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Response of *Marantaceae* and Pteridophytes potted plants for purification of formaldehyde polluted air

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Ten plants from *Marantaceae* families and ten plants from *Pteridophytes* were tested for their abilities of removing formaldehyde (FDH) in the air. Each of the plants was placed in a 1.0 ×1.0 × 0.8 m glass box filled with FDH for seven days with the initial concentration as 15 mg m^{-3}. These plants such as *Neottopteris nidus cv. Volulum, Calathea lubbersiana* showed the most resistant ability to FDH damage; species such as *Calathea ornata, Calathea setosa, Calathea freddy, and Calathea roseo-picta* showed more resistant ability to FDH damage; species such as *N. nidus, Pteris fauriei, Pteris ensiformis cv. Victoriae, Pteris cretica cv. Albolineata, Nephrolepis cordifolia, Cyclosorus parasiticus, Blechnum orientale, Maranta bicolor, and Calathea zebrina* showed the worst resistance to FDH. The absorption of FDH by plants in the glass box chamber was found especially apparent during the first three days. The fastest purification of FDH was found in species such as *C. zebrina, M. punctatum*, and the slowest was found in species such as *C. parasiticus, P. ensiformis cv. Victoriae, N. nidus cv. Volulum, and C. setosa.* In conclusion, 8 species of the potted plants which could be recommendable to be used for FDH purification were *N. nidus, Calathea rotundifolia, P. cretica cv. Albolineata, C. ornata, P. bifurcatum, N. nidus cv. Volulum, C. roseo-picta, and C. freddy.* These plants have high absorption ability to FDH and receive less damage.

Key words: Formaldehyde, Marantaceae, potted plants, Pteridophytes, purification.

INTRODUCTION

Increasing uses of resins and solvents such as formaldehyde (FDH) in construction and decoration materials have caused severe pollution of indoor air. FDH is a kind of colorless chemical with a strong pungent odor, and specially steadily releasable for three to fifteen years. FDH together with other chemical such as benzene causes serious hazards to human health and is classified as the first class of human carcinogens by International Agency for Research on Cancer (IARC) because it is capable of inducing cancers and tumors.

Interest in the indoor air quality has become an earnest issue in China since there is a serious problem of excessive use of FDH in housing construction, reformation and decoration. Yu and Tang (2005), monitored more than fifty new decorated bedrooms and found that the pollutants such as FDH, benzene and other volatile organic compounds exceeded the limited standards by 36.8, 38.4 and 12%, respectively (Yu and Tang, 2005). The adoption of energy-saving proposals to reduce releases of indoor pollutants in homes has

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Table 1. Twenty potted plants used from the *Marantaceae* and Pteridophytes.

Marantaceae	**Pteridophyte**
Calathea crocata	*Blechnum orientale*
Calathea freddy	*Cyclosorus parasiticus*
Calathea lubbersiana	*Microsorum punctatum*
Calathea makoyana	*Neottopteris nidus*
Calathea ornata	*Neottopteris nidus* cv.Volulum
Calathea roseo-picta	Nephrolepis cordifolia
Calathea rotundifolia	*Platycerium bifurcatum*
Calathea setosa	*Pteris cretica* cv.Albolineata
Calathea zebrina	*Pteris ensiformis* cv. Victoriae
Maranta bicolor	*Pteris fauriei*

caused problems of inefficience in improvement of indoor air quality and consequently allowed potential health hazards remaining. It is one of today's hot research subjects that the air pollutants from construction and decoration materials be absorbed and removed by indoor plants. The early research was carried out by Wolverton of National Aeronautics and Space Administration (NASA) and the research group listed the top ten plants which were effective in clearing and elimininting odor, purifying air, and absobing and decomposing FDH, benzene and other pollutants (Wolverton, 1997; Wolverton et al., 1985). These plants include spider plant (*Chlorophytum comosum*), English ivy (*Hedera nepalensis* var. *sinensis*), *Aloe vera*, *Dracaena sanderiana*, *Dracaena marginata*, *Dracaena fragrans* var. Massa-ngeana, mother-in-law's tongue (*Sansevieria trifasciata*), *S. trifasciata*, *Gerbera jamesonii*, Chinese evergreen (*Aglaonema spp*.), peace lily (*Spathiphyllum floribundum* cv. Clevelandii), and *Pritchardia gaudichaudii*. In recent years, many researchers and scientists focused on selection of plant species that are effective in absorbing or removing FDH from indoor air (Li, 2006; Zhou et al., 2006; Huang et al., 2008; Cao et al., 2009; Xiong and Su, 2009; Wu, 2006).

