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Evaluation of the Performance of Ornamental Plants for the Removal of Trimethylamine

Research Article

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Abstract: The study investigated the ability and effectiveness of ornamental plants in purifying indoor air by removing trimethylamine (TMA). To determine the best plant as a TMA removal agent, seven ornamental plant species were selected and placed in sealed fumigation chambers that were exposed to 100 ppm of TMA, and the remaining TMA concentration in their system was analyzed by gas chromatography (GC). The result showed that all seven ornamental plants effectively uptake TMA within 16 hours. *Euphorbia milii* had the highest removal efficiency of TMA (97.0%), followed by *Spathiphyllum cannifolium* (93.5%), *Anthurium andraeanum* (91.7%), *Sanchezia speciosa* (91.5%), *Pseuderanthemum atropurpureum* (90.6%), *Ixora chinensis* (89.6%), and *Asplenium nidus* (88.7%). There was no significant correlation between TMA uptake and photosynthesis (Fv/Fm ratio), stomatal density, or crude wax content, suggesting that other physiological factors such as cuticular properties or stress responses may play a role in purifying the TMA. Fatty acids, alkanes, and fatty alcohols in the plant leaf wax were identified and contributed to TMA adsorption. These findings highlight the potential of ornamental plants for the remediation of volatile organic compounds (VOCs) in indoor environments as natural indoor air purifiers due to their efficient ability to remove TMA from the air under controlled laboratory conditions, likely through a combination of adsorption, uptake, and possible internal processing.

1. Introduction

Trimethylamine (TMA), a volatile organic compound (VOC), poses health risks even at low concentrations and is associated with an unpleasant odour (Matheson et al., 2023; Mogilnicka et al., 2020). TMA emissions from the food and fishing industries average 20.60 parts per billion (ppb), with the highest concentration reaching 72.30 ppb, while emissions from gas exhausters are even higher, reaching 370 parts per million (ppm) (Siswanto et al., 2016). It is a gas under room temperature but normally sold in pressurized gas cylinders or as a 40% solution in water. TMA is also associated with taking large doses of choline and carnitine, while these two chemicals were determined to be nutrients found in foods like fish, meat, eggs, red meat, and dairy that benefit supporting the nervous system and energy production, respectively. However, choline and carnitine can be metabolized by gut bacteria into TMA, which may cause a fish-like odor and increase cardiovascular disease risk (Zhen et al., 2023). Odor threshold ranges of 0.0004 to 0.8 parts per million (ppm) of air have been reported (Papandreou et al., 2020). It is often released from fish-meal manufacturing processes, wastewater treatment, waste disposal, livestock farming, and hog manure (Aguirre et al., 2018; Ding et al., 2007). TMA is considered a strong environmental pollutant since it's potentially toxic and has carcinogenic properties (Ding et al., 2007; Yan

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et al., 2021). Additionally, TMA has been documented to have an adverse effect on health, resulting in respiratory system and skin and eye irritations and even coughing and death even in small amounts like 10 ppm (Aguirre et al., 2018; Wannomai et al., 2019). Effective removal of TMA from air could improve indoor air quality and contribute to better human health and well-being.

Various techniques, including absorption, biofiltration, and phytoremediation, have been employed to remove air pollutants and mitigate odour issues (Aguirre et al., 2018; Matheson et al., 2023; Sheoran et al., 2022; Siswanto et al., 2016). Biological treatment and biofiltration have emerged as reliable and efficient technologies for the removal of a wide range of offensive gases and pollutants in recent times (Aguirre et al., 2018; Raj et al., 2019). Since gaseous pollutants decompose into basic, non-toxic forms, biological treatments and biofiltration have been proven to be extremely effective and environmentally benign methods for removing low concentrations of these pollutants by microbial flora and aquatic plants (Barbusinski et al., 2017; Porté et al., 2019). Previous studies have demonstrated several bacterial species, including *Curvibacter* sp., *Sphingobacterium* sp. (Oyarzun et al., 2019), *Paracoccus* sp. (Kim et al., 2003), and *Aminobacter aminovorans* (Aguirre et al., 2018), can effectively remove TMA. The degradation pathway involves its mineralization to dimethylamine (DMA), which is further mineralized to monomethylamine (MMA) and finally into ammonia (Raj et al., 2019). Despite the effectiveness of microbial degradation, the complexity and cost of biofiltration systems may limit their practicality for indoor settings.

