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6 PHYTOPHTHORA DISEASES OF PLANTATION CROPS IN INDIA

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ABSTRACT

The genus *Phytophthora* began with type species *P. infestans* de Bary. At present, the genus contains 50 morphological species. The species of *Phytophthora* are unique and can be distinguished from other fungi by their special characters such as vegetative diploidy, presence of cellulose in the cell walls instead of chitin, heterokont flagella in zoospores and resistance to polyene antibiotics such as pimaricin. The genus *Phytophthora* belongs to the family Pythiaceae of the order Peronosporales within Oomycetes under kingdom Mycetae; most of them are serious plant pathogens causing wide range of diseases on food, vegetable, forage, fruit, ornamental, plantation crops and forest trees. They attack roots, stem bases, growing points, fruits and foliage of plants. Although a large number of taxonomic keys are available, the identification of *Phytophthora* is still seems to be difficult due to limited morphological criteria based on which species are being identified and a large amount of variability and overlapping exits within species. The biochemical and molecular evidences such as protein patterns, isozyme profiles, mt DNA-RFLP and r DNA sequence data have shown that *Phytophthora* taxonomic keys based on morphological criteria have limitation as exemplified by *P. megasperma* species complex, and *P. cryptogea* and *P. drechsleri*. Revised classification schemes involving a combination of both morphological and molecular criteria may be needed. Studies on host-pathogen interactions indicated that *Phytophthora* species do not possess unique specialised machinery for colonising their respective hosts. Structural features of the hosts, preformed chemical inhibitors, induced structural barriers, hypersensitive reaction and phytoalexins have been reported to provide resistance against *Phytophthora*. However, host resistance in all the crops is either inadequate or totally absent. Though integrated disease management is the strategy, fixed schedules of prophylactic copper fungicidal applications still hold good for coconut, arecanut, cocoa and rubber. The systemic fungicides like metalaxyl, Fosetyl-Al and potassium phosphonate were also found equally effective in checking *Phytophthora* on coconut, arecanut, black pepper and cardamom. Even though copper fungicides are effective, phytosanitation coupled with eco-friendly bio-control methods through soil application of *Trichoderma* and *Gliocladium*, VAM and fluorescent pseudomonads have been found to be highly promising for management of soil borne problems like capsule rot of cardamom and foot rot of black pepper. Biocontrol options are less attractive for other crops because of the target infections are aerial parts. Innovative methods like disease guards have been highly cost effective in managing arecanut *Phytophthora*.

1. INTRODUCTION

The name *Phytophthora* is derived from the Greek that literally means, "Plant destroyer". The genus *Phytophthora* was first created by Anton de Bary 1876 when he described the potato late blight fungus, *Phytophthora infestans* as type species. For several years, *P. infestans* was the sole representative of the genus. Later, many species of *Phytophthora* were described. At present, this genus contains more than 50 morphological species (193). Most are serious plant pathogens causing wide range of diseases on food, vegetable, forage, fruit, ornamental, tree crops and forest trees. They attack roots, stem bases, growing points, fruits and foliage of plants. European potato famine of the mid-19th century caused by *P. infestans*, devastation of *Eucalyptus* forest ecosystems in Australia due to *P. cinnamomi* root rot, destruction of pepper plantations by *P. capsici*, heavy loss of cocoa due to black pod caused by *P. palmivora* and *P. megakarya* and fruit rot of arecanut due to *P. meadii* in tropics are some of the examples of destructive diseases of crops and native vegetation caused by *Phytophthora* (27). Some *Phytophthora* species are host specific (e.g. *P. sojae* on soybean) while others have wide host range (e.g. *P. cinnamomi* is known to infect 900 different plants) (226). Moreover, different species can cause same disease on a particular host (e.g. *P. palmivora*, *P. megakarya*, *P. capsici* and *P. citrophthora* cause black pod on cocoa) (45). Thus, *Phytophthora* species cause considerable impact on agricultural economy.

2. UNIQUE FEATURES AND TAXONOMIC POSITION OF *PHYTOPHTHORA*

Species of *Phytophthora* have a number of unique characteristics, which can distinguish them from other fungi (27, 68, 226). The major part of the life cycle is

diploid, whereas other fungi are haploid. The cell walls of *Phytophthora* are made up of cellulose (β-glucans) while the common cell wall component of most of the other fungi is chitin. The zoospores have heterokont flagella (one tinsel and one whip lash). *Phytophthora* species do not synthesise sterols but require an exogenous source of β-hydroxy sterols for sporulation. They are resistant to polyene antibiotics such as pimaricin, a characteristic feature that is correlated with the requirement for an exogenous source of β-hydroxy sterols. The genus *Phytophthora* is closely related to the genus *Pythium* and both genera are placed in the family Pythiaceae of the order Peronosporales within Oomycetes under kingdom Mycetae. Both *Pythium* and *Phytophthora* have coenocytic mycelium and vegetative diploidy, produce zoosporangia in water and form sexual oospores singly within the oogonium after fertilisation by a nucleus from the antheridium. These genera can be differentiated by the morphology of sporangia, chlamydospores and oospores. The sporangia of *Phytophthora* are always terminal and ovoid or obpyriform whereas sporangia of *Pythium* can be globose, lobulate or filamentous and intercalary. In *Phytophthora*, protoplasm differentiates into zoospores within the sporangium whereas in *Pythium*, the protoplasm flows from the sporangium into a vesicle in which zoospores differentiate. The antheridia of *Phytophthora* can be amphigynous or paragynous but in *Pythium*, the antheridia are always paragynous. The species of *Phytophthora* are considered to be evolved from heterokont algae based on ultra-structural similarities such as heterokont flagella, tubular mitochondrial christae, flagellar rootlet structure, mitotic apparatus, electron dense bodies in zoospores and oogonia, endoplasmic reticulum and cell wall microfibril structure and bio-chemical similarities such as mode of dehydrogenase regulation, cytochrome system and oxidative metabolism, lysine and sterol synthesis pathways and mode of storage of β-1-3-glucans and nucleic acid sequence data (27). Because of these features, some place the Oomycetes to which *Phytophthora* belongs, in the kingdom Protista and others place Oomycetes within more natural group, kingdom Chromista, containing heterokont algae, diatoms and other tinsel flagellate protists (33, 58).

3. LIFE CYCLE (FIG. I)

The mycelium, the thallus of the fungus, consists of hyaline, branched, coenocytic filaments (Fig. 3), each of which is called as hypha. In younger cultures, the cytoplasm flows freely within mycelium and occasionally septa are seen in older cultures. The diameter of the mycelium ranges from 5 to 8 μm. Mycelium may be smooth, swollen, nodose or tuberculate. *Phytophthora* produces asexual spores under suitable conditions. Sporangia are asexual spores that are normally produced on stalks called sporangiophores, which differ slightly or indistinguishable from vegetative hyphae. Sporangia are hyaline to yellow. Some species of *Phytophthora* produce sporangia with a papilla at the tip. The papilla contains a hydrated material with a refractive index different from the wall material of hyphae, which dissolves before the release of zoospores. The sporangia may germinate in aqueous solution either by the production of germ tubes or production of uninucleate biflagellate zoospores within sporangium. The sporangia release the zoospores into membranous vesicle that soon breaks, allowing zoospores to swim away (Fig. 2). The zoospores are reinform in shape with two heterokont flagella (whiplash and tinsel) arising from the concave side. Zoospores swim for hours and round up and develop cell walls. The spores at this stage are called as cyst. The encysted zoospores germinate by production of germ tubes and mycelia. The zoospores are major infectious propagules.

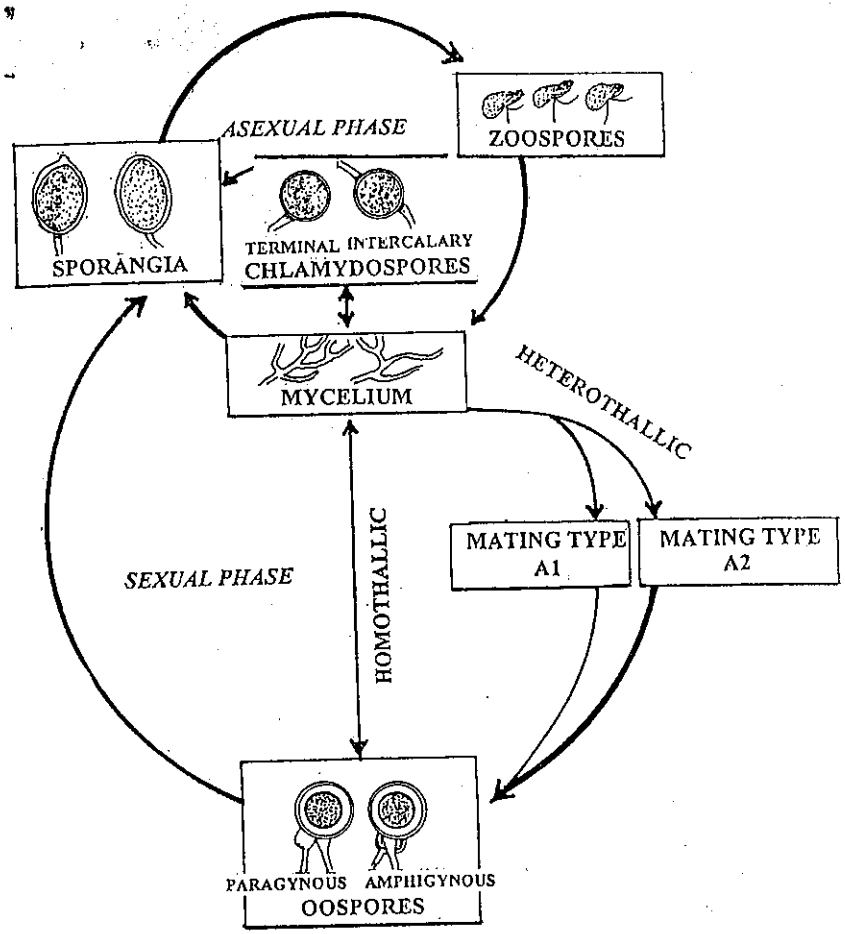
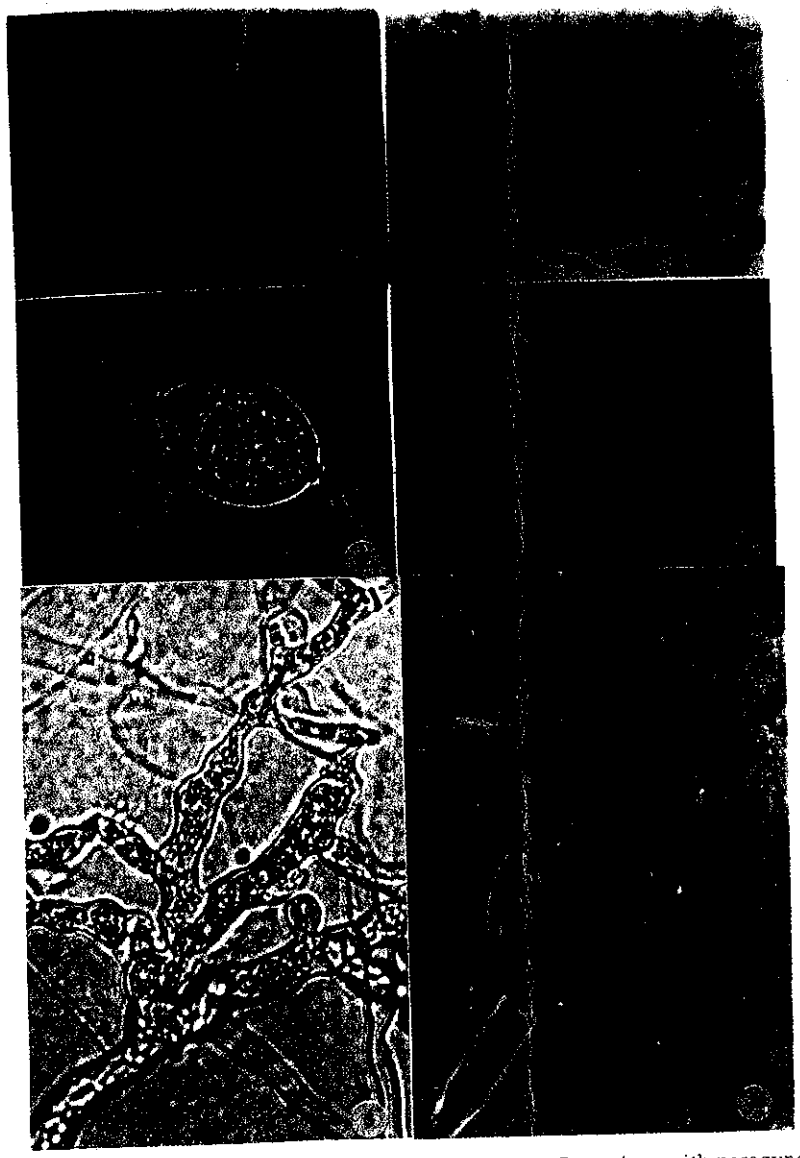
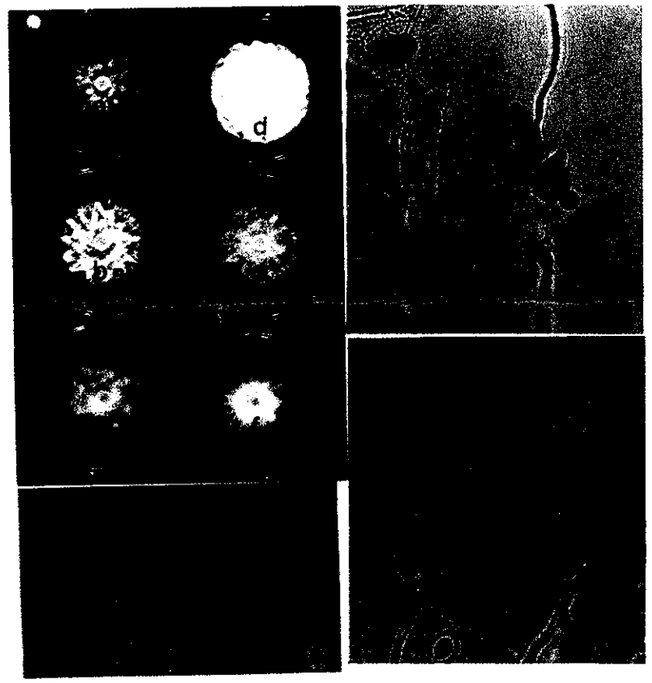


Fig. 1 : Life cycle of *Phytophthora*

Chalmydospores, another asexual spore of *Phytophthora,* are formed in soil, gravel or plant tissue during unfavourable environmental conditions. The chlamydospores are spherical to ovoid and are delineated from hyphae by a septum. They may be terminal at the hyphal tips or intercalary (Figs. 5 and 6). These structures are hyaline or deep brown and either thin or thick walled, ranging from 0.5 to 1.5 µm (86). The chlamydospores are distinguished from hyphal swellings because they are delimited from the mycelium by septa. Survival of chalmydospores in soil is similar to that of zoospore cysts. Chlamydospores can survive in the gastrointestinal tracts of birds and



Figs. 1-6. Morphological structures of *Phytophthora* : 1. Oogonium with paragynous antheridia of *P. capsici*; 2. Sporangium relasing zoospores; 3. Mycelium of *P. capsici*; 4. Oospore of *P. capsici*; 5. Terminal chlamydospore of *P. palmivora*; Intercalary chlamydospore of *P. palmivora*.



Figs.7-10. 7. Colony patterns of P. capsici: A, D, E & F. Cocoa isolates; B.Black pepper isolate; C. Bell pepper isolate; 8-10. Morpholoty of sporangiophores; 8. Irregular (*P. citrophthora*); 9. Umber pattern (*P. capsici*); 10. Simple sympodium (*P.palmivora*).

termites, which may spread the fungus. Chlamydospres germinate under favorable conditions and may form mycelium or sporangia or chlamydospres and apparently continue the cycle for many years.

The antheridia (male) and oogonia (female) are the sexual structures of *Phytophthora*. The antheridia are usually singles monoclinous or diclinous, spherical, oval, clavate or short cylindrical, often angular and borne on lateral hyphae. They are amphigynous or paragynous. The oogonia are usually terminal on lateral hypahe, occasionally intercalary, globose or sub-globose occasionally pyriform, delimited from hyphae by a thick septum (Fig. 1). Wall of oogonium is thin and hyaline in the beginning, and often coloured (yellow to brown) with the age, smooth in most cases, tuberculate or reticulate in few cases. Reduction of chromosomes from diploid to haploid occurs in coenocytic antheridium and oogonium. A fertilization tube from the antheridium ruptures the ooginal wall and deposits the antheridial nucleus. A single oospore forms within the oogonium. Oospores are spherical, smooth, hyaline or sometimes faint yellow (Fig. 4). Outer wall is thin and inner wall is characteristically thick composed largely of β-1-3-glucans. The oospore wall is electron dense and about 20 nm thick when viewed under electron microscope (86). Under light microscope (450x), ooplast (a birefringent body) and pellucid bodies can be seen within oospore. The haploid nuclei from the antheridium and oogonium fuse to form the diploid nucleus. The diploid oospore germinates under suitable conditions by production of single or multiple germ tubes at the tips of which sporangia may or may not form. Some species of *Phytophthora* are homothallic, whereas others are heterothallic. Oospores in heterothallic species form at the junction where A1 and A2 matin types grow together on a suitable medium. In heterothallic species, oospore production can also result from selfing by production of hormone like substances by the opposite mating type (106). In such cases, the progeny are selfs and genetic recombination of factors from both parental types does not occur. Wounding of a culture with a scalpel (169), exposure to volatile compounds produced by *Trichoderma viride* (26), and liquid extracts from roots of avocado (225), have been found to stimulate production of oospores in A2 isolates. These phenomena may help for survival and perpetuation of *Phytophthora* as oospores in field and they can withstand dry conditions much better than asexual spores and cause disease epidemics.

