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Review Article

Small-scale botanical in enhancing indoor air quality: A bibliometric analysis (2011-2020) and short review

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Abstract

Poor indoor air quality (IAQ) has developed a positive relationship with human health risks. Recently, research findings reported that the pollution level of indoor air could be 2 – 5 times higher than the outdoor air. In some studies, the poor IAQ could reach up to 100 times or more in a natural/ mechanical ventilated building. IAQ depends heavily on the ambient air quality and pollutants/ contaminants produced by household activities. Poor IAQ could lead to various health issues, i.e., asthma, lung cancer, dizziness, fatigue, headaches, etc. One of the possible solutions to overcome the poor IAQ problem is the utilisation of indoor botanical to improve the IAQ. The phytoremediation of botanical is an affordable and environmentally friendly approach to purify the polluted indoor air. Although there is no established recommendation for determining the best indoor botanical in improving the IAQ, many studies have revealed the ability of specific indoor botanicals to remove pollutants/ contaminants. These systems can use substrates containing a scale of activated carbon and a range of other materials to assist with pollutant filtration or substrate microbial up growth. According to the review, Golden Pothos is the most common indoor plant because it can reduce most common indoor air pollutant and its efficiency is better than other indoor plants. This paper presents the bibliometric analysis and short review based on 79 publications issued in 2011 – 2021. Indoor Air was identified as one of the top productive journals for this research topic.

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1 Introduction

Nowadays, people spend about 85 % - 90 % of their time staying indoors [1]. A recent study has proven that indoor air quality (IAQ) is usually worse than outdoor air quality [2]. The poor IAQ scenario should be prevented as there is a positive correlation between the IAQ and the public's health risk [3]. Indoor

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environments are made up of a mix of outdoor pollutants commonly associated with vehicular traffic and industrial activities, which can enter through infiltrations and/or natural and mechanical ventilation systems, as well as indoor contaminants that come from combustion sources (such as burning fuels, coal, and wood; tobacco products; and candles), emissions from building materials and furnishings, central heating and cooling systems, and other sources (i.e., smoking, painting, etc.). Gases (e.g., carbon monoxide, ozone, radon), volatile organic compounds (VOCs), particulate matter (PM) and fibres, organic and inorganic pollutants, and biological particles such as bacteria, fungi, and pollen could impose significant impacts on IAQ [4].

Hence, using plants in indoor spaces for phytoremediation as mitigation of IAQ has grabbed the society's interest and grown in popularity. Phytoremediation refers to the treatment of air using green plants that remove, degrade, or stabilise undesirable substances and pollutants. Appropriate plants or botanicals were used to improve the IAQ via botanical biofiltration [3]. In an actual situation, the poor IAQ comprises numerous pollutants and contaminants [5,6]. Therefore, utilising the phytoremediation approach to remove pollutants and contaminants requires properly designed research planning [7].

Botanical filtration is a mixture of biological filtration and phytoremediation. The polluted air will actively pass through the area with high biological activity. In this area, the pollutants will be neutralised by the biological process [8]. The combined application of biotechnology, environmental engineering and horticultural science has led to the growth of botanical air filters, as a promising avenue of research for the bioremediation of indoor air. Natural bioagents (plants and/or microorganisms) work as a system to remove pollutants from the atmosphere through photosynthesis. The pollutants contribute energy, carbon and other nutritional sources for the bioagents or are otherwise absorbed into or adsorbed onto the biological materials. In addition, these systems can use substrates containing a scale of activated carbon and a range of other materials to assist with pollutant filtration or substrate microbial up growth. Biological filters can effectively filter and degrade volatile organic compounds (VOC) in indoor air, indicating that they can reduce the exposure of residents to pollutants [9]. Apart from botanical biofiltration, the air conditioning unit is commonly used to improve the IAQ in indoor environments. However, this approach has some underlying disadvantages, such as the withdrawal of outdoor air might contain pollutants [8]. Consequently, the air supplied into the indoor environment is also contaminated. Also, the use of air conditioning units will increase energy consumption and potentially enhance the greenhouse effect [10]. On the contrary, placing an appropriate small-scale botanical indoor air biofilter could promote the detoxification of organic compounds [8].

Therefore, all these shreds of evidence justified the importance of botanical in improving the IAQ in an indoor environment. This objective of this paper is to reveal the research hotspots in BIAB related field and propose some recommendation for future exploration. In addition, this paper also helps researchers to identify their potential collaborative partners in advancing the field of interest.

2 Methodology

The typical databases for scholarly articles include WoS, Scopus, Google Scholar, etc [11]. Among these, WoS and Scopus are commonly used to search and retrieve indexed publications. The present study utilised the WoS database to explore and filter the related articles. The search was performed on June 30, 2021. An advanced searching method has been performed through WoS by using the following search string: TS = (("indoor plants*" OR "indoor plant*" OR "indoor botanical*" OR "indoor botanical plant*" OR "indoor botanical plants*" OR "biofiltration*" OR "phytoremediation*" OR "botany*" OR "biotechnology*") AND ("air quality*" OR "indoor air*" OR "airflow*" OR "indoor air quality*" OR "indoor airflow*"OR “indoor environment*"OR "sick building syndrome*")). As shown in the search string, the function of the asterisk placed behind keywords was to expand the search. The search string retrieved the articles published between 2011 and 2021, demanding a combination of terms in titles, abstracts, or keywords. The search has returned 278 results, including research articles, proceeding papers, review articles, book chapters, early access, editorial materials, and meeting abstracts. However, the present study only considered research articles, review articles, and conference proceedings from a total of 276 publications. Since the keywords in the designed search string are directly related to the research area, but not all of them are closely related to this specific topic, therefore criteria 2 needed to be filtered manually. Based on further filtration, only 79 publications are highly related to “indoor air quality" and "indoor plant" and were used for subsequent analysis. The search strategy and the number of publications remaining after each stage are shown in Fig. 1. The data of selected publications downloaded from WoS include information (file type, title, abstract, keywords, citations) and author (name, organisations) to import all data into Microsoft Excel file for further analysis.

VoSViewer is a software developed by van Eck and Waltman [12] to construct bibliometric maps based on the data. It also provides text mining functions that can be used to visualise the important terms extracted from the scientific literature, as well as to show the comparability between different objects [11]. Examples of the objects are journals, citations, authors, organisations, countries, keywords, sources, and other information of publications extracted from the database. In addition, VoSViewer can display the results in multiple clusters, and these clusters are grouped according to their connectivity in the network [13]. This study utilised the WoS to extract the bibliometric information to ease analysing the funding sources, countries, organisations, authors and keywords.

