# CHAPTER 5

# GENERAL DISCUSSION

Plant pests which include insects, pathogens and weeds, continue to be major constraints to food and agricultural production in parts of all regions of developing countries, and they are difficult to control because of their population are variable in time, space, and genotype. Their effects range from mild symptoms to catastrophes in which large areas planted to foods crops are destroyed. Crop losses significantly reduce the amount of food available for human and animal consumption, thus contributing directly to food insecurity. At least 10% of global food production is lost to plant disease (James, 1998; FAO, 2000). Among them, various taxa of plant pathogenic fungi including a group of *Cercospora* complex causing leaf spot on a wide range of plants, particularly, may cause catastrophic plant disease because of at least five reasons:

(1) Many of them sporulate prolifically, the spores providing copious inoculum, which may infect further plants (Agrios, 2005);

(2) Their latent period, i.e., the time between infection and the production of further infectious propagules, usually spores, is very short, may be only a few days (Deacon, 2006);

(3) The spores may be spread as high-density inoculum in surface water or in droplets by rain-splash or may be carried long distance by the wind (Deacon, 2006);

(4) They may produce chemical compounds which are phytotoxic and could also destroy the plant's structure, for example *Cercosporin* (Daub and Ehrenshaft, 2000);

(5) They may draw nutrients away from the economically valuable part of the plants by the production growth regulator inhibitors, such as Abscisic Acid (ABA) produced by *Cercospora rosicola*, and consequently depress yields (Norman *et al*., 1983).

At the present time, we noted that the threat is particularly greater in developing countries which are mostly located in tropical areas, where diversity of live and plant pathogens particularly are higher than temperate areas as previously suggested (Hawksworth, 1993; Shivas and Hyde 1997), but the infrastructures and number of plant pathologists are often poorly resourced. In fact, the problem of plant disease in developing countries is might also fundamentally be arised from two factors: *firstly, the difficulty of quantifying plant disease and relating to the failure of crops to reach achievable yields*. It is proved by this study where approximately 166 species of the true cercosporoid fungi have been recorded from 2004 until 2008 with the aid of several expertises worldwide either by helping in identification or by providing some importance literatures for identification. In fact, until 1994, only approximately 50 species of cercosporoid fungi were recorded from Thailand (Giatgong, 1980; Sontirat *et al*., 1980, 1994; Petcharat and Kanjanamaneesathian, 1989). The inability to supply such hard data to administrators and politicians has meant that plant pathology, in relation to its importance, continues to be grossly underfunded. *Secondly, globalizations of agriculture, its mean crops plants, often with narrow genetic base, are now grown far from their centers of origin, and therefore, also far from their pathogens that have coevolved with them*. As a result, these plants are unlikely to have evolved resistance to new strains of the pathogen that may have subsequently arisen in the center of origin. In addition, crops introduced to a new area may be poorly equipped to resist pathogenic organisms that may be resident there.

This study also found and revealed that approximately 40 species of plants infected by the true cercosporoid fungi species in northern areas of Thailand are not originally from Asian continent (table 10). Of the 43 species plants which are recorded as new hosts of the true cercosporoid fungi in this study, 16 species are also not originally from Asian continent (see chapter 2, table 1; chapter 5, table 10). We might reaffirm that, recently, globalizations of agriculture are well-established, and the plants either crops or ornamentals are well-distributed worldwide and introduced into new areas by various manners.

The following two suggestions are possibly useful in order to deal with the situations discussed above:

(1) *At the biological level, increasing level of the speed and accuracy of identification of the causal organisms, accuracy of estimation of the severity of disease and its effect on yield, and identification of its virulence mechanism* (Strange and Scott, 2005).

If these requirements are fulfilled well, disease may then be minimized by the reduction of the pathogen's inoculum, inhibition of its virulence mechanisms, and promotion of genetic diversity in the crops. Enhancing the capability of rapid disease detection and diagnosis will significantly increase the probability of achieving containment and eradication of high-risk pathogens. Therefore, study on biodiversity and conservation including surveying, collecting, and archiving pathogen cultures and associated data in a format that supports pathogen detection and diagnosis should be an important step in enhancing nationwide preparedness.

(2) *Secondly, creating plant diseases resistance crops by using conventional pant breeding.*

Lenné and Wood (1991) reviewed the need to broaden the genetic base of crops to combat genetic vulnerability, as the variation within and between the varieties of traditional agriculture are progressively replaced by more uniform and higher yielding varieties. Lenné and Wood (1991) also mentioned three main germplasm resources are available to plant breeders, viz, commercial varieties, landraces (traditional varieties), and a range of wild ancestral species and other wild relatives. Of them, wild ancestral species and other wild relatives are the most promising germplasm because of the closeness relationship to a crop has hitherto determined the value of wild germplasm in breeding. This relative closeness indicates possible resistances to comparable diseases because of the interface between crops and their wild relatives is an evolutionary dynamic one, and therefore, these resistances may be available to breeders using conventional crossing.