4. CULTURAL, MORPHOLOGICAL, BIOCHEMICAL AND MOLECULAR CRITERIA OF *PHYTOPHTHORA* SPECIES CHARACTERIZATION

4.1 Taxonomic schemes

Waterhouse *et al* (220) stated '*Phytophthora* has always been recognized as a notoriously difficult genus especially for those who wished only to identify an isolate and were not concerned with taxonomic problems and /or minute details'. The genus began with type species *P. infestans* de Bary in 1876, which was identified by monopodial branching habit of sporangiophores and papillate sporangia that release zoospores in free water. Later, Rosenbaum (170) described 11 additional species based on type of antheridium papillae on sporangium, sporangial dimensions and length: breadth ratio (l/b ratio), presence or absence and size of chlamydospores and abundance and size of oospores. He was the first researcher who utilized the l/b ratio of sporangia as an aid in distinguishing a species. The subsequent key developed by Tucker (212) was based not

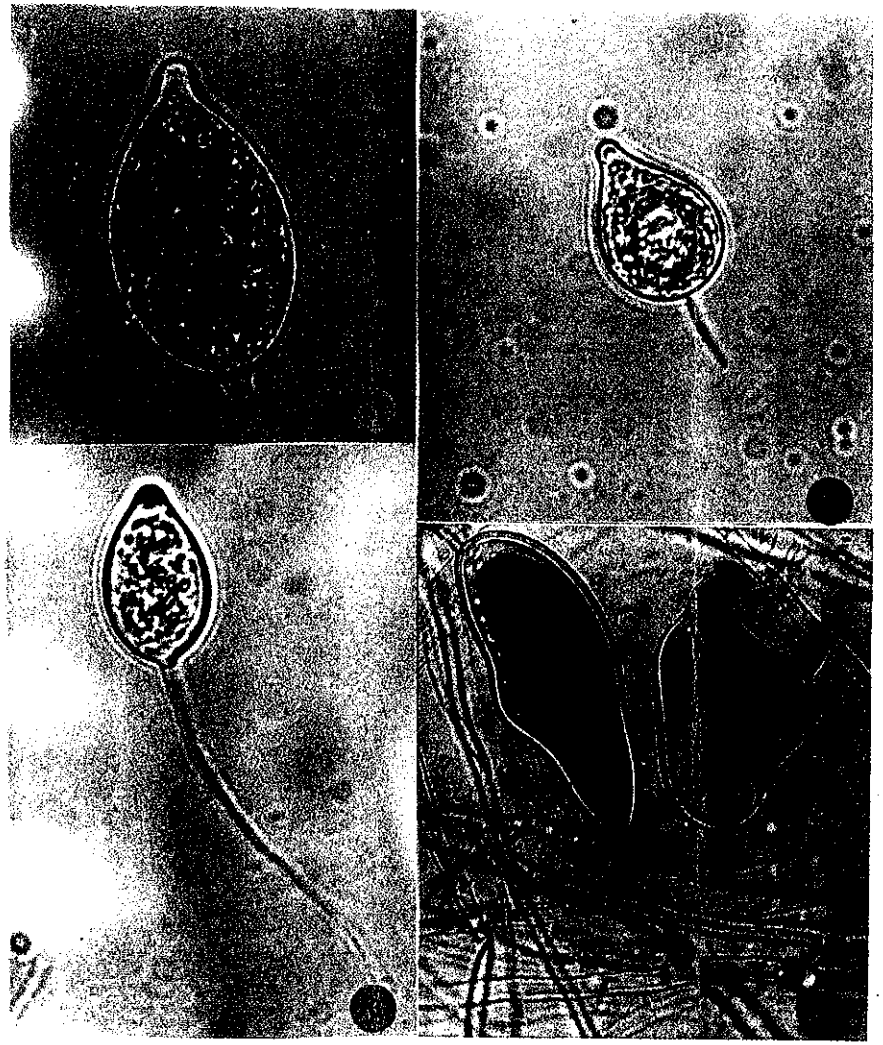
recognized 21 species. They were identified based on their ability to grow on certain media, host specificity, pathogenicity and cardinal temperature for growth in addition to morphological criteria of Rosenbaum. Leonian (111) developed identification key by utilizing most of the Tucker's criteria but added growth on malachite green and production of sporangia by transfer of mycelium in pea broth to water for differentiation of species. Leonian (111) included 22 species in his key. He objected to type species concept and saw the variability within a species that is now recognized to be a problem in *Phytophthora* taxonomy (67). He also exposed the need for physiological parameters to separate species. Subsequently, several other taxonomic keys based on *Phytophthora* species in local areas were published in South Africa (215), Argentina (75), Great Britain (219) and Germany (190).

Waterhouse's (217) taxonomic key was the first to classify the species into six morphological groups based on morphological (branching patterns of sporangiophores, sporangium apex, abundance of sporangia on solid media, caducous or persistent nature of sporangia, internal proliferation of sporangia, homothallic and heterothallic, nature of antheridium, sporangium shape and size, hyphal swellings, presence or absence of chlamydospores, oogonium size, ornamentation of oogonial wall), physiological (cardinal temperature) and host-specificity. Newhook *et al* (136) revised the Waterhouse's (217) key and included another six new specis and presented in tabular key format which was based on the same criteria as of 1963. The latest revision of this tabular key by Stamps *et al.* (193) incorporated the original groups of I-VI of the 1978s key besides group VII for marine species. This key contains 67 morphological species. Based on the occurrence of paragynous or amphigynous antheridia, papillation of sporangia and several other characters, Krober (1985) described 17 species of *Phytophthora* found in Germany in German language. Another key (75), which was published in Spanish, included species from Argentina. Ho (89) presented the synoptic key, which included 38 culturable species, but its utility has not been tested. Ho *et al* (91) presented a synoptic key for the 23 *Phytophthora* species that was prevalent in Taiwan.

4.2 Cultural and morphological criteria

The cultural and morphological criteria which have been formed as a basis for the taxonomic keys for identification of *Phytophthora* species are described below.

4.2.1. ***Colony morphologies*** **:** Waterhouse *et al* (220) suggested that colony patterns and hyphal branching would be useful for characterization of *Phytophthora*. Culture patterns depend on the media used to a certain extent. However, the characteristic colony patterns could be produced best on potato dextrose agar or corn meal agar or carrot agar. Waterhouse *et al* (220) recognized five typical culture patterns (stellate, uniform, radiate, chrysanthemum and camellia or rose) in *Phytophthora*. In the chrysanthemum pattern, the sectors are narrowly petalloid (*P. citricola*). In the camellia or rose types, the sectors are broadly rounded and petal like (*P. cinnamomi, P. syringae* and *P. dreschsleri*). In the stellate pattern, the colony radiates like star (*P. palmivora*). In some species, the mycelium grows without any definite pattern (*P. infestans*). In some species, the cultures display radiate pattern (*P. citrophthora*). The colony characters are not distinctive enough to be of diagnostic. For instance, *P. capsici* displayed large variability in colony morphologies (Figs. 7A, B, C, D, E, F). Leonian (111) also reported that



Figs. 11-14. Non-caducous and caducous sporangia with different pedicel lengths : ...rt pedicel length of *P. palmivora*; 12. Medium pedicel length of *P. meadii*; 13. ...lks of *P. capsici*; 13. Non-caducous sporangia of P. citrophthora.

Fig. 15. Bud rot of coconut caused by *P. palmivora*.

(89) reported that branching characters at the margin of colony are characteristic feature of certain species such as *P. cinnamomi*, *P. cactorum* and *P. sojae*. The apical segment ratio of the growth at the margin of the colony on 1/10 strength V8 juice agar was 1.7 for *P. cinnamomi*, 1.3-1.5 for *P. cactorum* and 4.3 for *P. megasperma*. However, branching angles do not differ much among the three species (70-80° for *P. cinnamomi*, 80° for *P. megasperma* and 65-70° for *P. cactorum*). A lot of data on many species and growth conditions need to be generated to find out the use of Ho's (87) study in *Phytophthora* taxonomy. Hyphal swellings as chains or clusters in the mycelium have been noticed in water cultures of some species such as *P. cinnamomi*, *P. cambivora*, *P. drechsleri*, *P. cryptogea*, and *P. megaspera*.

4.2.2 *Morphology of sporangia* : Some species of *Phytophthora* produce sporangia on natural solid agar media, whereas others need subsequent incubation in aqueous solution. In some species, sporangia borne on simple (*P. palmivora*) or compound sympodium (*P. infestans*) (Fig. 10) whereas some species (*P. capsici*) form sporangia in an umbel pattern (Fig. 9). Formation of sporangia through external or internal proliferation of sporangia characteristic feature in some species (68). External or internal proliferation of sporangia appears to be much more typical of taxonomic groups V and VI than of groups I, II, III and IV. Sporangia are classified as papillate (Waterhouse groups I-II), semi-papillate (Waterhouse groups III-IV), non-papillate (Waterhouse group VI) on the basis of apical thickening (217). Species that are definitely papillate include *P. capsici* and *P. palmivora*. Species with semi papillate sporangia are *P. primulae*, and *P. infestans*. Species such as *P. cinnamomi* and *P. cambivora* fall under the category of non-papillate sporangia. Although the morphological characteristics of papillate, semi-papillate and non-papillate species differ, the basic sequence of events leading to zoospore formation within sporangium and dissolution of the plug before emission of zoospore is the same for all species (220). Caducity and pedicel length of sporangia are characteristic features of certain species (218). The caducous types are categorized into short pedicels (< 5μm) as in *P. palmivora*, *P. infestans* and *P. cactorum*; intermediate (5-20 μm) as in *P. meadii*, *P. colocasiae* and *P. botryosa* and long (> 20 μm) as in *P. capsici* and *P. hibernalis* (3) (Figs. 11-14). They reported that pedicel length is more diagnostic feature for identification of *Phytophthora* rather than caducity. Sporangia are variable in shape and usually identified as sub-spherical, ovoid, obovoid, ellipsoid, limoniform, pyriform, obpyriform, or obturbinate (220). The size of sporangia is known to be influenced by environmental and cultural conditions and size differences may not be of much use in diagnostic purposes (68). The length: breadthy ratio of sporangia has been considered as useful in *Phytophthora* taxonomy but the data are not definitive.

4.2.3 *Chalmydospores* : Chlamydospores are globose, occasionally irregular to oblong in shape (220). They are terminal or intercalary and delimited by separation from the mycelium and can be confused with hyphal swellings that are not delimited by separation from mycelium (Figs. 5, 6) (24). Chlamydospore walls are thin or thick. Since the presence or absence and size and shape of chlamydospores do not vary among species, its significance in *Phytophthora* taxonomy is limited (68, 220). *P. palmivora* produces chlamydospores abundantly but only some isolates of *P. meadii* and *P. capsici* produce them. In this case presence or absence may be a useful indicator. *P. lateralis* is distinguished by production of sesile chlamydospores. Abundant chlamydospore production coupled with numerous hyphal swellings and non-papillate sporangia are the diagnostic features for identification of *P. cinnamomi*. *P. macrochlamydospora* is

Figs. 18-21. Bud rot, crown rot and collar rot of arecanut caused by *P.meadii* : 18. Bud rot (Spindle leaf affected); 19. Crown rot (outer leaves affected); 20. Rotting of crown portion due to crown rot; 21. Collar rot of seedlings.

electrophoretic protein banding patterns alone, Hamm and Hansen (84) described *P. pseudotsugae* as a new species of *Phytophthora.* Also in support of electrophoretic techniques as a functional taxonomic criteria protein profiles were employed as major criteria for distiguishing six protein subgroups of *P. megasperma* (85). Electrophoresis of native protein was also found useful in separating and grouping isolates of six species of *Phytophthora* encountered on deciduous fruit crops which could also be distinguished by cultural, morphological characters and cardinal temperature (23). Comparative studies on *Phytophthora* isolates of cocoa revealed that *P. palmivora, P. capsici, P. megakarya* and *P. citrophthora* could be resolved into different groups based on protein patterns and this variation has been correlated with differences in sporangial stalk length and other morphological characters (41, 100). From the foregoing, it could be inferred that morphological and physiological differences between species of *Phytophthora* are reflected in differences in protein banding patterns. Except in one case (*P. pseudotsugae*), protein profiles have been used more as confirmatory than primary evidence for identification of species. Forster and Coffey (69) indicated that biosynthesis of proteins might by under environmental or developmental control and then need not necessarily be constant.

4.3.2 ***Isozyme patterns*** **:** Variations in isozyme patterns have been successfully applied in identifying genetic diversity within population and clarifying difficult taxonomic problems facing *Phytophthora* (120, 124, 138, 140, 141, 142, 143, 144, 145) and has been found to be highly correlated with mt DNA RFLP (69, 70, 71, 72, 73, 74, 124). Isozyme banding patterns are less complex than protein banding patterns and can be differentiated and intepreted more easily. Using isozyme profiles, Old *et al* (140, 141) reported that genetic variability among the isolates of *Phytophthora cinnamomi* from Australia was relatively low. *Phytophthora megasperma* has long been reported as heterogeneous species (85). Six isozyme groups *P. megasperma* f.sp. *glycinea, P. megasperma* f.sp. *medicaginis, P. megasperma* f.sp. *trifoli,* apple, apricot and cherry, Douglas fir and broad host range groups within *P. megapserma* have been distinguished (138) similar to the protein groups of Hansel *et al* (85). These data have been found correlated closely with analysis of mt DNA RFLP (72, 73). These results provided evidence for elevation of these formae speciales into separate species, *P. sojae, P. medicaginis* and *P. trifoli.*

Ho *et al.,* (92) suggested that *P. camibivora* and *P. cinnamomi* might be related based on few common morphological criteria such as production of non-papillate, noncaducous, ovoid sporangia and some antheridia with two cells. Using isozyme analysis, Oudemans and Coffey (142) demonstrated that *P. camibivora* and *P. cinnamomi* were not related. Eight electrophoretic types (ETS) were distinguished within population of *P. cinnamomi.* Oudemans and Coffey (143) examined the intraspecific diversity and interspcific relatedness of *P. cactorum* (group I) and twelve papillate species of *Phytophthora* within group II of Waterhouse's (217) taxonomic key based on isozyme analysis and confirmed *P. botryosa, P. heveae, P. katsurae, P. meadii, P. palmivora* and *P. parasitica* as valid species. *P. arecae* was identical to *P. palmivora.* The two varieties, *P. nicotianae* and *P. parasitica,* which were separated based on oospore size and host specificity, were nonspecific. In contrast, *P. caspici, P. citrophthora* and *P. megakarya* exhibited higher level of variations in isozyme profiles and sub-groups were readily distinguished. Isolates of *P. capsici* including isolates of *P. palmivora* MF 4 were separated into three subgroups CAP 1, CAP 2 and CAP 3 whereas *P. citrophthora* isolates were divided into two

subgroups (CTR 1 and CTR 2). *P. megakarya* had two subgroups (MGK 1 and MGK 2). *P. cactorum* had the lowest level of genetic diversity. Further studies of Mchau and Coffey (120) indicated that *P. capsici* isolates were clustered into two subgroups Cap A and Cap B. Tucker (212) differentiated *P. drechsleri* and *P. cryptogea* by growth at 35° C for *P. dreschsleri* and no growth for *P. cryptogea* and also demonstrated that sporangia of *P. drechsleri* were longer than those of *P. cryptogea.* Later, many workers (29, 83, 90) proposed merging of these two species into *P. cryptogea* based on their similarities in morphology and variability in temperature. But, Mills *et al* (124) concluded that atleast seven molecular species exist within *P. cryptogea, P. drechsleri* group based isozyme and mt DNA RFLP patterns. Oudemans *et al* (145) distinguished five molecular subgroups (CIT1, CIT2, CIT3, CIT4 and CIT5) within *P. citricola* based on isozyme and mt DNA RFLP patterns. The isozyme patterns and mt DNA RFLP and ribosomal DNA analysis (110) indicated a close relationship between *P. citricola, P. capsici* and *P. citrophthora.* Oudemans *et al* (145) suggested that papillation of sporangia, sporangium caducity, hetero and homothallism and paragyny and amphigyny of antheridia may not be reliable taxonomic criteria.

4.3.3 *Restriction fragment length polymorphism (RFLP)* : Taylor (201) reviewed value of studying mitochondrial DNA (mt DNA) restriction fragment length polymorphism (RFLP's) and other mt DNA characteristics in fungal systematics. In recent years, molecular techniques particularly DNA RFLP's have been found to be highly useful for detailed analysis of genetic variability within and genetic relatedness between species (69, 70, 71, 72, 73, 74, 124). Forster *et al.* (72, 73) showed that DNA patterns are more effective in typing individual speceis because DNA molecules genetically determine the nature of organism whereas morphological, physiological and biochemical differences are based on minor genetic variations. RFLP technique involves digesting a DNA preparation with a restriction enzyme and separating the fragment according to their size by electrophoresis on gels. After transfers on to a membrane it is possible to localize a unique or newly repeated sequence by hybridization with an appropriate radioisotope labelled probe. Applying this method, some researchers (43, 48, 49, 146) demonstrated that after digestion and electrophoresis, the total DNA of *Phytophthora* had distinct restriction digestion patterns, whereas within any single species, all isolates showed identical profiles regardless of the enzymes used. Most of repetitive DNA was of nuclear origin. Based on this finding, they suggested that this method has practical advantage over the RFLP's that is possible to prepare DNA, digest it with restriction enzyme and to obtain it's electrophoretic patterns in a single day and therefore, there is no need to develop radio isotope labelled probes. A defect of this method is that it does not provide information at the sub-species levels.

