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## IMPORTANT DISEASES OF COCOA AND THEIR MANAGEMNET

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## ABSTRACT

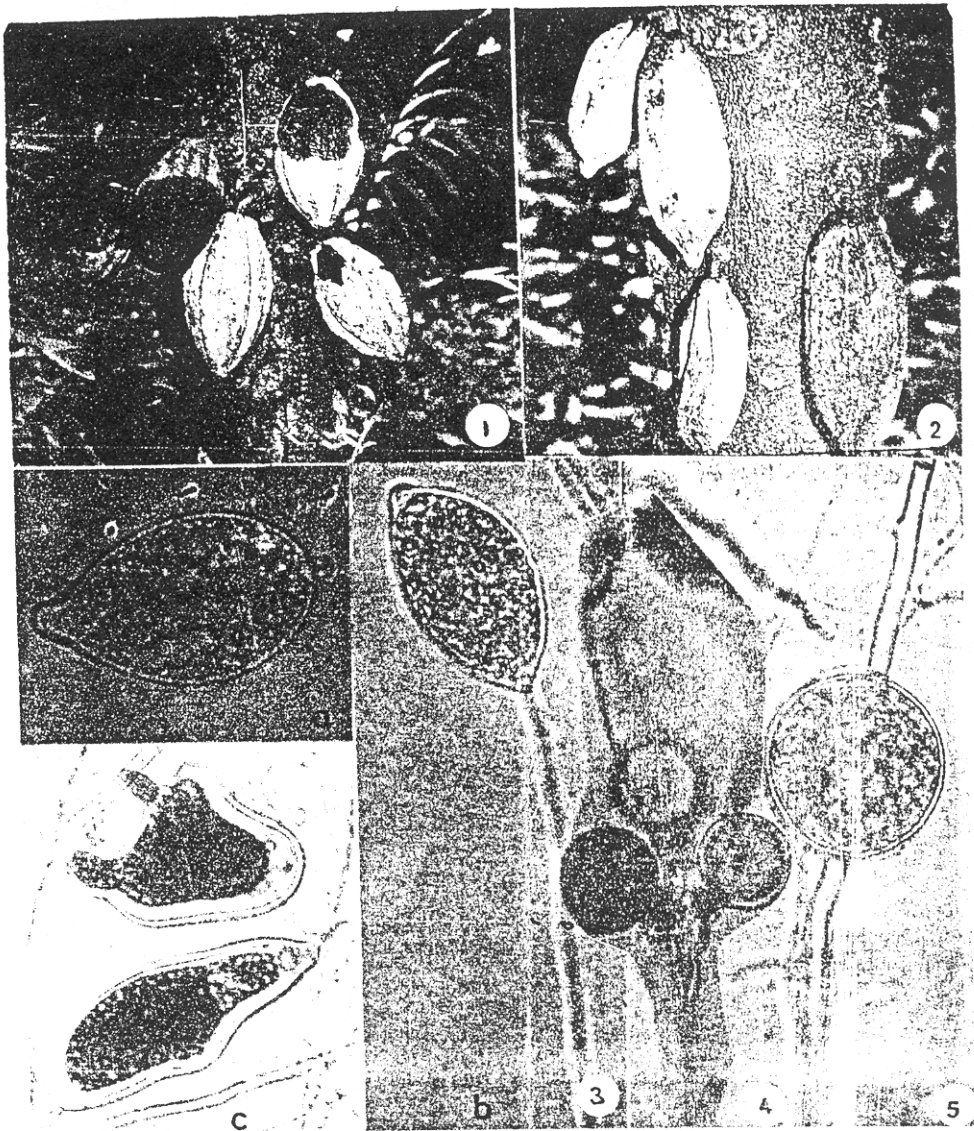
Though several diseases of cocoa have been reported from cocoa growing countries, only a few diseases are economically important. Among the nursery diseases, seedling dieback caused by *Phytophthora palmivora* has been found to be a serious problem during rainy season. Severity of the disease is very high in nurseries with very young seedlings during rainy season and warrants control measures. Pod diseases are very important from the economic point of view as they cause direct loss in yield. Black pod disease caused by *Phytophthora* spp. occurs in all cocoa growing countries during rainy season. In India too, it is a major problem owing to great economic loss it causes. *Phytophthora palmivora*, *P. capsici*, *P. megakarya* and *P. citrophthora* are the major *Phytophthora* species causing this disease. Effective control of black pod disease can be achieved through integrated disease management practices. Cherelle rot caused by *Colletotrichum gloeosporioides* is often mistaken as physiological wilt of cherelles due to close resemblance in the symptoms. Cherelle rot is controlled by spraying mancozeb or carbendazim. There are several other fungi causing pod rot of varying intensities in different countries. Among the fungal diseases affecting trunk and branches of cocoa, witches broom, vascular streak dieback and stem canker have been identified as major problems. Witches broom caused by *Crinipellis pernicioso* is a major threat to cocoa industry in some of the cocoa growing countries. An integrated disease management strategy consisting of phytosanitation, spraying with chemicals and use of host resistance has been recommended based on the studies conducted under the international witches broom project. Several fungi like *Phytophthora* spp., *C. gloeosporioides*, *Fusarium* spp. and *Marasmius* spp. cause foliar infection. But it may attain epiphytotic proportion only under certain environmental conditions. Cocoa swollen shoot disease caused by virus is the most economically important disease. It is still a major limiting factor in cocoa production in Ghana and Nigeria. Use of resistant/tolerant accession appears to be the ultimate solution to this problem. Since some of the diseases like witches broom, *Monilophthora* pod rot, cocoa swollen shoot etc. are confined only to certain countries, strict quarantine measures are necessary to prevent the introduction of these diseases into other countries.

## 1. INTRODUCTION

Cocoa (*Theobroma cacao* L.) was initially cultivated in tropical and central and south America. Subsequently it was found to be a suitable and profitable crop throughout the tropics. Cocoa is believed to have been introduced into India more than 200 years ago. But it was only from the early nineteen sixties that efforts were made to cultivate it as a commercial crop in the country. Large areas along the west coast of India are recognised as ideally suitable for the cultivation of cocoa. In this coastal region, arecanut (*Areca catechu* L.) and coconut (*Cocos nucifera* L.) are the major plantation crops grown, and the cultivation of cocoa as a mixed crop in these plantations has been accepted as a beneficial cropping system by the farmers in Kerala and Karnataka states. At present, cocoa cultivation is mainly concentrated in these two states. With the expansion of area under cocoa and with the increase in age of the plantations, pests and diseases are becoming more important. Crop loss due to diseases has been identified as one of the major production constraints in all cocoa growing countries. Yield loss of cocoa due to diseases is very difficult to estimate but various attempts have been made, showing 20-30% (39, 52, 80) loss. Several diseases of cocoa have been reported but only a few are economically important and are described in this chapter (Table 1).