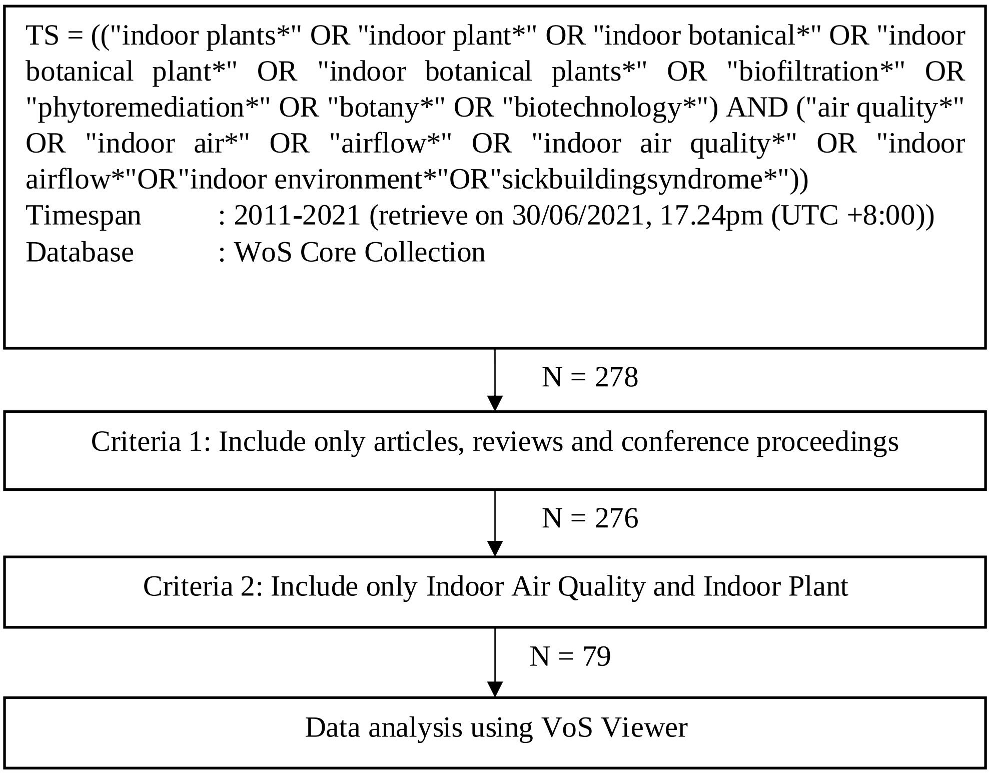

Fig. 1 Searching strategy used in this study to retrieve the relevant publications for bibliometric analysis (N denotes the number of publications that remained after each stage)

2.1 Bibliometric analysis

2.1.1 General publication trends

A total of 278 publications related to small-scale botanical in enhancing indoor air quality were available from 2011 to 2020. The breakdown number of the publications are 218 articles (78.98%), 35 proceedings papers (12.68%) and 28 reviews (10.14%). These numbers of publications reflect a significant impact of the subject field on the global scientific community. Among the publications, 268 (97.10%) were written in English, while the other languages used included Korean (1.08%), Chinese (0.72%), Spanish (0.72%) and Polish (0.36%).

Many indoor environments had been explored by researchers, i.e., lecture hall, office, home, etc. For example, South Korean researchers conducted experiments by placing indoor plants in classrooms of two elementary schools in Seoul from June 27 to October 7, 2016 [14]. Australian researchers had conducted a field study under fifty-five realistic office conditions within two buildings in Sydney's central business district in September 2013 [15]. In recent years, Australian researchers experimented on four green walls planted with different plant species commonly used for vertical indoor greening in a school environment [16].

The co-citation network map of these journals is shown in Fig. 2. It shows the nodes linking with lines represented the relationship of journal co-citation. The size of the node is related to the total connection strength of the journal, and the thickness of the line is proportional to the co-citation strength of the two linked journals. A strong co-citation relationship has been observed between Environment Science Technology, Indoor Air and Atmosphere Environment. In contrast, Environment Science and Pollutant is one of the highly cited journals. In Fig. 2, the journal is categorised into four clusters. Each cluster owns a distinct colour, which is Cluster 1 (red), Cluster 2 (green), Cluster 3 (blue), Cluster 4 (yellow) and Cluster 5 (purple). Since environmental pollution of indoor air quality is an emerging field of research, the journals in Cluster 1 either mainly focus on this topic or open access (OA). In contrast, the journals in Cluster 2 and 3 cover a wider variety of environmental issues while indoor air quality research is one of the subsets of accepted publications. Finally, Environmental Microbiology in Cluster 4 and 5 show a weaker connection with the other journal.

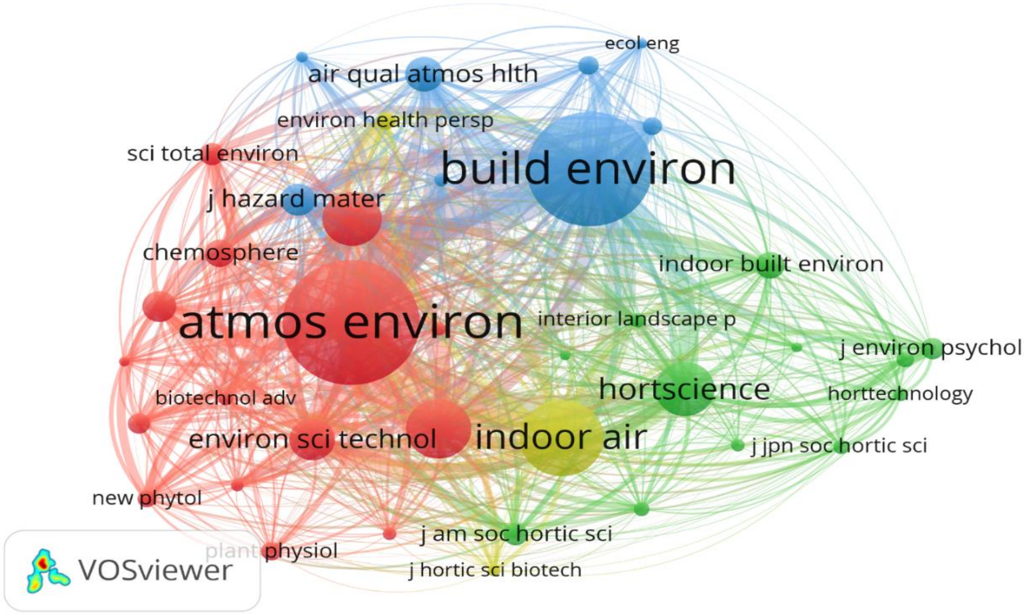

Fig. 2 Co-citation relationship among top productive journals for research on indoor air quality.

2.1.2 Countries/Regions

Within the ten years, 52 countries/regions contributed to the research on small-scale botanical in the indoor. Among the countries, 18 of them have published more than ten publications on this topic. Fig. 3 shows the productive countries that have contributed significantly to this subject area, while Table 1 tabulated the countries and their publications quantity for the decade. The USA is the earliest contributor to this subject area, as shown in its only publication in 1992 [17]. Subsequently, researchers in Australia, China, South Korea, Thailand, Poland, Malaysia and other countries published more articles between 2011 and 2020. This is due to more and more researchers realised the importance of investigating the existence of botanical in the indoor environment. Table 1 and Fig. 3 show that the research on BIAB is primarily promoted by western countries. Nonetheless, it is worth mentioning that Asian countries have rapidly increased productivity in recent years, especially China. China has published more than ten papers between 2017 and 2020, owing to the government who provided grant support for the research teams. However, China received a lower amount of citations (427) compared with the USA (2006) and Australia (1414), which have a long history in the field of research.

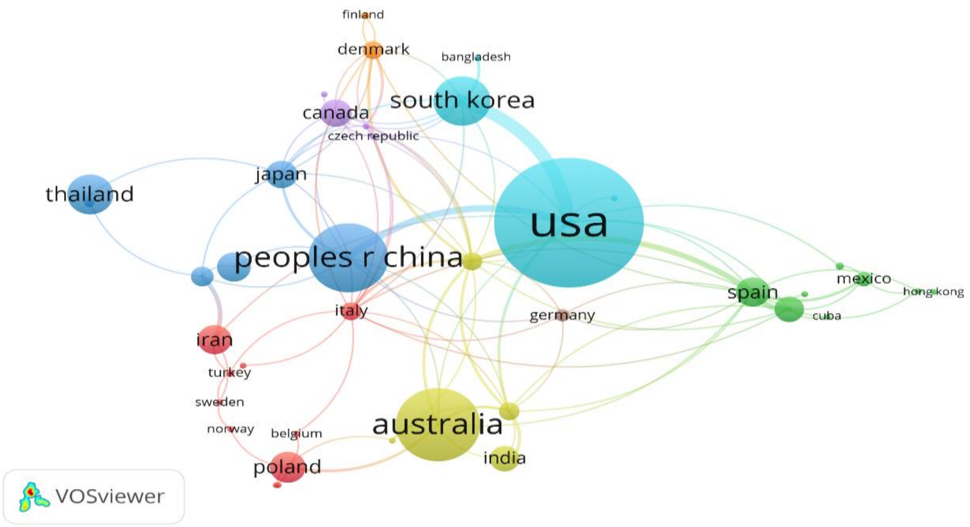

Fig. 3 Overlay visualisations of co-authorship network among countries in research on botanical in the indoor environment (minimum number of publications:1, the minimum number of citations:1, node size denotes total link strength).

