Measuring the Uptake Rates of Formaldehyde by 16 Plant Species in Taiwan

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Urban Air Quality in Taiwan

Most important air pollutants in Taiwan

	Pullutant	Distribution
Primary pollutants	Fluorides	Around industrial areas
	Chlorine	Around industrial areas
	Nitrogen oxides	Urban and suburbs
	Particles	Local areas or whole island
	HCl, C_2H_4, NH_3	Around industrial areas
Secondary pollutants	Ozone	Urban and suburbs
	PAN	Urban and suburbs
	Acid rain	Whole areas

Four big areas were found to be affected by PAN and ozone in Taiwan at present time

Major indoor air pollutants

- Gases：HCHO (Formaldehyde), CO_2 , SO_2, NO, NO_2, Cl_2, HCl, NH_3, H_2S, C_6H_6 (Benzene)
- Particles：Dust, suspended particles, PM10, PM2.5 = Respirable suspended particles, bioaerosal,

Adverse Effects of Formaldehyde

- Formaldehyde is an irritant to the conjunctiva and upper and lower respiratory tract, causing the syndrome of burning or tingling sensations to eyes, nose, throat, and may induce the respiratory illness or even asthma (Dally et.al., 1981; Olson & Dossing, 1982).
- It has been classified as a mutagen or probable human carcinogen by the US EPA or thought to be harmful to genetic substance (Chanet et al., 1975; Cooper 1979; Englesberg 1951; Nishioka 1973; Poverennyi et al., 1975; Wilkins & Macleod, 1976).
- The so-called sick building syndrome is also highly associated with this pollutant (Fischman 1997; Wu et al., 2003).
- Therefore WHO and Taiwan EPA have recommended the indoor concentration of formaldehyde as less than 0.1 ppm.

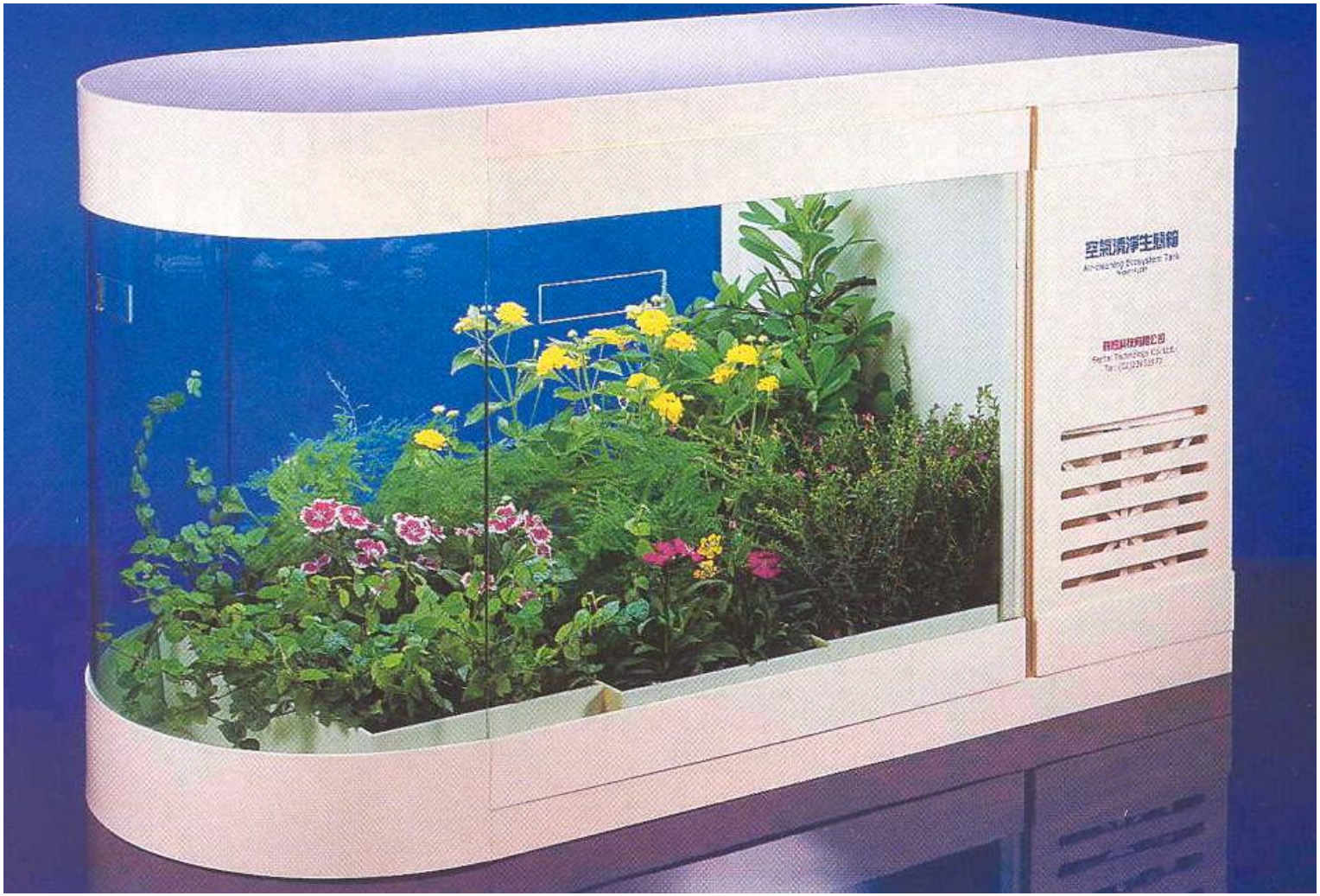
Indoor air quality standards proposed by Taiwan EPA