Table 1 : Cocoa diseases - their causal organisms and distribution

| Disease  | Causal organism  | Distribution  | Reference               |
|--|--|---|-------------------------|
| <b>A. NURSERY DISEASES</b>   |  |   |                         |
| 1. Seedling dieback  | <i>Phytophthora palmivora</i>  | World wide  | 18, 50                  |
| <b>B. PODROTS</b>  |  |   |                         |
| 1. Black pod disease   | <i>Phytophthora palmivora</i><br><i>Phytophthora capsici</i><br><i>Phytophthora citrophthora</i><br><i>Phytophthora megakarya</i>                          | World wide  | 33, 115                 |
| 2. Cherelle rot  | <i>Colletotrichum gloeosporioides</i>  | Malaysia, India, Ghana  | 22, 65                  |
| 3. <i>Monilophthora</i> pod rot/watery pod rot/queredo disease/ <i>Monilia</i> pod rot | <i>Monilophthora rorei</i>   | North west region of South America (Peru, Columbia, Ecuador, Venezuela), southern part of Central America (Panama, Costa Rica)                            | 44                      |
| 4. Mealy pod rot   | <i>Trachysphaera fructigena</i>  | West and central Africa (Cameroon, Zaire, Ghana, Ivory Coast, Nigeria, Sierra Leone)  | 54                      |
| 5. Charcoal pod rot  | <i>Botryodiplodia theobromae</i><br><i>Macrophoma</i> sp.  | Ghana, Papua New Guinea, Nigeria, India   | 65, 74                  |
| 6. Warty pod rot   | <i>Geotrichum candidum</i>   | Brazil  | 4                       |
| 7. Pythium pod rot   | <i>Pythium vexans</i> de Bary  | India   | 32                      |
| 8. Stripe disease of pod (Bacterial disease)   | <i>Erwinia aroideae</i><br>( <i>Bacillus aroideae</i> )  | Ghana   | 105                     |
| <b>C. TRUNK AND BRANCH DISEASES</b>  |  |   |                         |
| 1. Witches broom   | <i>Crinipellis pernicioso</i> (Stahel) Singer  | Upper Amazon region of Brazil, Bolivia, Colombia, Ecuador, Grenada, Guyana, St. Lucia, St. Vincent, Panama, Peru, Surinam, Trinidad, Venezuela and Tobago | 94                      |
| 2. Cocoa swollen shoot disease   | Cocoa swollen shoot virus (CSSV)   | West Africa (Ghana, Ivory coast, 67 Nigeria, Togo and Sierra Leone), Sri Lanka, Colombia, Trinidad, Venezuela, Indonesia, Sabah                           |                         |
| 3. Other virus diseases  | Cocoa Mottle-Leaf Virus (CMLV)<br>Cocoa Yellow Mosaic Virus (CYMV)<br>Cocoa Necrosis Virus (CNV)<br>Ceylon Cocoa Virus (CCV)<br>Cocoa Trinidad Virus (CTV) | Ghana, Nigeria,<br>Sierra Leone<br>Nigeria, Ghana<br>Sri Lanka<br>Trinidad  | 106<br>"<br>"<br>"<br>" |
| 4. Vascular streak die-back  | <i>Oncobasidium theobromae</i>   | Papua New Guinea, Malaysia, Pacific Islands, Sabah, Phillipines and India   | 20, 41                  |
| 5. Stem canker   | <i>Phytophthora palmivora</i>  | World wide  | 50, 65                  |
| 6. <i>Ceratocystis</i> wilt  | <i>Ceratocystis fimbriata</i><br><i>Ceratocystis moniliformis</i><br><i>Ceratocystis paradoxa</i>  | Brazil, Colombia, Ecuador, Guyana, Peru, Venezuela, Costa Rica, Guatemala, Mexico, Trinidad, Fiji, New Guinea, Phillipines, Sri Lanka                     | 106                     |
| 7. <i>Verticillium</i> wilt  | <i>Verticillium dahliae</i>  | Brazil, Uganda  | 65                      |



Figs.1-5 :1. Symptoms of black pod disease; 2. Black pod disease : pods dried and mummified as a result of infection at the end of rainy season; 3. Sporangia : a. *Phytophthora palmivora*, *P. capsici*, *P. cytophthora*; 4. Oogonium with amphigynous entheridium and oospores of *Phytophthora palmivora*; 5. Chlamydospores of *P. palmivora*

|   |  |  |             |
|---|--|--|-------------|
| 8. Blights of shoots,<br>Chupons and grafts | <i>Phytophthora palmivora</i>  | Surinam, Nigeria, Ghana, Costa Rica, Brazil, India   | 19,72       |
| 9. Pink disease                             | <i>Corticium salmonicolor</i>  | Brazil, Colombia, Cammeroon, Ghana, Nigeria, Malaysia, Papua New Guinea, Peru, Western Samoa, Trinidad, India                | 20,65, 106  |
| 10. Thread blights                          |  |  |             |
| i. White thread blight                      | <i>Marasmius scandens</i>  | Ghana, Colombia, Malaysia, India   | 20,65       |
| ii. Horse hair blight                       | <i>Marasmius equicrinus</i>  | Ghana, Colombia, Malaysia, India   | 20,65       |
| 11. Dieback                                 | <i>Calonectria rigidiuscula</i><br><i>Botryodiplodia theobromae</i><br><i>Phytophthora palmivora</i>   | World wide   | 14,106      |
| 12. Leaf blight and<br>shot hole            | <i>Colletotrichum gloeosporioides</i><br>and other <i>Colletotrichum</i> spp.  | Mexico, Nicaragua, Costa Rica, Jamaica, Brazil, India, Trinidad, Sri Lanka, Cameroon, Malaysia, Phillippines, Nigeria, Ghana | 21,22       |
| 13. Cushion gall diseases                   | <i>Calonectria rigidiuscula</i>  | Most of the cocoa growing countries  | 30,100, 106 |
| i. Green-point gall                         | -  | -  | -           |
| ii. Flowery gall                            | -  | -  | -           |
| iii. Fan gall                               | -  | -  | -           |
| iv. Knob gall                               | -  | -  | -           |
| v. Disc gall                                | -  | -  | -           |
| 14. Red rust (Algal disease)                | <i>Cephaleuros virescens</i>   | Most of the cocoa growing countries  | 106         |
| <b>D. ROOT DISEASES</b>                     |  |  |             |
| 1. Brown root disease                       | <i>Phellinus noxius</i>  | Ghana, Nigeria, Sri Lanka, Malaysia, Papua New Guinea  | 65          |
| 2. White root disease                       | <i>Rigidoporus lignosus</i>  | Ghana  | 65          |
| 3. Black root disease                       | <i>Rosellinia pepo</i>   | West Indies  | 65          |
| 4. Collar crack                             | <i>Armillaria mellea</i>   | Ghana, Nigeria, Cameroon, Mexico, Brazil, Colombia, Papua New Guinea, Ivory Coast and Uganda                                 | 65          |
| E. Nutritional disorders                    | Deficiencies of N,S,P,Ca, Mg,K,Fe,Mn,Cu,Zn,B,Mo and Toxicity of B,A1, Fe,Cl, Zn, Mn, Cu  | Trinidad, Ghana, Cameroon, Malaysia, Ecuador, India  | 29,106      |
| F. Parasitic Plants                         | <i>Mistletoes</i> ,<br><i>Oryctanthus</i> sp.<br><i>Phoradendron</i> sp.<br><i>Piperoides</i><br><i>Pthirusa</i> sp.<br><i>Psittacanthus</i><br><i>Loranthus ferrugineus</i><br><i>Dendrophthoe constricta</i><br><i>Tapinanthus bangwensis</i><br><i>Struthanthus diclotrianthus</i><br><i>Phragmanthera incana</i> | Colombia, Costa Rica, Malaysia, Trinidad, Ghana, India   | 65          |

## 2. NURSERY DISEASES

### 2.1. Seedling dieback

It has been observed as a serious problem in nurseries during rainy season. Disease spreads very fast and mortality rate is very high in nurseries where seedlings are very young during rainy season. The infection starts either from tip of the stem, from cotyledonary stalk or from collar region as dark brown to black water-soaked linear lesion. However, it generally starts from the tip of the stem and spreads downwards. The lesions also extend to leaves through petiole resulting in wilting and subsequent defoliation of the seedlings. Hence the disease is commonly known as seedling dieback. The infection initiating from the cotyledonary or collar region is also found spreading upwards and downwards causing wilting, defoliation and ultimately death of seedlings (13). *Phytophthora palmivora* (Butl. Butl.) has been found to be the causal organism of this disease. Severe infection of grafted and budded seedlings caused by *P. palmivora* has been observed in India. In such cases, infection mainly starts from the grafted or budded region and proceeds upwards and downwards. The infection also spreads internally even after the rainy season leading to high mortality.