Table 1 Top productive countries/regions on botanical research in the indoor environment.

Countries/ Regions	TP	%TP	Years										TC
			2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
USA	71	19.24	7	6	3	2	5	0	3	5	4	6	2006
AUSTRALIA	40	10.84	0	0	2	3	0	1	4	8	9	3	1414
CHINA	38	10.29	3	4	1	1	3	0	3	3	8	6	427
SOUTH KOREA	27	7.31	2	2	1	2	4	2	0	1	0	4	849
THAILAND	22	5.96	1	1	1	2	1	5	1	2	4	3	378
POLAND	17	4.60	1	0	0	0	4	2	1	0	5	3	494
IRAN	16	4.33	0	3	2	0	1	2	0	4	1	3	145
SPAIN	16	4.33	0	1	1	4	0	1	2	3	1	1	381
TAIWAN	16	4.33	2	1	2	1	1	0	1	0	3	3	53
CANADA	15	4.06	1	1	1	1	0	1	1	0	1	0	834
JAPAN	15	4.06	1	2	1	1	1	1	2	1	2	1	615
FRANCE	14	3.79	1	3	0	1	0	1	2	1	1	0	296
INDIA	14	3.79	0	1	0	0	0	1	1	3	3	4	33
MALAYSIA	11	2.98	0	0	2	0	0	3	3	0	1	2	60

2.1.3 Organisations

The publications of small-scale botanical in the indoor environment are contributed by 459 organisations. Among these, only 103 of them (27.91%) have contributed to more than one publication. Table 2 tabulates the prolific organisations that have published more than six papers. There are 21 papers published by University of Technology Sydney between 2017 and 2020, and a total number of 825 citations were recorded. Notably, the University of Technology Sydney is considered the most important organisations dedicated to this field of research in recent years. Fig. 4 shows the co-authoring linking among organisation cooperative networks view that is listed in Table 2.

Fig. 4 Collaboration network at organisation in research on botanical in the indoor environment (minimum number of publications: 2, minimum number of citations: 1, node size denotes total link strength).

Table 2 Top productive organisations on the finding of botanical in the indoor environment.

Organisations	Countries	TP	%TP	Years								TC
				2013	2014	2015	2016	2017	2018	2019	2020	
University of Technology Sydney	Australia	30	8.13	2	1	0	0	4	8	7	2	825
King Mongkuts University of Technology Thonburi	Thailand	19	5.14	1	2	1	5	1	2	3	3	326
Rural Development Administration RDA	South Korea	15	4.06	1	2	2	2	0	1	0	2	177
National Institute of Horticultural Herbal Science	South Korea	13	3.52	1	1	2	2	0	1	0	2	283
University of Georgia	USA	11	2.98	1	1	1	0	0	0	0	1	277
University System of Georgia	USA	11	2.98	1	1	1	0	0	0	0	1	581

2.1.4 Authors

A total of 1135 researchers investigated the impact of botanical on the IAQ in the indoor environment. However, only 167 (14.71%) have published more than one publication. Table 3 shows the authors who have published more than nine articles, while Fig. 5 shows the co-author network established for research on this topic. So far, Peter J. Irga has published 20 articles and those articles have been cited 365 times. He is the most prolific researcher and has made significant contributions to the research of botanical in improving the IAQ in the indoor environment. Paitip Thiravetyan is also one of the most prolific authors listed in Table 3. The author collaborated with several researchers to study the air absorption of toluene and ethylbenzene using 12 different plants [18]. He also investigated the effect of Zamioculcas Zamiifolia in enhancing the toluene and formaldehyde removal [19].

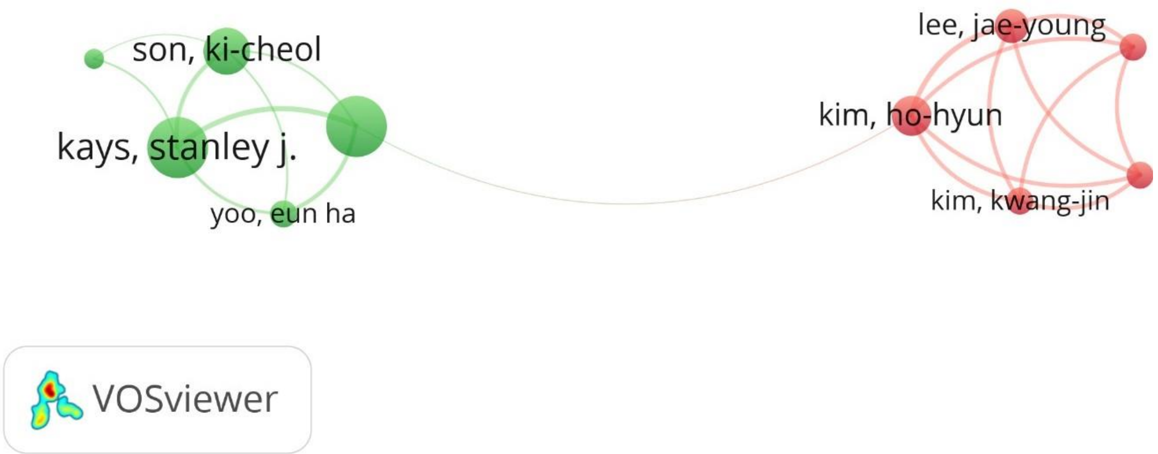

Fig. 5 Overlay visualisation of the co-authorship network visualisation for authors in research on botanical in the indoor environment (minimum number of publications: 3, the minimum number of citations: 1, node size denotes total link strength) (need to zoom in and set to 1000dpi).

Table 3 Top productive authors on effects of botanical in the indoor environment.

Authors	Countries	TP	%TP	Years								TC
				2013	2014	2015	2016	2017	2018	2019	2020	
Irga Peter J	Australia	20	5.42	2	1	0	0	4	4	7	2	365
Torpy FR	Australia	20	5.42	2	1	0	0	4	4	7	2	365
Thiravetyan P	Thailand	19	5.14	1	2	1	5	1	2	3	3	322
Kim KJ	South Korea	14	3.79	1	1	2	2	0	1	0	2	137
Treesubsuntorn C	Thailand	12	3.25	0	0	0	3	1	2	2	3	164
Kays SJ	USA	10	2.71	1	1	1	0	0	0	0	1	262
Pettit T	Australia	8	2.16	0	0	0	0	1	2	4	1	142
Burchett MD	Australia	7	1.89	2	1	0	0	0	0	0	0	150

2.1.5 Keywords

Checking keywords in any literature is crucial to revealing possible research hotspots. A total of 987 author keywords in the subject area can be extracted by using Vos Viewer. As shown in Fig. 6, the term “phytoremediation” is the most important keyword, with 98 link strength. Next, “indoor air quality” (total link strength of 68) and “biofiltration” (total link strength of 59) only differ with a slight variation of 9 link strengths. Those keywords in Fig. 6 can be divided into five categories (hence five research topics), as depicted by their respective colours. As shown in Fig. 6, “phytoremediation” is the central node of Cluster 1 (red) and followed by “indoor air quality”. These are the two major topics of researchers, mainly focusing on the most common contaminants detected in the indoor air. In an earlier study, the University of Technology Sydney represented the indoor potted plant system as a comprehensive biological filter to remove benzene and n-hexane [9].

These outcomes led many other researchers to develop experimental works to reduce indoor air pollutants. As mentioned above, these findings are initiated by cluster 1 and ultimately lead to the development of Cluster 2 (blue). Cluster 2 represented the research on indoor plant biofiltration and its effectiveness in the elimination of indoor air pollutants. Therefore, “Biofiltration” is the largest node in this cluster. The third cluster (green) represents the latest advancement of indoor air quality issues, an extended topic of air pollutants in the indoor environment, as shown in Fig. 6.

