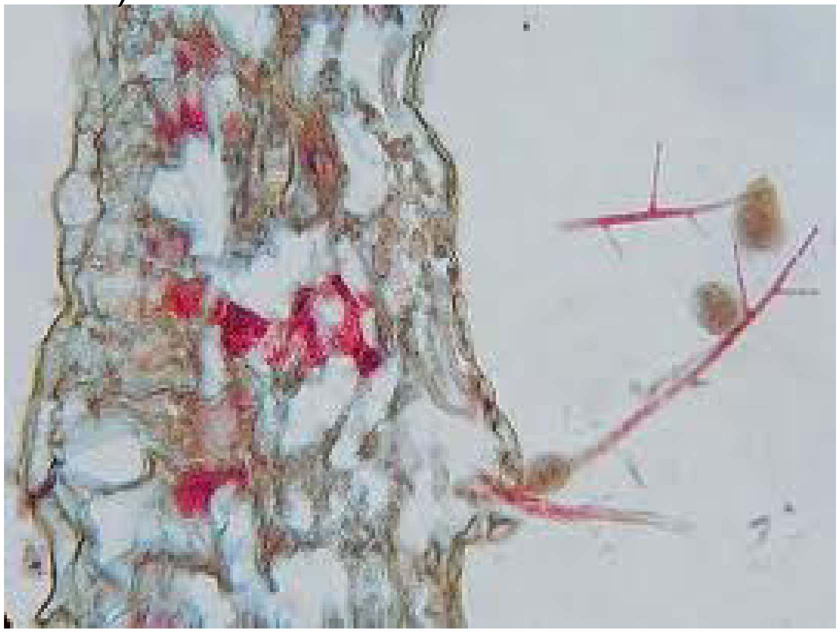
Their greatest impact on humans, however, comes from the many species of water mold which are parasites on flowering plants. These include root rotting fungi, seedling dampening mold, blister rusts, white rusts (*Albugo*), and the downy mildews that affect grapes, lettuce, corn, cabbage, and many other crop plants. Two of these disease-causing chromists have had a major impact on world history.

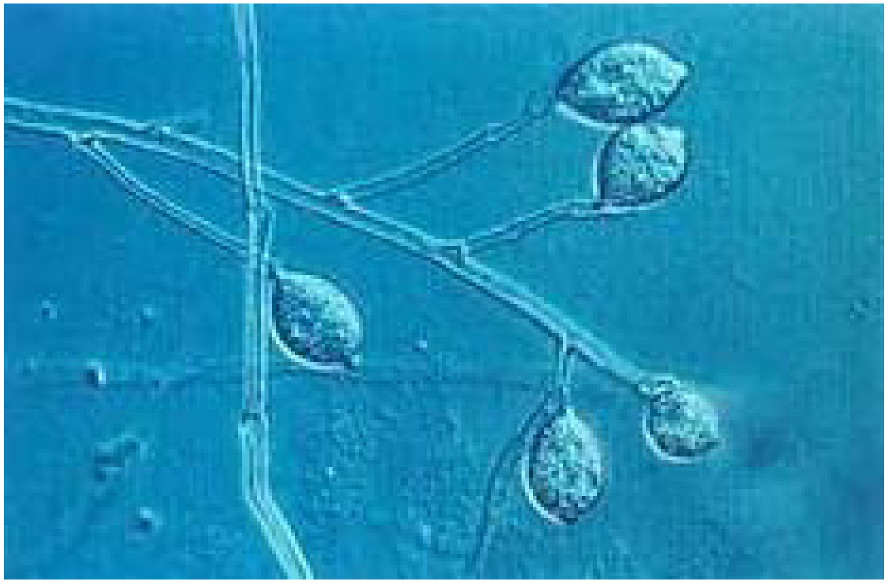
The first of these is *Phytophthora infestans*, the organism which causes late blight of potato. The potato is native to North America, but once it was introduced to Europe, it quickly became an important food crop.

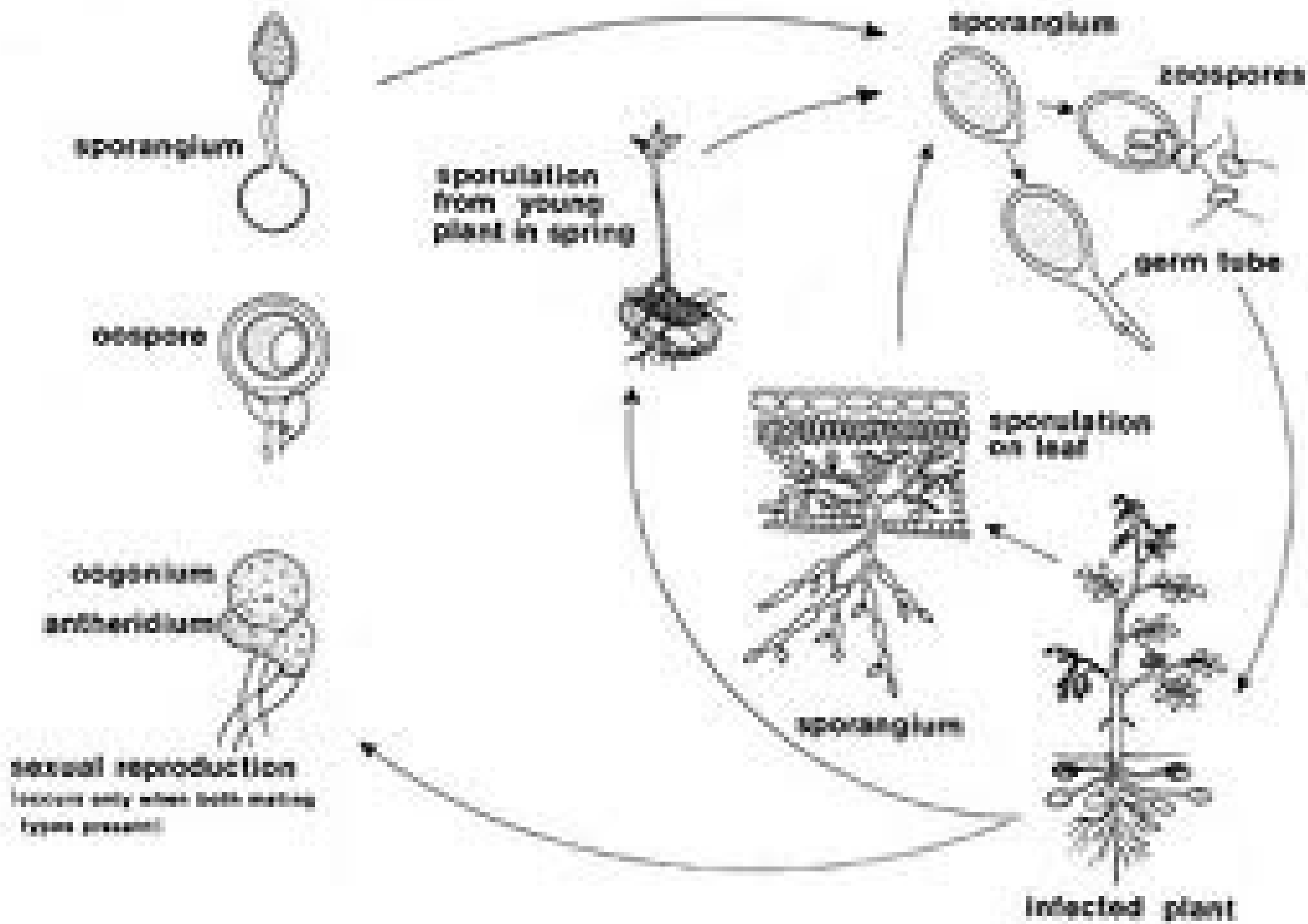
_ The other oomycete which has severely impacted recent history is *Plasmopara viticola*, the downy mildew of grapes.

The industry was saved by the serendipitous discovery of Bordeaux mixture, a mixture of lime and copper sulfate, which brought the disease under control when applied to the leaves of the plants. This discovery is also important for being the first known fungicide, and in fact the first chemical used to control a plant disease

Phytophthora infectans (Late blight of potato)






sporangium
sporulation from young plant in spring
sporangium
zoospores
germ tube
oospore
sporulation on leaf
oogonium
antheridium
sporangium
sexual reproduction
(occurs only when both mating types present)
infected plant

P. infectans on tomato fruit and leaves

Fuzzy grayish green mold on stored berry.

P. infectans on tomato fruit and leaves

Fuzzy grayish green mold on stored berry.

Alternaria solani (Early blight of potato)

Kingdom:	Fungi
Phylum:	Ascomycota
Class:	Dothideomycetes
Subclass:	Pleosporomycetidae
Order:	Pleosporales
Family:	Pleosporaceae
Genus:	*Alternaria*
Species:	***A. solani***

White sporangia and
sporangiophores

Botrytis blight and fruit rot

Botrytis cinerea

Symptoms

On leaves, brown, irregular lesions develop that sometimes distort leaves. Blighted blossoms turn brown and soon become covered with abundant gray mold. Infected twigs are first brown to black and later become tan to gray.

