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Study on Gaseous Formaldehyde Removal Capability of Some Native Plant Species in Vietnam

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ABSTRACT

This article presents the study results on gaseous formaldehyde removal capability of the ten native plant species in Vietnam. All of the selected tree species for this study are highly aesthetic so that they can be planted in pots and placed in a room as ornamental plants, including the following species: *Pteris ensiformis* (Burmf.), *Lindsaea javanensis* Bl., *Homalomena* occulta (Lour. Schott), *Alocasia odora* (Roxb) C.Koch, *Trevesia palmata* (Roxb. Vis.), *Strobilanthes affinis* (Griff.) Y.G. Tang, *Costus speciosus* Sm., *Ophiopogon japonicus* (L. f.) Ker-Gawl., *Ficus vasculosa Wall*. ex Miq., *Nageia fleuryi* (Hickel) de Laub. The study was implemented by the method of making these plants expose to the gaseous formaldehyde at the concentration of ranging from 10 mg/m^3 to 13 mg/m^3 in the airtight glass chambers having a volume of 0.36 m^{3}each. After 24 hours exposure, the experimented plant species absorbed formaldehyde from 0.27 µg/cm^2 to 16.4 µg/cm^2 of the leaf surface area. Plant species that had the highest efficiency in absorbing formaldehyde are *Pteris ensiformis* (Burmf.) (16.4 µg/cm^2), *Lindsaea javanensis* Bl. (6.5 µg/cm^2), and *Homalomena occulta* (Lour.) (5.1 µg/cm^2). After 48 hours exposure, experimented plant species absorbed formaldehyde from 0.34 µg/cm^2 to 18.3 µg/cm^2 of the leaf surface area and three species that displayed the best removal efficiency of the ten experimented species are still *Pteris ensiformis* (Burmf.) (18.3 µg/cm^2), *Lindsaea javanensis* Bl. (6.9 µg/cm^2) and *Homalomena occulta* (Lour.) (9.8 µg/cm^2).

Keywords: Gaseous formaldehyde, indoor air, indoor plant, native plant species.

INTRODUCTION

Formaldehyde is a highly toxic colorless gas and has a pungent odor. Being in contact with formaldehyde may cause allergic contact dermatitis, irritation of the upper respiratory tract and eyes, asthma and headaches [1]. According to the International Agency on Research of Cancer, formaldehyde is a strongly probable human carcinogen. In a research of Le Huy Ba [2], formaldehyde was proved of capable to break ADN strands resulting in mutation and chromosomal changes. According to the United States Environmental Protection Agency [3], when the concentration of formaldehyde in the air is from 0.1 to 25 ppm (equivalent to 0.01 to 20.33 mg/m^3), it will irritate the upper respiratory tract; and the LC50 values (lethal concentration for 50% of test organisms) via inhalation for rats is 203 mg/m^3. Unfortunately, formaldehyde has been widely used in many industries, especially the urea-formaldehyde glue production. This glue is used in the plywood manufacturing technology to create a lot of different furniture such as tables, chairs, beds, wardrobes. Formaldehyde is also applied to make heat and sound insulation foam and it even is used in some types of fabric curtains, cloth, floor coverings, carpet backing, fire retardants, and some kinds of grocery bags, facial tissues, and paper towels. Formaldehyde is also released from combustion process of natural gas and kerosene and tobacco smoke [1, 4]. Formaldehyde belongs to the VOCs group, so it is easily released into the air. On the other hand, because the circulation of indoor air is much less than that of the outdoor air, the risk of indoor formaldehyde pollution is very high. In houses built with heat and sound insulating materials of plastic or foam, the concentration of formaldehyde is in a range of 0.01 – 4 ppm [2]. According to Salthammer [5], in a regular living condition, averagely, one resident exposes formaldehyde at a concentration range of from 20 to 40 µg/m^3. In 2006, Gilbert studied formaldehyde concentration in 96 houses in Quebec (Canada) and found that the average values are from 30 to 1000 µg/m^3 and the highest concentration could reach up to 5000 µg/m^3.

