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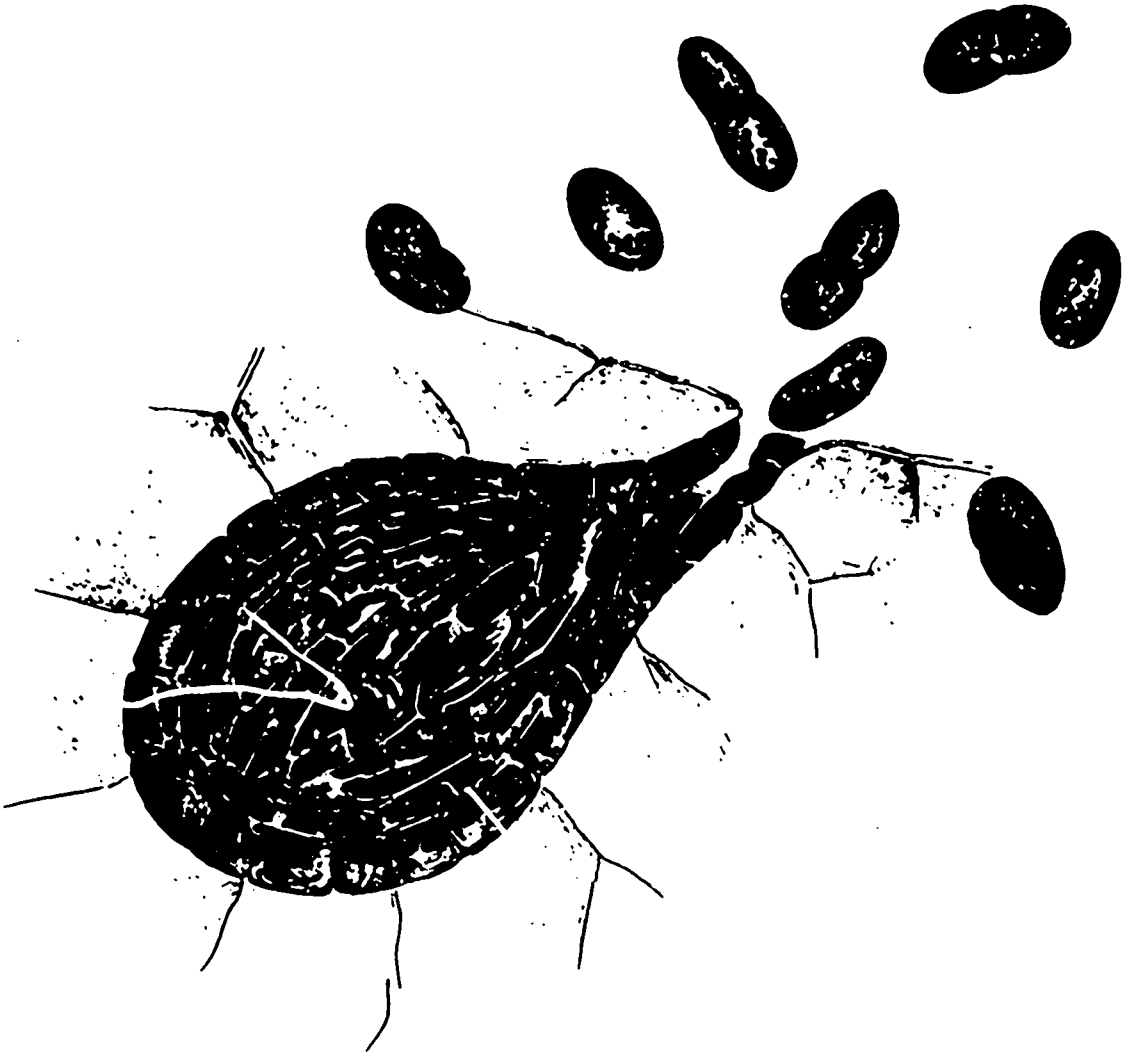
IMPORTANT LEGUME DISEASES OF WEST ASIA AND NORTH AFRICA



TECHNICAL MANUAL No. 5

THE INTERNATIONAL CENTER FOR AGRICULTURAL RESEARCH IN THE DRY AREAS

ICARDA 1982

PREFACE

This manual has been prepared specifically as background information for trainees in food legume improvement at ICARDA. It represents a compilation of up-to-date information from a number of scientists on the major organisms causing diseases in food legume crops in West Asia.

It should be emphasised that the manual as currently published only represents a foundation which will be regularly revised and modified in line with the changing base of knowledge on the subject and the developing needs of trainees. Through a continuous cycle of evaluation by both researchers and trainees such revisions will, it is hoped, ensure that the manual retains its maximum applicability and utility.

Throughout the manual emphasis is placed upon the applied considerations essential in the diagnosis of field disease symptoms and in the implementation of methods designed to reduce crop disease losses.

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CHAPTER 1.

INTRODUCTION

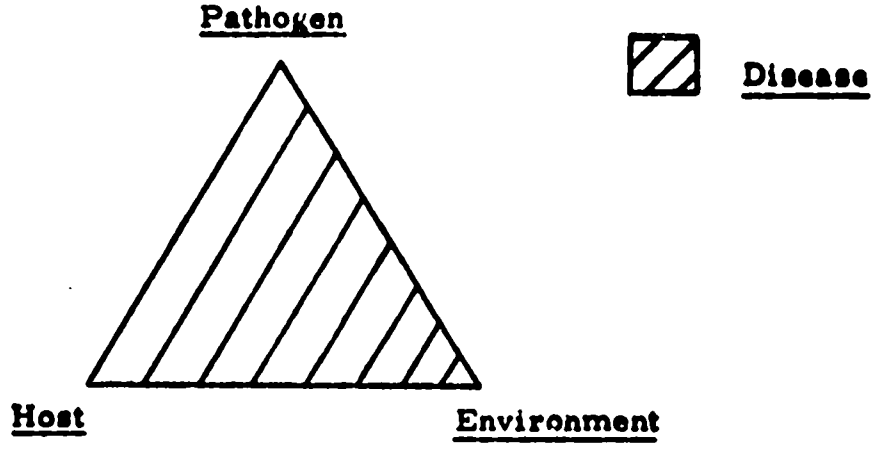
Plants are the fundamental source of nutrition for man, whether they are consumed directly or through an intermediary animal. Legume pulses are important crops in this respect both as a major component in the diets of a large part of the world's population and as an animal feed. Numerous diseases affect the productivity and stability of legume crops, causing periodic and sometimes severe disruptions to both the food supply and the income that they represent.

Diseases - defined as harmful changes in the physiological processes of plants leading to the disturbance of cellular activities - can be caused by a number of environmental factors (either biological, chemical or physical). The most serious production losses result from diseases caused by biological factors (known as plant pathogens) and it is thus these factors that require immediate and considerable attention.

Plant pathogens derive their nutrition from their plant host and are thus considered to be parasites. They can be either obligate (depending completely upon their host for nutrition) or facultative (being able to live both from their hosts and from non-living substrates).

Disease Development

The genetic make-up of the host and the pathogen, together with their reaction to the prevailing environment determine the extent of disease development.



The Disease Triangle

The degree of disease development depends upon the virulence of the pathogen, the susceptibility of the host and the favourability of the environment. If either of these factors is too low then disease will not occur (represented by the area outside the triangle). Environmental factors affecting disease development include: temperature, moisture, humidity, and the intensity and duration of light. Other factors which may also be important are the presence of root exudates and the microbial population of the soil.

Disease establishment and development involves three distinct stages, namely: inoculation, penetration and infection.

Inoculation

The first necessity in disease establishment is for the inoculum (the part of the pathogen which carries infection to a host) to come into contact with the host surface. The inoculum, which can be fungal spores,

bacterial cells, virus particles, fungal mycelia or plant seeds, is generated by previous infections and liberated into the environment. There it constitutes a reservoir of potential infection. This reservoir, in infected plants, plant debris, seeds, air, water, soil or insects, is further disseminated by wind, rain, and insect and animal vectors.

Penetration

Once the inoculum comes into firm contact with a host, penetration can occur. This proceeds in two distinct stages as follows: fungal spores germinate on the host surface, producing a germ tube; this germ tube then penetrates the host epidermis. Penetration can be either passive, through stomata or wounds, or active, by mechanical or chemical means. Mechanical penetration involves the use of pressure together with a sharp celular outgrowth, where as chemical penetration results from the secretion of enzymes which digest the plant cuticle and epidermis. Some fungal spores require a film of water or high humidity conditions for germination, while others appear able to germinate under a range of atmospheric conditions.

Bacterial and viral particles, however, can only penetrate their hosts passively; bacteria entering through wounds, stomata, hyathodes and lenticels, and viruses through wounds or directly via a vector. Wounds may be caused by handling, machinery or insect infestations and important vectors (especially of viruses) include pests, such as aphids and nematodes, and fungi.

Infection

Following penetration the pathogen multiplies within the host tissue, although disease symptoms may not be visible. This stage is commonly known as incubation, and true infection is said to occur when the first visible symptoms of infection appear.

The ability of a pathogen to cause disease is assessed by its 'inoculum potential', which is a measure of the 'biological energy available for the colonisation of its host'. Inoculum potential is a function of:-

1. Inoculum density - or the number of viable disease causing particles (spores, bacterial cells or viral particles) per unit area (in the case of leaves and stems) and per unit volume (in case of soils).

2. The availability of nutrients to the pathogen during germination and growth.

3. The environmental factors that play an important role in germination, penetration and infection (e.g. temperature and moisture).

4. The virulence or inherent ability of the pathogen to cause disease. This is controlled genetically and can be manifested, for example, in the toxicity of cellular breakdown enzymes secreted.

As the inoculum potential is a result of the interaction of all the above factors, it follows that a change in any of them will affect the overall disease-causing ability of the pathogen. An understanding of the inoculum potential and the factors that determine it can thus be very important in the formulation of disease prevention and control measures.

While the ability of a pathogen to cause disease varies with its genetic make-up and the environment, the extent of infection is largely determined by the physiological state of the plant host. At certain growth stages plants may be predisposed to attack by pathogens. Factors involved in this predisposition include:-

1. Plant age
2. Environmental conditions - moisture, humidity, temperature, pH, nutrients and light intensity.
3. Infection by other pathogens
4. Presence of chemicals - pesticides or herbicides.

An understanding of the interaction of these factors will thus also be of great value in achieving a comprehensive control or prevention of disease infections.

CHAPTER 2.

DISEASE DIAGNOSIS

The effective and long-lasting control of plant pathogens, and through it the reduction of yield losses, demands a good understanding of the pathogens concerned and the environmental factors favouring disease development. The first step in achieving this understanding is the correct identification of the organism or factor responsible for observed symptoms. Incorrect diagnosis and hence control can be disastrous and may result in total crop failure. A comprehensive knowledge of the crop species concerned is essential in diagnosis in order that diseased and healthy plants can be distinguished apart as early as possible, and before losses become serious.

The diagnosis of plant diseases involves two main considerations, namely; studies on a 'macro' level (of the whole field and of individual plants) to identify symptoms and signs of disease and thereby make a preliminary diagnosis of the causal agent; followed by studies on a 'micro' level (through isolation, culturing and microscopic examination) to firmly identify the causal agent by its specific characteristics. These two levels of disease diagnosis complement each other and should be seen as being inseparable if accurate identification is to be achieved. However the vast majority of diseases caused by plant pathogens induce characteristic symptoms and signs in infected plants at the macro-level. For most practical purposes these symptoms can be reliably used by trained operators for accurate diagnosis.

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Macro-level Disease Diagnosis

Field Observations

Fields should be regularly inspected for any signs of crop abnormality (e.g. areas of less vigorous plants, stunted plants or yellowing or dying plants).

When abnormalities are observed it is essential to learn as much as possible about the past history of the particular field (e.g. previous cropping, use of pesticides and herbicides, cultural practices and soil conditions). This may suggest a direct cause for the observed symptoms (i.e. chemical damage or localised soil compaction) and will also considerably affect disease development and the extent of crop damage if the symptoms are actually the result of biological factors.

The distribution of symptoms within the field (in localised foci or generally throughout the crop) also gives important indicators of the causal agent. Symptoms occuring initially in diffuse circular foci would suggest pathogenic organisms as the cause; whereas sharply defined areas of crop abnormality may result from mechanical or chemical damage; and generalised symptoms are often caused by bad soil conditions (compaction, water-logging or surface puddling) or nutrient deficiences (water, nitrogen, potassium, phosphorus or trace elements).

Individual Plant Studies

Following a consideration of the crop on a field scale, individual plants within an abnormal area of the crop should be examined in detail. It is important in this regard to note the location of the symptoms;

whether confined to individual plant parts (and if so which parts in particular) or systemic throughout the plant. This will give further indications of the causal agent; some diseases, for example, are observable on different parts of a plant in a sequential manner (e.g. the older leaves are affected first in the case of wilt and certain other pathogenic diseases and water and certain mineral deficiences, whereas in other mineral deficiency diseases the younger leaves show the first signs of damage).

Disease symptoms may thus be used for a rapid and practical identification of the specific causal agents concerned. Symptoms can generally be grouped into the following classes:-

Colour Changes: These may be of several types:-

Chlorosis, which is the most common form of plant discolouration. This results from a breakdown in the green chlorophyll pigment and is thus expressed as yellowing. Chlorosis can be caused by any agent which brings about chlorophyll breakdown. It may result from the production of toxins by certain pathogenic fungi (e.g. Alternaria); from chemical overdoses; from the alteration of cell metabolism by viruses or bacteria; or from deficiencies in essential nutrients (such as water, nitrogen, and iron) caused by soil conditions or an interference with nutrient uptake by the roots.

