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REVIEW

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Monitoring, distribution and clinical relevance of airborne pollen and fern spores in Southeast Asia – A systematic review

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ABSTRACT

Southeast Asia is witnessing a rapid increase in the prevalence of allergic diseases, including asthma and allergic rhinitis. Pollen grains stand out as one of the primary triggers for allergy, and monitoring aeroallergens plays a pivotal role in allergy prevention. However, our understanding of the diversity and abundance of allergenic pollen in tropical regions, as well as their clinical significance, remains limited. This review aims to address this issue by identifying the most potentially allergenic plants in Southeast Asia, examining sensitization rates to their pollen allergens, describing the dynamics of pollen seasons, and discussing the current state of aerobiological monitoring in the region. The selection of plants was conducted through a systematic review process (following PRISMA guidelines), by screening the Scopus and PubMed databases, and focusing on studies that provided clinical and aerobiological data. As a result, 73 studies related to pollen allergy in Southeast Asia were identified and reviewed. The list of potentially allergenic plants posing the highest risk in Southeast Asia has been narrowed down to 10, including 5 woody species, 2 primarily weed families, grasses, palms, and ferns. The descriptions of these plants are supplemented with information on their ecology, pollen seasons dynamics, and clinical significance.

Keywords: Allergy, Asia, Ferns, Palms, Pollen seasons

INTRODUCTION

Pollen allergy imposes significant health burdens, with a prevalence ranging between 10% and 30% of the global population.[1,2] Allergenic pollen grains are mainly produced by wind-pollinated plants, which release vast amounts of pollen grains into the atmosphere.[3] Monitoring of atmospheric dispersion of pollen is therefore essential for accurately identifying pollen exposure, given the significant daily and site-to-site variations in pollen concentration.[4] Such monitoring serves as a crucial tool in allergy prophylaxis, providing pollen information to a variety of end users, including pollen allergy sufferers and health care professionals.[5] By providing real-time and seasonal pollen information, monitoring allows individuals to take preventive measures such as adjusting outdoor activities, using antihistamines or nasal corticosteroids preemptively, and implementing environmental controls

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(eg, closing windows, using air purifiers). Moreover, it supports health professionals in advising patients on allergen avoidance strategies and optimizing treatment plans based on expected pollen exposure.[6,7]

Notedly, the majority of pollen monitoring stations are concentrated in the Northern Hemisphere, particularly in Europe (>500 stations), while other regions have alarmingly low number of pollen traps.[8] Southeast Asia, for example, has only 4 locations, ie, Manila, Singapore, Jakarta, and Bangkok, that have conducted continuous aerobiological monitoring using the standardized volumetric method (EN 16868:2019–09).[9-13] Consequently, our understanding of the spatiotemporal distribution of airborne pollen grains in Southeast Asia, as well as the basic knowledge about the diversity of allergenic plant species in tropical and subtropical regions remains limited. Importantly, the pattern of sensitization to pollen allergens is likely to be different between temperate and (sub)tropical areas,[14–16] which, without adequate allergen panels, may hinder the accurate allergy diagnosis. It should be stressed that with a population exceeding 675 million, Southeast Asia faces a significant lack of accessible information on daily pollen levels and even basic pollen calendars. This information gap is especially concerning given the rising prevalence of allergic diseases, including asthma and allergic rhinitis, in the region.[17] It has been emphasized that one of the significant knowledge gaps in tropical countries is the understanding of the role of pollen grains as risk factors for asthma and rhinitis.[14] In addition, better identification of triggers and risk factors, along with increased public awareness, is key to reducing the burden of allergic diseases in the Asia-Pacific region.[18] This review aims to address this challenge by exploring potentially allergenic plants in Southeast Asia, assessing their allergenicity, pollen season characteristics, and allergy prevalence.

METHODS – LITERATURE REVIEW

Systematic review of scientific literature followed the protocol proposed by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA).[19] The scientific databases “Scopus” and “PubMed” were used for this analysis. By searching for papers with the ("pollen” AND “allergy"), and the name of one of the Southeast Asian country, ie, Brunei, Cambodia, East Timor, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, a list of 201 records was returned (73 for Scopus and 128 for PubMed) (Fig. 1). Most of the records comes from Thailand, Singapore and Malaysia (62, 43, and 42 respectively). For 4 countries, ie, Cambodia, Myanmar, East Timor and Laos, no results were returned. Next, the duplicated records (n = 72) were removed. In the next step, the papers were screened for relevance based on title and abstract content what resulted in exclusion of 70 articles. In addition, records identified through other sources (ie, hand searching of references lists, etc) were selected (n = 16) and added to the first list. Finally, the available full length text were screened for relevance what resulted in removing 12 more studies. In total, 73 records were included in the analysis (Fig. 1, Tables S1 and S2). These studies were used to select plants with the highest potential to induce pollen allergies in Southeast Asia, specifically those showing high allergy prevalence and elevated pollen levels in the air. Additionally, the final selection incorporated an assessment of phylogenetic proximity to known allergenic species from other regions, based on established taxonomic classifications and molecular phylogenetic studies (Fig. 2). Species from the same family, genus, or those sharing conserved allergen families (eg, β-expansins, profilins, lipid transfer proteins) with globally recognized allergenic plants were prioritized due to their higher likelihood of cross-reactivity. Cross-reactivity potential was further evaluated by referencing allergen databases (eg, WHO/IUIS Allergen Nomenclature Database) and existing literature on molecular allergen homology. This approach ensured that selected species not only had local clinical relevance but also aligned with global patterns of pollen allergy sensitization.

RESULTS AND DISCUSSION

Pollen and fern spores monitoring in Southeast Asia

Aeroallergen monitoring studies from Southeast Asia were predominantly conducted in 5 countries: Thailand,[20-27] the Philippines,[11,28-31] Singapore,[10,32] Indonesia,[13] and Malaysia[12,33]

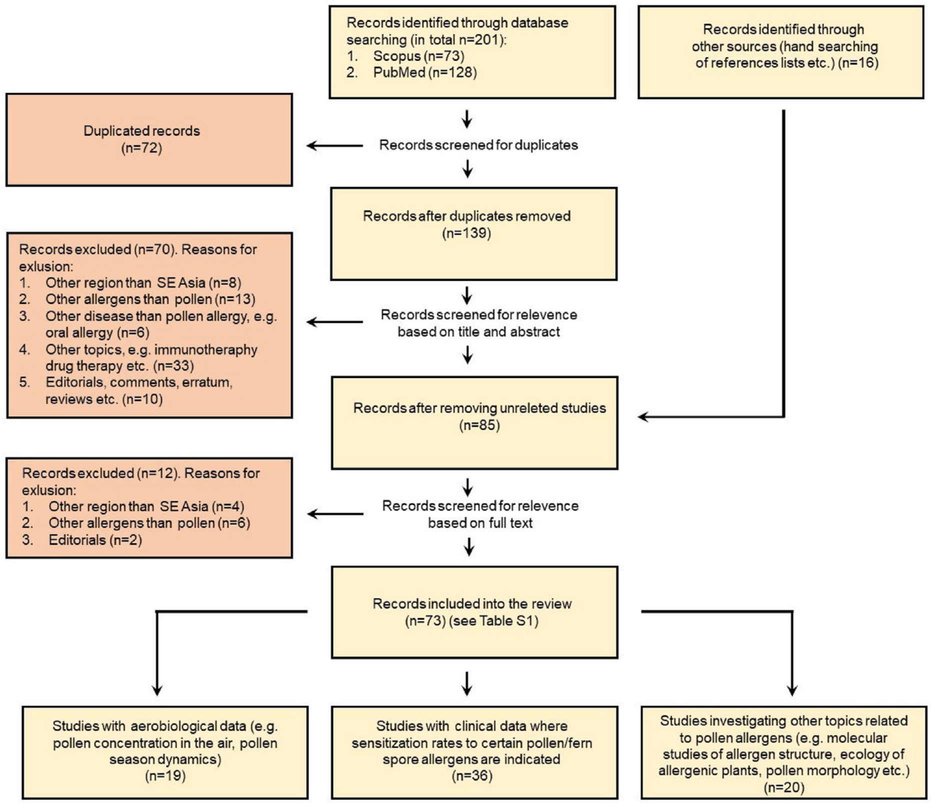

Fig. 1 Flow diagram summarizing the screening and selection process of studies used in the review.

