

Powdery mildew in Southeast Asia: host range, impact, and sources of resistance

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Abstract

Powdery mildews are important obligate biotrophic ectoparasites that cause severe damage to various plant species in Southeast Asia. So far, 14 genera and 96 species of powdery mildew have been reported in Southeast Asia, with Thailand having the most number of recorded species. Of the 14 genera reported, *Oidium* sp. had the most recorded host, including several important species of vegetables, fruits, vines, herbs, field crops, ornamentals, and tree species. This paper briefly reviews the knowledge of powdery mildew disease in Southeast Asia, focusing on the pathogens' host range, impact, and some sources of resistance to powdery mildew.

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Introduction

Since the origin of powdery mildew in the Late Cretaceous period and ancestral powdery mildew were first unearthed on broad-leaved deciduous trees in the high latitudes of the Northern Hemisphere, that continued further speciation while spreading southward in the Paleogene and Neogene periods^[1], numerous reports have been recorded globally. As a result, comprehensive studies on elucidating powdery mildew disease were established. Powdery mildews are obligate biotrophic ectoparasites classified in *Leotiomycetes* (with primitive cup-fungi), the order *Erysiphales*, and the family *Erysiphaceae*. This includes 26 genera, > 900 species presently known worldwide^[2,3]. Powdery mildews are generally white and dusty in the conidial state. They live epiphytically, coat, exclusively feed on living epidermal cells, and fulfill their (a)sexual life cycle on leaf and small stem surfaces. They primarily attack young shoots, leaves, and inflorescences. As a result, the fruit set is reduced, and those that reach maturity are small, crunched, and cracked. The plant becomes stunted or chlorotic and has severe defoliation. This disease can spread rapidly and is prevalent in high humidity but does not require moist conditions to germinate, grow, establish, and infect^[4-6], and they usually thrive well even under warm and dry conditions.

The intensive and extensive cultivation of crops and other plant species has resulted in large-scale perpetuation, build-up, and dissemination of powdery mildews on plant species in Southeast Asia (SEA) and worldwide. In addition, Southeast Asia generally has warm, humid, and cooler temperatures in highland areas, which is favorable for powdery mildew disease. This review provides a brief synthesis of the current understanding of powdery mildew disease in Southeast Asia, emphasizing its reported powdery mildew species, host range, impact, and sources of resistance. Moreover, research opportunities would

contribute to a better understanding of the powdery mildew pathogen.

Powdery mildew species in SEA and their host range

Of the 26 currently accepted genera^[3,7,8] and > 900 species^[2] of the *Erysiphaceae* or powdery mildews, so far 14 genera (*Blumeria*, *Brasiliomyces*, *Cystotheca*, *Erysiphe*, *Fibroidium*, *Golovinomyces*, *Leveillula*, *Microidium*, *Odiopsis*, *Oidium*, *Ovulariopsis*, *Phyllactinia*, *Podosphaera*, *Pseudoidium*,) and 96 species (based on currently accepted species)^[9,10] were reported and listed from Southeast Asia (Table 1). The genus *Erysiphe* had the most number of species (25) reported. In terms of frequency of reports, *Oidium* sp. had the greatest number of host reports with occurrences recorded in Thailand, Brunei Darussalam, Myanmar, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, and Vietnam (Table 1). Nevertheless, some of these records were only up to the genus level. Hence, future sampling of powdery mildews would aid in verifying the species of *Oidium* infecting various plants in SEA.

Powdery mildew has been reported to host up to 9,838 plant species worldwide, all of which are angiosperms (flowering plants), including several economically important plants, and not gymnosperms, ferns (pteridophytes)^[7] or lower plants such as mosses and liverworts (bryophytes)^[11]. Thus, powdery mildew is considered one of the most important plant pathogens. Economically significant hosts in SEA includes vegetables, fruits, vines, herbs, field crops, ornamentals, and tree species. Most genera and species of powdery mildew disease are explicit to plants of a single genus. An example of this is *Blumeria* infecting only grasses (*Poaceae*). Thus far in SEA, Thailand has the most recorded powdery mildew hosts in a generally tropical, warm, and humid climate and practices intensive

Table 1. Southeast Asian (SEA) records of powdery mildew species associated with various plant species.