Plants such as *Monstera deliciosa*, *Ficus elastic*, *C. comosum*, and *Opuntia strictia* have proved capable of absorbing FDH from air. However, effective species are still limited. Noticeably, it is still difficlut to eliminate FDH, benzene and other indoor air pollutants in low concentrations. The previous studies showed that many potted plants had more or less abilities of absorbing and decomposing FDH and benzene. Moreover, the pots, media and microorganisms in the media also showed ability of absorbing FDH to a some extents. However, the puricication effects of the tested plants, such as *C. comosum* and *Scindapsus aureun*, were inconsistent with different researches. Authough ten species of the plants such as *S. aureun*, *Asparagus setaceus*, *S. trifasciata* cv. Hahnii, *C. comosum*, *Aglaonema commutatum* cv. White Rajah, *Aglaonema commutatum* cv. Red Narrow, *Aglaonema commutatum* cv. Treubii, *Scindapsus pictus* cv.Argyraeus, *Gasteria gracilis*, *Philodendron sodiroi* cv. Wendimbe used were recommended for FDH purification (Zhou et al., 2011). But there is still much work to seek for more plants not only with the good performance to remove air pollutants, but also with less or no damage to human. Therefore, in the present study, plants from the *Marantaceae* and Pteridophytes were tested for their abilities to absorb or remove indoor FDH and other pollutants as well as the resistance to FDH damage, in order to provide reference to the utilization of plants for indoor air purification.

MATERIALS AND METHODS

Plant materials and experimental treatments

Twenty potted plants from the *Marantaceae* and Pteridophytes were used as experimental materials (Table 1). The tested potted plant was placed in a glass box chamber with a wall 0.8 mm thick and inside volume of 0.8 m^3 (1.0 × 1.0 × 0.8 m). Inside the chamber placed a small fan and a thermometer. The probe of formaldehyde (FDH) inspector (Ke Ernuo trading Co., Ltd. of Shenzhen) was inserted into the chamber through a hole of 1 cm in diameter. The mouth of the hole was removable and fitted with a rubber gasket and clamps to provide an airtight seal (Wolverton, et al., 1985). The initial concentration of formaldehyde was set up to 15 mg m^{-3}. The experimental temperature was controlled at 20±1°C. Three treatments were designed as 1) plant potted in the medium was placed in the chamber with 15 mg m^{-3} FDH, 2) the pot with medium but without plant was placed in the chamber with 15 mg m^{-3} FDH, and 3) the chamber only filled with 15 mg m^{-3} FDH as control.

Measurement of chlorophyll

Leaf chlorophyll was extracted by 95% ethanol (Wang, 2006). The concentration of the extracted chlorophyll was measured at 665 and 649 nm wave length using a UV-Vis spectrophotometer (TU-1810 Model, General analysis instrument Co., Ltd. of Beijing). Concentrations of chlorophyll *a* (C_A), chlorophyll *b* (C_B) and the total chlorophyll (C_T) were calculated using equations as $C_A = 13.7D_{665} - 5.76D_{649}$, C_B=$25.8D_{649} - 7.6D_{665}$, and $C_T = C_A + C_B - 6.10D_{665} + 20.04D_{649}$, where, D_{665} and D_{649} were the optical density (OD) values of chlorophyll at 665 and 649 nm, respectively.

Measurement of leaf cell membrane permeability

The leaf sample was rinsed 3 times with deionized water and the surface water was absorbed with filter paper. Then twenty leaf discs each in 0.5 cm diameter taken by hole puncher were immersed in 20 ml deionized water for three hours. The electrical conductivity (EC) (recorded as C_1) of the water after the leaf immersion was measured. Then the leaf sample was boiled for 15 min and the EC (C_2) was measured again after the water cooled down to the room temperature and was replenished to 20 ml with deionized water (Huang et al., 1990). The leaf cell membrane permeability (L_C) was calculated as L_C (%) = 100 × (C_1/C_2).

Other measurements

The formaldehyde concentration in the chamber was measured every day after the experiment began. The fresh aboveground part taken from the plant was weighed as fresh mass. Then these materials were dried in the microwave oven for dry mass

Table 2. Damage response and grade for twenty potted plants after treated by FDH.