In such a currently modern society, for indoor working people, one individual may spend up to 80-90% of the time living in the house, and 50% of the time for outdoor workers [2]. Therefore, removing indoor formaldehyde, as well as other volatile organic compounds is essential and urgent to protect human health. One of the "green" solutions to reduce formaldehyde pollution is to use plants to absorb the pollutants in the environment. There have been many researches using plants to absorb pollutants in soil, water, and obtained good results. Since 1980s, the National Aeronautics and Space Administration of the United States (NASA) has concentrated on biotechnology for dealing with waste treatment and indoor air pollution [4]. Some study results have been applied in practice. In 1984, NASA

at the National Space Technology Laboratories in south Mississippi, for the first time, presented the research results on formaldehyde removal ability of some plant species in which spider plant (*Chlorophytum elatum* var. *vittatum*) displayed the most efficient in eliminating formaldehyde [6]. In 1989, Godish and Guindon conducted one relatively similar experiment with *C. elatum* var. *vittatum* to assess the formaldehyde removal ability of this species under Laboratory Chamber Conditions. However, the study results did not support the conclusion obtained from the previous research of NASA [6] on the formaldehyde absorption ability of spider plants' leaves. It found that other factors such as soil moisture, plant roots, soil surface, microorganism or a combination of all, and a moisture-related source phenomenon [7] plays the major role in reducing the concentration of formaldehyde in the experimental chambers. In 1993, Wolverton B.C. and Wolverton J. D conducted the experiments with over thirty interior plants to test their formaldehyde removal ability and revealed that not only the role of plant leaves, but also the contribution of soil microorganisms in detoxifying indoor gaseous formaldehyde. In one study of Kim et al. [8], the researchers compared the volatile formaldehyde removal ability of above ground plant parts with that of the root zone during the day and night. The results also shown that root zone and microorganisms absorbed formaldehyde much more efficient than the aerial plant parts, particularly at night. Developing from experiments with airtight chambers under laboratory conditions, Kim et al [9] also evaluated formaldehyde removal ability of some plant species when these pot plants were placed in actual rooms. The assessment was based on the ratios between volume of pot plants and that of the room. The study acquirement suggested that pot plants making up 1% of the room's volume can diminish formaldehyde by about 7%. In many of other studies, some common plant species were chosen as the formaldehyde phytoremediation agents for indoor environment, singly or in group, such as: spider plant (*Chlorophytum elatum* var. *vittatum,* golden pothos *(Scindapsus aureus),* and English ivy *(Hedera helix)* [6-7, 10-13]. In all the researches, these species were proven efficient in abating indoor formaldehyde.

In Vietnam, up to present, researches on using plants to remove toxic pollutants in indoor air are still relatively new and limited. Therefore, this research is necessary and urgent in order to provide a scientific and practical basis for indoor formaldehyde pollution treatment by using native plant species in Vietnam.

MATERIALS AND METHODS

The selected plants species for study

Ten native plant species had been taken from the nature in January (2011). The qualified trees are selected and planted in pots which are maintained to make sure trees live and grow normally. The studied pots were placed in a room for one month before implementing the experiment. Characteristics of each experimental plant, such as: plant height, leaf area, canopy diameter, and leaf color are meticulously identified before the experiment (Table-1).