項　目（item）	建議值（proposed level）			單　位（unit）
二氧化碳（CO_2）	8小時值 (8 hr mean)	第1類 (Group 1)	600	ppm（體積濃度百萬分之一）
		第2類(G2)	1000	
一氧化碳（CO）	8小時值 (8 hr mean)	第1類(G1)	2	ppm（體積濃度百萬分之一）
		第2類(G2)	9	
甲醛（HCHO）	1小時值/11小時值(1h/11h)		013　0.1	ppm（體積濃度百萬分之一）
總揮發性有機化合物 (TVOC)	1小時值(1h)		3	ppm（體積濃度百萬分之一）
細菌(Bacteria)	最高值(max)	第1類(G1)	500	CFU/m^3（菌落數/立方公尺）
		第2類(G2)	1000	
真菌(Fungi)	最高值(max)	第2類(G2)	1 1000	CFU/m^3（菌落數/立方公尺）
粒徑小於等於10微米（μm）之懸浮微粒（PM_{10}）	24小時值(24h)	第1類(G1)	60	μg/m^3（微克/立方公尺）
		第2類(G2)	150	
粒徑小於等於2.5微米（μm）之懸浮微粒（$PM_{2.5}$）	24小時值(24h)		100	μg/m^3（微克/立方公尺）
臭氧（O_3）	8小時值(8 hr mean)	第1類(G1)	0.03	ppm（體積濃度百萬分之一）
		第2類(G2)	0.05	
溫度(Temperature)	1小時值(1h)	第1類(G1)	15至28	℃（攝氏）