The series of publications on mt DNA-RFLP's (72, 73, 74, 124) resolved the problems concerning whether the morphologically similar species of *P. drechsleri* and *P. cryptogea* should be merged (29, 83, 90), whether *P. nicotianae* var. *parasitica* and *P. niotianae* var. *nicotianae* were distinct and whether all the formae specialis included within *P. megasperma* were one species or more (67, 85). Mills *et al* (124) conclusively established that there were seven distinct molecular speceis within 123 isolates of *P. drechsleri* and *P. cryptogea* based on mt DNA RFLP and isozyme patterns. The DNA RFLP data of Panabieris *et al* (146) also showed *P. cryptogea* (two isolates) and *P. drechsleri* (two isolates) to be different. Thus, merging of these two species as suggested by earlier workers (28, 83, 90), based on morphological criteria might not be valid. RFLP patterns

Figs. 22-25. Management of fuit rot of arecanut caused by *P. meadii* : 22. Bordeaux mixture spray (Note diseased nuts); 23. Polythene covering of arecanut bunches (100% control); 24-25. Phytophthora disease of coca : 24. Black pod disease caused by *P. palmivora*; 25. Stem canker caused by *P. palmivora.*

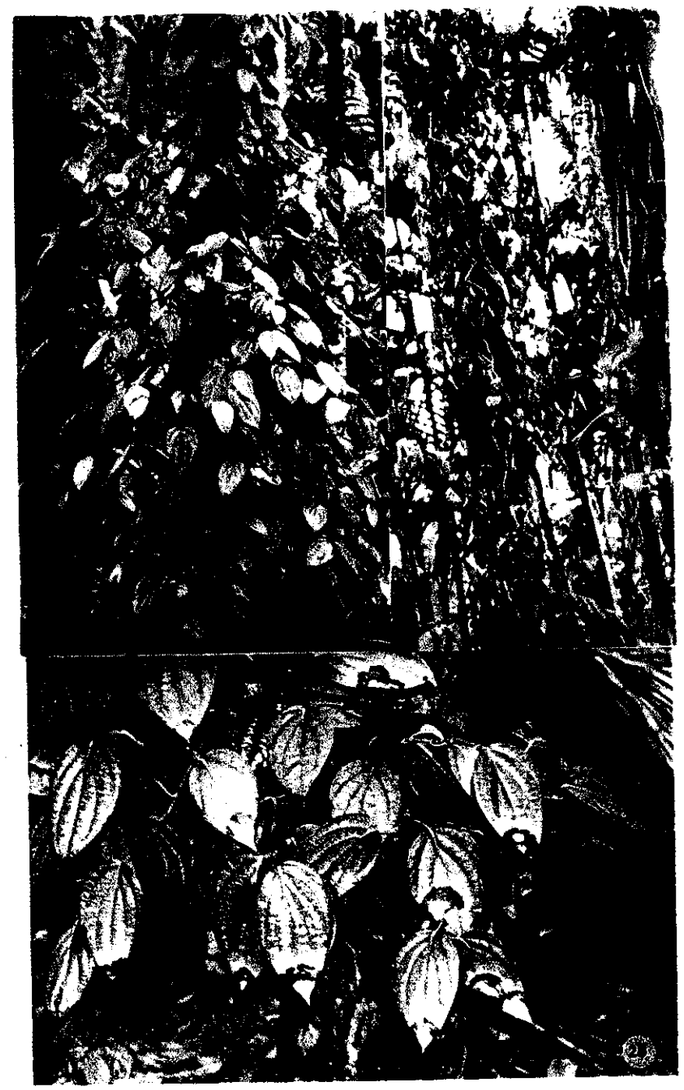
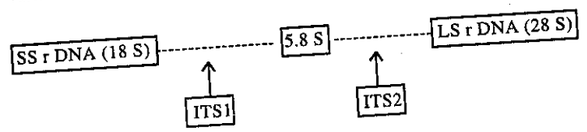


Fig. [illegible] Black pepper caused by P. capsici : 26. Initial infection; 27.

of Panabieres *et al* (146), Forster *et al* (74) and Forster and Coffey [illegible] *Phytophthora parasitica* var. *nicotianae* could not be differentiated from *P. parasitica* isolates supporting the conclusion of Ho and Jong (90) based on morphological grounds. Panabieres *et al.*, (146) reported that *P. cactorum, P. megakarya, P. parasitica, P. capsici, P. citrophthora, P. infestans, P. cambivora* and *P. cinnamomi* had distinct RFLP patterns. Similarly, cocoa pathogens, *P. palmivora, P. megakarya, P. citrophthora* and *P. capsici* were also distinguished by DNA RFLP profiles (43, 146). DNA RFLP profiles also showed that the Australian isolates of *P. vigne* from cowpea (*Vigna unguiculata*) were genetically similar to Japanese isolates from adzuki beans (*Vigna angularis*) (112). Thus, DNA RFLP patterns have been used in resolving complex problems facing *Phytophthora* (25).

4.3.4 ***Polymerase chain reaction (PCR) - amplified ribosomal DNA spacer polymorphisms*** : The methods used by Forster *et al* (74) required several grams of mycelium to extract sufficient amounts of mt DNA and procedures are cumbersome. However, the use of polymearse chain reaction (PCR) has largely overcome this problem since only nanogram quantity of DNA are required as a template for amplification. The ribosomal RNA gene repeat (r DNA) contains a mosaic of highly conserved and variable regions. The internal transcribed spacer regions (ITS1 and ITS 2) of r DNA, which lie between 18s and 28s lack a functional role (137), have been extensively used in studying variations in *Phytophthora* (53, 54, 55, 110).



Schematic representation of r DNA of *Phytophthora*

The ITS region of ribosomal gene repeat can be amplified as defined by primer pair (ITS 1 and ITS 4) by using polymerse chain reaction. Polymorphisms' have been revealed either by restriction digestion of the amplified product (Ca 900 bp) or by sequencing of a part or entire region. Analysis of the ITS 1 and ITS 2 regions of the r DNA of five *Phytophthora* species revealed excellent differentiation at the species level (110). It also showed a close evolutionary relationships between cocoa isolates of *P. capsici* and *P. citrophthora* and common lineage for *P. palmivora* and *P. megakarya* with *P. cinnamomi* being only distinctly related. Using sequence analysis of ITS region of r DNA, Crowford *et al* (55) showed that sporangium papillation has phylogenetic significance with the three groups (papillate, semi papillate and non-papillate) of taxonomic key of Waterhouse (217), each forming separate clusters. DNA sequence data also confirmed for reclassification of *P. medicaginis, P. trifoli* and *P. sojae* as separate biological species from *P. megasperma* complex. *P. cryptogea* and *P. drechsleri* were distinguished. *P. macrochalmydospora,* which has been reported only from Australia on soyabean, was closely related to *P. sojae.* Cooke and Duncan (54) published sequences of 16 species of *Phytophthora* with representatives from each of the six groups of Waterhouse (217) and showed differences at the species level. Thus, these studies indicated the potentiality of ITS restriction fragment analysis for developing molecular

database for rapid identification of *Phytophthora* species and further development of species- specific PCR primer and DNA probes for using in diagnostics.

The biochemical and molecular evidences such as mt DNA RFLP, isozyme and protein patterns and r DNA sequence data have shown that *Phytophthora* taxonomic keys based on morphological criteria have limitation as exemplified by *P. megasperma* species complex and *P. cryptogea* and *P. drechsleri*. Revised classification schemes involving a combination of both morphological and molecular criteria may be needed. Molecular criteria have advantages over morphological characters since they are not influenced by environmental and cultural conditions. The r DNA sequence data may provide species specific PCR primer and diagnostic probes, which will be useful for rapid identification of unknown isolates within a short period.

5. HOST - PATHOGEN INTERACTION

Some species of *Phytophthora* induce soft rot symptoms. Keen and Yoshikawo (103) reported that *Phytophthora* might produce enzymes that may macerate the host tissue and initiate infection process. For instance, soft rot pathogens such as *P. capsici* and *P. palmivora* have been reported to release active enzymes, which macerate and degrade cell walls (223). However, production of such enzymes by other species of *Phytophthora* seems to be low (50, 119). Toxic principles have been isolated from culture filtrates of *Phytophthora* species but their role in the disease development has not been demonstrated (103). Duniway (59) showed the involvement of fungal carbohydrate polymers in producing wilt symptoms. The purified mycolaminarans such as β-1-3 glucans from *Phytophthora* have been reported to cause wilting symptoms in bioassays with cuttings of several plant species (105, 222). However, role of these mycolaminarans in causing wilting symptoms either by plugging of the vascular elements or by a direct toxic effect on plant protoplasts is not clear. It was reported that cell wall carbohydrates from *P. infestans* caused agglutination and death of protoplasts from potato leaves (62, 144). Further, ultrastructural studies indicated no evidence for cell wall dissolution or toxigenic host cell responses in tissues infected by pathogenic races and species of *Phytophthora* (195). Exceptionally, several host cell changes were reported during early stages of infection in the *P. capsici* - bell pepper interaction system, possibly due to macerating factor produced by *P. capsici* (223). Thus, *Phytophthora* species do not possess unique, specialized machinery for colonizing their respective host tissues.

Structural features of the host, preformed chemical inhibitors, induced structural barriers and hypersensitive reaction (HR) and phytoalexins have been reported to be useful in providing resistance against *Phytophthora*. Production of encasements around haustoria of *P. infestans* and lignification in the resistant potato cultivars were considered to be associated with resistance to *P. infestans* (103). Preformed chemical substances such as mustard oils in cruciferous plants, barbonols -alkyl-substituted lactones in certain species of *Persea* against *P. cinnamomi* have been suggested but not proven as resistance factors. Phytoalexins, defined as antifungal compounds produced by plants in response to invasion of pathogens, have been found to play a vital role in the physiology of resistance (102, 194). These compounds can be inducible in plant tissues in response to inoculation with incompatible pathogens, elicitors produced from pathogens, chemicals such as heavy metals or physical injury caused by UV light or freezing. The phytoalexins that have been implicated in resistance to *Phytophthora* are rishitin in potato (*P. infestans*), glyceollin in soybean (*P. sojae*), capsidiol in pepper (*P. infestans* and

P. capsici), wighteone in lupine (*P. sojae*), medicarpin in alfalfa (*P. medicaginis*), kievitone in cowpea (*P. vignae*), scoparone in citrus (*P. citrophthora*) and safynol in safflower (*P. drechsleri*). The phytoalexins from legumes, glyceollin from soybean and medicarpin from alfalfa are derived from isoflavins whereas from solanaceous plants, rishitin from potato and capsidiol from pepper are derived from sesquiterprnoids.

The triggering of HR by elicitors leading to the production of phytoalexins in plants has received much attention (104, 105, 116, 194). The elicitors that have been reported to elicit the production of phytoalexins are : cryptogein (*P. cryptogea*) elicits capsidiol in tobacco (*P. parasitica* var. *nicotianae*); eicosapentaenoic and arachidonic acids (*P. infestans*) incite rishitin in potato; parasitician (*P. parasitica*) elicits capsidiol in tobacco (*P. parasitica* var *nicotianae*) and cinnamomin (*P. cinnamomi*) elicits capsidiol in tobacco. These elicitors are proteinious in nature and induce HR reaction both locally and at some distance from the point of inoculation in some plants belonging to curciferae and solanaceae.

Genetical resistance to *Phytophthora* is considered to be the most significant method of control measure. However, it is difficult to achieve for all disease systems and against all species (68). In potato, control of late blight caused by *P. infestans* was achieved by incorporating R-genes for resistance from *Solanum demissum*. Later, the physiological races developed within population of *P. infestans* capable of infecting plants with R-genes. Extensive research results showed that appearance of new races is highly correlated with development of race-specific resistanc cultivars. Now the present strategy of breeding program in potato is development of general resistance or non-specific resistance. In soybeans, cultivars with both race-specific and field resistance have been developed (216). Using soybean, cultivars carrying different dominant RPS genes, more than 29 races of *P. sojae* were differentiated. This trait has been found to be heritable and has not been found to be attacked by new races of *P. sojae*. In Australia, race specific resistant cowpea plants and cultivars with general resistance have been identified against three races of *P. vignae*. More than 10 races of *P. fragariae* capable of causing disease on different cultivars of strawberry have been identified. There is no known immunity in citrus against the gummosis and root rot caused by *P. citrophthora* and *P. parasitica*. The mechanisms for race-specific resistance are associated with the production of phytoalexins. Yoshikawo *et al* (224) showed that glyceollin is produced in soybean cultivasrs that are resistant to *P. sojae* at more rapid rate and at higher concentrations as compared to that in susceptible cultivars. Glyceollin appears to affect plasma membrane of *P. sojae* at 100 µg/ml concentration on agar. The evidence for function of phytoalexins in potato in response to *P. infestans* is associated with production of rishitin in resistant tubers, although it has not been identified in foliage of the resistant. plants.

6. *PHYTOPHTHORA* DISEASES OF PLANTATION CROPS

Plantation crops are perennial high value crops that occupy about four million hectares in India amounting to 2.3% of the total area under cultivation. They contribute to about Rs. 2,98,500 million to the gross national product (GNP) and fetch export earnings of about Rs. 30,295 million (1994-95), which form 27% of the total exports from agricultural commodities and 4.8% of total exports (79). Arecanut, coconut, cashew nut, coffee, tea, rubber, black pepper and cardamom are the important plantation crops that are mainly confined to South India. Pests and diseases are the major production

constraints. Because of the distribution of these crops in the wet humid tropical belt of South India, the wet weather plant pathogen *Phytophthora* takes a heavy toll because of the prevailing congenial climatic conditions conducive for the disease development. Of these crops, arecanut, coconut, cocoa, rubber and spices viz., black pepper and cardamom are seriously affectd by various *Phytophthora* spp. (Table 1) in India.

E.J. Butler, L.C. Coleman, W. McRae and M.J. Narasimhan were the pioneers of *Phytophthora* research in plantation crops during pre-independence era and researchers during post independence era substantially contributed for the better understanding of these diseases that led to the present level of disease management in the aforesaid crops. During the post independence period efforts are more towards integrated disease management (IDM).

Table 1 : *Phytophthora* diseases of plantation crops

Sl.	Crop	*Phytophthora* sp.	Affected plants parts and name of disease	Reference
1.	Arecanut (*Areca catechu* L.)	P. arecae, *P. meadii*	Bud and fruit (bud rot and fruit rot)	(51) (186)
2.	Coconut (*Cocos nucifera* L.)	*P. palmivora*	Bud and fruits (bud rot and fruit rot)	(30)
3.	Toddy palm (*Borassus flabellifer* L.)	P. palmovora	Bud (bud rot)	(30)
4.	Cocoa (*Theobroma cacao* L.)	P. palmivora	Pods (black pod)	(164)
			Stem (canker)	
			Seedling (die back)	(38)
		P. capsici	Chupon (blight)	(39)
		P. citrophthora	Twig (blight)	(40, 42, 43)
			Roots occasionally	(43)
5.	Rubber (*Hevea brassiliensis* L.) Muell. Arg.	*P. palmivora*	Leaves and pods	(150
		P. meadii	(abnormal leaf fall)	(162)
		P. nicotianae var. parasitica	Bark rot	(121)
			Patch canker	(207)
		P. botryosa		
6.	Black pepper (*Piper nigrum* L.)	*P. parasitica var piperina*	Collar (foot rot)	(172)
			All part of the plants	
		P. capsici		(184)
7.	Cardamom (*Elettaria cardamomum* Maton.)	*P. meadii*	Capsule, leaf	(186)
		P. nicotianae var *nicotianae*	(azhukal)	
			Pseudostem	(153)
		P. palmivora	Roots occasionally	

6.1 Coconut

Coconut (*Cocos nucifera* L.) is grown over an area of 18,92,000 ha accounting to the production of 12,987 million nuts. In India major area is confined to West Coast and East Coast regions. Among the diseases next to root wilt, bud rot and fruit rot caused by *Phytophthora,* are the most serious diseases that affect the crop. Bud rot was reported from India during 1906 (340). Nut (fruit) rot and premature nut fall was also reported to cause considerable damage (154, 189, 196). The problem has been reviewed earlier as well (132, 153).

6.1.1 *Crop loss* : In general 0.1 to 6.5% of disease incidence has been repoted from various parts of India and about 35-40% from certain areas of Kerala and Karnataka. During 1992, disease incidence was about 16.4% in Calicut district wherein about 5000 palms were affected (Nambiar personal communication). A severe outbreak of nut rot

Figs. 29-30. 29. Fruit rot of cardamom caused by *P. meadii*; 30 Fruit rot of rubber caused by *P. meadii*: A. Healthy; B. Initial infection (note water soaked lesions).

was rep... disease incidence and 7.41-53.3% nut fall (154).

6.1.2 *Symptoms* : Unopened tender leaf or spindle is affected leading to rotting of bud and death of palm. The first symptom is pale yellowing and withering of the tender leaf. With time it turns brown and bends off. Rotting starts from outer region and gradually extends inward showing varying degrees of brownish to pink discoloration and rotting. Affected tissues emit foul smell. Even though the palm may not die immediately, it succumbs to death finally due to loss of apical bud (Fig. 15). Though primary infection is caused by *P. palmivora*, subsequent colonization by bacteria enhances rotting. In the case of nut rot, it is opined that injury may pave the way for infection. *P. palmivora* from nuts is also reported to induce bud rot (154). Characteristic water soaked lesions appear on nut at any point which gradually enlarge causing brown discoloration of the inner region of husk as rotting advances. Infection also starts from stalk region leading to premature nut fall. Besides bud rot and fruit rot, root rot of coconut also has been reported causing foliar yellowing (181).

6.1.3 *Identity of Phytophthora* : The causal agent of both bud rot as well as fruit rot has been identified as *P. palmivora* (30, 196) and belongs to A2 mating type (109, 154). *P. arecae* (Coleman) Pethybr has been repoted causing bud rot epidemics in the past in Malabar region (196). Recently, *P. katsurae* as the causal agents of bud rot in Kannur, Kasaragod and Kozhikode districts of Kerala has been identified and it was found pathogenic to black papper. Although considerable genetic diversity was found amongst *P. palmivora* isolates in various coconut growing countries with eight electrophoretic types (ET's) based on isozyme analysis of 14 enzymes (120), no such studies have been conducted in India so far. Heterothallic nature of *P. palmivora* has been reported earlier (206), whereas *P. katsurae* is homothallic species.