Successful disease resistance in wild germplasm populations is related to both individual and population survival from the environmental factors including pathogens (Brown *et al*., 1989). Coexistence of wild relatives of crops and their indigenous pathogens in the center of origin of the crops is only one of many systems where field studies are needed to facilitate effective use of resistance. Therefore, at all stages of collection and maintenance of wild germplasm, at the collecting site, the biology of the wild species (life span, ecology, and breeding system) and the biology and ecology of their pathogen(s) will determine the pattern of distribution of disease resistance between and within host populations (Brown *et al*., 1989). As much of this type of information as possible should be available for pre-collecting planning, which should involve plant pathologists. Predictions on the presence or absence of hosts and pathogens will need to be verified in the field, necessitating a plant pathologist with the collecting mission. Disease evaluation data for previously collected germplasm should be used to target collecting sites. However, this important information that must be provided by plant pathologists is mostly lacking or could not be completed in the developing countries due to infrastructures and human resources are often poorly resourced.

**5.1. Important Findings in This Study**

This study has surveyed, collected, and investigated a diversity of *Cercospora* and allied genera particularly the genera belong to the true cercosporoid fungi proposed by Crous and Braun (2003) in several provinces of northern part of Thailand (chapter 2). In total, 166 species of the true cercosporoid fungi associated with 147 plants genera of 63 families have been examined and identified, consist of 78 *Cercospora*, 21 *Passalora*, and 67 *Pseudocercospora* species. Twenty-one species are new to science in which nine species have been validly published or are in the process of publication. Sixty-two species are new records to Thailand, and 43 plants species are new host to this group of fungi. Thirty species of genus *Cercospora* belong to *C. apii s. lat.* In addition, approximately 34 species of important crops such as tea (*Camellia sinensis*), coffee (*Coffea arabica*), banana (*Musa acuminata*), lettuce (*Lactuca sativa*), etc. (table 10), 97 species of ornamentals plants, 11 species weeds, and 30 species of plants with other properties, have been infected or associated with the true cercosporoid fungi.

**Table 10** List of the plant species associated with the true cercosporoid fungi in this study and their uses [Data of plant properties were cited from USDA plant database (http://www.plants.usda.gov/index.html) and Wikipedia (http://wikipedia.org/)].