Proper drainage in the nursery is very important in the control of this disease. Infected seedlings are removed from the nursery as soon as noticed and destroyed. Thus, secondary spread of the disease can be checked to a certain extent. Drenching the seedlings with Bordeaux mixture (1%) or copper oxychloride just before the onset of monsoon and thereafter at frequent intervals is essential in nurseries with high disease intensity (18). A combination of seed dressing and soil drenching with kocide @ 0.19 kg in 45 l of water has been found to be very effective in controlling pre- and post-emergence seedling deaths caused by *P. palmivora* (6).

### 2.2. Other diseases

Foliar infection caused by *Colletotrichum gloeosporioides* is common in nurseries. White thread blight caused by *Marasmius scandens* Masee leading to dieback of six months old seedlings has been reported as a problem in nurseries with high humidity and less aeration and sunlight (18).

## 3. POD ROT

Several fungi have been reported to be associated with pod rot (Table 1). But, only a few are of economic importance. Some of the major pod diseases are of serious concern to growers as they cause direct loss in yield, year after year.

### 3.1 Black pod disease

Black pod disease was first noticed in Guyana and West Indies (58) and referred as black cocoa. This disease has been referred by different names in different language (105) and is most commonly known as 'Black Pod'. At present, it is prevalent in all the cocoa growing countries (115). Black pod disease was reported for the first time from India in 1955 (89). As early as in 1956, global losses due to black pod were estimated to be 10% (89), followed by 30% of the world's cocoa production. Losses from black pod vary from country to country: Nigeria (30%), Brazil (30.8%), Ghana (25-30%), Cameroon (95%), Dominican

Republic (10-20%) and Togo (10-80%) (65). In India, incidence of this disease has been found to vary from 12.93 to 29.78%, depending upon locality and garden. (20, 1985)

Black pod disease occurs in rainy season when humidity is high with constant optimum temperature. In India, this disease is a serious problem during south-west monsoon period (June-September). It is the most important disease of cocoa in this country owing to great economic loss it causes year after year. Pods of all ages are susceptible to the disease. The infection appears as one or more small, chocolate brown to dark brown circular lesion(s) anywhere on the pod surface. Within four to seven days of infection, the lesion enlarges assuming an elliptical shape. As the lesion advances a whitish growth of the fungus consisting of mycelia and sporangia is produced over the dark brown pod surface (Fig. 1). The lesion increases rapidly and cover the whole pod surface. After about 15 days of infection, the whole pod and beans are invaded by the fungus and the pod turns black in colour. By this time several saprophytic microorganisms colonise the rotten pod. The beans in ripe pod may escape partly or wholly from infection as the beans get separated from the pod husk on ripening (50, 106). Pods affected by the disease at the end of rainy season remain on the tree as black mummified fruits with growth of the fungus on its surface, showing dull white powdery coating (Fig.2).

*Phytophthora palmivora* (Butl.) Butl., *Phytophthora capsici* Leonian, *Phytophthora megakarya* Brasier and Griffin and *Phytophthora citrophthora* (Smith and Smith) Leonian are the major *Phytophthora* species causing this disease in various cocoa growing countries (115). In addition to these four major species, several other species of *Phytophthora* viz., *P. heveae* Thompson, *P. botryosa* Chee, *P. meadii* McRae, *P. drechsleri* Tucker, *P. nicotianae* Breda de Haan var. *nicotianae* Waterhouse, *P. nicotianae* var. *parasitica* (Dast) Waterhouse, *P. megasperma* Drechsler and *P. katsurae* Ko and Chang have been described as minor pathogens of cocoa (69, 109, 110, 115).

Though the occurrence of black pod disease in India was reported in 1965, further detailed studies on *Phytophthora* diseases of cocoa were not carried out for about 12 years, probably, because of the reason that cultivation of this crop was limited to a very small area. The large scale cultivation was started only in 1970s. Detailed studies on *Phytophthora* associated with pods, shoots, leaves and cocoa plantation soils in different localities of Dakshina Kannada district of Karnataka state revealed that *P. palmivora* is the only species occurring in this region (102). Recent taxonomic studies on *Phytophthora* causing black pod disease in India indicate that *P. capsici* (37) and *P. citrophthora* (35) also cause natural incidence of black pod disease in certain localities of Kerala state although *P. palmivora* is the predominant species in all the cocoa growing areas in India (Fig. 3). Both A1 and A2 mating types are found in *P. palmivora*, world wide, though A2 is the predominant compatibility type (115). *P. megakarya* isolates are mostly A1 with very few A2. Both A1 and A2 mating types are common in *P. capsici* population. *P. citrophthora* has been found to be sexually sterile. In India, both A1 and A2 mating types are found among *P. palmivora* and *P. capsici* population. A2 mating type is predominant in *P. palmivora* and A1 in *P. capsici*. All heterothallic species of *Phytophthora* have amphigynous antheridia. Oospores are produced when A1 and A2 mating types are paired (Fig.4). The occurrence of both mating types of different species in same locality reveals the possibility of intra- and inter-specific hybridization in nature and formation of new strains (36). This possibility is further supported by the observation on oospore formation in nature on infected cocoa pods (63). Among the four

principal *Phytophthora* species, *P. palmivora*, *P. megakarya* and *P. citrophthora* normally produce chlamydospores on carrot agar cultures whereas *P. capsici* does not form chlamydospores. Chlamydospores are produced abundantly by *P. palmivora* (115) (Fig. 5). The classification of cocoa *Phytophthora* into different species based on morphological characters is also supported by characteristic electrophoretic protein profiles (60,33), repetitive DNA polymorphism (81, 34), isozyme patterns (79) and serological techniques (31).

Turner and Asomaning (108) have reported that *P. palmivora* infects root and survives in soil during unfavourable periods. *P. megakarya* has been found apparently living inside the feeding root under favorable conditions (51). The sporangia produced on roots liberate zoospores that move to the soil surface under the influence of geotaxis. Rain splashes carry these spores to the pods at lower part of stem causing infection. Pods touching soil surface get infected directly. Sporangia are produced abundantly on infected pod surface under conditions of high humidity, rainfall and constant optimum temperature. These sporangia are spread by rain splashes, insects and rodents (106). Tent building ants and scolytid beetles have also been reported as agents carrying sporangia from diseased pods to healthy pods (73). Secondary spread of the disease is very fast. In the presence of water, sporangia germinate and produce zoospores. They swim in water and eventually come to rest and germinate. The germ tubes penetrate pod tissue and typical black pod symptoms appear on pod surface.

The effective control of black pod disease involves three main strategies: phytosanitation, use of chemicals and development of resistance in host. Since infected pods will form main source of secondary infection, all the diseased pods should be removed at weekly intervals or during each harvest. Proper spacing between plants and pruning are also important to regulate the shade. As soil acts as a significant reservoir of inoculum, mulches around the trees can reduce infection of lower pods (115). As there has been little research on biological control of black pod, this line of work should be intensified. Recently, an epiphytic bacterium has been isolated from healthy pods from a tree in an area with high level of black pod disease incidence in Costa Rica (48) and Malaysia (42). Spraying of this bacterium on pods provides better protection than copper fungicide. Experiments conducted during last 25 years reveal that copper based fungicides offer good control though in high rainfall areas spraying needs to be done so frequently that it may not be economical. In addition to copper fungicides, three tin based compounds (triphenyl tin acetate, triphenyl tin chloride and triphenyl tin hydroxide) have given successful control. Unfortunately, these organo-tin compounds have a high mammalian toxicity. A systemic fungicide, metalaxyl, initially showed encouraging results in the control of *Phytophthora* which developed some resistance to metalaxyl after few years of usage.