Disease cycle

The fungus overwinters as mycelium or hard black mycelial masses (sclerotia) on infected plant material. In spring, numerous airborne spores develop on plant debris and sclerotia. The fungus infects tender green twigs, blossoms, leaves, and fruit. Older plant parts are rarely attacked. Moderate temperaturers (59 to 68ºF) and frequent rains favor disease development.

Management

Remove infected plant material; reduce humidity in the canopy; apply effective fungicides during bloom and fruit ripening; avoid excessive use of nitrogen fertilizer in the spring; cool berries rapidly after harvest.

Flower blight (left) and postharvest rot (below) caused by Botrytis.

Botrytis blight

Black rot of grapes- *Guignardia bidwellii*

On the leaves, light brown, roughly circular spots appear in the spring and summer. Fruit infections occur from bloom until the berries become naturally resistant (about 3 to 5 weeks after bloom in most varieties). The first symptom, a whitish dot within a rapidly expanding brown area, appears 10 to 14 days after infection. Within a few days, the berry starts to shrivel and becomes a hard, blue-black mummy. Initial berry lesions, which expand and may show growth rings. If berries are infected close to the onset of natural resistance, lesions remain localized. The fungus over-winters in mummies within the vine or on the ground. Ascospores are released shortly after bud break until about 2 weeks after bloom and are dispersed by wind and rain. Infected tissues can also yield conidia, which are dispersed by rain splash and cause secondary infections. The optimum temperature for disease development is 27°C (80°F). At that temperature, the wetness period required for infection is only 6 hours.

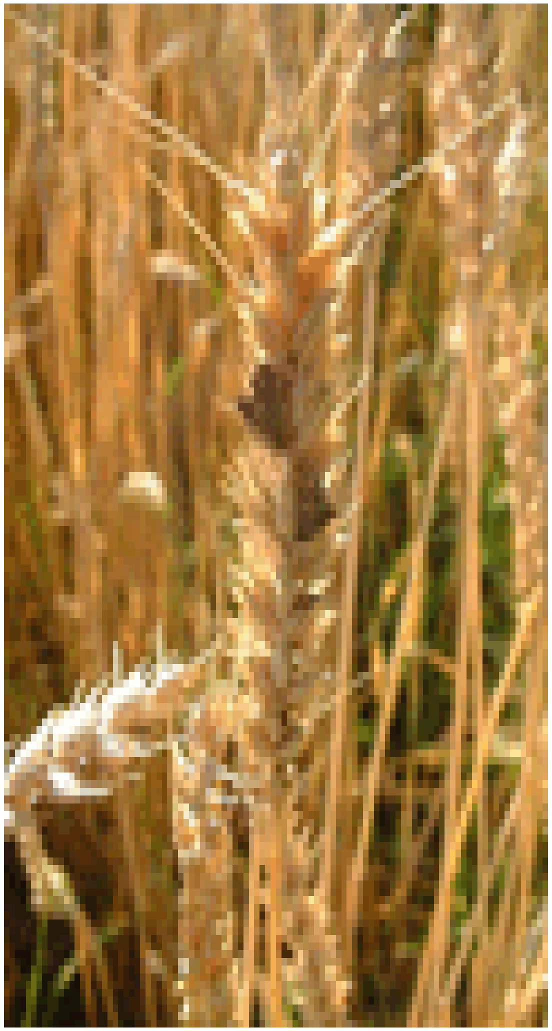
A:Initial berry lesions (above), which expand and may show growth rings B (right).

C: Mummified berries and D.

Ergot – Ascomycota

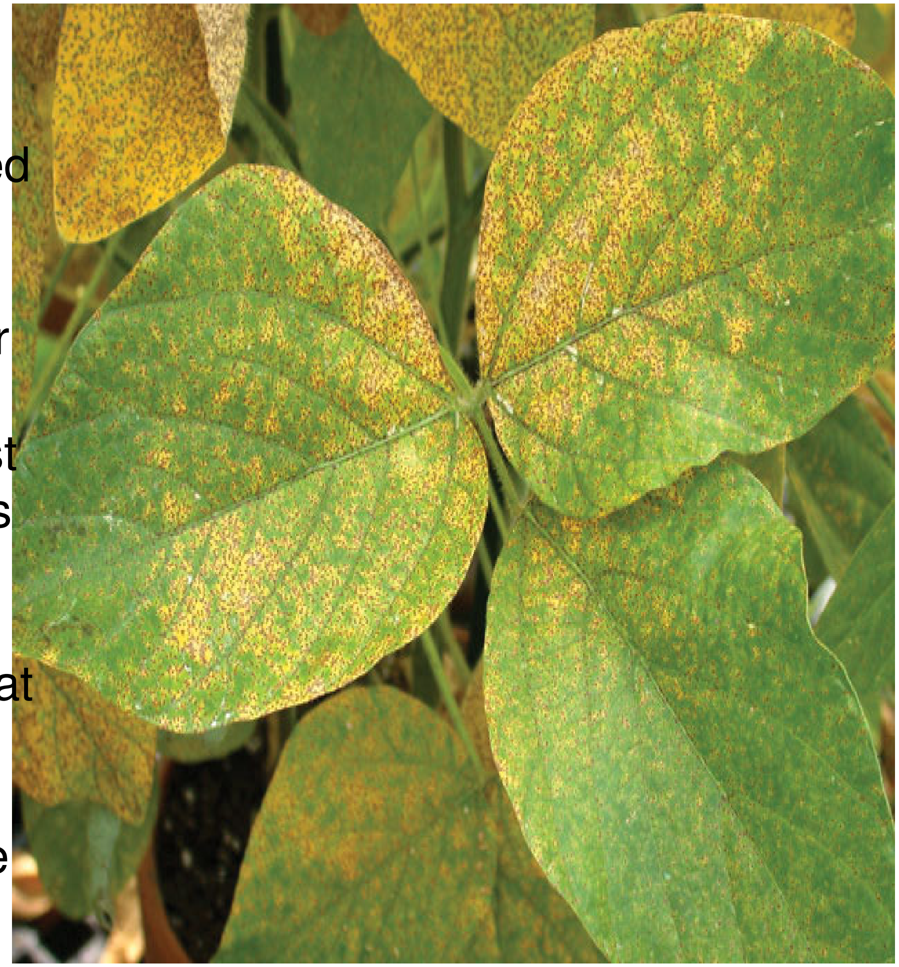
fungal disease of cereal grasses, especially rye, caused by the ascomycete fungus *Claviceps purpurea*. In an ear of rye infected with ergot, a sweet, yellowish mucus is exuded for a time, followed by a loss of starch as the ear ceases growth. The ovaries then become permeated by the mycelium, a mass of fungal filaments, which in autumn forms the spur-like purple-black sclerotium.

The sclerotium constitutes the source of the drugs ergonovine, which is used in obstetrics to control postpartum hemorrhage, and ergotamine, which is used in treating migraine headaches. After an overdose of medications derived from



Soybean rust

disease of thousands of economically important plants, as well as weeds, caused by more than 4,000 species of fungi. During their life cycle rust fungi parasitize either one species of plant (autoecious, or monoecious, rust) or two distinct species (heteroecious rust). One heteroecious rust with five spore forms during its life cycle is black stem rust (*Puccinia graminis*) of wheat and other cereals and grasses. Other heteroecious rusts include those that use junipers (red cedar) as one host and apple, Japanese quince, hawthorn, rose, and related plants as the other; white pine rust (*Cronartium ribicola*),

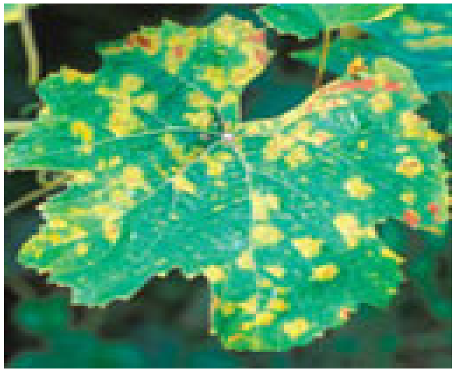


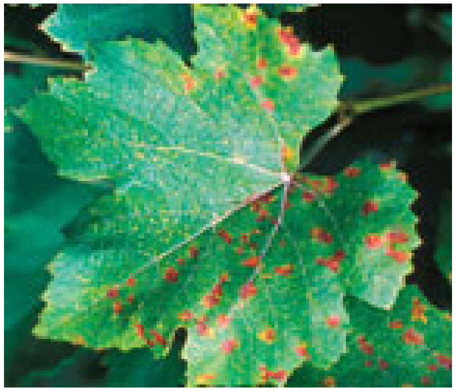
late blight, _ disease of potato and tomato plants that is caused by the water mold *Phytophthora infestans*. The disease occurs in humid regions with temperature ranges of between 40° and 80° F (4° and 29° C); hot, dry weather checks its spread. Potato or tomato vines that are infected may rot within two weeks. The Irish potato famines of the mid-19th century were caused by late blight. The disease destroyed more than half of the tomato crop in the eastern United States in 1946, leading to the establishment of a blight-forecasting service in 1947.