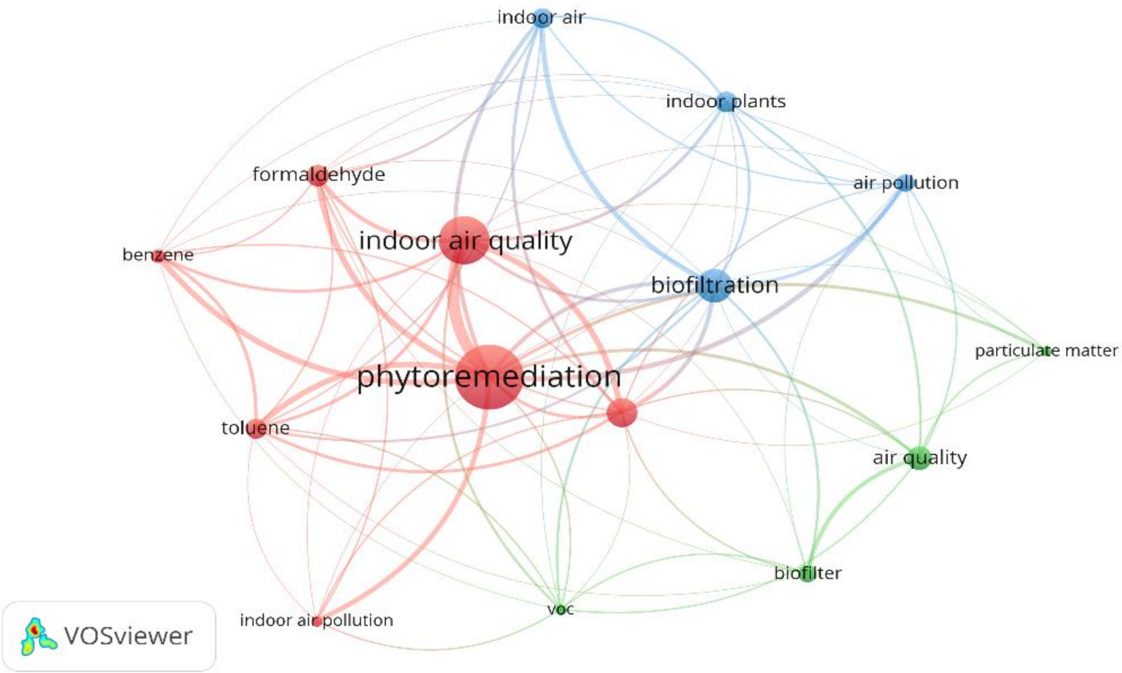

Fig. 6 Overlay of the keyword co-occurrence network for research on botanical in the indoor environment (minimum number of occurence:10, node size denotes total link strength).

2.2 Overview of Small-Scale Botanical

Botanical filtration has the potential to become an effective and sustainable approach to improve IAQ in the indoor environment [20]. The botanical filtration is described as a biological-based treatment method suitable for removing air pollutants and contaminants. The removal efficiency, however, depends heavily on the botanical types [2]. The previous studies revealed that most small-scale botanicals could reduce air pollutants that are commonly found in indoor environments, i.e. particulate matter, benzene, toluene, ethylbenzene, xylene, etc. [21]. Table 4 shows an overview of the efficiency of various botanicals in reducing pollutants and contaminants in the indoor environment.

Table 4 Summary of the efficiency of various botanical in reducing the pollutants and contaminants.

Plant Species	Substrate	Size of Pots	Pollutants/ Contaminants	Concentration		Efficiency	Author
				Initial	Final		
Dumb Cane	• Potting soil + clay + FE, Co Gramoflor	50(L) x 60(W) x 80(H)	a. Toluene, b. 2-ethylhexanol	a. 5.5uL b. 20mg	a. 2.2uL b. 8mg	Reduce: 60%	Hörmann et al. [22]
Peace Lily	• Potting soil + clay + FE, Co Gramoflor	50(L) x 60(W) x 80(H)	a. Toluene, b. 2-ethylhexanol	a. 4.2uL b. 14.6mg	a. 3.15uL b. 10.95mg	Reduce: 15%	
Vingersboom	• Bark:humus:sand (5:1:1)	19 cm diameter; 2.2 L in volume	a. Toluene b. Xylene	a.62. 3 µg.m b. 49. 4µg.m	a. 13. 3 µg .m b. 7. 0 µg .m	Reduce: a. 78.7% b. 85.8%	Kim et al. [23]
Banyan	• Bark:humus:sand (5:1:1)	19 cm diameter; 2.2 L in volume	a. Toluene b. Xylene	a. 50. 1µg.m b. 43. 0µg.m	a. 13 µg .m b. 7.3 µg .m	Reduce: a.74% b. 83%	
English Ivy	Sterilised media	90(L) x 50(W) x 50(H)	a. Formaldehyde b. CO2	a. 5ppm b. 750ppm	a. 0ppm b. 550ppm	Reduce: a.100% b.26.7%	Lin et al. [24]
Spider Plant	Roots wrapped in tissue paper and aluminum foil (130 cm2)	15.6 Liter	Benzene	500ppm	343.85ppm	Reduce: 31.23%	Setsungnern et al. [25]
Golden Pothos	Polyethylene Module with 9 holes (0.05m3(38 x 38 x 34cm))	0.6(L) x 0.6(W) x 0.6(H)m; 216L	a. TSP b. PM2.5 c. PM10	150L.s-1	a. 27L.s-1 b. 37. 20L.s-1 c. 42. 12.s-1	Reduce: a. 85% b. 75.2% c. 71.9%	Ibrahim et al. [26]
Parlor Palm	Loamy soil	84(L)x 62(W)x 72(H) cm	Formaldehyde	16.4 mg	1.47mg	Reduce: 91.1%	Teiri et al. [27]

	(30% sand, 30%slit, 15%clay and 25%humus)						
Boston Fern	A mixture of coconut fibre and peat into pockets of Fytotextile modules	80(L)x 40(W)x 40(H) cm	n-hexane	7.51mg, 70ul	5.69mg, 50 ul	Reduce: 76%	Suárez et al. [8]
American evergreen	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	29.04–30.36 µmol/m2/h	Reduce: 82%-83%	Sriprapat and Thiravetyan [28]
Viper's Bowstring Hemp	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	26.82–29.58 µmol/m2/h	Reduce: 82.6%-84%	
Christplant	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	27.66–27.94 µmol/m2/h	Reduce: 83.6%-83.8%	
Spider Plant	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	27.55–28.25 µmol/m2/h	Reduce: 83%-83.8%	
Golden Pothos	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	26.79–27.41 µmol/m2/h	Reduce: 83.9%-84.4%	
English Ivy	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	25.26–25.54 µmol/m2/h	Reduce: 85%-85.2%	
Dracaena	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	25.26–25.54 µmol/m2/h	Reduce: 85%-85.2%	
Butterfly Pea	MS medium supplemented with Gamborg vitamin	120 mL glass serum bottles	Benzene	170 µg	24.30–26.30 µmol/m2/h	Reduce: 84.5%-85.7%	
Areca Palm	Containing soil, sand and well decomposed Farm Yard Manure (1:1:1)	30(L) x 30(W)x 20(H) cm	a. TVOCs b. CO2 c. CO	a. 3000ppb b. 800ppm c. 0.6 ppm	a. 1000ppb b. 500ppm c. 0.1ppm	Reduce: a. 67% b. 37.5% c. 83%	Bhargava, B. [29]
Bird nest fern	mixed medium of peat, composting bark, cane-bagasse, paddy, and others	10(L)x 10(W)x 7.6(H) cm	a. CO2 b. HCHO	a. 2000ppm b. 2ppm	a. 800ppm b. 0.1ppm	Reduce: a. 60% b. 95%	Ying-Ming Su,Chia-Hui Lin [30]
ZZ plant	200 g of soil (pH 6.5–7.0, cation exchange capacity of 23.4 cmol mg kg−1, and 64% organic matter)	10(L)x 10(W)x 10(H) cm	a. toluene b. formaldehyde	a. 200ppm b. 200ppm	a. 0.5ppm b. 0.5ppm	Reduce: a. 99.75% b. 99.75%	Ullah [31]
Snake Plant	200 g of soil (pH 6.5–7.0, cation exchange capacity of 23.4 cmol mg kg−1, and 64% organic matter)	10(L)x 10(W)x 10(H) cm	a. toluene b. formaldehyde	a. 200ppm b. 200ppm	a. 0.5ppm b. 0.5ppm	Reduce: a. 99.75% b. 99.75%	
Peace Lily	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	2200ppm	361.2ppm	Reduce: 83.8%	N H Hashim et al. [32]
Dumb Cane	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	2200ppm	216.5ppm	Reduce: 90.2%	
Ficus tree	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	2200ppm	407.6ppm	Reduce: 81.5%	
Janet Craig	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	1200ppm	13.6mg	Reduce: 98.87%	
Golden Pothos	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	454ppm	28.33ppm	Reduce: 93.76%	
Arrowhead Plant	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	454ppm	19ppm	Reduce: 95.8%	
Prayer Plant	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	1010ppm	154.6ppm	Reduce: 84.7%	
Kadaka fern	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO2	458.67ppm	21.34ppm	Reduce: 95.3%	
Anthurium	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	452ppm	5ppm	Reduce: 98.9%	
Parlor Palm	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	1200ppm	118mg	Reduce: 90.2%	
Areca Palm	Garden Soil, Compost and Perlite (2:2:1)	70(L)x 70(W)x 70(H) cm	CO_2	1200ppm	139mg	Reduce: 88.5%	