Powdery mildew species (previously reported as)	Plant species	Country	References
<i>Blumeria graminis</i>	<i>Triticum glaucum</i>	Myanmar	[13]
<i>Brasiliomyces chiangmaiensis</i>	<i>Dalbergia cultrata</i>	Thailand	[2]
	<i>Dalbergia cultrata</i> var. <i>cultrata</i>	Thailand	[14]
<i>Cystotheca</i> (syn. <i>Setoidium castanopsidis</i>)	<i>Castanopsis javanica</i>	Indonesia	[15]
<i>Cystotheca tjobodensis</i>	<i>Castanopsis argentea</i>	Indonesia	[16]
<i>Erysiphe asiatica</i>	<i>Castanopsis diversifolia</i> , <i>Castanopsis echinocarpa</i>	Thailand	[17]
<i>Erysiphe baliensis</i>	<i>Gliricidia sepium</i>	Indonesia	[18]
	<i>Desmodium triflorum</i>	Thailand	[19]
<i>Erysiphe boehmeriae</i>	<i>Boehmeria siamensis</i>	Thailand	[20]
<i>Erysiphe caricae-papayae</i>	<i>Carica papaya</i>	Thailand	[21]
<i>Erysiphe cruciferarum</i>	<i>Brassica juncea</i>	Vietnam	[22]
	<i>Brassica parachinensis</i> , <i>Cleome chelidonii</i>	Thailand	[23]
<i>Erysiphe diffusa</i>	<i>Glycine max</i>	Vietnam	[24]
<i>Erysiphe diffusa</i> (syn. <i>Oidium caricae</i>)	<i>Carica papaya</i>	Indonesia	[7]
<i>Erysiphe elevata</i>	<i>Eucalyptus camaldulensis</i>	Thailand	[20]
<i>Erysiphe fernandoae</i>	<i>Fernandoa adenophylla</i>	Thailand	[25]
<i>Erysiphe heraclei</i>	<i>Hydrocotyle javanica</i>	Thailand	[23]
	<i>Apiaceae</i> , <i>Coriandrum sativum</i>	Myanmar	[13]
<i>Erysiphe javanica</i>	<i>Castanopsis javanica</i>	Indonesia	[26]
<i>Erysiphe kydiae-calycinae</i>	<i>Kydia calycina</i>	Thailand	[20]
<i>Erysiphe lespedezae</i>	<i>Bauhinia purpurea</i>	Thailand	[27]
	<i>Phanera purpurea</i>	Thailand	[19]
<i>Erysiphe liquidambaris</i> (syn. <i>Erysiphe liquidambaris</i> var. <i>acalycinae</i>)	<i>Liquidambar acalycina</i>	Thailand	[28]
<i>Erysiphe monoperidiata</i>	<i>Castanopsis argyrophylla</i> , <i>Castanopsis calathiformis</i> , <i>Castanopsis indica</i> , <i>Castanopsis tribuloides</i> , <i>Lithocarpus elegans</i> , <i>Lithocarpus polystachyus</i>	Thailand	[2,17]
<i>Erysiphe mori</i>	<i>Tectona grandis</i>	Thailand	[28, 29]
<i>Erysiphe necator</i> (syn. <i>Erysiphe necator</i> var. <i>necator</i>)	<i>Vitis vinifera</i>	Thailand	[28]
<i>Erysiphe necator</i> (syn. <i>Oidium tuckeri</i>)	<i>Vitis vinifera</i>	Cambodia, Indonesia, Malaysia, Myanmar, Vietnam	[7]
		Thailand	[7,30]
<i>Erysiphe necator</i> (syn. <i>Uncinula necator</i>)	<i>Fragaria × ananassa</i>	Philippines	[31]
	<i>Vitis vinifera</i>	Philippines	[32,33]
<i>Erysiphe nyctaginacearum</i>	<i>Mirabilis jalapa</i>	Indonesia	[2]
		Thailand	[20]
<i>Erysiphe pisi</i> (syn. <i>Erysiphe pisi</i> var. <i>pisi</i>)	<i>Pisum sativum</i>	Thailand	[19]
	<i>Pisum arvense</i> ; <i>Pisum sativum</i>	Myanmar	[13]
<i>Erysiphe platani</i> (syn. <i>Microsphaera platani</i>)	<i>Platanus</i> sp.	Brunei Darussalam	[34]
<i>Erysiphe polygoni</i>	<i>Phaseolus aureus</i> , <i>Pisum sativum</i> , <i>Vigna sinensis</i>	Cambodia	[35]
	<i>Calendula</i> sp	Thailand	[36]
	<i>Antigonon leptopus</i> , <i>Muehlenbeckia platyclada</i> , <i>Polygonum odoratum</i>	Thailand	[20]
	<i>Clitoria ternatea</i>	Vietnam	[37]
	<i>Citrus nohilis</i>	Philippines	[38]
	<i>Vigna radiata</i> , <i>Pisum sativum</i> , <i>Phaseolus aureus</i> , <i>Phaseolus radiatus</i>	Philippines	[31,39–42]
	<i>Crotolaria incana</i> , <i>Crotolaria mucronata</i> , <i>Crotolaria pallida</i> , <i>Crotolaria saltiana</i> , <i>Heliotropium indicum</i> , <i>Cleome rutidosperma</i>	Philippines	[43]
	<i>Vigna sesquipedalis</i> , <i>Vigna sinensis</i> x <i>Vigna sesquipedalis</i>	Philippines	[44]
<i>Erysiphe pseudolonicerae</i>	<i>Cyclea barbata</i>	Thailand	[20]
<i>Erysiphe quercicola</i>	<i>Acacia auriculiformis</i>	Thailand	[45]
	<i>Cassia fistula</i> , <i>Castanopsis argyrophylla</i> , <i>Hodgsonia macrocarpa</i> , <i>Kydia calycina</i> , <i>Jatropha curcas</i> , <i>Mallotus philippinensis</i> , <i>Mimosa pudica</i> , <i>Tamarindus indica</i> , <i>Ziziphus jujuba</i>	Thailand	[46]
	<i>Hevea brasiliensis</i>	Thailand	[46–48]
	<i>Quercus</i> sp.	Thailand	[47–50]
		Vietnam	[48,51]
		Malaysia	[47,48]
	<i>Bauhinia purpurea</i>	Indonesia	[47,52]
<i>Erysiphe quercicola</i> (syn. <i>Oidium citri</i>)	<i>Citrus limon</i> , <i>Citrus sinensis</i>	Timor-Leste, Malaysia	[47,53]
	<i>Citrus reticulata</i>	Vietnam	[48,51]

(to be continued)

Powdery mildew in Southeast Asia

Table 1. (continued)