(Fig. 3, Tables S3 and S4). Recently, a short-term airborne pollen monitoring study was also carried out in Vietnam.[34] As a result, vast areas of Southeast Asia, especially those south of the equator, lack any information about airborne pollen and fern spore distribution. Additionally, in the countries where aerobiological research has been conducted, the available data often originates from only 1 site, mainly the largest cities (Bangkok, Kuala Lumpur, Jakarta, and Manila). Thus, the aerobiological situation in agricultural areas and natural environments (eg, forests) is practically unknown. On the other hand, it should however be highlighted that airborne pollen studies in Southeast Asia have a well-established historical background. The earliest documented pollen monitoring can be traced back to the 1960s, during which gravimetric analysis was performed in the Philippines.[29] In Thailand, pollen monitoring efforts commenced in the 1970s, employing Durham pollen traps.[24] The fact that in the Philippines aerobiological studies were combined with observations of grass flowering is also commendable.[35,36] Such studies are extremely valuable by indicating exact time of flowering and providing important information about the species that contribute most to the production of allergenic pollen grains. The longest documented pollen time series extends for 15 years.[24] However, most studies are considerably shorter, typically spanning 1–2 seasons (Table S4). Consequently, there is a lack of continuity in aerobiological sampling, which hampers overall data interpretation. This limitation becomes especially pertinent when considering issues such as the impact of climate change and changes in land use on airborne pollen composition.

Selected allergenic plant species in Southeast Asia

The list of potentially allergenic plants (selected based on aforementioned criteria, see Methods section) posing the highest risk in Southeast Asia has been limited to 10, encompassing 5 woody species (*Carica papaya*, *Acacia* sp., *Casuarina* sp., *Artocarpus heterophyllus*, *Mangifera indica*), 2 predominantly weed families (Urticaceae, Amaranthaceae), grasses (Chloridoideae and

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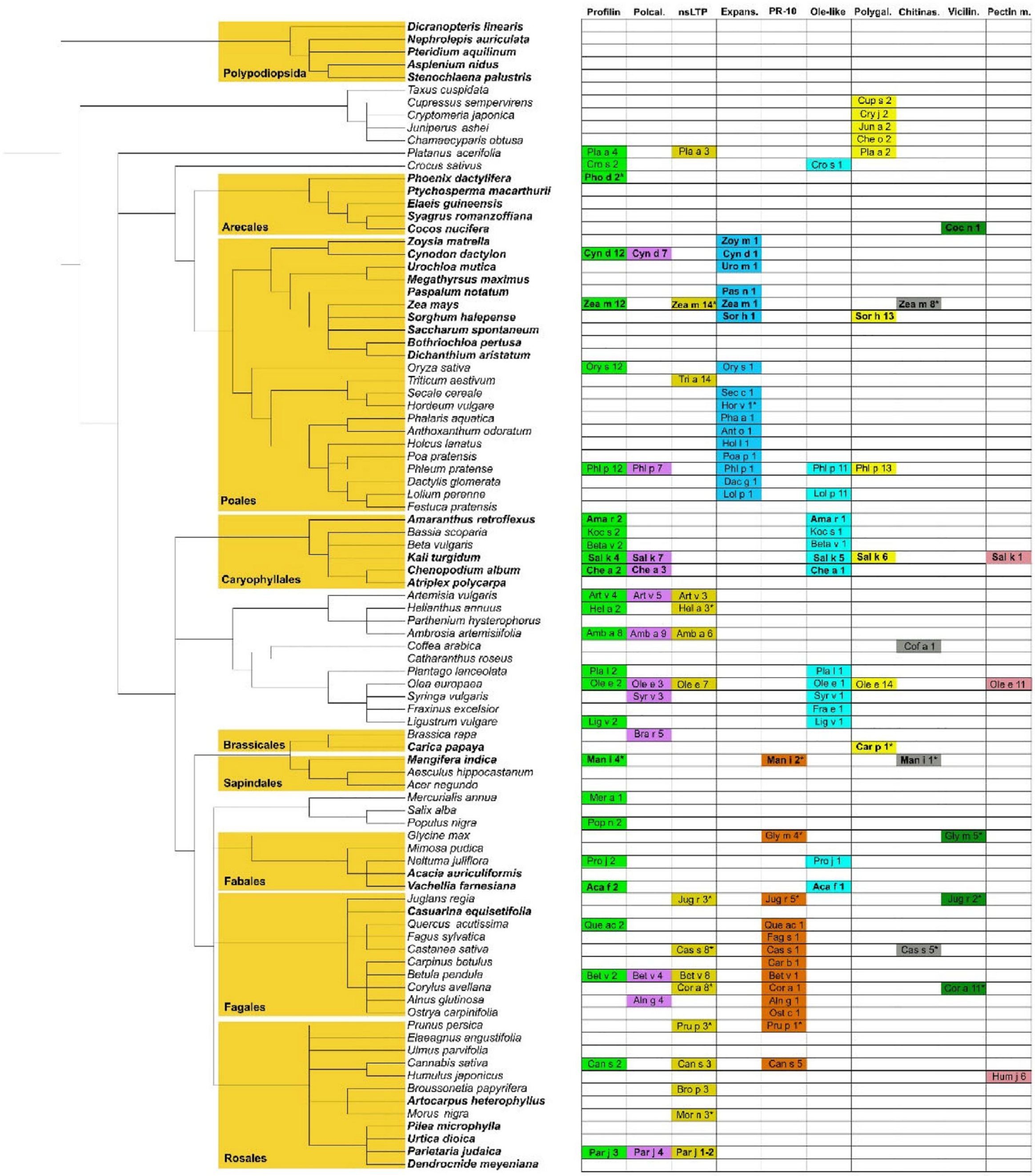

Fig. 2 Selected plant taxa from Southeast Asia (indicated in bold) are presented in relation to their phylogenetic relationships, along with their allergens from 10 major protein families listed in the IUIS/WHO database. Please note that rarer allergens are not included. Allergens marked with an asterisk (*) are designated as food allergens in the IUIS/WHO database. Orange rectangles highlight common clades (primarily orders) that encompass both the selected plants and known allergenic species from other regions. Phylogenetic tree was generated using the software phyloT (http://phylot.biobyte.de/). Abbreviations: Polcal. - polcalcin, nsLTP - nonspecific Lipid Transfer Protein, Expans. – expansins, mainly β-expansins, PR-10 – pathogenesis-related proteins 10, Ole-like - Ole e 1-like protein family, Polygal. – polygalacturonase, Chitinas. – chitinase and chitinase-like protein, Vicilin. – Vicilin and vicilin-like protein, Pectin m. - pectin methylesterase (see IUIS/WHO database for more information).