On the other hand, in natural ecosystems, plants act as filters and metabolize substances generated by nature. Phytoremediation presents an attractive alternative due to its low cost, environmental sustainability, simplicity, and high public acceptance (Ding et al., 2007; Siswanto et al., 2016), which can often be carried out on-site. While previous studies have focused on microbial degradation, few have explored the comparative efficacy of common ornamental plants for TMA removal under controlled conditions. Hence, this study aims to fill this gap by comparing seven commonly available ornamental plants for their TMA removal efficiency and identifying physiological traits that may influence uptake.

2. Methodology

2.1. Selection and preparation of plant species

Seven ornamental plant species were selected and used for the experiment. Those plants are *Asplenium nidus*, *Anthurium andraeanum*, *Euphorbia milii*, *Ixora chinensis*, *Pseuderanthemum atropurpureum*, *Sanchezia speciosa*, and *Spathiphyllum cannifolium*. The healthy plants that have a similar size of leaf area (130 cm^2) were determined. Distilled water was used to thoroughly clean the plant leaves. Plant roots were covered with aluminium foil (Figure 1) and placed in the fumigation chambers with trimethylamine (TMA) at 100 ppm, then scummed, and sealed again by paraffin tape.

2.2. Experimental design

After plant preparation, each plant was placed in a 15.6 L glass fumigation chamber. A total of 28 chambers were used in this study. For each experimental condition, four chambers were used simultaneously, consisting of three independent replicate chambers containing plants and one time-matched control chamber (100 ppm TMA without plants). All chambers were closed and sealed with paraffin tape and maintained at room temperature during the experiment. TMA was injected into the chambers at a concentration of 100 ppm using a 40% aqueous TMA solution, and the mixture was stirred to ensure good distribution. For investigation of the TMA equilibrium time, the volatilization of TMA was completed in 4 hours; thus, the air samples were collected after every 4 hours. In this treatment, plants were fumigated, and sampling time was set for 4, 8, 12, 16, 20, and 24 hours to be analyzed by gas chromatography (Shimadzu Corporation, GC-17A, Japan). To measure trimethylamine (TMA) concentrations in post-treatment air, a 4 mL air sample taken from fumigation chambers at room temperature was analyzed using a Shimadzu GC-17A gas chromatograph equipped with a flame ionization detector (FID) and fitted with a polar column (0.32 mm I.D. × 30 m, 0.25 µm film thickness). The injection and detector temperatures were set at 250 °C, while the column temperature was maintained at 100 °C under isothermal conditions. The carrier gas (N_2) flow rate was 6 mL/min, and the analysis was performed in splitless mode.

Figure 1. Seven ornamental plant species were covered the port with aluminum foil with leaf area of 130 cm^2.

2.3. Stomata counting and photosynthesis

Nail varnish was used to copy the pattern of stomata on the clean leaf surface of both abaxial (underside) and adaxial (upper side) leaf surfaces. A scalpel was used to cut around the area where the varnish was applied to the leaf 1 cm^2 and counted under a light microscope. For photosynthesis, the chlorophyll fluorescence was measured before and after the plant was exposed to TMA by an FMS-2 portable pulse-modulated fluorometer. Fv/Fm measurements were conducted after 5 minutes of dark adaptation. During measurement, plants remained under room light conditions (~32°C, normal ambient laboratory light) except for the dark-adapted leaf area being covered. For each species, three plants (three replicates) were used, and one representative leaf per plant was measured for Fv/Fm analysis.

2.4. Crude wax extraction

The leaves of seven plant species were cut into small pieces with the leaf area around 130 cm^2, extracted by chloroform, and shaken at 240 rpm for 24 hours at room temperature. After the shaking process, the solvents were evaporated in each Erlenmeyer flask bottle for around 16 hours in the fume hood. The dry crude wax on the aluminum plate (5 cm^2) was fumigated with 100 ppm of TMA in the glass chamber, then measured by GC.

2.5. Removal efficiency

TMA removal efficiency (%) was calculated based on the following equation:

$$\text{TMA removal efficiency (\%)} = 100\ [C_{control} - C_{\text{treatment}}]\ /\ C_{control}$$

where $C_{control}$ and $C_{\text{treatment}}$ are the trimethylamine (TMA) concentrations in the gas from control (without plants) and treatment (with plants) glass fumigator's chambers, respectively.