Powdery mildew species (previously reported as)	Plant species	Country	References	
<i>Erysiphe quercicola</i> (syn. <i>Oidium bixae</i>)	<i>Citrus</i> sp.	Timor-Leste	[53]	
	<i>Bixa orellana</i> ,	Myanmar	[13]	
<i>Erysiphe quercicola</i> (syn. <i>Oidium mangiferae</i>)	<i>Mangifera indica</i>	Thailand	[47,53]	
		Indonesia	[54]	
<i>Erysiphe sidae</i>	<i>Sida rhombifolia</i>	Thailand	[47,53]	
<i>Erysiphe tectonae</i> (syn. <i>Uncinula tectonae</i>)	<i>Tectona grandis</i>	Myanmar	[13]	
		Indonesia	[18]	
<i>Erysiphe trifoliorum</i>	<i>Aeschynomene americana</i> var. <i>Americana</i> , <i>Sesbania grandiflora</i> , <i>Tamarindus indica</i>	Thailand	[28,29]	
		Myanmar	[7,8,13]	
<i>Erysiphe</i> sp.	<i>Aristolochia indica</i> , <i>Viburnum inopinatum</i> , <i>Wrightia arborea</i> , <i>Luffa acutangula</i> , <i>Ostodes paniculata</i>	Thailand	[19]	
	<i>Clitoria ternatea</i> , <i>Indigofera dosua</i> , <i>Indigofera linnaei</i> , <i>Lithocarpus lindleyanus</i> , <i>Lithocarpus vestitus</i> , <i>Microtoena insuavis</i> , <i>Mucuna bracteata</i> , <i>Ocimum sanctum</i> , <i>Pueraria mirifica</i> , <i>Pueraria wallichii</i> ,	Thailand	[23]	
	<i>Ficus subincisa</i>	Thailand	[19]	
	<i>Nicotiana tabacum</i>	Thailand	[20]	
	<i>Vigna sinensis</i> , <i>Vigna unguiculata</i> , <i>Sesamum orientale</i> , <i>Phaseolus vulgaris</i>	Thailand	[7,30]	
	<i>Solanum lycopersicum</i>	Philippines	[40,55]	
	<i>Carica papaya</i>	Philippines	[40,55–57]	
	<i>Annona squamosa</i>	Philippines	[40,55,58]	
	<i>Justicia adhatoda</i>	Philippines	[7]	
	<i>Solanum melongena</i>	Indonesia	[7]	
	<i>Hibiscus ficulneus</i> , <i>Hibiscus sabdariffa</i>	Laos	[7]	
	<i>Fibroidium abelmoschi</i> (syn. <i>Oidium abelmoschi</i>)	<i>Hibiscus ficulneus</i> , <i>Hibiscus sabdariffa</i>	Myanmar	[13]
	<i>Fibroidium balsaminae</i> (syn. <i>Oidium balsaminae</i>)	<i>Impatiens balsamina</i>	Myanmar	[13]
<i>Fibroidium heliotropii-indici</i> (syn. <i>Oidium heliotropii-indici</i>)	<i>Heliotropium indicum</i> , <i>Heliotropium ovalifolium</i> , <i>Heliotropium supinum</i>	Myanmar	[13]	
	<i>Heliotropium indicum</i>	Indonesia, Philippines	[2,8]	
<i>Fibroidium tingitaninum</i> (syn. <i>Oidium tingitaninum</i>)	<i>Citrus aurantium</i> , <i>Citrus nobilis</i> var. <i>deliciosa</i> , <i>Citrus sinensis</i>	Indonesia	[7]	
	<i>Citrus mitis</i> , <i>Citrus nobilis</i> var. <i>deliciosa</i>	Philippines	[7]	
<i>Golovinomyces ambrosiae</i>	<i>Helianthus annuus</i>	Thailand	[59]	
<i>Golovinomyces biocellatus</i>	<i>Momordica charantia</i>	Thailand	[36]	
<i>Golovinomyces biocellatus</i> (syn. <i>Oidium erysipoides</i>)	<i>Cucurbita moschata</i> , <i>Lagenaria siceraria</i> , <i>Luffa acutangula</i> , <i>Momordica charantia</i>	Thailand	[30]	
	<i>Cajanus cajan</i>	Myanmar	[37]	
<i>Golovinomyces bolayi</i>	<i>Vigna umbellata</i>	Thailand	[60]	
<i>Golovinomyces cichoracearum</i>	<i>Cucurbita ovifera</i>	Myanmar	[13]	
	<i>Dahlia</i> sp.	Thailand	[61]	
	<i>Mangifera indica</i>	Indonesia	[7]	
	<i>Zinnia</i> sp.	Philippines	[62]	
<i>Golovinomyces cichoracearum</i> (syn. <i>Erysiphe cichoracearum</i>)	<i>Capsicum annum</i> ; <i>Capsicum frutescens</i> , <i>Cucurbita maxima</i>	Philippines	[40]	
	<i>Cucumis melo</i> , <i>Cucumis melo</i> var. <i>cantalupensis</i>	Philippines	[31,63,64]	
	<i>Vigna radiata</i> , <i>Phaseolus aureus</i> , <i>Phaseolus radiatus</i>	Philippines	[31,39–42]	
	<i>Solanum lycopersicum</i>	Philippines	[65]	
	<i>Cucumis sativus</i> , <i>Cucurbita moschata</i> , <i>Nicotiana tabacum</i>	Philippines	[31]	
	<i>Citrullus lunatus</i>	Philippines	[63,64,66]	
	<i>Citrullus lunatus</i> , <i>Citrullus vulgaris</i> , <i>Cucurbita pepo</i>	Philippines	[64]	
	<i>Lagenaria leucantha</i> , <i>Lagenaria siceraria</i> ; <i>Benincasa hispida</i>	Philippines	[67]	
	<i>Chrysanthemum coronarium</i> , <i>Chrysanthemum morifolium</i>	Philippines	[67]	
	<i>Myosotis scopioides</i>	Thailand	[59]	
	<i>Solanum lycopersicum</i>	Myanmar	[13]	
<i>Golovinomyces cynoglossi</i>	<i>Ocimum gratissimum</i>	Myanmar	[13]	
<i>Golovinomyces lycopersici</i> (syn. <i>Oidium lycopersici</i>)	<i>Ocimum tenuiflorum</i>	Thailand	[59]	
	<i>Coccinia indica</i> , <i>Coccinia grandis</i> , <i>Vigna umbellata</i>	Thailand	[59]	
<i>Golovinomyces spadiceus</i>	<i>Dahlia x hortensis</i> , <i>Dahlia pinnata</i> , <i>Laggera crispata</i> , <i>Verbena x hybrida</i>	Thailand	[59]	
<i>Golovinomyces sonchicola</i>	<i>Sonchus oleraceus</i>	Thailand	[59]	
<i>Golovinomyces sordidus</i>	<i>Plantago major</i>	Vietnam	[68]	

(to be continued)

Table 1. (continued)