| Genus | Notes |
|---|---|
| *Acalypha wilkesiana* | Ornamentals, distributed from southern United States to Uruguay and northern Argentina. |
| *Alangium salviifolium* | Ornamentals, native to western Africa, Madagascar, southern and eastern Asia (China, Malaysia, Indonesia, and the Philippines), tropical Australia, the western Pacific Ocean islands, and New Caledonia. |
| *Alcea rosea* | Ornamentals, native to southwest and central Asia. |
| *Alpinia purpurata* | Ornamentals, native to Malaysian peninsula. |
| *Andrographis paniculata* | Medicinal properties, especially leaves, native to India and Sri Lanka. |
| *Arachis hypogaea* | Important crops, native to South America, Mexico and Central America. |
| *Areca catechu* | Important crops and ornamentals as well, native to tropical Pacific, Asia, and parts of east Africa. |
| *Argyreia henryi* | Ornamentals, mainly tropical Asia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Aristolochia tagala* | Medicinal properties, distributed from the Himalaya to Sri Lanka through South East Asia (includes Myanmar, Indonesia, Indochina, and Thailand) and China, to Oceania (includes the whole of Malesia, the Solomon Islands and Queensland in Australia). |
| *Artemisia indica* | Ornamentals and medicinal properties, growth in temperate climates of the Northern Hemisphere and Southern Hemisphere, usually in dry or semi-dry habitats. |
| *Barleria cristata* | Ornamentals, native of India and Myanmar. |
| *Barleria lupulina* | Ornamentals, native of India and Myanmar. |
| *Basella alba* | Foods/vegetables, distributed in the tropics where it is widely used as a leaf vegetable. |
| *Bauhinia racemosa* | Ornamentals, many species are widely planted in the tropics as "orchid trees", particularly in northern India, Vietnam and southeastern China. |
| *Beta vulgaris* | Important crops, the wild ancestor is found throughout the Mediterranean, the Atlantic coast of Europe, the Near East, and India. |
| *Bidens pilosa* | Foods/vegetables, it is also considered as a weed in some tropical habitats. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Bougainvillea spectabilis* | Ornamentals, native to South America from Brazil west to Peru and south to southern Argentina. |
| *Blumea balsamifera* | Medicinal properties, distributed in tropical area especially Asia. |
| *Brassica campestris* | Important crops, distributed worldwide. |
| *Brassica juncea* | Important crops, distributed worldwide. |
| *Brassica oleracea* | Important crops, distributed worldwide. |
| *Brassica pekinensis* | Important crops, distributed worldwide. |
| *Bridelia ovata* | Wild plant, found from Africa to Asia. |
| *Broussonetia papyrifera* | The bark can be used for making high quality paper, native to eastern Asia. |
| *Brunfelsia hopeana* | Ornamentals, origin from South and Central America, the Mexican lowlands, the Caribbean islands, and southern Florida. |
| *Buddleja asiatica* | Ornamentals, distributed from tropical to warm areas worldwide. |
| *Butea monosperma* | Timber and medicinal properties, native to tropical southern Asia, from Pakistan, India, Nepal, Sri Lanka, Myanmar, Thailand, Laos, Cambodia, Vietnam, Malaysia, and western Indonesia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Camellia sinensis* | Important crops, cultivated in the countries lie on the equator area. |
| *Capsicum annuum* | Important crops, distributed worldwide. |
| *Capsicum annuum* var. *acuminatum* | Important crops, distributed worldwide. |
| *Capsicum frutescens* | Important crops, distributed worldwide. |
| *Carica papaya* | Important crops, it is native to the tropics of the Americas. |
| *Cassia agnes* | Ornamentals, distributed worldwide in tropical area. |
| *Celosia argentea* | Foods/vegetables, distributed in Africa and Southeast Asia. |
| *Celosia argentea* var. *cristata* | Foods/vegetables, distributed in Africa and Southeast Asia. |
| *Centrosema pubescens* | Ornamentals, origin from tropical American. |
| *Corchorus capsularis* | Cotton and fibres properties, distributed in tropical countries. |
| *Christella parasitica* | Weeds, in tropical countries in Asia. |
| *Chrysanthemum* sp. | Ornamentals, native to Asia and northeastern Europe. |
| *Cichorium endivia* | Important crops/vegetables, distributed worldwide. |
| *Citrullus vulgaris* | Important crops, originally from southern Africa. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Citrus reticulata* | Important crops, it can be grown in tropical and subtropical areas. |
| *Clerodendrum fragrans* | Ornamentals, native to tropical and warm temperate regions of the world, with most of the species occurring in tropical Africa and southern Asia. |
| *Clerodendrum paniculatum* | Ornamentals, native to tropical and warm temperate regions of the world, with most of the species occurring in tropical Africa and southern Asia. |
| *Clitoria ternatea* | Ornamentals, native to tropical and equatorial Asia, but has been introduced to Africa, Australia and Europe. |
| *Coccinia grandis* | Crops, natives of Thailand, Indonesia, and other southeast Asian countries. |
| *Codiaeum variegatum* | Ornamentals, occurs naturally in southern Asia, Indonesia and other Eastern Pacific islands. |
| *Coffea arabica* | Important crops, indigenous to Ethiopia and Yemen. |
| *Conyza sumatrensis* | Weeds, annual herb native to North America but naturalized worldwide. |
| *Cosmos sulphureus* | Ornamentals, it is usually weeds, native habitat is Central America. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Crotalaria montana* | Ornamentals, world-wide, mostly distributed in the tropics. |
| *Cucumis sativus* | Important crops, worldwide, originated from India. |
| *Cucurbita moschata* | Important crops, widely cultivated in south and central America and Asia. |
| *Cuphea hyssopifolia* | Ornamentals, native to Mexico, Guatemala and Honduras. |
| *Cynara scolymus* | Foods/vegetables, originating from southern Europe around the Mediterranean. |
| *Dahlia* sp. | Ornamentals, native to Mexico, Central America, and Colombia. |
| *Dalbergia cultrata* | Timber properties, wide distributed, native to the tropical regions of Central and South America, Africa, Madagascar and southern Asia. |
| *Dalbergia stipulacea* | Timber properties, wide distributed, native to the tropical regions of Central and South America, Africa, Madagascar and southern Asia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Datura alba* | Weeds, dangerous for human or animals, exact natural distribution is uncertain, due to extensive cultivation and naturalization throughout the temperate and tropical regions of the globe, but is most likely restricted to the Americas, from the United States south through Mexico, where the highest species diversity occurs. |
| *Dioscorea alata* | Foods and vegetables properties, native to south east Asia. |
| *Dioscorea bulbifera* | Foods and vegetables properties, native to south east Asia. |
| *Dioscorea glabra* | Foods and vegetables properties, native to south east Asia. |
| *Diospyros kaki* | Mostly timber properties, majority are native to the tropics, with only a few species extending into temperate regions. |
| *Dolichos lablab* | Important crops, widespread as a Foods Crops throughout the tropics, especially in Africa, India and Indonesia. |
| *Doryopteris ludens* | Ornamentals fern , origin from peninsular Malaysia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Dracaena sanderiana* | Ornamentals, native to Cameroon in tropical west Africa. |
| *Dregea volubilis* | Ornamentals, which occurs widely throughout the hotter parts of India and South East Asia. |
| *Duranta erecta* | Ornamentals or weeds, originally native to Central and South America and the Caribbean, it is widely naturalized throughout the tropics and has become an invasive species in Australia, China, South Africa and on several Pacific Islands. |
| *Duranta repens* | Ornamentals or weeds, originally native to Central and South America and the Caribbean, it is widely naturalized throughout the tropics and has become an invasive species in Australia, China, South Africa and on several Pacific Islands. |
| *Elaeagnus conferta* | Ornamentals, vast majority of the species are native to temperate and subtropical regions of Asia. |
| *Elaeocarpus grandiflorus* | Wild plant or ornamentals, distributed from Madagascar in the west through India, Southeast Asia, Malaysia, southern China, and Japan, through Australia to New Zealand, Fiji, and Hawaii in the east. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Erythrina* sp. | Ornamentals, distributed in tropical and subtropical regions worldwide. |
| *Eucalyptus* sp. | Important crops, native to Australia. |
| *Eupatorium adenophorum* | Weeds, native to Mexico, but it is known in many other parts of the world as an introduced species and often a noxious weed. |
| *Eupatorium odoratum* | Weeds, native to Mexico, but it is known in many other parts of the world as an introduced species and often a noxious weed. |
| *Euphorbia cotinifolia* | Ornamentals, widely distributed in Central America. |