Panicoideae subfamilies), palms (Arecaceae), and ferns (Polypodiopsida). The detailed characteristics of plant distribution and pollen morphology are described in Table 1, while the prevalence of pollen allergy for selected plant taxa is listed in Table 2. Characteristics of pollen seasons for selected taxa are based on 19 aerobiological studies (Fig. 3, Tables S1, S3 and S4). The most

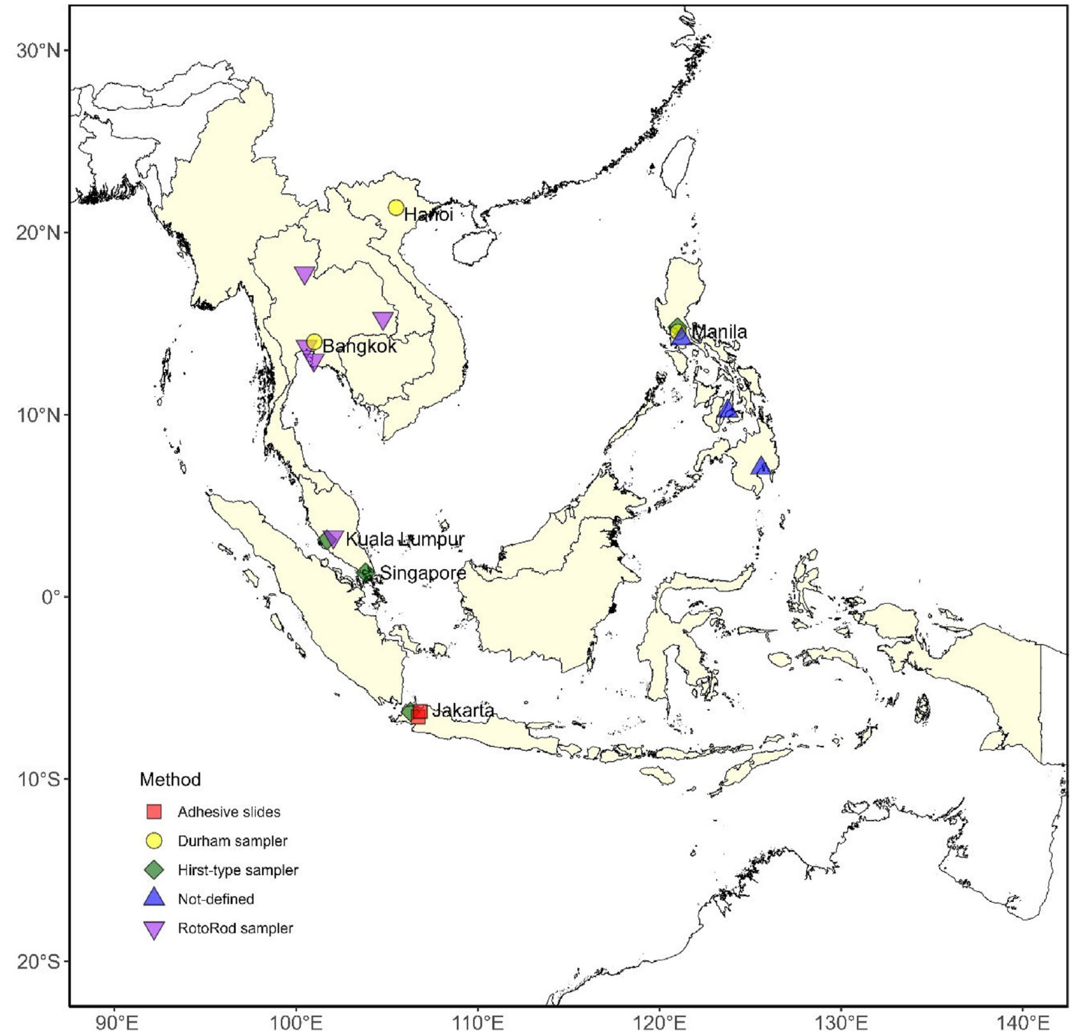

Fig. 3 Aerobiological monitoring sites in Southeast Asia with reference to sampling method used (see Table S4 for more information).

important information related to pollen season dynamics, diversity of pollen allergens, and possible cross-reactivity with other plant species growing in Southeast Asia is presented below.

Grasses (Chloridoideae and Panicoideae subfamilies)

Looking globally, over 95% of the allergenically important grass species belong to the 3 subfamilies Pooideae, Chloridoideae, and Panicoideae.[37] The first subfamily dominates in temperate climate of the Northern Hemisphere (Europe and the United States) in terms of species commonness, abundance, and consequently, has the most significant impact on allergy sensitization.[38,39] In contrast, the importance of Chloridoideae and Panicoideae markedly increases in Southeast Asia (Table 1). In this region, the most common and predominant grass species include *Cynodon dactylon* (known as Bermuda grass, Chloridoideae subfamily), *Eleusine indica* (Chloridoideae), *Dichanthium aristatum* (Panicoideae), *Saccharum spontaneuam* (Panicoideae), *Brachiaria mutica* (Panicoideae), *Eriochloa procera* (Panicoideae), *Pennisetum polystachya* (Panicoideae), *Polytrias praemorsa* (Panicoideae), *Urochloa mutica* (Panicoideae), *Imperata cylindrica* (cogongrass, Panicoideae), *Paspalum distichum*, and *P. notatum* (Bahia grass, Panicoideae), *Sorghum halepense* (Johnson grass, Panicoideae), and *Panicum repens* (Panicoideae).[35,36,40]

The prevalence of sensitization to grass pollen allergens in Southeast Asia varied significantly between regions, cohorts, and grass species (Table 2).

Taxon (Family)	Plant form	Origin/habitat/distribution	Pollen characteristics	Pollination behavior	Pollen/spore transport ability
Chloridoideae and Panicoideae	Grasses, herbaceous, monocotyledon plants	Widely distributed in Southeast Asia, includes a significant number of major crop species (corn, broomcorn), pasture grasses; have considerable ecological importance as grassland ecosystems	Size: 25–40 µm (wild), >40 µm (cultivated) Shape: Spheroidal to suboblate Apertures: Monoporate Exine: Areolate, microechinate	Wind-pollinated	Medium to high
Carica papaya (Caricaceae)	Semi-wood, tree-like plant (5–10 m)	Native to tropical America, introduced and widely distributed in tropical and sub-tropical zones of Southeast Asia; cultivated for fruits (papaya)	Size: 25–35 µm Shape: Oblate to sub-spheroidal Apertures: 3-Colporate Exine: Psilate or finely reticulate	Insect and wind-pollinated	Low to medium
Mangifera indica (Anacardiaceae)	Evergreen tree (up to 30 m)	Native to Southeast Asia, commercially cultivated for fruits (mango) - Asia is the largest mango-producing region	Size: ~26 µm Shape: Elliptic to oblong Apertures:3-colpate Exine: Reticulate-perforate	Insect and wind-pollinated	Low to medium
Artocarpus heterophyllus (Moraceae)	Small to medium-sized evergreen tree (10–25 m)	Native to India, cultivated throughout tropical and subtropical Southeast Asia for fruits (jackfruit)	Size: 15–19 µm Shape: Spheroidal Apertures:3-porate Exine: Smooth	Insect and wind-pollinated	Very high
Amaranthaceae	Annual or perennial herbs and shrubs, rarely lianas and small trees	Worldwide distribution in tropical and warm temperate regions, many species have certain economic importance, eg, leafy vegetables, psuedocereals, ornamental plants; number of species are considered invasive	Size: 20–40 µm Shape: Spheroidal Apertures: Pantoporate (from 4 to app. 250 pores) Exine: Microechinate, perforate	Wind-pollinated	High
Casuarina equisetifolia (Casuarinaceae)	Monoecious evergreen tree (30–40 m)	Native to Southeast Asia and Australia, grow in a wide range of different	Size: 19–33 µm Shape: Circular, oblate	Wind-pollinated	High

		environments, from tropical forests to arid woodlands and coastal dunes; extensively cultivated for beach establishment, wind breaking, and coastal sand dune stabilization	Apertures: 3-Porate Exine: Scabrate/rugulate		
Urticaceae	Primarily annual or perennial herbs, small shrubs, rarely, lianas, and trees	Distributed worldwide with the largest concentration of genera and species found in tropical Southeast Asia; many species play an ecologically important role in the understory vegetation of tropical forests, while others are common ruderal plants	Size: 10–20 µm Shape: Round to oblate Apertures: Often 2- or 3-porate Exine: Microverrucate or microechinate	Wind-pollinated	Very high
Acacia auriculiformis (Fabaceae)	Evergreen tree (up to 30 m)	Native to Australia and to Southeast Asia, become highly invasive in Southeast Asia, spreading intensively in coastal areas, tropical lowlands, and a variety of forest types	Size: ∼46 µm Shape: Polyads (16 microspores) Apertures: 3–4 porate Exine: Faintly foveolate	Primarily insect-pollinated	Low
Elaeis guineensis (Arecaceae)	Palm, perennial, arborescent, stem-less plant (up to 20 m)	Native to Africa, introduced to Southeast Asia, as an ornamental tree crop, extensively cultivated for oil	Size: 21–34 µm Shape: Elliptical Apertures: 3-Sulcate Exine: Reticulate-vermiculate	Primarily insect-pollinated (beetles)	Low
Polypodiopsida	Ferns, including epiphytic and epilithic, and tree-like species (up to 20 m)	Widely distributed; in Southeast Asia the highest species diversity globally; ferns may constitute the primary components of tropical forests	Size: 20–70 µm Shape: Spheroidal, tetrahedral, ellipsoidal Apertures: Monolete, trilete Exine: various (echinate, granulate, verrucate, reticulate)	Wind-dispersed	Medium to high

Table 1. Characteristics of selected plant taxa with potential allergic significance in Southeast Asia.