Other discolourations, such as purpling (resulting from deficiences of phosphorus and other minerals) and reddening (caused by deficiencies of some minerals or heat damage) may also be important under certain conditions. Further detailed information on mineral deficiency symptoms is given in Technical Mannual No 6.

Cell Death: This often occurs as an advanced stage of chlorosis and is characterised by blackening and browning symptoms. It is commonly known as necrosis, and may be localised in specific areas or generalised throughout the plant. Necrosis can be caused by a number of factors, such as mineral deficiences or excesses, insect damage, or pathogenic organisms (particularly fungi and bacteria).

Wilting: A further example of disease symptoms is the wilting and collapse of whole plants. Wilting is basically caused by an interference with the uptake of water and, like other disease symptoms,can have a variety of causes, including; damage by root and crown pathogens or soil living insects; excessive transpiration due to high temperatures; lack of soil water; or mechanical damage.

Stunting: This results from an interference with cell metabolism, growth and development and may be caused by pathogens (such as viruses), by nematodes or through deficiences of water or mineral nutrients.

Galling: Usually rather localised, galling is an abnormal increase in plant tissues, either through an increase in cell size (hypertrophy) or an increase in cell number (hyperplasia). Galling may result from attacks by plant pathogens, but is more usually caused by infestations of certain nematode and insect species.

Macro-level diagnoses may be guided by the use of the field-key booklet.

Micro-level Disease Diagnosis

To conclusively identify the cause of an observed disease, micro-level studies are essential. These studies primarily involve detailed observations of diseased plant parts and isolates made from them.

Using a low-power binocular microscope it is possible to identify characteristic fungal structures on the surfaces of the tissue. However these are not necessarily the agents primarily responsible for the disease. Further, more detailed analyses through a high-powered light microscope and by growing cultures from infected tissue may thus be necessary. Having isolated a specific pathogen from infected tissue proof of its association with the disease requires the following conditions (known as Koch's postulates) to be met:-

1. The pathogen must be in constant association with the disease.
2. The pathogen must be isolated in pure culture and its characteristic features determined.
3. The pathogen isolated from pure culture must, under favourable environmental conditions, be able to produce the disease when inoculated into a healthy plant of the same genotype.
4. The pathogen must be re-isolated from inoculated plants and when grown again in pure culture and examined must prove to be the same as that previously identified in isolation (2).

It is obvious that in many cases in practice this 'total' identification is unnecessary and overly time-consuming. In addition it is impossible to follow in the case of pathogens (e.g. obligatory parasitic fungi and viruses) that cannot be cultured. Thus in practice most micro-level disease identification rests upon making intelligent observations of structures under a binocular or light microscope. Where structures are not visible diagnosis may be based upon observed macro-symptoms (particularly with viruses), simple culturing (especially for fungi and bacteria) and intelligent deductions made from knowledge of the past history of the crop, its location and any currently visible abnormalities in the field.

It should be emphasised that accurate disease diagnosis requires skilful and detailed observations together with intelligent deductions and is primarily a function of operator experience with the specific diseases and the local environmental conditions.

Simple Isolation and Culturing

A disease caused by one pathogenic organism (the primary pathogen) may also have a number of other pathogens (termed secondary) associated with it, especially when the infection is older. Thus micro-level diagnosis may be complicated by the presence of several pathogens not directly responsible for the disease. For correct diagnosis it is therefore essential to obtain the primary pathogen free from other contaminating organisms (i.e. in isolation).

Isolation

A simple but effective isolation technique involves the washing of the infected tissue in water to remove surface debris, such as soil, followed by the sterilisation of the outer surface to guard against contamination by surface living organisms. Sterilisation may be achieved by dipping the tissue into a solution of sodium hypochlorite, 60% ethanol or any similar chemical. A sample of the infected tissue should then be taken, preferably from the advancing margin of infection as this is most likely to contain only the primary pathogen. This sample can then be used for culturing or microscopic examination in the case of those pathogens that cannot be grown in culture.

Culturing

The sample of infected tissue to be cultured should be placed on a medium suitable for the growth of micro-organisms. A common medium

used to culture fungi and bacteria is potato dextrose agar (PDA) - prepared from cooked potatoes with added glucose and agar. The transfer of infected material to the growth medium can be carried out using a sterilised needle to puncture the infected tissue and then to streak the material onto the surface of the medium. When culturing fungi antibiotics are often added to the medium to prevent bacterial growth, and bacterial cultures may need the addition of specific growth requirements. In both cases however the culture plates are then incubated at suitable temperatures and in some instances under appropriate light conditions. The characteristics of the colonies formed and the structures present, analysed under a microscope, are than used in diagnosis.

The above procedures may be used in the identification of fungal and bacterial pathogens, but when dealing with viruses a different course must be followed. The infected tissue should be ground in a suitable buffer of known pH and the non-virus particles eliminated by filtration and centrifuging. The resultant solution should then be applied to a suitable virus susceptible host and the specific virus identified by its symptoms. Viral identification may also be based on studies of particle size, nucleic acid or protein content, or other physical and chemical measurements.

CHAPTER 3.

FUNGI AS PLANT PATHOGENS

The fungi are considered to be the most important group of plant pathogens both in terms of the number and frequency of diseases that they cause and in the economic damage that results from these diseases. Although infections can be detected with the naked eye and fungal structures are often visible using a hand lens, examinations of most species require a greater magnification, such as may be achieved by a binocular microscope (or for more detail a standard light microscope).

Fungal Structure

Although fungi lack the ability to photosynthesise as well as a number of other typical plant characteristics, they are included as part of the plant kingdom because they possess a rigid cell wall. Both the vegetative and reproductive structures of fungi show considerable variation. The vegetative bodies range from small groups of non-specialised cells in the lower orders to large masses of cylindrical tube-like structures (called hyphae) in the more highly specialised orders. Similarly the reproductive bodies are rather simple in the lower orders and increase in complexity with increasing fungal specialisation. Both the vegetative and the reproductive hyphae may be divided along their length by septae (septate) or be continuous, lacking septae, (aseptate or coenocytic) and are usually entangled together forming a mass of fungal tissue known as a mycelium.

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Reproduction in Fungi

Fungal reproduction generally involves the formation of spores, either single or multi-celled, with each cell containing one or more nuclei (carrying their basic genetic code). These structures are usually surrounded by a protective wall, designed to withstand the rigours of the environment and thus to protect the fungal 'germ' from dessication from the time that it is shed by its parent tissue until it comes into contact with its new host.

These spores may be produced either asexually (the imperfect stage) through simple mitotic division, or sexually (the perfect stage), by the formation of gametes at meiosis and their recombination at fertilisation.

Asexual Reproduction

As it only involves the relatively simple process of mitosis, asexual reproduction may result in the production of a very large number of spores (inoculum) at a very rapid rate given favourable conditions. However the genetic make-up of these spores is identical to their parent tissue and thus asexual reproduction is primarily a bulking stage, involving no genetic advance. Spores produced in this way constitute the most important mechanism of secondary disease spread from an initial early infection. They may take a variety of different forms (often used as the basis for species identification) and can in general be classified into three major types:-

Chlamydospores ; which are perhaps the simplest form of spores, being formed by a simple swelling and thickening of certain hyphae. The cell wall is very resistant and thus chlamydospores often constitute over-wintering forms which cause primary infections when the environment again becomes favourable in the spring (Figure 1a).

Sporangiospores ; which are somewhat more specialised and produced in abundance within a simple fruiting body (the sporangium). Sporangiospores are, in general, characteristic of the less developed fungi and in some species take the form of motile zoospores, dependant upon water for their dispersal (Figure 1b).

Conidia ; which are produced by the fungi more highly adapted to a terrestrial lifestyle. They are non-motile and thus rely upon wind, water, animal and mechanical means for their dispersal. Conidia, perhaps the most common form of asexual fungal spores, may be produced freely, either in chains or from a specialised stalk (the conidiophore), or enclosed within specialised fruiting bodies such as pycnidia, acervuli and sporodochia. These more specialised bodies serve to give the spores appreciable protection from the environment as they mature. They are thus considered to be hallmarks of considerable fungal specialisation. (Figure 1c and d).

Sexual Reproduction

This process involves the production of gametes through meiotic division and their recombination to form a fertilised 'egg'. Unlike asexual reproduction, therefore, the sexual stage allows a reassortment of genes and the production of progeny of a different genetic make-up to the parents.

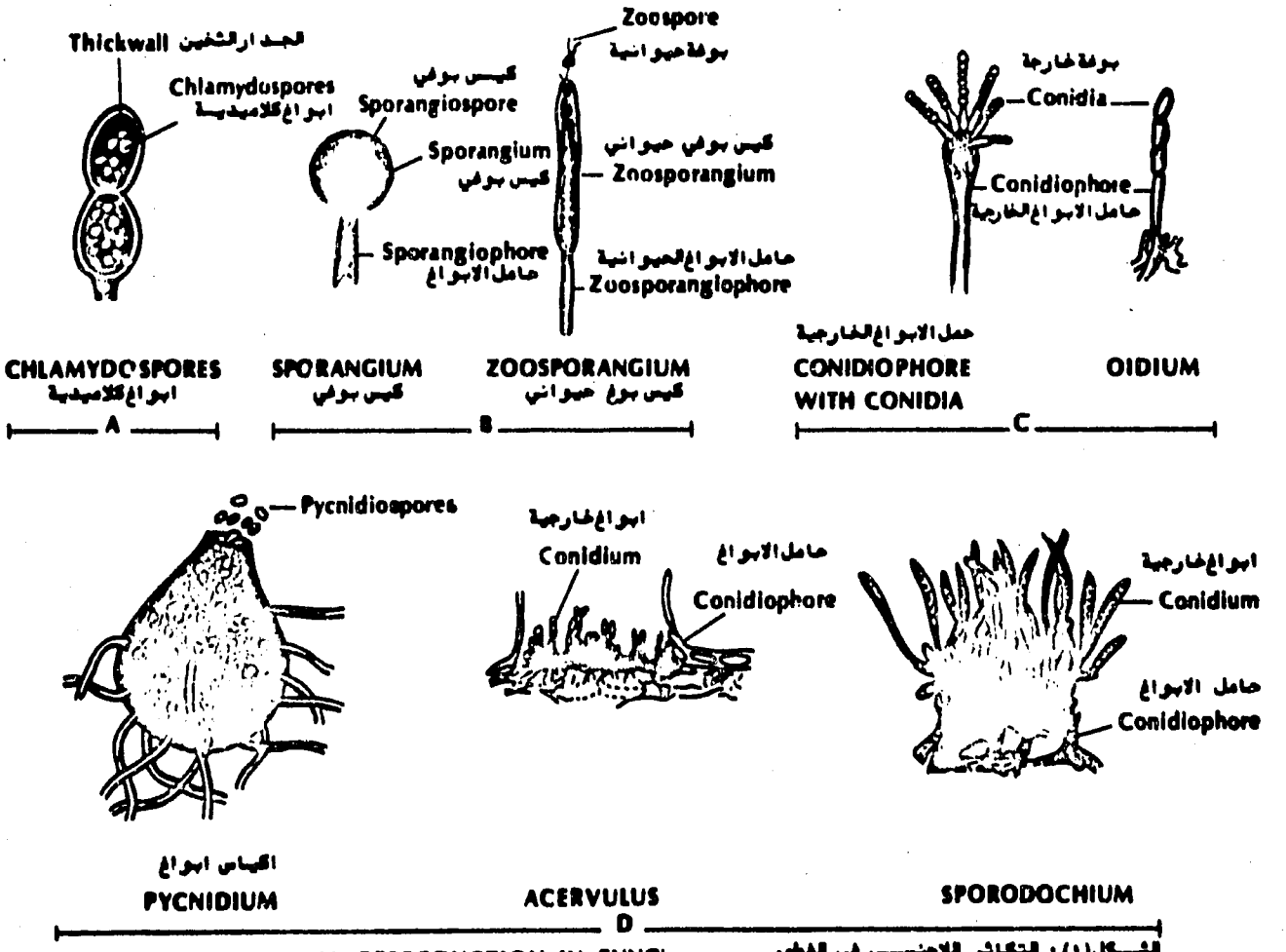
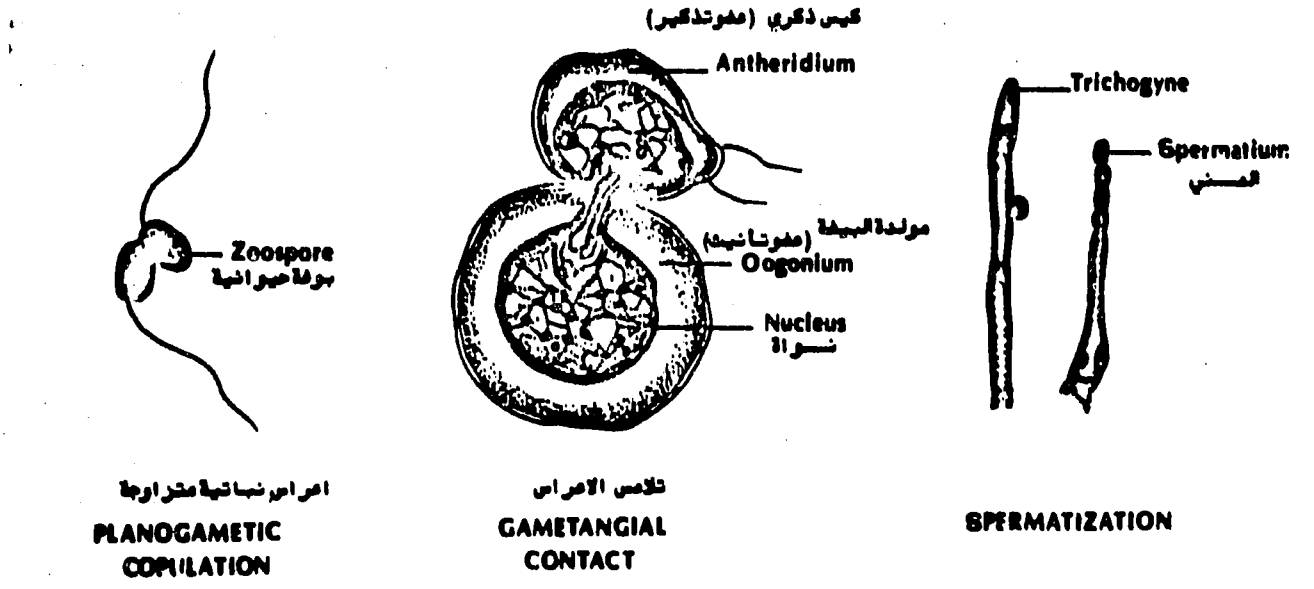