From the results of screening of 51 cultivars for *P. palmivora* resistance in Costa Rica, nine cultivars viz., EET 59, EET 376, UF 713, UF 715, Sca 6, Sca 12, Pound 7, Catongo and Diamantes 800 have been found exhibiting promising degree of resistance (66). As *P. palmivora* is the only species reported in Costa Rica, the results may be still valid for that country. The cocoa accession, C 78 has been found to be comparatively less susceptible to wound inoculation by *P. palmivora* (15). Chowdappa (31) identified C 44 as comparatively tolerant accession to all the three species of *Phytophthora* occurring in India. Penetration of pods by the pathogen and growth of the pathogen after penetration are the two phases when resistance mechanism operates in cocoa pods (92). Integrated disease management practices have to

be evolved involving chemical, cultural and biological agents vis-a-vis planting tolerant / resistant cultivars for effective control of black pod disease.

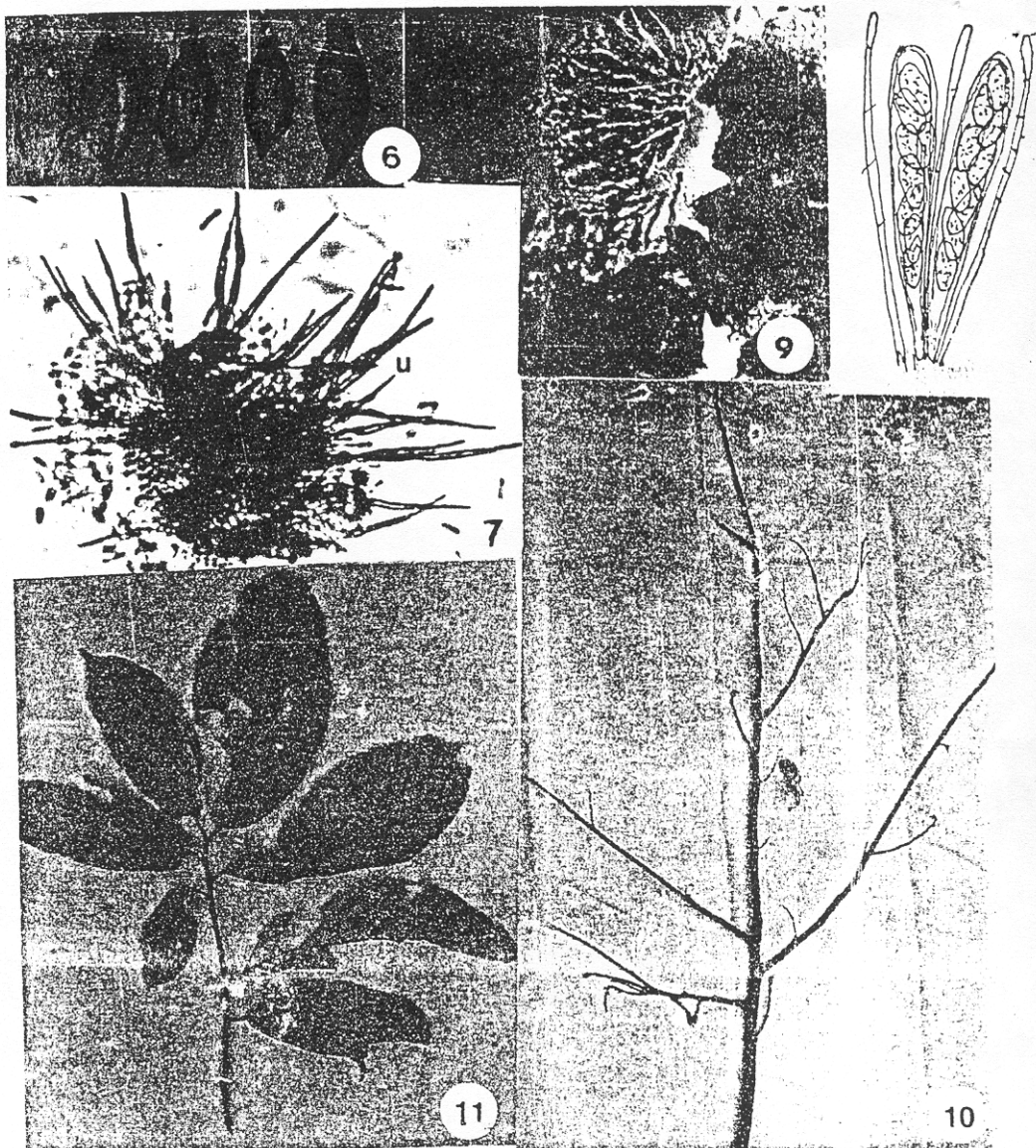
### 3.2. Cherelle rot

*Colletotrichum* disease was reported by Delacroix from Antilles in the french colonies of Africa as early as in 1905. Since then it has been recorded from various cocoa growing countries. In India, its occurrence was reported for the first time in 1976 (91,98). In the recent years the incidence of this disease is being increasingly noticed in all cocoa growing areas of the country (21). *Colletotrichum* spp. cause infection on pods, leaves, stems and roots of cocoa. The infection on pods has often been called pod rot (38,43,75). Since *Colletotrichum* infection is found only on younger pods, ChandraMohanani (18) has referred the disease as cherelle rot. Nearly mature pods are free from *Colletotrichum* infection.

The symptoms of cherelle rot mostly start from the stalk end, particularly at the point of attachment of stalk to the pod. The infection proceeds towards the tip of the pod as dark brown sunken lesion with a diffused yellow halo (Fig.6). The infection also extends to the stalk and reaches the cushion, but does not spread further in the cushion. The infected stalk becomes highly shrunken and can be easily distinguished from healthy stalk. As the infection progresses, the internal tissue of the pod also becomes discoloured. The infection may also start from anywhere on pod surface other than stalk region as dark brown sunken lesion. Such lesions coalesce and form bigger lesions. Abundant conidia of the fungus are produced as pinkish slimy mass on the lesions. Microscopic examination of this pinkish slimy mass reveals the presence of acervuli with setae and abundant conidia of *C.gloeosporioides* (Fig.7). Ultimately, the pod turns dark brown to black and remains on the tree as mummified fruit (21). At this stage, these pods can be easily confused for pods affected by cherelle wilt, which is a physiological phenomenon. The physiological wilt begins as a general yellowing of the entire pod (cherelle) followed by browning and blackening of the entire pod. Thus the physiological wilt of cherelles is distinguishable from cherelle rot. *Colletotrichum* pod rot is found only on cherelles and young pods with the maximum incidence on cherelles (16). Detailed studies have been conducted on the epidemiology of *Colletotrichum* diseases of cocoa occurring in India (27). The critical period for cherelle rot is February-May, when the susceptible stages of the pods are plenty (Fig.8).

Various species of *Colletotrichum* infecting cocoa pods have been reported and include *C.theobromae*, *C.luxificum* and *C.cradwickii* from West-Indies; *C.incarinatum* from Cameroon and Sri Lanka (9); *C.fructitheobromae* from Brazil and *C.theobromicolum* from Congo (106). *C.gloeosporioides* Penz has been reported as the causal organism of cherelle rot occurring in India (21,27). Though many species of *Colletotrichum* are reported, no effort has been made so far for a comparative study of isolates of *Colletotrichum* spp occurring in different cocoa growing countries so as to find out whether they are one and the same species. Detailed studies on *C.gloeosporioides* isolates collected from various localities in India reveal that there is a great variability in cultural and morphological characters as well as pathogenicity among the isolates (25,26). *C.gloeosporioides* isolates also exhibit marked variability in growth response to fungicides and antibiotics (28). Genetically, *Glomerella cingulata* (Fig.9), the perfect stage of *C.gloeosporioides* is known to be a variable fungus (111).

Bavistin WP (carbendazim 0.05%) and indofil M - 45 (mancozeb) 0.2% are reported to be promising fungicides for the control of *Colletotrichum* infection on cocoa (24). No study has been conducted to screen cocoa accessions against *Colletotrichum* infection.



Figs.6,7,9-11:6. Cherelle rot caused by *Colletotrichum gloeosporioides*; 7. *A. cervulus* of *C. gloeosporioides*; 9. Perithecium of *Glomerella cingulata*, a group of asci; 10. Vascular streak dieback : initial symptom of yellowing of leaves; 11. Vascular streak die back : axillary buds, sprouted and dead.

