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RESEARCH ARTICLE OPEN ACCESS

Effect of Several Native Moss Plants on Particulate Matter, Volatile Organic Compounds and Air Composition

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ABSTRACT

Experiments were carried out to investigate the effects of mosses on the removal of particulate matter (PM 10) and volatile organic compounds (VOCs) in an indoor space and on the composition of air. For particulate matter removal experiments, 0.2 g mosquitto coil was burned in a glass chamber, where three kinds of mosses (*Plagiomnium cuspidatum*, *Myuroclada maximowiczii*, *Etodon luridus*) were placed. For VOCs removal experiments, 1 mL paint thinner was volatilized in a glass chamber, where *Plagiomnium cuspidatum* and *Myuroclada maximowiczii* were used. As a result, it was found that particulate matter was effectively removed by the three mosses, and the removal efficiency of particulate matter increased as the amount of mosses increased. The amount of VOCs was similar to the level in the control when a low amount of mosses (2 and 4 plates) was used. However, the removal efficiency of VOCs was significant when 6 plates of mosses were used. On the other hand, formaldehyde concentration was 40 times more than the control and carbon monoxide 30 times, when 0.2 g of mosquito repellent was completely burned in a glass chamber. Also formaldehyde removal effect was significant when 6 plates of mosses were placed. However, there was no change in the concentration of indoor oxygen, temperature and humidity by moss plants. In conclusion, the moss plants were effective in removing particulate matter and VOCs, and they are expected to be used for indoor decoration and landscape in order to improve indoor air quality in the future.

Keywords: *Etodon luridus*, formaldehyde, indoor air quality, *Myuroclada maximowiczii*, *Plagiomnium cuspidatum*

Introduction

Moss plants are situated between green algae and pteridophytes according to the botanical classification of plants, and are largely categorized into Musci, Antocerotae and Hepaticae. Moss plants belong to the Bryophyte class including Musci and Hepaticae, and they are first plant that adapted themselves for living on land from water, and are known to have about 24,000 species (Richardson, 1981). The Bryophyte class is also called moss plants, taxonomically close to peteridophytes, but does not have special conducting tissues unlike peteridophytes. Mosses morphologically have distinct stems and leaves or thalluses, but do not show histodifferention. They have rhizoids, but hardly absorb water unlike higher plants (Choi, 1980). Despite their small size compared to other plants, mosses have a high moisture holding ability, and thus are known

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to effectively control humidity in an dry indoor space (Kim et al., 2009). As their shade tolerance is also strong, they grow well in shade and thus are very suitable to use them as a ground cover plant in indoor spaces. Moreover, since people living in urban areas in modern society stay longer in indoor spaces, and the market of indoor landscaping has been expanded (Bang, 2009), and mosses are expected to be utilized more broadly. Moss plants are known to remove heavy metals in water (Choi, 1992), and are reported to effectively remove toluene, an indoor pollutant (Kim et al., 2010). Meanwhile, particulate matter has recently become a serious social problem in Korea, and volatile organic compounds (VOCs) released by construction materials used in new houses have also seriously threatened people's health, which has increased interest in developing plant materials that can remove particulate matter or improve the quality of air (Han, 2001; Hong, 2000). Horticultural products including *Dracaena fragrans*, *Ficus elastica*, *Sansevieria trifasciata* and *Spathiphyllum cannifolium* were reported to remove formaldehyde (Sung, 2007), and Park et al. (2010) reported that *Pachira aquatica* and *Ficus elastica* are effective in removing carbon dioxide. Han et al. (2007) reported that *Aglaonema* and *Ficus benjamina* are effective in removing soluble formaldehyde, and that *Aglaonema* and *Spathiphyluum* are effective in removing benzene and toluene. Lee (2003) highlighted the importance of sustainable eco-friendly filters using plants and microorganisms for clean indoor air. Mosses are known to be effective in removing particulate matter due to their large surface per unit area, but there has been no study on the effects of mosses on VOCs. Against this backdrop, this study conducted experiments using several native moss plants in order to identify their effects of removing particulate matter, VOCs and changing the composition of air in indoor spaces.