FIG 1 : GENERAL ASEXUAL REPRODUCTION IN FUNGI. الشكل(١): التكاثر اللاجنسي في الفطور



Meiosis is however a more complex process and thus sexually produced spores are not generally produced at a very rapid rate. For this reason the sexual stage normally occurs towards the end of the environmentally favourable season and sexual spores, protected within a resistant covering, are the most important mechanism by which fungi survive the unfavourable 'winter' environment until conditions again become favourable for growth.

In the lower fungi, which still rely almost exclusively upon water for growth and reproduction, the sexual stage involves a union of motile zoospores(planogametic copulation); whereas in the more highly adapted orders it takes place through gametangial contact (direct associattion between the male organ - the antheridium - and the female organ - the oogonium) or spermatization (the transfer of spermatia, produced by the male organ, to the female trichogyne). Details are illustrated in Fig.2.

Fungal Classification

Because of the great variation of fungal vegetative and reproductive structures on which it is based, the classification of fungi is very complex and in some cases incomplete. In general though the Division Mycota (Fungi) of the Plant Kingdom may be classified into two sub-divisions; namely the Myxomycotina (slime moulds), none of which are plant parasites, and the Eumycotina (true fungi) which contains all the important plant disease-causing fungi.

The Eumycotina is divided in turn into a number of classes, of which only the Oomycetes, the Ascomycetes, the Basidiomycetes and the Deuteromycetes (Fungi Imperfecti) contain pathogens of importance to crop production. It is thus only members of these classes that will be considered here.

Oomycetes

Fungi belonging to this class are considered to be less adapted to terrestrial life than those of the other classes. They are characterised by a coenocytic mycelium and the production of sporangiospores. Sexual reproduction is through gametangial contact, and results in the production of thick-walled oospores (the resistant stage).

The Oomycetes is made up of two major families: the Peronosperaceae (with branched conidiophores) and the Pythiaceae (which have simple conidiophores). Both families contain genera of importance to legume production, namely Peronospora, causing downy mildew, and Pythium, causing damping-off disease. (Figure 3).

Ascomycetes

This class of relatively more developed fungi is characterised by members with septate mycelia, producing spores asexually as conidia (either in acervuli or sporodochia) or sexually in sac-like structures, known as asci. The class may be divided into three sub-classes on the basis of the way in which these asci are borne. Only members of one of these sub-classes - the Euascomycetes - in which the asci are contained in a structure called an ascocarp, are important pathogens of legume crops. Of this group two genera, Erysiphe and Leveillula, both of which produce closed ascocarps (cleistothecia), are particularly important, causing the diseases known as powdery mildew (Figure 4).

Basidiomycetes

All members of this very highly adapted and specialised group of fungi also have septate mycelia. Chlamydospores (also known as

teliospores and urediospores) are produced asexually and the sexual stage is represented by basidiospores borne on thallus-like fruiting bodies, known as basidia. The class is made up of two sub-classes, of which again only one, the Heterobasidiomycetes (whose members have a septate basidium) contains the most important disease causing orders; the Uredinales (rusts) and the Ustilaginales (smuts). The smut diseases are of little importance to legume crops, but the rusts, and more specifically members of the genus Uromyces, often precipitate major disease losses (Figure 5).

Deuteromycetes

This is a very large, diverse and incompletely understood class, containing all those fungi in which the sexual stage is absent or unknown. It is thus commonly known as the "Fungi Imperfecti". The class is divided into four orders:

The Mycelia-sterilia; whose members have no observable reproductive structures and who survive adverse conditions in the form of resistant sclerotia (e. g. Rhizoctonia, causing root rot);

The Moniliales: whose members produce asexual conidia on exposed conidiophores (e. g. Botrytis, causing chocolate spot, Verticillium, causing wilts; Alternaria, causing brown spot; Stemphylium, causing leaf blight; and Thielaviopsis, causing root rot/wilts);

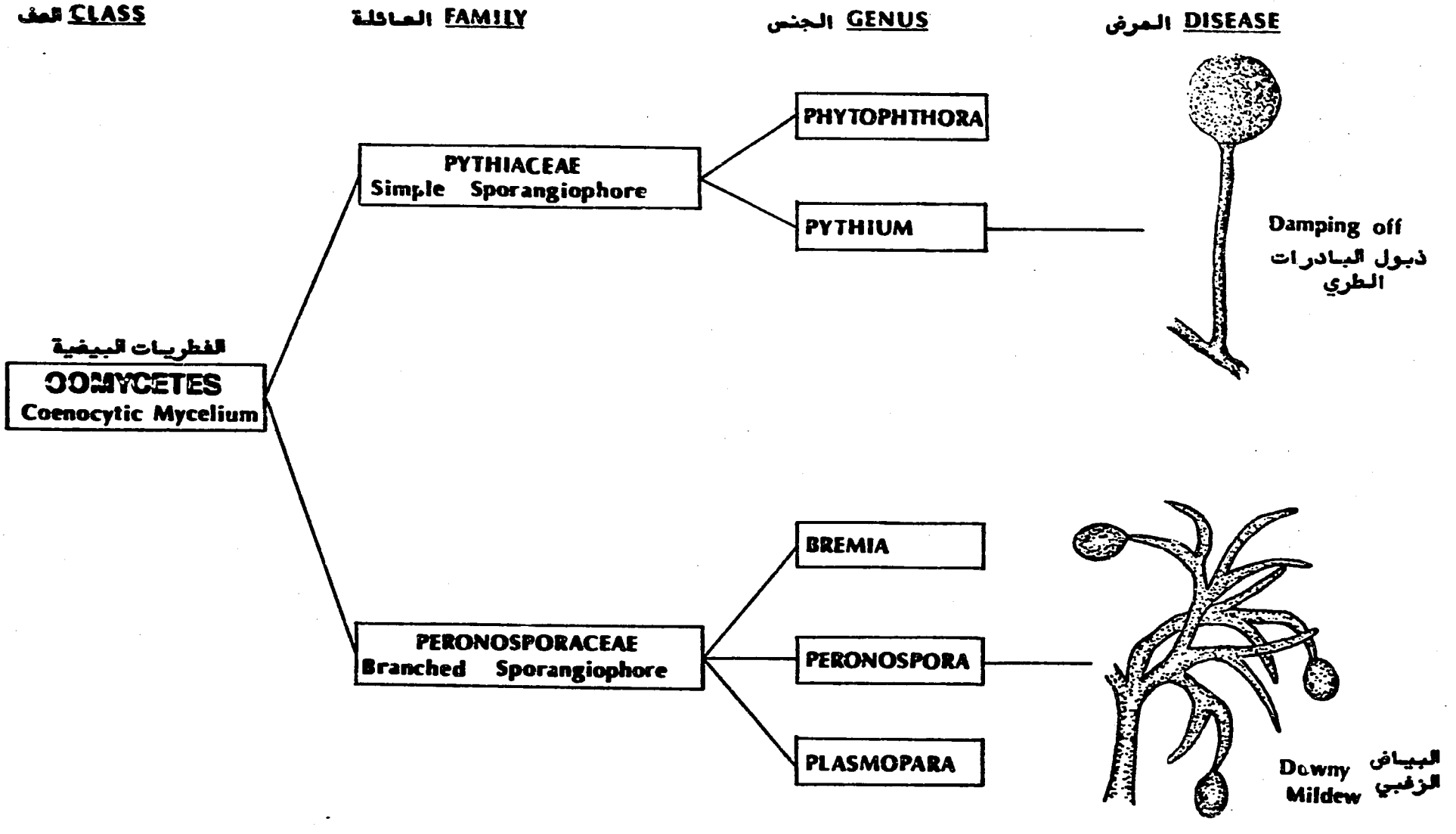
The Melanconiales; in which conidia are produced in acervuli (e. g. Colletotrichum, causing antrachnose);

The Sphaeropsidales; where the conidia are borne in pycnidia (e. g. Ascochyta, causing blight)

Details are illustrated in Figure 6.

الشـــكل(٣): تصنيف الفطور البيضيةوصفاتها المميزة

FIG 3 : CLASSIFICATION AND DISTINCTIVE FEATURES OF OOMYCETES :



الشكل (٤) : تصنيف الفطريات الاسكية وصفاتها المميزة

FIG 4 : CLASSIFICATION AND DISTINCTIVE FEATURES OF ASCOMYCETES :

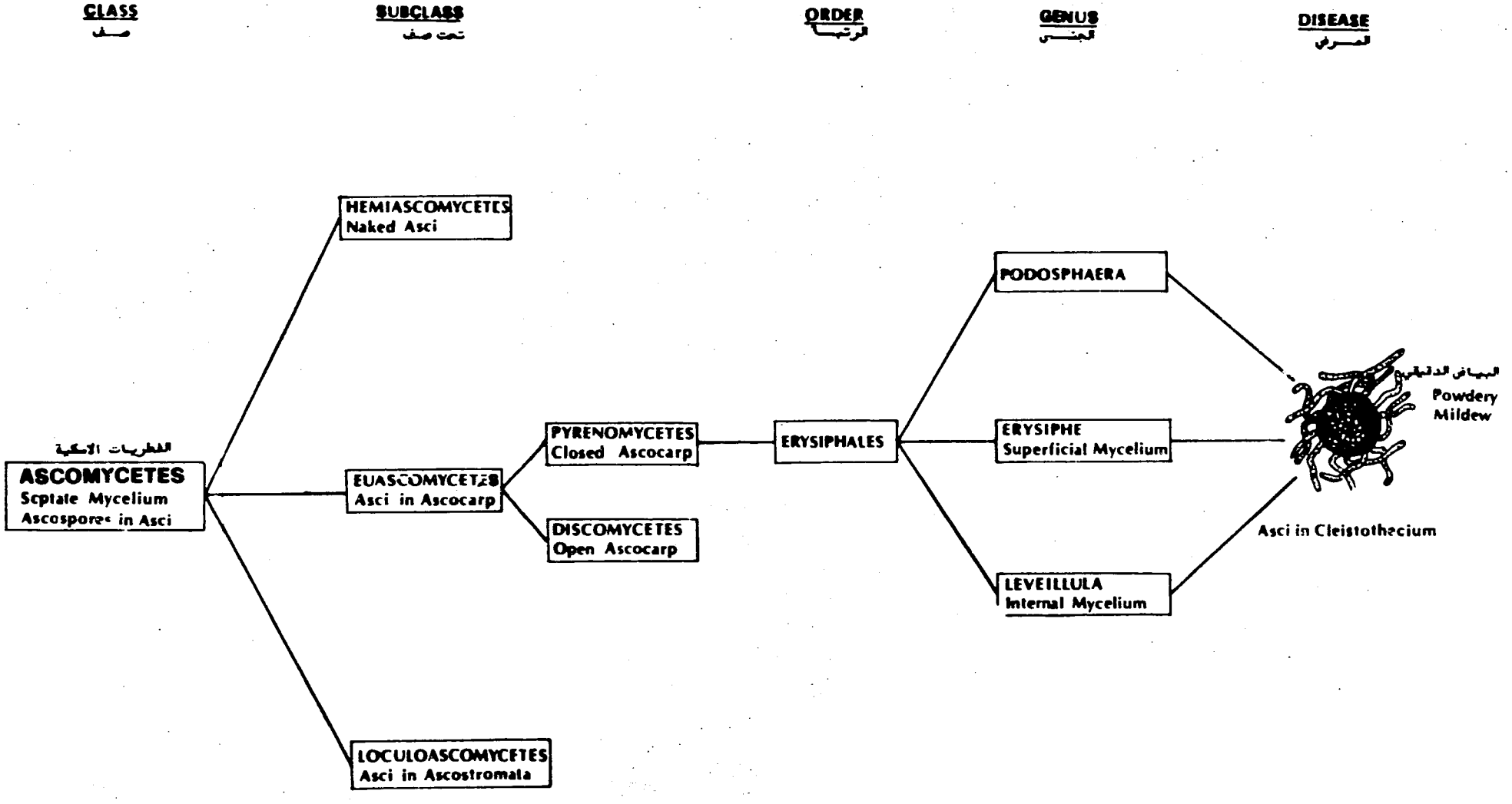


FIG 5 : CLASSIFICATION AND DISTINCTIVE FEATURES OF BASIDIOMYCETES :