6.1.4 *Epidemiology* : The disease is generally noticed during south-west monsoon and north-east monsoon peridos when wet weather prevails and younger palms are more vulnerable (122). Detailed epidemiological investigations carried out showed that tempeature of 21-24°C and 98-100% RH were found highly congenial for the disease development and such favorable days determined the disease incidence. Incubation period of 35 days was found essential for manifestation of the diseae and micro-climatic factors at the axil of the leaves were considered important (99). Rainfall appears to be important factor and high rainfall that prevailed during October 1992 was attributed to heavy disease incidence, when about 5000 palms of 25-30 years age group were affected in Kuttiady area of Calicut district of Kerala (Nambiar personal communication). In case of nut rot, nuts of 3/4 maturity on palms of age group of 10-25 years were mostly affected (154). The fungus was reported to survive at the base of the fronds in the crown (122). Surivval of the fungus upto five months in the affected crown was reported and also formation of oospores when the cultures were contaminated with *Thielaviopsis paradoxa* (99). These oospores if found in crown might serve as survival mechanim of the fungus. Coconut isolates of *Phytophthora* have been found to be pathogenic to arecanut, oil palm, rubber, Jack, cocoa and cardamom (56).

6.1.5 Disease management : Chemical control with Bordeaux mixture was found effective. Early detection of the disease becomes important, since such palms can be saved by careful removal of the infected tissues, application of Bordeaux paste and later covering the crown with polythene sheet (122). In view of the reported phytotoxicity

of copper on dwarf coconuts, use of mancozeb (Dithane M45) has been advocated. Effective control of the disease was reported by placing in the leaf axils a perforated polythene bag containing mixture of dithane M45 and sawdust (132). Efficacy of demosan controlling bud rot was established in laboratory experiments (99). Removal of infected plants in the plantation as a phytosanitary measure and prophylactic spraying of the palms around the infected palms with the recommended package (18). Although systemic fungicides are promising in India they have not been tested intensively. Metalaxyl (Ridomil MZ 72 WP) @ 3.5g/palms as root feeding and 0.3% of copper oxychloride spray were found effective in checking fruit rot in coconut (154). Although, root feeding of coconut with metalaxyl @ 3.5g and 7g/palm did not leave detectable level of residue in coconut water but a waiting period of 30 days was suggested after application, for human consumption (133).

No information is available in India on the host resistance in coconut to *Phytophthora*, though such information is available from other countries (132). Detailed crop loss surveys. *Phytophthora* spp. involved in coconut diseases, survival of the pathogen, mode of disease spread, and forecasting system, sources of host resistance, biocontrol programs and cost effective and safe chemical control methods should receive attention in future programs.

6.2 Arecanut

Arecanut (***Areca catechu*** L.) is grown over an area of 2,64,000 ha amounting to production 3,13,000 tonnes per annum. Although India has attained self-sufficiency in this crop, fruit rot (Mahali in Malayalam and Koleroga in Kannada vernacular) caused by *Phytophthora* spp. and yellow leaf disease (YLD) caused by Phytoplasma are the two major production constaints in arecanut. The fruit rot of arecanut was reviewed earlier (167, 168). *Phytophthora* disease was first recorded by Butler (30) in erstwhile Mysore State and later was intensively investigated by Coleman (51).

6.2.1 ***Crop loss*** : Annual crop loss due to fruit rot ranged from 10-90% (51, 52, 101, 128, 168). Losses of about 75-350 kg nuts/acre, and death of about 20-50 palms/acre due to bud rot were reported from Uttara Kannada (187). About 10-15% bud rot ws recorded (174). The incidence of crown rot ranged from 0.05 to 15% in Dakshina Kannada district of Karnataka (Chowdappa, unpublished.)

6.2.2 ***Symptoms*** : Rotting and shedding of the nuts are the diagnostic symptoms of fruit rot disease (Figs. 16, 17). Nuts of all ages are prone to infection. Water soaked lesions appear on the nuts, invariably from the stalk end. The rotting extends from the calyx downwards. The affected nuts show greyish to whitish growth cosisting of abundant sporulation (30, 51, 196). Heavy shedding of ntus at the base of the plam is a clear indication of Mahali. When infection occurs late in the season, the affected nuts dry and are not shed (118). Nuts at all stages are prone to infection. Bud rot unlike Mahali is sporadic in its occurrence, and generally seen during south-west as well as during north-east monsoon. The affected palms show yellowing of the spindle leaf (Fig. 18). As the disease progresses the spindle loses its natural luster, turns yellow, slumps to a side emitting foul smell and infections spread to the bud (51, 128). In recent years, another *Phytophthora* disease, crown rot has increasingly become important. Unlike bud rot, *Phytophthora* initiates infection from the fruit rot affected bunches or outermost whorls of the leaves and spreads internally towards bud region, resulting in death of the

palms and collapse of the crown after south-west monsoon (Figs. 19, 20). Collar rot of seedlings has also been noticed (Fig. 21).

6.2.3 ***Identity of Phytophthora*** : Sydow and Butler (200) identified the fungus as *Phytophthora omnivora* de Bary. Later, Coleman (51) designated it as *P. omnivora* var. *arecae*. Pethybridge (148) found it differnt from *P. omnivora* and named it as *P. arecae*. Subsequently, it was redesignated as *P. arecae* (Coleman) Pethybridge (31). *P. arecae* has been retained as distinct species (136, 193, 217) even though *P. palmivora* and *P. arecae* were considered synonymous (37, 212). Another species, *P. meadii* McRae has been reported from Karnataka causing fruit rot and bud rot of areca (60, 187). Recent isozyme and mt DNA RFLP analysis (74, 142, 144) showed that *P. palmivora* and *P. arecae* are synonymous.

The detailed studies on biology and physiology of *P. arecae* and *P. meadii* are limited in India. However, studies have been conducted elsewhere on their growth requirements and nutrition. Detailed studies on morphology of *P. meadii* of areca have been conducted (174, 187). Growth and sporulation of *P. meadii* of arecanut was noticed at 24-30°C and 27-30°C respectively (174). Chlamydospores were not recorded in cultures of *P. meadii* of arecanut (1987) but were noticed in older cultures (174). Homothallic and hetrothallic nature of *P. arecae* has been reported (51, 117, 163). Sastry and Hegde (187) reported heterothallic nature of *P. meadii* and isolates belong to A1 mating type.

6.2.4 ***Epidemiology*** : The disease is dependent on monsoon and starts 15-20 days after the onset of south-west monsoon during May-June and extends upto August-September. High humidity, high rainfall and low temperature (20-23°C) are congenial for the disease development. Alternate sunshine and rainfall favours the disease development (51, 134). Reddy and Anandaraj (168) reported severe disease incidence which coincided with high rainfall (5086.6 mm) and high relative humidity (80%) during 1978 when the crop loss ranged from 50-90%. Disease spread is mainly through rain splashes and is favored by heavy winds during the rainly season (5). Disease also spreads through birds and small insects (51, 134). Zoospores once released from the sporangia, swim, germinate and enter the nut through stomata. After incubation period of four days, the mycelium from the affected nut surfaces sporulates abundantly. However, a regular pattern of the disease spread could not be observed (15). Based on the daily average temperature and taking into consideration of four days as the incubation period, a linear model of predicting the disease four days in advance was reported (10). However, further refinement of this model for idffernt agroclimatic regions is needed. Disease incidence has been reported to be severe in gardens located in valleys and those surrounded by thick belt of shade trees and this might be due to build up of high humidity and optimum temperature. The fungus might be surviving in the form of mycelia, chlamydospres in the soil on the dried bunches, and on bud rot affected palms left in the plantation (214). Saraswathy (174) observed mycelia, sporangia in the infected dried bunches and oospores in the fruit rot affected nuts. Their role in the survival and perennation of the pathogen needs in depth study.

6.2.5 ***Disease management*** : Integrated disease management involving cultural practices, phytosanitation and chemical control is the present strategy adopted, which is fairly effective. A cultural practice of covering the branches with 'Kotte' or a cover made out of areca leaf sheath or 'Karada', cover made out of grass, was in vogue (51). Probably this operation migth have helped in reducing the rain splashes and consequent reduction

... the disease spread. However, recent studies with modification of the old method by covering the bunches with polythene covers was found to be highly effective in checking the disease. Based on multi-location trials during 1998 and 1999 at different localities of Uttara Kannada, Dakshina Kannada and Shimoga districts of Karnataka, Chowdappa *et al* (48B) showed that pre-monsoon covering of arecanut bunches with polythene covers (125 gauge, 75 × 60 cm) could ahieve 100% control (Fig. 23). The cost of polythene covering of arecanut bunches varied from Rs 5.29 to 8.69/ tree and Bordeaux mixture spray varied from Rs. 6.34 to 7.46. Crop loss in Bordeaux sprayed gardens ranged from 6.67 to 62.2% depending upon variety. The total loss of chali ranged from 240 to 1211 kg chali/ha amounting to Rs. 21,000 to 1,08,940. The additional advantages of polythene covering are avoiding exposure of climbers to hazardous chemicals, environmental pollution and climbing of slippery palms during monsoon. Further, it is one time operation in crop season. The efficacy of Bordeaux mixture for the control of fruit rot was reported earlier (51) (Fig. 22). The use of adhesive like washing soda, resin alongwith Bordeaux mixture was also reported to be effective (51, 134a). A combination of potash alum and casein with Bordeaux mixture was recommended (135). Bordeaux mixture (1%) alone was reported to have the tenacity and was effective without any sticker (205). The spray deposit of Bordeaux mixture retained 45 days after spray with or without adhesives was on par, thus indicating that Bordeaux mixture without adhesives was equally effective (6). Copper oxychloride (0.5%) was found to be toxic and the oil based copper like Fycol 8 and 8E, oleocap were inferior to Bordeaux mixture in disease reduction (18). At present the prophylactic premonsoon and post-monsoon sprays are recommended and a third round would be necessary if the monsoon is prolonged. An improved type of sprays 'Primus' was developed as early as 1938. Among the two systemic fungicides tested, metalaxyl and Fosetyl Al (Aliett at 0.5%), Fosetyl-Al was found superior and was at par with 1% Bordeaux mixture treatment (16). Just like coconut, bud rot affected areca palms if detected early can be saved by removal of infected tissues and application of Bordeaux paste and drenching the crown of the surrounding palms with 1% Bordeaux mixture and is in vogue. Phytosanitary measures like removal of disease affected palms and bunches should be resorted, to realize better protection with Bordeaux mixture treatment (113, 128).

6.2.6 *Host resistance* : In a recent study, out of 49 types of *Areca* and related species screened with *P. meadii*, none were found tolerant. However, *A. normabyii, A. concinna* and *Actinorthytis calapparia* remained unaffected indicating their high degree of resistance (174). The sources of resistance may be exploited in future programs to induce resistance in *Areca catechu* to *P. arecae* or *P. meadii* through hybridization and biotechnological approaches. Studies are warranted on the distribution of different *Phytophthora* species, in monocropping and mixed cropping systems, their correct identity on population basis and their degree of pathogenic potential. As the disease is spread by rain splashes, covering the bunches with polythene sheet protects the fruits against *Phytophthora* infection. In the event of imposing ban on the use of plastics in the agriculture, attempts are being made to evolve bio-degradable, eco-friendly 'disease guards' made out of areca leaf sheaths and integrate the same with effective systemic fungicides to protect the palms during vulnerable monsoon period.

6.3. Cocoa

Cocoa (*Theobroma cacao* L.) though reported to have been introduced about 200 years ago, its expansion on plantation scale mostly as mixed crop in arecanut garden is only a recent phenomenon. It is grown over an area of 14,000 ha ... tonnes of production. It is mainly confined to Kerala and Karnataka and to a small extent in Tamilnadu and Andhra Pradesh. Black pod caused by *Phytophthora* spp. is one of the most serious diseases that affect the crop, followed by canker, chupon blight and twig dieback.

6.3.1 *Crop loss:* Crop losses are reported to vary from 12.4-29.7% due to pod rot and further systematic surveys are needed to estimate the same in totality. About 22% of the gardens in Kerala, Karnataka and Tamilnadu showed the presence of stem canker (36).

6.3.2 *Symptoms:* The pod rot disease is generally prevalent during south-west monsoon period. Early symptom occurs as small chocolate brown to dark brown circular lesions, which expand and cover the major area of pod assuming elliptical shape. The mature lesion supports whitish mycelium sporulating abundantly (Fig.24). The infected pod turns dark within 15 days and rot involving the inner portion of the pod and beans. Apart from pod rot, occurrence of stem canker caused by *P. palmivora* (32, 166), seedling die back (34), chupon blight and twig die back (35) has been reported . The occurrence of stem canker is recorded on all age groups of the plant. Initially water soaked greyish spots occur on the stem and tissue beneath the spot turns brown. This further changes and brownish fluid oozes out from the canker (Fig. 25). When infection is seen on younger plants, dieback sets in (34).

6.3.3 *Identity of Phytophthora*: Black pod caused by *P. palmivora* was reported for the first time on Criollo variety at Kallar in Tamil Nadu (164). Later, it was identified as a major problem in Forastero variety (36). In Dakshina Kannada district of Karnataka prevalence of *P. palmivora* as the incitant of black pod has been reported (192). Subsequently, occurrence of *P. capsici* (40) and *P. citrophthora* (42) causing black pod in certain localities of Kerala state besides *P. palmivora* (39) has been recorded. The identification of three species of *Phytophthora* based on morphological criteria was also supported by characteristic electrophoretic protein profiles (41), repetitive DNA polymorphism's (43) and serological reactions (45). Both A1 and A2 mating types of *P. palmivora* and *P. capsici* are prevalent but A2 mating type of *P. palmivora* is still predominant (45). *P. citrophthora* isolates have been reported to be sterile. Diversity among different isolates of *Phytophthora* causing disease in cocoa in Africa was established using isozyme and RAPD markers (139).

6.3.4 *Epidemiology*: Extensive epidemiological investigations on black pod of cocoa viz., the role of infected plant debris on primary source of inoculum, weather factors that favor disease, the splash dispersal of the disease, the role of ants in passive dispersal of the inoculum, have been carried out in other cocoa growing countries (80, 82). In India, except that the disease is known to occur during south-west monsoon period, detailed investigation has not been made.

6.3.5 *Disease management*: Phytosanitary measures such as frequent removal of infected pods and twigs, prophylactic application of contact fungicides like Bordeaux mixture and also systemic fungicides like metalaxyl, fosetyl Al, and trunk injection with phosphorous acid have been tried with varying degree of success in other cocoa growing countries. Based on the discontinuous vertical infection gradient, Gregory *et al* (81) suggested the application of fungicide directly to the pods and soil application of powdered formulation of copper fungicides to reduce the soil-borne inoculum. In India, at present, prophylactic premonsoon spraying of Bordeaux mixture mixed with adhesive

(Kosh washing soda preparation) after removal of all infected and dried pods from the tree, is the package adopted (18).

6.3.6 *Host resistance:* Since various cultivars of the crop are recently introduced, high variability to resistance is lacking. At present resistant genotypes both for pod rot as well as stem canker have been identified elsewhere and these sources need to be obtained and tested for their reaction in India to determine their level of resistance, since variability in virulence of the pathogen in different geographical conditions is known to exist. Chowdappa and ChandraMohanan (46) reported that the cocoa accessions C78 and C44 were found to be tolerant to all the three species of *Phytophthora* prevalent in India, whereas Landas 364 was highly susceptible. Out of 105 types screened, GV1-14 (C78) showed moderate resistance with least infected pod area and rest were found susceptible (1).

The basic studies on molecular characterization of the *Phytophthora* spp. which have been done using limited number of isolates belonging to *P. palmivora*, *P. capsici* and *P. citrophthora* (41, 43, 48, 49) are required to be extended to a large number of isolates, since such studies on population basis are important. Development of disease resistant clones and basic studies on host-parasite interactions need to be pursued. Potential biocontrol agents associated with pods as well as roots need to be isolated and tested for their suppressive activity of *Phytophthora* in field. In India future priorities should be on the studies on precise crop losses under different cropping systems, epidemiology of the disease and standardization of effective disease management practices to develop integrated disease management strategies.

6.4 Rubber

Para rubber (*Hevea brasiliensis* Muell. Arg.) is grown over an area of 5,30,000 ha with annual production of 5,80,000 tonnes of rubber. Abnormal leaf fall caused by *Phytophthora* spp. is a serious problem in Kerala, Karnataka and Tamilnadu. The disease was first reported during 1910 in Palapilly in Trichur district of Kerala (121).

6.4.1 *Crops loss :* Young trees below three years when affected in addition to defoliation, shoot rot and die back also occur. In infected trees yield reduction upto 35-36% has been reported (160). Clipping of leaves at 50 and 75% resulted in yield loss of 23 and 31%, thereby indicating the yield loss due to defoliation when infected (152). In a recent study, 9-16% crop loss was observed if prophylactic foliar spray is skipped. Besides the growth of the affected trees, it also increased weed growth in plantation (95).

6.4.2 *Symptoms :* Green mature pods are the first target of infection. Infection starts as water soaked lesions (Fig. 30) from which a drop of latex oozes out, coagulates and forms dark spots. The mycelium ramifies inside pod and appears as whitish fluffy growth on the pod. This sporulates abundantly forming a cheesy coating on the surface of the pod under wet humid conditions. The affected pods rot, fail to open and remain attached to the branches. Foliar infection is mainly confined to the petiole. Infection occurs as water soaked spots that turn brown to dark with maturity. A drop of latex comes out of the lesion. As the disease advances, leaves turn yellow to brown and drop causing varying degrees of defoliation. Subsequently the pathogen infects shoots and causes die back. Defoliation is often sudden and whole process is completed within a fortnight if the climatic conditions remain favorable. Shoot rot, bark rot (162) and patch canker (161) at the tapping panel or at any injured point on the plant caused by *Phytophthora* have also been reported (64, 161, 162).

6.4.3 *Identity of Phytophthora :* The pathogen responsible for [illegible] identified as *P. meadii* (121). In addition to *P. meadii*, three other *Phytophthora* spp. viz., *P. nicotianae* var *parasitica* (207), *P. palmivora* and *P. botryosa* have also been recorded to be associated with abnormal leaf fall (203). Oudemans and Coffey (143) reported that *P. meadii* and *P. botryosa* probably represent two geographically separate populations of single species based on isozyme analysis of 16 enzymes. Both A1 and A2 mating types have been reported in *P. meadii*. Interspecific hybridization has been reported between *P. palmivora* and *P. meadii* (202, 204).