Species	Response of potted plant	Grade
N. nidus cv.Volulum	A few spots on leaves.	1
C. lubbersiana	Only 8 tiny spots on leaves.	1
C. ornata	Only 1 etiolatied lower leaf blade, more spots on other leaves, most leaves were normal.	2
C. setosa	Only 2 etiolatied lower leaf blades, a few spots on other leaves, most leaves were normal.	2
C. freddy	Only 3 etiolatied lower leaf blades, a few spots on other leaves, most leaves were normal.	2
C. roseo-picta	Only 3 entirely brown lower leaf blades, more brown spots on other leaves, but stem in good condition.	2
P. bifurcatum	Browning and rotten on half leaves. The plant would recover from the damage.	3
C. makoyana	8 etiolatied leaves, densely black or water stains spots on some leaves.	3
M. punctatum	Black moldy on top leaf blades, normal damage on lower stem. The plant would recover from the damage.	3
C. crocata	4 etiolatied leaves, severe water stains spots on other leaves. The plant would recover from the damage.	3
C. rotundifolia	5 etiolatied leaves, many spots on other leaves, but stem in good condition. The plant would recover from the damage.	3
N. nidus	Completely water stains spots and mould on most leaves.	4
P. fauriei	Water stains spots on all leaves, plant dried.	4
P. ensiformis cv.Victoriae	Water stains spots on all leaves, plant dried.	4
P. cretica cv.Albolineata	Water stains on whole plant and died.	4
N. cordifolia	Most leaves were dropped, water stains on whole plant and died.	4
C. parasiticus	Water stains on whole plant and died.	4
B. orientale	Water stains on whole plant and died.	4
M. bicolor	Only few leaves were green, putrescence and sear on most leaves.	4
C. zebrina	Only 1 leaf blade was green, completely browning and died on other leaves.	4

determination (Yu et al., 2007). The degree of the plant hurt was scored from 0 through 1, 2 and 3 to 4 according to the extent of damage caused by formaldehyde.

RESULTS

Plant response caused by formaldehyde

The ranking for hurt response of potted plants to formaldehyde (FDH) pollution is as shown in Table 2 according to (Zhou et al., 2011). It was suggested that species such as *N. nidus* cv.Volulum, *C. lubbersiana* showed more resistant ability to FDH damage and grouped into Grade 1. These plants such as *N. nidus*, *P. fauriei*, *P. ensiformis* cv. Victoriae, *P. cretica* cv. Albolineata, *N. cordifolia, C. parasiticus, B. orientale, M. bicolor* and *C. zebrina* showed lower resistance to formaldehyde. The plants before (left in the frame) and after (right in the frame) were subjected to FDH pollution are shown in Figure 1. The concentration of formaldehyde in the chamber decreased fast in the first three days. The fastest purification of FDH was found in species such as *C. zebrine* and *M. punctatum* and the slowest was found in species such as *C. parasiticus*, *P. ensiformis* cv.Victoriae, *N. nidus* cv.Volulum, *C. setosa*, and *N. cordifolia* (Table 3).

Absorption of FDH by potted plants

As shown in Table 4, the top five plants which had high FDH absorption per dry weight were *N. nidus, C. rotundifolia*, *P. cretica* cv. Albolineata, *P. bifurcatum* and *C. ornata*. The hurt response of potted plants to FDH pollution was divided into 10 scores according to Zhou et al. (2011). The score of the FDH absorption per dry mass was made an adjustments, that was, used the 4th day's concentration substituted for the seventh day's. The integrated evaluation on the FDH purification effect of potted plants was shown in Table 5. The top eight plants for FDH purification effect according to their integrated evaluation are listed in Table 5. *N. nidus*, *C. rotundifolia*, *P. cretica* cv. Albolineata, *C. ornata*, *P. bifurcatum*, *N. nidus* cv.Volulum, *C. roseo-picta*, and *C. freddy* for the integrated score was surpass 3.60 respectively.

Changes in total chlorophyll concentration and cell membrane permeability

According to changes in cell membrane permeability (CMP), plants were divided into three groups. The first group, with change of more than 10%, includes 11 species such as *P. ensiformis* cv. Victoriae, *P. fauriei*, *P. cretica* cv. Albolineata, *C. parasiticus*, *C. makoyana*,

Figure 1. Photos of some potted plants before (left in the frame) and after (right in the frame) subjected to FDH pollution.