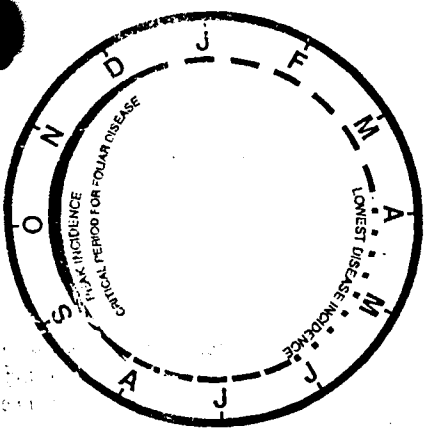
## 4. TRUNK AND BRANCH DISEASES

### 4.1. Witches brooms

Witches broom (WB) was first reported from Surinam in 1895. WB has long been known in low lands of tropical south America namely Bolivia, Colombia, Ecuador, Guyana, Peru, Surinam, Venezuela and West-Indies Islands of Grenada, Tobago and Trinidad (96). Average global loss due to WB is estimated to be 30% though upto 90% loss can occur where no cultural practices for the management of this disease are followed (95). The cocoa industry was closed in Surinam because of the recurring disease problem. The loss due to WB is set to increase in various cocoa growing countries as the disease continues to spread. As a result of infection characteristic shoots or brooms which are thicker than the normal healthy shoots are produced. Over development of meristematic tissue produces hypertrophied and proliferated growth of a normal bursting bud leading to characteristic broom. The internodes of such brooms are shortened. These brooms produce short lateral shoots with underdeveloped leaves. Fan brooms and chupon brooms can be seen on the affected plants. The brooms which are green initially turn to dark brown as a result of death of the tissue. Cushion infection leads to hypertrophied growth of flowers and shoots. Small pods on such cushions die. Pod symptoms vary very much depending on their maturity. Cherelles and young pods exhibit malformation. In larger pods the beans become liquified or adhere to the pod husk (94).

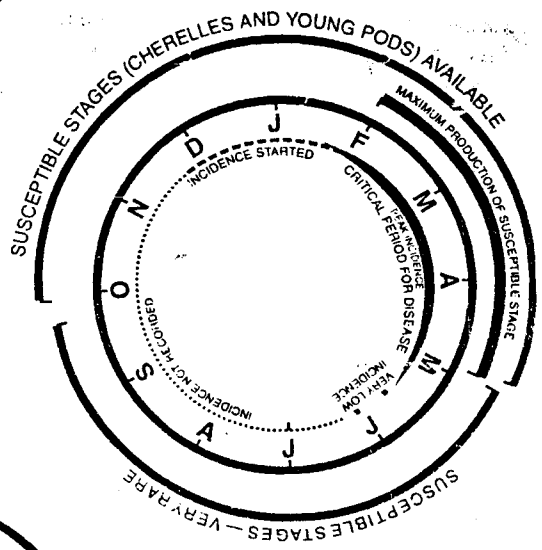
*Crinipellis perniciosa* (Stahl) Singer, a member of basidiomycetes, is the causal agent of witches broom. There seems to be considerable variation in both morphology and pathogenicity among the isolates of *C. perniciosa*. Based on the variability, two pathotypes have been identified among *C. perniciosa* population. *C. perniciosa* also infects *Herrania* and *Solanum rugosum*, a solanaceous weed, a host totally unrelated to the genus *Theobroma* or *Herrania* (44). *Crinipellis perniciosa* colonises host tissue and lives initially as an obligate biotroph and the fungus reverts to saprophytic mode when nutrients become a limiting factor. At this stage the fungus lives in dead tissues. Then, pink or red basidiocarps appear on the dead tissues after long incubation period of 6-66 weeks (96). Pure culture of *C. perniciosa* does not produce basidiospores. Successive wetting and drying during rainy season, temperature between 25° to 35°C and light intensity of 100  $\mu$  E/m<sup>2</sup>/s are considered to be more conducive for basidiocarp production. The brooms which are pruned and left on the ground act as source of inoculum (44). Basidiospores are thin walled and short lived. The maximum life expectancy of basidiospores does not exceed 48 hours. Germination of spores on suitable host tissue is completed in four hours after the spores are lodged under high humidity, and cause infection on expanding tissues resulting in a broom, diseased cushion or infected pod. Each broom appears from a separate infection. The fungus does not cause a systemic infection. The spores are light and carried by wind to a considerable distance. Long distance dispersal is limited largely due to fragile nature of spores and its limited life expectancy. During cloudy days, spores survival is enhanced. The other means of spread of the pathogen are through water, probably limited to within crop situation and through planting material carried by man.

Effective control measures have not been possible because of the complex interaction between pathogen, host growth and physiology, and agronomic practices (44). However, potential methods for managing disease formulated under the international witches broom project (IWBP) consist of 3 major strategies viz., phytosanitation, spraying with chemicals and use of host resistance (96). Phytosanitation includes regular pod harvesting, manual



(A) Disease incidence on leaves (leaf blight & shot hole)

(B) Disease incidence of pods (J to D- January to December)



(C) Phylloplane population of *C. gloeosporioides* in relation to climatic factor (DWP-dry weather period) (SWW-south west monsoon period)

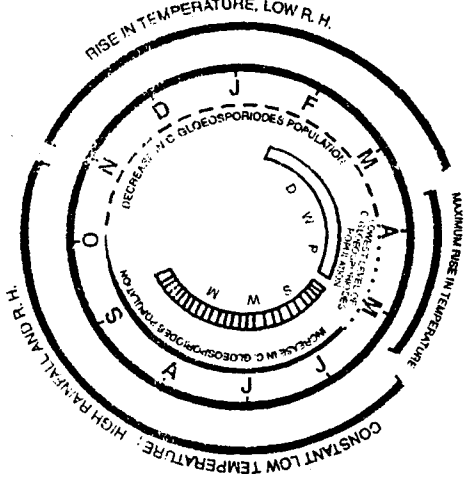


Fig.8. Seasonal cycle of *C. gloeosporioides* disease of cocoa in relation to climatic factors and phylloplane population of *C. gloeosporioides* (Chandramohanam *et al.* 1989)

weed control, structural pruning, chupon removal, withches broom removal and insect pest control. IWBP work clearly shows that phytosanitation methods reduce disease incidence dramatically in some but not in all situations, particularly in well managed plantations. Phytosanitary pruning in cocoa gardens with high incidence of WB markedly reduced infection level on flushes followed by reduction in pod loss from 50 to 27% in Brazil (3).

Commercial application of fungicides for the control of WB has not been adopted in any cocoa producing country because increase in production has not given considerable economic return. Among the various inorganic and organic protectant and systemic fungicides tested, copper fungicides have been found to be better if residual activity can be improved. Laker and Rudgard (1989) identified two main strategies for the management of WB: (a) protection of pods with a broad spectrum residual fungicide such as copper, (b) inhibition of broom formation and eradication of mycelium in shoots and flowers using a systemic fungicide.

The search for resistance to WB began in late 1930s when PFT Pound collected apparently immune cocoa from commercial estates in Ecuador and wild cocoa from the forest in Peru (The upper Amazon material). This germplasm was established in Trinidad where the incidence of WB was high. Based on this work, two clones Sca 6 and Sca 12 were selected and used in subsequent breeding programmes. Although, there was some success with these hybrids in Trinidad but they were severely infected in Ecuador where it is now known that different pathogenic forms of *C. perniciosa* exist. Success in breeding for resistance to WB has thus been limited and remained so.