Table-1: Studied native plant species

No	Experimental species		H_a (cm)	D_a (cm^2)	S_a (cm^2)
	Native Vietnamese names	Scientific names			
1	Cỏ seo gà	*Pteris ensiformis* (Burmf.)	54	70	115
2	Cơm nếp	*Strobilanthes affinis* (Griff.) Y.G. Tang	26	59	6096
3	Đa xanh lá bóng	*Ficus vasculosa* Wall. ex Miq.	95	78	5020
4	Đu đủ rừng	*Trevesia palmata* (Roxb.) Vis.	65	70	630
5	Kim giao	*Nageia fleuryi* (Hickel) de Laub.	62	78	4535
6	Mạch môn đông	*Ophiopogon japonicus* (L. f.) Ker-Gawl.	54	74	5121
7	Mía dò	*Costus speciosus* Sm.	83	78	4669
8	Ráng vi lân	*Macrothelypteris torresiana* (Gaud.) Ching.	70	55	4724
9	Ráy	*Alocasia odora* (Roxb) C.Koch.	73	78	366
10	Thiên niên kiện	*Homalomena* occulta (Lour.) Schott	65	50	165

H_a: average height of tree clusters in the experimental chambers;
D_a: average canopy diameter of tree clusters in the experimental chambers;
S_a: average leaf area of tree clusters in the experimental chambers.

Formaldehyde formation

Formaldehyde was extracted from formalin solution sold on the market with a concentration of 37-40% by headspace method. 150 ml of formalin solution was poured into a three-neck flask of 500 ml. The main neck of the

flask is sealed with a rough button, the first auxiliary neck is connected to the valve of the experimental chamber, and the second auxiliary one is connected to the output of the pump. The flask was placed in a bain – marie at a temperature of 50^0C and a clean air flow from the pump with velocity of 1lit/minute passed through the surface of the formalin solution to carry formaldehyde escaped from the liquid into the test chamber.

Design of the experimental chambers

Sealed experimental chamber is made of glass with dimensions of 60 x 60 x 100 cm (length x width x height). Inside the experimental chambers, fans are mounted to stir the air in the chamber. Each experimental chamber has two alloy valves, in which one valve was used to transfer formaldehyde from the outside into the inside of experimental chamber and, simultaneously, it also was used to suck the air from the experimental chamber after the studied plant had been in contact with formaldehyde for a specific period of time. The remaining valve was used to add air into the chamber to balance the pressure during the air suction process from the chamber to analyze the concentration of formaldehyde.

The equipment and chemicals used for formaldehyde analysis

- An air sampling machine HS-07 made by the Kimoto (Japan) has two connected impinger tubes, and a speed of air suction of from 0.5 to 2.5 l/min;
- A UV-VIS Spectro Dualbeam is made in the United States;
- A shaking temperature controller is made in Korea, heated up to 100^0C;
- Chromotropic acid is made in England;
- Purely concentrated H_2SO_4 acid and formalin concentration of from 37 to 40%.

Experimental arrangement method

Each experimental species were conducted with three replicates by placing three pots in three chambers and using vazolin to hermetically seal the chamber covers. Formaldehyde extracted from the formalin solution was directly pushed into the test chambers for 8 minutes. In the process of pushing formaldehyde into the experimental chambers, to avoid increasing pressure in the experimental chambers, a second valve of the chamber is connected to the suction of the pump. Therefore, these experiments had used the air in the test chamber to push formaldehyde separated from formalin solution into the experimental chambers. After the process of transferring formaldehyde into the chamber finished, fans in the experimental chamber were turned on to stir the air for 10 minutes. After that, 8 liters of air in the test chamber were taken to determine the beginning formaldehyde concentration of the experiment process. The formaldehyde sampling method followed the procedure of the 3500 method of NIOSH [14] in which 1% $NaHSO_3$ solution was used as the absorption liquid; the gas flow rate through the absorption solution was 1 l/min; two impinger tubes connected in series were used to absorb formaldehyde and each tube contained 20 ml of $NaHSO_3$ solution. Clean air after passing through two absorption solution was sent back into the test chamber through the second valve. Thus, the process of sucking the air from the chambers to analyze the concentration of formaldehyde did not reduce the pressure in the experimental chamber.

Fig.-1: Formaldehyde transfer to the experimental chambers.