Table 3. FDH concentration per day (mg m^{-3}) in the chamber.

Species	----------Day after being treated-------------						
	1	2	3	4	5	6	7
N. nidus cv.Volulum	14.74	12.00	5.96	1.64	0.32	0.00	0.00
C. lubbersiana	13.40	12.45	3.54	1.27	0.28	0.00	0.00
C. ornata	14.09	11.56	1.94	0.36	0.07	0.04	0.01
C. setosa	14.87	13.40	5.63	2.79	0.98	0.12	0.00
C. freddy	14.09	6.07	1.47	0.14	0.00	0.00	0.00
C. roseo-picta	14.09	7.45	2.56	0.35	0.01	0.01	0.01
P. bifurcatum	13.40	4.73	1.23	0.32	0.11	0.07	0.07
C. makoyana	13.40	12.70	5.09	1.89	0.42	0.00	0.03

Table 3. Contd.

M. punctatum	14.09	1.11	0.23	0.05	0.00	0.00	0.00
C. crocata	14.74	10.32	4.62	2.99	0.56	0.26	0.04
C. rotundifolia	14.87	8.78	1.94	0.36	0.04	0.00	0.01
N. nidus	14.09	8.87	4.54	1.03	0.18	0.00	0.01
P. fauriei	13.40	7.44	4.66	2.47	1.29	0.47	0.04
P. ensiformis cv. Victoriae	14.87	7.95	6.24	4.30	2.65	1.09	0.26
P. cretica cv. Albolineata	14.09	3.85	1.94	0.62	0.26	0.05	0.03
N. cordifolia	13.40	13.40	5.15	2.23	0.12	0.12	0.05
C. parasiticus	14.74	12.61	7.34	3.30	2.12	0.48	0.08
B. orientale	14.09	8.12	2.60	1.34	0.11	0.08	0.04
M. bicolor	14.09	9.34	1.60	0.07	0.01	0.00	0.00
C. zebrina	14.74	7.29	0.07	0.04	0.04	0.04	0.04

Table 4. The FDH absorption content and absorption content per dry material of potted plants.

Species	Plant DM	Decrease in FDH	FDH absorption	FDHAB per DM
N. nidus cv.Volulum	10.53	13.10	2.84	0.27
C. lubbersiana	21.60	12.12	1.86	0.09
C. ornata	9.94	13.73	3.47	0.35
C. setosa	27.10	12.08	1.82	0.07
C. freddy	13.09	13.96	3.70	0.28
C. roseo-picta	10.86	13.75	3.49	0.32
P. bifurcatum	7.29	13.08	2.82	0.39
C. makoyana	12.81	11.51	1.25	0.10
M. punctatum	18.01	14.04	3.78	0.21
C. crocata	11.59	11.75	1.49	0.13
C. rotundifolia	8.82	14.51	4.25	0.48
N. nidus	4.66	13.06	2.80	0.60
P. fauriei	5.95	10.93	0.67	0.11
P. ensiformis cv. Victoriae	11.48	10.57	0.31	0.03
P. cretica cv. Albolineata	7.00	13.48	3.22	0.46
N. cordifolia	7.92	11.17	0.91	0.11
C. parasiticus	10.15	11.44	1.18	0.12
B. orientale	7.75	12.75	2.49	0.32
M. bicolor	11.58	14.03	3.77	0.33
C. zebrina	13.56	14.70	4.44	0.33

Plant DM, plant dry mass (g); Decr in FDH, decrease in FDH (mg m^{-3}); FDH absor, actual FDH absorption (mg m^{-3}); FDHAB per DM, actual FDH absorption per dry mass.

M. bicolor, *C. ornata*, *N. cordifolia*, *N. nidus*, *M. punctatum*,and *N. nidus* cv.Volulum. The second group with CMP change between 5 and 10% includes 6 species such as *C. ornata*, *C. crocata*, *C. zebrina*, *C. roseo-picta*, *P. bifurcatum* and *C. freddy*. The third group with CMP changes less than 5% includes 3 species such as *C. rotundifolia*, *B. orientale* and *C. lubbersiana*. However, there were no obvious relations of the FDH absorption ability with both the changes in total chlorophyll concentration, and the changes in cell membrane permeability (Table 6).

