Volatile Organic Compounds Emanating from Indoor Ornamental Plants

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Abstract. A broad cross-section of volatiles emanating from four species of popular indoor ornamental plants (Spathiphyllum wallisii Regel, Sansevieria trifasciata Prain, Ficus benjamina L., and Chrysalidocarpus lutescens Wendl.) was identified and categorized based on source. Volatile organic compounds from individual plants were obtained using a dynamic headspace system and trapped on Tenax TA during the day and again at night. Using short-path thermal desorption and cryofocusing, the volatiles were transferred onto a capillary column and analyzed using gas chromatography–mass spectroscopy. The volatiles originated from the plants, media/micro-organisms, pot, and pesticides. A total of 23, 12, 13, and 16 compounds were identified from S. wallisii, S. trifasciata, F. benjamina, and C. lutescens, respectively. The night emission rate was substantially reduced (i.e., by 30.1%, 69.5%, 73.7%, and 63.1%, respectively) reflecting in part the regulation of biosynthesis and the greater diffusion resistance when the stomata were closed. S. wallisii had the highest emission rate, releasing 15 terpenoid compounds [e.g., linalool oxide, linalool, (Z)-β-farnesene, farnesal, (+)-δ-cadinene, (+)-β-costol] into the surrounding air. Alpha-farnesene (90.3%) was quantitatively the dominant volatile present followed by (Z)-β-farnesene (1.4%), (+)-β-costol (1.4%), and farnesal (1.1%). Substantially fewer terpenoids (i.e., two, nine, and eight) emanated from S. trifasciata, F. benjamina, and C. lutescens, which quantitatively emitted fewer volatiles than S. wallisii. Most terpenoids from the four species were sesquiterpenes rather than monoterpenes. Methyl salicylate, a plant-signaling compound, was emitted by all four species. Certain volatiles (e.g., 2-chlorobenzonitrile, 1-ethyl-3,5-dimethylbenzene) were released from growth media and/or micro-organisms therein; other sources included the plastic pot (e.g., 2-ethyl-1-hexanol, octamethyl cyclotetrasiloxane) and pesticide ingredients [e.g., 2-(2-methoxy-ethoxy)ethanol, 2-ethylhexyl salicylate, homosolates].

The use of ornamental plants in interiorscapes is increasingly being studied for their ability to remove volatile organic compounds, thereby improving the air quality of indoor environments (Kim et al., 2008; Yoo et al., 2006). Deterioration of indoor air quality can result in “multiple chemical sensitivity,” “new house syndrome,” and “sick building syndrome” and a cross-section of adverse physical symptoms for those exposed (e.g., allergies, frequent fatigue, asthma, headache, a feeling of un easiness) (Jones, 1999; Kostiainen, 1995). 2-Ethyl-1-hexanol, formaldehyde, and benzene are common indoor pollutants that are detrimental to health and are emitted from a cross-section of materials found inside buildings (Orwell et al., 2004). The indoor concentration of benzene and toluene was reduced by Hedera helix L., Spathiphyllum wallisii Regel, Syngonium podophyllum Schott., and Cissus rhombifolia Vahl. (Yoo et al., 2006). There are substantial differences in the rate of removal resulting from the chemical characteristics of the volatile, plant species, and ambient conditions; as a consequence, a mixture of species is recommended for effective biofiltration (Orwell et al., 2004).

In addition to the removal of pollutants, plants also release a diverse cross-section of volatiles into the surrounding environment. These primary pathways of volatiles [e.g., isoprenoids (e.g., camphene, p-cymene, δ-3-carene, α-humulene, limonene, linalool, (E)-β-ocimene, α-pinene, δ-3-cadinene, δ-3-cadinene, δ-cadinene, (+)-isocynane, δ-3-carene, limonene, α-pinene) with the fragrance of Heliotropium arborescens (Kays et al., 2005). In addition, volatiles synthesized in some plants have specific health properties: curcumin in turmeric (anti-inflammatory and antitumor activities); curcumene, gingerol, and gingersone in ginger (antioxidant and antitumor activities); and camphor and methyl cinnamante in galangal (antimicrobial activity) (Goff and Klee, 2006). Although significant advances have been made in the identification of critical odorants, much less is known about volatiles that have little or no odor and on the dynamics of the interaction between indoor plants and air quality.

The objective of this study was to identify and quantify volatiles emanating from four popular potted indoor ornamental species, establish the source of the volatiles, and determine if the rate of emanation differed between day and night.