Using Green Plants to Uptake Indoor Pollutants

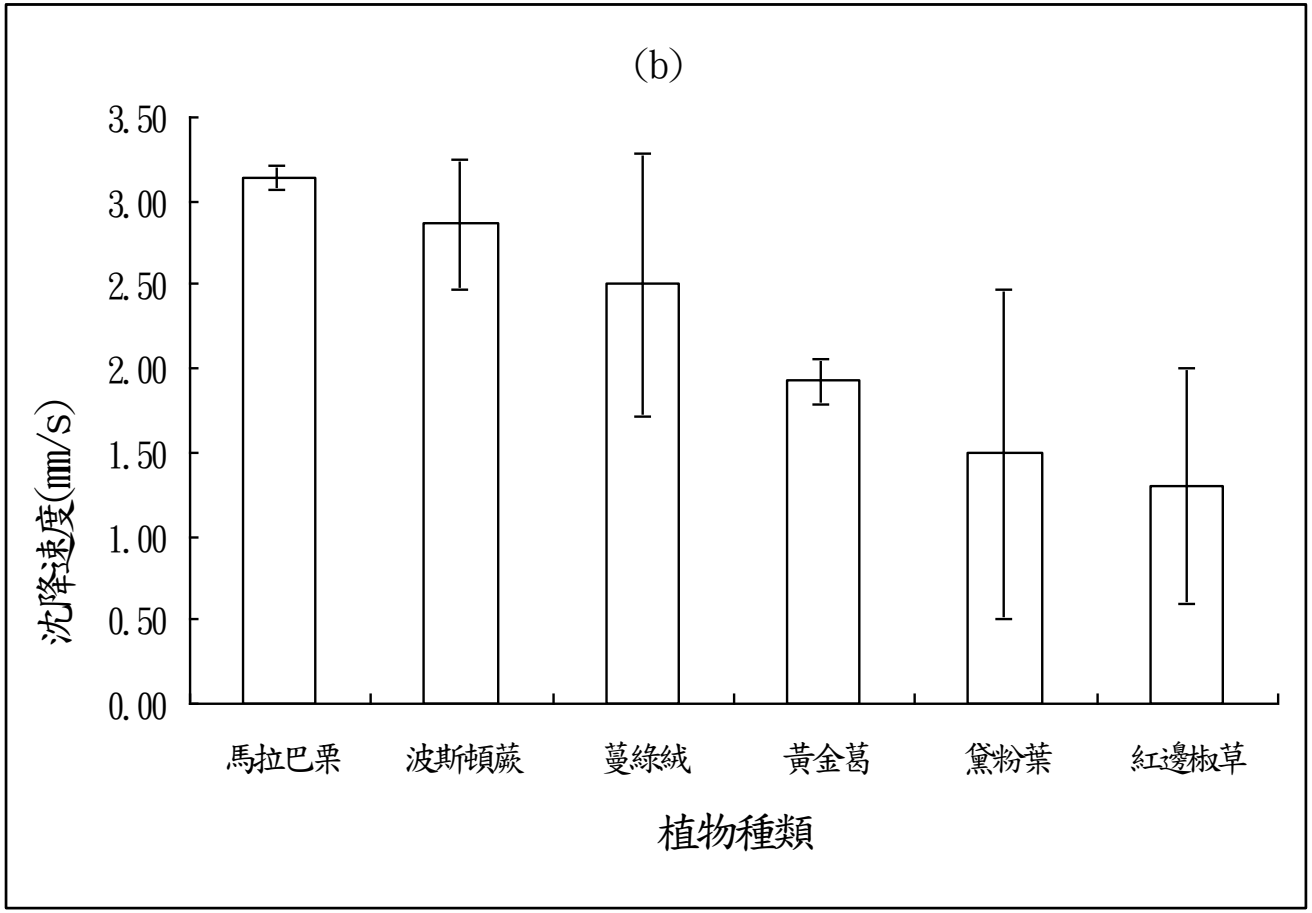
- National Aeronautics and Space Administration (NASA), had ever supported many researches on this topic.
- Wolverton & Wolverton (1992) published the 「Interior Plants and Their Role in Indoor Air Quality: An Review」, proving that indoor plants can remove the formaldehyde (HCHO) etc.

Air-cleaning Ecosystem Tank Developed by NTU



Air-cleaning Ecosystem Tank on desktop

Example: Uptake rate as deposition velocity of formaldehyde at concentration of 1.19±0.20 ppm on six plant species reported by our laboratory



Purpose of this study

☆The purpose of this study is to measuring the uptake rates of formaldehyde by 16 plant species in Taiwan.

☆ The tested species are camphor tree (*Cinnamomum camphora*), rose wood (*Pterocarpus indicus*), Formosan michelia (*Michelia compressa*), Formosan ash (*Fraxinus formosana*), red cedar (*Bischofia javanica*), Taiwan zelkova (*Zelkova serrata*), golden dewdrop (*Duranta repens*), azalea (*Rhododendron* spp.), common lantana (*Lantana camara*), common jasmin orange (*Murraya paniculata*), Chinese ixora (*Ixora chinensis*), South American wax mallow (*Malvaviscus arboreus*), umbrella plant (*Schefflera arboricola*), Malabar chestnut (*Pachira macrocarpa*), fan palm (*Livistona chinensis*), and bird's nest fern (*Asplenium nidus*).