Downy mildew - *Plasmopara viticola* Annemiek Schilder, MSU Plant Pathology

Downy mildew is a widespread, serious disease of grapevines. Initial leaf symptoms are light green to yellow spots, called “oil spots” because they may appear greasy. Under humid conditions, white, downy spore masses can be seen on the lower leaf surface. These spores are wind dispersed.

The pathogen overwinters in infected leaves on the ground. In spring, spores are carried by rain splash to new leaves, where they require a film of water for infection. Lesions appear 5 to 17 days after infection. The disease can spread rapidly under warm conditions with frequent rain or dew.





White spore masses develop on infected berries.

A:Young lesions. B:White downy spore masses on the lower surface of the leaf. C:Older lesions that have turned brown

Oomycetes

The oomycetes are not true fungi but are fungal-like organisms. They include some of the most destructive plant pathogens including the genus *Phytophthora* which includes the causal agents of potato late blight and sudden oak death.

Despite not being closely related to the fungi, the oomycetes have developed very similar infection strategies and so many plant pathologists group them with fungal pathogens.

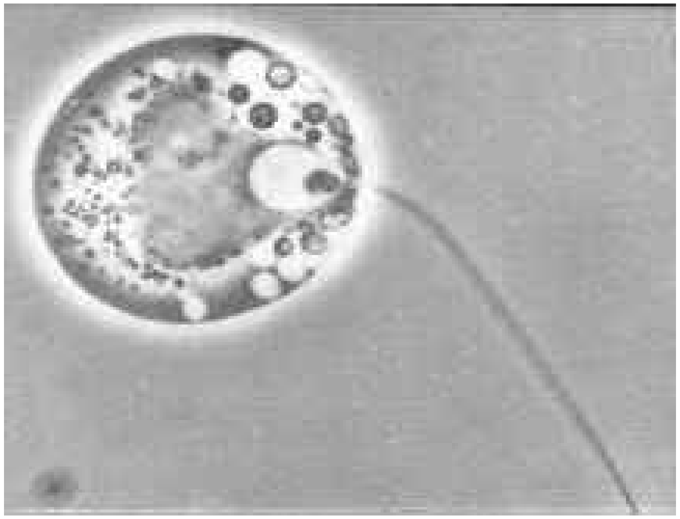
Significant oomycete plant pathogens

Pythium spp.

Phytophthora spp.; including the causal agent of the Great Irish Famine (1845–1849)

Rice blast is hemibiotrophic

DIVISION: CHYTRIDIOMYCOTA

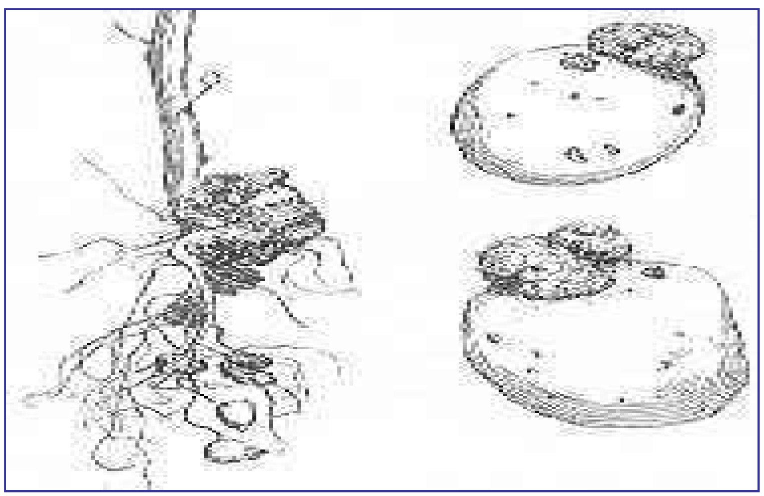


Chytridiomycota - **Blastocladiales –** zoospore of *Allomyces* (phase contrast illumination)

X 2000

Chytridiales - *Chytridium* releasing zoospores.

X 500



Chytridiomycota - Chytridiales - wart of potato caused by *Synchytrium endobioticum*

Alternaria leaf spot and fruit rot of Blueberries

Symptoms

Leaf lesions are circular to irregularly shaped, tan to gray, 1 to 5 mm in diameter, and surrounded by a reddish brown border. In most cases only lower leaves are infected, but a severe infection can defoliate the plant. On ripe fruit, sunken areas near the calyx are covered by a dark green, velvety growth. On stored fruit, a grayish-green mold may appear on the stem scar or calyx end and spread over the entire berry. Infected fruit becomes soft and shrivelled.

Disease cycle

The fungus overwinters in old twigs and in plant debris on the ground. Leaf infections occur in the spring during periods of cool, wet weather. Fruit infections occur as berries start to ripen. Disease development is optimal at 68ºF (20ºC).

Management

Plant resistant cultivars; reduce humidity in the planting; apply fungicides from bloom until harvest; harvest in a timely manner; handle berries dry; cool fruit rapidly after harvest.

Alternaria leaf spot and fruit rot
Alternaria tenuissima (fungus)

Plant Pathology is the study of (1) the living entities and the environmental conditions that cause disease in plants; (2) the mechanisms by which these factors produce disease in plants; (3) the interactions between the disease causing agents and the diseased plant; and (4) the methods of preventing or controlling disease and alleviating the damage it causes (Agrios, 1997

While plant diseases may be caused by environmental factors, viruses, mycoplasma, bacteria, nematodes, a few protozoa, and parasitic higher plants, by far the majority (more than 3/4) of plant diseases are caused by fungi. All of the major groups of fungi we studied in the initial sessions of this course hav

Magnaporthe grisea - Rice blast

Magnaporthe grisea – Powdery mildew

Management

Quarantine

Wherein a diseased patch of vegetation or individual plants are isolated from other, healthy growth. Specimens may be destroyed or relocated into a greenhouse for treatment/study. Another option is to avoid introduction of harmful non-native organisms by controlling all human traffic and activity (for e.g., AQIS) although legislation and enforcement are key in order to ensure lasting effectiveness.

Cultural

Farming in some societies is kept on a small scale, tended by peoples whose culture includes farming traditions going back to ancient times. (An example of such traditions would be lifelong training in techniques of plot terracing, weather anticipation and response, fertilization, grafting, seed care, and dedicated gardening.) Plants that are intently monitored often benefit not only from active external protection, but a greater overall vigor as well. While primitive in the sense of being the most labor-intensive solution by far, where practical or necessary it is more than adequate.

Plant resistance

Sophisticated agricultural developments now allow growers to choose from among systematically cross-bred species to ensure the greatest hardiness in their crops, as suited for a particular region's pathological profile. Breeding practices have been perfected over centuries, but with the advent of genetic manipulation even finer control of a crop's immunity traits is possible. The engineering of foodplants may be less rewarding however, as higher output is frequently offset by popular suspicion and negative opinion about this "tampering" with nature.

Chemical

(See: pesticide application) Many natural and synthetic compounds exist that could be employed to combat the above threats. This method works by directly eliminating disease-causing organisms or curbing their spread; however it has been shown to have too broad an effect, typically, to be good for the local ecosystem. From an economic standpoint all but the simplest natural additives may disqualify a product from "organic" status, potentially reducing the value of the yield.

Biological

Crop rotation may be an effective means to prevent a parasitic population from becoming well established, as an organism affecting leaves would be starved when the leafy crop is replaced by a tuberous type, etc. Other means to undermine parasites without attacking them directly may exist.

Integrated

The use of two or more of these methods in combination offers a higher chance of effectiveness.

Cassava

Cassava (*Manihot esculenta*) typically grows as a shrub. Cassava is native of Latin America and was introduced to the African continent by Portuguese traders in the late 16th century.

Cassava is grown on an estimated 80 million hectares in 34 African countries. It is an important crop in subsistence farming, as it requires few production skills or inputs. It is drought tolerant and produces reasonable yields under adverse conditions. Most important is its ability to remain in the soil as a famine reserve. Other factors that make cassava popular with small-scale farmers, particularly in Africa, are that it requires little labour, there are no labour peaks because the necessary operations in its production can be spread throughout the year, and its yields fluctuate less than those of cereals.