Materials and Methods

Plant material and collection of volatiles. Four potted indoor ornamental plant species were purchased from a commercial market (Spathiphyllum wallisii Regel, Sansevieria trifasciata Prain, Ficus benjamina L., and Chrysalidocarpus lutescens Wendl.) and acclimatized for 2 weeks to indoor conditions, i.e., 25 ± 1 °C, 50% relative humidity, and 5.45 μmol·m−2·s−1 photosynthetically active radiation. S. wallisii was in flower during the test period. The dry weights of the aerial part in S. wallisii, S. trifasciata, F. benjamina, and C. lutescens were 16.7, 61.4, 43.1, and 34.3 g, respectively. Individual plants planted in 15-cm-diameter pots were placed in a meticulously cleaned 39-L glass container with inlet and outlet ports. The inlet port was connected to a charcoal filter (Alltech Assoc. Inc., Deerfield, IL) [Pyrex glass tube (10 cm × 1 cm i.d.) with 7 cm of 2.5 g of charcoal] to supply purified air and the outlet port was connected to a sorbent trap (10 cm long, 6 mm o.d., 4 mm i.d. stainless steel sorbent trap; Scientific Instrument Services, Inc., Ringoes, NJ containing 150 mg of 60/80 mesh Tenax-TA® (Alltech Assoc. Inc.) followed by a portable air sampling pump (LFS-113DC; Sensidyne Inc., Clearwater, FL). Volatile compounds emanating from the plant were collected for 10 h by flowing purified air into the container at 20 mL/min. Samples were also collected from empty

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chambers to verify the absence of contaminants. Samples were collected during both the day and night (12-h photoperiod). The rates of emanation for the individual volatiles are relative and do not represent absolute amounts. Collection began 2 h after the plant was placed in the container. Volatiles from the plastic pot with the media and the plastic pot alone were similarly assessed to determine the source of the individual compounds, i.e., plant, media/micro-organisms, and pot.

**Short-path thermal desorption.** An automated short path thermal desorption system (TD-5; Scientific Instrument Services) mounted on the injection port of the gas chromatograph–mass spectrometer (GC-MS) (6890N/5973; Agilent, Palo Alto, CA) desorbed the volatiles from the Tenax trap at 250 °C for 5 min. The volatiles were collected on the first 4 cm of the capillary column using a cryofocus trap (SIS 2°C Cryo-Trap; Scientific Instrument Services) cooling to −40 °C with liquid CO₂, and subsequently released by rapidly heating the trap to 200 °C.

**Separation, identification, and quantification of volatiles.** Volatiles were identified and quantified using a GC-MS equipped with a 30-m length × 0.25-mm i.d., 0.25-μm film thickness of 5% phenyl methyl siloxane, fused silica capillary column (HP-5MS; Agilent). The injection port temperature was 225 °C with a split ratio of 5:1. Helium was used as the carrier gas at a flow rate of 1.0 mL/min. The column temperature was held at 40 °C for 1 min and then programmed 5 °C/min to 280 °C and held for 5 min. MS conditions were: ion source 230 °C, electron energy 70 eV, multiplier voltage 1247 V, GC-MS interface zone 280 °C, and a scan range of 35 to 350 mass units. The volatiles were identified based on comparison of their mass spectra and relative abundances with NIST 02 and Wiley 7 spectral libraries. The concentrations of individual volatiles were expressed as δ-carvone equivalents and were considered relative because recovery and calibration factors were not determined. The internal standard was introduced by placing 5 mL of δ-carvone in a sealed 1-L Erlenmeyer flask. After 24 h, 50 mL of air saturated with δ-carvone was removed and injected into the glass container holding the test plant at the beginning of volatile collection. The concentration of the internal standard in the trapped sample was determined using a concentration range of authentic standards in hexane directly injected into the GC.

### Results and Discussion

Volatile organic compounds emanating from individual plants. A total of 23, 12, 13, and 16 volatile organic compounds were identified from *S. wallisii*, *S. trifasciata*, *F. benjamina*, and *C. lutescens*, respectively (Table 1). The volatiles were comprised of terpenoids, alcohols, ketones, and esters (Fig. 1). Based on the relative proportion of the primary classes, terpenoids were quantitatively dominant in *S. wallisii* (97.8%), *F. benjamina* (79.0%), and *C. lutescens* (66.9%); however, esters (34.6%) were quantitatively dominant in *S. trifasciata* followed by ketones (26.9%), alcohols (26.6%), and terpenoids (11.9%). Certain compounds were found in all four species, i.e., butyl butyrate, methyl salicylate, and isopropyl myristate.