Research Methods

Plant materials and experimental methods

In this study, experiments were conducted on particulate matter and total volatile organic compounds (TVOCs) separately. For the particulate matter experiment, *Plagiomnium cuspidatum* (Hedw.) (T.J. Kop.), *Myuroclada maximowiczii* (G.G. Borshch.) (Steere & W.B. Schofield), and *Etodon luridus* (Griff.) (A. Jaeger.) were used, and for the TVOCs experiment, *P. cuspidatum* and *M. maximowiczii* were used. Each type of mosses were collected from mountains with their owners' permission, and were identified by moss classification experts of the National Institute of Biological Resources. The collected mosses were stored and maintained within a plastic greenhouse in the Gyeongnam National University of Science and Technology. Mosses showing good growth were selected for the experiments. A glass chamber (width × length × height: 70cm × 30cm × 130cm) was specially produced and two holes (diameter: 5 mm) on one glass wall were created in order to install plastic tubes connected with devices for measuring air quality. The chamber was designed to circulate the air inside the glass chamber, flowing in and out of the devices through the plastic tubes. A rectangular plastic plate (width × length: 21cm × 29.7cm) was evenly filled with mosses, and was placed inside the glass chamber. In order to test different amounts of mosses, 2, 4 and 6 plates were placed within the glass chamber respectively. The moss-filled plates were placed into a multi-story frame, keeping a certain distance between plates. To compare mosses and foliage plants, a hanging pot (diameter: 25cm) of *Scindapsus aureus* was separately placed within a glass chamber. Environmental conditions within the glass chamber were maintained as follows: temperature, 24±2°C, and light intensity, 30±10 $\mu mol \cdot m^{-2} \cdot s^{-1}$. A small fan (diameter: 10cm) was installed within the chamber for air circulation, and was also utilized to burn a mosquito repellent, or to volatilize a thinner.

Generation of particulate matter and total volatile organic compounds (TVOCs)

To generate particulate matter (PM 10), 0.2 g of a mosquito repellent (F-Killer non-pigmented, Johnson, Malaysia) was

lit, and placed on top of the small air circulation fan within the glass chamber until it was completely burned. As soon as the mosquito repellent was put inside the glass chamber, the front door was airtightly closed. To generate TVOCs, 1.0 mL of a thinner (enamel thinner, Namyoung, Korea) was poured into a glass Petri dish, and was placed on top of the air circulation fan within the glass chamber until it was completely volatilized. It took over 10 minutes to volatilize the thinner.

Measurement of particulate matter, TVOCs and air quality

Particulate matter, TVOCs and air quality within the glass chamber were measured using an air quality measurement device (ISR-400, Sensoronic Co, Korea) in the particulate matter experiment. Since it took about 20 minutes to stabilize air composition within the chamber after completely sealing the chamber, the first analysis was conducted at 20 minutes after initiating the experiment. And then, the analysis of air composition was conducted five times at an interval of one hour. In the TVOCs experiment, it took about 10~15 minutes to completely evaporate the thinner within the glass chamber, and another 15 minutes to stabilize the concentration of the thinner within the chamber. For this reason, the quality of air started to be measured 30 minutes after initiating the experiment, three times at an interval of one hour. The items measured included particulate matter (PM 10), total volatile organic compounds (TVOCs), formaldehyde (HCHO), carbon monoxide (CO), carbon dioxide (CO_2), temperature (°C) and relative humidity (%). Each experiment was repeated over three times under the same conditions. After one experiment was completed, every item inside the glass chamber was removed, and the door of the chamber was left open overnight. The experiment was repeated after one day.

Statistical analysis

Variance analysis was conducted on the collected data using SPSS 12.0 (IBM, New York, USA), and Duncan's multiple range test was performed to test significance between the groups at the 5% significance level.