The storage root (some people refer to it as "tuber") is a major source of energy and the leaves, which contain a high level of Vitamin A and up to 17 % protein, are often used as green vegetables. Its limitations are its poor nutritive value (mainly carbohydrates) and its cyanogenic glucoside content (HCN) that can lead to poisoning unless precautions (proper peeling/soaking in water/fermenting/drying/cooking) are taken during preparation of the tubers. The latter is only applicable to bitter cassava varieties. Sweet varieties can even be eaten raw and fresh as they have very low content of HCN.

What are the common cassava diseases?

The common diseases of cassava are cassava mosaic disease, cassava bacterial blight, cassava anthracnose disease, cassava bud necrosis, and root rots. Some of these diseases attack the leaves and stems of cassava plants while others attack the storage roots.

Leaf and stem diseases

Common leaf and stem diseases of cassava are cassava mosaic disease, cassava bacterial blight, cassava anthracnose disease, cassava bud necrosis, and brown streak disease.

Cassava mosaic disease

Cassava mosaic disease is caused by a virus which occurs inside cassava leaves and stems.

Damage symptoms: The leaves of cassava plants with the disease are discolored with patches of normal green color mixed with light green, yellow, and white areas (Figure 4). This discoloration is known as chlorosis. The chlorotic patches can be confused with cassava green mite feeding damage (Figure 5). When cassava mosaic attack is severe, the leaves are very small and distorted and the plants are stunted. The disease symptoms are more pronounced on younger plants (Figure1), usually under 6 months, than on older plants.

Method of spread: The main sources of the virus which causes cassava mosaic disease are cassava plants with the disease and the whitefly *Bemisia tabaci* (Figure 6). The virus occurs in the saliva of the whitefly. During feeding, the insect injects saliva containing the virus into cassava leaves. The virus multiplies and occurs in large numbers in the leaves and stems. Cassava mosaic disease is also spread by planting stem cuttings from plants infected with the disease.

Cassava leaf mosaic It is spread through infected cuttings and by whiteflies (*Bemisia tabaci*)

Cassava stem cutting sprouted with cassava mosaic disease

Cassava plant damaged by cassava mosaic disease

Cassava leaves with chlorotic (pale) patches of
cassava mosaic disease

Cassava leaf with white leaf spot disease

Cassava anthracnose disease

Cassava anthracnose disease is caused by a fungus which occurs on the surface of cassava stems and leaves.

Damage symptoms: Cassava anthracnose disease appears as cankers ("sores") on the stems and bases of leaf petioles (Figure). Cankers weaken the petioles so that the leaf droops downwards and wilts. The wilted leaves die and fall causing defoliation and shoot tip die-back or complete death of the shoot. Soft parts of cassava stems become twisted under severe attack by the disease.

The disease usually starts at the beginning of the rains and worsens as the wet season progresses.

Method of spread: The main sources of the fungus that causes cassava anthracnose disease are cassava plants with the disease. The fungus spreads by wind carrying spores from cankers on the stems, or by planting stem cuttings with cankers. The fungus enters cassava plants through wounds and feeding punctures made by the bug *Pseudotheraptus devastans*. Dead cassava stems and leaves with the fungus also serve as sources of the disease if they are not destroyed after root harvest.

Other crops attacked: The fungus that causes cassava anthracnose disease affects other crops as well as cassava, for example, coffee, pepper, and pawpaw.

Cassava bud necrosis

Cassava bud necrosis is caused by a fungus which occurs on the surface of cassava stems and leaves.

Damage symptoms: The disease appears as patches of brown or grey fungal matter covering the stem. The fungal matter sometimes covers buds ("eyes") on cassava stem cuttings. The affected buds die, which reduces the sprouting ability of stem cuttings.

Method of spread: The main sources of the fungus that causes bud necrosis are cassava plants with the disease. Dead cassava stems and leaves with the fungus also serve as sources of the disease if they are not destroyed after root harvest. The fungus spreads by wind, however, planting of infected stem cuttings is the main method by which the disease spreads.

Other crops attacked: The fungus that causes bud necrosis causes leaf spots on a variety of plants including grasses, cereal crops, banana, and mango.

Cassava anthracnose -**Anthracnose (*Glomerella manihotis*)**

Cankers of cassava anthracnose disease on stem

Cankers of cassava anthracnose disease at the bases of cassava leaf petioles

Cassava shoot with wilted leaves caused by cassava anthracnose

Cassava bacterial blight (*Xanthomonas campestris* pv. *Manihotis)*

Cassava leaf with angular leaf spots of cassava bacterial blight

Cassava leaf blighting caused by cassava bacterial blight

cassava bacterial blight

Leaf blighting and wilting caused by cassava bacterial blight

Brown leaf spot (*Cercosporidium henningsii*) Henningsii

Cassava brown streak virus disease (Potyvirus - Potyviridae

Cassava leaves with chlorotic (pale) patches of cassava brown streak disease

Cassava stem with "streaks" of cassava brown streak

Stem and root diseases

Cassava brown streak disease

Cassava brown streak disease is caused by a virus (Potyvirus – Potyviridae). Presently the disease is reported only from cassava-growing regions in East and Southern Africa.

Damage symptoms: Symptoms appear on the leaves, stems, and storage roots. On the leaves, the disease appears as patches of yellow areas mixed with normal green color. The yellow patches are more prominent on mature leaves than on young leaves. The damaged leaves do not become distorted in shape as occurs with leaves damaged by cassava mosaic disease. On the stems, the disease appears as dark brown "streaks" with dead spots on leaf scars. These streaks are most prominent on upper, green portions of the stems. The diseased plants may show shoot tip die-back. Cassava brown streak disease distorts the shape of the storage roots and may cause cracks and discoloration in the storage roots.

Method of spread: The main sources of the virus that causes cassava brown streak are cassava plants with the disease. The disease is spread through the planting of stem cuttings from diseased plants and from plant to plant by insects.

Other crops attacked: Cassava brown streak disease is not known to attack other crops.

Cassava bugs

Cassava leaf with chlorotic (pale) spots caused by cassava green mite

Adults of *Bemisia* whitefly (as seen enlarged under the microscope

The bug *Pseudotheraptus devastans* on cassava leaf

The lesser grain borer (*Rhizopertha dominica*),

Grasshoppers (*Zonocerus variegatus*) They feed on cassava plants, chewing leaves and stemsand may cause defoliation and debark stems. This is particularly severe in fields next to the bush when the dry season is prolonged.

Different species of termites damage cassava stems and roots. Termites damage cassava planted late or in the dry season, in particular when the crop is still young at the peak of the dry season.

Whiteflies (*Bemisia tabaci*,

Larger grain borer (*Prostephanus truncatus*) infests cassava chips in storage particularly during the rainy season in West Africa

Tuber diseases

Cassava storage roots damaged by cassava brown streak disease

Cassava root rot diseases

Cassava root rot diseases are caused by various kinds of fungi living on or in the soil. The fungi occur mainly in soils that do not drain properly and in forest fallow land that has been recently cleared.

Damage symptoms: The leaves on cassava plants affected by root rot disease turn brown, wilt, and the plant appears scorched. The leaves may or may not remain attached to the plant, but the plant loses a lot of water and dies. If you suspect a cassava plant as having root rot disease, you should confirm this by uprooting it and examining the roots for the damage symptoms. Root rot diseases kill both feeder and storage roots of cassava. The storage roots may swell unusually and develop light brown coloration which you can see if the roots crack in the soil or if you cut them open. The roots may give out a bad smell as they rot.

Method of spread: The important sources of cassava root rot fungi are soils, and cassava root and stem debris contaminated with the fungi. The fungi enter cassava plants through wounds caused by pests or farming tools or by piercing the roots by themselves. Farm tillage tools used in cassava farms with the disease should be cleaned after use to prevent the fungi on them from spreading to other areas. Similarly, cassava plant debris in farms with the disease serve as sources of root rot fungi and should be destroyed by burning.

Other crops attacked: Cassava root rot fungi attack a wide range of other crops including maize, soybean, sunflower, and coffee.

Cassava storage root destroyed by root rot disease

Good cassava storage root yield

Control measures

To control diseases and grow a healthy crop of cassava:

• Identify the common cassava diseases, their damage symptoms, and know the conditions under which they will cause severe losses.

• Select sites with dense vegetation, deep loamy soils, and flat or gently sloping land to grow cassava.

• Improve the soils by manuring, mulching, and intercropping to encourage cassava plants to grow vigorously and offset damage by cassava diseases.

• Grow cassava varieties that tolerate the common cassava diseases in your area.

• Plant stem cuttings from healthy plants without leaf chlorosis, shoot tip die-back, cankers, fungus patches, or streaks on the stems.

• After root harvest destroy storage roots showing any symptom of disease and discard cassava ste ms with shoot tip die-back, cankers, fungus patches, streaks or any other disease.