The phenolic compound methyl salicylate, known to emanate from a number of species, comprised 0.2%, 17.8%, 7.8%, and

### Table 1. Relative concentration of volatile organic compounds emanating from four species of indoor ornamental plants (*Spathiphyllum wallisii*, *Sansevieria trifasciata*, *Ficus benjamina*, and *Chrysalidocarpus lutescens*) during the day and night.

| Compound                                | *S. wallisii*       | *S. trifasciata* | *F. benjamina* | *C. lutescens* |
|-----------------------------------------|---------------------|-----------------|----------------|----------------|
|                                         | Day     | Night | Day     | Night | Day     | Night | Day     | Night | Day     | Night |
| 3-Hydroxy-2-butanone                    | 314     |       | 129.5   |       | 74.4    | 18.8  | 21.7    | 22.6  |
| 4-Hydroxy-4-methyl-2-pentanone          | 529     |       |         |       | 18.7    |       | 18.7    |       |
| 3,4-Dimethyl-2-hexanone                 | 569     |       | 172.6   | 47.8  | 21.4    | 8.2   | 25.0    |       |
| 1-Hexanol                               | 583     |       |         |       | 14.9    |       |         |       |
| 2-Heptanone                             | 635     |       | 239.7   |       |         |       |         |       |
| D-Limonene                              | 811     |       |         |       | 16.6    |       |         |       |
| (Z)-β-ocimene                           | 1078    |       | 101.2   | 72.3  |         |       |         |       |
| 3,3,5-Trimethylcyclohexanol              | 1085    |       | 168.6   | 61.8  | 71.3    | 25.8  | 39.7    | 18.0  |
| 1-Octanol                               | 1145    |       | 43.1    |       | 12.3    |       |         |       |
| (Z)-Linalool oxide                       | 1153    |       | 259.8   | 111.5 |         |       |         |       |
| (E)-Linalool oxide                       | 1197    |       | 110.9   | 37.3  |         |       |         |       |
| 2-Nonanone                               | 1207    |       | 138.8   | 211.2 |         |       |         |       |
| Linalool                                | 1230    |       | 110.9   | 37.3  |         |       |         |       |
| (E)-4,8-Dimethyl-1,3,7-nonatriene        | 1278    |       | 380.5   | 235.9 |         |       |         |       |
| Methyl salicylate                       | 1502    |       | 248.4   | 51.3  | 51.1    | 20.7  | 68.3    | 23.1  |
| 4-Cubeane                               | 1928    |       |         |       | 305.6   | 85.1  |         |       |
| (+)-Cyclosativosatene                   | 1970    |       | 142.6   | 109.4 |         |       |         |       |
| Butyl butyrate                          | 1988    |       | 130.1   | 78.0  | 76.1    | 22.3  | 116.1   | 29.5  |
| Copaeane                                | 1997    |       |         |       |         |       | 385.4   | 137.3 |
| β-Cubeane                               | 2034    |       |         |       |         |       | 87.8    |       |
| Caryophyllene                            | 2106    |       | 81.3    |       |         |       | 54.9    | 29.0  |
| Methyl 4-tet-butylbenzoate              | 2168    |       |         |       |         |       | 22.2    | 18.5  |
| (Z)-β-Farnesene                         | 2199    |       | 869.3   | 522.5 |         |       |         |       |
| (+)-Alloaromadendrene                   | 2213    |       |         |       | 37.7    |       |         |       |
| 1-Tetradecanol                          | 2238    |       |         |       | 15.2    |       | 38.2    | 29.9  |
| Germacrene D*                           | 2263    |       |         |       |         |       | 55.4    | 41.5  |
| (E)-β-Farnesene                         | 2272    |       | 146.6   |       |         |       |         |       |
| (3Z,6E)-α-Farnesene                     | 2293    |       | 483.1   |       | 294.1   |       |         |       |
| α-Farnesene                             | 2345    |       | 55,531.3| 40,512.0|         |       |         |       |
| Farnesal                                | 2388    |       | 679.2   | 226.5 |         |       |         |       |
| Sesquioleandrin                         | 2430    |       | 274.9   | 225.2 |         |       |         |       |
| Santanol                                | 2466    |       | 109.0   | 59.9  |         |       |         |       |
| (+)-β-Costol                            | 2546    |       | 859.9   | 63.9  |         |       |         |       |
| E-Farnesene epoxide                     | 2585    |       |         |       | 38.9    | 18.4  | 111.1   | 26.6  |
| Isopropyl myristate                     | 3031    |       | 53.4    | 20.7  | 49.3    | 24.5  | 19.1    |       |
| Total concentration                     |         |       | 61,464.6| 42,958.0| 427.1   | 130.3 | 1,486.5 | 391.3 |

| 1| Values expressed as δ-carvone equivalent.
| 2| Retention time (min).
| 3| Monoterpenes.
| 4| Sesquiterpenes.