2.3 Types of small-scale botanical

2.3.1 Dumb Cane

Dumb Cane, or scientifically known as *Dieffenbachia maculata*, belongs to the Araceae family [33]. Araceae family, or commonly known as Ariods, has 114 genera and 3,750 recognised species. A large number of genera are important plants for decoration, especially in the foliage plant industry. Some genera are produced for edible roots or used as medicinal plants, while others are aquatic plants. Traditionally, Aroids are reproduced by cutting, splitting, rhizomes or tubers [34]. Aroids are found in tropical America, with the shady moist condition (relative humidity of 60 % - 70%), and humid tropical lowlands in the United States, Brazil and North to West Indies or India [33].

Dumb Cane has two types of calcium oxalate crystals (dust and insecticide). A chemical survey shows it contains a proteolytic enzyme that is poisonous. When leaf extract plant-skin contact occurs, it may cause itching, swelling, salivation and loss of speech potential for about two days [33]. It often leads to accidental intake and exposure. Its most common impact occurs among children and uncareful adults who misjudge Dumb Cane stem as sugar cane [35]. Dumb Cane is usually placed indoors, such as home, office and others. It is praised for its attractive variegated leaves, tolerance to the internal environment and ease of production. In addition, the space requirement for Dumb Cane was not demanding. The favourite conditions for a Dumb Cane consist of air temperature of 20 °C to 25 °C, relative humidity of 60 to 70% and light intensity of 20000Lux [22,32]. Fig. 7 shows different types of biobox used in different studies.

Fig. 7 Small-scale botanical test rig using the dumb cane for air purifying (Retrieved from Hörmann, Brenske and Ulrichs [22]).

2.3.2 Peace Lily

Peace Lily, or scientifically known as ***Spathiphyllum wallisii,*** is a genus of the Araceae family. Peace lilies originated in the dense rain forests of tropical America and Southeast Asia [36]. The peace lily family members are popular plants worldwide because of its dark green leaves, long-lasting showy white flowers, and shade tolerance. In China, the peace lily is also known as "successful wind, " indicating that the life journey will go smoothly [37]. Peace Lily is a popular indoor plant, and it is obtained from a foliage plant grower in Korea [38]. Peace lily is a herbaceous, commercially important ornamental plant, which is characterised by greening its initial white stalks in the post-flowering period and developing its fruits [39]. The Peace Lily should be nurtured in the environmental conditions with a temperature of 20 °C to 22 °C, relative humidity of 60 to 70% and light intensity of 20000Lux. Fig. 8 shows a picture of Peace Lily, while Fig.s 9 and 10 demonstrate different types of biobox that are used in various studies.

Fig. 8 Digital image of Peace Lily [40].

Fig. 9 Small-scale botanical test rig using the peace lily for improving IAQ (Retrieved from Hörmann, Brenske and Ulrichs [22]).

Fig. 10 Test rig setup by Hashim, Teh and Rosli [32] to study the effects of potted plant on the CO_2 reduction.

2.3.3 Golden Pothos

Golden Pothos, or scientifically known as *Epipremnum Aureum*, is a member of Araceae family [41]. Golden Pothos is a foliage plant (plant that grows mainly on leaves), and it was obtained from the commercial market in Korea for experimentation [42]. This plant is native to Southeastern Asia and New Guinea [43]. Golden Pothos is a high-altitude and vascular plant with vascular tissue through allocated resources [44]. It can withstand environmental pressure and survive for some time in the area of interest. However, it should have sufficient sensitivity to deal with suspected pollutants (e.g. VOC's, CO_2, TSP, $PM_{2.5}$, PM_{10}) [45]. It can remove air pollution and withstand high temperature and humidity, including pests, therefore favoured as an indoor decorative plant [46]. Golden Pothos can be grown in water-filled containers without soil. It outperformed other hydroponic plants by growing without any added nutrients (e.g. carbohydrate) [45]. Golden Pothos grows well in the combined conditions with a light intensity of 300 Lux, temperature of 22 to 27°C and relative humidity of 50-70%. A digital image of Golden Pothos is presented in Fig. 11.

Fig. 11 Digital image of Golden Pothos (Retrieved from Aydogan, Usman, Peck, Jung, Li and Biddinger [45]).

2.3.4 Vingersboom

Vingersboom**,** scientifically known as *Schefflera Actinophylla*, is an evergreen tree in the Araliaceae family. It is native to tropical rainforest and gallery forests in Australia, New Guinea and Java [47]. Araliaceae family is one of the most prominent families in the plant kingdom, which includes 43 genera and 1,400 species, and is widely used in traditional and modern phytotherapy [48]. The Araliaceae family is rich in secondary metabolites, such as triterpenes, triterpene saponins, sterols, diterpenes, cerebrosides, and acetylenic lipids have anti-proliferation, anti-inflammatory, anti-parasitic, anti-diabetic and many biological activities related to the nerve and cardiovascular system [49]. Species in the Araliaceae family represent perennial shrubs with a longer reproductive life, is characterised by the production of new flowering [50] and vegetative buds every year and are usually planted in Southeast Asia and the Pacific [48]. Vingersboom is commonly grown as a decorative tree in gardens in China regions with mild to warm climates. The adult plant has bright red flowers in inflorescences with up to 20 racemes that develop in summer or early autumn [51]. A light intensity of 946 to 1156Lux, the temperature of 21 to 25°C and relative humidity of 35 to 45% encourage the growth of Vingersboom. A digital image of Vingersboom and a small-scale study are shown in Fig. 12 and Fig. 13, respectively.

Fig. 12 Digital image of Vingersboom (Retrieved from Compendium [52]).