Family	Species	Country	Freq. (%)	Test	Cohort	References
Caricaceae	*Carica papaya*	Philippines	9.23	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	50
			6.92	IgE		
Arecaceae (palms)	*Cocos nucifera*	Philippines	4.62	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	50
			20.77	IgE		
		Thailand	12.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100)	43
	Elaeis guineensis	Singapore	29.8	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	94
			11.8	SPT	Control healthy group (n = 76)	
			40.9	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			4.2	IgE	Control healthy group (n = 24)	
		Thailand	5.6	SPT	Adult asthmatics (n = 71),	121
			8.3	SPT	Pediatric asthmatics (n = 84), Thailand	
			0.0	SPT	Control group of adults (n = 71), Thailand	
		Indonesia	22.4	SPT	Subjects with allergic rhinitis or/ and asthma (n = 107)	123
			0.0	SPT	Control volunteers (n = 20)	
			1.0	IgE	Subjects with respiratory allergy confirmed by SPT (n = 100)	48
		Malaysia	9.6	IgE	Subjects required from young university students (n = 564)	135
	Phoenix dactylifera	Malaysia	4.4	SPT	Subjects with asthma and asthma-like symptoms (n = 127)	133

	Arecastrum romanzoffianum	Singapore	29.93	SPT	Subjects attending allergy clinic (n = 1069)	**30**
	Ptychosperma macarthurii	Philippines	5.38	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	**50**
			15.38	IgE		
Anacardiaceae	*Mangifera indica*	Philippines	63.85	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	**50**
			2.31	IgE		
			19.3	SPT	Randomly selected subjects (n = 523)	**49**
			15.1	IgE		
		Thailand	16.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100)	**43**
Fabaceae (subfamily Mimosoideae)	*Acacia auriculiformis, Acacia sp.*	Philippines	27.69	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	**50**
			3.85	IgE		
		Singapore	27.7	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	**94**
			7.9	SPT	Control healthy group (n = 76)	
			29.0	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			0.0	IgE	Control healthy group (n = 24)	
			~10.0	SPT	Subjects attending allergy clinic (n = 1069)	**30**
			1.5	IgE	Volunteers responded to questionnaire and underwent SPT (n = 206)	**124**

(continued)

Family	Species	Country	Freq. (%)	Test	Cohort	References
		Thailand	19.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100)	43
			1.0	SPT	Adolescent asthmatics (n = 198)	122
			~4.0	SPT	Adult subjects with allergic symptoms or urticaria (n = 1516)	88
			2.8	SPT	Adult asthmatics (n = 71)	121
			3.6	SPT	Pediatric asthmatics (n = 84)	
			1.4	SPT	Control group of adults (n = 71)	
		Indonesia	12.15	SPT	Subjects with allergic rhinitis or/and asthma (n = 107)	123
			0.0	SPT	Control volunteers (n = 20)	
			10.0	IgE	Subjects with respiratory allergy confirmed by SPT (n = 100)	48
		Malaysia	21.5	SPT	Patients with clinical symptoms of asthma (n = 200)	10,89
Casuarinaceae	*Casuarina equisetifolia*	Singapore	27.7	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	94
			6.6	SPT	Control healthy group (n = 76)	
			18.8	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			0.0	IgE	Control healthy group (n = 24)	
			27.8	SPT	Subjects attending allergy clinic (n = 1069)	30
		Indonesia	2.0	IgE	Subjects with respiratory allergy confirmed by SPT (n = 100)	48

Poaceae (only Chloridoideae and Panicoideae subfamilies)	*Dichanthium aristatum, Dichanthium spp.*	Philippines	14.62	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	**50**
			4.61	IgE		
			9.4	SPT	Randomly selected subjects (n = 523)	**49**
			7.5	IgE		
	Urochloa mutica	Thailand	30.4	SPT	Subjects with allergic rhinitis (n = 168)	**40**
			47.1	SPT	Adult subjects with allergic rhinitis (n = 121)	**44**
			49.4	SPT	Subject with allergy (n = 736)	**42**
			35.2	SPT	Subjects with chronic rhinitis (n = 3871)	**46**
			2.7	SPT	Subjects (priests) with allergic rhinitis (n = 110)	**86**
			19.4	SPT	Volunteers with allergic histories requited from a questionnaire (n = 36)	**47**
	Urochloa eminii	Thailand	2.7	SPT	Volunteers with allergic histories requited from a questionnaire (n = 36)	**47**
	Megathyrsus maximus	Thailand	2.7	SPT	Volunteers with allergic histories requited from a questionnaire (n = 36)	**47**
	Saccharum spontaneum	Philippines	5.7	SPT	Randomly selected subjects (n = 523)	**49**
			9.6	IgE		
	Zoysia martella	Thailand	16.1	SPT	Subjects with allergic rhinitis (n = 168)	**40**

(continued)

Family	Species	Country	Freq. (%)	Test	Cohort	References
			16.5	SPT	Adult subjects with allergic rhinitis (n = 121)	44
	Ischaemum sp.	Malaysia	14.1	SPT	Subjects with allergic rhinitis (n = 85)	51
	Cynodon dactylon	Singapore	6.8	IgE	Volunteers responded to questionnaire and underwent SPT (n = 206)	124
			∼13.0	SPT	Subjects attending allergy clinic (n = 1069)	30
		Philippines	25.0	IgE	Subjects who reported allergy symptoms (n = 79)	39
		Thailand	24.4	SPT	Subjects with allergic rhinitis (n = 168)	40
			39.7	SPT	Adult subjects with allergic rhinitis (n = 121)	44
			52.3	SPT	Subject with allergy (n = 736)	42
			37.2	SPT	Subjects with chronic rhinitis (n = 3871)	46
			18.9	SPT	Adult subjects with allergic symptoms or urticaria (n = 1516)	88
			9.1	SPT	Subjects (priests) with allergic rhinitis (n = 110)	86
			17.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100)	43
			7.1	SPT	Adolescent asthmatics (n = 198)	122
			2.8	SPT	Adult asthmatics (n = 71)	121
			1.2	SPT	Pediatric asthmatics (n = 84)	

			1.4	SPT	Control group of adults (n = 71)	
		Malaysia	16.3	SPT	Undiagnosed volunteers responded to questionnaire (n = 321)	62
			20.5	SPT	Subjects with clinical symptoms of asthma (n = 200)	10,89
			13.5	IgE	Subjects required from young university students (n = 564)	135
		Indonesia	3.0	IgE	Subjects with respiratory allergy confirmed by SPT (n = 100)	48
			3.8	IgE	Subjects with respiratory allergy confirmed by SPT (n = 106)	105
	Bothriochloa pertusa	Thailand	11.9	SPT	Subjects with allergic rhinitis (n = 168)	40
			16.5	SPT	Adult subjects with allergic rhinitis (n = 121)	44
	Paspalum notatum	Malaysia	6.5	SPT	Subjects with clinical symptoms of asthma (n = 200)	10,89
		Thailand	16.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100)	43
	Sorghum halepense	Thailand	21.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100)	43
			19.8	SPT	Adult subjects with allergic rhinitis (n = 121)	44
			13.1	SPT	Subjects with allergic rhinitis (n = 168)	40
			~7.0	SPT	Adult subjects with allergic symptoms or urticaria (n = 1516)	88
			6.6	SPT		122

(continued)