6.4.4 *Epidemiology :* The disease occurs during south-west monsoon period coinciding with heavy rainfall. Prevalence of rainfall of 112 mm or more with at least of 1 mm/day for five days, minimum temperature 22-23°C, maximum temperature of 29-31°C with a mean RH of 80% and a minimum of 0.1 hr. sunshine/day during south-west monsoon is reported to cause leaf fall within 9-15 days. Hence, it is possible to predict the disease outbreak when such weather conditions prevail (96). The disease incidence in Kanyakumari district of Tamil Nadu always was minimum because of low rainfall. But severe disease incidence was recorded in 1974 because of heavy rainfall (150). In general disease appears during second week of June and reaches its peak during middle of July. Soil with infected plant debris serves as the primary source of inoculum. Presence of chlamydospores and oospores in the infected twigs and germination of oospores has been reported (78, 202). Disease spread is through rain splashes and the profuse sporulating mycelium on the pods/petioles/leaves might get dispersed during heavy winds and flight of inoculum as high as 1.2 m from the source has been recorded. The role of cockroaches, ants, vinegar flies and beetles is that of carriers of inoculum, aiding thereby in disease spread.

6.4.5 *Disease managment :* The present approach to disease management is mainly through fungicidal sprays as a premonsoon operation. Since the fruits are infected first, they serve as source of secondary spread of the disease. Defruiting of infected branches was resorted to, but with little success (121). Subsequent spraying of foliage with 0.75% Bordeaux mixture was found effective (20). Spraying of 1% Bordeaux mixutre @ 3000l/ ha as a high volume spray was found effective (94). In view of the difficulty for large quantities of water required for high volume sprays, low volume sprays were standardized using micron sprays to be applied from ground or as aerial sprays through helicopter. Oil based copper fungicides were found effective. Aerial spraying with oil based copper oxychloride in 6.2 litre of oil, or 1 kg of copper oxychloride in 37-42 l of oil was found effective in controlling the disease (150). Copper oxychloride mixed with spray oil in 1:5 proportion was used @ 30-37 l/ha. for micron sprayers and 37-42 l/ha for aerial sprayers (151). Micron spray power 400, and Turblow were also found to be effective in using low volume spraying. Thermal fogging of Tart/Tiga was also found effective (63) but not very popular becasue of the high cost of equipments. For shoot rot, spraying the plants with 1% Bordeaux mixture and for bark rot and panel rot patch canker, removal of rotten tissues followed by application of mancozeb have been recommended (64).

6.4.6 *Host resistance :* Clones like RRIM 600, RRI M628, GTI, PB86, Tjr 1, Tjr 16, and RRI07 are highly susceptible and protection with copper fungicides is not adequate for these clones. However, tolerant clones RRII 33, F4542, FX516 when crown budded increased the leaf retention. Pillai *et al.* (152) reported higher yields of RRIM 600 and RRIM 628. RRII 105 is a high yielder and also has been found to be tolerant to *Phytophthora*. At present these two approaches i.e. popularization of RRII 105 and

crown budding are of immediate practical importance and should be taken up on large-scale, in addition to fungicidal sprays.

Except for the report of *P. botryosa* from Andamans, the distribution of rest of the three species, their pathogenic potential and precise crop losses they cause for an extended period of 2-3 years are lacking and need be pursued. Biocontrol options though less attractive, but efforts to suppress the soil-borne inoculum through augmentation of the plantation soil with *Phytophthora* suppressive bioagents need be explored. Any manipulation in evolving sterile clones that would preclude flowering and fruits will be of great practical value, since infected pods become source of disease spread.

6.5 Black pepper

Black pepper (*Pepper nigrum* L.) the 'King of Spices' is native of Western Ghats of India and is grown over an area of 1,95,100 ha accounting for a production of 53,100 tonnes. *Phytophthora* foot rot and slow decline are the two important diseases that effect the black pepper in India and also in other countries where black pepper is grown. Even though disease was reported in 1902 from Wynad area of Kerala, *Phytophthora* was isolated from black pepper in 1929. Subsequently, Samraj and Jose (172) proved Koch's postulates on black pepper and adopted the terminology as *P. parasitica* var *piperis*. The problem of black pepper *Phytophthora* in India was reviewed earlier (131, 175, 182). The terminology of the disease from 'quick wilt' to *Phytophthora* foot rot was changed during 1988 (125).

6.5.1 ***Crop loss :*** In India, precise crop loss figures are not available for all pepper growing areas even though its occurrence is known in Kerala, Karnataka, Tamil Nadu, Andaman Nicobar Islands and also in Assam. In Kerala, the crop losses upto 25-30% were reported (131). Systematic crop loss surveys carried out in Calicut and Cannannore districts of Kerala showed 3.7 and 9.4% disease incidence resulting in a loss of 119 and 905 tonnes of black pepper (8, 9, 21).

6.5.2 ***Symptoms :*** All parts of black pepper are susceptible to *Phytophthora* which casues typical cortical rots even though it was considered as wilt erroneously. However, involvement of toxins in disease etiology has been reported (184, 185). Dark brown round lesions with fast advancing fimbriate margins on the leaves is characteristics (Figs. 26, 28) and occasionally lesions with concentric rings with whitish to grey centre are also noticed. Aerial stems and spikes are also infected and this leads to varying degrees of defoliation. The fungus infects the feeder roots and gradually spreads to foot or collar leading to foot rot resulting in death of the affected vine (11, 17) (Fig. 27).

6.5.3 ***Identity of Phytophthora*** : Taxonomical investigations on black pepper *Phytophthora* received considerable attention in recent years. Although black pepper *Phytophthora* was designated as *P. parasitica var. piperis* (172), it was subsequently adopted as *P. palmivora* (131). The intensive investigation on taxonomy of black pepper *Phytophthora* (211) led to rechecking the identity of black pepper *Phytophthora* and is designated as *P. palmivora* MF4 (182). The further studies led to redesignation of *P. palmivora* MF4 to *P. capsici*, Leonian emend A. Alizadeh and P.H. Tsao (208, 211) based on sporangial morphology, ontogeny and caducity and its pedicel length. *P. capsici* is heterothallic and predominantly belongs to A1 mating type (182, 184). However, both A1 and A2 have been reported from Karnataka (186). Oudemans and Cofffey (143)

demonstrated the presence of two distinct isozyme sub groups (CAP 1 and CAP 2) within population of *P. capsici*. Later, based on detailed morphological, physiological and isozyme profiles, black pepper population are reported to belong to Cap A and Cap B sub-species (120) corresponding to CAP 1 and CAP 2 respectively.

6.5.4 ***Epidemiology : Phytophthora*** being a wet weather pathogen, intensity of infection is mainly during south-west monsoon period (June-August) and also during north-east monsoon period (September-October). Black pepper is grown both as a pure crop on *Erythrina* standards and also as a mixed crop trained on coconut, arecanut and also on shade trees in coffee, tea and cardamom plantations. The type of infection purely depends on micro-climatic conditions in a given cropping system. Infected plant debris and left over infected vines in the plantations remain as perennial source of inoculum.

With the oneset of monsoon, soil moisture builds up resuling in *Phytophthora* population build up which coincides with new flush formation (7). Soil and water splashes have been reported as the main mode of disease spread in foliar phase. Foliar infection spreads from the lower region of the bush to upper region in a 'ladder like' fashion resulting in different degrees of defoliation (157). Increasing phase of foliar infection was associated with daily rainfall of 15.82 mm, 81-99% RH, 22.7-29°C temperature and 2.8 - 3.5 hrs of sunshine (156). In the soil phase, infection spreads through soil water and root contact. Spread of infection through water channel in arecanut garden has been reported (185). The phenology of crop growth in relation to infection has been well worked out (7). The importance of feeder root damage and its culmination into foot rot has been established (17). The weather parameters especailly the rainfall, number of rainy days, RH and temperature have been positively correlated to the disease (115, 213). The increased root rot in combined infection with plant parasitic nematodes viz., *Radopholus similis* and *Meloidogyne incognita* has been reported (13) and thus *P. capsici* also forms an important component of 'slow decline' etiology (13, 165). Root loss to root regeneration ratio appears to be deciding factor for the vigour and productivity of the pepper vine (180).

The importance of *Phytophthora* spp. that infect all the plantation crops like coconut, arecanut, rubber and cardamom and their relation to black pepper received considerable attention and the possibility of appearance of new *Phytophthora* strains due to natural hybridization was suggested (173). However, none of the *Phytophthora* spp. affecting these crops were isolated from black pepper so far and hence were not considered epidemiologically significant (184). The recent reports of *P. capsici* from cocoa (40) and also on *Piper chaba, P. betle* and *Bauhinia* (Sarma unpublished) and their relation to black pepper need further investigation. The involvement of more than one species of *Phytophthora* in black pepper infection is a possibility and should be looked into.

6.5.5 ***Disease management :*** The importance of integrated disease management (IDM) involving nursery hygiene phytosanitation, cultural, chemical and biocontrol methods and host resistance has been highlighted (11, 159, 179, 184). In view of the involvement of *Phytophthora* and plant parasitic nematodes in disease etiology and based on the epidemiological investigations a 'holistic approach' to suppress these three soil borne pathogens to boost up the health and productivity was considered as important in disease management strategy (177).

6.5.5.1 ***Cultural practices :*** Since the disease is soil borne, phytosanitary measures both in the field and nursey become highly relevant. Systematic rouging of infected

vines along with root system would reduce the chances of inoculum build up. Pruning of runner shoots, minimum tillage practices, shade regulation, provision of drainage and maintenance of a green cover to reduce soil splash were found important in reducing chances of infection.

6.5.5.2 ***Agronomic considerations*** *:* Reduction in root infection with phosphorus amendements has been noticed (Rajan, Personal communication). However, detailed studies on host nutrition in relation to disease incidence are needed. Though pepper is a rainfed crop but in view of the changed agroecological conditions, the importance of irrigation becomes significant during dry period of the year. Organic soil amendment with neem oil cake @ 1 kg reduced infection and this was found to suppress both *P. capsici* and nematode. The high production technology in black pepper involving balanced nutrition and crop protection reduced infection and resulted in yield increase (171). Population density of pepper in mixed cropping systems in relation to disease needs investigation.

6.5.5.3 ***Nursery management*** *:* Production of disease free planting material and the importance of nursery hygiene become utmost important (175, 183). In view of the soil borne nature of the disease, solarisation of nursery mixture, fortification of the same with biocontrol agents and adoption of single node multiplication of pepper resulting optimum root production are the suggested nursey practices that would ensure healthy robust nursery stock (175).

6.5.5.4 ***Chemical control*** *:* Prophylactic premonsoon spraying of the vines with Bordeaux mixture (1%) and drenching the base with copper oxychloride (0.2%) or Bordeaux mixture are the recommended packages (159) and the efficacy of the same was demonstrated, on a large-scale in farmers field in one lakh ha in Kerala during 1993-1996. Any of the contact fungicides like copper gets leached off due to heavy rainfall. Since the fungus also remains in deeper layers of the soil (upto 90 cm), its targetablity to fungicide also remains problematic. In this context systemic fungicides have become handy. The efficacy of systemic fungicides like phenyl amides and phosphonates has been established in reducing the disease incidence in black peper (157, 159). Metalaxyl (100ppm) (ridomil-ziram) formulation both as a foliar spray and soil drench as a pre- and post monsoon treatment was found effective in checking *Phytophthora* infection in black pepper (157). Incidentally metalaxyl was found compatible with endosulfon and quinalphos insecticides used against 'pollu' beetle and synergetic in the activity. These insecticides were also found inhibitory to *Phytophthora* (156). The metalaxyl residue in black pepper berries was below 0.8 ppm, when metalaxyl (100ppm) (ridomil-mancozeb) was used both as foliar spray and soil drench thrice during May-August period (177). Potassium phosphonate (Akomin) was equally effective in checking the infection (18). Both metalaxyl and potassium phosphonates were found compatible with biocontrol agents like *Trichoderma*, and *Gliocladium* and would be ideal in the IDM.

6.5.5.5 ***Biocontrol*** *:* Biocontrol being one of the important components of IDM, and also its importance in suppression of soil borne diseases of spice crops, has been reviewed (179). The role of *Glomus fasciculatum* (VAM) in suppressing root rot caused by *P. capsici*, *R. similis* and *M. incognita* has been established (14) and would be ideal in IDM. Besides, *Trichoderma harzianum* and *Gliocladium virens* were found antagonistic to *P. capsici* and the field application of the inoculum either in coffee husk/pulp or sorghum meal was found effective in reducing the disease (Sarma *et al.*, unpublished) and the adoption of this package at farmers field in Kerala and Karnataka on a large-scale is in progress. Besides, incorporation of VAM, *T. harzianum* and *G. virens* in the solarised nursery mixture would ensure disease free robust rooted crop. In addition, there are several fluorescent Pseudomonads and *Verticillium* spp. which have good disease suppressive potential in black pepper (Sarma *et al.*, unpublished) need further testing.

6.5.6 ***Host resistance*** *:* The centure of origin of black pepper being Western Ghats of India, considerable variations were noticed in the available germplasms with respect to the quality but not for the resistance to *P. capsici.* However, few tolerant lines have been identified. Open pollinated seedling progenies like P-24, P-339, P-1534, cultivars like ACC-1047, ACC-1095 and hybrid HP 780 were found field tolerant (176, 182, 184). The possibility of obtaining resistant/tolerant genotypes through transgressive segregation in breeding programme has been suggested (184). Among the wild types, *Piper colubrinum* and *P. arboreum* were found resistant to *P. capsici. P. columbrinum* was also found resistant to *R. similis* and *M. incognita.* Root stocks of *P. colubrinum* though were found useful in checking the disease, due to graft incompatibility this was reported to be ineffective. However, efforts are being continued on various methods of grafting. Since available variability for resistance to *P. capsici* at present is limited, efforts have been initiated, to induce somaclonal variations and *in vitro* screening of cell lines with toxins of *Phytophthora.* Identification of resistant genes in *P. colubrinum* and transfer of the same to *P. nigrum* through recombinant DNA technology is an important biotechnological approach (175). Since monoculture is prone to epidemics, cultivation of mixture of disease tolerant lines is the suggested strategy towards integrated disease management.

The technical and socil constraints in the implementation of disease management technology have been highlighted (178). However, the implementation of the IDM through community approach is the only practical solution to tackle foot rot of black pepper. Future priorities should be to evolve genotypes with horizontal resistance, biochemical aspects of disease resistance and induction of resistance through biotechnological approaches. Nursery hygiene and biocontrol strategies compatible with effective agrochemicals should be evolved as a part of integrated disease management.

6.6 Cardamom

Cardamom (*Elettaria cardamom* Maton) the 'Queen of Spices' is native of Western Ghats of Inida. It is grown over an area of 83, 700 ha amounting to production of 7000 tonnes. The crop is mainly confined to Kerala, Karnataka and Tamil Nadu. It is a rhizomatous crop grown under the shade of forest trees. Apart from important vital diseases that affect this crop viz., Katte, Nilgiri necrosis and vein clearing (Kokke kandu), capsule rot (azhukal) of cardamom caused by *Phytophthora* is serious, causing severe crop losses. The problem has been reviewed earlier (98, 127, 178).

6.6.1 ***Crop loss*** *:* Precise crop loss figures due to *Phytophthora* infection in cardamom are lacking. However, about 30% crop loss due to capsule rot (Azhukal) disease has been reported (130) and occasionally it may go up to 40% (18).

6.6.2 ***Symptoms*** *:* Infection occurs as water soaked spots on capsule. Later, the capsule turns dull green, rots and drops off (Fig. 29). Infection occurs on rachis and its further

development is arrested. In general, it is the capsule rot and premature drop that amounts to loss, however the clump rot is negligible. Infection occurs at all stages of maturity of capsule and rachis. However, the tender ones are more susceptible. Water soaked leaf spots appear and the adjacent spots coalesce and rot, exhibiting finally leaf shedding symptom. Leaf shedding is seen in severe form during winter (18). Apart from this it also infects pseudostems causing water soaked to brownish discoloration, followed by rotting. The younger affected pseudostems come off with a gentle pull and the new buds fail to develop. Infection spreads to root causing severe root rot.

6.6.3 *Identity of Phytophthora* : The fruti rot disease was first reported to be caused by *Phytophthora* sp. (123) and later the fungus was identified as *P. nicotianae* Bred de Hann var. *nicotianae* (204). *P. palmivora* Butler was also recorded on cardamom. Currently *P. meadii* Mc Rae is considered as the major pathogen involved (18, 147, 187, 188). However, it appears that more than one *Phytophthora* species is involved in capsule rot of cardamom. Formation of oospores in culture was reported in *P. nicotianae* (127). However, formation of oospores was reported only when paired with *Phytophthora meadii* from rubber (204). *P. meadii* of cardamom has been reported to be of A2 mating type (18). The temperature requirement of the isolates from capsule and rhizome differs and the former showed maximum growth at 20°C and the latter at 30°C. Chlamydospore formation was rarely noticed in *P. meadii* (98). Howevr, its abundance was reported in *P. nicotianae* var. *nicotianae* (126, 204).

6.6.4 *Epidemiology* : Detailed studies on epidemiology of 'Azhukal' showed that maximum disease incidence (11%) was noticed during August when rainfall of 400.4 mm, 28 rainy days, RH of 90.6% and temperature of 21°C prevailed which coincided with high soil population of *Phytophthora* (786/g soil). Since infected, dried and left over panicles in soil debris form the primary source of inoculum, and the newly produced panicles being in direct contact with the soil, the chances of infection are very high. The disease is absent during March-April, the dry period of the year. The fungus survives in the form of chlamydospores and the infected rhizomes also serve as the source of inoculum. The propagules decreased from base of the plant with increase in distance and depth of soil, maximum being at the surface. The disease, which appeared during May with an incidence of 0.4%, reached its peak during August. *Colocasia* plant infected by *Phytophthora* has been reported as collateral host (126).