Powdery mildew species (previously reported as)	Plant species	Country	References
<i>Golovinomyces tabaci</i>	<i>Cucumis sativus</i>	Myanmar	[13]
	<i>Coccinia grandis</i>	Thailand	[60]
<i>Golovinomyces</i> sp.	<i>Ageratum conyzoides</i> , <i>Bidens pilosa</i> , <i>Lactuca indica</i> , <i>Lygisma inflexum</i>	Thailand	[59]
<i>Leveillula clavata</i>	<i>Euphorbia pulcherrima</i>	Indonesia	[2]
<i>Leveillula taurica</i>	<i>Oxalis barrelieri</i>	Singapore	[7]
	<i>Euphorbia pulcherrima</i> , <i>Tropaeolum majus</i> , <i>Capsicum frutescens</i>	Indonesia	[7]
	<i>Capsicum annuum</i> var. <i>longum</i>	Malaysia	[7]
	<i>Capsicum annuum</i>	Malaysia	[69]
		Brunei Darussalam	[70]
		Thailand	[7]
		Myanmar	[13]
	<i>Tropaeolum majus</i>	Myanmar	[7,13]
	<i>Solanum melongena</i>	Myanmar	[7,13]
	<i>Solanum lycopersicum</i>	Myanmar	[13]
		Philippines	[31,63,64]
	<i>Solanum aculeatissimum</i> , <i>Solanum torvum</i> , <i>Euphorbia heterophylla</i>	Thailand	[71]
	<i>Euphorbia geniculata</i>	Thailand	[7]
	<i>Hibiscus sabdariffa</i>	Thailand	[7,30]
<i>Leveillula taurica</i> (syn. <i>Oidiopsis sicula</i>)	<i>Capsicum frutescens</i> , <i>C. annuum</i> var. <i>grossum</i> , <i>C. frutescens</i> × <i>C. chinense</i> (Bhut Jolokia), <i>Capsicum</i> sp.	Thailand	[72]
<i>Leveillula</i> sp.	<i>Glycine max</i> , <i>Lagerstroemia speciosa</i>	Thailand	[7]
<i>Microidium agatidis</i> (syn. <i>Oidium agatidis</i>)	<i>Sesbania grandiflora</i>	Vietnam	[2]
	<i>Agati grandiflora</i>	Vietnam	[8]
<i>Microidium phyllanthi</i>	<i>Phyllanthus urinaria</i>	Vietnam	[73]
<i>Microidium phyllanthi</i> (syn. <i>Oidium phyllanthi</i>)	<i>Phyllanthus acidus</i> , <i>Phyllanthus amarus</i> , <i>Phyllanthus reticulatus</i>	Vietnam	[74,75]
	<i>Phyllanthus nanus</i>	Myanmar	[13]
	<i>Phyllanthus</i> sp.	Brunei Darussalam	[34]
<i>Microidium phyllanthi-reticulati</i>	<i>Phyllanthus reticulatus</i>	Thailand	[76]
<i>Oidiopsis</i> sp.	<i>Capsicum</i> sp., <i>Solanum lycopersicum</i>	Thailand	[30]
	<i>Chrozophora plicata</i>	Myanmar	[13]
<i>Oidium arachidis</i>	<i>Arachis hypogaea</i>	Indonesia	[7]
<i>Oidium caricae-papayae</i>	<i>Carica papaya</i>	Myanmar	[13]
		Brunei Darussalam	[34]
<i>Oidium euphorbiae-hirtae</i>	<i>Euphorbia pilulifera</i>	Indonesia	[7]
<i>Oidium heveae</i>	<i>Hevea collina</i> , <i>Hevea guianensis</i> , <i>Hevea spruceana</i>	Indonesia	[7,77]
	<i>Hevea brasiliensis</i>	Brunei Darussalam	[7,70]
		Cambodia	[7,35]
		Indonesia	[77]
		Malaysia	[69, 77–80]
		Myanmar	[7,13]
		Thailand	[7,30,78]
		Vietnam	[7]
<i>Oidium indigoferae</i>	<i>Indigofera hirsuta</i>	Singapore	[8]
<i>Oidium nephelii</i>	<i>Durio zibethinus</i>	Indonesia	[47,52]
		Thailand	[30,46]
	<i>Nephelium lappaceum</i>	Brunei Darussalam	[7,70]
		Indonesia	[2,81]
		Malaysia	[80]
		Singapore	[7]
		Thailand	[30,46]
<i>Oidium oxalidis</i>	<i>Oxalis corniculata</i>	Philippines, Indonesia	[7]
	<i>Oxalis repens</i>	Philippines	[82]
<i>Oidium papaveracearum</i>	<i>Argemone mexicana</i>	Myanmar	[13]
<i>Oidium</i> sp.	<i>Brassica chinensis</i> , <i>Coccinia grandis</i> , <i>Cosmos caudatus</i> , <i>Durio zibethinus</i> , <i>Lagenaria leucantha</i> , <i>Litchi chinensis</i> , <i>Luffa acutangula</i> , <i>Momordica charantia</i> , <i>Sesbania grandiflora</i> , <i>Coccinia indica</i> , <i>Cucumis melo</i> var. <i>cantalupensis</i> , <i>Dahlia rosea</i> , <i>Heliotropium indicum</i> , <i>Impatiens balsamina</i> , <i>Pedilanthus tithymaloides</i> , <i>Phaseolus aureus</i> , <i>Pisum sativum</i> , <i>Rosa</i> sp., <i>Sesamum indicum</i> , <i>Triticum vulgare</i> , <i>Vigna sesquipedalis</i> , <i>Zinnia elegans</i> , <i>Ziziphus jujube</i> , <i>Ziziphus mauritiana</i>	Thailand	[30]
	<i>Cassia</i> sp.	Thailand	[37]

(to be continued)

Table 1. (continued)