• In the control of cassava mosaic disease, select planting material mainly from stem branches; avoid the basal and main stem portions as sources of stem cuttings.

• Plant cassava mainly at the beginning of the wet season; try and avoid late planting.

Good farm sanitation helps to reduce the sources of the pathogens that cause cassava diseases in farms. Crop debris of storage roots, leaves, and stems with symptoms harbor the pathogens and should be destroyed to reduce the sources of disease spread. Farm tools should be cleaned before and after tillage to reduce the spread of root rot fungi through tools contaminated with the pathogen. If only a few stem cuttings sprout with disease it is advisable to remove them and replace them with healthy stem cuttings. This is called roguing. Roguing of cassava plants is best done at 3–4 weeks after planting when controlling cassava mosaic disease.

<u>COCOA</u> (*Theobroma cacao* L.) (Sterculiaceae), is an important tropical rain forest species. It is grown for its oil-rich seed, to produce cocoa and cocoa butter. Cocoa seeds are a major cash crop of the tropical world.

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COCOA PULP

Cocoa seeds are surrounded by an aromatic pulp which arises from the seed teguments. The mucilaginous pulp is composed of spongy parenchymatous cells containing cell sap rich in sugars (10 to 13%), pentosans (2 to 3%), citric acid (1 to 2%), and salts (8 to 10%).

During on-farm processing of cocoa seed, the pulp is removed by fermentation and is hydrolyzed by microorganisms. Hydrolyzed pulp is known in the industry as "sweatings." During fermentation, the pulp provides the substrate for various microorganisms which are essential to the development of chocolate flavor precursors, which are fully expressed later, during the roasting process.

»Excess pulp, which has a delightful tropical flavor has been used to produce the following products: cocoa jelly, cocoa butter, alcohol and vinegar..

Cocoa jelly is produced by cooking fresh pulp mixed with sugar at the rate of 300 to 600 g to one liter pulp.

» The pulp contains about 1% pectin. The jelly has a fruit-acid flavor and is a popular delicacy in Brazil.

» By controlled fermentation and distillation, sweatings can be made into an alcoholic spirit with 43% ethanol. Alcohol produced can be further fermented by *Acetobacter* sp. to produce acetic acid.

CACAO POD HUSK

At the present time, pod husks are a waste product of the cocoa industry, and present a serious disposal problem. They become a significant source of disease inoculum when used as a mulch inside the plantation. Fresh or dried husks may be used as livestock feed, but theobromine content (ca. 0.4%) restricts the proportion that can be consumed. Reports indicate that pod meal can constitute 20% of ration for poultry, 30 to 50% for pigs, and 50% for sheep, goats, and dairy cattle.

Potassium Salts for Soap

Pod husk ash has been used to make soap in Ghana and Nigeria.

Cacao Pigment

A cocoa husk extract called cacao pigment, which is a mixture of condensed or polymerized flavonoids (such as anthocyanidins, catechins, leukoanthycyanidin, has been utilized by food industries in Japanese .

Pod Gums

There are lysigenous cavities in cocoa, filled with mucilaginous substances occur in roots, stems, flowers, and leaves as well as fruit husks. Potential uses for pod gums include binders for such products as pet food, emulsifiers, and fixatives

Healthy cocoa pods

Cocoa beans

Healthy cocoa tree with pods

Healthy pod

Diseased pod with infected seeds

Depending on where cacao is grown, one or more of three diseases (black pod, witches' broom, and frosty pod rot) may reach epiphytotic proportions that cause devastating losses (Table 1)

Table 1. Estimated annual reduction in potential cocoa production by major diseases.

Diseases	**Pathogen**	**Region**	**Reduced Production**	
			(tons x 1000)	**($ million)***
Black Pod	*Phytophthora* spp.	Africa/Brazil/ Asia	450	423
Witches' Broom	*Crinipellis perniciosa*	Latin America	250	235
Frosty Pod Rot	*Moniliophthora roreri*	Latin America	30	47
Swollen Shoot	Cocoa swollen shoot virus	Africa	50	28
Vascular-streak dieback	*Oncobasidium theobromae*	Asia	30	28

Taylor, M. 2001, LMC International Ltd/Trade Discussions

Black pod disease of cocoa caused by
Phytophthora capsici in Costa Rica

Seedling blight of cacao caused by
P. megakarya common in West Africa,

Sporangia of *P. megakarya* forming on the surface of an infected pod in Cameroon

Sporangium and zoospores of *P. megakarya*

Witches broom - *Crinipellis perniciosa*

Basidiocarp of *C. perniciosa*

Vegetative branches (brooms) arising from a flower cushion infected by *C. perniciosa*

Witches' broom disease, caused by the fungus *Crinipellis perniciosa* (Stahel) Singer.
The disease is initiated by basidiospores produced and released from pinkish mushrooms called basidiocarps that are dispersed by wind and rain onto leaves, flowers, and fruit (pods) of cacao plants. It is estimated that a single basidiocarp can release 80 to 90 million basidiospores. In the presence of free moisture (rain and de and high relative humidity, basidiospores germinate and penetrate young meristematic tissues in vegetative and floral buds through stomata, epidermis, or trichomes. The colonized tissues undergo several physiological and hormonal changes leading to swelling and formation of numerous succulent vegetative branches, known as brooms, within flower cushions and on vegetative apical or axillary bud . The brooms are usually formed within 5 to 6 weeks following infection.

Basidiocarps (pinkish structures) formed on a dry broom and pod infected with *C. perniciosa*

Witches' broom debilitates cacao trees by diverting energy to the numerous brooms that do not form flowers, thus reducing yield potential. Further yield loss is incurred by the prevention of seed formation in pods infected early in their development. If seeds are formed prior to infection they may be unusable depending on the extent of pod colonization by *C. perniciosa*

Control measures

Broadly, there are four major strategies that are adopted: phytosanitation, chemical control, genetic resistance, and biological control . Phytosanitation, by removal and destruction of diseased plant parts, has been shown to reduce pod loss and delay disease epidemics. However, this strategy is tedious and in one study it has been shown that 95% removal is required to achieve 50% reduction in pod loss. Chemical control of witches' broom with protectant and systemic fungicides is not a routine practice in cocoa production because of high costs and risks associated with cocoa bean contamination and environmental health. The development of genetically resistant cacao cultivars is an on-going endeavor in many countries, and it is expected that the use of these cultivars would reduce the incidence of the disease.

Prospects of managing witches' broom disease of cacao through biological control have been investigated for over 20 years leading to the isolation of a new species, *Trichoderma stromaticum*, a parasite on the mycelium and basidiocarps of *C. perniciosa*. In Brazil, commercial formulations of *T. stromaticum* are currently used in managing witches' broom.

Cocoa viruses

Cocoa is affected by a number of viruses which include *Cocoa swollen shoot virus* (CSSV), *Cocoa necrosis virus* (CNV), *Cocoa yellow mosaic virus* (CYMV), *Trinidad cocoa virus* (TCV), and two virus-like particles causing symptoms of different degrees of severity during different stages of the plant's growth and development. However, when the extent of damage is taken into consideration, only CSSV can be regarded as a major viral disease with characteristic symptoms such as red vein-banding on young leaves, yellow vein-banding, interveinal flecking, and mottling of mature leaves as well as pronounced swelling of stems. CSSV which is largely restricted to West Africa has caused incalculable damage to cocoa industries in Nigeria and Ghana where several millions of cocoa trees have been destroyed. In Ghana and Nigeria, virulent and mild strains of CSSV are known to occur with severe strains killing cocoa within two years.

This virus is known largely transmitted by mealybugs, of which Planoccoides (*Pseudococcus njalensis* (Laing) and *Planococcus citri* (Risso) are the commonest vectors distributed by attendant ants, particularly *Crematogaster straiatula* (Emery). None of the other viruses is known to cause any serious diseases on cocoa.

Vascular streak dieback, caused by *Oncobasidium theobromae*, Frosty Pod Rot - *Moniliophthora roreri*

Frosty pod rot.

Frosty pod rot (or Moniliophthora pod rot), caused by *Moniliophthora roreri* (Ciferi & Parodi) Evans et al., is a devastating disease of cacao pods. The conidia (the only known infective propagules) infect by penetrating the surface of the pods. The pods are highly susceptible during the first 90 days of their growth. Early symptoms include discolored areas of swelling on the pods followed by a dense formation of cream-colored spores, the so called frosty pod, developing on the pod surface within 2 weeks after infection. The area of the pod with sporulation spreads rapidly. The spores are later released by wind or by water droplets during rainy periods.