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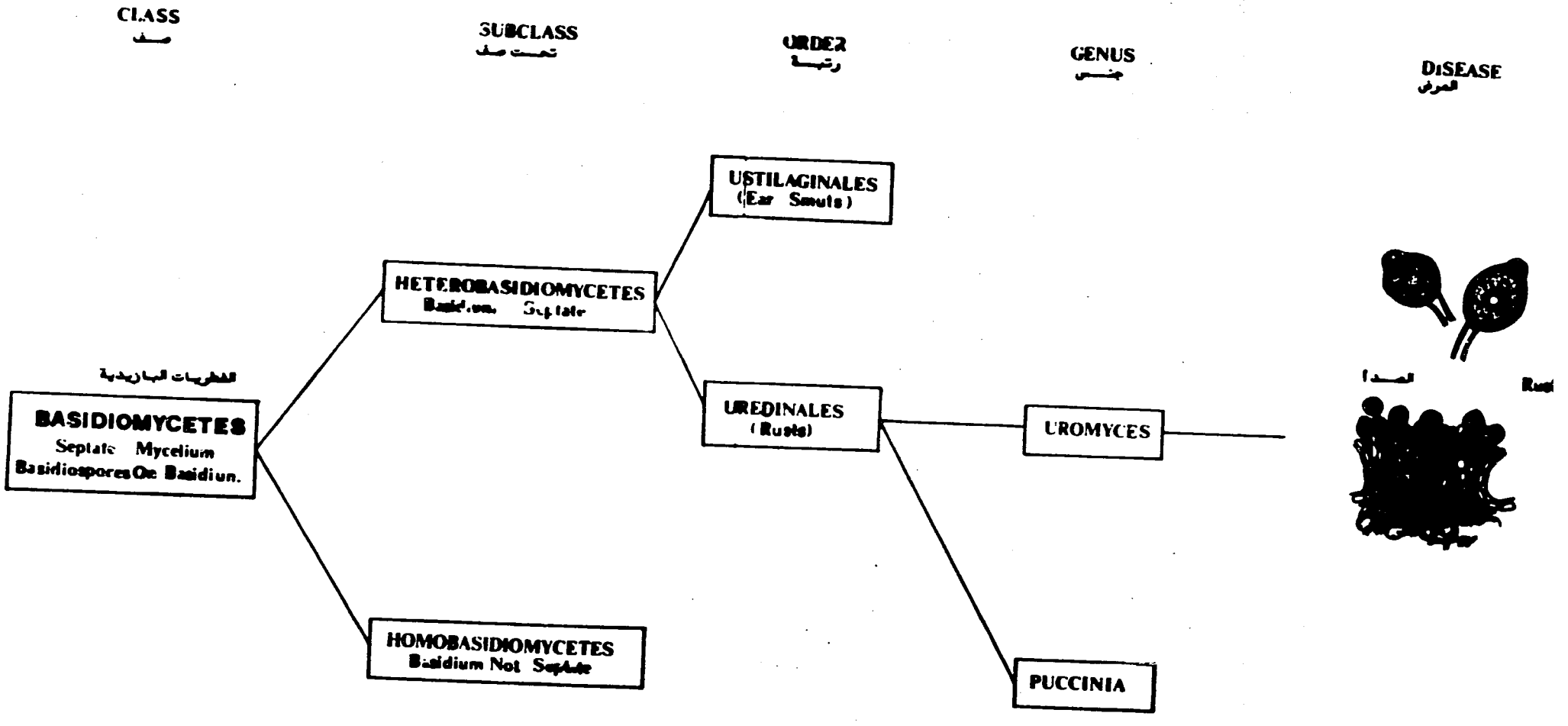
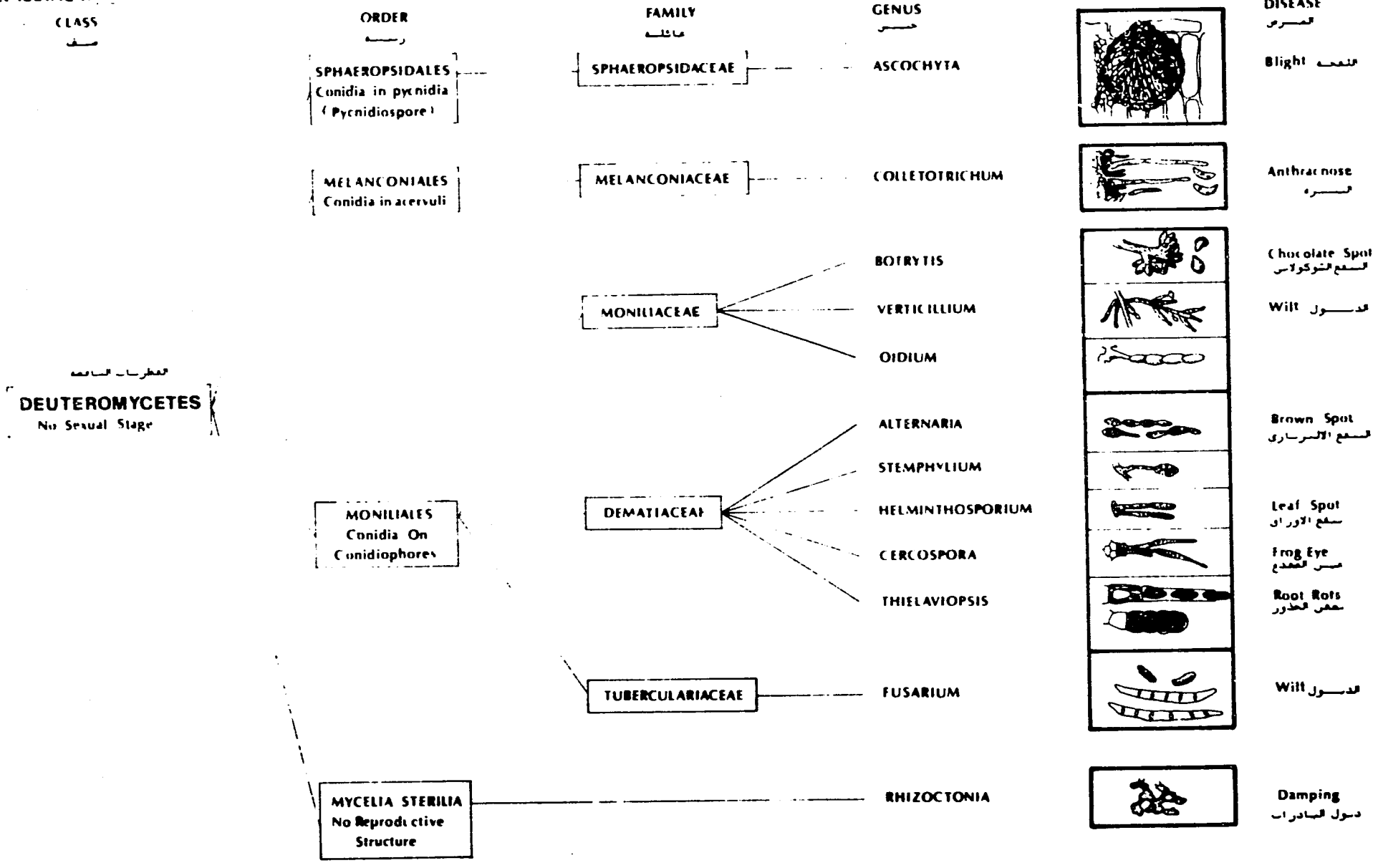


الشكل (٦) تصنيف الفطريات الناقصة وصفاتها المميزة

FIG 6 · CLASSIFICATION AND DISTINCTIVE FEATURES OF DEUTEROMYCETES:



CHAPTER 4.

FUNGAL PATHOGENS OF SPECIFIC IMPORTANCE

A large number of pathogenic fungi are of considerable importance to crop production in the losses that they cause. Of these however only a few are of specific importance to food legume production and fewer still cause appreciable and regular yield losses in the region of West Asia and North Africa.

Diseases caused by pathogenic organisms tend to develop much more readily under higher moisture conditions. Thus disease problems in this predominantly dry and hot region tend to be confined to the higher precipitation areas and the areas where crops are produced under irrigation. Where sufficient moisture is available broadbeans predominate amongst the food legume crops. It is thus in this crop that perhaps the most severe and regular effects of pathogenic fungi may be observed. The other two major grain legumes - lentils and chickpeas - which are largely produced under lower rainfall dryland conditions are consequently less affected by fungal pathogens. This is not to say, however, that these crops possess a higher inherent resistance to fungi, only that they are less exposed and predisposed to attack.

Studies of disease severity and prevalence and the level of crop disease losses on a country basis throughout the region indicate that root rotting and wilting diseases are the most frequently occuring and

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serious problems in all food legume crops; while Ascochyta blight may be very severe in broadbeans and chickpeas (especially under high moisture conditions); and chocolate spot disease is a particular problem of broadbean crops. Other diseases which may assume considerable importance under certain conditions or in specific locations include; rust, Alternaria leaf spot, and powdery mildew.

The importance, occurrence, causal organisms, specific symptoms and life cycles of these diseases are thus considered in detail in this chapter. In this way it is aimed to provide a solid background to the identification and understanding of the diseases and the pathogens that cause them and thus to the development of measures designed to reduce the often severe crop losses that they precipitate.

Root Rot/Wilt

Importance and Occurrence

Root rot/wilt diseases are very common throughout the whole of Western Asia and North Africa;being reported as major food legume production problems in the majority of the countries of the region. All the pulse crops may be affected, but broadbeans and winter sown chickpeas are, in general, more severely attacked than lentils. Although losses can be very severe, they are highly dependant upon the stage at which the crop is attacked; younger plants generally being more susceptible than older ones. Disease development tends to be greater on wet and heavy soils (probably due to their superior water retention characteristics) and when spring planted crops are sown early, during the rainy part of the season.

Causal Organisms

This complex of diseases is caused by a number of different pathogenic fungi. Several species may be present in any one field and the individual pathogens are often indistinguishable on the basis of observable symptoms. As a result pathogenicity tests are normally the only reliable means of identifying the organisms involved. Such tests have shown the most important causal organisms of root rot/wilt disease in legume crops to be fungi of the genera Fusarium, Verticillium and Rhizoctonia.

Of these, Fusarium oxysporum and Rhizoctonia solani are the species of major importance, although other species, such as F. orthoceras, F. lateritium and R. bataticola have also been reported.

Identification and Symptoms

Both Fusarium and Rhizoctonia infections result in stunting of plants and yellowing of leaves and culminate in total plant collapse.

Fusarium oxysporum causes a blackening of the root system and a severe reduction in the numbers of lateral roots; sections of infected roots show a brown discoloration of the vascular tissue (Plate 1) Rhizoctonia solani on the other hand, destroys the root tips and attacks both the roots and the stems at the soil surface, forming brown/reddish brown water-soaked lesions on infected tissue.

Life Cycle

Fusarium oxysporum

This pathogen survives in the soil in the form of smooth, spherical, one or two celled chlamdospores which can persist for long periods if conditions are adverse. Under moist soil conditions and with the proximity of susceptible host roots the chlamdospores germinate, producing a mycelium which enters the roots, usually via wounds which expose the xylem tissue. The pathogen invades the water carrying xylem vessels and causes severe clogging of the elements, which, together with its toxic secretions, causes the observable symptoms. Microspores and chlamdospores,formed within the xylem vessels and released into the soil when the roots die or are shed and decompose, constitute the primary inoculum for future infections.

Rhizoctonia solani

As saprophytic mycelium or as brown/black sclerotia this pathogen can survive indefinately in the soil. When it comes into contact with a suitable host under suitable moisture conditions the mycelium enters the

root through wounds or natural openings. Once inside the host this mycelium grows vegetatively by producing long brown mycelial cells without asexual fruiting bodies or spores. Sclerotia constitute the principal way in which the organism survives over long periods of adverse conditions.

Control

These diseases can best be controlled by ensuring that the crop is planted in a clean, disease-free soil using clean equipment. Soil treatments with fungicides or fumigants are uneconomical on a field scale, but where small areas are concerned steam, formaldehyde or terraclor may be used to kill the sclerotia and other resting bodies. Seed treatment with Thiram, Ceresan or Captan will also help to reduce seed rot and pre-emergence seedling damage.

Much can be done to reduce the incidence of root rots by altering cultural practices; crop rotations, planting date and the timing and frequency of irrigations all affecting disease development. Shallow planting and the wide spacing of plants will also help to reduce disease incidence, as will the removal and burning of crop debris at the end of the season.

In the long term, however, control must depend primarily on the development of resistant cultivars. The variation that has already been observed in the susceptibility of legume varieties to these diseases provides an encouraging base for breeding efforts to this end, although the large number of species and strains of pathogen involved makes this task all the more difficult.