2.6. Statistical analysis

Data were analyzed by one-way analysis of variance (ANOVA) using the Statistical Program for Social Sciences (SPSS) version 23. Duncan's multiple range tests were used to determine significant differences among treatments with a 95% confidence level.

3. Results and Discussion

3.1. Efficiency of TMA removal by plants

Seven ornamental plant species were evaluated for their ability to remove 100 ppm TMA over a 16 h exposure period. All plant species demonstrated the ability to remove TMA from the chamber atmosphere. After 16 h, *E. milii* exhibited the highest numerical TMA removal efficiency (97.0%), followed by *S. cannifolium* (93.5%). According to Duncan's multiple range test, these two species were not significantly different, as they belonged to the same statistical grouping (Table 1).

Table 1. Trimethylamine (TMA) removal efficiency by 7 plant species in fumigation chambers.

Plant species (Scientific name)	**Leaf area average (cm^2)**	**Percentage (%) TMA removal**			
		Time (hours)			
		4	8	12	16
A. nidus	131	63.9 ± 3.3^{c}	79.4 ± 0.5^{c}	83.6 ± 0.8^{d}	88.7 ± 0.2^{c}
A. andraeanum	130	81.8 ± 1.7^{b}	85.5 ± 2.0^{b}	88.5 ± 1.7^{bc}	91.7 ± 1.4^{b}
E. milii	129.3	87.7 ± 0.9^{a}	89.4 ± 1.0^{a}	92.6 ± 1.0^{a}	97.0 ± 4.7^{a}
I. chinensis	128	81.6 ± 4.4^{ab}	84.6 ± 2.5^{b}	87.0 ± 1.7^{c}	89.6 ± 1.1^{bc}
P. atropurpureum	130	86.0 ± 1.4^{a}	87.8 ± 0.7^{ab}	88.7 ± 0.3^{b}	90.6 ± 0.6^{b}
S. speciosa	128.3	82.9 ± 2.2^{ab}	85.6 ± 2.0^{ab}	88.8 ± 1.4^{b}	91.5 ± 1.4^{b}
S. cannifolium	133	78.5 ± 2.4^{b}	85.8 ± 0.8^{ab}	87.1 ± 0.4^{c}	93.5 ± 1.2^{a}

The initial concentration of TMA was 100 ppm. Data are listed as average ± SD for three replications. Duncan's multiple range tests with a 95% confidence level were used to classify the group of data. Values in the same column with the same superscript are not significantly different ($\alpha = 0.05$).

The remaining species showed TMA removal efficiencies ranging from 88.7% to 91.7%, with *A. andraeanum* (91.7%), *S. speciosa* (91.5%), and *P. atropurpureum* (90.6%) belonging to the second statistical grouping, while *I. chinensis* (89.6%) and *A. nidus* (88.7%) exhibited comparatively lower removal efficiencies. These findings demonstrate the potential of ornamental plants to remove airborne TMA under controlled laboratory conditions, supporting their potential application as natural systems for improving indoor air quality. This finding is consistent with previous studies reporting the ability of ornamental plants to remove airborne pollutants, highlighting their potential use in phytoremediation and indoor biofiltration systems (Matheson et al., 2023; Sheoran et al., 2022; Siswanto et al., 2016).

3.2. Effect of photosynthesis, number of stomata, and crude waxes for TMA removal

Photosynthesis of the plant before and after exposure to TMA was measured (Table 2). The ratio between variable fluorescence and maximal fluorescence (Fv/Fm) after 5 min of dark adaptation, which shows the photochemical quenching capacity of photosystem II and represents photosynthesis, was observed. Among the seven ornamental plants, there was no significant difference in the Fv/Fm between non-exposed plants (control plants) and exposed plants. A relationship between photosynthesis and TMA uptake was not found. Typically, a healthy Fv/Fm value is around 0.75 to 0.85, which reflects optimal photosystem II efficiency under non-stress conditions (Guidi et al., 2019; Jia et al., 2019; Lin et al., 2013; Singh et al., 2017).

Table 2. Photosynthesis of each plant before and after the experiment of fluorescence and maximal fluorescence (Fv/Fm) after 5 min of dark adaptation.