Results and Discussion

The effects of moss plants on particulate matter were as shown in Figure 1. All the three moss types used in the particulate matter experiment were found to be effective in removing particulate matter, and the higher the amount of mosses, the higher the effect of reducing the concentration of particulate matter. When 0.2 g of a mosquito repellent was completely burned within the glass chamber, the concentration of particulate matter exceeded the maximum measurable value (1,000 $\mu g \cdot m^{-3}$) of the air quality measurement device used in this study. Thus, until the amount decreased below 1,000 $\mu g \cdot m^{-3}$, the amount was recorded as 1,000 $\mu g \cdot m^{-3}$. The concentration of particulate matter in the non-treated group (no plant within the chamber) was found to be naturally reduced over time. When *Etodon luridus* was tested, particulate matter decreased below 1,000 $\mu g \cdot m^{-3}$ after 3 hours, and below 800 $\mu g \cdot m^{-3}$ after 4 hours. However, when *P. cuspidatum* and *M. maximowiczii* were tested, particulate matter was over 1,000 $\mu g \cdot m^{-3}$ even after 4 hours. Meanwhile, when *Scindapsus aureus* was placed within the glass chamber, the concentration of particulate matter decreased below 1,000 $\mu g \cdot m^{-3}$ after 3 hours, and down to 400-800 μg·m-3 after 4 hours, which indicates that *Scindapsus aureus* was effective in removing particulate matter. The effect of mosses on particulate matter, however, was clearer. When 2-4 plates filled with mosses were placed within the chamber, the concentration of particulate matter started to decrease below 1,000 $\mu g \cdot m^{-3}$ even after 2 hours, and down to 200-500 $\mu g \cdot m^{-3}$ after 4 hours. When 6 plates filled with *Etodon luridus* were placed, particulate matter started to decrease below 1,000 $\mu g \cdot m^{-3}$ even after 1 hour, and below 200 $\mu g \cdot m^{-3}$ after 4 hours. When *P. cuspidatum* was used, particulate matter decreased below 100 $\mu g \cdot m^{-3}$ after 4 hours, similar to the result of *Etodon luridus*. When M. maximowiczii was used, it took a longer time, but similar patterns to the other two species were observed. Many earlier studies reported that foliage plants