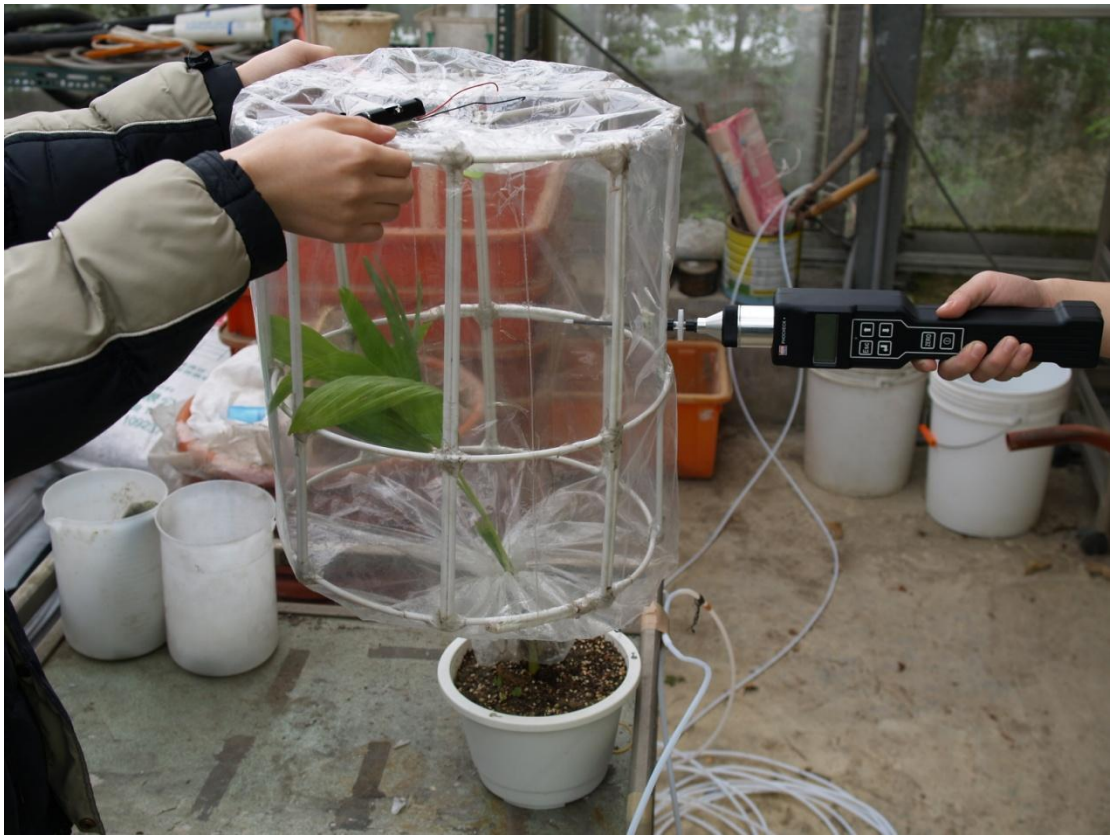
☆ A PP plastic bag branch chamber with size of 45 L was designed for measuring the formaldehyde uptake rates of these species.

Materials and Methods

- **Instruments for Measuring Formaldehyde Uptake**

A bag branch enclosure chamber was designed for measuring the formaldehyde uptake rate (Sun & Ho, 2005; Sun et al., 2009). It is made by a cylindrical plastic frame that is enclosed by a PP plastic bag with size of 45 L (Fig. 1). The diameter of the cylindrical chamber is 36 cm and the length is 42 cm to fit the size of PP bag. On the inner top of the bag chamber a mini electrical fan driven by dry battery was installed at the center to produce wind and circulate the target gas in the chamber.

The PP branch enclosure chamber for measuring formaldehyde uptake



Benzene detector

Sixteen test plants

- Six tree species：

camphor tree
(*Cinnamomum camphora*)

rose wood
(*Pterocarpus indicus*),

Formosan michelia
(*Michelia compressa*)

Formosan ash
(*Fraxinus formosana*)

red cedar
(*Bischofia javanica*)

Taiwan zelkova
(*Zelkova serrata*),

- Six shrub species：

golden dewdrop
(*Duranta repens*),

azalea
(*Rhododendron* spp.),

common lantana
(*Lantana camara*),

common jasmin orange
(*Murraya paniculata*),

Chinese ixora
(*Ixora chinensis*)