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6.9% in the volatiles of *S. wallisii*, *S. trifasciata*, *F. benjamina*, and *C. lutescens*, respectively. The compound acts in signal transduction and plant defense; it activates resistance in the healthy tissues of damaged and neighboring plants against pathogens. Methyl salicylate is also thought to attract predators of certain herbivores (Holopainen, 2004). Many of the volatile compounds emanating from the test species differed. There was a wide range of terpenoid compounds (Table 1), some of which have been implicated in survival and quality attributes (e.g., pollinator attraction, nogenic, antimicrobiological) and ecological significance (e.g., pollinator attraction, defense) (Aharoni et al., 2005).

The specific terpene synthesized varied among species (Owen and Peñuelas, 2005). Fifteen terpenoids were identified from *S. wallisii* of which four were monoterpenes [e.g., (Z)-β-ocimene, (Z)-linalool oxide, (E)-linalool oxide, linalool], 10 sesquiterpenes [e.g., α-farnesene, (Z)-β-farnesene, farnesal, (3Z,6E)-β-farnesene, (E)-β-farnesene, (+)-β-sesquiphellandrene, (+)-cycloisosativene, santalol, caryophyllene], and one homoterpene (e.g., (E)-4,8-dimethyl-1,3,7-nonatriene) (Table 1). Alpha-farnesene (90.3%) was quantitatively the dominant volatile present followed by (Z)-β-farnesene (1.4%), (+)-β-sesquiphellandrene (1.4%), and farnesal (1.1%). Alpha-farnesene, a component of the surface coating of apple, is known to be induced in plants damaged by herbivores (Holopainen, 2004). An oxygenated product (farnesal) and isomers thereof [i.e., (Z)-β-farnesene, (E)-β-farnesene, and (3Z,6E)-β-farnesene], present in *S. wallisii* (Table 1), are known to function as insect pheromones as does α-farnesene (Dawson et al., 1982). Santalol, present in *S. wallisii*, has been reported to have a relaxing and sedative effect in humans (Hongratanaworakit et al., 2004). Several monoterpenes identified in *S. wallisii* have been reported as major compounds in a variety of species, e.g., linalool in lavender and jasmine tea (Baser et al., 2005; Ito et al., 2002), linalool, and its derivatives [(Z)-linalool oxide and (E)-linalool oxide] in carnation flowers (Lavy et al., 2002). Linalool is known to have a sedative effect on autonomic nerve activity and mood and antifungal activity (D’Auria et al., 2005). Substantially fewer terpenoids (i.e., two, eight, and eight) emanated from *S. trifasciata*, *F. benjamina*, and *C. lutescens*, which were not in flower and quantitatively emitted fewer volatiles than *S. wallisii*. Germacrene D and E-farnesene epoxide were found only in *F. benjamina* and *C. lutescens*; α-cubebene, β-cubebene, and (−)-alloaromadendrene in *F. benjamina*; and limonene in *S. trifasciata*.

Most terpenoids from the four species were sesquiterpenes rather than monoterpenes. Generally, monoterpenes are synthesized in the plastids by way of the mevalonylithitol phosphate (MEP) pathway, whereas sesquiterpenes are synthesized in the cytosol through the mevalonate (MVA) pathway (Schwab et al., 2008). Mono- and sesquiterpenes are generally sequestered in specialized structures such as ducts or glandular storage cavities and their emanation appears to be developmentally regulated (Holopainen, 2004). For example, in *S. wallisii*, the number of terpenes increased markedly on flowering (data not shown). Therefore, variation in the biosynthesis and emission of monoterpenes and sesquiterpenes depends on the species and developmental stage. In addition to the mono- and sesquiterpenes, a 