After the exposure periods of 24 hours and 48 hours, 8 liters of air were respectively taken from the chambers to check the remaining formaldehyde concentration in the experimental chamber method according to the 3500 method as described above. During the experiment process (48 hours), the temperature and humidity in each chamber were carefully controlled via a thermal hygrometer placed in the chamber. Along with three experimental chambers conducted for the same species, experiments were simultaneously carried out with three control chambers (without trees) following the same procedure described above. This experiment was used to evaluate the deposition as well as biodegradation of formaldehyde in each experimental chamber.
Formaldehyde in absorbing solution was analyzed by the 3500 method of NIOSH. This solution reacted with chromotropic acid in the concentrated H_2SO_4 acidic condition to form a purple complex. The absorbance of this complex was measured by the UV-Visible Spectroscopy to quantify formaldehyde in the solution.

Fig.-2: Formaldehyde sampling from the experimental chambers

Method of experimental result processing

Formaldehyde in the experimental chambers removed by plants is calculated by the following equation [15, 16]:

$$m_{i\text{-}t} = \frac{H_{i-t} - H_{dc-t}}{100S} C_i V \text{ , } (\mu g/cm^2)$$

Where:

$m_{i\text{-}t}$: amount of formaldehyde absorbed by species i per one unit of leaf surface area (cm^2) in the experimental chambers for a period of t (hour), ($\mu g/cm^2$);

$H_{i\text{-}t}$: formaldehyde removal efficiency of species i at time t,%;

$H_{dc\text{-}t}$: formaldehyde removal efficiency in the control chambers at time t,%;

$$H_{i-t} = \frac{C_i - C_{i-t}}{C_i} x100,\%$$

$$H_{dc-t} = \frac{C_{dc} - C_{dc-t}}{C_{dc}} x100,\%$$

C_i, C_{dc}: formaldehyde concentration in the experimental chambers and control chambers, respectively, as soon as after the first air suction from the chambers, $\mu g/m^3$;

$C_{i\text{-}t}$, $C_{dc\text{-}t}$: the concentration of formaldehyde in the experimental chambers and control chambers at time t ($\mu g/m^3$)

V: volume of the experimental chamber, V = 0.36 m^3

S: the total surface area of leaves of the plants in the experimental chambers (cm^2)

$$C_i = C_{0i} - \frac{V_{ri} x C_{0i}}{0.36}$$

$$C_{dc} = C_{0dc} - \frac{V_{rdc} x C_{0dc}}{0.36}$$

C_{0i}, C_{0dc}: formaldehyde concentration in the experimental chambers and control chamber immediately after injecting formaldehyde into the chambers, ($\mu g/m^3$);
V_{ri}, V_{rdc}: volume of air in the experimental chambers placed trees and the control chamber drawn out to determine the concentration of formaldehyde.

RESULTS AND DISCUSSION

Environmental Conditions in the Experimental Chambers:

Humidity

After placing trees into the experimental chambers, humidity in the chambers is usually increased. For example, in this study, when the environmental moisture with the lowest value in the experiment was 65%, after placing trees in the experimental chambers, the humidity increased and reached 95% after 2 to 3 hours. For the experimental chambers without plants (control chambers), the humidity also increased but with slower rates. Although without trees, the humidity in the control chambers still reached the value of 95%, but the period to reach this value was 30 minutes longer than that of the experimental chambers. Cause of the increased humidity in the control chambers was that the pots placed in the chamber still contained soil with certain moisture. In a closed environment without air exchange with the outside, humidity in the experimental chamber increased gradually with time. Notably, after from 2.5 to 3.0 hours, humidity in both the experimental and control chambers were equal and reached 95%. In other words, moisture in two kinds of chambers was relatively equilibrium. Therefore, moisture factor could not significantly affect the process of removing formaldehyde during the experiment. Figure 03 shows the change in humidity in the experimental chambers.