| *Euphorbia milii* | Ornamentals, native to Madagascar. |
| *Ficus carica* | Fruit as foods source, native to southwest Asia and the eastern Mediterranean region (from Greece to Pakistan). |
| *Ficus punctata* | Fruit as foods source, native to southwest Asia and the eastern Mediterranean region (from Greece to Pakistan). |
| *Ficus religiosa* | Ornamentals, native to India, Nepal, Sri Lanka, southwest China and Indochina east to Vietnam. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Ficus rumphii* | Ornamentals, native throughout the tropics with a few species extending into the semi-warm temperate zone. |
| *Flacourtia jangomas* | Ornamentals, widely cultivated in Southeast and East Asia. |
| *Fuchsia* sp. | Ornamentals, great majority are native to South America, but with a few occurring north through Central America to Mexico, and also several from New Zealand, and Tahiti. |
| *Gardenia jasminoides* | Ornamentals, originated in Asia, and is most commonly found growing in Vietnam, Southern China, Taiwan and Japan. |
| *Gerbera jamesonii* | Ornamentals, discovered in Barberton, Mpumalanga Province, South Africa. |
| *Glochidion sphaerogynum* | Ornamentals, distributed from Madagascar to the Pacific Islands. |
| *Glycine max* | Important crops, native to East Asia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Gmelina arborea* | Ornamentals, timber, and medicinal properties, occurring naturally throughout greater part of India at altitudes up to 1500 meters, and also in Myanmar, Thailand, Laos, Cambodia, Vietnam, and in southern provinces of China, and has been planted extensively in Sierra Leone, Nigeria, Malaysia. |
| *Habenaria susannae* | Ornamentals, widely distributed in both tropical and temperate zones. |
| *Haldina cordifolia* | Ornamentals, native to southern Asia, from India east to southern China and Vietnam. |
| *Helianthus annuus* | Ornamentals, foods, and oil properties, native to the Americas. |
| *Hibiscus rosa-sinensis* | Ornamentals, native to East Asia. |
| *Hibiscus sabdariffa* | Ornamentals, native to Europeans, Asians, and Africans. |
| *Hibiscus* sp. | Ornamentals, native to warm, temperate, subtropical and tropical regions throughout the world. |
| *Holmskioldia sanguinea* | Ornamentals, origin from China |
| *Houttuynia cordata* | Foods/vegetables, native to Japan, Korea, southern China and Southeast Asia. |
| *Hydrangea macrophylla* | Ornamentals, native to Japan. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Impatiens balsamina* | Ornamentals or foods/vegetables, native to southern Asia in India and Myanmar. |
| *Impatiens walleriana* | Ornamentals, native to eastern Africa from Kenya to Mozambique. |
| *Ipomoea aquatica* | Foods/vegetables, found throughout the tropical and subtropical regions of the world. |
| *Ipomoea nil* | Foods/vegetables, native to most of the tropical world and it has been introduced widely. |
| *Ipomoea obscura* | Foods/vegetables, native to most of the tropical world and it has been introduced widely. |
| *Iresine herbstii* | Ornamentals, found in the wild in tropical America. |
| *Jasminum nobile* | Ornamentals, native to tropical and warm temperate regions of the Old World (Europe). |
| *Jasminum sambac* | Ornamentals, native to southern Asia, in India, Philippines, Myanmar and Sri Lanka. |
| *Jatropha curcas* | Ornamentals, originating in Central America, whereas it has been spread to other tropical and subtropical countries as well and is mainly grown in Asia and in Africa. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Justicia betonica* | Ornamentals, native to tropical to warm temperate regions of the Americas, with two species occurring north into cooler temperate regions. |
| *Kopsia fruticosa* | Ornamentals, native to tropical and warm regions |
| *Lablab purpureus* | Important crops throughout the tropics, especially in Africa, India and Indonesia. |
| *Lactuca sativa* (7 cultivars) | Important crops, widely distributed. |
| *Lagenaria siceraria* | Important crops, distributed worldwide. |
| *Lagerstroemia speciosa* | Ornamentals and medicinal properties, native to tropical southern Asia. |
| *Lantana camara* | Ornamentals, native to tropical regions in Central and South America. |
| *Leucaena leucocephala* | Firewood, fiber and livestock feed properties, weeds in Taiwan, the Hawaiian islands and Fiji. |
| *Liquidambar formosana* | Ornamentals and wood properties, distributed in east Asia to Europe. |
| *Lycopersicon esculentum* var. *pyriforme* | Important crops, native to Central, South, and southern North America. |
| *Mallotus pierrei* | Wild plant, timber properties, found in tropical Africa and Madagascar. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Manihot esculenta* | Important crops, annual crops in tropical and subtropical regions. |
| *Melia azedarach* | Timber properties, native to India, southern China and Australia. |
| *Mikania cordata* | Weeds in the tropics, originates from South America. |
| *Mitracarpus villosus* | Ornamentals and medicinal properties, distributed in tropical and warm areas. |
| *Momordica charantia* | Important crops, widely grown in South and Southeast Asia, China, Africa, and the Caribbean |
| *Morus alba* | Medicinal properties, native to northern China, and is widely cultivated (and even naturalized) elsewhere. |
| *Morus* sp. | Foods and medicinal properties, native to warm, temperate, and subtropical regions of Asia, Africa, Europe, and the Americas, with the majority of the species native to Asia. |
| *Mucuna bracteata* | Ornamentals, found worldwide in the woodlands of tropical areas. |
| *Musa acuminata* | Important crops, native to northern Australia. |
| *Myrica esculenta* | Ornamentals, has a wide distribution, including Africa, Asia, Europe, North America and South America, and missing only from Australasia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Nelumbo nucifera* | Ornamentals, native to Greater India and commonly cultivated in water gardens, the lotus is the national flower of India and Vietnam. |
| *Nephrolepis biserrata* | Ornamentals fern, distributed in tropical areas. |
| *Nephrolepis cordifolia* | Ornamentals fern, distributed in tropical areas. |
| *Nerium oleander* | Ornamentals, widely distributed. |
| *Nicotiana tabacum* | Important Crops, originally from southern America |
| *Nymphaea stellata* | Ornamentals, can be found almost anywhere around the world. |
| *Operculina turpethum* | Ornamentals or as vegetables, distributed in tropics or warm areas. |
| *Oroxylum indicum* | Ornamentals and medicinal properties, distributed throughout India and South East Asia. |
| *Oxalis debilis* var. *corymbosa* | Ornamentals, species diversity is particularly rich in tropical Brazil and Mexico and in South Africa. |
| *Pentalinon luteum* | Ornamentals, naturally occurring in sunny locales throughout the coastal areas and rock pinelands of South Florida and the Caribbean area. |
| *Pericampylus glaucus* | Ornamentals and medicinal properties, distributed in Philippines and south east Asia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Phyllanthus acidus* | Ornamentals and the fruits are also edible, south Asia. |
| *Phyllanthus* sp. | Ornamentals and the fruits are also edible, south Asia. |
| *Physalis angulata* | Ornamentals and also edible, naturalized in Australia, but in the Northern Territory its arrival is thought to pre-date European settlement, so it is considered native there |
| *Platycerium bifurcatum* | Ornamentals fern, native to tropical areas of South America, Africa, Southeast Asia, Australia and New Guinea. |
| *Platycerium wallichii* | Ornamentals fern, native to tropical areas of South America, Africa, Southeast Asia, Australia and New Guinea. |
| *Polyscias scutellaria* | Ornamentals, widely distributed. |
| *Psophocarpus tetragonolobus* | Important crops, native to Papua New Guinea. |
| *Pteris biaurita* | Ornamentals fern, native to tropical and subtropical regions of the world |
| *Prunus persica* | Important crops, native to China. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Pueraria phaseoloides* | Weeds, widely distributed in tropical areas. |
| *Punica granatum* | Ornamentals and foods, native to the region from Iran to the Himalayas in northern India and has been cultivated and naturalized over the whole Mediterranean region and the Caucasus since ancient times. |
| *Quisqualis indica* | Ornamentals, found in Asia. |
| *Raphanus sativus* | Important crops, domesticated in Europe in pre-Roman times, they are grown and consumed throughout the world. |
| *Rhinacanthus nasutus* | Ornamentals/wild plants, natural habitats are subtropical or tropical dry shrub-land and subtropical or tropical dry lowland grassland. |
| *Ricinus communis* | Source of castor oil/medicine, indigenous to the southeastern Mediterranean region, Eastern Africa, and India; today it is widespread throughout tropical regions. |
| *Rosa hybrida* | Ornamentals, most are native to Asia, with smaller numbers of species native to Europe, North America, and northwest Africa. |