#### 4.2. Vascular streak dieback

Vascular streak dieback (VSD) was first recognised as a serious disease of cocoa in Papua New Guinea in the early 1960s (41). It is a serious problem not only in Papua New Guinea but also in Malaysia and in Pacific Islands. In India at present, VSD has been observed in Thiruvananthapuram, Kottayam, Idukki, Kozhikode and Wyanad districts of Kerala state (18). Byrne (11) reported that the yield loss due to VSD was 25-50% in some parts of South-East Africa and Papua New Guinea. The first visible symptom of VSD is the yellowing of a single leaf in the second or third flush from the tip of twig with islets of green patches scattered over the yellowish lamina. Such leaves fall off prior to the older leaves of the same branch. Further, leaves up and down of the stem from the first fallen leaf develop similar symptoms and are lost (Fig. 10). This leads to distinctive appearance where the youngest and oldest leaves are still present but all the middle ones have fallen. The bark in the leaf fall region of the branch becomes rough due to swelling of the lenticels. The axillary buds of the fallen leaves sprout and then rapidly die (Fig. 11). At the later stage dieback symptoms appear on these branches. As a result of infection the xylem vessels turn brownish which appear as streaking within the vascular tissues. Hence the disease is known as vascular streak dieback.

The disease can be easily diagnosed in the field by stripping the bark or by splitting the affected stem longitudinally and observing the brownish streaks. If a thin layer of tissue is removed from the leaf scar left by the abscission of the infected leaf, dark brown to black dots, which are the discoloured vascular traces, can be seen. The discoloured vascular traces are also visible when the infected leaves are removed. In wet weather the fruiting bodies of the fungus appear as white crust around the leaf scars. The disease is most apparent in cocoa seedlings upto 18 months old, which are usually killed and is a major problem during seedling establishment (61).

VSD is caused by the fungus *Oncobasidium theobromae* Talbot and Keane (Basidiomycotina: Tulasnellales). The fungus is not seed borne. The disease is spread by basidiospores. These colourless basidiospores are shed only at night and are carried by wind. These spores that land on the surface of young unhardened cocoa leaves germinate and penetrate through the epidermis and mesophyll into the veins. From the leaf, fungus grows into stem through veins. An incubation period of three to five months occurs before the first symptoms are visible. Sporocarps have an average life span of ten days. The difference in symptoms and behaviour of the pathogen in callus culture (62,83) provides an evidence that different countries may have different strains of the pathogen and therefore strict quarantine measures are necessary while introducing new planting material.

There are three main phases in the disease cycle of *O. theobromae* which could be manipulated to manage the disease: (i) establishment of infection which can be measured as number of new infections per unit number of shoots per unit time, (ii) the rate at which the fungus colonises host tissue which can be determined from the length of vascular streaking in infected stem and (iii) the rate at which the fungus sporulates. The only known propagules of *O. theobromae* are basidiospores which are produced externally on sporophores. All these three phases of life cycle can be reduced by both chemicals and host genotypes (53,86,103). One of the first practices recommended for controlling VSD, apart from the use of resistant genotypes, is regular pruning of infected branches. For this, the branches are split open from the tip to reveal the extent of brown streaking in the wood. Then they are cut off 30 cm below the last point of visible streak as the fungus may be present beyond the brownish streak. Such regular pruning helps to remove infection from the plant by reducing internal colonisation of the fungus and also prevents spread of the disease by reducing the number of fungal propagules (41). Removal of the prunings from the garden is not necessary because the fungus can not live in dead and decaying plant parts. Monthly spraying of trizole fungicides (hexaconazole, tebuconazole and triadimenol) has been found to offer good protection against VSD (53). Nursery losses from VSD can be controlled by the use of a plastic roof over nursery (101) and this has been found to be cheaper and easier than chemical control. Although cultivars of upper Amazon and Trinitario origin are, in general, less susceptible to the disease than Amelonado or its hybrids, considerable variation exists within these populations. Among the cultivars of upper Amazon origin, PA 7 appears to be highly susceptible while KA 2-101 is resistant (84).

#### 4.3. Stem canker

Cocoa canker is of greatest significance in high rainfall areas. Canker disease was first reported in Sri Lanka (112). Since then it has been reported from various cocoa growing countries. In India, cocoa canker was first reported from Dakshina Kannada district of Karnataka state in 1978 (12). Now this disease is prevalent in all cocoa growing countries. Yield loss of cocoa due to stem canker is not available. A detailed survey of cocoa gardens in Kerala, Karnataka and Tamil Nadu states in 1980 revealed the occurrence of canker in 22% of the gardens surveyed (20). Incidence and intensity of the disease vary from country to country as well as from locality to locality.

In nature, canker lesions are observed on plants of all age groups. The symptoms on surface of the bark can be detected only by close examination. Usually the external lesions appear as round to oval, greyish brown or dark brown water soaked lesions on the external bark of the main stem and branches. A reddish brown liquid oozes out from the

lesion which later dries up to form a rusty deposit (Fig. 12). Usually collar infection (collar canker) in older plants appears as dark brown, irregular, water-soaked lesion with reddish brown liquid oozing out. The exudation is more at the collar region than other parts. The collar infection spreads to tap root and main stem and the tree succumbs to death much earlier (90). Tissues beneath outer lesion always appear as reddish brown discolouration which can be clearly distinguished from the surrounding creamy white healthy tissue (Fig. 13). The internal spread of the infection is always faster than the spread in the outer bark. Infection spreads from the cortical tissues to wood where it appears as dark brown to black streaks. When canker girdles the main stem or branches, the pods present on the tree wilt, leaves discolour and defoliate. Thus the branches show dieback symptoms and eventually the tree dies. Usually the disease is noticed only in advanced stages, when defoliation and dieback of twigs occur.

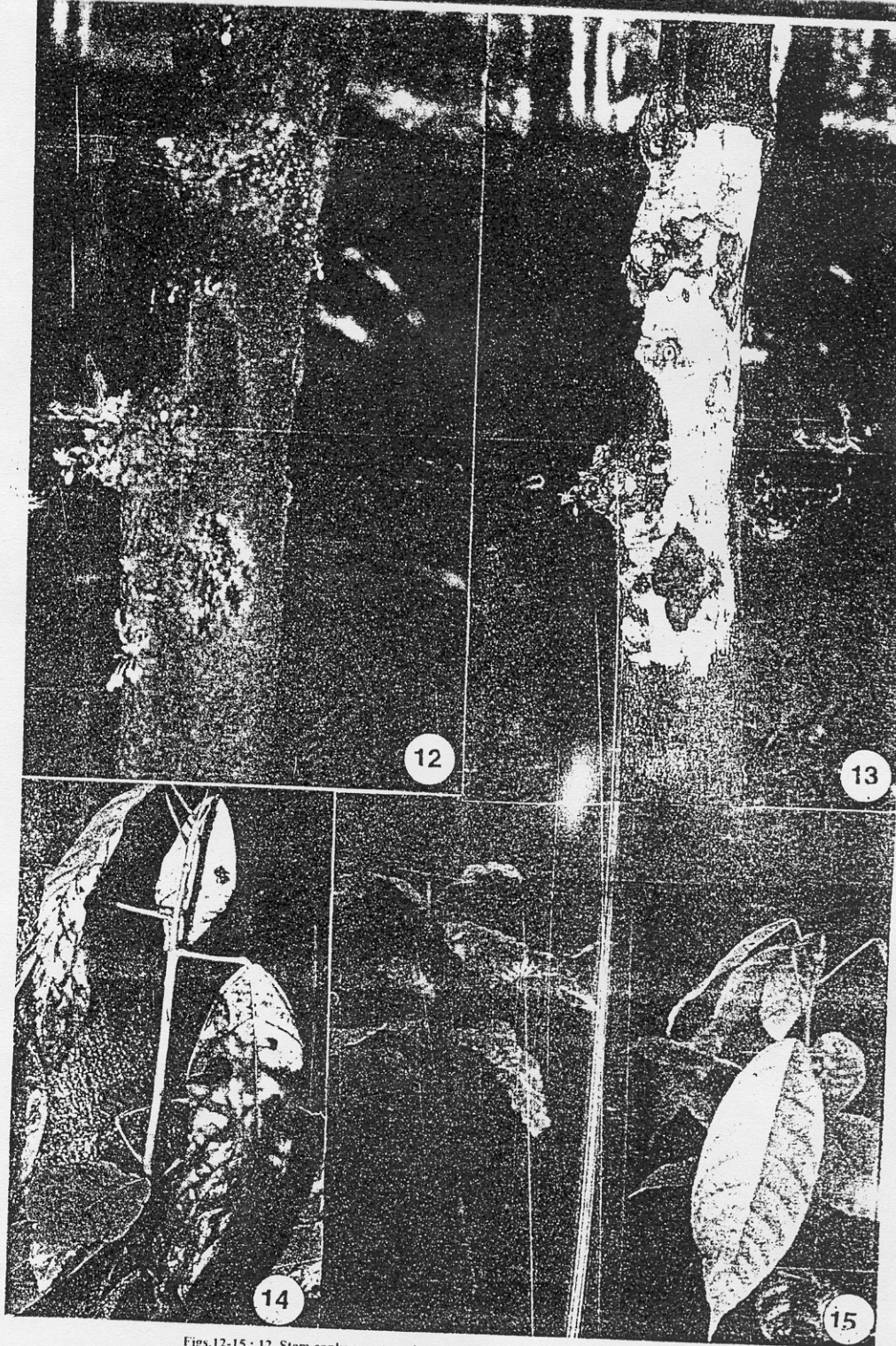
Based on the detailed studies on etiology and pathogenicity, *P. palmivora* has been identified as the causal organism of stem canker. Several workers have suspected connection between black pod and canker (9,46,85,93,104). They found that infection spreads from pod to peduncle and then to cushion and bark. High humidity and rain fall are predisposing factors for disease development. The occurrence of most of the lesions within 30 cm height above ground level might be indicative of the likelihood of soil acting as a reservoir for infection (51). Lesions higher up the trunk could have resulted either from infected propagules contained in soil splash during heavy rain or from infected pods (50). Although the entry of the pathogen has been reported to occur without any surface wounding, minute cracks in the bark may provide points of entry. Canker can also be associated with attack by the weevil *Antorhytes platus* (87). The disease is also transmitted mechanically when pruning knives contaminated by cutting through diseased bark are used to prune healthy trees (114).