A cacao clone from a breeding program in Columbia

Control measures

The most economical way of controlling the spread of this disease is to eliminate the inoculum sources, which are dead sporulating pods, with frequent harvests on regular cycles. Other practices include reduction of tree height (maximum 3.5 m) to facilitate removal of diseased pods, biological control, and planting of resistant or tolerant cultivars as they become available. Major genetic improvement efforts are underway in Costa Rica, Colombia, and Ecuador to select genotypes resistant or tolerant to *M. roreri*, and new hybrid clones are being distributed to farmers. Breeding for disease avoidance may be one of the safest methods to reduce field losses, as this form of resistance is less vulnerable to adaptive changes by the pathogens.

Ustilago maydis (Maize smut)

Septoria tritici

Septoria leaf blotch is a fungal disease caused by *Septoria tritici*, that affects wheat and occasionally other grasses including barley. It is the major disease of wheat in the UK.

Septoria are *Ascomycete* fungi that causes numerous leaf spot diseases on, forages and many vegetables, thereby causing yield losses.

Fusarium ear blight (also called **FEB**, **Fusarium head blight** , **FHB** or **scab**), is a fungal disease in plants. It is responsible for the most common damaging disease that affects golf course grass. From an economic stand point, it is one of the major cereal diseases, being responsible for significant grain yield reduction in wheat and oats. It also represents a serious threat to human health, because it is responsible for dangerous mycotoxin-infected grain and food items. The Fusarium ear blight is due to a *Fusarium* fungus. There are five major species of *Fusarium*:

Water mould

Soybean diseases

The Brazilian Census Bureau (IBGE) estimates an harvest of 59.2 million tonnes of soybeans in 2005-06, up from 51.1 million tonnes in 2004-05. Some crop losses due to dry weather in the previous season were reported.

Asian rust is another factor that could endanger some part of the Brazilian crop. Small and medium-sized farmers cannot pay the spray if rust attacks. Asian soybean rust was first found in Brazil in 2002 and has since spread to Brazil‘ major soy regions.

Extreme heat and drought in much of the Midwest in 2005 limited the spread of soybean rust to the southern United States. However, the disease is still a serious threat to all U.S. soybean growing areas.

Asian soybean rust: It is a fungal disease caused by **Phakopsora pachyrhizi**. It can defoliate plants and reduce pod set, pod fill, seed quality and yield.

Similar looking diseases Diseases which are similar looking to asian soybean rust are:

Bacterial Blight Pseudomonas syringae pv glycinea

Bacterial PustuleXanthomonas campestris pv. glycines

Cercospora Blight caused by the fungus Cercospora kikuchii

Frogeye Leaf Spot Cercospora sojina

Downy Mildew fungus Peronospora manshurica

Brown Spot is a fungal disease caused by Septoria glycines

POTATO DISEASES

Potato late blight is caused by the fungus Phytophthora infestans and is the most important potato disease. Specially the US-8 genotype is strongly resistant to the fungicide mefenoxam and is together with the genotype US-11 very aggressive. The spores of the fungi are carried by wind or other infection ways from one field to another. Once the fungi is established in the plant no chemical fungicide can kill it. Prevention is therefore the best way to prevent great damage. Fungicides must always be applied before the crop shows any signs of infection. The fungus hibernates in infected potato tubers as mycelium. New sprouts of the mycelium invades the cortical tissue of the tubers. Reaching the aerial part of the plant sporangiosphores will be created and which emerge through the stomata of leaves or stems.The sporangia which are then produced can infect other wet plants by means of wind and rain. Infection of tubers may not be seen during harvest, but it will go on during storage.

The sporangia can also spread on soil and tubers near the surface.

Potato late blight is caused by the fungus Phytophthora infestans and is the most important potato disease. The spores of the fungi are carried by wind or other infection ways from one field to another. Once the fungi is established in the plant no chemical fungicide can kill it. Prevention is therefore the best way to prevent great damage.

Fungicides must always be applied before the crop shows any signs of infection. The fungus hibernates in infected potato tubers as mycelium.
.
The sporangia can also spread on soil and tubers near the surface.
Prevention of potato late blight depends on the forecast of temperature and humidity of the specific region
Preventive application of fungicides are necessary if the environmental conditions are favorable for the disease.

Copper free compounds had either no or limited effects on blight compared with copper fungicides
The EU project leaded by Professor Carlo Leifert aims the development of management of late blight in EU organic potato production. In this project it is being notet that there is a widespread view that a copper fungicide ban will have serious consequences for organic potato production unless effective alternatives are available.

Diseases of potatoes

Tuber diseases:

Pink rot: is caused by the fungus ***Phytophthora erythroseptica*** which is soil-borne. Pink rot can be detected by a smell of ammonia prior of visual symptoms.

Phytium leak is caused by the fungi ***Phytium debaryanum*** and ***Phytium ultimum***. Also known as water rot is caused by the fungus Phytium spp. living in the soil. The fungus invades the tubers through wounds made during harvest. It causes internal wet spongy rot with hollow cavities leaving behind only the tuber shells as thin paper skins.

Avoid overwatering near harvest. Avoid unnecessary damage to the tubers during harvest.

Fusarium dry rot:It is a postharvest disease of potatoes. It is caused by several soilborne fungus ***Fusarium***. Infected tubers have wrinkled, sunken, brown to black lesions. The Fusarium fungi are common in soil and decaying plants as resistant spores. After low-temperature storage, internal tissues become firm and dry or even powdery.

Potato bacterial ring rot: is caused by **Clavibacter michiganensis subsp**. **sepedonicus** producing yellow areas which start on leave margins later turning brown. The leaves look like being burned.

Brown necrosis of the tubers are formed from the middle of the tuber, progressing to surface, leaving sometimes only hollow shells.

Rhizoctonia Canker: It is a disease of potatoes caused by the fungus Rhizoctonia solani. It is known as black scurf Hard black bodies called sclerotia are formed on the surface of the tubers. Delayed budding is caused by an attack of the buds by the fungus.

Silver scurf: Is a potato disease caused by the fungus ***Helmithosporium solani.*** It causes a metallic discoloration of the epiderma and causes weight loss during storage due to increased water loss of the tubers. Shrinking and flabbiness affects peeling of the tubers reducing consumer acceptance and rejection. It is a seed-borne disease.

Spongospora, Powdery Scale Is a disease of potatoes caused by ***Spongospora subterranea*** which can be the vector of the mop-top furovirus.

Net necrosis:

Foliar diseases

Early blight: Potato early blight is caused by the fungus ***Alternaria solani***. It is a disease of stressed and senescing plants. Lesions of the leaves are circular with a target look. They turn out yellow and drop. Tubers develop dry rot lesions which appear sunken.

Infection is possible during wet and warm weather conditions (dew, rain or sprinkler irrigation). Tubers can be contaminated by lifting them through the surface soil.

Early blight can be reduced with optimum growing conditions like fertilization, irrigation and other pest controls in order to strengthen the plants. Fungicide application is recommended only when the plants become diseased in a very early stage so the damage will be considerable.