Family	Species	Country	Freq. (%)	Test	Cohort	References
					Adolescent asthmatics (n = 198)	
			0.0	SPT	Adult asthmatics (n = 71)	**121**
			2.4	SPT	Pediatric asthmatics (n = 84)	
			2.8	SPT	Control group of adults (n = 71)	
			16.6	SPT	Volunteers with allergic histories requited from a questionnaire (n = 36)	**47**
			13.8	IgE		
		Malaysia	11.9	IgE	Subjects required from young university students (n = 564)	**135**
		Singapore	22.73	SPT	Subjects attending allergy clinic (n = 1069)	**30**
	Sorghum bicolor	Thailand	16.6	SPT	Volunteers with allergic histories requited from a questionnaire (n = 36)	**47**
	Zea mays	Indonesia	15.0	IgE	Subjects with respiratory allergy confirmed by SPT (n = 100)	**48**
		Thailand	16.6	SPT	Volunteers with allergic histories requited from a questionnaire (n = 36)	**47**
		Singapore	23.01	SPT	Subjects attending allergy clinic (n = 1069)	**30**
	Zea mays (var. White)	Philippines	6.9	SPT	Randomly selected subjects (n = 523)	**49**
			9.6	IgE		
	Zea mays (var. Yellow)		6.1	SPT		
			5.0	IgE		

	Mix of *Sorghum halepense*, *Cynodon dactylon*, *Phleum pretense* (Poideae) and *Amaranthus palmeri* (Amaranthaceae)	Thailand	39.3	SPT	Subjects with chronic rhinitis (n = 655)	**41**
	Mix of *Cynodon dactylon* and 11 grass species from Poideae	Indonesia	11.4	SPT	Adult asthmatic patients (n = 105)	**54**
Amaranthaceae	*Amaranthus spinosus*	Philippines	21.54	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	**50**
			10.0	IgE		
	Amaranthus retroflexus	Malaysia	8.0	SPT	Subjects with clinical symptoms of asthma (n = 200)	**10,89**
	Amaranthus palmieri	Thailand	~~5.0	SPT	Adult subjects with allergic symptoms or urticaria (n = 1516)	**88**
			45.4	SPT	Subject with allergy (n = 736)	**42**
			29.9	SPT	Subjects with chronic rhinitis (n = 3871)	**46**
			8.2	SPT	Subjects (priests) with allergic rhinitis (n = 110)	**86**
	Amaranthus hybridus	Thailand	30.6	SPT	Adult subjects with allergic rhinitis (n = 121)	**44**
		Singapore	~21.0	SPT	Subjects attending allergy clinic (n = 1069)	**30**
	Amaranthus sp.	Thailand	16.0	SPT	Subjects with allergenic rhinitis with clinical presentation (n = 100), Thailand	**43**
	Kochia sp. (=Bassia sp.)	Thailand	14.0	SPT		

(continued)

Family	Species	Country	Freq. (%)	Test	Cohort	References
	Atriplex polycarpa	Singapore	21.32	SPT	Subjects attending allergy clinic (n = 1069)	30
	Salsola kali	Singapore	~2.5	SPT	Subjects attending allergy clinic (n = 1069)	30
	Chenopodium album, Chenopodium sp.	Singapore	22.26	SPT	Subjects attending allergy clinic (n = 1069)	30
		Indonesia	5.7	IgE	Subjects with respiratory allergy confirmed by SPT (n = 106)	105
Urticaceae	*Pilea microphylla*	Philippines	16.15	SPT	Subjects positive to pollen confirmed by SPT (n = 130)	50
			3.07	IgE		
	Dendrocnide meyeniana		6.92	SPT		
			9.23	IgE		
	Parietaria judaica,	Indonesia	4.7	IgE	Subjects with respiratory allergy confirmed by SPT (n = 106)	105
	Parietaria sp.	Singapore	~20.0	SPT	Subjects attending allergy clinic (n = 1069)	30
	Urtica dioica	Singapore	35.55	SPT	Subjects attending allergy clinic (n = 1069)	30
Polypodiopsida (ferns)	*Dicranopteris linearis, D. curranii*	Singapore	30.7-34.2	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	94
			9.2	SPT	Control healthy group (n = 76)	
			23.3	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			8.3	IgE	Control healthy group (n = 24)	
		Thailand	1.4	SPT	Adult asthmatics (n = 71)	121
			1.2	SPT	Pediatric asthmatics (n = 84)	
			0.0	SPT	Control group of adults (n = 71)	

		Indonesia	11.21	SPT	Subjects with allergic rhinitis or/ and asthma (n = 107)	**123**
			0.0	SPT	Control volunteers (n = 20)	
	Asplenium nidus	Singapore	25.5	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	**94**
			3.9	SPT	Control healthy group (n = 76)	
			17.0	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			0.0	IgE	Control healthy group (n = 24)	
	Nephrolepis auriculata		29.4	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	
			9.2	SPT	Control healthy group (n = 76)	
			21.6	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			4.2	IgE	Control healthy group (n = 24)	
	Stenochlaena palustris		21.6	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	
			11.8	SPT	Control healthy group (n = 76)	
			16.5	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			0	IgE	Control healthy group (n = 24)	
	Pteridium aquilinum		20.3	SPT	Subjects with allergic rhinitis and/or asthma (n = 231)	
			7.9	SPT	Control healthy group (n = 76)	
			16.5	IgE	Subjects with allergic rhinitis and/or asthma (n = 176)	
			0	IgE	Control healthy group (n = 24)	

Table 2. (Continued) Prevalence of pollen allergy to selected plant taxa in Southeast Asia (Note: number of reviewed studies = 27, SPT - Skin Prick Test, IgE - specific IgE detection).

Generally, the highest sensitization rates (approximately >20% among individuals with allergies or asthma) were observed for pollen extracts from *C. dactylon*,[12,41-44] *S. halepense*,[32,45,46] *U. mutica*[42,46-49], and *Zea mays* (corn).[32,49,50] Other species could also be regionally important, eg, *Dichanthium aristatum* and *Saccharum spontaneuam* in the Philippines,[51,52] and *Paspalum notatum* and *Ischaemum* sp. in Malaysia.[12,53] Compared to Europe,[54] the sensitization rate to grass pollen in South-Eastern Asia appears to be lower. However, it should be noted that allergen panels tests used in clinical trials were sometimes based mainly on grass pollen taxa characterized for temperate regions (Poideae subfamily), not on native Asian plants (from Chloridoideae and Panicoideae subfamilies).[55-57] For example, in a clinical survey conducted in Vietnam,[58] a panel of mixed grass pollen allergens, specifically *Dactylis glomerata, Anthoxanthum odoratum*, *Lolium perenne*, *Poa pratensis*, and *Phleum pretense* was employed to assess the rate of sensitization to grass pollen. Although these species are indeed highly allergenic, they are rare in Southeast Asia and possess a different combination of major allergens compared to native grass species from the Panicoideae subfamily.[59] There are clinically relevant differences between Chloridoideae/Panicoideae and Pooideae.[60,61] For instance, the group 2 and 5 allergens, by which temperate grass pollen extracts are standardized for allergen content, appear to be absent from Chloridoideae and Panicoideae subfamilies[60,62] (Fig. 2). Consequently, the highest degree of allergenic cross-reactivity exists among pollen extracts derived from grass within the same subfamily. However, studies have demonstrated partial or high cross-reactivity between pollen allergens of Chloridoideae/Panicoideae and Pooideae.[40,61-63] This cross-reactivity can be attributed to shared allergenic components, particularly β-expansins (Group 1 allergens), as well as the presence of cross-reactive carbohydrate determinants (CCDs) (for more information, see Section 3.3). While some allergens remain subfamily-specific, the potential for cross-reactivity across grass subfamilies should not be overlooked, particularly in the context of allergy diagnosis and immunotherapy.