**Table 10** (continued)

| Genus | Notes |
| --- | --- |
| *Sambucus simpsonii* | Ornamentals, native in temperate-to-subtropical regions. |
| *Sechium edule* | Important crops, origin from south and central America. |
| *Sida mysorensis* | Ornamentals, worldwide distribution, mostly found in the tropics and subtropics, although some species extend into temperate regions. |
| *Solanum indicum* | Important crops, native to India and Sri Lanka. |
| *Solanum melongena* | Important crops, native to India and Sri Lanka. |
| *Solanum nigrum* | Medicinal properties, native to Asia and Europe. |
| *Solanum trilobatum* | Important crops, native to South Asia. |
| *Solanum verbascifolium* | Weeds, naturalized in Australia and New Zealand. |
| *Solanum xanthocarpum* | Weeds, leaves are edible, distributed in tropical area. |
| *Solanum torvum* | Important crops, tropical and warm regions. |
| *Solenostemon scutellarioides* | Ornamentals, origin from Southeast Asia and Malaysia |
| *Spinacia oleracea* | Important crops, native to central and southwestern Asia. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Tabebuia* sp. | Ornamentals or timber properties, distributed from northern Mexico and the Antilles south to northern Argentina and central Venezuela, including the Caribbean islands of Hispaniola (Dominican Republic and Haiti) and Cuba |
| *Tagetes erecta* | Ornamentals, native to Mexico and Central America. |
| *Talinum triangulare* | Foods/vegetables, grown in West Africa, South Asia, Southeast Asia, and warmer parts of North America and South America. |
| *Tecoma stans* | Ornamentals, native to South and Central America, north to Mexico and the southwestern United States. |
| *Tectona grandis* | Ornamentals and timber properties, native to the south and southeast of Asia, and is commonly found as a component of monsoon forest vegetation. |
| *Tithonia diversifolia* | Ornamentals, distributed in tropical and subtropical areas such as Central America, Southeast Asia and Africa. |
| *Tridax procumbens* | Weeds, native to the tropical Americas but it has been introduced to tropical, subtropical, and mild temperate regions worldwide. |
| *Triplaris surinamensis* | Ornamentals, distributed in the Americas. |