Ascochyta Blight

Importance and Occurrence

Ascochyta Blight is without doubt the most important disease problem in chickpeas and is also responsible for considerable yield reductions in broadbeans. It is a major constraint to pulse production in many countries of the region, especially in Algeria, Tunisia, Lebanon, Syria, Turkey, Cyprus and Iran. Infections, which are favoured by cool and wet conditions, often reach epiphytotic proportions early in the year (January - March) and cause serious crop losses. In winter sown chickpeas (November), particularly in the more humid coastal areas, blight infections may be very severe and cause complete crop loss. The disease is thus considered to be one of the major factors limiting the widespread adoption of the practice of winter planting of chickpeas with its proven yield benefits.

Causal Organisms

This disease, variously known as blight, leaf spot (not to be confused with *Alternaria* spot), pod spot and anthracnose (not to be confused with anthracnose of *Phaseolus* beans, caused by species of *Colletotrichum*), is caused by pathogens of the genus *Ascochyta*; *A. fabae* in the case of broadbeans and *A. rabiei* in chickpeas. Studies have indicated that a number of different strains of *A. rabiei* exist and may occur in different regions.

Identification and Symptoms

Blight infections may occur on all plant parts. On the leaves they take the form of variably shaped, slightly sunken lesions, which are reddish brown in colour with pale centers containing characteristic small black fruiting bodies, known as pycnidia (Plate 1). As the disease develops these lesions enlarge & may coalesce, forming large, irregular necrotic patches. Pod and stem infections have similar symptoms; the lesions generally being more sunken on the pods and elongated on the stems.

Life Cycle

Ascochyta species are seed-borne pathogens, overwintering under the testa of host seeds. However the pathogens also survive on infected plant debris and volunteer plants in the field. Primary infections arise either from seed-borne mycelium or from spores produced by overwintering pycnidia. The growing mycelium produces asexual conidia in pycnidia during the season and these cause secondary infections when rain-splashed to uninfected plant parts. Towards the end of the growing season thick walled pycnidia are produced abundantly. These resting bodies, together with mycelium that penetrates the developing seeds, form the primary source of inoculum for infections in following season.

Control

The use of pathogen-free seed is an obvious way of reducing infections. However, while this will effectively reduce the introduction of inoculum on the seed, it does nothing to combat infections resulting from overwintering bodies in the field. Good field sanitation is thus a necessary

complement to seed treatment. All stubble and crop debris should be removed from the field as soon after harvest as possible and burnt. In addition any remaining residues left in the field should be ploughed-in deeply.

Other methods of control practised include: late planting (to avoid the cool damp conditions so favourable to disease development); deep sowing; and field spraying with Zineb or Maneb on the appearance of the first symptoms.

Ultimately, however, the only really effective control of this disease is through the use of resistant varieties. Resistance has been found in a number of chickpea varieties and the likelyhood of identifying further useful sources of resistance in the crop is good. In contrast no resistance has yet been observed in broadbeans.

Sunken Ascochyta lesious on Broad bean leaflet and pod

Chocolate Spot

Importance and Occurrence

This disease is widespread in broadbean crops throughout the region and is a particular problem where the crop is produced at high rainfall, high humidity coastal locations (i.e. in Egypt, and Ethiopia). In contrast chocolate spot has not been reported as a problem on either chickpeas or lentils, which tend to be grown under dryland and relatively lower rainfall conditions. Weather conditions to a large extent determine the severity of infections. Disease development is favoured by cool and wet conditions and for this reason severe damage may be caused in winter beans. For example, under extended periods of cool and wet conditions infections may result in total crop loss. Humidity also favours the disease and, provided that the temperature remains below 25 °C, chocolate spot becomes an imminent danger once the relative humidity reaches 90-95%. In addition any set of conditions inducing premature senescence is believed to be conducive to disease development in humid areas; sudden increases in severity occurring when mildly infected crops begin to senesce.

Causal Organism

Chocolate spot disease of broadbeans is caused by the pathogen *Botrytis fabae*. A related species, *B. cinerea*, also causes leaf spots in some areas but is less destructive as the lesions never become aggressive. The genus *Botrytis* is very widely distributed and causes a number of diseases in many vegetable and field crops. It has also been reported infecting lentils but is generally considered to be unimportant on this crop in the Mediterranean region.

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Identification and Symptoms

Botrytis infects the foliage, the stems and the flowers of susceptible plants. Two types of symptoms are produced: a non-aggressive type, in which infection is characterised by small discrete circular spots with reddish brown margins and tan coloured centres (Plate 2); and an aggressive type, having irregular reddish brown lesions which later coalesce and may engulf the entire leaf surface (Plate 2). The aggressive form of the disease appears to be responsible for the majority of the crop losses, which result from serious pod drop, stem collapse and in severe infections, the death of the whole plant.

Life Cycle

Botrytis is an imperfect fungus and persists in the soil as saphrophytic mycelium or in the form of black sclerotia. It can be transmitted on plant debris and with seed stocks, but it is not certain whether the fungus is truly seed-borne.

The sclerotia germinate and produce a coating of mycelium which, as is also the case with the saprophytic mycelium, then gives rise to conidia borne on branched conidiophores. These spores are blown or splashed onto the leaves of the host crop and when moisture conditions are favourable, penetrate the cuticle both chemically and mechanically. The lesions formed by infections enlarge as the mycelium grows and produce further asexual spores. These spread the disease very rapidly from the original isolated foci of infection throughout the crop under wet and humid conditions. Towards the end of the season minute black sclerotia are formed in the center of the, by now large, lesions and these resting bodies drop to the soil when the plant dies or is harvested.

Control

A number of cultural and chemical methods are used to reduce the damage caused by Botrytis infections. The most important of these are:-

- Spacing the plants more widely to reduce the relative humidity around the leaves;
- Removing and burning all crop debris in the field, after harvesting;
- Spraying with Dithane M 45 at a concentration of 40 g/20 litres of water. Thiram, Captan or Terraclor may also be used where the disease is particularly severe.

Rust

Importance and Occurrence

Rust disease is very common and widely distributed on legume crops, particularly broadbeans, throughout Western Asia. It becomes especially severe in crops grown under conditions of high humidity. If infection occurs early in the season total crop loss may result, but as the disease is normally only found towards the end of the crop growth period, yield losses are usually minimal. Lentils and chickpeas are also attacked by rusts, although significant losses are rare.

Causal Organisms

The pathogen causing rust disease of broadbeans has been identified as *Uromyces fabae*. This same species also attacks lentils , but chickpeas are infested by another species, namely *U. ciceris-arietini*. A number of different strains of *U. fabae* are known to occur in the region.

Identification and Symptoms

Infections start as minute, slightly raised pustules on the leaves. These are white in colour, but soon develop into larger reddish brown circular sori occasionally surrounded by narrow halos of chlorotic tissue (Plate 2). In severe cases the infected leaves become shrivelled and may dry out and fall to the ground.

Life Cycle

Uromyces fabae, in contrast to many rust pathogens, completes its whole life cycle on a single host plant. However it is able to infect a wide

range of host plants in the genera Vicia, Lathyrus and Lens. Wild species of these plants thus constitute the major way in which the pathogen survives from one season to another. U. fabae produces a large number of different types of spores. In cold climates over-wintering takes place in the telial stage, which produces free-living basidia and, in turn, basidiospores in the spring. These spores then constitute the primary infection mechanism. Once the host been infected the fungal mycelium spreads within the leaf and forms fruiting bodies (uredia) beneath the epidermis. As the uredospores form within these bodies they press against the leaf epidermis and rupture it to emerge as the characteristic reddish brown pustules. The uredospores which are produced abundantly and disseminated widely, are very effective in secondary spread of the fungus throughout the crop. Uredospores can germinate, infect a new host and produce further uredia in a matter of days and thus several generations are produced in a single season. In colder areas, as the season progresses the fungus enters into the telial stage, but where conditions permit it usually survives the whole year on crop plants, volunteers or related species in the uredial stage.

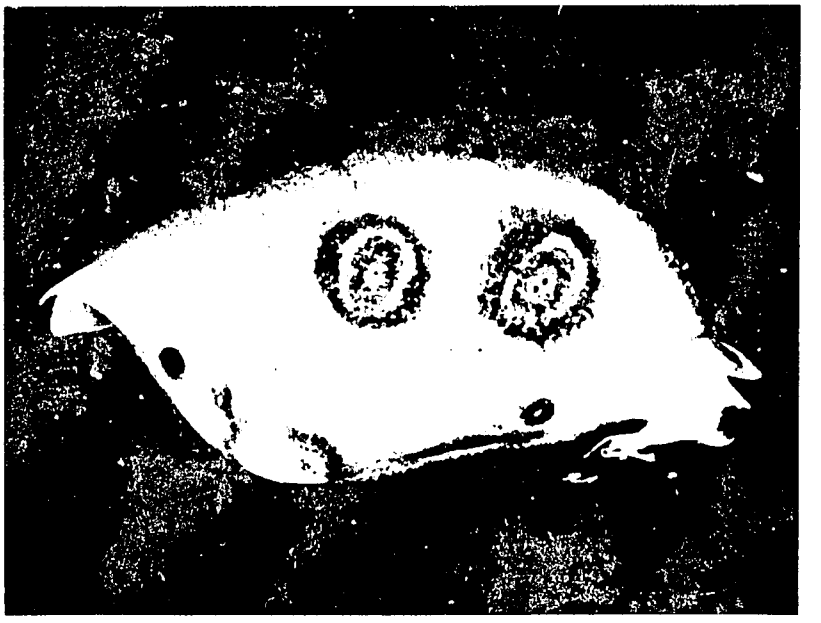
Control

Since rust infections normally occur late in the season, damage can be minimised by early planting or the use of early maturing varieties.

Chemical control is also possible; either with zinc sulphate dust (in which case care should be taken as crop injury can result through applications in hot weather) or through sprays of Ferbam or Zineb.

Good control of weeds and volunteer plants assists in red the disease inoculum carried over from one season to another makes an important contribution to the minimisation of the dise

Some genotypes of broadbean showing partial resistance t have been identified, but as yet no major gene resistance sourc come to light. In view of the number of different rust strains a consequently high probability of major gene resistance being br down in a short time, consideration should be given to building of field resistance in the crop so that disease infections always some damage but this is seldom severe enough to be economic.



1) Ascochyta blight symptoms on chikpea pod

2) Rust symptoms on faba beans leaves caused by Uromyces fabae

Alternaria Leaf Spot

Importance and Occurrence

Alternaria leaf spot, also known as brown spot, may cause a serious disease of broadbean crops, especially in Egypt, Sudan, Algeria, Morocco, Iraq, Lebanon and Syria, but is not generally considered to be of great importance in the region as a whole. Severe infections may occur during periods of wet weather and considerable damage in these cases results from the death of leaves and premature defoliation. Infections of Botrytis and Ascochyta appear to enhance the severity of leaf spot.

Causal Organism

Leaf spot is caused primarily by the pathogen Alternaria tenuis, of which there are many strains, varying in their ability to attack different hosts. A. solani has also been reported to cause leaf spot in broadbeans.

Identification and Symptoms

Leaf spot lesions first appear on the lower leaves and spread upwards as the disease develops. The lesions, which start as small, irregular shaped, brown, water-soaked, leathery spots surrounded by a narrow ring of chlorotic tissue, enlarge and tend to become circular with concentric grey rings and dark margins . In some cases the centers of these lesions may drop out leaving a shot-hole appearance

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to the leaves. Alternaria lesions may also occur on the petioles, the stems and the pods, causing them to rot. Under humid conditions both leaf and stem spots may enlarge very rapidly and coalesce rendering leaves entirely worthless and causing stems to collapse.

Life Cycle

Alternaria overwinters as mycelium in woody plant debris, in other crops and in weeds and, because of its wide host range, is invariably present in most fields.

This mycelium produces conidia which infect the lower leaves of the crops when conditions become favourable in the spring. Further conidia are produced from these initial infections and these spread the disease to the other leaves and stems. The overwintering mycelium itself may remain viable for periods of up to a year in the absence of a suitable host.

Control

The incidence and severity of infections may be reduced by: ensuring that only clean, disease-free seed is used; removing infected plants from the field; and keeping a good control of weeds in the crop. Fields in which leaf spot infections have been particularly severe should not be planted with broadbeans in successive years. Foliar applications of Maneb or Dithane M 45 may also be used to control outbreaks of the disease, but are unlikely to be economic in most environments.

The use of resistant varieties could constitute an effective control measure, but considerable research is required on this aspect before any positive recommendations can be made.

Powdery Mildew

Importance and Occurrence

Powdery mildew disease is fairly common throughout the region and affects a wide range of crops. It has been reported as a production problem of legumes in Algeria, Cyprus, Ethiopia and Sudan and in the latter country causes severe damage to broadbeans grown under irrigation . However, elsewhere the disease usually appears only late in the cropping season and significant yield losses thus tend to be rare.

Causal Organisms

All powdery mildews are caused by members of the family *Erysiphaceae.* Of specific importance in food legume crops in western Asia are the species *Erysiphe polgoni* and *Leveillula taurica.*

Identification and Symptoms

These pathogens may infect any above ground plant part. Infections of *E. polygoni* first appear as white or grey 'mildewed' areas, which may enlarge and coalesce. In the later stages of disease development the crop tissue becomes necrotic and small black resting bodies may be seen throughout the infected parts (Plate 3). In the case of *Leveillula* infections, because the mycelium is mainly inside the plant cells (in contrast to *Erysiphe* mycelium which is almost entirely external), the symptoms consist only of pale green to yellow lesions with or without purple specks.

Mildew infections usually block respiratory activity and thus tend to cause chlorosis of infected tissues, which may also become stunted and distorted before dropping to the ground.