The use of panels of "*non-local grass species*" in clinical trials may, on the one hand, underestimate the prevalence of allergy to grass pollen grains and, on the other hand, impede immunotherapy and allergy treatment. As demonstrated, more people react to local plant species, and these should be incorporated into clinical trials.[16] For instance, in Malaysia, only 2.8–7.0% of patients reacted to the extract of mixed Poideae grasses, while 16.3–20.5% were sensitized to common *Cynodon dactylon*.[12,64] Similarly, in the Philippines 25% of symptomatic patients showed an almost exclusive IgE reactivity to nCyn d 1 whereas recombinant grass pollen allergens of *Phleum pretense* (Phl p 1, Phl p 2, Phl p 5, and Phl p 6) were almost not recognized.[41] There should be increased pressure on entities such as pharmaceutical and research companies to develop local allergen panels as diagnostic options suitable for the Southeast Asian population.[59,65]

The flowering and pollination periods of grasses in Southeast Asia, although observed throughout the year, are predominantly limited to the dry period, mainly occurring from September to April. For instance, the highest airborne grass pollen concentration was recorded in Singapore in September,[10] in Thailand in November-December,[21,24,27] and in Malaysia between January-April[12,33] (Fig. 4, Table S3). A detailed field survey conducted in Manila[35,36] showed that the majority of grass species flowered between October and December. During flowering, the grass pollen concentration in the atmosphere of Southeast Asia varied from medium to high,[11,27] often constituting the major component of the pollen load in the air.[12,24,26,33]

Cultivated woody plants – mango, papaya and jackfruit

Many potentially allergenic plants selected in this review are cultivated species, including such economically important as mango (*Mangifera indica*), papaya (*Carica papaya*), and jackfruit (*Artocarpus heterophyllus*). Mango is a perennial tree native to Southeastern Asia cultivated in tropical and subtropical regions, with its production expanding globally[66] (Table 1). *M. indica* pollen has been reported to be allergenic, with the prevalence among individuals with allergenic rhinitis ranging from 16.0% in Thailand[45] to 64.0% in the Philippines[52] (Table 2). Notedly, in

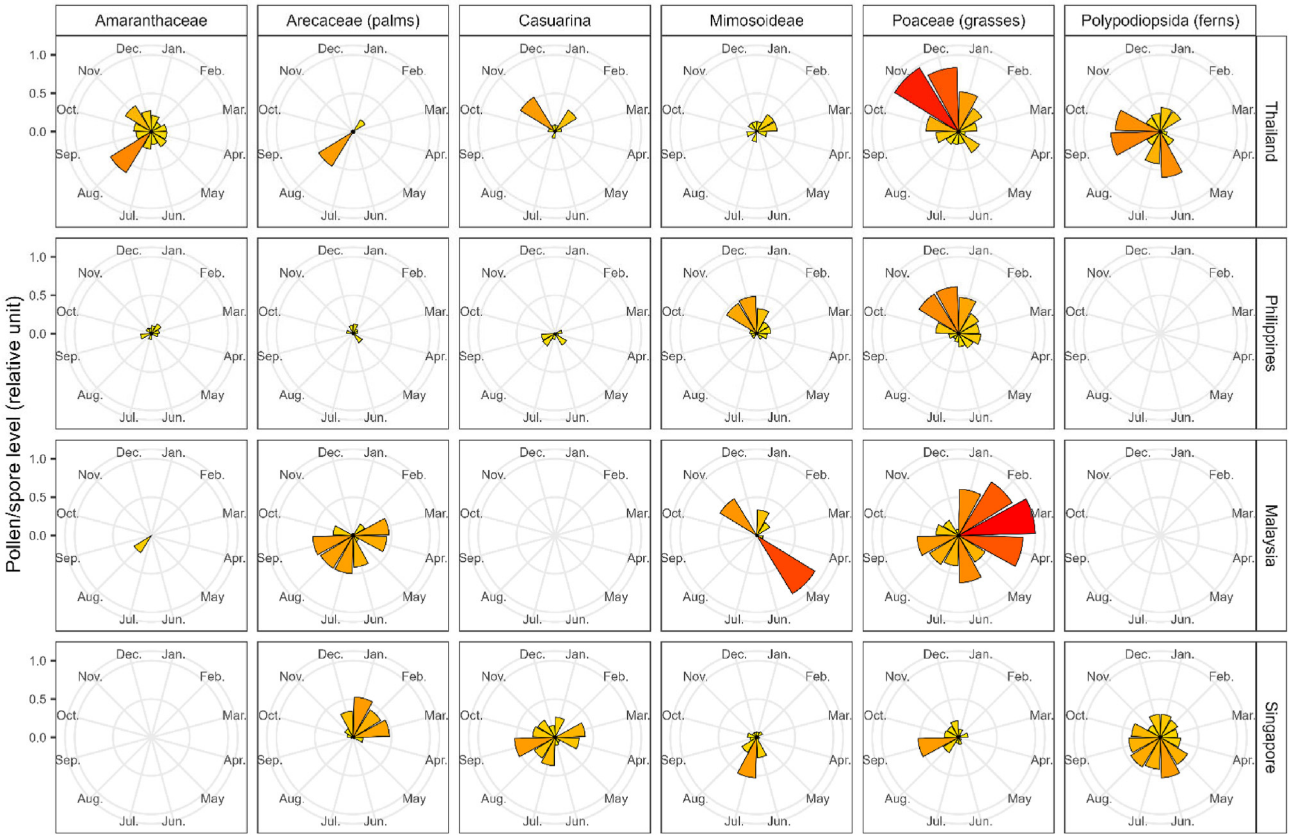

Fig. 4 Pollen seasons of selected allergenic taxa in Southeastern Asia. Note: a) pollen data retrieved from studies listed in Tables S1 and S3, b) pollen data for Mimosoideae include both *Acacia* and *Mimosa*, c) for better visibility, the maximum pollen level was adjusted to 1 and proportionally scaled based on the average pollen levels of the selected taxa, d) taxa and countries with limited data representativeness, eg, *Carica* pollen and Laos, have not been shown, e) empty panels indicate a lack of data.

the recent study conducted in Thailand the sensitization rate to mango pollen allergen in general population was reported to be 15.1% and 19.3% (based on sIgE and SPT, respectively).[51] The cross-reactivity is possible with other cultivated members of Anacardiaceae family such as cashew (*Anacardium occidentale*), and Peruvian papper (*Schinus molle*).[67,68] Similarly, papaya (*Carica papaya* L.) is a major fruit crop in tropical and sub-tropical regions[69-71] (Table 1). In tropical Asia, *Carica* pollen is present in the air throughout the year, and pollen can contribute markedly to the aeroallergen load in areas where papaya plants are cultivated.[72] *C. papaya* pollen has been associated with allergic diseases such as asthma and allergic rhinitis.[73] In the Philippines, the rate of sensitization to *C. papaya* pollen among atopic patients reached 9.2%[52] (Table 2). Although the highest exposure to pollen of mango and papaya is often observed in close proximity to crop fields (due to limited transport ability of pollen grains), the nearby areas may also be at risk. For instance, pollen grains of *C. papaya* were recorded in Manila city.[11] Two allergenic proteins of *C. papaya* are listed in the IUIS/WHO database, and both are categorized as food allergens (www.allergen.org). However, Cari p 1 (56 kDa) was also detected in pollen grains, suggesting that Car p 1 plays a role in both respiratory sensitization via pollen inhalation and sensitization of the gut mucosa via fruit consumption.[74] Cari p 2 (chymopapain, 28 kDa) shows IgE reactivity and cross-reactivity with proteins from kiwi and pineapple, triggering respiratory and food allergy symptoms in sensitized patients.[75] Additionally, the pollen extract of *C. papaya* contains an important IgE-reactive protein component with a molecular weight of 100 kDa and esterase activity.[76]

The clinical relevance of *A. heterophyllus* pollen is not well described. This species was selected mainly based on its abundance, pollen morphology facilitating airborne transport (light and tiny pollen grains) and its phylogenetic relevance (Fig. 2) with some known allergenic genera, like *Morus* and *Braussonetia* (belonging also to Moraceae family).[77] There are evidences that 17 kDa peptides derived from jackfruit exhibited a substantial level of similarity (76%) to the major birch pollen allergen (Bet v 1).[78] In individuals sensitized to birch, 91% demonstrated positive skin test reactions to fresh jackfruit, suggesting the potential for cross-reactivity.[78,79] As the pollen and fruits often share similar allergens (eg, as in papaya, olive, or hazel) it can be assumed that a similar phenomenon may occur in *A. heterophyllus*. Jackfruit pollen has been shown to elicit allergic reactions in individuals sensitized to latex derived from *Ficus* sp. (Moraceae family).[80] Considering that in some regions of Southeast Asia (eg, Thailand and Indonesia) there are vast plantations of jackfruits[81] and that its pollen can be easily dispersed in the atmosphere, jackfruit pollen should be considered the potential and specific aeroallergen for Southeast Asia.