**Table 10** (continued)

| Genus | Notes |
|---|---|
| *Vigna radiata* | Important crops, native to Pakistan and India. |
| *Vigna unguiculata* | Important crops, legume crops in the semi-arid tropics covering Asia, Africa, southern Europe and Central and South America. |
| *Vigna unguiculata* var. *sesquipedalis* | Important crops, legume crops in the semi-arid tropics covering Asia, Africa, southern Europe and Central and South America. |
| *Vitex quinata* | Weeds, native to tropical, subtropical and also warm temperate regions throughout the world. |
| *Zantedeschia* sp. | Ornamentals, native to southern Africa from South Africa north to Malawi. |
| *Zinnia elegans* | Ornamentals, originally from scrub and dry grassland in an area stretching from the American Southwest to South America, but primarily Mexico. |
| *Zinnia grandiflora* | Ornamentals, originally from scrub and dry grassland in an area stretching from the American Southwest to South America, but primarily Mexico. |

A high number of the true cercosporoid fungi collected in this study represent the expectation of several previous authors (Rossmann *et al.*, 1987; Hawksworth 1991, 1993; Shivas and Hyde, 1997) that plant pathogens in tropical regions are more diverse than temperate regions. This facts possibly due to two-thirds of the world's flowering plants occur in the tropics (Heywood, 1985), thus the enormous diversity of plant species in the tropics will undoubtedly support an equally diverse flora of plant pathogens including fungi that are generally thought to have co-evolved with their hosts (Pirozynski, 1988).

In a smaller scale, a high number of the true cercosporoid fungi found in this study also represent a high number of total plant pathogens associated with various plants in Thailand. In this study alone, approximately 34 species of important crops in Thailand (table 10) have been infected by members of the true cercosporoid fungi. With a highly number of the members of the true cercosporoid fungi infecting crops were found and tracked in this study, it is possible that epidemics caused by the members of this group of plant pathogens in uniformly monoculture plants or crops will occur in Thailand. Cases of epidemics caused by the cercosporoid fungi with a significant damage to the crops production were reported from several countries, for examples, severe cercospora leaf spots epidemics in sugar beet (*Beta vulgaris* L.) were reported from southern Germany caused by *C. beticola* during the late 1980s and early 1990s (Wolf and Verreet, 2005); a similar epidemic case by the same fungus, *C. beticola*, was also found in Hokkaido, Japan in 2000 (Yuko *et al*., 2002). Therefore, consequently, as plant pathologists we have to realize in a cautious way to the impacts and threats caused by this group of pathogens to the agricultural systems and food security, because when pathogens are present in an area (and no official efforts are made for its eradication), it can be considered an established pathogen. Damage by established pathogens can be severe and may change from year to year. This situation could only be avoided by developing our capacities and capabilities in identification, tracking, and diagnosing plant pathogens associated with crops in farming area or from natural ecosystems.

We also found many plants associated with the true cercosporoid fungi are not originally from Asian continent or tropical areas (table 10). Thus, this finding is very important to be cautioned by plant pathologists in Thailand because many current pathogens have the capacity for rapid multiplication and for long distance migration and can cause extensive crop damage in the new areas. For example, *C. zeae-maydis,* a foliar pathogen causing gray leaf spot of maize / corn (*Zea mays* L.), first discovered in 1924 in Illinois, U.S.A. At first, *C. zeae-maydis* did not become an important pathogen of maize until the 1980s, however, by the mid-1990s, the fungus caused significant losses throughout the corn belt of the U.S., and it is now the most devastating foliar pathogen of maize in much of the world (Ward *et al*., 1999). Unfortunately, such a migratory pathogen is very difficult to avoid nowadays because of many factors, include international trade and food aid that increases the movements of plants and often their accompanying pathogens, and migration and tourism that increase movements of people who carry plant materials.