The removal and burning of infected trees, use of pruning knives without any contamination and application of a wound dressing fungicide are recommended in Solomon Islands (47). However, excision of the diseased tissue followed by fungicide treatment and wound sealing have been widely practised (45). Scrapping away the bark over and around the canker followed by painting with 1% metalaxyl solution has been found to be effective in controlling stem canker in Papua New Guinea in comparison with captafol, cuprous oxide and copper hydroxide pasted on the scrapped portion (88). In Brazil, canker portion is surface sterilized with 2.5% cuprous oxide, 0.5% sodium hypochlorite and painted with 0.25% ridomil.

The susceptibility of criollo material to *Phytophthora* canker is widely known. Based on the studies on canker development in six cocoa genotypes in West-Indies, Oker et al (77) found IMC 67 to be resistant, TSH 1188 moderately resistant and TSH 1076, Sca and P 18 as susceptible. In Brazil, Pinto et al (82) reported BE 5 and EEG 8, showing the highest level of horizontal resistance, MA 15, EET 103, SPA 17, EEG 9 and EEG 65 intermediate and ICS 84, CAS 1 high susceptibility to stem canker.

#### 4.4. Chupon blight and twig dieback

Chupon blight and twig dieback caused by *P. palmivora* occur during rainy season. *Phytophthora* infection of chupons and twigs is very important as these phases of infection serve as sources of inoculum for severe incidence of black pod and canker diseases. The infection usually initiates in the axils of leaves at the tip of twigs or chupons. It also starts from anywhere on the leaf lamina (Fig. 14) or petiole and extends to the stem. The characteristic symptom is the appearance of water soaked lesions turning brown to black. When the



Figs.12-15 : 12. Stem canker : external symptoms on bark; 13. Stem canker : reddish discolouration of the internal bark; 14. Chupon blight : *Mythophora* infection starting from base of stem; 15. Chupon blight : *Mythophora* infection starting from base of stem.

lesions girdle the stem, the portion above the point of infection dies causing twig dieback or chupon blight. The infection results in severe defoliation in high rain fall area (19). The disease can be controlled by removing and destroying the infected twigs and chupons. In cases of severe incidence, the plants may be sprayed with 1% Bordeaux mixture or any other copper fungicide after removing the infected twigs and chupons.

#### 4.5. Leaf blight and shot hole

*Colletotrichum* infection of leaves has been recorded in most of the cocoa growing countries. *Colletotrichum* leaf blight has attained epiphytotic proportion in Ghana during 1975 (40). Foliar infection caused by *C.theobromicolum* was reported as one of the serious problems in Colombia (97). In recent years, leaf blight and shot hole symptoms have been increasingly noticed in different localities of the cocoa growing areas of India (21). Leaf blight is a serious problem in heavily shaded gardens like forest plantations and cocoa-areca mixed cropping systems and is mostly noticed on older leaves. Shot hole symptoms occur on plants which are more exposed to sun especially on border plants under mixed cropping systems and cocoa plants raised as a monocrop. Shot hole symptoms initiate on flush leaves. It has been observed as a serious problem in nurseries without adequate shade. Leaf blight initiates anywhere on the lamina, but more usually from the tip or margin. It appears as round to slightly irregular chlorotic spot which later turns to brown or grey with a clear yellow halo around the lesion. Such spots increase in size or coalesce to form large blighted areas. Defoliation occurs in advanced stages. Appearance of minute, round, sunken, light brown spots with distinct yellow halo on flush leaves is the initial symptom of shot hole disease. When such spots attain 4-6 mm diameter size, the centre of the necrotic spots shrivel and drop off forming shot holes. In advanced stages shrivelling of the leaves can be noticed. Affected seedlings in nurseries show retarded growth and unhealthy appearance (22). Foliar infection is found throughout the year in India. Studies on the effect of seasonal variation in disease intensity in India indicate that the intensity of leaf blight and shot hole gradually increases from July, reaches to a peak during September-November and decreases thereafter, reaching to the lowest level during April-June (Fig.8). The increase in disease intensity is associated with south-west monsoon period i.e. June-Novembe (27).

Detailed studies reveal that *Colletotrichum gloeosporioides* Penz. (perfect state: *Glomerella cingulata*) is the casual organism of leaf blight and shot hole disease. Acervuli with setae and conidia are found on the lesions. Conidia are oblong to cylindrical, hyaline, single celled with both ends rounded or one end tapering. The setae are dark brown to black and septate (16). The isolates of *C.gloeosporioides* exhibit great variability in cultural and morphological characters and virulence, indicating that there is considerable amount of genetic heterogeneity (25,26). Among the different species of *Colletotrichum* studied for variability, *C.gloeosporioides* was found to show greater variability (8). Genetically *Glomerella cingulata* is a variable fungus (111). Among the isolates of *G.cingulata* var. *orbiculare* are having relatively broad base of genes for pathogenecity (57).

Control measures are taken up in cocoa gardens with high disease intensity as well as in nurseries. Foliar infection caused by *C.gloeosporioides* can be controlled by spraying indocil M-45 (mancozeb) (0.2%) or 0.05% bavistin WP (carbendazim) (18).