It maybe suggested that the lower the change in cell membrane permeability was, the stronger the FDH absorption ability was

DISCUSSION

Currently, it seems a bit confusing in ranking of the ability of plants to absorb and purify FDH. We suggested top 8 species in purification of FDH as *N. nidus*, *C. rotundifolia*, *P. cretica* cv. Albolineata, *C. ornata*, *P. bifurcatum*,

Table 5. Integrated evaluation for the purification effect of potted plants on FDH pollution.

Species	HR	AF	IS	SO
N. nidus cv.Volulum	8.9	2.7	3.94	6
C. lubbersiana	8.9	0.9	2.50	13
C. ornata	6.9	3.5	4.18	4
C. setosa	6.9	0.7	1.94	15
C. freddy	6.8	2.8	3.60	8
C. roseo-picta	6.8	3.2	3.92	7
P. bifurcatum	4.9	3.9	4.10	5
C. makoyana	4.9	1.0	1.78	16
M. punctatum	4.9	2.1	2.66	12
C. crocata	4.9	1.3	2.02	14
C. rotundifolia	4.9	4.8	4.82	2
N. nidus	2.6	6.0	5.32	1
P. fauriei	2.7	1.1	1.42	18
P. ensiformis cv. Victoriae	2.9	0.3	0.82	20
P. cretica cv. Albolineata	2.8	4.6	4.24	3
N. cordifolia	2.9	1.1	1.46	17
C. parasiticus	1.1	1.2	1.18	19
B. orientale	1.9	3.2	2.94	11
M. bicolor	2.1	3.3	3.06	9
C. zebrina	2.0	3.3	3.04	10

HR, hurt response; AF, absorption fraction; IS, integrated score SO, sort order.

Table 6. Changes in the total chlorophyll content and cell membrane permeability of potted plants.

Species	Change in chlorophyll (g kg^{-1} FW)	CMP (%)
N. nidus cv.Volulum	0.07	10.49
C. lubbersiana	-0.27	3.28
C. ornata	-0.14	9.31
C. setosa	-0.31	15.51
C. freddy	0.09	5.16
C. roseo-picta	1.63	6.20
P. bifurcatum	0.72	6.08
C. makoyana	0.29	16.64
M. punctatum	1.01	10.57
C. crocata	0.89	8.13
C. rotundifolia	0.73	4.21
N. nidus	0.68	11.97
P. fauriei	1.07	19.46
P. ensiformis cv. Victoriae	0.48	21.82
P. cretica cv. Albolineata	2.13	18.96
N. cordifolia	0.99	14.73
C. parasiticus	-3.28	16.94
B. orientale	-1.52	4.07
M. bicolor	-1.13	16.54
C. zebrina	0.11	7.75

CMP, cell membrane permeability.

N. nidus cv.Volulum, *C. roseo-picta*, and *C. freddy*. Surprisingly, there were 4 plants from Pteridophytes and 4 plants from *Marantaceae* in the top plants, outstanding for their low hurt response and high absorption ability. We could not compare our results with other researchers such as Zhou et al. (2006), Li (2006), Wang et al. (2007), Huang et al. (2008), Cao et al. (2009) Xiong and Su (2009) and Tian et al. (2011). Although they tried to give the ranking of FDH purification ability, the number of tested potted plants were both few and insystemic, or there were some ploblems in their experiment designs. For example, they wraped or sealed the pot, media and the bottom of the tested plants with plastic bags or films (Zhou et al., 2006; Achkor et al., 2003; Song et al.,2007), without enough number of plants, in turn, without enough tillers or shoots, which could not ensure high FDH absoption.

There may be three ways for potted plants to react to FDH air pollution. The first with high absorpation but weak resistance to FDH damage, showing obvious hurt morphology, for example, in plants such as *N. cordifolia*, *P. fauriei*, *C. parasiticus* and *P. ensiformis* cv.Victoriae. The second shows weak absorpation but strong risistance with normal morphology by taking avoidance strategy to protect itself. Plants such as *C. lubbersiana* and *C. ornata* belong to this group. The third shows absorpation and transforming ability with more or less hurt responses, included plants such as *C. rotundifolia*, *C. setosa*, and *C. roseo-picta*.

Conclusions

Eight species of the indoor potted plants which could be recommendable to be used for formaldehyde purification were *N. nidus*, *C. rotundifolia*, *P. cretica* cv. Albolineata, *C. ornata*, *P. bifurcatum*, *N. nidus* cv. Volulum, *C. roseo-picta* and *C. freddy*.

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