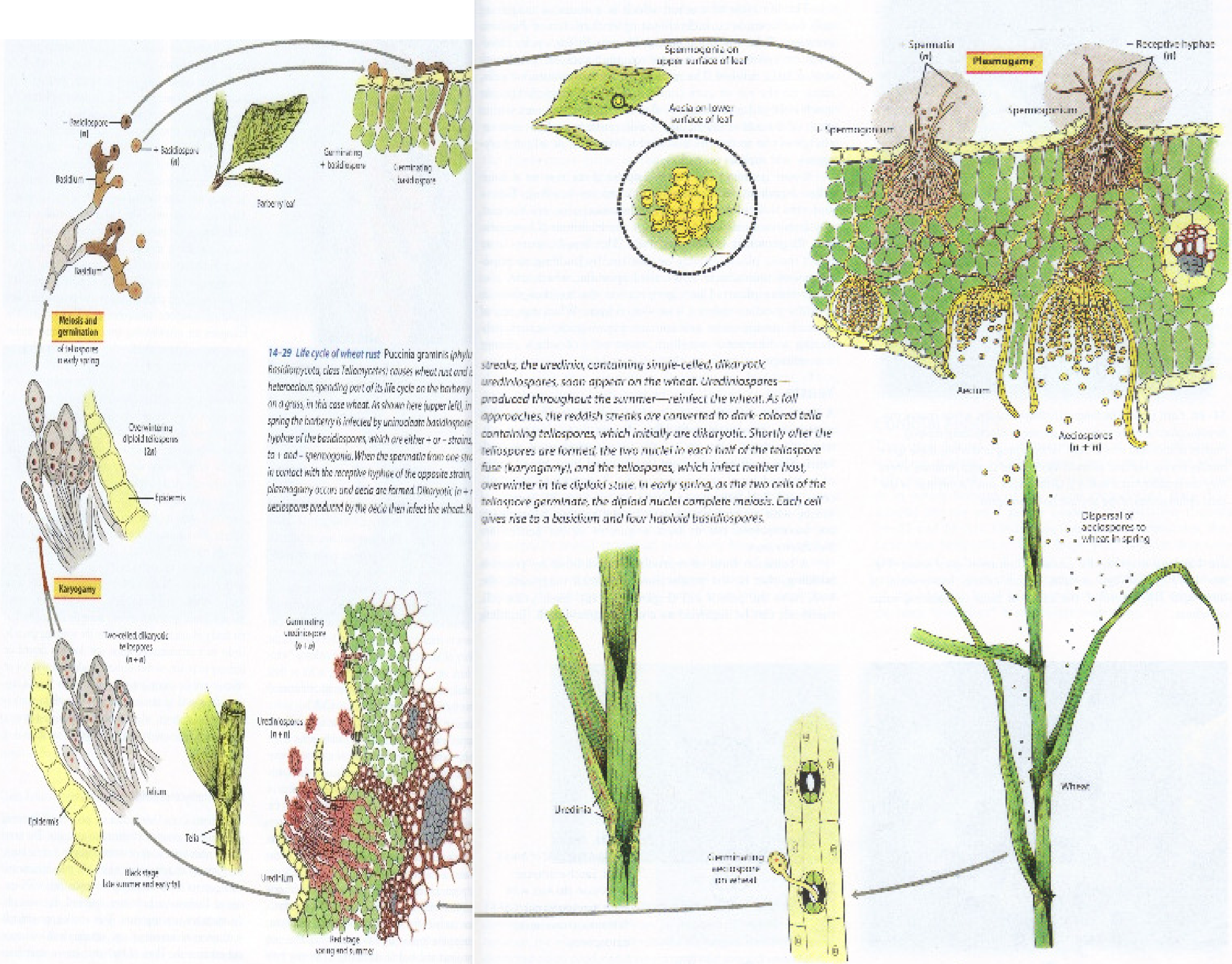
Potato late blight

Potato blight is caused by ***Phytophthora infestans*** a fungus-like organism whose sporangia are dispersed by wind.

Control measures
To avoid damage caused by blight the potato farmers watch weather forecasts for the climatic conditions which favor the spread of the disease.

Spraying fungicides may be unnecessary when blight spores are not present in the air current.
More efforts are being done to control spore flight with air sampler in connection with flow cytometer. Particles collected by the sampler are stained and analyzed in the cytometer using laser light. Airborne potato blight spores are identified and counted against a background of other fungal spores, pollen and inert particles. This system is being developed by Dr. Gareth Griffith of the Institute of Biological Sciences at the University of Wales, Aberystwyth. The forecast of the potato blight disease which has caused the Irish Potato Famine, 1845-1847 leading to the death of 1 million people could be improved using data of the climatic forecast (suitable conditions for pathogen growth) and detection of the sporangia in air (inoculum). With the help of these data the decision to spray the crops could could reduce excessive fungicides

Prevention of potato late blight depends on the forecast of temperature and humidity of the specific region
When the relative humidity is below 80% the sporangia will lose its ability to germinate in 3 to 6 hours. Free moisture or dew makes germination possible. Best conditions for growth of the fungus is 100% of relative humidity.



14-29 Life cycle of wheat rust Puccinia graminis *(phylu*
Basidiomycota, class Teliomycetes) causes wheat rust and i
heteroecious, spending part of its life cycle on the barberry
on a grass, in this case wheat. As shown here (upper left), in
spring the barberry is infected by uninucleate basidiospore
hyphae of the basidiospores, which are either + or − strains,
to + and − spermogonia. When the spermatia from one str
in contact with the receptive hyphae of the opposite strain,
plasmogamy occurs and aecia are formed. Dikaryotic (n + n
aeciospores produced by the aecia then infect the wheat. R

streaks, the uredinia, containing single-celled, dikaryotic urediniospores, soon appear on the wheat. Urediniospores—produced throughout the summer—reinfect the wheat. As fall approaches, the reddish streaks are converted to dark colored telia containing teliospores, which initially are dikaryotic. Shortly after the teliospores are formed, the two nuclei in each half of the teliospore fuse (karyogamy), and the teliospores, which infect neither host, overwinter in the diploid state. In early spring, as the two cells of the teliospore germinate, the diploid nuclei complete meiosis. Each cell gives rise to a basidium and four haploid basidiospores.

Several fungal diseases are characterized in the table.

Some fungal diseases of plants

disease	causative agent	hosts	symptoms and signs	additional features
late blight of potato	*Phytophthora infestans*	potato	water-soaked dark green to black or purplish lesions with pale green margins on lower leaves, white mildew at edge of lesions	responsible for Irish famine; caused starvation and death and mass migration of population
chestnut blight	*Endothia parasitica*	chestnut tree	yellowish to reddish brown patches appear on bark; lesions spread quickly and girdle twigs or limbs, which die	disease accidentally imported from Asia; first observed in New York in 1904 and rapidly spread across the United States, practically eliminating native American chestnuts
Dutch elm disease	*Ceratocystis ulmi*	elm tree	leaves wilt, turn dull green to yellow or brown, and drop off; branches die	the causative fungus is believed to have entered Europe from Asia during World War I and was later transported to the United States (1930) on elm burl logs imported for furniture veneer; elm bark beetles spread the pathogen in the United States
black stem rust of wheat	*Puccinia graminis*	wheat; many grasses	on wheat, rust-coloured pustules with spores, chlorosis of surrounding tissue, followed by development of black teliospores; on barberry, chlorosis and hypertrophy of infected tissue, orange spore masses	disease occurs wherever wheat is grown; in 1935 it destroyed about 60 percent of the total hard red spring wheat crop in Minnesota and South Dakota; fungus has a complex life cycle, partly on wheat and partly on the barberry plant; eradication of the barberry plant is an important

coffee rust	*Hemileia vastatrix*	coffee	orange-yellow powdery spots on lower side of leaves; centres turn brown and leaves fall	most destructive disease of coffee; has caused devastating losses in all coffee-producing countries
white-pine blister rust	*Cronartium ribicola*	white pine tree	small, discoloured, spindle-shaped cankers surrounded by narrow band of yellow-orange bark; blisters exude secretion followed by bright orange pustules	one of the most important forest diseases in the United States; currant is the alternate host, and its eradication is an important control measure
corn smut	*Ustilago maydis*	corn	minute galls form on young corn seedlings; on older plants, large galls are produced on the silk of ears and on tassels, leaves, and stalks	occurs wherever corn is grown; may cause serious crop damage
loose smut	*Ustilago nuda*	barley, oats, wheat	infected heads are covered with masses of olive-green spores	worldwide occurrence; destroys kernels of the infected plant
downy mildew	many species of the family Peronosporaceae	many types of plants: grapes, grasses, vegetables, and others	yellow irregular spots appear on upper leaf surface; downy fungus growth appears on underside; leaves die	one of the first plant diseases controlled by a fungicide—i.e., Bordeaux mixture, a mixture of lime and copper sulfate used on grapes
powdery mildew	many species of the family Erysiphaceae	many types of plants: grasses, vegetables, shrubs, and trees	spots of powdery mildew growth that enlarge to cover leaves or other plant organs	one of the most common and widely spread plant diseases
apple scab	*Venturia inaequalis*	apple	small olive-coloured areas appear on young leaves, later turn black, and may coalesce; black circular spots appear on fruit	occurs almost everywhere apples are grown; infection reduces fruit size and quality

black spot of rose	*Diplocarpon rosae*	rose	large circular black lesions on leaves; leaves turn yellow and fall off	classified as an anthracnose, which affects leaves, stems, and fruits of many plants
anthracnose of grape	*Elsinae ampelina*	grape	(as above)	(as above)
nectria canker	*Nectria galligena*	apple and pear and many hardwood forest trees	initially small circular brown areas that enlarge and become depressed with raised edges; callus tissue produced around canker	one of the most important diseases of pear, apple, and hardwood forest trees
black knot of plum and cherry	*Plowrightia morbosum*	plum and cherry	small black knotty swellings on twigs and branches	occurs primarily in the eastern half of the United States and New Zealand
brown rot	*Monilinia fructicola*	stone fruits	brown spots on blossoms; twigs develop small sunken brown cankers; fruit develops brown spots that spread rapidly	worldwide occurrence; can cause heavy losses both in orchards and in shipment
soft rot	*Rhizopus* species	flowers, fruits, and vegetables with fleshy organs	tissues become soft with water-soaked appearance that often spreads rapidly, followed by development of fuzzy gray mycelium and black spores	infection develops most rapidly on ripe fruits with favourable conditions (moderate temperature and high humidity)
fusarium wilt of tomato	*Fusarium oxysporum*	tomatoes	leaves are bent down, growth is stunted, plant dies; dark streaks appear in vascular tissue	one of the most destructive diseases of tomato; entire fields can be destroyed
wilts of vegetables, flowers, and some trees	*Verticillium* species	cotton, potato, tomato, alfalfa, shade trees, and others	similar to fusarium wilts; develops primarily in seedlings that die shortly after infection; older plants also are attacked	worldwide distribution; the fungus infects hundreds of species of plants

Biological control of plant diseases

Introduction

Plant diseases need to be controlled to maintain the quality and abundance of food, feed, and fiber produced by growers around the world. Different approaches may be used to prevent, mitigate or control plant diseases. Beyond good agronomic and horticultural practices, growers often rely heavily on chemical fertilizers and pesticides. Such inputs to agriculture have contributed significantly to the spectacular improvements in crop productivity and quality over the past 100 years. However, the environmental pollution caused by excessive use and misuse of agrochemicals, as well as fear-mongering by some opponents of pesticides, has led to considerable changes in people's attitudes towards the use of pesticides in agriculture. Today, there are strict regulations on chemical pesticide use, and there is political pressure to remove the most hazardous chemicals from the market. Additionally, the spread of plant diseases in natural ecosystems may preclude successful application of chemicals, because of the scale to which such applications might have to be applied. Consequently, some pest management researchers have focused their efforts on developing alternative inputs to synthetic chemicals for controlling pests and diseases. Among these alternatives are those referred to as biological controls .