Life Cycle

The fungi overwinter either in mycelial mats on the leaves of hosts or as cleistothecia, which represent the perfect stage. These sexual resting bodies split when conditions are favourable, releasing asci, which in turn release ascospores, the primary mechanisms of spring infection. In the case of Leveillula taurica the mycelium then enters the host through the stomata and proliferates within the mesophyll, producing asexual conidia borne on long chains and emerging through the stomata. With E. Polygoni, however, the mycelium grows on the surface of the plant and obtains its nutrition through short haustoria (feeding tubes) which invade the epidermal cells of the host. Conidia are produced at a very rapid rate throughout the season and are the main way in which the fungi spread as, unlike those of other fungi, they are able to germinate in the absence of free water on leaf surface. When conidial production slows down and eventually ceases cleistothecia are produced on the host surface. These change from white through brown to black as they mature and are very resistant to adverse environmental conditions.

Control

The use of resistant cultivars constitutes the most comprehensive control measure. Variation in susceptibility to the disease has been observed in a number of different crops (e.g. broadbeans) but highly resistant varieties have so far proved elusive. Partial resistance may be useful in minimising losses but is only likely to be effective when infections are not severe.

Cultural practices, such as early planting (so that the crop is past its critical stage when the disease is likely to become severe) and the careful selection of rotations involving non-susceptible crops may also be used to reduce disease losses.

In addition treatment with fungicides, such as Karathane or wettable sulphur may be economic in some situations but as infections usually occur towards the end of the season, often resulting in little loss in yield, the cost of spraying is, in general, prohibitive.

CHAPTER 5.

BACTERIA AS PLANT PATHOGENS

Although, as a group, considerably less important than the fungi in causing yield losses, plant pathogenic bacteria can cause appreciable crop damage under certain conditions. Because these organisms have no active mechanism for penetrating their host plants, they are usually found associated with other disease infections or pest damage. They normally precipitate generalised rotting and wilting symptoms.

Bacteria are microscopic and thus a light microscope of reasonable power is required for their detection and identification.

Bacterial Structure

Again, possessing a rigid cell wall, these organisms are considered as part of the Plant Kingdom. They are either unicellular or consist of small undifferentiated groups of cells and, unlike the more highly specialised cells of relatively more advanced plant groups, lack well defined membranebound nuclei and mitochondria. A typical bacterial cell is illustrated in Figure 7. Some species are motile, possessing flagellae as an aid to directional movement. These features are used by taxonomists in classification: bacteria possessing only one flagellum being known as monotrichus; those with a number of flagella concentrated at one end of the cell multitrichus; and those with flagella scattered all over the body peritrichus (Figure 8).

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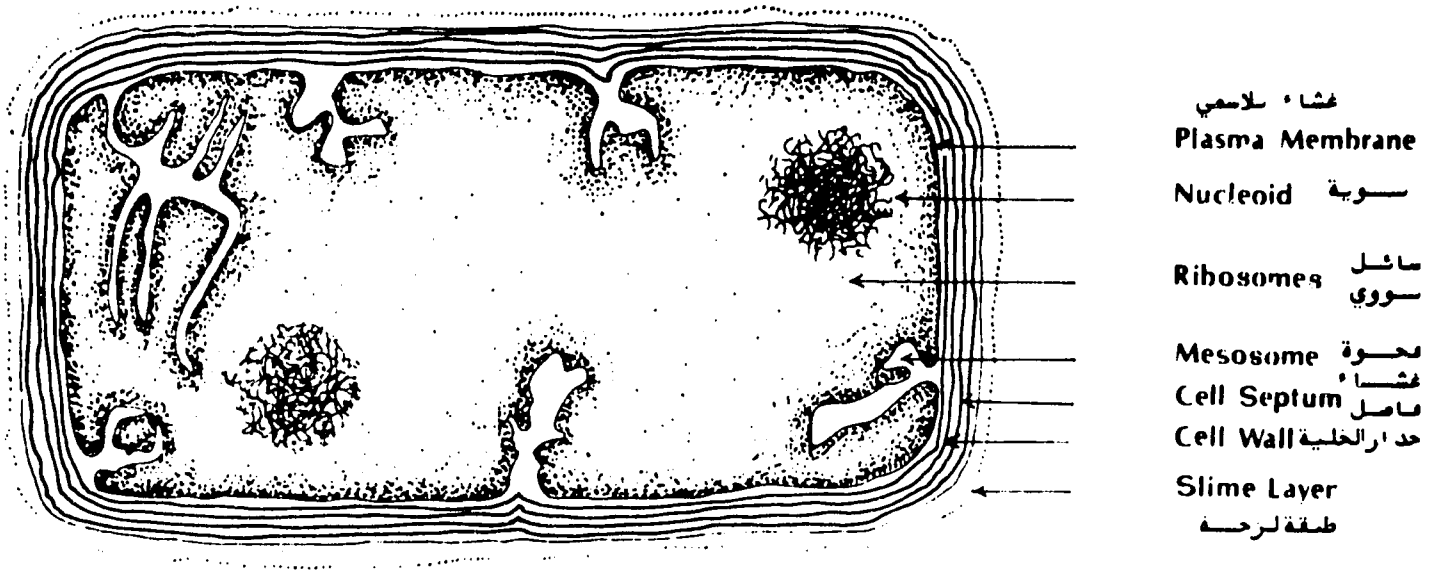
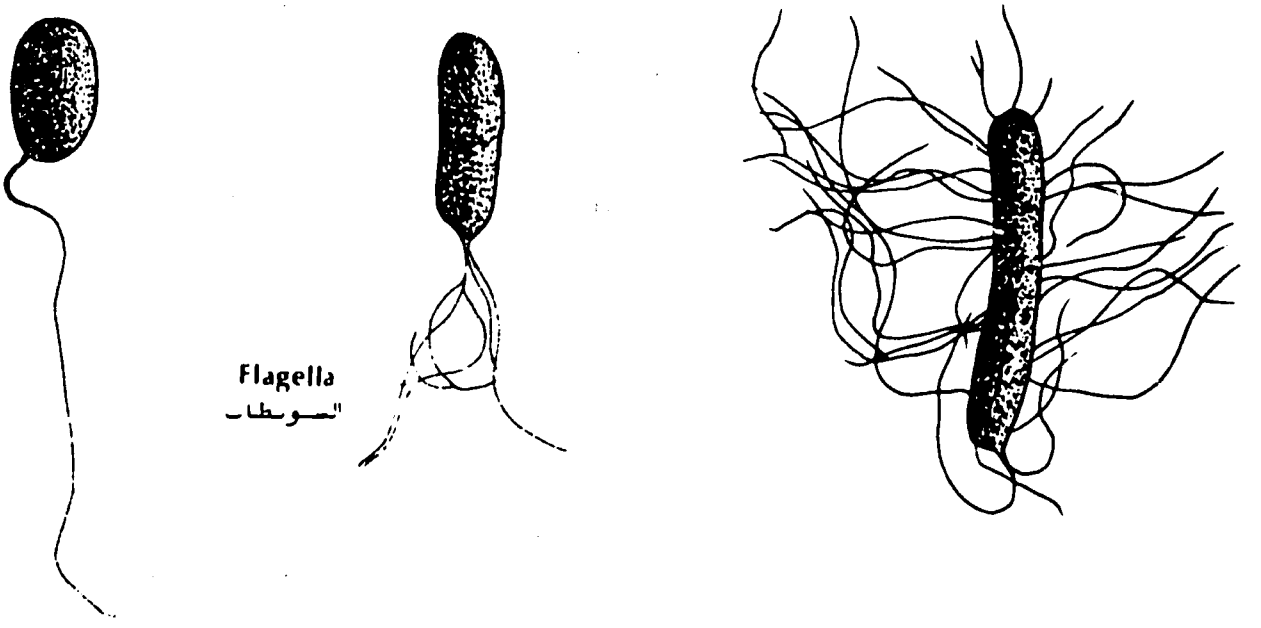


الشكل (٧): شكل موضح لخلايا البكتريا

FIG : 7 A DIAGRAMMATIC ILLUSTRATION OF A BACTERIAL CELL .



(AGROBACTERIUM)
MONOTRICHOUS
(حادية الهدب)

(PSEUDOMONAS)
MULTITRICHOUS
(متعددة الاهداب)

(ERWINIA)
PERITRICHOUS
(الاهداب تغطي سطح الخلية)

الشكل (٨): بعض أنواع بكتريا PHYTOPATHOGENIC

FIG. 8 SOME IMPORTANT PHYTOPATHOGENIC BACTERIA

Reproduction in Bacteria

As befits one of the simplest members of the Plant Kingdom, bacteria reproduce through simple cell mitosis, splitting into two approximately equal parts in a process commonly known as binary fission. Under favourable conditions this process can occur very rapidly leading to logarithmic population increases on a large scale.

Bacterial Classification

Because of their wide diversity of characteristics, bacteria have proved notoriously difficult to classify. Several classifications based on a number of biochemical tests, host range studies and characteristics when grown in culture, are currently in use, adding considerably to the confusion. The most widely accepted classification scheme divides the plant pathogenic bacteria into three orders, namely:-

Pseudomonadales, which, if motile, possess polar flagella and stain gram negative. Two genera (Pseudomonas and Xanthomonas) are particularly important.

Eubacteriales, which stain gram negative and gram positive and have various different types of flagellation, if motile. Rhizobium (which when present in legume root nodules is capable of symbiotic nitrogen fixation), Agrobacterium, Erwinia and Corynebacterium are the important genera of this order.

Actinomycetales, which are generally non-motile and filamentous fungal or algal-like bacteria. Members of the genus Streptomyces, having amycelial-type growth and a fungal-like reproductive pattern, are particularly important.

CHAPTER 6.

VIRUSES AS PLANT PATHOGENS

Plant pathogenic viruses cause a variety of disease symptoms in a large number of different plant species. These symptoms may be expressed differently in different hosts and range from stunting and galling to severe leaf curling and discolourations. In general, however, the symptoms are systemic, being found evenly distributed over individual plant parts or the whole plant. Yield losses resulting from viral infections are difficult to estimate, except in cases of severe attack, and may be considerably more serious than is usually supposed.

Viruses are sub-microscopic entities parasitising individual plant cells and can thus only be resolved and studies with an electron microscope.

Viral Structure

The structure of virus particles has been found, by a number of techniques, to fall into three major classes; namely rod-like, polyhedral and bacteriod-shaped. However electron microscopy, combined with a range of chemical tests, has enabled viral structure to be considerably clarified from this morphological base. It is now known that viruses consist basically of a nucleic acid, carrying their genetic code. This strand of nucleic acid may be surrounded by a sheath of protein in one of several different ways or it may be naked, (lacking a protein covering). A typical virus structure is illustrated in Figure 9 .

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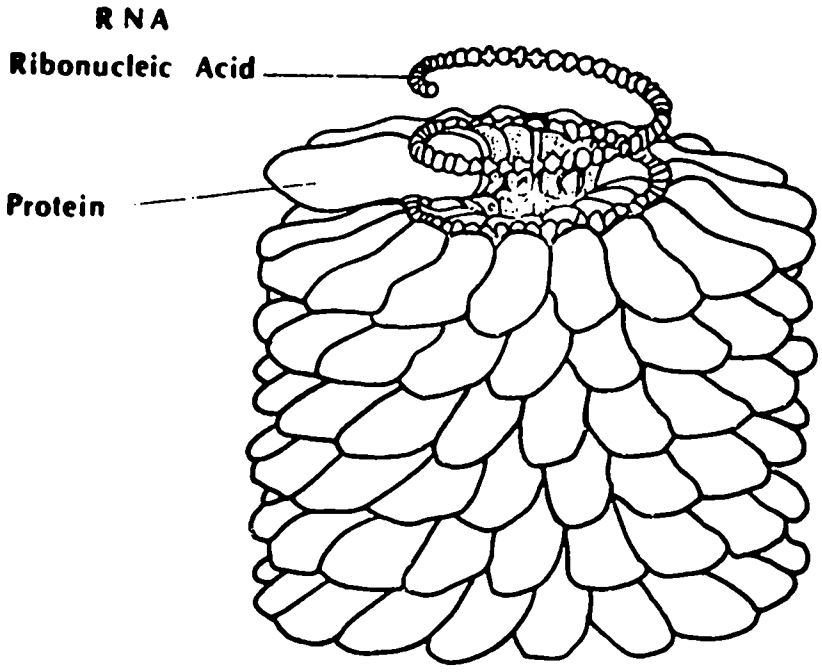

FIG : 9 MODEL OF A PORTION OF THE TOBACCO MOSAIC VIRUS

Reproduction of Viruses

Since virus particles lack all metabolic capabilities they are unable to multiply by classical growth and fission methods. However it appears that viruses are able, through their nucleic acids (which closely resemble some plant cell nucleic acids, specifically those found on the ribosomes and considered to be responsible for the building of cell tissue), to redirect the metabolism of their host cells to produce viral rather than cell tissue. In this way the viruses are able to utilise plant cells and their growth and reproductive systems in place of their own. They are thus considered to be truly parasitic.

Viral Classification

Because of the difficulty of detailed virus studies and the wide range of different symptoms that any one virus can cause (probably dependant on the physiology of the individual host), viral classification is rather flexible and incomplete. Viruses are identified on the basis of the reaction of host (or a test species), their transmission characteristics, their longevity in vitro, serological tests and other more detailed analysis when the equipment is available. They are usually named with reference to their host and the characteristic disease symptom that they cause.