South American wax mallow
(*Malvaviscus arboreus*),

- Four indoor plants：

umbrella plant
(*Schefflera arboricola*),

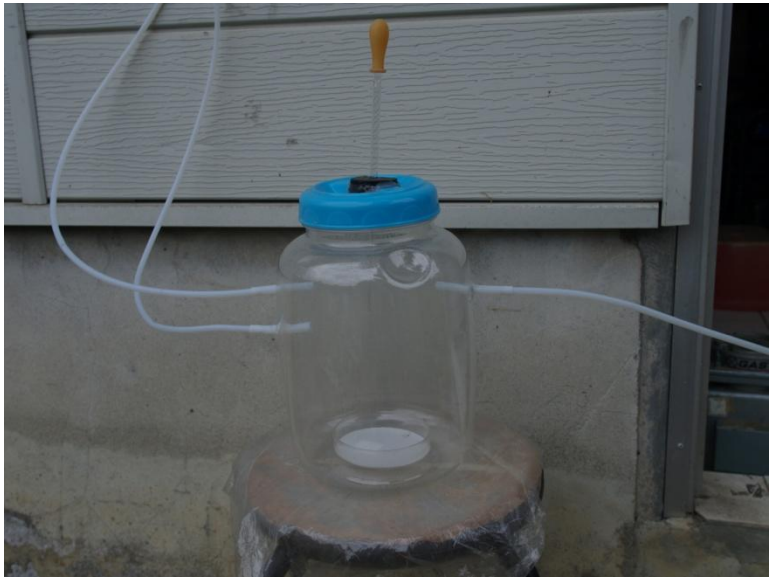
Malabar chestnut
(*Pachira macrocarpa*),

fan palm
(*Livistona chinensis*),

bird’s nest fern
(*Asplenium nidus*).

The formaldehyde generator developed by constant evaporation technique

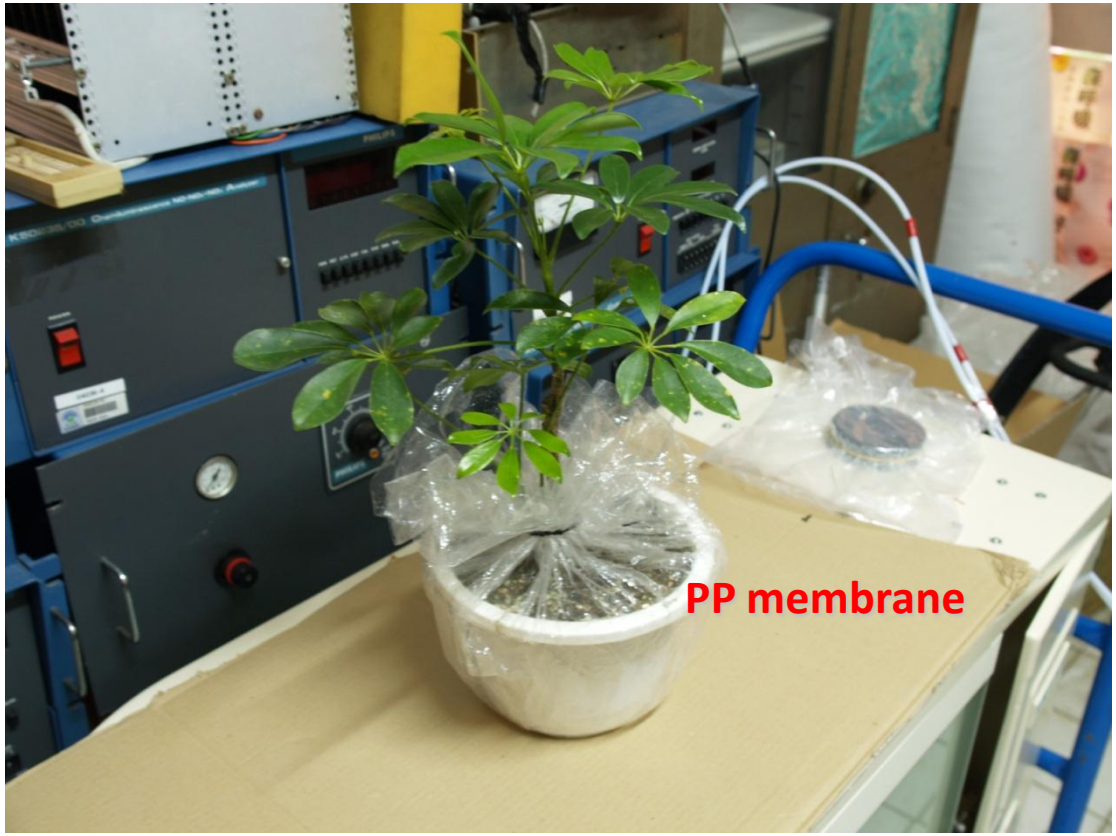
- The formaldehyde generator including a constant evaporation bottle and the blowing pump to conduct the gas to branch chamber
- The initial formaldehyde concentration in the branch chamber is 1-2 ppm.



evaporation bottle

The formaldehyde detector (middle) and CO_2 detector (right)

Before the plant pots were enclosed into the branch chamber the soil pot were sealed with PP membrane to avoid the uptake by soil.