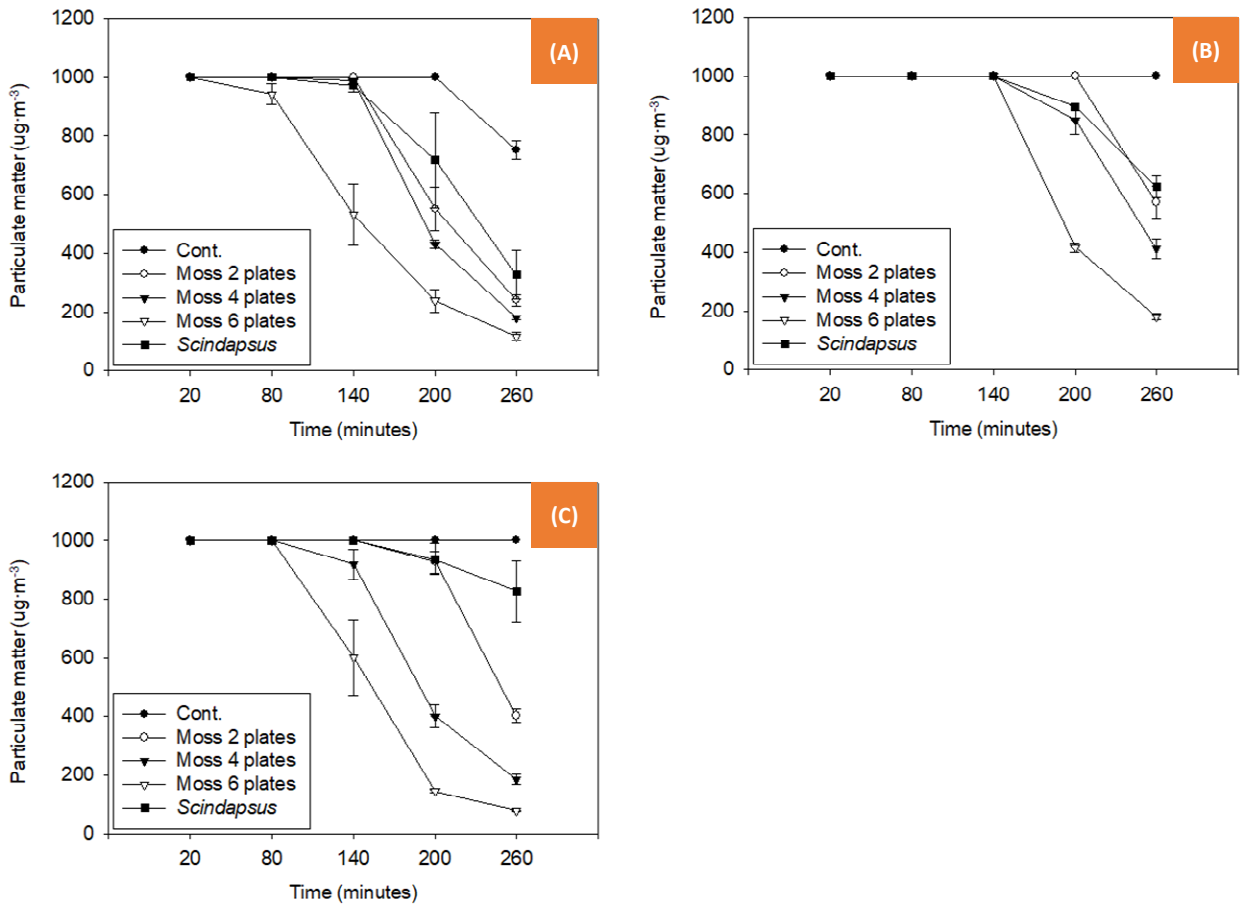

Figure 1. Changes of particular matter (PM 10) affected by *Plagiomnium cuspidatum* (A), *Myuroclada maximowiczii* (B), and *Etodon luridus* (C) for about 4 hours in glass chamber. Mosquito repellent (0.2g) was burned completely to generate particulate matter in a glass chamber. Vertical bars present ± SEs (n=3).

are effective in removing particulate matter. Kwon and Park (2018) compared the effect of *Dieffenbachia* and *Spathiphyllum wallisii* on the concentration of particulate matter depending on the intensity of light, and reported that the higher the intensity of light, the more particulate matter was removed, and that *Spathiphyllum wallisii* was more effective than *Dieffenbachia* in removing particulate matter. Lohr and Pearson-Mims (1996) recommended to fill an indoor space with foliage plants by 20% in order to efficiently remove indoor particulate matter.

The effects of moss plants on TVOCs were as shown in Figure 2. The quality of air was measured after the thinner was placed within the glass chamber and completely volatilized. It took about 30 minutes to be stable in TVOCs concentration. Almost treated groups including the control showed a similar change in TVOCs, excepting 6 plates mosses. The starting concentration of 6 plates mosses was 30% lower than the rest treated groups and the control. Mosses seemed to absorb TVOCs for the first 30 minutes after the experiment was initiated. This tendency was similarly observed on both mosses of *P. cuspidatum* (Figure 2A) and *M. maximowiczii* (Figure 2B). In the case of *P. cuspidatum*, when 2 plates were placed within the chamber, the concentration of TVOCs was similar to the control. However, when 4 plates were placed, the concentration of TVOCs was significantly reduced. On the 6 plates experiment, the concentration of TVOCs was less than 50% of the control, showing the clearly higher effect of removing TVOCs. In the case of *M. maximowiczii*, only when 6 plates were placed within the chamber, the concentration of TVOCs was significantly reduced. Two or 4 plates mosses and *Scindapsus aureus* showed no significant difference compared to the control. Since indoor VOCs is 2-100 times higher than outdoor