Plant species (Scientific name)	**Photosynthesis (Fv/Fm) (Control plants)**	**Photosynthesis (Fv/Fm) (Treated plants)**
A. nidus	0.85 ± 0.00[a]	0.85 ± 0.00[a]
A. andraeanum	0.75 ± 0.02[a]	0.77 ± 0.03[a]
E. milii	0.82 ± 0.00[a]	0.83 ± 0.00[a]
I. chinensis	0.77 ± 0.00[a]	0.78 ± 0.00[a]
P. atropurpureum	0.78 ± 0.01[a]	0.77 ± 0.00[a]
S. speciosa	0.77 ± 0.00[a]	0.78 ± 0.00[a]
S. cannifolium	0.79 ± 0.00[a]	0.80 ± 0.00[a]

Data are listed as average ± SD for three replications. Duncan's multiple range tests with a 95% confidence level were used to classify the group of data. Values in the same column with the same superscripted letter are not significantly different ($\alpha = 0.05$).

Generally, plants have stomata on the abaxial surface of leaves (under part of leaves); however, some plant species have stomata on both the adaxial and abaxial surfaces of leaves. The number of stomata and crude wax that were extracted with chloroform in each plant was observed. The relations choline hip between the amount of crude wax extracted by chloroform, stomata number, and TMA uptake was not found (Table 3). *I. chinensis* and *P. atropurpureum* showed the highest stomata density, with 9416 ± 381 and 8333 ± 260 stomata per cm^2, and removal efficiency of 89.6% and 90.6%, respectively. A higher number of stomata enhances gas exchange, promoting the uptake of air pollution compounds like TMA. *A. nidus* contained the highest wax content with 173.79 μg cm^{-2}, with a removal efficiency of 88.7%. However, *S. cannifolium*, with the lowest wax content, can remove 93.5% of TMA, suggesting that other physiological factors contribute to the removal efficiency. *E. milii* achieved the highest removal efficiency of 97.0%

even with average stomatal density and wax content, compared to other species. Its performance may be due to its unique physiological traits or effective stomatal and leaf wax synergy in VOC uptake (Jia et al., 2019; Roy et al., 2024).

Table 3. TMA removal efficiency, number of stomata, and crude waxes of seven plant species.

Plant name	Leaf area average (cm^2)	Stomata number (number of stomata cm^{-2} of leaf area)	Crude wax ($\mu g\ cm^{-2}$ leaf area)	Removal Efficiency (%) at 16 hours
A. nidus	128	750 ± 0.00[a]	173.79 ± 11.83[e]	88.7
A. andraeanum	130	1833 ± 144[b]	85.34 ± 3.35[b]	91.7
E. milii	133	5250 ± 125[c]	146.54 ± 16.19[d]	97.0
I. chinensis	129	9416 ± 381[f]	77.94 ± 4.44[b]	89.6
P. atropurpureum	132	8333 ± 260[e]	112.97 ± 9.98[c]	90.6
S. speciosa	131	5625 ± 125[c]	137.01 ± 2.61[d]	91.5
S. cannifolium	128	1833 ± 144[b]	26.56 ± 1.73[a]	93.5

Data are listed as average ± SD for three replications. Duncan's multiple range tests with a 95% confidence level were used to classify the group of data. Values in the same column with the same superscripted letter are not significantly different ($\alpha = 0.05$).

Table 4. Percentage composition (% of the total) of the wax constituents from seven plant leaves.

Plant leave	Relative composition (% of the total) of plant leaf waxes extracted with chloroform			
	Fatty acids	Alkanes	Aldehyde	Fatty alcohol
A. nidus	63.84	31.86	0.00	3.72
S. speciosa	66.36	28.69	0.00	4.94
E. milii	58.08	38.43	0.00	3.48
P. atropurpureum	44.01	53.17	0.00	2.80
I. chinensis	74.56	19.74	0.00	5.68
A. andraeanum	76.99	3.71	10.01	9.00
S. cannifolium	62.58	28.17	0.00	9.23