#### 4.6. Thread blight

Thread blight occurs in most of the cocoa growing countries. There are two main types of thread blights in cocoa : white thread blight caused by *Marasmius scandens* and

horse hair blight caused by *Marasmius equicrinis* (65). Another type of thread blight caused by *Koleroga noxia* is important in some parts of Colombia (7). White thread blight kills the leaves by spreading a network of white mycelial threads over leaves, petioles and branches. The dead leaves remain suspended by strands of mycelia. Extensive death of young branches and suspended leaves in rows are the common field symptoms. Horse hair blight forms a tangle of thin black threads through the canopy of leaves. Due to this disease the dehisced leaves along with healthy leaves remain together and form a dense mass preventing the development of new flush. The thread blight spreads from plant to plant as well as to different branches of the same plant through affected plant parts, especially leaves carried by wind (23). The dead leaves with mycelial mat are easily carried by wind on to the leaves and stems of healthy plants and initiate the disease under favourable environmental conditions. Thread blight has been found to be more severe under conditions of heavy rainfall and humidity (9, 20). This disease can be effectively managed by removal of dead material and pruning of the affected parts. Shade reduction and structural pruning of the branches may help to reduce the disease incidence to a greater extent.

#### 4.7. Cocoa swollen shoot disease

Cocoa swollen shoot disease is still a major limiting factor in cocoa production in Ghana and Nigeria and is one of the most economically important plant disease in the world (107). The disease is wide spread in Ghana, Ivory Coast, Nigeria, Togo and Sierra Leone, Sri Lanka, Colombia, Trinidad, Venezuela, Indonesia and Sabah. Over 150 million cocoa trees have been destructed due to the disease since 1946 in Ghana (67). The yield loss varies from 5-20% in other cocoa growing countries (70). This disease is caused by a virus known as cocoa swollen shoot virus (CSSV) belonging to badnavirus group. The virus particles are bacilliform and about 121-130 x 28nm in size (10). There are 90 strains within CSSV. Of these, new juaben strain (*Theobroma virus* 1 A) which is prevalent in Ghana causes severe disease. CSSV strain 1 A produces typical swellings on fan branches, chupons and roots. Young flush leaves exhibit symptoms of red vein banding followed by chlorosis along side the veins. At a later stage of infection, a fern leaf pattern is produced. Pods become mottled, smoother than normal and rounded containing only half the normal weight of beans. Some strains do not produce swellings and most do not produce any pod symptom. All of them produce leaf symptoms which vary, enabling the distinction of strains. The virus infection is diagnosed by viro-bacterial agglutination (VBA) (56) and indirect protein-A sandwich ELISA (56) methods. These techniques can be used by plant quarantine for diagnostic purpose/detection. The CSSV group was differentiated into serogroups using seven antibodies by VBA (56). Virus specific proteins of MW 20,000 - 35,000 have been identified in CSSV infected plants by western blotting (56) which is used in diagnosis of the disease.

The disease is mainly spread through mealy bugs. It is also transmitted by grafting but not through pollen or seed. At least 14 mealybug species capable of transmitting the disease have been reported (10). Of these, *Ferrisia virgata*, *Planococcoides njalensis*, *Planococcus kenyae* and *Planococcus citri* are generally most abundant in the field with *P. njalensis* often the most important in transmitting CSSV. The mobile young mealy bugs and third instar nymphs are mainly responsible for transmitting the disease (5). In nature CSSV survives on various alternate hosts such as *Cola carticaefolia*, *Adansonia digitata*, *Corchorus stridens*, *Cola chlamyrantha*, *Ceiba pentadra*, *Cola gigantea* and *Sterculia tragacantha*.

Since CSSV is a major threat to cocoa industry in West Africa, it is important to enforce strict quarantine measures to prevent introduction of CSSV to other countries. There is no effective control measure for managing CSSV infection but its spread can be restricted by destruction of the virus sources. Attempts to control mealy bugs (vectors) with insecticides (rogor, metasystax, azodrin and bidirn) and biological control using exotic parasites and predators have not met any success. However, two unidentified Lepidoptera spp. have been suspected to be good predators on mealy bugs. In lab tests, predation on *P. njalensis* by two predators was found to be 63-83.3%. Attempts have been made to protect cocoa seedlings against the effects of severe *Theobroma* virus 1 A strain by using two mild strains SS 167E and SS 365B in Ghana but the results have been unsuccessful (78). Recent studies in Ghana have shown that inoculation of seedlings in green house with mild strain N is more successful than with strain SS 365 B in protecting the trees from the severe strain 1 A (55).

Amelonado variety is uniformly susceptible to CSSV but Amazon types exhibit variations in susceptibility. Legg (68) has shown that T 85/799 crossed with Sca 6, T 65/238 and PA 7; T 63/967 crossed with T 17/524, T65/238, IMC 60, T 73/612 and GA 11; T 79/467 crossed with T17/524, IMC 76, T65/202; and T63/971 crossed with T 65/238, IMC 60 and IMC 76 were promising in exhibiting tolerance to CSSV. Gamma rays induced mutants from amelonado, trinitario and upper amazon collections were found to be tolerant to CSSV and these were confirmed by ELISA and inoculation with viruliferous *Plamococoides njalensis* nymphs (1).

Most of the virus diseases occurring in West Africa are caused by isolates of CSSV. Three other viruses, cocoa mottle leaf virus, cocoa necrosis virus and cocoa yellow mosaic virus have also been reported from Nigeria and Ghana. Cocoa necrosis virus produces distinctive leaf symptoms of translucent distorted patches along the veins. The shoots may wilt and exhibit dieback symptoms. The virus is not transmitted by mealy bugs. Cocoa mottle leaf virus produces red mottle symptoms on flush leaves followed by vein clearing and banding. Cocoa yellow mosaic virus produces irregular chlorotic blotches or chlorotic mosaic. It is neither transmitted through seed nor mealy bugs but by mechanical inoculation.

## 5. NUTRITIONAL DISORDER

### 5.1. Zinc deficiency

Zinc deficiency in cocoa has been reported in Ghana (2,49), New Guinea (99) and West Malaysia (76). It has been observed as a serious problem in some of the gardens in Kerala and Karnataka (29). Chlorosis of leaves is the initial symptom of zinc deficiency. In advanced stages green portion is found only along the sides of the veins, exhibiting a vein banding appearance to the leaves. Leaves are malformed due to mottling and crinckling with wavy margin. Young leaves are narrow, small and sickle shaped showing characteristic little leaf symptoms (Fig. 15). Twigs show rosette type of growth due to shortening of internodes. Premature defoliation and dieback of twigs occur in severe cases (71, 113).

Jurinak and Thorne (59) have reported that zinc solubility in soil is minimum within the pH range of 6-8. High pH and poor aeration of the soil are attributed as the main causes of zinc deficiency in New Guinea (99). Schroo (99) has reported that spraying with 2.5g zinc sulphate every ten days corrected zinc deficiency within seven months. Application of zinc sulphate at the rate of 2 kg per/ha either to the soil or as a foliar spray corrected zinc deficiency in two and half years old potted Amazon cocoa seedlings (2). Detailed studies on the correction of zinc deficiency in cocoa plantings in India reveal that foliar spray of 3 g zinc

sulphate and 1.5 g lime per litre of water corrects the deficiency to a greater extent (29).

## 6. CONCLUSIONS

Among the fungal pathogens, *Phytophthora* has been found to be the most important pathogen infecting all parts of cocoa plant. Very detailed investigation on black pod disease has been carried out in all the cocoa growing countries. Other phases of *Phytophthora* infection may also be considered as equally important as they help in inoculum build up in the garden. The intensity of *Colletotrichum* disease is increasing year by year. The virulence of the pathogen may vary with the ecologically distinct strains. Hence susceptibility of cocoa cultivars to *Phytophthora* and *Colletotrichum* infections varies not only from country to country but also within the country. While formulating disease management strategies, it is important to consider host-pathogen-environment interactions so that effective control of the disease can be achieved through an integrated approach.

*Pythium* pod rot has so far been reported only from Indian. Though this disease is not important at present, the pathogen may attain epiphytotic proportion in future. Hence, effective management needs to be evolved to avert likely flare up of this disease in coming years.

Some of the diseases like swollen shoot, witches broom, *Moniliophthora* pod rot etc. are not present in all the cocoa growing countries. Therefore, strict quarantine measures are necessary to prevent the introduction of these diseases into such countries.

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