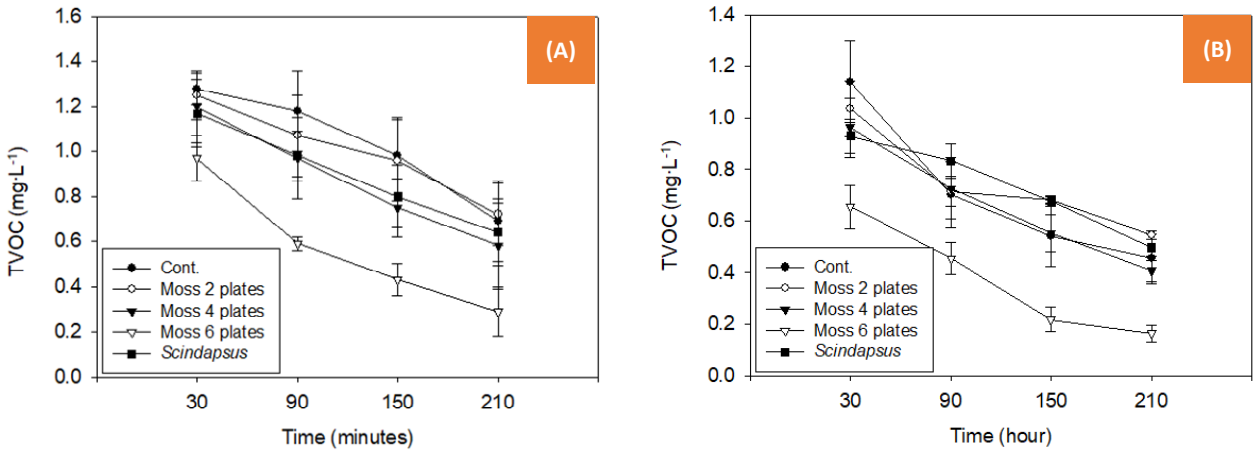

Figure 2. Changes of total volatile organic compounds affected by *Plagiomnium cuspidatum* (A) and *Myuroclada maximowiczii* (B) for about 4 hours in glass chamber. Paint thinner (1 mL) was vaporized completely to generate volatile organic compounds in a glass chamber. Vertical bars means present ± SEs (n=3).

VOCs (Godish, 1994), long-term exposure to VOCs in daily life can cause disorders in the respiratory system and the central nerves, and exposure to high-concentration VOCs increases the risk of cancer (Yang et al., 2003). For this reason, it is important to find ways to reduce VOCs by introducing mosses and plants to indoor spaces.

When mosquito repellent was burned or thinner was volatilized, changes in the composition of indoor air and the effects of moss plants on the composition of air were analyzed and the results were as shown in Table 1 and 2. When 0.2 g of a mosquito repellent was completely burned within the glass chamber, the concentration range of formaldehyde (HCHO) was 0.4-0.6 mg·L^{-1}, 20-40 times higher than those measured in the thinner experiment (0.01-0.02 mg·L^{-1}). Azizi and Henry (1991) reported that when mosquito repellents are burned, formaldehyde and acetaldehyde are produced, and Yim et al. (2007) also reported that when a coil-type mosquito repellent (12.23g) was completely burned, the level of PM 2.5 generated from it was similar to that generated when 41-56 cigarettes were burned. These results indicate that the mosquito repellents widely used in daily life can produce a large quantity of formaldehyde and particulate matter, and thus need to be carefully used. Meanwhile, there was no effect of moss plants on formaldehyde until 4 plates were placed within the glass chamber, but when 6 plates were placed, a significant decrease compared to the control was observed. *Scindapsus aureus* also did not show any effect of removing formaldehyde. Many earlier studies reported that indoor plants have the ability to remove harmful gases including formaldehyde (Hong, 2000; Wolverton et al., 1984; Wolverton and Wolverton, 1993), but moss plants did not effectively remove formaldehyde while their effect of removing particulate matter was high.

When a mosquito repellent was burned, the concentration of carbon monoxide (CO) was 13.5-16.5 mg·L^{-1}, 30 times higher than those measured in the thinner experiment (0.5 mg·L^{-1}). The higher the amount of moss plants, regardless of their types, the less the concentration of carbon monoxide. These results indicate that mosses are effective in removing carbon monoxide, but there was no significant difference in the case of *Scindapsus aureus*. Meanwhile, in the thinner experiment (TVOCs), the concentration of carbon monoxide was not decreased by moss plants, because the initial concentration of carbon monoxide was low in this experiment.