2.3.5 English Ivy

English Ivy, scientifically known as Hedera Helix, is a rich, evergreen climbing vine widely available in Europe and most parts of West Asia. The main feature of its phenotype is the difference in morphology and growth habits between juvenile and adult stages. Phenotype means the observable characteristics or traits of a disease. Usually, young plant stems will initially grow into pro-shaped, oblique branches on the ground, and this stage can sustain a long time [53]. In some cases, the possibility of ivy growing on the masonry and causing damage is beyond doubt. For historical buildings, the enormous damage is related to the stem growth with existing defects (i.e. holes, cracks, mortar deterioration, etc.), where very thick stems grow under the wall foundation and plants produce "true" in the roots. Although these destructive effects do not always occur, ivy has gained a wide reputation as a considerable nuisance to historic buildings and those responsible for their management and protection. Active measures are often taken to prevent ivy from growing wild. Whenever ivy is discovered, it is usually decided to eradicate it [53]. In recent years, there has been an increasing interest in bioactive molecules from the leaves of English ivy. Early studies analysed the antifungal and antibacterial activities of English ivy saponins (any of various mostly toxic glucosides that occur in plants (such as soapwort or soapbark) and are characterised by the property of producing a soapy lather). Other findings reported the anti-inflammatory and anti-aging properties of active compounds from English ivy. In addition, studies have shown that d-rhamnose-β-hederin (DRβ-H) from the Asian plant Clematis has a pro-apoptotic effect on breast cancer cells [54]. The favourite conditions for English Ivy comprised the light intensity of 1200Lux, the surrounding temperature of 22 to 26 °C and relative humidity of 40 to 60%. An English Ivy plant in a small-scale test rig is demonstrated in Fig. 14.

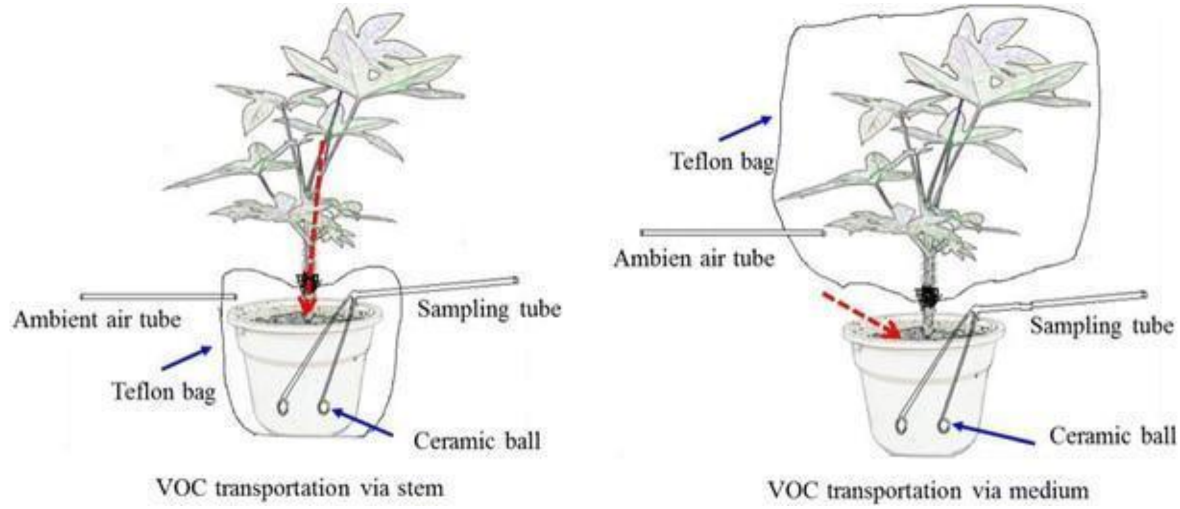

Fig. 13 Parametric study on VOC using the Vingersboom (Retrieved from Kim, Kim, Khalekuzzaman, Yoo, Jung and Jang [23]).

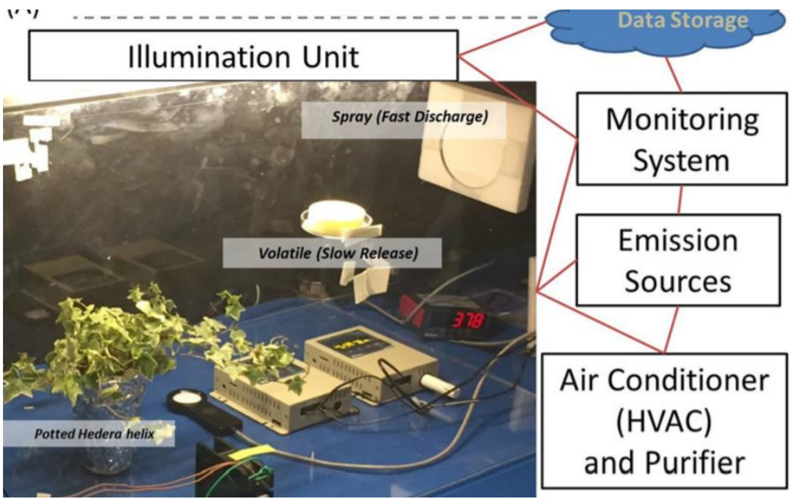

Fig. 14 Test rig using the botanical of Hedera Helix to purify the contaminated air (Retrieved from Lin, Chen and Chuah [24]).

2.3.7 Spider Plant

Spider Plant, scientifically known as *Chlorophytum Comosum*, is an evergreen horticultural plant native to southern Africa and belongs to the Asparagus family [55]. Asparagus family is an important economic crop, rich in nutrients and conducive to solving ecological and environmental problems. Plants may benefit from endophytic bacteria associated with roots. However, the composition of the endophytic bacterial community associated with asparagus roots is challenging to elucidate [56]. Spider Plant is characterised by high biomass yield, easy cultivation, intense competitiveness, and wide geographical distribution [55]. Due to the easy cultivation of the Spider plant, it became one of the most popular indoor plants. It can purify indoor air by absorbing carbon monoxide, formaldehyde, xylene and many other harmful gases. In addition, these plants are non-toxic and safe for pets and children [57]. A Spider plant can survive in the ideal conditions with the light intensity of 2000 to 4000Lux, the temperature of 24 to 26 °C and air humidity: 40 to 60%. A digital image of the Spider plant is shown in Fig. 15.

Fig. 15 Digital image of Spider Plant (Retrieved from Shamsuri, Leman, Hariri, Rahman, Yusof and Afandi [58]).

2.3.8 Parlor Palm

Parlor Palm, scientifically known as *Chamaedorea Elegans*, is a species from the tropical rainforest region of south-eastern Mexico and parts of Central America [59]. Parlor Palm belongs to the Aceraceae family. Its extraordinary tolerance under low light conditions and low water requirements enable it to become a common indoor plant [60]. Among the most commercialised tropical fronds belong to the genus Parlor Palm, which includes more than 105 species. The trade names assigned to different species are clear to the industries that constantly deal with them. The deep green Parlor Palm leaves have multiple uses and enhance the beauty of flower arrangements, bouquets and other decorations, making them look fresh and exotic [61]. In Mexico, the leaves belonging to Parlor Palm are the most commercialised. There are about 11 common names in the local area to distinguish and highlight the physical characteristics of its commercial use, especially for those international florists who regard camedor palm leaves in tropical forests as the most representative leaves in these areas [62]. The recommended climate conditions for this tropical plant would be a temperature of 29.31 to 30.53 °C, relative humidity of 40 to 80% and light intensity of 1928.6 Lux. A digital image of Parlor Palm and a small-scale botanical test rig are displayed in Fig. 16 and Fig. 17, accordingly.

Fig. 16 Digital image of Parlor Palm (Retrieved from Jansen, Zuidema, van Ast, Bongers, Malosetti, Martínez-Ramos, Núñez-Farfán and Anten [63]).