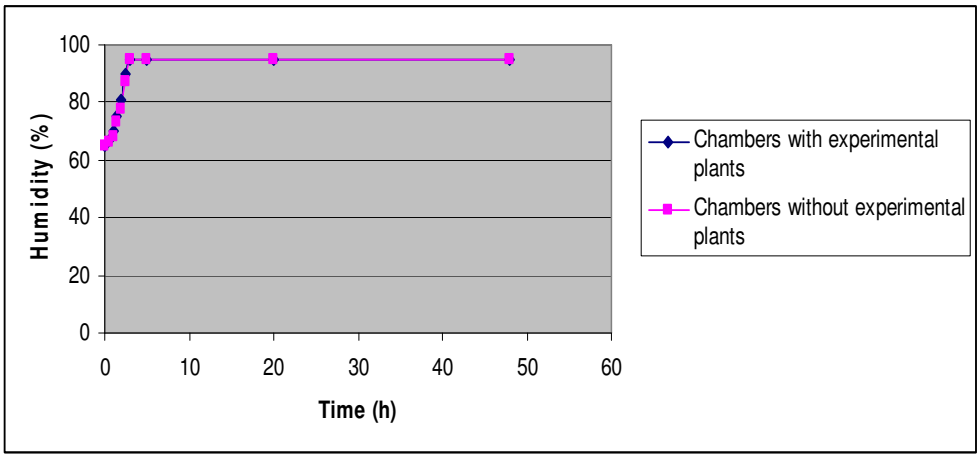

Fig.-3: Humidity in the experimental and control chambers

Temperature

Temperature in the experimental chamber was also monitored during the experiment. The results showed that there was any significant difference between temperature in plant - placed experimental chambers and that in the control chambers. Temperature in the whole process of the study ranged from 18 to 28^0C.

Light

Study results showed that light measured in the experimental chambers always had a value of 95% of that outside the experimental chambers. In other words, light factor could not significantly affect the photosynthetic capacity of the plant during the experiment.

Input concentration of formaldehyde

Initial concentration of formaldehyde in each experimental chamber ranged from 10 to 13 mg/m^3. Although this concentration level is higher than the concentration of formaldehyde in a real indoor environment, it is necessary to conduct the research at this exposure concentration in order to ensure the detection limit and appropriate sampling period for study.

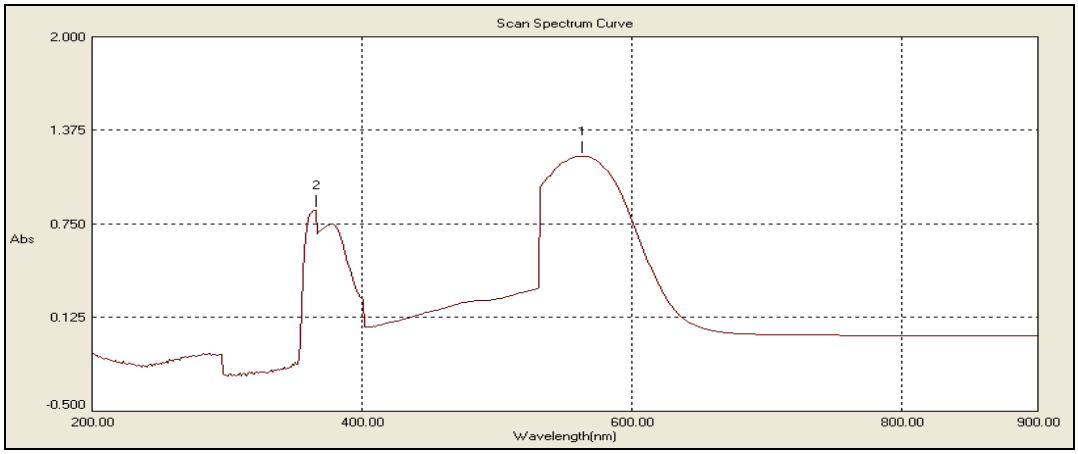

Fig.-4: Molecular absorption spectrum of formaldehyde after reacting with chromotropic acid

Formaldehyde removal capability of ten native plant species

Formaldehyde removal capability of ten native plant species under the exposure condition at a concentration range of 10 to 13 mg/m^3 in a sealed chamber and exposure periods of 24 hours and 48 hours are shown in Table-2.