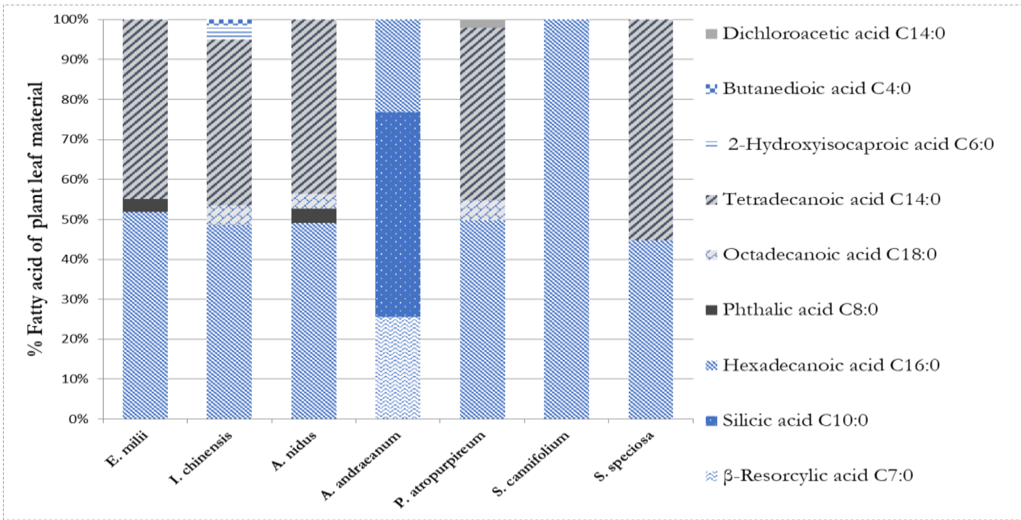

Figure 2. Percentage of fatty acid composition in the waxes of each plant leaf.

3.3. Efficiency of trimethylamine (TMA) uptake by a whole plant and a whole plant without leaves

According to the results of TMA removal, those seven plants had no significant difference; however, *E. milii* had a higher removal percentage of TMA than the other plants. Therefore, *E. milii* was selected for future investigation on the TMA removal efficiency between a whole plant and a whole plant without leaves accordingly.

E. milii plant took out all the leaves; only the stem and roots were covered by aluminum foil and kept in the closed system with 100 ppm of TMA in a chamber and analyzed by GC. To compare the whole plant (*E. milii* with leaves, 130 cm^2) with the whole plant without leaves (only stem), it showed that the whole plant could remove TMA 100%, while *E. milii* without leaves could remove TMA only 60% within 24 hours (Figure 3). The whole plant had stomata and plant leaf waxes for enhancing TMA removal completely (Wannomai et al., 2019). In addition, the whole plant without leaves contained only the stem, which enhanced TMA removal. Therefore, the stem might have other mechanisms for the removal of TMA. Since the Euphorbia genus *E. milii* has a high latex content, the latex should play a role in TMA adsorption (Benjamaa et al., 2022; Siswanto et al., 2016).

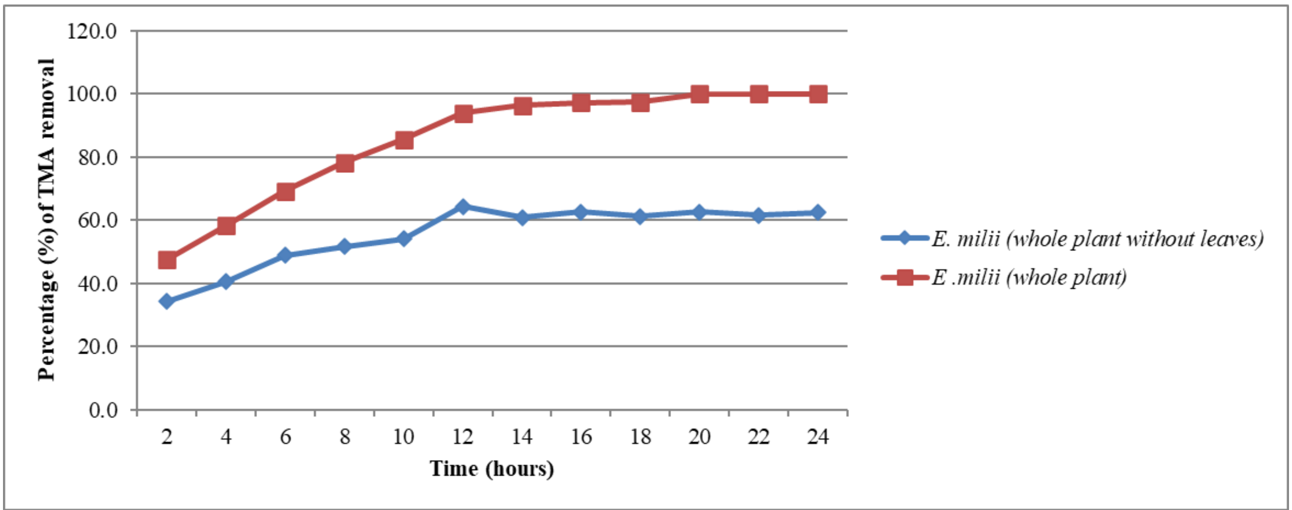

Figure 3. Efficiency of TMA uptake by the whole plant of *E. milii* compared to the whole plant without leaves.