CHAPTER 7.

PLANT PARASITIC WEEDS

In addition to micro-organisms, such as fungi, bacteria and viruses, a number of higher 'plants', which parasitise crop species are known to cause very considerable yield losses especially in the semi-arid areas. Of particular importance to legume crops are the broomrapes (*Orobanche spp.*). These parasitic weeds attack a wide range of broad-leaved crops, causing particularly serious damage to broadbeans, lentils, chickpeas, peas, tomatoes, tobacco, potatoes and sunflower. Infestations of broadbeans may be particularly heavy and cause complete crop devestation.

Approximately 140 species of *Orobanche* have been identified throughout the world, the majority being able to parasitize several crop and wild species. Of these only four, namely *O. aegypticiaca*, *O. crenata*, *O. lutea* and *O. minor*, are considered to be important in legume crops.

Identification

Infestations of *Orobanche*, which may occur regularly each season in specific areas, are easy identified by the characteristic aerial flowering shoots (Plate 3). These shoots are erect, may be either branched or unbranched (depending upon the species), contain no chlorophyll and bear a large number of tubular flowers which may range in colour from white to faint yellow and from violet to blue.

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Life Cycle

Orobanche seeds are able to remain viable in the soil in a dormant state for over 10 years. They will germinate only when stimulated by a specific chemical released by the roots of certain plant species, most of which are capable of acting as hosts. After germination an unconnected seedling is formed. This soon establishes direct contact with the host plant roots through haustoria, thus becoming truly parasitic. Following the establishment of parasitism the life cycle of an Orobanche plant may be divided into two distinct stages, the hypogeal stage, of about 50 days duration during which the subterranean vegetative organs of the parasite develop; and the epigeal stage, in which the vegetative organs grow rapidly, producing aerial reproductive shoots. This latter stages normally lasts for about 30 days. The aerial shoots bear numerous flowers which are insect pollinated and produce very numerous and minute seeds. These seeds are disseminated mechanically and may be spread through handling, by water or with the wind. After dispersal the seeds undergo a period of after-ripening which may take up to two years. They are then capable of germinating and causing fresh infestations given suitable conditions.

Control

As yet there is no proven consistent and economical method available for the control of this parasite. Various cultural measures, including deep ploughing, dry fallowing, various rotations, heavy manuring, lowering of the soil pH and planting in deep furrows, although often advocated have been found largely ineffective as control measures. However recent investigations have suggested a number of measures which may be of use in reducing infestations to a managable level.

The introduction of plant species that are able to stimulate the germination of Orobanche but that are unsuitable hosts (trap crops) into rotations is one such possibility. However it is only the seeds in very close proximity to the plant roots that are stimulated to germinate in this way and thus the use of trap crops appears only of marginal value . Along the same lines, the development of synthetic germination stimulants is currently underway and holds some promise for the future.

Studies of a wide range of toxic chemicals (including fungicides, herbicides and even nematicides) have revealed a few which have a reasonable level of activity against Orobanche. Preplanting incorporation of chlorpropham, dalapon, TCA and DCU and pre-emergence applications of sesone and allyl-alcohol have variously been reported as giving good control; double applications of metham-sodium (autumn and spring) have been shown to give an effective kill of the seeds of some species; and control of Orobanche in broadbeans has been achieved using 1, 2- dibromo-3-chloropropane applied in irrigation water. In addition foliar applications of allyl-alcohol, MH-triethylamine and hedolit (a DNOC derivative) appear to give a fair control and applications of glyphosate have proved particularly successful in reducing infestations of O. crenata in broadbeans.

Current work on the screening of legume varieties for resistance to Orobanche, although as yet only in its early stages, has already given some promising indications that levels of resistance may be built up.

At present however the most commonly used and only really effective control measure involves the regular cutting or physical removal of the weed. Reductions in infestation levels of 85% in two years and 96% over four years have been achieved by the removal of plants on a weekly basis (before they come into full flower) followed by incineration, to prevent the development of seed on removed tissue. This is, however, a very labour intensive operation.

CHAPTER 8

DISEASE CONTROL

Over the past millions of years plant species have evolved in intimate contact with the pathogenic organisms endemic to their particular regions. They have thus developed mechanisms which allow them to survive and reproduce despite the presence of these pathogens. In general, however, individual plant species have evolved in rather isolated geographical locations and have therefore failed to come into contact with many of the pathogens that are capable of infecting them. The domestication of certain plants by man, his invention of agriculture, and the subsequent spread of many species over wide areas have served to upset the delicate evolutionary balance between plants and their pathogens built up in the course of their development in specific areas. The introduction of plants into new areas (which have different populations of pathogens), the spread of pathogens into new areas (with different populations of plants) and the practice of monoculture have all served to increase the incidence and severity of plant diseases. This situation has, in addition, been exacerbated by the trend, initially through unintentional selection and more recently through breeding programs, towards decreasing the genetic differences between individuals, both within "varieties" and between "varieties" in the major crop species.

Thus the evolution of crop plants has been directed, albeit unintentionally, by man towards increasing the possibilities of serious plant damage through the effects of pathogenic organisms. Although, previously the productivity of species may have been relatively low, crop

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plants were rarely devestated by diseases. In contrast crop productivity is currently rather high but the possibility of very serious disease losses (and hence the instability of cropping) is also high.

In recognition of this situation considerable emphasis in recent years has been placed upon developing methods, physical, biological and chemical, to control the spread and occurrence of plant diseases and to minimise the losses which they precipitate.

As with pest species, the control of disease will only be of long lasting effectiveness if it is developed through a good understanding of the causal organism, the host crop and the effect of environmental conditions on both. Although the concepts of economic threshold and ecological balance are less well defined in the case of plant pathogens, they are still fundamental to effective and economic control. Economic thresholds are at present difficult to apply to disease control, due to the complex and fluid process of disease development. In addition very little is known about the degree of environmental disruptions caused by particular control methods. However when considering measures to control specific problems it is more than ever essential to do this with regard to the amount of damage that can be tolerated, and thus the level of control necessary together with an appreciation of the consequences of this control on pathogen populations, the crop itself and the overall environment in the widest sense.

With this background disease control measures can be divided into two types: those which aim to minimise the degree of disease establishment; and those which set out to minimise crop losses given disease establishment.

Minimisation of Disease Establishment

As detailed in the general considerations of disease development at the beginning of this manual, disease establishment involves the three distinct stages of inoculation, penetration and infection. Control measures aimed at minimising the degree of disease establishment thus also fall into three main groups, involving the minimisation of disease development at each of these stages.

Minimising Inoculation

This implies reducing the amount of disease inoculum that comes into contact with the host plant, and can be achieved through measures designed to reduce the inoculum density in the vicinity of the host together with means of restricting the transfer of this inoculum to the host.

Reducing the Inoculum Density

The amount of inoculum in the vicinity of the host crop may be minimised indirectly, by growing the crop under conditions of inherently low inoculum density, or directly, by reducing the environmental inoculum reservoir.

Indirect reductions in the inoculum density involve avoiding inoculum (by planting at times when, and in places where, the inoculum is ineffective, rare or absent) or inoculum exclusion (preventing the introduction or establishment of a pathogen within an uninvaded area).

Avoidance: This may involve adjustments to the location (both geographical and local) or the timing of planting. Temperature and humidity are the major environmental factors determining the varying incidence of diseases

between geographical areas. Thus lentils, chickpeas and broadbeans suffer considerably from fungal foliar diseases when grown in humid coastal regions but can be successfully produced with minimal disease problems in the drier inland areas.

Within geographical areas the choice of field may also be important in avoiding diseases caused by certain soil inhabiting pathogens and airborne organisms with somewhat localised dispersion characteristics (e.g. Fusarium, Rhizoctonia and Orobanche.)

In avoiding disease infections the timing of planting may also be important; the aim being to provide environmental conditions more favourable for the growth and development of the host plant than for the pathogen. Thus, although winter planting of chickpeas gives considerable yield increases, most chickpeas are spring planted in order to avoid the cool moist winter period so conducive to the development of Ascochyta blight, which often results in complete devestation

Exclusion: The local inoculum density may also be minimised by mechanisms, such as seed treatment and inspection and quarantine, designed to exclude certain pathogens from an area of crop culture. These methods are usually enforced on a country or district level through legislation and are only effective against pathogens which are carried by the host itself (in seeds or propogative material) or on soil and debris contaminating such material.

However for most individual producers the location of cropping is fairly rigidly fixed and other methods of indirectly minimising inoculation density are not controllable . Thus direct methods of minimising the environmental inoculum reservoir in the vicinity of crops are particularly

applicable for farmers. Due to the very rapid rate of the multiplication and dissemination of pathogen inoculum these methods can at best only hope to prevent or delay the early season build-up of inoculum. However, regular practice of direct controls will result in steadily declining inoculum levels through depletion and, if complemented by other mechanisms, can constitute a very effective disease control measure. There are a large number of different methods available for the control of inoculum reservoirs. Environmental reservoirs of inoculum vary considerably in form, distribution and potential between different pathogens. The selection of particular methods for the control of specific pathogens must thus be based upon a good knowledge of the inoculum characteristics of the pathogens concerned. The most commonly used methods for reducing inoculum densities are as follows:-

Crop Rotation: Designed to give control by reducing the frequency of growing susceptible crops on a particular area, this method is limited in its effectiveness to those pathogens which cannot survive long periods of isolation from their host and to those which have rather narrow host ranges. Pathogens which can survive over long periods in the form of thick-celled resting spores (e.g. *Fusarium* and *Botrytis*) or as a saphrophytic mycelium (e.g. *Rhizoctonia* and *Botrytis*); which have a very wide host range, including numerous weedy species (e.g. *Alternaria*); or which can be transmitted over long distances (e.g. *Uromyces* and *viruses*) are thus rarely affected by rotational methods. However the carry over of bacterial diseases may be very effectively minimised in this way.

Field Sanitation: A large number of pathogens survive the 'winter period' on or within crop debris, volunteer plants or weedy species. In addition, early season infections usually start initially in isolated foci and then spread

by secondary infection to wider areas. Good sanitation, which aims to eliminate the 'over-wintering' inoculum reservoirs and the primary infection foci (constituting dangerous inoculum sources) is thus an important way of limiting the degree of inoculum in the field. The removal and burning of infected plants and weeds early in the season and crop debris, weeds and volunteer plants after harvest constitute the most important elements of good field sanitation. When coupled with deep ploughing (involving soil inversion) in order to bury pathogens on any remaining debris too far below the soil surface to be able to cause infection, these practices enable great reductions in the inoculum of most fungal pathogens.

Crop Hygiene: For diseases which are primarily soil or seed-borne a high standard of crop hygiene (planting 'clean' seeds in a 'clean' soil) provides the best method of reducing the inoculum density in a given area.

A 'clean' seedbed involves the use of soil treatments to reduce or inactivate soil-borne inoculum. Such treatments may utilise chemicals (such as chloropicrin, carbon disulphide or methyl bromide), heat (through steam or stubble burning) or water (flooding).

Chemical and steam treatments are very costly both in terms of the degree of treatment required and the time involved, as large volumes of soil must be processed. They are thus only of use on a small scale in glasshouses or seedling nursery areas and only economic in areas where problems such as root rot/wilt or Orobanche are particularly severe. Stubble burning and flooding may be more relevant to field-scale operations but do not generally give good control.

The incidence of seed-borne diseases may be reduced by steam or chemical seed treatments. In legume seeds which tend to be rather vulnerable to excessive heat, only chemcial treatments are important.

Seed dressings may assist in reducing the carry-over of Botrytis and Ascochyta and may be combined with dressings designed to give protection from certain insect pests. The use of certified and debris-free seed will also do much to combat the carry-over of these and other pathogens.

Restricting Inoculum Transfer

Before inoculation can occur the disease inoculum must be transferred from its environmental reservoir to the host surfaces. This can be accomplished in a number of ways: through the air, by water splashes and drainage, and via certain insect vectors. Restricting this transfer of inoculum will thus contribute considerably to minimising inoculation. While little can be done to reduce the dissemination of inoculum on air currents, there are a number of ways in which inoculum transfer through the other agents outlined above may be restricted.

Controlled Watering: In the region of West Asia and North Africa, the seasonal rainfall rarely coincides with the period of maximum inoculum potential; a notable exception being in the case of Ascochyta blight. Thus in the drier crop producing regions, diseases are most serious under irrigated conditons. Modification of watering regimes, involving for example reducing the frequency of watering, will reduce the transfer of root infecting pathogens from the soil surface into the root zone. Similarly the use of furrow irrigation in place of sprinklers prevents periodic leaf wetting and water splashes and thus assists in reducing the transfer of inoculum onto the aerial plant parts.

Pest Control: Pests, particularly those that are more mobile and that move over great distances, are important vectors of a large number of diseases. They are particularly important in the transmission of viruses, which in the case of a number of sucking insects and nematodes, occurs internally. Most pests however are able to transmit a wide range of diseases externally as they move through the crop(s). Methods which reduce the incidence and occurrence of pests (especially aphids) will thus also be very beneficial in reducing the spread and severity of diseases.

Minimising Penetration

However effective the mechanisms of minimising the degree of inoculation, considerable numbers of disease particles will invariably come into contact with the surface of host crops. As very few initial infections can result in very serious losses through secondary spread, minimising the penetration of the host assumes particular importance in the overall scheme of minimising disease establishment.