The concentration of carbon dioxide in the mosquito repellent experiment was 500-800 mg·L^{-1}, higher than the level in the air (350 mg·L^{-1}). The concentration of carbon dioxide in the chamber in which mosses and *Scindapsus aureus* were placed was higher than the control by 100-150 mg·L^{-1}, which was inconsistent with the general knowledge that the concentration of carbon dioxide around plants decreases in the daytime. At the moment, it is difficult to interpret the pheno-

Table 1. Effect of moss plants on indoor air composition including formaldehyde (HCHO) and carbon monoxide (CO) after exposure to particulate matter

Scientific name	Treatment	HCHO ($mg \cdot L^{-1}$)	CO ($mg \cdot L^{-1}$)	CO^2 ($mg \cdot L^{-1}$)	O^2 (%)	Temperature (°C)	Relative humidity (%)
Etodon luridus	Control	0.50a[z]	13.5a	798.7b	21.6a	23.9a	65.3a
	Moss 2 plates	0.50a	11.8a	824.2b	21.6a	24.4a	67.2a
	Moss 4 plates	0.60a	10.3a	934.2a	21.6a	24.0a	65.5a
	Moss 6 plates	0.40b	7.9b	908.0a	21.6a	24.1a	64.5a
	Scindapsus aureus	0.43ab	10.0ab	930.5a	21.6a	24.2a	66.7a
Myuroclada maximowiczii	Control	0.60a	16.5a	552.8b	21.8a	25.0a	65.9a
	Moss 2 plates	0.70a	15.4a	609.0ab	21.7a	24.9a	63.5b
	Moss 4 plates	0.65a	13.2ab	684.3a	21.7a	25.2a	65.7a
	Moss 6 plates	0.50b	11.6b	633.3ab	21.7a	24.5a	66.9a
	Scindapsus aureus	0.60a	14.9ab	663.7ab	21.7a	25.6a	64.6ab
Plagiomnium cuspidatum	Control	0.52a	13.6a	502.5c	21.7a	24.7a	65.0a
	Moss 2 plates	0.58a	14.9a	578.8b	21.7a	24.9a	65.8a
	Moss 4 plates	0.57a	12.4ab	639.0a	21.7a	24.8a	66.0a
	Moss 6 plates	0.44b	9.1b	639.0a	21.7a	24.9a	64.7a
	Scindapsus aureus	0.47ab	12.1ab	640.0a	21.7a	25.2a	65.8a

Note. Mosquito coil (0.2g) was burned completely to generate particulate matter in a glass chamber and analysis of indoor air composition was conducted after 260 min.
[Z]Duncan's multiple range test $p = .05$

Table 2. Effect of moss plants on indoor air composition including formaldehyde(HCHO) and carbon monoxide(CO) after exposure to volatile organic compounds

Scientific name	Treatment	HCHO ($mg \cdot L^{-1}$)	CO ($mg \cdot L^{-1}$)	CO^2 ($mg \cdot L^{-1}$)	O^2 (%)	Temperature (°C)	Relative humidity (%)
Myuroclada maximowiczii	Control	0.02a[z]	0.5a	486.0a	21.5a	22.1a	70.9b
	Moss 2 plates	0.02a	0.6a	497.0a	21.5a	21.9a	71.7a
	Moss 4 plates	0.02a	0.8a	496.0a	21.5a	22.6a	73.3a
	Moss 6 plates	0.02a	0.5a	493.0a	21.5a	22.6a	75.0a
	Scindapsus aureus	0.02a	0.5a	497.0a	21.5a	22.7a	74.7a
Plagiomnium cuspidatum	Control	0.01a	0.5a	486.0a	21.6a	23.0a	72.0a
	Moss 2 plates	0.01a	0.6a	497.0a	21.6a	22.8a	72.9a
	Moss 4 plates	0.01a	0.8a	496.0a	21.6a	23.1a	70.4a
	Moss 6 plates	0.01a	0.5a	493.0a	21.6a	23.1a	72.6a
	Scindapsus aureus	0.01a	0.5a	497.0a	21.6a	23.4a	72.1a