3.4 Mechanistic interpretation of TMA uptake

The high TMA removal efficiencies observed across all seven ornamental plants indicate that TMA uptake is governed by a combination of physical, physiological, and biochemical processes rather than a single plant trait. According to established VOC uptake theory, airborne amines such as TMA are first adsorbed at the leaf surface and diffuse across the boundary layer before entering through stomata or the cuticle, after which they may be internally translocated and biochemically transformed (Wang & Erb, 2022; Yamane & Tani, 2024; Zhang et al., 2025). In this study, the absence of a direct relationship between TMA removal efficiency and leaf area, stomatal density, or total wax content suggests that boundary layer diffusion and uptake are influenced more by synergistic interactions among surface properties than by any single parameter. Leaf cuticular waxes containing short-chain fatty acids (C14–C16), particularly hexadecanoic acid, likely enhanced initial TMA adsorption, consistent with reports demonstrating the role of wax composition in VOC capture (Bandehali et al., 2021; He & Ding, 2020; Sriprapat et al., 2014). Following entry, internal translocation within plant tissues contributed to whole-plant removal, as evidenced by complete TMA elimination in intact plants compared to only partial removal by leafless *E. milii*, supporting foliar uptake as the dominant pathway with additional contributions from stems and roots (Vleeming et al., 2026; Wei et al., 2017). The unchanged photosystem II efficiency (Fv/Fm) after exposure indicates that TMA uptake did not impose photochemical stress, implying effective biochemical degradation or sequestration rather than passive accumulation (Guidi et al., 2019). The exceptionally high removal efficiency of *E. milii* may further reflect species-specific biochemical traits, such as latex production, which has been suggested to act as an additional sink for VOC adsorption and transformation (Benjamaa et al., 2022; Siswanto et al., 2016). Overall, these findings support a multistep model of TMA uptake involving boundary layer diffusion, internal translocation, and biochemical processing, consistent with current conceptual frameworks for plant-based VOC phytoremediation.

4. Conclusion

This study demonstrated the potential of ornamental plants for the removal of TMA from indoor environments under controlled laboratory conditions with artificially elevated TMA concentrations (100 ppm). All seven species significantly reduced TMA concentrations in sealed chamber experiments within 16 hours. *E. milii* showed consistently superior performance of TMA removal efficiency at 97% compared to the other species like *S. cannifolium* at 93.5% and *A. andraeanum* at 91.7%, while the lowest efficiency was 88.7% by *A. nidus*. Notably, commonly measured physiological parameters did not correlate with uptake efficiency, suggesting alternative mechanisms may be involved, such as cuticular properties or stress responses, which may influence TMA absorption. Even plants without leaves comprising only stems retained some ability to remove TMA, achieving 60% efficiency within 24 hours, implying additional uptake pathways such as cuticular or latex-mediated absorption. These findings highlight the viability of using certain ornamental plants for indoor air purification, particularly in environments where TMA and other VOCs are prevalent. These plants show potential for incorporation into plant-based biofiltration systems; however, real-world validation is needed to confirm their effectiveness under practical conditions. Integrating these plants into biofiltration systems could provide a cost-effective and eco-friendly approach to improving air quality in both residential and industrial settings. For the future studies should examine the durability of TMA uptake over time, interactions with multiple VOCs, and the potential role of plant latex or cuticle chemistry in driving removal efficiency.

Author contributions

Chhon, Y. conceptualizations, data collection and analysis, wrote and edited the manuscript; Yar, S., and Ay, B. wrote and reviewed the manuscript. Sorn, V. data curation, wrote, reviewed, and edited the manuscript. All authors contributed to the article and approved the submitted version.

Data availability

Data are available upon request.

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Conflicts of interest

The authors declare no competing interests.

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