Powdery mildew species (previously reported as)	Plant species	Country	References
	<i>Antigonon leptopus</i> , <i>Cucurbita pepo</i> var. <i>medullosa</i> , <i>Impatiens balsamina</i> , <i>Luffa aegyptiaca</i> , <i>Rosa</i> sp.,	Brunei Darussalam	[7]
	<i>Cucumis melo</i> , <i>Cucumis sativus</i> , <i>Cucurbita maxima</i> , <i>Cucurbita pepo</i> , <i>Dahlia</i> sp., <i>Hibiscus mutabilis</i> , <i>Luffa acutangula</i> , <i>Luffa cylindrical</i> , <i>Vigna sesquipedalis</i> , <i>Zinnia elegans</i> ,	Brunei Darussalam	[7,70]
	<i>Helianthus annuus</i> , <i>Euphorbia tithymaloides</i> , <i>Acacia</i> sp.,	Brunei Darussalam	[34]
	<i>Baliospermum axillare</i> , <i>Bougainvillea spectabilis</i> , <i>Coccinia indica</i> , <i>Codiaeum variegatum</i> , <i>Eclipta alba</i> , <i>Helianthus annuus</i> , <i>Lagerstroemia indica</i> , <i>Psoralea corylifolia</i> , <i>Sechium edule</i> , <i>Sesamum indicum</i> , <i>Tephrosia purpurea</i> , <i>Tinospora cordifolia</i> ,	Myanmar	[13]
	<i>Cajanus cajan</i> , <i>Croton calococcus</i> , <i>Cucumis sativus</i> , <i>Cucurbita</i> sp., <i>Glochidion</i> sp., <i>Lagenaria leucantha</i> , <i>Phaseolus aureus</i> , <i>Piper betle</i> , <i>Pisum sativum</i> , <i>Vigna unguiculata</i>	Myanmar	[7]
	<i>Capsicum frutescens</i> , <i>Citrus reticulata</i> , <i>Corchorus capsularis</i> , <i>Cucurbita pepo</i> , <i>Sesamum indicum</i> , <i>Vigna sesquipedalis</i> , <i>Vitis vinifera</i> , <i>Zinnia elegans</i>	Cambodia	[35]
	<i>Corchorus olitorius</i> , <i>Cucumis sativus</i>	Cambodia	[7]
	<i>Acacia</i> sp.	Indonesia	[53]
	<i>Albizia falcate</i> , <i>Albizia moluccana</i> , <i>Angelonia salicariifolia</i> , <i>Blumea balsamifera</i> , <i>Boehmeria nivea</i> , <i>Capsicum annum</i> var. <i>grossum</i> , <i>Capsicum frutescens</i> , <i>Cassia multijuga</i> , <i>Cassia occidentalis</i> , <i>Cassia surattensis</i> , <i>Cassia tora</i> , <i>Celtis tetrandra</i> , <i>Citrus hystrix</i> f. <i>acida</i> , <i>Clitoria ternatea</i> , <i>Crotalaria juncea</i> , <i>Cucumis sativus</i> , <i>Cucurbita maxima</i> , <i>Cucurbita pepo</i> , <i>Cucurbita</i> sp., <i>Deguelia microphylla</i> , <i>Desmodium gyroides</i> , <i>Elatostema sessile</i> , <i>Eugenia densiflora</i> , <i>Heliotropium indicum</i> , <i>Indigofera sumatrana</i> , <i>Justicia adhatoda</i> , <i>Lagerstroemia</i> sp., <i>Luffa aegyptiaca</i> , <i>Manihot glaziovii</i> , <i>Mirabilis jalapa</i> , <i>Morus alba</i> , <i>Myristica fragrans</i> , <i>Phaseolus vulgaris</i> , <i>Phyllanthus niruri</i> , <i>Physalis minima</i> , <i>Rosa</i> sp., <i>Sida acuta</i> , <i>Tamarindus indica</i> , <i>Torenia asiatica</i> , <i>Verbena laciniata</i>	Indonesia	[7]
	<i>Cucurbita</i> sp., <i>Solanum melongena</i>	Laos	[7]
	<i>Antigonon leptopus</i>	Malaysia	[70]
	<i>Angelonia salicariifolia</i> , <i>Benincasa cerifera</i> , <i>Cassia occidentalis</i> , <i>Cassia tora</i> , <i>Cucumis</i> sp., <i>Cucurbita moschata</i> , <i>Heliotropium indicum</i> , <i>Hydrangea</i> sp., <i>Impatiens balsamina</i> , <i>Luffa acutangula</i> , <i>Solanum lycopersicum</i> , <i>Physalis minima</i> , <i>Psophocarpus tetragonolobus</i> , <i>Tamarindus indica</i> , <i>Vigna sinensis</i>	Malaysia	[69]
	<i>Corchorus capsularis</i> , <i>Euphorbia hirta</i> , <i>Hibiscus mutabilis</i>	Malaysia	[83]
	<i>Benincasa hispida</i> , <i>Corchorus olitorius</i> , <i>Indigofera hirsute</i> , <i>Nephelium mutabile</i> , <i>Solanum melongena</i> , <i>Stachytarpheta indica</i> , <i>Vigna sesquipedalis</i>	Malaysia	[7]
	<i>Cucumis sativus</i> , <i>Cucurbita maxima</i> , <i>Cucurbita pepo</i> , <i>Phaseolus vulgaris</i> , <i>Sesamum indicum</i>	Malaysia	[69,]
	<i>Sauropus androgynous</i> , <i>Vitis vinifera</i> , <i>Zinnia elegans</i>	Malaysia	[84]
	<i>Senna occidentalis</i> , <i>Senna tora</i>	Malaysia	[37]
	<i>Capsicum annum</i> , <i>Cucurbita maxima</i> , <i>Desmodium procumbens</i> , <i>Heliotropium indicum</i> , <i>Oxalis repens</i> , <i>Phaseolus</i> sp., <i>Pisum sativum</i> ,	Philippines	[7]
	<i>Samanea saman</i>	Philippines	[85]
	<i>Stachytarpheta indica</i> , <i>Peltophorum pterocarpum</i>	Singapore	[7]
	<i>Cucumis melo</i> , <i>Hevea</i> sp., <i>Nicotiana tabacum</i> , <i>Prunus persica</i> , <i>Prunus triflora</i> , <i>Prunus triloba</i> , <i>Sesbania grandiflora</i>	Vietnam	[7]
	<i>Acacia auriculiformis</i>	Thailand, Malaysia	[53]
		Philippines	[86]
	<i>Acacia mangium</i>	Thailand, Malaysia, Philippines	[85]
	<i>Nicotiana tabacum</i>	Thailand, Cambodia, Indonesia, Vietnam	[7]
		Malaysia	[69]
		Myanmar	[13]
<i>Ovulariopsis moricola</i>	<i>Morus alba</i>	Thailand	[30]
<i>Phyllactinia alangii</i>	<i>Alangium kurzii</i>	Thailand	[71]
<i>Phyllactinia broussonetiae-papyriferae</i>	<i>Broussonetia papyrifera</i>	Thailand	[71]
<i>Phyllactinia cassiae-fistulae</i>	<i>Cassia fistula</i>	Thailand	[87]
<i>Phyllactinia dalbergiae</i>	<i>Dalbergia lanceolaria</i>	Thailand	[71]
<i>Phyllactinia gmelinae</i>	<i>Gmelina arborea</i>	Thailand	[71]
<i>Phyllactinia guttata</i> (syn. <i>Phyllactinia corylea</i>)	<i>Morus alba</i>	Thailand	[30]
	<i>Morus</i> sp.	Myanmar	[13]
		Indonesia	[77]