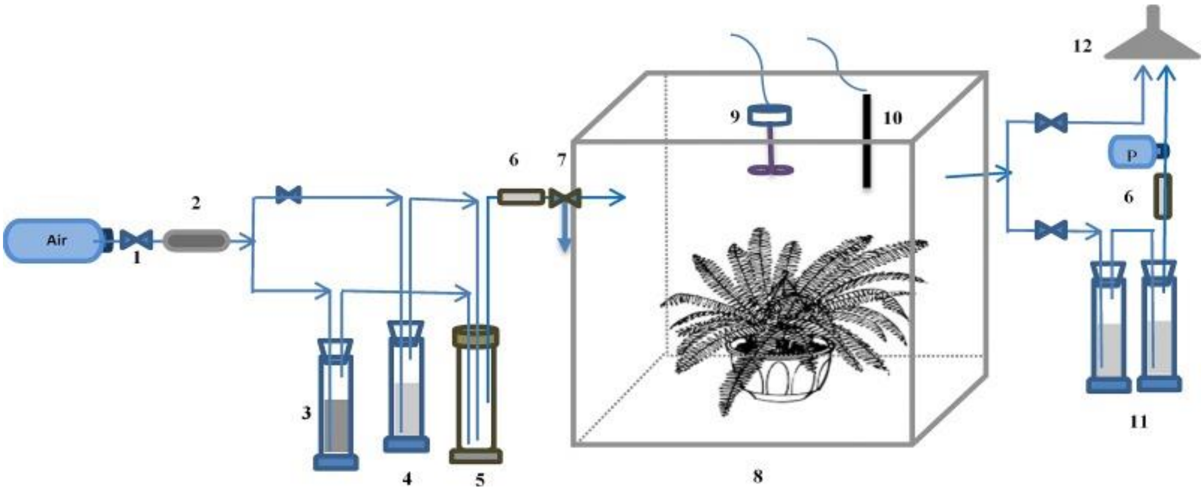

Fig. 17 Small-scale botanical test rig for air purifying research using Parlor Palm (Retrieved from Teiri, Hajizadeh, Samaei, Pourzamani and Mohammadi [60]).

2.3.9 Boston Fern

Boston Fern, scientifically known as *Nephrolepis exaltata*, is a species that normally present in East Asia and Oceania [64]. It is tolerant to dry conditions and easy to reproduce. Hence, it is a very popular ornamental plant, usually can be found in hanging baskets. [65]. Its moderate size and maximum leaf length of 30 cm make this dwarf fern ideal for smaller pot sizes and arrangements [66]. Boston fern is a fast and uniform grower of the Nepenthes family [66]. Nepenthes is the only genus of the Nepenthes family and one of the largest carnivorous plants. It is widely distributed in the Malay Islands, especially in Borneo, the Philippines and Sumatra. Up to date, 151 species have been discovered, most of which exhibit a high degree of endemism, usually limited to a single area [67]. Boston Fern was employed to remove copper from aqueous solutions to replace traditional treatments [65]. In late 1970, most people used tissue culture liners as their Boston Fern resource, with fewer disease problems and a more uniform growth rate than rooted rhizomes removed from anvil bed [68]. The proper environmental condition for Boston Fern comprised light Intensity of 946-1156Lux, the surrounding temperature of 21 to 25°C and relative humidity of 35 to 45%. A complete set of small-scale botanical test rig setup is demonstrated in Fig. 18.

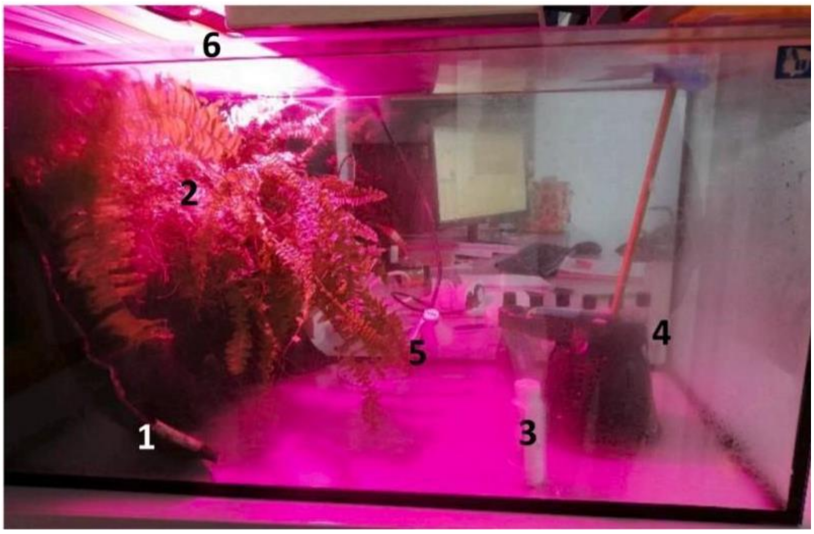

Fig. 18 The botanical test rig setup consists of: (1) Fytotextile; (2) Boston Fern; (3) Temperature sensor; (4) TVOCs sensor; (5) Portable Fan; and (6) Grow Lamp (Retrieved from Suárez-Cáceres, Fernández-Cañero, Fernández-Espinosa, Rossini-Oliva, Franco-Salas and Pérez-Urrestarazu [8]).

2.3.10 American Evergreen

American Evergreen, scientifically known as *Syngonium Podophyllum*, is a member of the Araceae family [69]. It is an evergreen climbing plant found in humid tropical forests and disturbed areas in Mexico and other countries in Central and South America. The stems are 10 to 20 meters long and support plants on the trunk by adventitious roots. Its leaves change significantly as plants age. They have the shape of arrows when they are young, but as they mature, this change will develop into lobes at the roots of the leaves. Therefore, the older the plant, the more the leaves exist [70]. American Evergreen is a popular multi-leaf indoor potted plant. The tissue culture is established mainly through in vitro bud culture [71]. It is similar to Boston Fern, but there are some noticeable differences. For example, both plants are popular ornamental plants and can grow or more in hanging baskets, but both came from different families. Also, American Evergreen leaves will change greatly as plants age, while Boston Fern leaf size will only reach a maximum length of 30 cm, as claimed in the study by *Sivanesan* et al. [66]. An American Evergreen typically grows in conditions with light intensity of 133–328Lux, surrounding temperature of 18 to 22°C and relative humidity of 75 to 85%. A digital image of American Evergreen and its small-scale botanical test are shown in Fig. 19 and Fig. 20, respectively.

Fig. 19 Digital image of American Evergreen (Retrieved from Urrestarazu [72]).

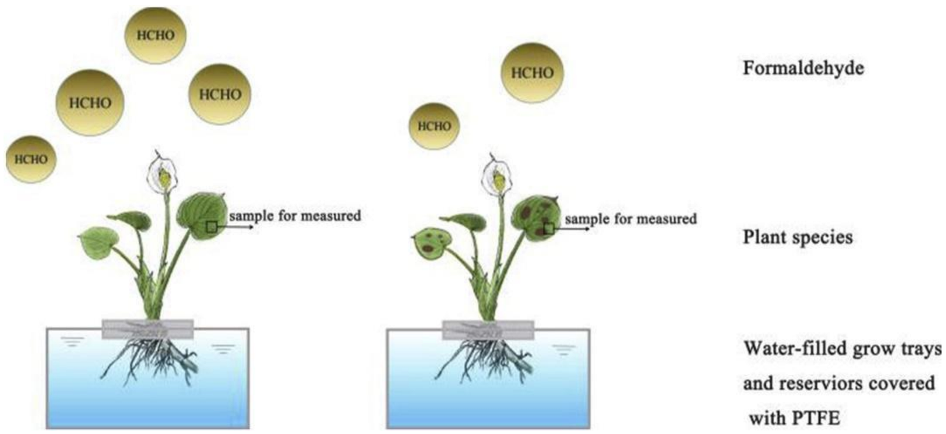

Fig. 20 Test rig of using American Evergreen as the botanical subject for assessing the effect on formaldehyde (Retrieved from Wang, Sheng, Zhang, Xu, Zhang and Zhu [73]).

2.3.11 Snake Plant

Snake Plant, scientifically known as *Sansevieria Trifasciata*, is a popular indoor and outdoor plant worldwide. Other than being an ornamental plant, it is also known as a medical plant. In traditional, certain species has an ethnopharmacological background, therefore would be used as antitussive and expectorant in South America. It was sold as a raw material to relieve cough, snake bite, sprain, bruise, boil, abscess, respiratory inflammation, and hair loss [74]. Biological activities conducted by the Snake Plant involving analgesic, antipyretic, antiallergic, anti-anaphylactic, antidiabetic and thrombolytic activities were listed [75]. Snake plant that belongs to the Agavaceae family is a herbaceous, succulent and perennial plant growing to a height of 90 centimetres. The leaves form a basal rosette, which is flat, thick, leather-like, sword-shaped and variegated off white horizontal markings. The plant is native to India and widely distributed in the Philippines, Malaysia etc. [76]. The ideal environmental conditions for the snake plant include air temperature of 24°C, relative humidity of 40% and light intensity of 1500 Lux. A digital image of the Snake plant and its small-scale botanical test rig is presented in Fig. 21 and Fig. 22, respectively.