Measuring the formaldehyde uptake rate

- Healthy pot plants were enclosed with the branch chamber and the bottom of the bag was tied tightly to keep the chamber in a cylindrical shape.
- The formaldehyde gas was produced by gas generator and introduced into the branch chamber from the bottom immediately.
- The formaldehyde concentrations were monitored by the formaldehyde detector since the pot plant was enclosed. The concentration change was calculated and the deposition velocity could be obtained.

Calculation

The concentration change in each experiment was calculated, adjusted by the blank change value, and converted to deposition velocity by the following equation:

$$Vd = \{[HCHO_{cp}] - [HCHO_{cb}] \}/ [HCHO_{co}] \times S \div A \div t$$

- Where Vd is deposition velocity in unit of mm/sec.
- $HCHO_{cp}$ is formaldehyde concentration change when plant shoot or branch was enclosed, in unit of ppb.
- $HCHO_{cb}$ is blank formaldehyde concentration change when blank stem was enclosed, in unit of ppb.
- $HCHO_{co}$ is formaldehyde concentration at starting point, or time 0, in unit of ppb.
- S is the chamber size in unit of mm3.
- A is the total leaf area in unit of mm2.
- t is the measuring time for the experiment, in unit of sec.

Results and Discussion 1

1-1. Performance of the Bag Branch Enclosure chamber for measuring the formaldehyde uptake

☆ The formaldehyde detector (Formaldemeter, PPM Ltd.) used in this study worked pretty well and performed constantly, although its responding time was longer.

☆ For each measurement it inhaled a constant volume of air and showed up the result in about 1 minute. While this formaldehyde detector needs another 2-3 minutes for self-cleaning, so it can do the job only at the interval of 4-5 minute.

Blank depletion of formaldehyde in this PP chamber

Table 2. Concentration change of formaldehyde in empty bag enclosure chamber

	Concentration change of HCHO in empty bag chamber over the time of 900 seconds				Slope* (ppb/sec)	slope/ppb** (/sec)
Time (sec)	0	300	600	900		
Run 1	1.01	0.83	0.75	0.68	-0.00036	-0.00035
Run 2	1.23	1.17	1.09	1.05	-0.00021	-0.00017
Run 3	1.11	0.8	0.7	0.6	-0.00054	-0.00049
Run 4	1.35	1.14	1	0.75	-0.00065	-0.00048
Run 5	0.98	0.82	0.79	0.72	-0.00027	-0.00028
Average						-0.00035

Concentration change of formaldehyde and deposition velocity of 2-year-old camphor tree

	Concentration change of HCHO in bag branch chamber over the time of 900 seconds				Slope/ ppb (/sec)	Total leaf area (cm^2)	Vd* (mm/s)
Time (sec)	0	300	600	900			
Plant 1	0.8	0.56	0.45	0.36	-0.0006	273.7	0.439818
Plant 2	0.65	0.4	0.25	0.22	-0.00074	668.9	0.285726
Plant 3	0.99	0.73	0.54	0.45	-0.00061	316	0.402282
Blank	1.01	0.83	0.75	0.68	-0.00035		
Mean							0.38

* $Vd = \{[HCHO_{cp}] - [HCHO_{cb}] \} / [HCHO_{co}] \times S \div A \div t$

Results 2 **Screening the Common Plant Species for High Formaldehyde Uptake in Taiwan**

Table 4. Deposition velocity of formaldehyde on 16 common plant species measured with bag branch enclosure method

Tree	Vd(mm/s)	Shrub	Vd(mm/s)	Indoor plant	Vd(mm/s)
Camphor	0.38^{abcde}	Golden dewdrop	0.25 ^{cdefgh}	Umbrella plant	0.20 ^{efgh}
Rose wood	0.23 ^{defgh}	Azalea	0.19 ^{fgh}	Malabar chestnut	0.27 ^{cdefg}
Formosan michelia	0.28 ^{cdefg}	Common latana	0.08 ^{h}	Fan palm	0.22 ^{efgh}
Formosan ash	0.26 ^{cdefg}	Jasmin orange	0.55 ^{a}	Bird's nest fern	0.17 ^{gh}
Red cedar	0.41 ^{abc}	Chinese ixora	0.53 ^{ab}		
Taiwan zelkova	0.36 ^{bcdef}	South American wax mallow	0.41 ^{abcd}		