Note. Paint thinner (1 mL) was completely vaporized to generate volatile organic compounds in a glass chamber. Analysis of indoor air composition was conducted after 210 min.
[Z]Duncan's multiple range test $p = .05$

menon. It could be suggested that since formaldehyde within the body of plants is converted into formic acid and produced carbon dioxide (Kim et al., 2014), the high level of formaldehyde, over 40 times higher than the normal concentration, seemed to produce more carbon dioxide within the body of plants. For the precise analysis of the results, additional experi-

ments need to be conducted. In the thinner experiment (TVOCs), the concentration of carbon dioxide in the control was 486 mg·L^{-1}, higher than that in the air, similar to the concentration measured in the moss or *Scindapsus aureus*–treated groups. In general, when plants are placed within a certain space with light, photosynthesis occurs, and the concentration of indoor carbon dioxide decrease. However, in this experiment, there was no change in the concentration of carbon dioxide in the chamber, even when mosses or *Scindapsus aureus* was placed within the chamber. It seems likely that they fail to photosynthesize enough due to exposure to the high-concentration thinner, but additional experiments need to be conducted to identify precise causes.

There was no change in the concentration of indoor oxygen, temperature and humidity caused by the mosquito repellent and moss plants (Table 1). No significant difference was observed in all the treated groups, compared to the control. In the thinner experiment, there was no significant difference in the concentration of oxygen, temperature and humidity between all the treated groups and the control group (Table 2). Many earlier studies reported that plants increased the concentration of oxygen and humidity in air (Han, 2001; Hong, 2000), but there was no significant change in this experiment. This can be attributed to the exposure to the high-concentration formaldehyde and thinner, which seemed to inhibit plants from sufficiently photosynthesizing.

Earlier studies reported that the effects of removing air pollutants vary depending on the species of plants. Benzene was effectively removed by *Kalanchoe blossfeldiana*, *Pelargonium domesticum*, *Chlorophytum comosum*, etc. (Cornejo et al., 1999; Han, 2001; Wolverton et al., 1989), and formaldehyde was removed by *Nephrolepis exaltata* '*Bostoniensis*', *Chrysanthemum morifolium*, *Gerbera jamesonii*, etc. (Wolverton, 1996). Toluene and xylene were found to be well removed by *Chrysalidocarpus lutescens*, *Phoenix roebelenii* and *Phaelenopsis* spp. (Wolverton, 1996).

In conclusion, moss plants were effective in removing particulate matter, and a sufficient amount of mosses was required to remove TVOCs. For this reason, moss plants are expected to be utilized for the purpose of indoor decorating or landscaping in order to reduce indoor particulate matter and VOCs.

Conclusion

This study conducted experiments using a few native moss plants (*Plagiomnium cuspidatum*, *Myuroclada maximowiczii*, *Etodon luridus*) to identify their effects of removing particulate matter and volatile organic compounds (VOCs) in an indoor space and their effects on the composition of air. As a result, it was found that all the three moss plants were effective in removing particulate matter, and the higher the amount of mosses, the higher the effect of removing particulate matter. In terms of total volatile organic compounds (TVOCs), when the amount of mosses was small (2 or 4 plates filled with mosses), the level of TVOCs was similar to that in the control and Scindapsus aureus-treated groups, but when 6 plates were placed within the glass chamber, the effect of removing TVOCs increased. Meanwhile, when 0.2 g of a mosquito repellent was completely burned, the concentration of formaldehyde was over 40 times higher, and the concentration of carbon monoxide was over 30 times higher than those in the control group. However, there was no effect of removing formaldehyde by moss plants. In conclusion, moss plants were found to be very effective in removing particulate matter and VOCs, and thus they are expected to be highly utilized for the purpose of indoor decorating and landscaping in order to improve the quality of indoor air.

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