Study results showed that *P. ensiformis* (Burmf.) had the highest efficiency in removing formaldehyde of the 10 species studied. In 24 hours, this plant removed 16.4 µg/cm^2 leaf surface areas. The two following species are *L. javanensis* Bl. which eliminated 6.5 µg/cm^2 and *H. occulta* (Lour.) Schott having formaldehyde removal ability of 5.1 µg/cm^2. Three species that had the lowest efficiency of formaldehyde removal are *O. japonicus* (L. f.) Ker-Gawl. (0.57 µg/cm^2), *F. vasculosa Wall*. ex Miq. (0, 56 µg/cm^2) and *N. fleuryi* (Hickel) de Laub. (0.27 µg/cm^2).

Table-2: Formaldehyde removal capability of ten native plant species (Unit: µg/cm^2)

Vietnamese native names	Scientific names	Exposure period	
		24 hours	48 hours
Cỏ seo gà	*Pteris ensiformis* (Burmf.)	16.40	18.30
Ráng vi lân	*Lindsaea javanensis* Bl.	6.50	6.90
Thiên niên kiện	*Homalomena occulta* (Lour.) Schott	5.10	9.80
Ráy	*Alocasia odora* (Roxb) C.Koch.	4.30	5.20
Đu đủ rừng	*Trevesia palmata* (Roxb.) Vis.	2.20	2.80
Cơm nếp	*Strobilanthes affinis* (Griff.) Y.G. Tang	1.28	1.30
Mày dò	*Costus speciosus* Sm.	1.17	2.20
Mạch môn đông	*Ophiopogon japonicus* (L. f.) Ker-Gawl.	0.57	0.58
Đa xanh lá bóng	*Ficus vasculosa Wall*. ex Miq.	0.56	0.57
Kim giao	*Nageia fleuryi* (Hickel) de Laub.	0.27	0.34

Research results also showed that the formaldehyde removal capability of ten native plant species in the first 24 hours of exposure was much larger than that in the next 24 hours of exposure. In the first 24 hours, the ability to remove formaldehyde was from 0.27 µg/cm^2 to 16.4 µg/cm^2 leaf surface area. In the next 24 hours, the removal ability was from 0.07 µg/cm^2 to 1.9 µg/cm^2 leaf surface area.

Growth situation of these species after the experiments

After having been in contact with formaldehyde for 48 hours, the plants were removed from the experiment chambers and placed in a room. The growth of these plants was monitored in next 15 days. Monitoring results showed that only *O. Japonicus* (L. f.) Ker-Gawl. Species had the leaf chlorosis phenomenon after exposure to formaldehyde gas for 48 hours. The number of leaf chlorosis accounted for 50% of the total number of leaves of the tree and fell out after a few days later. The remaining leaves continued to growth when the exposure ended. All the remaining trees had no phenomenon and grew normally after 15 days of observation.

CONCLUSIONS

The study has identified the formaldehyde removal capability of ten indigenous species. Three species that had the highest efficiency in removing formaldehyde are *P. ensiformis* (Burmf.) (0.38 - 0.68 μg/cm^2/hour), *L. javanensis* Bl. (0.14 - 0.27 μg/cm^2/hour) and *H. occulta* (Lour.) Schott (0.20 - 0.21 μg/cm^2/hour). The species with the least capability to remove formaldehyde are *O. japonicus* (L. f.) Ker-Gawl., *F. vasculosa Wall*. ex Miq., and *N. fleuryi* (Hickel) de Laub. After 48 hours of exposure to formaldehyde at a concentration range from 10 to 13 mg/m^3, *O. japonicus* (L. f.) Ker-Gawl. species had the leaf chlorosis phenomenon and grew poorly. The remaining trees grew normally. The plant species studied are highly aesthetic and can be grown indoor as ornamental plants. In addition, they have the capability to remove toxic formaldehyde in the air.

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