| Source | Relative concn (pg/potted plant/hour)z |
|--------|-------------------------------------|
| Micro-organisms | Cyclohexanol 623 | 33.7 | 8.3 |
| + media | 2-Ethyl-1-pentanol 747 | — | 34.0 |
| | Heptanol 853 | 8.9 | 10.8 |
| | 2-Chlorobenzonitrile 1431 | 53.3 | 70.0 |
| | (E)-2-Decenal 1689 | 7.5 | — |
| | 2,4,6-Trimethylcyclohexanone 1762 | — | 9.2 |
| | 2-Unodecanone 1777 | 19.5 | 9.7 |
| | 2-Ethyl-2-methylpentane 1798 | — | 8.0 |
| | 2,3-Dihydro-4-propyl-1H-indene 1867 | 10.2 | — |
| | 2-Unodecanal 1961 | 7.9 | 20.4 |
| | Tetracycloxirane 2328 | 8.7 | — |
| Total concentration (pg/potted plant/hour) | 2866 | 29.5 | — |
| Plastic pot | Hexamethylycyclohexane 474 | 150.1 | 141.8 |
| | Octamethylcyclotetrasiloxane 942 | 556.5 | 317.3 |
| | 1-(2-Methoxypropanoyl)-2-propanone 988 | 58.5 | 16.4 |
| | 2-Ethyl-1-hexanol 1022 | 101.8 | 180.0 |
| | 4-Ethyldecane 1105 | 19.0 | 17.9 |
| | 3,7-Dimethyloctane 1236 | 7.0 | 8.0 |
| | 2,4-Bis(trimethylsiloxy)benzaldehyde 1398 | 76.0 | 6.3 |
| | 8-Methylheptadecane 1739 | 31.8 | 54.5 |
| | 2,6,11-Trimethylhexadecane 1862 | 19.1 | 29.6 |
| | 2,6-Di-tert-butylquinone 2225 | 20.7 | 18.9 |
| | 5,9,13-Trimethyl-4,8,12-tetracatricenal 3059 | 8.2 | 18.7 |
| Total concentration (pg/potted plant/hour) | 1048.7 | 932.2 | 775.8 |
| Pesticides | 2-(2-Methoxyethoxy)ethanol 768 | 9.3 | 20.5 |
| | 2-Ethylhexylsalsicylate 2993 | 9.4 | 10.1 |
| | Homosalate 3155 | 5.2 | 5.6 |
| Total concentration (pg/potted plant/hour) | 23.9 | 276.7 | 36.2 |

Table 2: Relative concentration of volatile organic compounds emanating from the media/ micro-organisms, plastic pot, and pesticides of four species of potted indoor ornamental plants (*Spathiphyllum wallisii*, *Sansevieria trifasciata*, *Ficus benjamina*, and *Chrysalidocarpus lutescens*).
Volatiles from individual plants of some of the species during the production of the compounds are known to have undesirable effects on animals. For example, 2-chlorobenzonitrile has been shown to stimulate root formation in bean seedlings and 1-ethyl-3,5-dimethylbenzene is considered an allelochemical substance found in rice root exudate (Kim and Kim, 2000). Therefore, the media/micro-organisms are not only involved in removing indoor pollutants, but also release volatiles into the air.

Eleven volatile compounds originated from the plastic pots (Table 2). The silicone compounds hexamethyl cyclosiloxane, octamethyl cyclosiloxane, and 2,4-bis (trimethylsiloxy) benzaldehyde were quantitatively the most abundant emitted. Several of the compounds are known to have undesirable effects on animals. For example, low-level octamethyl cyclosiloxane exposure has been shown to cause altered immune responses in animals. One of the compounds, 2-ethyl-1-hexanol in the 2 to 32 μg m⁻³ concentration range, is associated with “sick building syndrome,” which can cause asthma in humans (Norbäck et al., 2000). 2-(2-Methoxyethoxy)ethanol, 2-ethylhexyl salicylate, and homosalate are ingredients of lipoidic acid derivatives (e.g., alcohols, ketones, esters) by MVA and MEP pathways; volatile fatty acid derivatives (e.g., alcohols, ketones, esters) by α-oxidation, β-oxidation, and lipoxygenase pathways involving a number of enzymes (Schwab et al., 2008). Emanation is affected by the physical properties of the individual compounds and the characteristics of their site of accumulation (e.g., cellular and intracellular membranes, secretory compartment) (Dudareva et al., 2004). The rate of biosynthesis and release is greatly influenced by abiotic factors such as light (Dudareva et al., 2004; Sharkey and Yeh, 2001). Light decreases the diffusion resistance of stomata during the day and the availability of glyceraldehyde-3-phosphate, a precursor of terpenes formed during photosynthesis (Niinemets et al., 2004). There are a number of reports indicating the effect of light on monoterpene synthesis and emission (Kesselmeier and Staudt, 1999; Logan et al., 2000; Loreto et al., 1996; Staudt and Bertin, 1998; Yokouchi and Ambe, 1984).

Although indoor ornamental plants have been shown to remove certain volatile air pollutants from the air (Yoo et al., 2006), they also emit a diverse cross-section of compounds, some of which are known to be biologically active. The longevity and fate of these compounds have not been adequately studied. Also, the positive or negative impact of these compounds on humans balanced with the ability of plants to remove other volatile organic compounds is unknown.

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