(to be continued)

Table 1. (continued)

Powdery mildew species (previously reported as)	Plant species	Country	References
<i>Phyllactinia guttata</i> (syn. <i>Phyllactinia suffulta</i>)	<i>Morus alba</i>	Philippines	[31,40,55]
<i>Phyllactinia lagerstroemiae</i>	<i>Lagerstroemia macrocarpa</i> , <i>Lagerstroemia speciosa</i>	Thailand	[88]
<i>Phyllactinia mori-macrourae</i>	<i>Morus macroura</i>	Thailand	[71]
<i>Phyllactinia moricola</i>	<i>Morus</i> sp.	Myanmar; Vietnam	[7,13]
	<i>Morus alba</i>	Thailand	[71]
	<i>Morus rubra</i>	Thailand	[71]
<i>Phyllactinia poinsettiae</i>	<i>Euphorbia pulcherrima</i>	Indonesia	[12]
<i>Phyllactinia pyri-communis</i>	<i>Pyrus communis</i>	Myanmar	[13]
<i>Phyllactinia terminaliae</i>	<i>Terminalia bellirica</i>	Thailand	[71]
<i>Phyllactinia</i> sp.	<i>Ehretia laevis</i>	Thailand	[71]
	<i>Rosa</i> sp.	Philippines	[89]
<i>Podosphaera aphanis</i>	<i>Fragaria ×ananassa</i>	Thailand	[36]
<i>Podosphaera caricicola</i>	<i>Carica papaya</i>	Thailand	[21]
<i>Podosphaera euphorbiae-hirtae</i>	<i>Euphorbia hirta</i>	Myanmar	[13]
<i>Podosphaera fuliginea</i> (syn. <i>Sphaerotheca fuliginea</i>)	<i>Phaseolus aconitifolius</i>	Myanmar	[7]
	<i>Cucurbita moschata</i> , <i>Impatiens balsamina</i> , <i>Luffa aegyptiaca</i>	Malaysia	[7]
	<i>Benincasa hispida</i> , <i>Cucurbita moschata</i> , <i>Dahlia variabilis</i> , <i>Impatiens balsamina</i>	Singapore	[7]
<i>Podosphaera fusca</i>	<i>Bidens</i> sp.	Malaysia, Singapore	[36]
	<i>Cosmos caudatus</i>	Malaysia	[90]
	<i>Zinnia elegans</i>	Thailand	[61]
<i>Podosphaera fusca</i> (syn. <i>Sphaerotheca fusca</i>)	<i>Carica papaya</i>	Brunei Darussalam	[34]
<i>Podosphaera pannosa</i> (syn. <i>Sphaerotheca pannosa</i>)	<i>Rosa</i> sp.	Brunei Darussalam	[70]
		Myanmar	[13]
		Thailand	[30]
	<i>Rosa hybrida</i>	Thailand	[36]
	<i>Rosa</i> sp.	Philippines	[91]
<i>Podosphaera perseae-americanae</i>	<i>Persea americana</i>	Indonesia	[92]
<i>Podosphaera pruni-cerasoidis</i>	<i>Prunus cerasoides</i>	Thailand	[93]
<i>Podosphaera xanthii</i> (syn. <i>Podosphaera caricae-papayae</i>)	<i>Carica papaya</i>	Thailand	[45]
<i>Podosphaera xanthii</i>	<i>Cajanus cajan</i> , <i>Cucurbita maxima</i> , <i>Cucurbita ovifera</i> , <i>Cucurbita pepo</i> , <i>Lagenaria vulgaris</i> , <i>Luffa aegyptiaca</i> , <i>Phaseolus aconitifolius</i> , <i>Phaseolus mungo</i> , <i>Pisum sativum</i> , <i>Sesamum indicum</i> , <i>Vicia unguiculata</i> , <i>Vigna catjang</i>	Myanmar	[13]
	<i>Vigna unguiculata subsp. sesquipedalis</i> , <i>Vigna radiata</i> , <i>Solanum melongena</i>	Philippines	[94,95]
	<i>Ageratum conyzoides</i>	Thailand	[61]
	<i>Cucumis melo</i>	Thailand	[96]
	<i>Bidens pilosa</i> , <i>Carica papaya</i> , <i>Chamaesyce hirta</i> , <i>Cleome rutidosperma</i> , <i>Cosmos sulphureus</i> , <i>Crotalaria pallida</i> , <i>Cucumis sativus</i> , <i>Cucurbita pepo</i> , <i>Cyanthillium cinereum</i> , <i>Dahlia pinnata</i> , <i>Euphorbia hirta</i> , <i>Euphorbia tithymaloides</i> , <i>Galinsoga parviflora</i> , <i>Gymnema inodorum</i> , <i>Heliotropium indicum</i> , <i>Impatiens balsamina</i> , <i>Justicia comata</i> , <i>Macroptilium atropurpureum</i> , <i>Millingtonia hortensis</i> , <i>Momordica charantia</i> , <i>Phaseolus vulgaris</i> , <i>Physalis angulate</i> , <i>Pouzolzia zeylanica</i> , <i>Senna occidentalis</i> , <i>Solanum melongena</i> , <i>Spilanthes labadicensis</i> , <i>Vigna radiata</i> , <i>Vigna unguiculata subsp. sesquipedalis</i>	Thailand	[36]
	<i>Capsicum frutescens</i>	Vietnam	[97]
	<i>Jatropha gossypifolia</i>	Vietnam	[98]
<i>Podosphaera</i> sp.	<i>Aster</i> sp., <i>Cleome viscosa</i> , <i>Coccinia grandis</i> , <i>Cucurbita moschata</i> , <i>Helianthus annuus</i> , <i>Hibiscus mutabilis</i> , <i>Hibiscus sabdariffa</i> , <i>Hydrocleys nymphoides</i> , <i>Kydia</i> sp., <i>Lagenaria siceraria</i> var. <i>gourda</i> , <i>Leucas decemdentata</i> , <i>Prunus mume</i> , <i>Prunus persica</i> , <i>Raphistemma pulchellum</i> , <i>Sesamum indicum</i> , <i>Viola tricolor</i> , <i>Zinnia elegans</i>	Thailand	[36]
<i>Pseudoidium antigononis</i> (syn. <i>Oidium antigononis</i>)	<i>Antigonon leptopus</i>	Brunei Darussalam	[2]
<i>Pseudoidium azadirachtae</i> (syn. <i>Oidium azadirachtae</i>)	<i>Azadirachta indica</i>	Myanmar	[13]
<i>Pseudoidium clitoriae</i> (syn. <i>Oidium clitoriae</i>)	<i>Clitoria ternatea</i>	Cambodia, Indonesia	[2,8]
<i>Pseudoidium fabacearum</i>	<i>Sesbania grandiflora</i>	Thailand, Vietnam	[2]