Cultivated weeds - amaranth

Many species from Amaranthaceae family have certain economic importance, eg, in agriculture as leafy vegetables or psuedocereals (*Amaranthus* sp., *Spinacia oleraceae*, *Beta vulgaris, Chenopodium quinoa*) and in horticulture as ornamental plants (*Celosia* sp., *Alternanthera* sp., *Gomphrena* sp.)[82,83](Table 1). In Southeast Asia, pollen from the Amaranthaceae family can be found in the air throughout the year (Fig. 4). In Thailand, Amaranthaceae pollen grains dominate in the atmosphere, constituting 3–8% of the annual pollen load,[26,27] and becoming one of the most common airborne pollen types in 2 provinces: Bangkok and Uttaradith.[25] The peak of pollen emission was observed in Thailand mainly between August and November.[21,24,27] In the Philippines, airborne Amaranthaceae pollen was recorded at lower concentrations, mainly between February and May[11] or in September[30] (Fig. 4). Various taxonomically related members of Amaranthaceae (Fig. 2) can induce allergic sensitization, with the most significant genera being *Amaranthus*, *Chenopodium*, and *Salsola*.[84] Traditionally, the high prevalence of allergy to Amaranthaceae has been linked to dry, warm regions, such as the Mediterranean Basin.[85-87] However, considering the commonness and abundance of genera like *Amaranthus* in Southeast Asia, and its economic significance, one should also consider this region at risk for Amaranthaceae pollen. Notedly, this has already been documented by several clinical studies from Southeast Asia, where SPT to pollen allergens from various *Amaranthus* species have been observed. For example, positive reactions have been reported for *A. spinosus* in the Philippines,[52] *A. hybridus* and *A. palmeri* in Thailand,[47,48,88-90] and *A. retroflexus* in Malaysia[12,91] (Table 2).

Native woody plants - *Casuarina*

The genus *Casuarina* (known as Australian pine) includes 17 arborescent species belonging to Casuarinaceae family (Fagales order). Casuarinas grows naturally in South-East Asia, Malaysia, Australia, and Pacific Islands[92,93] (Table 1). Thanks to morphological adaptation to wind dispersal, as well as high pollen production,[94] pollen grains of *Casuarina* can attain high concentrations in the air.[10,95] For instance, in Singapore, *Casuarina* pollen grains were one of the most abundant pollen taxa in the atmosphere.[10] Casuarinaceae pollen has also been noted in Bangkok (Thailand)[26,27] and Manila (Philippines),[31] although in lower concentrations. In Singapore, the emission peak of *Casuarina* pollen grains occurred in September; however, they were practically recorded all year round[10,32] (Fig. 4). Positive skin reactions to *Casuarina* pollen were documented in Singapore[32,96] and Indonesia[50] (Table 2), but also in other regions, eg, Australia (*Casuarina glauca*),[97] the United States (*Casuarina equisetifolia*, *Casuarina lepidipholia*),[98,99] Mexico (*Casuarina equisetifolia*),[100] Spain (*Casuarina cunninghamiana*),[95] and India (*Casuarina equisetifolia*).[101] Patients sensitized to *Casuarina* pollen may experience either rhinitis and/or asthma.[95] Due to the close phylogenetic relationship between Casuarinaceae and other members of the Fagales order (Fig. 2), such as the Betulaceae family (birch, alder, hazel), there is a possibility of cross-reactivity between pollen allergens of *Casuarina* and the aforementioned genera.[95,98,102]

Native weeds – Urticaceae

The family Urticaceae consists of more than 2600 species,[103] primarily annual or perennial herbs (eg, *Urtica* sp., *Parietaria* sp., *Pilea* sp.), small shrubs (*Elatostema* sp., *Laportea* sp., *Boehmeria* sp.), and rarely, lianas (*Urera* sp.) and trees (*Cecropia* sp., *Dendrocnide* sp.). They are distributed worldwide with the largest concentration of genera and species found in tropical Asia[104–106] (Table 1). Due to the commonness, abundance, and high pollen production of many Urticaceae species, their pollen concentration in the air is often very high. In the Philippines, Urticaceae pollen accounted for 38% of all the pollen recorded in the air,[9] while in Thailand, it was one of the five most common airborne pollen taxa.[25] In contrast, airborne Urticaceae pollen grains, specifically *Pilea microphylla*, were rare in Singapore (trapped on less than 5% of total sampling days),[10] and no Urticaceae pollen grains were indicated during an aerobiological survey in Malaysia.[33] There isn't much data available regarding the temporal variation in Urticaceae pollen in Southeast Asia. However, in the Philippines, Urticaceae pollen grains were primarily observed between February and May with an emission peak in March[11] (Table S3). The importance of Urticacaceae pollen as a cause of allergies is ambiguous. On the one hand, *Parietaria* pollen is considered one of the most allergenic pollen taxa in the Mediterranean area, with allergy prevalence ranging from 17.5% in Portugal to 33.2% in Italy.[54] Also in Southeast Asia, the positive reactions to *Parietaria* pollen allergens have been documented.[32,107] On the other hand, *Urtica* pollen has traditionally been considered a less potent allergen compared to *Parietaria* pollen. Earlier studies reported a lack of cross-reactivity between *Parietaria* and *Urtica* pollen based on RAST-inhibition tests,[108] and monoclonal antibodies specific to Par j 1.[109] This suggests that both pollen species have distinct allergenic profiles despite their taxonomic proximity and cross reactivity may be possible through other allergenic components. Given that monoclonal antibodies and RAST-based assays may not detect all potential cross-reactive epitopes, broader immunological methods are needed to clarify the full extent of cross-reactivity between these species. From that perspective, it is interesting to note that some studies showed that exposure to *Urtica* pollen can indeed induce allergic reactions.[108,110] For instance, in Singapore the sensitization rate to *U. dioica* pollen among allergy clinic patients reached 35.55%.[32] The allergenic importance of other members of Urticaceae, common in the tropics, is even less known. The sensitivity to pollen of *Boehmeria nivea*, a widely distributed species in Southeast Asia,[111] was investigated in Japan, showing that the rate of positive reactions reached 11.7%.[112] Similarly, as with *Urtica*, there was no cross-reactivity between *B. nivea* and *P. judaica* pollen allergens. In contrast, possible cross-reactivity was suggested in the case of the pollen allergens of *P. judaica* and *Holoptelea integrifolia*.[113] *H. integrifolia*, a naturalized tree in Southeast Asia, belongs to the botanical family of Ulmaceae, which is closely related to Urticaceae.[114] In the Philippines, the prevalence of allergies to 2 members of Urticaceae, specifically *Dendrocnide meyeniana* and *Pilea microphylla*, was 6.9% and 16.5%, respectively[52] (Table 2). The major pollen allergens of Urticaceae were described from *P. judaica* (Par j 1 and Par j 2) (Fig. 2), showing that both allergens belong to the same family of plant proteins named nonspecific lipid transfer proteins (nsLTP).[115] In *Urtica*, several potential pollen allergens were characterized, ie, a thaumatin-like protein (osmotin) with a relative molecular mass of 27–29 kDa, a pectinesterase (40 kDa), and 2 other basic proteins (14–16 kDa and 43 kDa).[110]