Fig. 21 Digital image of Snake Plant [77].

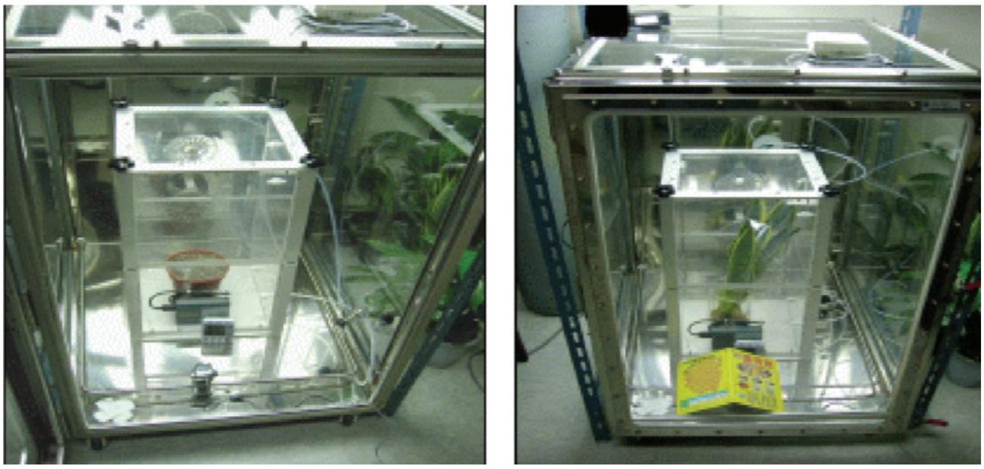

Fig. 22 Small-scale BIAB test rig using *Snake Plant* for air purifying research in Lee et al. study [78].

2.3.12 Chris Plant

Chris plant, scientifically known as *Euphorbiamilii*, is a seasonal bloom [79]. The genus Chris plant includes one of the medicinal plants distributed in tropical regions of Pakistan, India and China [80]. Due to their substantial therapeutic potential, various species of Chris plant are traditionally used as folk medicine to treat various diseases, such as warts, eczema and eradication of intestinal parasites [81]. It is listed as one of the most famous medicinal plants in this category because they have folklore meaning and can be used to treat skin infections, warts, cancer and liver diseases [82]. According to reports, the Christ plant is a Pakistani herb applied to cure various infectious diseases due to its anti-fungal, anti-harm, and molluscicidal properties [80]. In addition, it contains a variety of phytochemicals, such as cycloartenol, amyloid acetate, triterpenes, lupeol acetate, flavonoids and lectin [83]. The optimal conditions for the Chris plant are the light intensity of 4000 to 8000 Lux, a surrounding temperature of 18 to 32°C, relative humidity of 35 to 50%. A digital image of Chris plant is displayed in Fig. 23.

Fig. 23 Digital image of Chris plant (Retrieved from Patt, Tarshis Moreno and Niedz [84]).

2.3.13 Dracaena

Dracaena, scientifically known as *Dracaena Sanderiana*, is a popular indoor plant that can survive in various indoor environments [80]. It is also one of the essential plants to be exported in Southern China [85]. It is an ornamental plant in the Asparagaceae family. It grows in small bushes with slim stems and flexible straps. It is indigenous to Cameroon in tropical West Africa, growing on the ground in the rainforest [86]. It is a small plant with a height of 40 to 50 cm, and it has green lanceolate leaves and white fringe stripes on the erect stem. This plant is regularly found in gardens. The popularity of dracaena can be attributed to its excellent performance and diversification in the indoor environment. Their colourful leaves are enhanced by various leaf variegations modes [87]. The variegated varieties of dracaena are prevalent. However, different environmental factors can change the variegation from strong expression to less noticeable [88]. It usually breeds from short cuts in the water. In South Korea, it is known as lucky bamboo because it is believed to bring happiness and prosperity when they grow in houses. This belief makes it becoming more widespread [89]. In Egypt, lucky bamboo is the most popular indoor factory plant, where it is frequently imported and resold in an attractive basin [90]. A surrounding air temperature of 26.8 to 32.6°C and relative humidity of 57.6 to 60.8% are suitable growing conditions for dracaena. Fig. 24 shows a digital image of adult dracaena.

Fig. 24 Digital image of adult Dracaena (Retrieved from Choi, Lee, Kang, Kim and Kim [86]).

2.3.14 Bird's Nest Fern

Bird's Nest Fern, scientifically known as *Asplenium Nidus*, is a possessed plant that belongs to the Polypodiaceae family. The Polypodiaceae family is one of the largest species of ferns in existence, showing significant morphological and systematic diversity [91]. Most of the species in Polypodiaceae are epiphytes. This family represents one of the most extensive and abundant pantropical vascular epiphytes in tropical and subtropical forests [92]. It is native to tropical rainforests in South East Asia and Africa [93]. The leaves of a Bird's Nest Fern can appear in various shapes: wide and short, narrow and long, or some leaf tips are bifurcated. During the rainy season, some fronds may grow to 150 cm long and a width of 20 cm [94]. Several advantages of Bird's Nest Fern were discovered. It can be used for ornamental plants, potted plants, hanging plants, and can even be installed on plants in garden branches [95]. It also possesses medicinal benefits. In Hawaii, it was convinced that the juice of Bird's Nest Fern and its buds could treat general weakness and oral infection [96]. In some instances, it was found useful to treat chest pain [97]. According to a finding by Benniamin et al. [98], the rootstock of Bird's Nest Fern can fight against fever and elephantiasis. The recommended climate conditions for bird nest fern are light intensity of 512.5 Lux, surrounding air temperature of 21.8 to 23.9 °C, relative humidity of 51 to 61 % The sample of bird nest fern is shown in Fig. 25.

Fig. 25 Digital image of Birds Nest Fern (Retrieved from Pimsuwan, Watcharinrat, Kanchanaphusanon and Suksa-ard [95]).

After comparing the efficiency of the mentioned small-scale botanical in enhancing the IAQ, Golden Pothos is the most popular and effective indoor plant because it can reduce most indoor pollutants and outperform other indoor plants as shown in Table 4, respectively.

3.0 Conclusion

This paper presents the bibliometric analysis and short review of small-scale botanical in enhancing the IAQ in the indoor environment. The bibliometric analysis and short review were performed based on 79 publications through a careful examination and extraction from the WoS database. According to the data analysis, the research publications showed an emerging trend starting from 2017. These publications are mainly research articles, review papers and proceedings papers. Most of the research articles and review papers focus on the small-scale botanical in enhancing IAQ in lecture hall, office, home, patient ward, etc. The short review indicates that Golden Pothos is the most efficient indoor plant because it could reduce most indoor air pollutants and could withstand high temperature and humidity. Besides, it could grow in water-filled containers without soil and nutrients, outperforming than other plants. In this subject field, the Australian Government was the primary funding agency, leading to high productivity in Australia. Meanwhile, the University of Technology Sydney is recognised as the most prolific institution that has contributed significantly to small-scale botanical research in enhancing indoor air quality. At the individual level, Irga PJ and Torpy FR are the top researchers dominant in this research area. Research on small-scale botanical in enhancing IAQ is an emerging interdisciplinary field that requires the support of funding agencies because researchers need to purchase experimental instruments and materials. Some scholars have also contributed to the development of this subject with the least resources. Small-scale botanical findings in the indoor environment of all countries are equally crucial for understanding the benefits beyond human health.

Declaration of Conflict of Interest

The authors declare that is no potential conflict of interest.

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