6.6.5 *Disease managment* : In the light of epidemiological investigation and to obtain quick disease control, greater stress has been given for chemical control. Premonsoon and post monsoon spraying and drenching with 1% Bordeaux mixture was very effective in reducing the disease incidence (129). In a detailed study undertaken using systemic and contact fungicides, it was found that three rounds of Fosetyl-Al (0.3%) and 1% Bordeaux mixture were superior to dithane M45 (0.3%). The importance of shade regulation, phytosanitation and correct timing of application of fungicides was emphasized (97). Spraying and drenching with 0.2% Dexon @ 4kg/ha was found effective in checking the disease (2).

In view of the soil-borne nature of the disease, increased attention towards biocontrol received in recent times. Soil amendment with neem cake reduced capsule rot and was mainly attributed to increased population of *Aspergillus* spp., *Trichoderma* sp. and actinomycetes (126). The antagonistic effects of *Trichoderma* spp., *Laetisaria arvalis* and *Bacillus subtilis* to *P. meadii* and suppression of disease was also reported through the soil application of these organisms (198, 199). A good correlation to the

level of pathogen and its suppression due to soil application of *Trichoderma* inoculum around consequent reduction of disease incidence has been establshed (Suseela Bhai, personal communication).

6.6.6 *Host resistance* : Variability in the existing cardamom germplasm for resistance to *P. meadii* appears to be little and out of the 123 accessions screened, two cultivars each from Mysore and Malabar types were found to be tolerant (147, 197). In view of the leads obtained in biocontrol, efforts should be more towards phytosanitation, coupled with biocontrol, which would be more rewarding. Shade regulation that would ensure better light penetration and air circulation is very important to alter the microclimate less conducive to the disease. Need based fungicide application should be resorted to under high disease pressure. Thus a need based location specific disease management would become relevant to check crop losses due to azhukal. The distribution of different *Phytophthora* spp. in plantation of Kerala and Karnataka, development of disease resistant clones through conventional breeding, identification of potential biocontrol agents compatible with agrochemicals and identification of botanicals suppressive to *Phytophthora* in order to develop IDM would be future strategies. Since cardamom is a export oriented crop, any practice that would lead to pesticide residue should be abandoned.

7. FUTURE STRATEGY

The present review of the *Phytophthora* programs in plantation crops did show some of the achievemnts in disease management and certain lacunae in others. The main focus continued to be on chemical control, however some success in biocontrol has been achieved. Furthermore, future priorities would be basic researches on molecular plant pathological aspects with a greater emphasis on host-parasite interactions, nature of resistance, role of elicitors, induction of host resistance through biotechnological tools and development of diagnostics with polyclonal and monoclonal antibodies for important *Phytophthora* spp. The main thrust would be development of host resistance, which forms an important component of IDM. Molecular characterization of *Phytophthora* spp.is important especially to assist the screening programs for resistance, since the idea is to develop horizontal resistance against more than one pathotypes. A strict quarantine regulation through adoption of new technology for seed health testing and in view of worldwide movement of seeds (116) must be observed.

Development of integrated disease management strategy involving cultural, chemical, biocontrol coupled with host resistance would be the major focus. Phytosanitation, nursery hygiene and biocontrol would remain major thrusts for the management of soil borne problems like *Phytophthora* foot rot, black pod of cocoa and capsule rot of cardamom. Utilization of biocontrol agetns like *Trichoderma, Gliocladium* and *Fluorescent* pseudomonads compatible with agrochemicals would be ideal for the IDM. In order to intensify both basic and applied aspects of *Phytophthora* research, Indian Council of Agricultural Research (ICAR) has set up National Network of *Phytophthora* Diseases of Horticultural Crops (PHYTONET) with nine centres all over India with its headquarters at Indian Institute of Spieces Research, Calicut.

8. REFERENCES

1. Abraham, K., Edwin Prem, E. and Nair, R.V. 1996. Screening of cocoa types for resistance to *Phytophthora* foot rot. *J. Plantn. Crops* Supplement 24 : 218-234.
2. Alagianagalingam, M.N. and Kandasamy, T.K. 1981. Control of capsule rot and rhizome rot of cardamom (*Elettaria cardamomum* Maton). *Madras Agric. J.* 68 : 554-557.
3. Al-Hedaithy, S.S.A. and Tsao, P.H. 1979. Sporangium pedicel length in *Phytophthora* species and the consideration of its uniformity in determining sporangium caducity. *Trans. Brit. Mycol. Sci.* 72 : 1-13.
4. Anandaraj, M. 1982. *Phytophthora* diseases of arecanut. *Indian Cocoa, Arecanut & Spices Jouranal* 6 : 37-38.
5. Anandaraj, M. 1985a. On the mechanism of spore dispersal in *Phytophthora arecae,* the causal organism of Koleroga of arecanut. In: *Arecanut research and development* (eds. K. Sharma Bhat and C.P. Radhakrishnan Nair) CPCRI, Kasaragod, pp. 83-85.
6. Anandaraj, M. 1985b. Effect of adhesives in the retention of Bordeaux mixture on arecanut bunches. *Ann. Trop. Res.* 7 : 62-65.
7. Anandaraj, M. 1997. *Ecology of Phytophthora capsici (Leonian, 1922 emend Alizadeh, A and Tsao, P.H.) causal organism of foot rot disease of black pepper (Piper nigrum L.).* Ph.D. Thesis. University of Calicut.
8. Anandaraj, M., Abraham, J. and Balakrishnan, R. 1989a. Crops loss due to foot rot disease of blackpepper. *Indian Phytopath.* 42: 473-476.
9. Anandaraj, M., Abraha, J., Sarma, Y.R. and Balakrishnan, R. 1989b. Incidence of foot rot disease of black pepper (*Piper nigrum* L.) in Kerala in relation to cultivation practices. *Indian J. Agric. Sci.* 59 :751-753.
10. Anandaraj, M., Arora, P. and Nagarajan, S. 1992. A linear model for predicting the prevalence level of Koleroga disease of arecanut four days in advance. *Indian J. Plant Prot.* 20 : 75-76.
11. Anandaraj, M. and Sarma, Y.R. 1999. How to manage *Phytophthora* in black pepper? *Planters' Chronicle* 95 : 277-280.
12. Anandaraj, M., Ramana, K.V. and Sarma, Y.R. 1996a. Sequential inoculation of *Phytophthora capsici, Radopholus similis* and *Meloidogyne incognita* in causing slow decline of black pepper. *Indian Phytopath.* 49: 297-299.
13. Anandaraj, M., Ramana, K.V. and Sarma, Y.R. 1996b. Role of *Phytophthora capsici* in the etiology of slow decline disease of black pepper. *J. Plantn. Crops (Supplement)* 24 : 166-170.
14. Anandaraj, M., Ramana, K.V. and Sarma, Y.R. (1996c). Suppressive effects of VAM on root damage caused by *Phytophthora capsici, Radopholus similis* and *Meloidogyne incognita* in black pepper. In : *Proc. IUFRO Symposium on impact of diseases and insect pests in tropical forests* (eds. K.S.S. Nair, J.K. Sharma and R.V. Verma) pp. 232-238.
15. Anandaraj, M. and Saraswathy, N. 1985. Disease surveillance on koleroga of arecanut caused by *Phytophthora arecae.* In : *Arecanut research and development* (eds. K. Shama Bhat and C.P. Radhakrishnan Nair) CPCRI, Kasaragod, pp. 95-96.
16. Anandaraj, M. and Saraswathy, N. 1986. Effect of systemic fungicides on fruit rot of arecanut. *Indian Phytopath.* 39: 607-609.
17. Anandaraj, M., Sarma, Y.R. and Ramachandran, N. 1994. *Phytophthora* foot rot of black pepper in relation to age of the host and its culmination in foot rot. *Indian Phytopath.* 47 : 203-206.
18. Anonymous 1995. *Annual report for 1994-95.* Indian Institute of Spices Research, Calicut, Kerala.

19. Aragaki, M. and Uchida, J.Y. 1992. Recent findings in *Phytophthora capsici (P. tropicalis)* (Abstr.). *Phytopathology* 82 : 1164.
20. Ashplant, H.T. 1928. *Bordeaux and burgandy spraying mixture.* Sci. Dept. Bull. United Plantation Association of South India.
21. Balakrishnan, R., Anandaraj, M., Nambiar, K.K.N., Sarma, Y.R., Brahma, R.N. and George, M.V. 1986. Estimates on the extent of loss due to quick wilt disease of black pepper (*Piper migrum* L.) in Calicut district of Kerala. *J. Plant Crops* 14: 15-18.
22. Bavappa, K.V.A., Nair, M.K. and Premkumar, T. 1982. (Eds.) *The arecanut palm* (*Areca catechu* L.). Central Plantation Crops Research Institute, Kasaragod, Kerala.
23. Bielenin, A., Jeffers, S.N., Wilcox, W.F. and Jones, A.L. (1988). Separation by protein electrophoresis of six species of *Phytophthora* associated with deciduous fruit crops. *Phytopathology* 78 : 1402-1408.
24. Blackwell, E. 1949. *Terminology in Phytophthora. Mycological paper no. 30.* Commonwealth Mycological Institute, London.
25. Bonants, P., Weerdt, M.H. de, Kema, G., Boogert, P. Van Den, Waalwijk, C. and Bayen, R. 1999. AFLP DNA finger printing of plant pathogenic fungi at IPO-DLO. *Petria* 9: 97-104.
26. Brasier, C.M. 1971. Induction of sexual reproduction in single A2 isolates of *Phytophthora* species by *Trichoderma viride. Nature New Biol.* 231-283.
27. Brasier, C.M. 1992. Evolutionary biology of *Phytophthora* : I. Genetic system, sexuality and the generation of variation. *Annu. Rev. Phytopathol.* 30: 153-171.
28. Brasier, C.M. 1983. Problems and prospects in *Phytophthora* research. In : *Phytophthora : its biology, taxonomy, ecology and pathology* (eds. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phytopathological Society, St. Paul, Minn, pp. 351-364.
29. Bumbieris, M. 1974. Characteristics of two *Phytophthora* species. *Aus. J. Bot.* 22: 655-660.
30. Butler, E.J. 1906. Some diseases of palms. *Agric. J. of India* 1: 299-310.
31. Butler, E.J. 1918. *Fungi and diseases in plants.* Thacker spink Calcutta.
32. Chandra Mohanan, R. 1978. Cacao canker caused by *Phytophthora palmivora. Plant Dis. Reptr.* 62: 1080-1082.
33. Cavalier-Smith, T. 1986. The kingdom Chromista : origin and systematics. In : *Progress in phycological research Vol. 4* (eds. I. Round and D.J. Chapman) Bio Press, Bristol, England.
34. Chandra Mohanan, R. 1979. Cacao seedlings die-back. *Indian Cocoa, Arecanut & Species Journlas* 111: 5-6.
35. Chandra Mohanan, R., Anandaraj, M. and Joshi, Yateendra 1979. *Studies on Phytophthora diseases* (eds. C.S. Venkata Ram) *Annual Symposium on Plantation Crops,* CPCRI, Kasaragod, pp. 335-342.
36. ChandraMohanan, R. and Kaveriappa, K.M. 1981. Occurence and distribution of cocoa diseases in South India. In : *Proc. 8th Int. Cocoa Res. Conf. 18-23 October, 1981,* Cartegena, Columbia, pp. 445-449.
37. Chee, K.H. 1974. Hosts of *Phytophthora palmivora.* In : *Phytophthora diseases of cocoa* (ed. P.H. Gregory) Longman, London.
38. Chowdappa, P. 1995. *Phytophthora* causing black pod disease of cocoa (*Theobroma cacao* L.) in South India. *Ph.D. Thesis, Mangalore University, Mangala Gangothri,* India.
39. Chowdappa, P. and ChandraMohanan, R. 1993. Morphological variability among isolates of *Phytophthora palmivora* causing black pod disease of cocoa in India. *J. Plantn. Crops.* 21 (Supplement) : 129-133.
40. Chowdappa, P., ChandraMohanan, R. and Ramanujam, B. 1993. Occurrence of *Phytophthora capsici* on cocoa in Kerala. *Indian Phytopath.* 46 : 92-93.

41. Chowdappa, P. and ChandraMohanan, R. 1995. Electrophoretic protein patterns of three species of *Phytophthora* associated with black pod disease of cocoa. *J. Biosci.* 20 : 637-644.

42. Chowdappa, P. and ChandraMohanan, R. 1996a. Occurrence of *Phytophhora citrophthora* on cocoa in India. *Trop. Agric. (Trinidad)* 73: 158-160.

43. Chowdappa, P. and ChandraMohanan, R. 1996b. Restriction digestion patterns of DNA of three species of *Phytophthora* responsible for black pod disease of coca. In : *Souvenior of national symposium on horticultural biotechnology,* 28-30, October, 1996, Bangalore, India.

44. Chowdappa, P. and ChandraMohanan, R. 1997a. Occurrence and distribution of mating types of *Phytophthora* spp. causing black pod disease of cocoa. *Indian Phytopath.* 50 : 87-90.

45. Chowdappa, P. and ChandraMohanan, R. 1997b. Taxonomy of *Phytophthora* spp. causing black pod disease of cocoa (*Theobroma cacao* L.). *J. Plantn. Crops* 25 : 127-145.

46. Chowdappa, P. and ChandraMohanan, R. 1997c. Serological differentiation of three species of *Phytophthora* causing black pod disease of cocoa (*Theobroma cacao* L.) In : *International conference on integrated plant disease management for sustainable agriculture* (Abstract) 10-15, November, 1977, New Delhi.

47. Chowdappa, P. and ChandraMohanan, R. 1997d. Pathogenic variability in isolates of *Phytophthora* causing black pod disease of cocoa in India in relation to host reaction. In : *International conference on integrated plant disease management for sustainable agriculture* (Abstract), 10-15, November, 1997, New Delhi.

48. Chowdappa, P. and ChandraMohanan, R. 1998. An integrated study of morphological and molecular patterns of *Phytophthora* causing black pod disease of cocoa in India. In : *Proc. 7th international congress of plant pathology,* 9-16 August, 1998, Edinburgh, Scotland, U.K.

48B. Chowdappa, P., Saraswathy, N., Vinayagopal, K. and Somala, M. 1999. Control of fruit rot of arecanut through polythene covering. In : *Plant disease management for sustainable agriclture,* 14-16 December, 1999, Kayangulum, Kerala.

49. Chowdappa, P. and ChandraMohanan, R. 2000. Molecular characterisation of *Phytophthora* causing black pod disease of cocoa in India. In : *Proc. national seminar on recent advances in plant biology,* 3-5 February, 2000, Kasaragod, India.

50. Clarke, D. 1966. Production of pectic enzymes by *Phytophthora infestants. Nature* 211: 649.

51. Coleman, L.C. 1910. Disease of the areca palm (*Areca catechu* L.). I. Koleroga or rot diseases. *Ann. Myc.* 8 : 591-626.

52. Coleman, L.C. and Venkata Rao, M.K. 1918. The cultivation of areca palm in Mysore. *General Ser. Bull. Dept. Agric. Mysore* 10:32.

53. Cooke, D.E.L., Kennedy, D.M., Guy, D.C., Russel, J., Unkles, S.E. and Duncan, J.M. 1996. Relatedness of Group I species of *Phytophthora* as assessed by randomly amplified polymorphic DNA (RAPDs) and sequences of ribosomal DNA. *Mycol. Res.* 100 : 297-303.

54. Cooke, D.E.L. and Duncan, J.M. 1997. Phylogenetic analysis of *Phytophthora* species based on ITS1 and ITS2 sequences of the ribosomal RNA gene repeat. *Mycol. Res.* 101 : 667-677.

55. Crowford, A.R., Bassam, B.J., Drenth, A. and Irwain, J.A.G. 1996. Evolutionary relationships among *Phytophthora* species deduced from r DNA sequence analysis. *Mycol. Res.* 100: 437-443.

56. Das, T.P.M. and Cheeran, A. 1986. Infectivity of *Phytophthora* species on cash crops in Kerala. *Agri. Res. J. Kerala* 24: 7-13.

57. de Vallavieille, C. and Erselius, L.J. 1984. Variation in protein profiles of *Phytophthora* : survey of a composite population of three species of citrus. *Trans. Brit. Mycol. Soc.* 83: 473-479.

58. Dick, M.W. 1990. Phylum Oomycota. In : *Handbook of Protoctista* (eds. L. Margulis, J.O. Corlis, D.J. Melkonian, Jones and Bartlett) Boston, USA.

59. Duniway, J.M. 1977. Changes in resistance to water transport in safflower during the development of *Phytophthora* root rot. *Phytopathology* 67 : 331-337.

60. Dutta, P.K. and Hegde, R.K. 1987. Studies on two *Phytophthora* diseases (Koleroga of arecanut and black pepper wilt) in Shimoga district, Karnataka State. *J. Plant Path. News Letter.* 5: 29.

61. Drechler, C. 1931. A crown rot of hollyhocks caused by *Phytophthora megasperma* n.sp. *J. Wash. Acad. Sci.* 21 : 513-526.

62. Doke, N. and Tomiyama, K. 1980. Effect of hyphal cell was components from *Phytophthora infestans* on protoplasts of potato tuber tissues. *Physiol. Plant Pathol* 16: 169-176.

63. Edathil, T.T., George, M.K., Krishnankutty, V., Jacob, C.K. and Pillai, P.N.R. 1984. Thermal fogging for controlling *Phytophthora* and *Oidium* leaf diseases of rubber in India. Paper presented in IV *International Rubber Conference,* June 24-26, Sauo Paulo, Brazil.

64. Edathil, T.T., Idicula, S.P. and Jacob, C.K. 1988. Field evaluation of fungicides to identify a substitute for organomercurials in the control of black stripe disease of rubber in India. *Indian Journal of Natural Rubber Research* 1 : 42-47.

65. Erselius, L.J. and de Vallavieille, C. 1984. Variation in protein profiles of *Phytophthora* : comparison of six species. *Trans. Brit. Mycol. Sco.* 83 : 463-472.

66. Erwin, D.C. 1966. Varietal reaction of alfalfa to *Phytophthora megasperma* and variation in virulence of the causal fungus. *Phytopathology* 56 : 653-657.

67. Erwin, D.C. 1983. Variability within and among species of *Phytophthora.* In : *Phytophthora : its biology, taxonomy, ecology and pathology* (eds. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phytopathological Society, St. Paul, Minn., pp. 149-165.