(to be continued)

Table 1. (continued)

Powdery mildew species (previously reported as)	Plant species	Country	References
<i>Pseudoidium hortensiae</i> (syn. <i>Oidium hortensiae</i>)	<i>Hydrangea</i> sp.	Indonesia	[7]
		Thailand	[61]
		Thailand	[19]
<i>Pseudoidium ipomoeae</i> (syn. <i>Oidium ipomoeae</i>)	<i>Hydrangea macrophylla</i> <i>Ipomoea aquatic</i> , <i>Ipomoea obscura</i>	Thailand	[23]
<i>Pseudoidium javanicum</i>	<i>Ipomoea reniformis</i> <i>Acalphya argentea</i> , <i>Acalypha wilkesiana</i>	Myanmar	[13]
		Indonesia	[25]
<i>Pseudoidium leptadeniae</i> (syn. <i>Oidium leptadeniae</i>)	<i>Leptadenia reticulata</i>	Myanmar	[13]
<i>Pseudoidium moluccanum</i> (syn. <i>Oidium moluccanum</i>)	<i>Aleurites moluccana</i>	Timor-Leste	[2,99]
<i>Pseudoidium neolycopersici</i>	<i>Physalis</i> sp.	Thailand	[20]
<i>Pseudoidium peltophori</i> (syn. <i>Oidium peltophori</i>)	<i>Peltophorum pterocarpum</i>	Singapore	[2,8]
<i>Pseudoidium schmiedeknechtii</i> (syn. <i>Oidium schmiedeknechtii</i>)	<i>Hibiscus floccosus</i> , <i>Schoutenia glomerata</i> , <i>Urena lobata</i>	Thailand	[20]
<i>Pseudoidium stachytarphetae</i> (syn. <i>Oidium stachytarphetae</i>)	<i>Stachytarpheta indica</i>	Singapore	[2,8,100]
<i>Pseudoidium tamarindi</i> (syn. <i>Oidium tamarindi</i>)	<i>Tamarindus indica</i>	Indonesia, Singapore	[2,8]
		Myanmar	[13]
<i>Pseudoidium urenae</i> (syn. <i>Oidium urenae</i>)	<i>Urena lobata</i>	Myanmar	[13]

agriculture, which makes them favorable for the proliferation of powdery mildew conidia. However, most of the host plants in the SEA are herbaceous species. This difference undoubtedly reflects the growth habit of the powdery mildew fungus, which is limited mainly to leaves and succulent shoots and stems.

Southeast Asian countries have a relatively low level of exploration, perhaps due to the limited number of experts or mycologists studying powdery mildews relative to Eastern Asia, Europe, and the rest of the world. Moreover, surveys and reports of powdery mildew in Southeast Asia have been sparse in recent years, which should contribute to and be updated to understand this ubiquitous plant pathogen better. Also, in subtropics and tropics, the powdery mildew's sexual reproductive stage (teleomorph), essential for accurate species identification, is largely absent^[12].

Impact

Diseases constitute a significant factor in diminishing yield and productivity in Southeast Asia, as they do elsewhere. Compared to other fungal diseases, powdery mildew causes less debilitating losses due to the lack of systemic and root infections and minimal host death^[101]. However, with the impact of climate change — the increased CO₂ emissions and rising temperatures in Southeast Asia (Myanmar, Philippines, Vietnam, and Thailand being among the most affected in the world by climate change^[102]), powdery mildew disease may continuously aggravate in the future^[103–108] through increased colony establishment^[109] and effect in plant host's physiology and susceptible openings such as stomata^[110], resulting in a higher risk of infection. Powdery mildew disease may cause a disease outbreak which brings plant growth reduction, premature defoliation, and reduction in fruit quality and yield, especially of economically important crops resulting in significant economic loss if not managed in the early stages since fungal growth covers entire photosynthetic green areas of the plant hindering food manufacturing mechanism of host plants^[101].