In the molecular phylogenetic study of the true cercosporoid fungi with related taxa based on ITS region of rDNA sequence data using NJ, MP and Bayesian analyses (chapter 3), it is clear that *Cercospora*, *Passalora*, and *Pseudocercospora*, are well defined morphologically and phylogenetically as previously suggested (Stewart *et al*., 1999; Goodwin *et al*., 2001; Crous and Braun, 2003; Hunter *et al*., 2006; den Breeÿen *et al.*, 2006; Burgess *et al.*, 2007). However, further molecular investigation of genus *Stenella* with larger dataset is necessary due to the genus *Stenella* is still polyphyletic in the analysis. In addition, genus *Stigmina* appeared as a sister group to genus *Phaeoisariopsis,* and morphologically, both species share a similarity characteristics in having multi septate and obclavate conidia with truncate and unthickened hila, sometimes verruculose, and composed of transverse and longitudinal septate (Ellis, 1971). Although both species are separated due to synnematous conidiophores of *Phaeoisariopsis*, however, conidiophores in *Stigmina* also in packed closely together forming a pulvinate sporodochia (synnematous-like, but very short in size). Therefore, further molecular analysis with more sequences included is needed to determine the relationship between the two genera.

Another important finding from the molecular analysis in this study, that is, most of the members of *Cercospora* and *Pseudocercospora* are possibly not host-specific based on ITS region of rDNA sequence analysis using NJ, MP, and Bayesian inference approaches. This is probably true because the genus *Mycosphaerella* and its anamorphs (*Cercospora*-complex) encompass both saprobic and parasitic life forms (Aptroot, 2006), although the parasitic species are supposed to be host-specific. However, in some cases experimental evidence exists of the contrary (Crous and Braun, 2003). Therefore, at present time, it is still difficult to determine which species are specific to their host, and which species have a multi-hosts relationship. The saprobic species, although in the past often described repeatedly from different hosts, are generally accepted to be less host-specific.

In the study of diversity of the cercosporoid fungi associated with weeds (chapter 4), it is revealed that one species, *C. christellae* associated with exotic weed

*Christella parasitica*, is a new to science. In addition, this novel fungus is possibly potential as a source of biocontrol agent due to it has an ability to produce red pigment (cercosporin) in the artificial medium. In this study also found that four species of weeds associated with the true cercosporoid fungi in northern Thailand are not origin from Asian continent.

**5.2. Problems Encountered**

The fundamental problems in this study are a limitation source of sequences in the Web-based GenBank database available although over 3,000 names have been published as *Cercospora* and allied genera (Crous and Braun, 2003), and facilities and funding for doing molecular analysis. Lacking of available sequences for molecular phylogenetic analysis have been serious problems not only in this study but also many scientists worldwide, therefore, the study regarding the phylogenetic relationships among taxa in this group remains few until present time. Study on the cercosporoid fungi evolution, their association with host, and pathogenicity analysis which are depending on the availability of sequences data become difficult to carry out, and taxonomically, many genera proposed based on traditional method (morphological description only) are still uncertain. This is partly due to the fact that these organisms are cultivated with difficulty, and also that the first to address the taxonomy of this complex based on DNA sequence data was only relatively recently published (Stewart *et al*., 1999). We also face another difficulty during our molecular analysis, that is, in the NCBI GenBank database alone, most of the cercosporoid fungi taxa sequences available are generated from ITS region. Other genes, such as β-tubulin, calmodulin, etc., are very limited if not lacking. Therefore, in this study, we sequenced only ITS regions, and consequently, we found that it is difficult to make any conclusion on the evolution study of *Cercospora* complex and their host specificity based on the single gene locus sequence analysis.

In simpler manner of systematic works in this study, biodiversity work based on morphological elucidation, literatures which are key in studying biodiversity, are also lacking and very difficult to obtain due to the limitation in our library, and possibly, in other libraries in developing countries as well. The literatures used and obtained for the identification in this study are very scattered and limited. Although we have successfully collected most of the literatures of the cercosporoid fungi from Thailand such as Giatgong (1980), Sontirat *et al.* (1980, 1994), Petcharat and Kanjanamaneesathian (1989), however, it is definitely still not sufficient enough to fulfill the need of literatures for this study due to those literatures are only represent less than 1% of total cercosporoid fungi taxa recorded worldwide. Fortunately, we have established cooperation and relationship with other scientists worldwide and with their kind assistance and help, some important references were available in order to identify our collections. Without the collaborations with other scientists, definitely, it will not be possible to study biodiversity and systematic of plant pathogens appropriately in developing countries such as Thailand due to limited resources and infrastructures.



**5.3. Conclusions and Future Directions**

Mycologists and plant pathologists share a common goal, that is, to understand the biology of incredible plant pathogenic fungi, and more specifically, to understand the genetic basis of pathogenicity and host-specificity. The *Cercospora* complex or cercosporoid fungi affords the opportunity to study plant pathogens that may have adaptive value for plant pathogenicity, survival from various controls and human treatments, and the latter contributing to their systematic and evolution.

In this study, it is revealed that one species, *C. christellae* associated with exotic weed *C. parasitica*, is a new to science. This fungus possesses an ability to produce red pigment (cercosporin), a broad spectrum photoactivated toxin which is potential as herbicides, in the artificial medium (chapter 4). Therefore, it is important to carry out further intensive study on the biology of this pathogen in order to develop alternative control strategies of weeds, particularly invasive weeds in Thailand.