68. Erwin, D.C. and Ribeiro, O.K. 1996. *Phytophthora diseases - worldwide.* American Phytopathological Society, USA.

69. Forster, H. and Coffey, M.D. 1991. Approaches to the taxonomy of *Phytophthora* using polymorphisms in mitochondrial and nuclear DNA. Ih : *Phytophthora* (eds. J.A. Lucas, R.C. Shattock, D.S. Shaw and L.R. Cooke) Cambridge Uni. Press, Cambridge, U.K., pp. 164-183.

70. Forster, H. and Coffey, M.D. 1992. Molecular characterisation of *Phytophthora* isolates with non-papillate sporangia causing root rot of raspberry using mt DNA restriction fragment length polymorphisms. *Mycol. Res.* 97: 571-577.

71. Forster, H. and Coffey, M.D. 1993. Molecular taxonomy of *Phytophthora megasperma* based on mitochondrial and nuclear DNA polymophisms. *Mycol. Res.* 97 : 1101-1112.

72. Forster, H., Kincherf, T.G., Legon, S.A. and Maxwell, D.P. 1988. Estimation of relatedness between *Phytophthora* species by analysis of mitochondrial DNA. *Mycologia* 80: 466-478.

73. Forster, H., Kincherf, T.G., Leong, S.A. and Maxwell, D.P. 1989. Restriction fragment length polymorphisms of the mitochondrial DNA of *Phytophthora megasperma* isolated from soybean, alfalfa and fruit trees. *Can. J. Bot.* 67 : 529-537.

74. Forster, H., Oudemans, P. and Coffey, M.D. 1990. Mitochondrial and nuclear DNA diversity within six species of *Phytophthora. Exp. Mycol.* 14 : 18-31.

75. Frezzi, M.J. 1950. Las especies de *Phytophthora* en la Argentina (The species of *Phytophthora* in Argentina). *Rev. Invest. Agric. Buenos Aires* 4: 47-133 (in Spanish).

76. Friend, J. 1991. Host-pathogen interactions : current questions. In : *Phytophthora* (eds. J.A. Lucas, R.C. Shattock, D.S. Shaw and Cooke, L.R.) Cambridge Uni. Press, Cambridge, U.K., pp. 46-49.

77. Gallegly, M.E. 1983. New criteria for classifying *Phytophthora* and critique of existing approaches. In : *Phytophthora : its biology, taxonomy, ecology and pathology* (eds. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phytopathological Society, St. Paul, Minn., pp. 167-173.

78. George, M.K. and Thomson, T.E. 1975. Over summering of *Phytophthora* causing abnormal leaf fall disease of rubber. *Rubb. Board Bull.* 12: 112-114.

79. George, M.V. 1997. Status of plantation crops in India. *J. Plantn. Crops.* 25: 1-14.

80. Gregory, P.H. 1974. *Phytophthora disease of cocoa.* Longman, London.

81. Gregory, P.H., Griffin, M.J., Maddison, A.C. and Ward, M.R. 1984. Cocoa black pod : a re-interpretation. *Cocoa Growers Bull.* 35: 5-22.

82. Griffin, M.J., Odowu, O.L., Maddison, A.C., Taylor, B. and Ward, M.R. 1981. Sources of infection. In : *Epidemiology of Phytophthora of cocoa in Nigeria* (eds. P.H. Gregory and A.C. Maddison), *Phytopathological paper (CMI) No.* 25 : 75-95.

83. Halsell, D.M. 1979. Specificity of the cytoplasmic and cell wall antigens from four species of *Phytophthora. J. Gen. Microbiol* 94 : 149-158.

84. Hamm, P.B. and Hansen, E.M. 1983. *Phytophthora pseudotsugae,* a new species causing root rot of Douglass-fir. *Can. J. Bot.* 61 : 2626-2631.

85. Hansen, E.M., Brasier, C.M., Shaw, D.S. and Hamm, P.B. 1986. The taxonomic structure of *Phytophthora megasperma* : evidence for emerging biological species groups. *Trans. Brit. Mycol. Soc.* 87 : 557-573.

86. Hemmes, D.E. 1983. Cytology of *Phytophthora.* In : *Phytophthora : its biology, taxonomy, ecology and pathology* (eds. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phyto pathological Society, St. Paul, Minn., pp. 9-40.

87. Ho, H.H. 1978. Hyphal branching systems in *Phyophthora* and other Phycomycetes. *Mycopathologia* 64 : 83-86.

88. Ho, H.H. 1979. Electronmicroscopic studies of oogonial wall and elemental composition of oogonia in *Phytophthora. Mycopathologia* 68 : 17-21.

89. Ho, H.H. 1981. Synoptic keys to the species of *Phytophthora. Mycologia* 73 : 705-714.

90. Ho, H.H. and Jong, S.C. 1986. A comparison between *Phytophthora cryptogea* and *P. drechsleri. Mycotaxon* 27: 289-319.

91. Ho, H.H., Ann, F.J. and Chang, H.S. 1995. *The genus Phytophthora in Taiwan.* Institute of Botany, Academic Sinica, Monograph Series 15.

92. Ho, H.H., Zentmyer, G.A. and Erwin, D.C. 1977. Morphology of sex organs of *Phytophthora cambivora. Mycologia* 69: 641-646.

93. Hutcheson, Steven W. 1998. Current concepts of active defense in plants. *Ann. Rev. Phytopath.* 36: 59-90.

94. Idicula, S.P., Edathil, T.T. and Jacob, C.K. 1986. Spray volume requirements in high volume spraying of rubber. *Journal of Plantation Crops* 16: 273-275.

95. Jacob, C.K., Edathil, T.T., Idicula, S.P. and Jayarathnam, K. 1989. Effect of abnormal leaf fall disease caused by *Phytophthora* spp. on the yield of rubber tree. *Indian Journal of Natural Rubber Research.* 2 : 77-80.

96. Jayarathnam, K., Rao, S.P. and Krishnankutty, V. 1987. A study on the weather associated with abnormal leaf fall disease of rubber (*Hevea brasiliensis*). *National Seminar on Agrometeorology of Plantation Crops,* March 1987, Pilicode, Kerala, India.

97. Joseph, T., Suseela Bhai, R. and Naidu, R. 1991. Capsule rot disease of small cardamom (*Elettaria cardamomum* Maton) and its control. *J. Plantn. Crops* 18 (Supplement) : 264-268.

98. Joseph, T., Suseela Bhai, R. and Naidu, R. 1994. Present status of *Phytophthora* on small [illegible] (*Elettaria cardamomum* Maton). In: *National group meeting on Phytophthora* [illegible] Spices.

99. Joseph, T. and Radha, K. 1975. Role of *Phytophthora palmivora* in bud rot of coconut. *Pl. Dis. Reptr.* 59 : 1014-1017.

100. Kaosiri, T. and Zentmyer, G.A. 1980. Protein, esterase and peroxidase patterns in the *Phytophthora palmivora* complex from cacao. *Mycologia* 72 : 988-100.

101. Kamat, M.N. 1956. *Introductory Plant Pathology.* Prakash Publishing House, Pune, Maharashtra, India.

102. Keen, N.T. 1990. Phytoalexins and their elicitors. In : *Microbes and microbial products as herbicides* (eds. R.E. Hoagland) Am. Cem. Soc. Symp. Ser. 439, Washington DC, pp. 114-129.

103. Keen, T.N. and Yoshikawa, M. 1983. Physiology of disease and the nature of resistance to *Phytophthora.* In: *Phytophthora : Its biology, taxonomy, ecology and pathology* (eds. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phytopathological Society, St. Paul, Minn., pp. 279-287.

104. Keen, N.T. and Yoshikawa, M. 1990. The expression of resistance in soybeans to *Phytophthora megasperma* f. sp. *glycinea.* In : *Biological control of soil-borne plant pathogens* (eds. D. Hornby, R.J. Cook, Y. Henis, W.H. Ko, A.D. Rovira, B. Schppers and P.R. Scott) CAB International, Oxford, U.K., pp. 329-344.

105. Keen, N.T., Wang, M.C., Bartnicki-Garcia, S. and Zentymer, G.A. 1975. Phytotoxicity of mycolaminarins-β-1, 3-glucans from *Phytophthora* spp. *Physiol. Plant Patholol.* 7: 91-97.

106. Ko, W.H. 1978. Heterothallic *Phytophthora* : evidence for hormonal regulation of sexual reproduction. *J. Gen. Microbiol.* 107 : 15-18.

107. Krober, H. 1985. Erfahrungen mit *Phytophthora* de Bary und *Pythium* Pringsheim. *Mitt. Biol. Bundesanst. Land. Forstwirtsch Berl. Dehlem* 225, 175 pp.

108. Kuan, T.I. and Erwin, D.C. 1980. Formae speciales differentiation of *Phytophthora megasperma* isolates from soybean and alfalfa. *Phytopahtology* 70 : 333-338.

109. Kumari, P.S. and Hegde, R.K. 1987. Studies on *Phytophthora* diseases of plantation crops. *Pl. Path. Newsletter* 5: 28.

110. Lee, S.B. and Taylor, J.W. 1992. Phylogeny of five fungus - like protoctistan *Phytophthora* species, inferred from the internal transcribed spacers of ribosomal DNA. *Mol. Bio. Evol.* 9 : 636-653.

111. Leonian, L.H. 1934. Identification of *Phytophthora* species. *W. Va. Uni. Agric. Exp. Stn. Bull.* 262, 36 pp.

112. Liew, E.C.Y., Maclean, D.J., Manners, J.M., Dawson, D. and Irwin, J.A.G. 1991. Use of restriction fragment legnth polymorphisms to genetic relationships between Australian and Japanese isolates of *Phytophthora vignae. Aust. J. Bot.* 39 : 335-346.

113. Lingaraj, D.S. 1969. Bud rot disease of coconut and arecanut and their control. *J. Mysore. Hort. Soc.* 14 : 19-21.

114. Liyange, N.I.S. and Wheeler, B.E.J. 1989. *Phytophthora katsurae* from cocoa. *Plant Pathol.* 40 : 436-444.

115. Mammootty, K.P., Manmohandas, T.P., Sasikumaran, S., Unnikrishnan Nair, P.K. and Abicheeran 1991. Some aspects on epidemiology of foot rot (quick wilt) disease of black pepper (*Piper nigrum L.*). In : *Diseases of black pepper-Proceedings of the international pepper community workshop on black pepper disease* 27-29 October, 1988, Goa, India (eds. Y.R. Sarma and T. Premkumar) National Research Centre for Spices, Calicut, Kerala, India, pp. 102-113.

116. Maleck, K. and Dietrich, R.A. 1999. Defense on multiple fronts : How do plants cope with

117. Marudarajan, D. 1941. Observations on production of sexual organs in paired cultures of *Phytophthora* species of *Palmivora* group. *Proc. Indian Acad. Sci. B.* 14 : 384-389.

118. Marudarajan, D. 1950. Fruit rot of arecanut (mahali or Koleroga). *ICAR Monthly Bulletin* 1: 5-6.

119. Mc Intyre, J.L. and Hankin, L. 1978. An examination of enzyme production by *Phytophthora* species on solid and liquid media. *Can. J. Microbiol.* 24 : 75-78.

119a. Mchau, G.R.A. and Coffey, M.D. 1994. Isozyme diversity in *Phytophthora palmivora* : evidence for south-east Asia center of origin. *Mycol. Res.* 98 : 1035-1043.

120. Mchau, G.R.A. and Coffey, M.D. 1995. Evidence for the existence of two sub-population in *Phytophthora capsici* and a rediscription of the species. *Mycol. Res.* 99 : 89-102.

121. Mc Rae 1919. A disease of the para rubber tree caused by *Phytophthora meadii* Mc Rae. *Agricultural Journal of India* 14 : 566-577.

122. Menon, K.P.V. and Pandalai, K.M. 1958. *The coconut palm - a monograph.* Indian Central Coconut Committee, Ernankulam, India.

123. Menon, M.R., Sajood, B.V., Ramakrishnan, C.K. and Rema Devi, L. 1972. A new *Phytophthora* disease of cardamom (*Elettaria cardamomum* Maton). *Curri Sci.* 41 : 231.

123a. Menon, M.R., Sajood, B.V., Ramakrishnan, C.K. and Rema Devi, L. 1973. Control of *Phytophthora* disease of cardamom. *Agricultural Research J. Kerala.* 11 : 93-94.

124. Mills, S.D., Forster, H. and Coffey, M.D. 1991. Taxonomic structure of *Phytophthora cryptogea* and *P. drechsleri* based on isozyme and mitochondia DNA analysis. *Mycol. Res.* 95 : 31-48.

125. Nair, M.K. and Sarma, Y.R. 1988. International pepper community workshop on joint research for the control of black pepper diseases, October 27-29, 1988 at Goa - a report. *J. Plantn. Crops.* 16 : 146-149.

126. Nair, R.R. 1979. *Investigations on fungal diseases of cardamom* (*Elettaria cardamomum* Maton). Ph.D. Thesis, Kerala Agricultural University, Vellanikkara, Trichur, Kerala.

127. Nair, R.R. and Menon, M.R. 1982. Azhukal disease of cardamom. In : *Proceedings of the workshop on Phytophthora diseases of tropical cultivated plants,* CPCRI, Kasaragod, pp. 24-33.

128. Nambiar, K.K.N. 1956. *Arecanut cultivation in India.* ICAR, New Delhi.

129. Nambiar, K.K.N. and Sarma, Y.R. 1974. Chemical control of capsule rot of cardamom. *J. Plant. Crops.* 2: 30-31.

130. Nambiar, K.K.N. and Sarma, Y.R. 1976. Capsule rot of cardamom : *Pythium vexans* de Bary as a causal agent. *J. Plant. Crops.* 4: 21-22.

131. Nambiar, K.K.N. and Sarma, Y.R. 1977. Wilt disease of black pepper. *J. Plantn. Crops* 5: 92-103.

132. Nambiar, K.K.N. and Rawther, T.S.S. 1993. Fungal diseases of coconut in the world. In : *Advances in coconut research and development* (eds. M.K. Nair, H.H. Khan, P. Gopalasundaram and E.V.V. Bhaskara Rao), Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, pp. 545-561.

133. Narasimharao, B., Reddy, K.N., Sultan, M.A, Reddy, D.J. and Rajamannar, M. 1994. Residues of metalaxyl in coconut water and copra when administered through root. *Indian Coconut J.* 24 : 9-10.

134. Narasimhan, M.J. 1922. The arcea koleroga work during 1921. *Mysore Agric. Calendar for* 1921: 4-8.

134a. Narasimhan, M.J. 1924. Method of preparing casein Bordeaux mixture against supari

135. Narasimhan, M.J. 1928. A new spraying mixture against areca Koleroga. *Mysore Agric. Calendar* for 1927: 24-25.

136. Newhook, F.J., Waterhouse, G.M. and Stamps, D.J. 1978. Tabular key to the species of *Phytophthora* de Bary. *Mycological paper No.* 143, CMI London.

137. Nues, R.W., Rienties, J.M.J., Van der Sande, C.A.F., Shuraila, F.Z., Sluiter, C., Venema, J., Planta, R.J. and Raue, H.A. 1994. Separate structural elements within internal transcribed spacer I of *Saccharomyces cerevisiae* precursor ribosomal RNA direct the formation of 17S and 26S r RNA. *Nucleic Acids Research* 22 : 912-919.

138. Nygaard, S.L., Elliot, C.K., Cannon, S.J. and Maxwell, D.P. 1989. Isozyme variability among isolates of *Phytophthora megasperma. Phytopathology* 79 : 773-780.

139. Nyasse, S., Grivet, L., Risterucci, A.M., Blaha, G., Berry, D., Lanaud, C. and Despreaux, D. 1999. Diversity of *Phytophthora megakarya* in central and west Africa revealed by isozyme and RAPD markers. *Mycological Research* 103 : 1225-1234.

140. Old, K.M., Moran, G.F. and Bell, J.S. 1984. Isozyme variability among isolates of *Phytophthora cinnamomi* from Australia and Papua New Guinea. *Can. J. Bot.* 62 : 2016-2022.

141. Old, K.M., Dudzinsky, M.J. and Bell, J.S. 1988. Isozyme variability in field population of *Phytophthora cinnamomi* from Australia. *Aus. J. Bot.* 36 : 355-366.

142. Oudemans, P. and Coffey, M.D. 1991a. Isozyme comparision within and among worldwide sources of three morphological distinct species of *Phytophthora. Mycol. Res.* 95 : 19-30.

143. Oudemans, P. and Coffey, M.D. 1991b. A revised systematics of twelve papillate *Phytophthora* species based on isozyme analysis. *Mycol. Res.* 95 : 1025-1046.

144. Oudemans, P. and Coffey, M.D. 1991c. Relationships between *Phytophthora* species : evidences from isozyme analysis. In : *Phytophthora* (eds. J.A. Lucas, R.C. Shattock, D.S. Shaw and L.R. Cooke) Cambridge Uni. Press, Cambridge, U.K., pp. 184-203.

145. Oudemans, P., Forster, H. and Coffey, M.D. 1994. Evidence for distinct isozymes subgroups within *Phytophthora citricola* and close relationships with *P. capsici* and *P. citrophthora. Mycol. Res.* 98 : 189-196.

146. Panbieres, A., Marais, A., Trentin, F., Bonnet, P. and Ricci, P. 1989. Repetitive DNA polymorphism analysis as a tool for identifying *Phytophthora* species. *Phytopathology* 79 : 1105-1109.

147. Peethambaran, C.K., Suseela Bhai, R., Joseph Thomas and Naidu, R. 1991. Standardisation of screening techniques against Azhukal disease of small cardamom (*E. cardamomum* Maton). *J. Plant. Crops.* 18 (Supplement) : 252-256.

148. Pethybridge, G.H. 1913. On the rotting of the potato tubers by a new species of *Phytophthora* having a method of sexual reproduction hitherto undescribed. *Sci. Proc. Royal Dublin Soc. Ns* 13 : 529-565.