Some recorded powdery mildew impacts in SEA are from legumes and important tree species. Yield reduction of 21%^[111] up to 58%^[112] in the Philippines, 50% in Thailand^[113], and 20%–40% in Southeast Asia^[41,114,115] have been recorded in mungbean that can lead to complete plant loss during seedling or early plant stage^[116]. A decline in soybean seed quantity, weight, physical quality, and germination of 50%–52%^[117] and a yield reduction of 10%–90% was recorded in Indonesia^[118]. In Indonesia, powdery mildew disease of rubber trees also posted a reduction in rubber latex yields by up to 45%, including damage to young rubber leaves, buds, inflorescences, and other immature tissues^[119,120]. Powdery mildew infection of 90%–100% of *Acacia auriculiformis* seedlings was recorded in Thailand, where about 75% of the seedlings were wiped out^[121]. Known tree hosts of powdery mildew may overcome the disease as it matures, as observed on > 2-year-old trees^[122].

Sources of resistance

Host plant resistance has been widely used in crop breeding to develop powdery mildew disease-resistant cultivars for avoiding or minimizing yield losses due to disease infestation. Some sources of resistance against powdery mildew have been identified in SEA (Table 2). The resistant genotypes listed range from highly resistant (HR) to moderately resistant (MR). These sources can be incorporated through conventional and biotechnological approaches to breeding powdery mildew-resistant cultivars.

Though these genotypes are reported to have powdery mildew resistance (high to moderate), races or shifts in virulence of the population occur since some of the resistance reported from the past years weakened or were not resistant anymore. Besides the possibility of race, other factors like inoculum density and environments can also influence the resistance or susceptibility of plant genotypes to powdery mildew^[123]. Nevertheless, a more stable resistance may be established using a combination of quantitative and major

Table 2. Some sources of powdery mildew resistance in Southeast Asia.

Powdery mildew species	Crop	Country	Resistant genotypes	References
<i>Erysiphe diffusa</i> (syn. <i>Microsphaera diffusa</i>)	Soybean	Vietnam	HR- SV1, SV2, SV3, SV4, SV14, SV17 R- SV7, SV11, SV12, SV13, SV24, SV26, SV27, SV28, SV29, SV33	[125]
		Indonesia	HR- UP-104, UP-106, UP-108, UP-111, UP-112, UP-113, UP-114, UP-125, UP-127, UP-130, UP-136, UP-137, Argomulyo, Arjasari, Mintani	[118]
<i>Erysiphe polygoni</i>	Mungbean	Philippines	HR- CES ID-21 (Pag-asa)	[111]
		Thailand	HR- VC 6468 R- Kamphaeng Saen 2	[124]
			HR- VC1973A and VC2778A HR- VC1210A R- VC1482A, VC2273, VC3528A	[126,127]
			R- M5-10 and M5-25	[128]
			R- V4718 and RUM5	[129]
			MR- VC 2764 Y, VC 1163, VC 2768, VC 3876	[129]
<i>Erysiphe</i> sp.	Melon	Myanmar	HR- I-7, I-10, I-18, I-19, B-1 R- I-4, I-11, I-12, I-21, I-22 I-23, N-1	[130]
<i>Oidium</i> sp.	Mungbean	Thailand	MR- Chai Nat 36, Kamphaeng Saen 1, Kamphaeng Saen 2	[131]
<i>Phyllactinia guttata</i>	Mulberry	Vietnam	HR- EC-493900 Vietnam-2	[132]
		Indonesia	MR- <i>M. multicaulis</i> (M), EC-493895 <i>M. multicaulis</i> (B)	
		Myanmar	EC-493973 <i>M. rotundiloba</i>	
		Thailand	EC-49352 Thailand Lobed	
<i>Podosphaera xanthii</i>	Eggplant Bittergourd	Philippines	HR- PPLEgpAcc042 and PPLEgpAcc049	[95]
		Myanmar, Philippines, Thailand, Vietnam	R- THMC 113, THMC143, THMC153, THMC167, THMC 170	[133]
		Vietnam	R- THMC 60-1, THMC 354	[134]
		Philippines	R- THMC 28-2-2, THMC 30, THMC 31, THMC 33, THMC 35, THMC 37, THMC 42, THMC 43, THMC 44	[134]

HR - Highly resistant; R - Resistant; MR - Moderately resistant.

genes in resistance breeding. The former serves as a buffer to the resistant cultivar, therefore supporting extending the lifespan of a resistant cultivar^[124].

Conclusions and research prospects

Many plant species in Southeast Asia are affected by powdery mildew dispersed to and from different parts of the world. It threatens various economically important vegetables, fruits, vines, herbs, field crops, ornamentals, and tree species in Southeast Asia and worldwide. A comprehensive survey of powdery mildews in these localities may be warranted to verify and update the existing genera and species and their hosts in Southeast Asia and clarify the biodiversity and evolution of this important plant pathogenic fungal group. It is also crucial to study the effects of climate change on the powdery mildew disease-host plant pathosystem, which may contribute to the exacerbation of the disease. Climate changes could alter virulence under cultivation and in natural habitats. Hence understanding how these abiotic factors and their interactions affect virulence has vital implications. It is also imperative to formulate cost-effective integrated disease management, i.e., cultural, chemical, biological, and host resistance to powdery mildew management strategies at each level, considering prevailing environmental conditions under several plant species.

Moreover, sources of powdery mildew resistance listed in Southeast Asia should also be described appropriately whether resistance in these genotypes is race-specific, based on a form of slow mildewing resistance, or non-host resistance, because studies show that race-nonspecific resistance to powdery mildew provides more durable disease resistance^[135]. Furthermore, the mechanism of non-host resistance against powdery mildew of various plant species should also be exploited, which is considered more durable and robust resistance^[101].

Conflict of interest

The authors declare that they have no conflict of interest.

Dates

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