A variety of biological controls are available for use, but further development and effective adoption will require a greater understanding of the complex interactions among plants, people, and the environment.

Definitions

The terms "biological control" and its abbreviated synonym "biocontrol" have been used in different fields of biology, most notably entomology and plant pathology. In entomology, it has been used to describe the use of live predatory insects, entomopathogenic nematodes, or microbial pathogens to suppress populations of different pest insects. In plant pathology, the term applies to the use of microbial antagonists to suppress diseases as well as the use of host specific pathogens to control weed populations. In both fields, the organism that suppresses the pest or pathogen is referred to as the **biological control agent (BCA).**

Types of interactions contributing to biological control

Throughout their lifecycle, plants and pathogens interact with a wide variety of organisms. These interactions can significantly affect plant health in various ways. In order to understand the mechanisms of biological control, it is helpful to appreciate the different ways that organisms interact. Note, too, that in order to interact, organisms must have some form of direct or indirect contact. Odum (1953) proposed that the interactions of two populations be defined by the outcomes for each. The types of interactions were referred to as mutualism, protocooperation, commensalism, neutralism, competition, amensalism, parasitism, and predation.

Mutualism is

an association between two or more species where both species derive benefit. Sometimes, it is an obligatory lifelong interaction involving close physical and biochemical contact, such as those between plants and mycorrhizal fungi. However, they are generally facultative and opportunistic. For example, bacteria in the genus *Rhizobium can reproduce either in the soil or, to a much greater degree, through their* mutualistic association with legume plants. These types of mutualism can contribute to biological control, by fortifying the plant with improved nutrition and/or by stimulating host defenses.

Parasitism is a symbiosis in which

two phylogenetically unrelated organisms coexist over a prolonged period of time. In this type of association, one organism, usually the physically smaller of the two (called the parasite) benefits and the other (called the host) is harmed to some measurable extent. The activities of various hyperparasites, i.e., those agents that parasitize plant pathogens, can result in biocontrol. And,interestingly, host infection and parasitism by relatively avirulent pathogens may lead to biocontrol of more virulent pathogens through the stimulation of host defense systems. Lastly,**predation refers to the hunting and killing of one organism by another for consumption** and sustenance. While the term predator typically refer to animals that feed at higher trophic levels in the macroscopic world, it has also been applied to the actions of microbes, e.g. protists, and mesofauna, e.g. fungal feeding nematodes and microarthropods, that consume pathogen biomassf or sustenance.

Hyperparasites and predation

In **hyperparasitism, the pathogen is directly attacked by a specific BCA that kills it or its** propagules. In general, there are four major classes of hyperparasites: obligate bacterial pathogens, hypoviruses, facultative parasites, and predators. *Pasteuria penetrans is an obligate* bacterial pathogen of root-knot nematodes that has been used as a BCA.

Hypoviruses are hyperparasites. A classical example is the virus that infects *Cryphonectria parasitica, a fungus* causing chestnut blight, which causes **hypovirulence, a reduction in disease-producing capacity** of the pathogen. The phenomenon has controlled the chestnut blight in many places (Milgroomand Cortesi 2004). However, the interaction of virus, fungus, tree, and environment determines the success or failure of hypovirulence. There are several fungal parasites of plant pathogens,including those that attack sclerotia (e.g. *Coniothyrium minitans) while others attack living* hyphae (e.g. *Pythium oligandrum). And, a single fungal pathogen can be attacked by multiple* hyperparasites. For example, *Acremonium alternatum, Acrodontium crateriforme, Ampelomyces quisqualis, Cladosporium oxysporum, and Gliocladium virens are just a few of the fungi that* have the capacity to parasitize powdery mildew pathogens (Kiss 2003). Other hyperparasites attack plant-pathogenic nematodes during different stages of their life cycles (e.g. *Paecilomyceslilacinus and Dactylella oviparasitica). In contrast to hyperparasitism, microbial predation is* more general and pathogen non-specific and generally provides less predictable levels of disease control. Some BCAs exhibit predatory behavior under nutrient-limited conditions. For example, some species of *Trichoderma produce a range of enzymes that are directed against cell walls of fungi.*

Antibiotic-mediated suppression

Antibiotics are microbial toxins that can, at low concentrations, poison or kill other microorganisms. Most microbes produce and secrete one or more compounds with antibiotic activity. In some instances, antibiotics produced by microorganisms have been shown to be particularly effective at suppressing plant pathogens and the diseases they cause. Some examples of antibiotics reported to be involved in plant pathogen suppression are listed in Table 1. In all cases, the antibiotics have been shown to be particularly effective at suppressing growth of the target pathogen *in vitro and/or in situ. To be effective, antibiotics must be produced in sufficient* quantities near the pathogen to result in a biocontrol effect. *In situ production of antibiotics by* several different biocontrol agents has been measured (Thomashow et al. 2002); however, the effective quantities are difficult to estimate because of the small quantities produced relative to the other, less toxic, organic compounds present in the phytosphere.

Lytic enzymes and other byproducts of microbial life

Diverse microorganisms secrete and excrete other metabolites that can interfere with pathogen growth and/or activities. Many microorganisms produce and release **lytic enzymes that** can hydrolyze a wide variety of polymeric compounds, including chitin, proteins, cellulose, hemicellulose, and DNA. Expression and secretion of these enzymes by different microbes can sometimes result in the suppression of plant pathogen activities directly. For example, control of *Sclerotium rolfsii by Serratia marcescens appeared to be mediated by chitinase expression* (Ordentlich et al. 1988). And, a b-1,3-glucanase contributes significantly to biocontrol activities of *Lysobacter enzymogenes strain C3 (Palumbo et al. 2005). While they may stress and/or lyse* cell walls of living organisms, these enzymes generally act to decompose plant residues and nonliving organic matter. Currently, it is unclear how much of the lytic enzyme activity that can be detected in the natural environment represents specific responses to microbe-microbe interactions. It seems more likely that such activities are largely indicative of the need to degrade complex polymers in order to obtain carbon nutrition. Nonetheless, microbes that show a preference for colonizing and lysing plant pathogens might be classified as biocontrol agents.

Lysobacter and Myxobacteria are known to produce copious amounts of lytic enzymes, and some isolates have been shown to be effective at suppressing fungal plant pathogens (Kobayashi and El-Barrad 1996, Bull et al. 2002).

So, the lines between competition, hyperparasitism, and antibiosis are generally blurred. Furthermore, some products of lytic enzyme activity may contribute to indirect disease suppression. For example, oligosaccharides derived from fungal cell walls are known to be potent inducers of plant host defenses. Interestingly, *Lysobacter enzymogenes strain C3 has been shown to induce plant host resistance to disease (Kilic-Ekici and*

Chitosan is a non-toxic and biodegradable polymer of beta-1,4-glucosamine produced from chitin by alkaline deacylation. Amendment of plant growth substratum with chitosan suppressed the root rot caused by *Fusarium oxysporum f. sp. radicis-lycopersici in tomato (Lafontaine and Benhamou 1996).*

Other microbial byproducts also may contribute to pathogen suppression. **Hydrogen cyanide (HCN**) effectively blocks the cytochrome oxidase pathway and is highly toxic to all aerobic microorganisms at picomolar concentrations. The production of HCN by certain fluorescent pseudomonads is believed to be involved in the suppression of root pathogens. *P. fluorescens CHA0 produces antibiotics, siderophores and HCN, but suppression of black rot of* tobacco caused by *Thielaviopsis basicola appeared to be due primarily to HCN production* (Voisard et al. 1989). Howell et al. (1988) reported that volatile compounds such as ammonia produced by *Enterobacter cloacae were involved in the suppression of Pythium ultimum-induced* damping-off of cotton.