•Vd data are mean of three replicates, those with the same letter were not significantly different

• by least significant difference test (P=0.05)

Results and Discussion 2

☆ **Results in Table 4 showed that formaldehyde is uptaken most effectively by the shrub jasmin orange, Chinese ixora, and South American wax mallow.**

☆ **For trees the higher uptake happened on red cedar, camphor tree, and Taiwan zelkova.**

☆ **Shrubs such as golden dewdrop, azalea, trees such as Formosan michelia, Formosan ash, and rose wood, and indoor plants such as Malabar chestnut, fan palm, and umbrella plant, showed medium levels of uptake of formaldehyde.**

☆ **Whereas common lantana and bird's nest fern showed the lowest uptake rates.**

Results 3-1 Comparison of deposition velocity of formaldehyde at different light intensity

Table 5. Comparison of deposition velocity of HCHO on 13 plant species at different light intensity

Plant name	Deposition velocity of HCHO at different light intensity (mm/sec)		
	5000 lux	500 lux	Dark room
Camphor	0.38 a	0.36 a	-0.13 b
Rose wood	0.23 a	0.02 b	-0.09 b
Formosan michelia	0.28 a	0.16 ab	0.09 b
Formosan ash	0.26 a	0.14 ab	-0.26 b
Red cedar	0.40 a	0.16 b	0.29 ab
Taiwan zelkova	0.37 a	0.22 a	-0.05 b
Golden dewdrop	0.25 a	0.13 a	-0.05 b
Jasmin orange	0.55 ab	1.00 a	0.21 b
South American wax mallow	0.41 a	0.34 a	0.36 a
Umbrella plant	0.20 a	0.20 a	0.28 a
Malabar chestnut	0.27 a	0.25 a	0.10 b
Fan palm	0.22 a	0.07 b	0.07 b
Bird's nest fern	0.17 a	0.22 a	0.13 a

Results and Discussion 3-1

☆ **Results in Table 5 indicated that most plant uptake less formaldehyde in dark situation. Two exceptions are umbrella plant and South American wax mallow, that they can uptake even higher in dark.**

☆ **Under higher light level of 5000 lux, most plants uptake more formaldehyde than in common room light condition of 500 lux, but with a few exceptions such as jasmin orange, bird's nest fern, and umbrella plant.**

Results 3-2 Comparison of deposition velocity of formaldehyde at different CO_2 level

Plant name	Deposition velocity of HCHO at different CO_2 level (mm/sec)※		
	Low CO_2	High CO_2	Ratio of Low/High
Camphor	0.64	0.41	1.56
Rose wood	0.03	0.04	0.75
Formosan michelia	0.34	0.30	1.13
Red cedar	0.22	-0.36	—*
Taiwan zelkova	0.17	0.14	1.21
Common latana	0.17	0.17	1.0
Jasmin orange	0.67	0.53	1.26
Chinese ixora	0.36	0.18	2.0
South American wax mallow	0.88	0.63	1.4
Umbrella plant	0.27	0.20	1.35
Malabar chestnut	0.28	0.07	4.0*
Fan palm	0.10	0.06	1.6
Bird's nest fern	0.04	0.05	0.8

※ Low CO_2 level was 300-400 ppm, high CO_2 level was 600-700 ppm or about doubling the lower ones, the ratio with * mark meant that there was significantly difference between the pair by the paired-t test (P=0.05).

Results and Discussion 3-2

☆ **Generally the formaldehyde uptake rates were decreased when ambient CO_2 concentrations were doubled. Whereas rose wood and bird's nest fern did not show apparent difference.**

☆ **Because high level of CO_2 had been reported to make the stomata close quickly, the uptake rate was therefore decreased.**

Conclusion and Recommendation

☆ All the above results indicated that most plant are useful for formaldehyde uptake.

☆ Thus if people grow a lot of them in indoor or office areas, they can work as the formaldehyde remover as Wolverton (1996) reported in his book: How to Grow Fresh Air -- 50 – Houseplants that Purify Your Home or Office.

☆ Our data, however, were more precisely to compare the uptake efficacy of common plant species found in Taiwan.

☆ We recommend that people and organizations have better to select the better plant species for growing in indoor areas or even neighborhood parks to clean the dirty air.

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