Reducing the degree of penetaration involves two main mechanisms, namely: those designed to prevent or delay 'germination'; and those which prevent or reduce actual entry of the pathogen into the host.

Inhibiting 'Germination'

Once the inoculum has come into contact with a host it must enter into a pre-penetration stage of active growth based upon its own stored nutrient resources (germination). Whether as a dormant or saphrophytic mycelium or as a spore this process requires certain environmental conditions for its initiation. Only under conditions of reasonable tempe-

rature and humidity (to allow active growth), the presence of sufficient moisture on the plant surface (to prevent drying out of the developing germ-tube) and moderate pH and light intensity (to prevent chemical or photo-chemical dessication of the germ-tube) will this process occur.

Alterations in the crop micro-environment which reduce the occurrence of such conditions will thus tend to prevent or delay 'germination'. For example, the wider spacing of plants in a crop will serve to reduce the humidity of the canopy and soil micro-environments, increase the intensity of light in these environments and thus increase the ambient temperatures; all factors which will reduce or inhibit 'germination'. Similarly reducing the watering frequency in irrigated crops, in reducing the free water on plant surfaces, will also serve to discourage 'germination'. Furthermore, extreme pH conditions, precipitated by the presence of certain chemicals (e.g. herbicides and pesticides) are also inhibitory to 'germination' of pathogenic structures.

The 'germination' of certain pathogens (particularly Orobanche) is stimulated by the presence of specific root exudates produced by its host crops. Inhibition of germination in these species can thus be achieved by eliminating these exudates. Considerable attention is being focussed on this aspect in current Orobanche resistance breeding work.

Inhibiting Entry into the Host

From germination to actual penetration the pathogen growing on the host surface is highly vulnerable to dessication resulting from unfavourable environment conditions. In addition, unless penetration is achieved fairly rapidly the pathogen will exhaust its food reserves and die from malnutrition. Thus the creation of unfavourable conditions on the plant surfaces together with the establishment of barriers to the

pathogen's entry can give good reductions in disease establishment.

Protective Chemical Control: The best known method of precipitating lethal conditions for pathogens on plant surfaces is through the use of toxic chemicals. Copper and sulphur-based compounds (e.g. Bordeaux mixture and Lime Sulphur), dithiocarbamates (e.g. Ferbam, Ziram, Zineb, and Maneb), hetero-cyclic nitrogen compounds (e.g. Captan) and aromatics (e.g. chloranil, PCNB and DCNA) are used in this regard. Details of these groups of chemicals and their application are given in Appendix I. Protection against diseases affecting the aerial parts may be achieved by spray applications, whereas seed dressings are used to protect young seedlings from parasites which attack the plant below the soil surface. In order to give adequate effects protective chemicals must be applied before infection, giving a complete coverage of vulnerable plant surfaces, and remain in a toxic state on these surfaces for a reasonable period of time. They must thus be applied in relatively high volumes. Coupled with their initial purchase cost, this means that such chemicals are generally only economical in the protection of plants against diseases of great and regular importance. Care must be taken in the use of toxic chemicals, as many are highly phytotoxic and may thus precipitate severe crop damage if applied at a vulnerable stage of plant growth or in excessive concentrations.

Host Defence Mechanisms: The use of chemicals in a protective role, besides being costly, often fails to give good control of diseases. This may be because coverage is inadequate, the chemical is rapidly washed off the plant surfaces, or a high degree of penetration has already occurred prior to application. A much more effective way of preventing or inhibiting actual entry into the host plant is through using or enhancing the hosts' own defense mechanisms.

During their long evolution plants have developed a multitude of mechanisms which reduce the numbers of pathogens able to penetrate and infect their tissues. Resistance to penetration is usually accomplished by features of plant structure, such as a thick epidermis, narrow stomatal openings and the presence of specialised protective layers. These are termed mechanical or passive resistance mechanisms and, together with elements of functional resistance (represented for example, by the timing of stomatal closure) they constitute a broad based resistance to a wide range of pathogenic organisms. A thick and tough epidermis will confer a good resistance to all pathogens that enter in an active way, either chemically or mechanically, as will certain external protective wax layers. Likewise plants with narrow stomatal openings and certain stomatal closure characteristics will be much more difficult to colonise by pathogens that enter passively. In addition the exudation of liquid and the formation of cork tissue stimulated by wounding also serves to reduce penetration through wounds. Such mechanisms may be profitably introduced into commercial varieties through breeding and although they may be controlled by relatively few genes, give a resistance which may not be total but is generally long lasting due to its broad base.

In general however the majority of passive host defense mechanisms develop only as plants grow and mature. Thus at an early stage of crop development most plants tend to be more susceptible to penetration (probably due to their relatively thin and uncuticularised epidermal layers). Defense mechanisms of a passive nature may therefore be considerably enhanced by practices such as early planting and the use of early maturing varieties which enable the plants to be past their more susceptible stages by the time that the disease inoculum has built up to a dangerous level in the spring.

The resistance mechanisms of mature plants may be severely affected by nutrition (especially water, nitrogen and potassium deficiencies) and environmental stresses (such as high temperatures, infections by other pathogens or pests and the presence of certain toxic chemicals). Thus if effective control of penetration is to be achieved through exploitation of the hosts' own defense mechanisms every effort should be made to ensure that the incidence and severity of such environmental stresses are minimised.

Minimising Infection

Once the pathogen is inside the plant host it is inaccessible to any of the control mechanisms already detailed. However there are still a number of ways in which the development of the pathogen and thus the future production of inoculum (which spreads the disease within the crop) can be arrested or hindered.

Host Defense Mechanisms: In addition to the passive and functional defense mechanisms outlined previously plants possess a number of active mechanisms which are initiated in response to the presence of certain pathogens and which restrict or retard their development. These mechanisms, being largely chemical, are numerous and varied and often highly specific to particular pathogens.

Although they may be very effective in reducing pathogenic development, these mechanisms tend to be highly pathogen specific in their action. Thus the invasion of the host by some individuals may fail to induce control responses. Like all populations, pathogens consist of a large number of individuals all differing in their composition .

As their reproductive rate is very rapid, the presence of mechanisms which inhibit only certain individuals will very quickly result in a dominance of those individuals able to overcome this barrier. Therefore the use of varieties possessing only these rather specific forms of resistance may result in very widespread crop losses, and is thus inadvisable.

Curative Chemical Control: In recent years a number of chemicals capable of inhibiting the development of pathogens within plant tissues have been synthesised and made available for disease control. These chemicals have to be absorbed by the plant and translocated to the site of pathogen infection before becoming active. They are thus termed systemic. Their action usually involves one or a combination of the several mechanisms: the inactivation of toxins produced by pathogens; direct fungitoxic (killing) or fungistatic (development limiting) effects on the pathogen itself; enhanced host resistance; and/or alteration of the host metabolism, making it a less suitable substrate.

In addition to a number of fungicides, several antibiotics have also been found to be effective when used in plants. Little information is currently available on the use of systemic chemicals in legume crops as much of the original experimental work related to cereal crops. However systemic chemicals in general are known to be considrably more persistant that the protective types and require much less frequent and accurate spraying for effective action. Thus the development of systemics suitable for use in legume crops holds considerable promise for future disease control.

Minimising Losses from Infection

All the mechanisms outlined so far involve minimising disease losses through the minimisation of the diseases themselves. A further and equally important aspect of disease loss minimisation is however the reduction of the effect of diseases without actually reducing their incidence. Methods designed to achieve this basically depend upon stimulating the rapid and vigorous growth of plants so that tissues are replaced more rapidly than they are destroyed by the action of the pathogens. In such a way reasonable and stable yields may be obtained despite appreciable levels of disease infection.

Plant Tolerance

Some plant varieties possess mechanisms which stimulate more rapid growth in response to pathogen infections. Others have overall a more vigorous growth pattern. In either case, such plants are able to survive and yield considerably better than other types subjected to similar levels of infection.

Tolerance mechanisms do not involve any inhibition of pathogens and thus do not generate a selection pressure upon pathogen populations for types able to overcome such inhibitions. The use of varieties with tolerance will thus lead to much less disruption of the ecological balance and hence a much greater inherent stability of cropping than will result from inhibitory control measures. However tolerance may be detrimental to integrated systems of disease control as it allows the pathogens to develop and spread, preventing the achievement of steadily declining pathogen populations.

At present techniques for recognising tolerance in the field are ill-developed. However work is currently underway on the evolution of screening techniques to permit the identification of tolerant varieties. Once tolerance can be easily and practically identified the way will be open for its use in developing crops inherently better able to withstand the effects of a wide range of diseases. Such developments if introduced into commercial varieties will provide a very effective complement to the less stable but more complete resistance mechanisms outlined above.

Agronomic Improvement: Even in varieties that do not exhibit specific tolerance responses, the effects of disease can be reduced by methods which encourage the development of healthy and vigorous crops. These include; early sowing, providing good nutrition and preventing environmental stresses. Ensuring good agronomic conditions is therefore an important way of minimising the effects of disease, and is likely to produce added bonuses when integrated with the used of varieties showing varying degrees of tolerance, and/or resistance.

It should be emphasised that the large number of mechanisms designed to reduce the impact of pathogens on crop production outlined here, are not mutually exclusive. Indeed effective and lasting control of crop losses caused by pathogens requires an integration of such mechanisms in a comprehensive control strategy based upon a good understanding of the pathogen (how it survives, infects, develops and spreads), the host (how it protects itself from infection and damage) and the environment

(how it effects both the pathogenicity of the pathogen, the susceptibility of the host and thus the extent and severity of disease development). Such intelligently formulated control strategies can do much to increase the productivity of legume crops, at present often severely limited by pathogenic organisms.

Appendix I: Chemicals for Fungal Disease Control in Food Legumes: Some Available Possibilities.

Name	Action	Application *	Formulation +	Possible ** Control Spectrum
INORGANICS				
Bordeaux Mixture	Protective	F	S	Ascochyta
Copper Oxychloride Sulphate (C-0-C-S)	Protective	F	D:S	Pythium Ascochyta Powdery Mildew
Basic Copper Sulphate	Protective	F	D:S	Ascochyta
Copper Hydroxide	Protective	F	S:D	Bacterial Blight Ascochyta
Copper Oxide	Protective	F:S	S:D	Root Rot
Ammoniacal Copper	Protective	F	S:D	Bacterial Blight Ascochyta Powdery Mildew
Elemental Sulphur	Protective	F	D:S	Powdery Mildew Ascochyta
METAL ORGANICS				
Copper Lineolate	Protective	F	S	Bacterial Blight Powdery Mildew
Copper Oleate	Protective	F	S	Ascochyta Powdery Mildew Bacterial Blight
Phenyl Mercuric Acetate (Ceresan)	Protective	F:S	S:G:A	Root Rot
CARBAMATES				
Maneb (Dithane M-22)	Protective	F	S:D	Ascochyta Alternaria Rust
Ferbam	Protective	F	D:G	Rust Pythium Botrytis Ascochyta
Ziram	Protective	F	D:S	Ascochyta Rust
Zineb	Protective	F:S	S:D	Rust Ascochyta Alternaria Pythium
Dithane M-45	Protective	F	S:G:D	Ascochyta Rust Alternaria Botrytis Pythium Rhizoctonia
OTHER ORGANICS				
Pentachloronitrobenzene (PCNB - Terrachlor)	Protective	I:S	D:S:G	Botrytis Rhizoctonia Pythium
= Oxycarboxin (Plantvax)	Systemic	I:S:F	D:S:G	
= Carboxin (Vitavax)	Systemic	I	D	Rhizoctonia Pythium

Appendix I. Cont'd

Name	Action	Application *	Formulation +	Possible ** Control Spectrum
Captan	Protective	F:S	D:S	Botrytis Pythium Ascochyta
Captafol	Protective	F	S:D	Root Rot Ascochyta
Chlorothalonil	Protective	F:S	S:G	Powdery Mildew Ascochyta Alternaria
Terrazole	Protective	I	D:S	Botrytis Pythium Fusarium Rhizoctonia
Chloroneb	Protective	I:S	S:D	Rhizoctonia Pythium
Thiram	Protective	S	D:S	Botrytis Pythium
Dexon	Protective	I:S	S:G:D	Pythium Ascochyta
Dichlozoline	Protective	F	S:G	Botrytis
Drazoxolon	Protective	S	S	Powdery Mildew
Dichloronitroanaline (DCNA)	Protective	F:I:S	S:D	Botrytis Pythium
Chemagro 1843	Protective	S	S	Fusarium Pythium
Dichlone	Protective	F	S:D	Ascochyta
Nitrit	Protective	F	S	Rust
Karathane (Dinocap)	Protective	F	S:D	Powdery Mildew
Thiabendazole (TBZ)	Systemic	F	S:D	Fusarium
Benomyl	Systemic	F:S:I	S:D	Powdery Mildew Botrytis Fusarium Rhizoctonia Ascochyta
= Pyracarbolid	Systemic	F	S:D	Rust Rhizoctonia

* Application : F=Foliar; S=Seed Dressing; I=Soil Incorporated.

\+ Formulation : S=Spray; D=Dust; G=Granule, A=Aerosol.

** Possible Control Spectrum: Fungal species that have been controlled in legume crops; Commonly used controls Underlined.

= Experimental stage of development.

Source : Agricultural Chemicals; Book IV, Fungicides by W.T. Thomson.