Invasive alien species – *Acacia*

The list of invasive alien species which pollen may potentially cause allergic reactions in Southeast Asia is long, including genera such as *Mimosa* sp., *Acacia* sp. and *Lantana* sp. All of these species gain a reputation as some of the most noxious and the worst alien plants,[116,117] and positive SPT reactions to their allergens have been reported.[52,118,119] Here we will focus only on *Acacia* (family Fabaceae, subfam. Mimosoideae), which is a large genus with over 1200 deciduous or evergreen trees and shrubs globally.[120] Certain *Acacia* species, such as *A. auriculiformis* and *A. mangium*, have become highly invasive, spreading intensively in coastal areas, tropical lowlands, and a variety of forests, displacing indigenous species in Southeast Asia[121,122] (Table 1). Elevated concentrations of *Acacia* pollen have been recorded in the air in Malaysia[12] and at moderate levels in Singapore.[10] In contrast, the *Acacia* pollen concentration in Thailand were very low.[24,26] Although *Acacia* pollen is present in the atmosphere throughout the year, the peak pollen emissions mainly occur during the dry season (June and August in Singapore,[10] and November–March in Thailand[24] and in the Philippines[11,29]) (Fig. 4, Table S2). *Acacia* pollen has been reported to induce allergic diseases in Southeast Asia with the prevalence among asthmatic/allergic patients ranging from 1.0 to 19.0% in Thailand,[45,123,124] 10–12% in Indonesia,[125] 21.5% in Malaysia,[12,91] 27.7% in the Philippines,[52] and 1.5–29.0% in Singapore[32,96,126] (Table 2). Several allergenic protein bands (12–85 kDa) have been recognized by IgE-specific antibodies from *Acacia* allergic patients.[127] Two allergens have been identified from *A. farnesiana* (=*Vachellia farnesiana*) pollen, ie, Aca f 1, which is a member of the Ole e 1-like protein family,[128] and Aca f 2 belonging to the family of profilins.[129] Consequently, the cross-reactivity between *Acacia* allergens and homologues of the aforementioned allergens has been showed.[127,129] Due to *Acacia's* close phylogenetic relationship to other allergenic members of the Fabaceae family (Fig. 2), such as *Mimosa* sp., mesquite (*Prosopis* sp.), and alfalfa (*Medica sativa*), there is a high likelihood of cross-reactivity between these allergens.[127,130,131] Notedly, cross-reactivity with unrelated species, eg, ryegrass (*Lolium perenne*) and gladioli (*Gladiolus gandavesis*), have also been documented.[132]

Palms (Arecaceae)

Palms (Areceae family) hold a prominent position as one of the most economically significant plant families within tropical regions, as they provide sources of food, construction materials, clothing, medicine, and fuel.[133] There are numerous palm species that carry both economic and clinical significance, such as the date palm (*Phoenix dactylifera*), coconut tree (*Cocos nucifera*), and areca palm (*Areca catechu*).[52,134,135] Among them, one of the most important palms is *Elaeis guineensis*, ie, the oil palm. South-East Asia is a major producer of palm oil, with Indonesia accounting for over half of the global production and Malaysia contributing approximately one-quarter[136] (Table 1). The presence of oil palm pollen has been documented in the atmosphere of South East Asia from September to May, with the highest concentration observed in January-March.[10] Palm pollen has also been reported from other countries in the region, eg, in Thailand, in the Philippines and Malaysia (Fig. 4). *E. guineensis* pollen has been found to be capable of triggering allergic reactions in susceptible individuals, and there is a significant association with an increased risk of asthma.[137] The mean rates of sensitization to *E. guineensis* pollen among allergic or asthmatic patients in Thailand and Indonesia were 6.9% and 22.4%, respectively[123,125] (Table 2). In Singapore, extracts of *E. guineensis* pollen were observed to elicit the highest frequency of positive reactions (40%) among patients with atopic diseases.[96] In a recent study conducted in a Singapore/Malaysia cohort, the sensitization rate to oil palm pollen was determined to be 9.6%. Furthermore, asthmatic patients with sensitization to oil palm pollen exhibited increased risks of wheezing, nocturnal cough, and exacerbations.[137]

Ferns

Certainly, the most characteristic and intriguing feature of South-East Asia's aeroallergens is the high concentration of airborne fern spores, resulting in a relatively high prevalence of fern spore allergies (up to 34.2% in Singapore) (Table 2). Traditionally, ferns have not been considered a significant source of inhalant allergens.[138] This perception mainly arises from the fact that in temperate regions, ferns are not the dominant species, and the concentration of fern spores in the air is often very low.[139,140] However, in tropical and subtropical regions where ferns grow abundantly the situation is likely to be different.[138] Due to the exceptionally high annual spore production by individual ferns (ranging from 100,000 to 3 billion), high concentration of fern spores is observed in the air of tropical and subtropical areas.[10] In Singapore, the total fern spore level was comparable to the pollen grain level, exceeding 4000 spores per month.[10] Similarly, in Bangkok (Thailand), fern spores were found to be the third most common biological particle in the air.[47] In tropical and subtropical Asia, fern spores occur in the air almost all year-round, with the highest spore levels observed in May-June and September–October[10,25,141] (Fig. 4, Table S3). Diurnal spore concentration may have a different profile depending on the site's character; however, the peak in spore levels was often recorded between 10:00 and 18:00.[10,142] The most abundant airborne fern spores observed in Singapore belong to genera such as *Nephrolepis*, *Dicranopteris*, *Stenochlaena,* and *Pteridium*.[10,143] The available clinical studies from Southeast Asia[47,96,123,125] have shown that these 4 taxa could be relevant causes of allergic reactions. For instance, the positive SPT to *Dicranopteris* spp. varied from 11.2% to 34.2% in Malaysia[125] and Singapore,[96] respectively (Table 2). A high percentage of allergic reactions was also observed with spore extracts of *Acrostichum aureum*[47,144] and *Asplenium nidus*.[96] Although there are not many studies focused on fern spore allergy, the available data from all over the world[25,138,145,146] undoubtedly show that fern spores should be considered an important trigger of inhalant allergies, especially in tropical and subtropical regions. However, the number of clinical trials investigating allergies to fern spores is limited, and more research is needed to draw robust conclusions in this regard.

Limitations and considerations in pollen allergy diagnosis

It is important to note that data on IgE reactivity to different pollen extracts can be influenced by several factors, including the presence of IgE specific to cross-reactive carbohydrate determinants (CCDs) and pan-allergens such as profilins, polcalcins, and cyclophilins.[147,148] CCDs are glycan structures found on multiple unrelated allergens and can lead to cross-reactivity that is not clinically relevant, potentially overestimating the prevalence of genuine sensitization to specific pollen allergens.[149] Similarly, some allergens, such as profilins and calcium-binding proteins, are highly conserved across different plant species, leading to broad IgE recognition. However, their prevalence of sensitization is usually low, indicating that broad IgE recognition does not always correlate with clinically relevant allergy symptoms.[150,151] Furthermore, the quality of pollen extracts used in IgE testing plays a crucial role, as differences in extraction methods, allergen stability, and the presence or absence of key allergenic molecules may impact results.[152,153] As a result, the prevalence data reported in various studies should be interpreted with caution, keeping in mind these potential confounders. Future studies should aim to distinguish between genuine IgE-mediated sensitization and cross-reactivity by using well-characterized extracts, inhibition assays, or component-resolved diagnostics.[154,155]

CONCLUSIONS

Every region in the world possesses its own unique "*allergenic signature*," characterized by a distinctive allergen composition and abundance. Southeast Asia is no exception, harboring a combination of allergenic species, including both native (such as ferns and palms) and introduced plants (ornamentals and crops). There are numerous other species not mentioned in this review that could also have allergenic significance in Southeast Asia (refer to, for example,[11]). Many plant families in the tropics have wind-pollinated members that have never been studied regarding their allergenic potential. Can their pollen also induce allergic reactions? Without close collaboration between aerobiologists, local botanists, and physicians, finding an answer to this crucial question would be challenging. Among the necessary actions that should be taken in this regard, we recommend the following: 1) increase the number of aeroallergen monitoring stations using standardized aerobiological methods, 2) determine the key characteristics of pollen seasons, as well as the flowering periods and pollen production of tropical species with allergenic significance, 3) develop relevant clinical panel tests based on aeroallergens specific to Southeast Asia, 4) investigate the structure and functions of allergenic proteins from tropical pollen and spores.

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