149. Peters, B.M., Cribbs, D.H. and Stelzing, D.A. 1978. Agglutination of plant protoplasts by fungal cell wall glucans. *Science* 201 : 364-365.

150. Pillai, P.N.R. 1982. Abnormal leaf fall disease of rubber caused by *Phytophthora spp.* In : *Phytophthora disease of tropical cultivated plants* (ed. K.K.N. Nambiar) Central Plantation Crops Research Institute, Kasaragod - 670124, Kerala, pp. 17-23.

151. Pillai, P.N.R. and George, M.K. 1973. Recent experiments on the control of abnormal disease of rubber in India. *RRIC* 50 : 223.

152. Pillai, P.N.R., George, M.K., Rajalakshmy, V.K. and Krishnankutty, V. 1980. Crown budding - a method to avoid abnormal leaf fall disease of rubber. *International Rubber Conference* India, 1980, Kottayam, Kerala.

154. Rajamannar, M., Prasad, J.K. and Sarma, Y.R. 1996. Etiology and control of nut rot of coconut. *J. Plantn. Crops* (Supplement) 24 : 225-228.

155. Ramachandran, N. 1990. *Bioefficacy of systemic fungicides against Phytophthora infections in black pepper (Piper nigrum* L.). Ph.D. Thesis, University of Calicut, Kerala, India.

156. Ramachandran, N. and Sarma, Y.R. 1988. Fungitoxic effect of endosulfan and quinalphos on *Phytophthora palmivora* the foot rot pathogen of black pepper. Tests of agrochemicals and cultivars No. 9. *Annals of Applied Biology* 112 (Supplement), : 26-27.

157. Ramachandran, N., Sarma, Y.R. and Anandaraj, M. 1990. Vertical progression and spread of *Phytophthora* leaf infection in arecanut - black pepper mixed cropping system. *Indian Phytopath.* 43 : 414-419.

158. Ramachandran, N., Sarma, Y.R., Anandaraj, M. and Jose Abraham 1988. Effect of climatic factors on *Phytophthora* leaf infection in black pepper grown in arecanut, black pepper mixed cropping system. *J. Plantn.* 16 : 110-118.

159. Ramachandran, N., Sarma, Y.R. and Anandaraj, M. 1991. Management of *Phytophthora* infections in black pepper. In : *Diseases of black pepper, Proceedings of the international pepper community workshop on black pepper diseases* 27-29 October, 1988, Goa, India (eds. Y.R. Sarma and T. Premkukar) National Research Centre for Spices, Calicut, Kerala, India, pp. 158-174.

160. Ramakrishnan, T.S. 1957. Shoot rot of young rubber caused by *Phytophthora palmivora Butl. Rubber Board Bulletin* 4: 76.

161. Ramakrishnan, T.S. 1964. Patch canker or bark canker caused by *Phytophthora palmivora* Butl. and *Pythium wexans De Bary. Rubber Board Bulletin.* 7 : 11-13.

162. Ramakrishnan, T.S. and Pillai, P.N.R. 1961. Abnormal leaf fall disease of rubber caused by *Phytophthora palmivora (Butl.) Butl. Rubber Board Bulletin* 5 : 11-20.

163. Ramakrishnan, T.S. and Seethalakshmi, V. 1956. Studies in the genus *Phytophthora* III homothallic strains of *Phytophthora* on *Areca catechu. Indian Acad. Sci.* 25 : 308-313.

164. Ramakrishnan, K. and Thankappan, M. 1965. First report of pod pepper disease of cocoa in India. *S. Indian Hort.* 13 : 33-34.

165. Ramana, K.V., Sarma, Y.R. and Mohandas, C. 1994. Slow decline of black pepper (*Piper nigrum.* L) and role of plant parasitic nematodes and *Phytophthora capsici* in the disease complex. *J. Plantn. Crops.* 20 (Supplement) : 65-68.

166. Rao, G.K.R. 1989. *Fungi associated with stem canker of cocoa.* M. Phil. Dissertation, Mangalore University, Mangalagangothri, Mangalore, Karnataka, India.

167. Rawther, T.S.S., Nair, R.R. and Saraswathy, N. 1982. In : Diseases in the arecanut palm. (eds. K.V.A. Bavappa, M.K. Nair and T. Premkumar) Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 185-218.

168. Reddy, M.K. and Anandaraj, M. 1982. Koleroga of arecanut. In : *Proc. workshop on Phytophthora diseases of tropical cultivated plants* (ed. K.K.N. Nambiar) CPCRI, Kasaragod, India, pp. 71-79.

169. Reeves, R.J. and Jackson, R.M. 1974. Stimulation of sexual reproduction in *Phytophthora* by damage. *J. Gen. Microbiol.* 84 : 303-310.

170. Rosenbaum, J. 1917. Studies on genus *Phytophthora. J. Agric. Res.* 8 : 232-276.

171. Sadanandan, A.K., Jose Abraham and Anadaraj, M. 1992. Impact of high production technology on productivity and disease of black pepper (*Piper nigrum* L.). *J. Plantn. Crops.* 20 : 384-387.

172. Samraj, J. and Jose, P.C. 1966. *Phytophthora* wilt of pepper (*Piper nigrum* L.). *Sci. & Cult.*

173. Santhakumari, P. 1987. *Studies on Phytophthora diseases of plantation crops.* Ph.D. thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.

174. Saraswathy, N. 1993. *Studies on Phytophthora species of arecanut and arecanut based cropping systems.* Ph.D. thesis, Mangalore University, Karnataka, India.

175. Sarma, Y.R. and Anandaraj, M. 1997. *Phytophthora* foot rot of black pepper. In : *Management of threatening plant diseases of national importance* (eds. V.P. Agnihotri, A.K. Sarabhoy and D.V. Singh) Malhotra Publishing House, New Delhi, pp. 237-248.

176. Sarma, Y.R., Anandaraj, M. and Rajan, P.P. 1994a. *Phytophthora* - a threat to black pepper - present status and future strategies of disease management. *Spice India* 7 : 10-13.

177. Sarma, Y.R., Anadaraj, M. and Ramachandran, N. 1992. Recent advances on *Phytophthora* foot rot research in India and the need for holistic approach. In : *Proceedings International Workshop on Black Pepper Diseases,* Bandar Lampung, Indonesia (eds. P. Wahid, D. Sitepu, S. Deciyanto and U. Suparman) Agency for Agricultural Research and Development, Research Insitute for Spice and Medicinal Crops, Bogor - Indonesia, pp. 133-143.

178. Sarma, Y.R., Anandaraj, M. and Venugopal, M.N. 1994b. Diseases of spice crops. In : *Advances in horticulture, plantation and spice crops,* Part 2, Vol. 10 (eds. K.L. Chadha and P. Rethinam) Malhotra Publishing House, New Delhi, pp. 1015-1058.

179. Sarma, Y.R., Anandaraj, M. and Venugopal, M.N. 1996. Biological control in spices (eds. M. Anandaraj and K.V. Peter) Indian Institute of Spices Research, Calicut, Kerala, pp. 10-19.

180. Sarma, Y.R. and Nambiar, K.K.N. 1992. Foot rot disease of black pepper (*Piper nigrum* L.). In : *Phytophthora diseases of tropical cultivated plants - Proceedings of the workshop* (ed. K.K.N. Nambiar) Central Plantation Crops Research Institute, Kasaragod, India, pp. 209-224.

181. Sarma, Y.R., Nambiar, K.K.N. and Anandaraj, M. 1993. Foliar yellowing and root rot in coconut seedlings affected by *Phytophthora* sp. *Poster paper presented at international symposium on coconut research and development II,* 26-29 Nov. 1991 CPCRI, Kasaragod.

182. Sarma, Y.R., Nambiar, K.K.N. and Nair, M.K. 1982. Screening of black pepper, *Piper nigrum* L. and *Piper* spp. against *Phytophthora palmivora.* In : *Phytophthora diseases of tropical cultivated plants - Proc. of workshop on Phytophthora diseases of tropical cultivated plants* (ed. K.K.N. Nambiar) Central Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 242-247.

183. Sarma, Y.R., Ramachandran, N. and Anandaraj, M. 1988. Integrated disease management of quick wilt (foot rot) of black pepper caused by *Phytophthora palmivora* MF4. *J. Coffee Research* (Supplement) 18 : 68-72.

184. Sarma, Y.R., Ramachandran, N. and Anandaraj, M. 1991b. Black pepper diseases in India. In : *Diseases of black pepper - Proceedings of the international pepper community workshop on black pepper diseases, Goa, India* (eds. Y.R. Sarma and T. Premkumar) National Research Centre for Spices, Calicut, Kerala, India, pp. 55-101.

185. Sarma, Y.R., Ramachandran, N. and Nambiar, K.K.N. 1981. Sources of inoculum of *Phytophthora palmivora* of blackpepper (*Piper nigrum L.*) in disease spread and the improtance of morphology of the fungus. In : *Third International Symposium on Plant Pathology,* December 14-18, 1981, Indian Phytopathological Society, IARI, New Delhi, India.

186. Sastry, M.N.L. 1982. *Studies on species of Phytophthora affecting plantation crops in Karnataka with special reference to Koleroga of Arecanut and wilt of black pepper.* Ph.D. thesis, University of Agricultural Sciences, Bangalore, College of Agriculture, Dharwad, 188 pp.

187. Sastry, M.N.L. and Hegde, R.K. 1987a. *Phytophthora* associated with arecanut (*Areca catechu*

188. Sastry, M.N.L. and Hegde, R.K. 1987b. Distribution of mating types and their role in perpetuation of *Phytophthora palmivora* and *P. meadii*. *Indian Phytopath* 40 : 370-373.

189. Shaw, F.J. and Sundararaman, S. 1914. Bud rot of coconut palms in Malabar. *Annals Mycologia* 12 : 251-262.

190. Schwinn, F.J. 1959. Untersuchungen zur Systematik der Gattung *Phytophthora* de Bary (Research on the systematics of the genus *Phytophthora* de Bary). *Arch. Microbiol.* 33: 223-252 (In Germany).

191. Sahu, A.K., Maheswari, S.K., Sriram, S. and Misra, R.S. 2000. Effect of temperature and pH on the growth of *Phytophthora colocasiae*. *Annals of Plant Protection Sciences* 8: 112-114.

192. Sreenivasan, T.N. and Chandra Mohanan, R. 1984. *Phytophthora* associated with cocoa (*Theobroma cacao L.*) in South Kanara district, Karnataka, India. *Tropical Agric.* (Trinidad) 62 : 186-187.

193. Stamps, D.J., Watershouse, G.M., Newhook, F.J. and Hall, G.S. 1990. Revised tabular key to the species of the *Phytophthora*. *Mycological papers* 162, CAB International Mycological Institute, Kew, London.

194. Stoseel, P. 1988. Pathogenesis in host-parasite specificity in *Phytophthora*. In : *Experimental and conceptual plant pathology, Vol. 2* (eds. W.M. Hess, R.S. Singh, C.S. Singh and D.J. Weber) Gordon and Breach Sci. Pub., pp. 139-456.

195. Stossel, P., Lazarovtis, G. and Ward, E.W.B. 1980. Penetration and growth of compatible and incompatible races of *Phytophthora megasperma* var *sojae* in soybean hypocotyls tissues differing in age. *Can. J. Bot.* 58 : 2594-2601.

196. Sundararaman, S. and Ramakrishnan, T.S. 1924. The mahali disease of coconuts in Malabar. *Memoris Dept. of Agri. India, Bot. Ser.* 13 : 87-97.

197. Suseela Bhai, R., Joseph, T. and Naidu, R. 1992. Evaluation of promising selections of small cardamom against Azhukal disease. *J. Plant Crops* (Supplement) 20 : 90-91.

198. Suseela Bhai, R., Joseph, T. and Naidu, R. 1993. Biological control of Azhukal disease of small cardamom caused by *P. meadii* Mc Rae. *J. Plantn. Crops* (Supplement) 21 : 50-52.

199. Suseela Bhai, R., Joseph, T. and Naidu, R. 1994. Evaluation of carrier media for field application of *Trichoderma* spp. in cardamom growing soil. *J. Plantn. Crops* 22 : 50-52.

200. Sydow, H. and Butler, E.J. 1907. Fungi Indiae orientalis, Part II. *Ann. Mycol.* 5 : 485-515.

201. Taylor, J.W. 1986. Fungal evolutionary biology and mitochondrial DNA. *Exp. Mycol.* 10 : 259-269.

202. Thankamma, L. 1969. Germination of oospores formed by interspecific mating of *Phytophthora palmivora* (Butl.) Butl. and *P. meadii* (Mc Rae.) causing abnormal leaf fall disease of rubber in India. *Rubber Board Bulletin* 10 : 197-199.

203. Thankamma, L. and Pillai, P.N.R. 1970. Sexual compatibility of *Phytophthora* isolates causing diseases of *Hevea* in India. *Rubber Board Bulletin* 11 : 0-13.

204. Thankamma, L. and Pillai, P.N.R. 1973. Fruit rot and leaf rot diseases of cardamom in India. *F.A.O. Plant Protection Bulletin* 21: 83-84.

205. Thomas, K.M. and Marudarajan, D. 1938. Some aspects of the control of koleroga or mahali disease of areca palm. *ICAC Month. J.* 26 : 435-438.

206. Thomas, K.M., Ramakrishnan, T.S., Soumini, C.K. and Balakrishnan, M.S. 1947. Studies on the genus *Phytophthora* 1. Oospore formation and taxonomy of *Phytophthora palmivora* Butl. *Proc. Indian Acad. Sci.* 26(B) : 147-163.

207. Thomson, T.E. and George, M.K. 1973. A report on *Phytophthora nicotianae* var *parasitica* [illegible] rubber in India. *Rubber Res. Inst. Bull.* 13 : 3-4.

209. Tsao, P.H. and Sisemore, D.J. 1978. Morphological variability in *Phytophthora parasitica* (*P. nicotianae*) from citrus, tomato and tobacco. *Phytopathol. News* 12 : 213. (Abstract).

210. Tsao, P.H. and Alizadeh, A. 1988. Recent advances in the taxonomy and nomenclature of the so-called "*Phytphthora palmivora* MF4 occurring on cocoa and other tropical crops. *In : Proc. 10th Int. Cocoa Res. Conf., Santo Damingo,* 17-23 May, 1987, pp. 441-445.

211. Tsao, P.H., Sarma, Y.R., Kasim, R., Mustika, I. and Kuech, T.K. 1985. Variation in *Phytophthora palmivora* MF4 (*P. capsici*) isolates from black pepper in India, Indonesia and Malaysia. *Phytopathology* 75 : 1315 (Abstr.)

212. Tucker, C.M. 1931. Taxonomy of the genus *Phytophthora* de Bary. *Uni. Mo. Agric. Exp. Stn. Res. Bull.* 153 : 1-207.

213. Unnikrishnan Nair, P.K., Sasikumaran, S., Sukumara Pillay, V. and Prasada Rao, G.S. L.H.V. 1988. Influence of weather on foot rot disease of black pepper (*Piper nigrum* L.). In : *Agrometerology of plantation crops* (eds. G.S.L.H. Prasadarao and R.R. Nair) Kerala Agrl. University, Trichur, pp. 98-113.

214. Uppal, B.N. and Desai, M.K. 1939. Koleroga disease of arecanut. *Curr. Sci.* 8 : 122-124.

215. Wager, V.A. 1940. Description of South African Pythiaceae with records of their occurence. *Bothalia* 4: 3-35.

216. Ward, E.W.B. 1990. The interaction of soybeans with *Phytophthora megasperma* f. sp. *glycenia* pathogenicity. In : *Biological control of soil-borne plant pathogens* (eds. D. Hornby, R.J. Cook, Y. Henis, W.H. Ko, A.D. Rovira, B. Schppers and P.R. Scott) CAB International, Oxford, U.K., pp. 311-327.

217. Waterhouse, G.M. 1963. Key to the species of *Phytophthora* de Bary. *Mycological papers* (CMI) 92 : 1-22.

218. Waterhouse, G.M. 1974. *Phytophthora* and some related speices. In : *Phytophthora* disease of cocoa (eds. P.H., Gregory) Longman, London, pp. 51-70.

219. Waterhouse, G.M. and Blackwell, E.M 1954. Key to the species of *Phytophthora* recorded in the British Isles. *CMI papers* 57.

220. Waterhouse, G.M., Newhook, F.J. and Stamps, D.J. 1983. The present criteria for classification of *Phytophthora*. In: *Phytophthora : its biology, taxonomy, ecology and pathology* (ed. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phytopathological Society, St. Paul, Minn., pp. 139-147.

221. Whittaker, R.H. and Magulis, L. 1978. Protist classification and the kingdoms of organisms. *Bio Systems* 10 : 3-15.

222. Woodward, J.R., Keane, P.J. and Stone, B.A. 1980. Structures and properties of wilt-inducing polysacharides from *Phytophthora* species. *Physiol. Plant Pathol.* 16 : 439-454.

223. Yoshikawa, M., Tsukadaira, T., Masago, H. and Minuora, S. 1977. A non-pectolytic protein from *Phytophthora capsici* that macerates plant tissue. *Physiol. Plan. Patholo.* 11: 61-70.

224. Yoshikawa, M., Yamaguchi, K. and Masago, H. 1978. Glyceollin : its role in restricting fungal growth in resistant soybean hypocotyls infected with *Phytophthora megasperma* var. *sojae*. *Physiol. Plant. Patholo.* 12 : 73-82.

225. Zaki, A.I., Zentymer, G.A., Sims, J.J. and Keen, N.T. 1983. Stimulation of sexual reproduction in the A-2 mating type of *Phytophtho]ra cinnamomi* by oleic acid and lipids from avocado roots. *Phytopathology.* 73 : 199-203.

226. Zentymer, G.A. 1983. The world of *Phytophthora*. In : *Phytophthora : its biology, taxonomy, ecology, and pathology* (eds. D.C. Erwin, S. Bartnicki-Garcia and P.H. Tsao) American Phytopathological Society, St. Paul, Minn., pp. 1-8.

227. Zheng, X.B. and Ho, H.H. 2000. Sexual stage of *Phytophthora polygoni* Saw: *Botanical Bulletin of Academia Sinica* 41: 57-60.