In taxonomy study by using molecular phylogenetic analysis of ITS region sequence dataset (chapter 3), it is clear that the members of three genera noted as true cercosporoid fungi, viz, *Cercospora*, *Passalora*, and *Pseudocercospora* are monophyletic as previously suggested (Stewart *et al*., 1999; Goodwin *et al*., 2001; Hunter *et al*., 2006; den Breeÿen *et al*., 2006; Burgess *et al*., 2007). These three taxa are well established morphologically by Crous and Braun (2003). The three genera form well supported monophyletic clades with high bootstrap support by using three molecular phylogenetic analyses, viz, Neighbor Joining (NJ), Maximum Parsimony (MP), and Bayesian Inference. However, another genus of the true cercosporoid fungi, *Stenella*, is still polyphyletic, and therefore, further investigation using more taxa are necessary to be carried out in order to clarify morphological elucidation of this genus due to the number of sequences of this taxa is a few (only 12 sequences). In this study, it is also revealed that most taxa of the cercosporoid fungi have not showed a sign of host specificity by using ITS sequences dataset alone, at least at some degree of host levels, such as genus or family. This is probably true even if the molecular analysis executed by using more genes, either from other regions of nuclear rDNA such as 28S and 18S regions (Crous *et al.* (2007), or protein genes such as Elongation Factor 1-α gene (EF), Actin gene (ACT), Calmodulin gene (CAL), and Histone H3 gene (HIS) (Ayala-Escobar *et al.* (2005). Therefore, at present time, it is still difficult to determine the host specificity of this group of fungi. In addition, because the identification of the cercosporoid fungi taxa until now is host-based approaches, therefore, the significant achievement in molecular study of host-pathogens association in this group of fungi will affects greatly to the systematic and other advances study in plant pathology.

Vast number of the true cercosporoid fungi species has also been collected and preserved in this study (chapter 2) which indicated a highly diversity of plant pathogens in tropical area as previously predicted (Hawksworth *et al*., 1993; Shivas and Hyde, 1997). Although the study of biodiversity and conservation of plant pathogen such as the cercosporoid fungi diversity is counter-intuitive to any plant pathologist dedicated to the prevention or eradication of plant diseases that causes 30% of losses of agricultural production worldwide (Agrios, 2005) and have sometimes devastated native species (Newhook and Podger, 1972), these subjects are now being recognized as key components in developing effective and efficient control of plant diseases, and are potentially producing a great benefit to humankind, for example, in basic scientific research, in biotechnology and novel drug, and pesticide production. Moreover, surveying and preserving plant pathogens associated with crops in farming area or from natural ecosystems are basically necessary in order to anticipate plant pathogens epidemics occurs in uniformly monoculture plants or natural ecosystems, for example, *Cercospora* leaf spot epidemic in southern

Germany, caused by *C. beticola* (Wolf and Verreet, 2005). In this context, anticipation of the threat of further epidemics in the future and recognition of disease control in such situation are very important, and these actions can only be prepared by studying the biology and diversity genetics of plant pathogens collected from the field and well-preserved.

Economically, benefits from study on plant pathogens biodiversity and conservation are numerous. Firstly, genetically defined collections of plant pathogens are essential to the process of revealing diversity and in selection for disease resistance in plant breeding. Secondly, pathogens may also be important as sources of novel drugs, for example *Cercosporin*, a non-host-selective perylenequinone toxin produced by many phytopathogenic *Cercospora* species, are now being investigated as antiviral agents and photodynamic tumor therapy (a process that utilizes photosensitizers and targeted laser irradiation to destroy tumors) (Daub and Ehrenshaft, 2000). Thirdly, plant pathogens or infected hosts may be good sources of novel fungicides, pesticides and herbicides. For example, *Cercosporin* are now also being investigated because their broad spectrum toxicity which are potential as bactericides, herbicides, insecticides (Daub and Ehrenshaft, 2000). Fourth, plant pathogens may produce or induce their hosts to produce chemical molecules which, although not of direct significance to the pharmaceutical or agrochemical industries, may be of indirect importance in producing chemical templates for novel bio-active molecules, for example chitinase production on leaves of sugar beet induced by *C. beticola* (Nielsen *et al.*, 1993; ten Kate and Laird, 1999). Fifth, by surveying and collecting plant pathogens, widespread species and strains will be available, and it will significantly facilitate the sharing information among researchers and allow inclusion of a high diversity of strains in genetic, taxonomic, fungicides resistance analysis, and pathogenicity test. Finally, it is important to end this section by making a point that is so obvious that as long as there is a need to control the devastating effects of pathogens on plants, there is an equal need to study in depth the ways in which pathogens interact with their hosts and with their environment at every level and the way that epidemics occur and develop, especially in natural and traditional agro-ecosystems. Only as a result of such research will it be possible to continue to develop effective strategies for the control of diseases into the future. For this reason alone, if for no other, it is essential that the diversity of plant pathogens is needed to conserve in appropriate ways. The challenge in this study is great, and it will take a concerted effort by plant scientists, mycologists, molecular taxonomists, and plant pathologists willing to engage in truly collaborative studies to unravel this fascinating subject.

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