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Indoor potted plants of Marantaceae and Pteridophytes for purification of formaldehyde polluted air

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Abstract: 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 for seven days in a 1.0 m×1.0 m×0.8 m glass box filled with FDH with the initial concentration of 15 mg/m^3. Some plants such as *Neottopteris nidus* Volulum, *Calathea lubbersiana* showed the top resistant ability to FDH; some plants such as *Calathea ornata*, *Calathea setosa*, *Calathea freddy*, and *Calathea roseo*-picta showed medium resistant ability to FDH; other species such as *Neottopteris nidus*, *Pteris fauriei*, *Pteris ensiformis* cv. Victoriae, *Pteris cretica* cv. Albolineata, *Nephrolepis cordifolia*, *Cyclosorus parasiticus*, *Blechnum orientale*, *Maranta bicolor*, and *Calathea zebrina* showed no resistance to FDH. The absorption of plants for FDH in the glass chamber was found especially apparently different during the first three days. The fastest purification rates of FDH were found in species such as *C. zebrina*, *Microsorum punctatum*, and the slowest were 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*, *Platycerium bifurcatum*, *N. nidus* cv. Volulum, *C. roseo*-picta, and *C. freddy*, because these plants have high absorption ability to FDH and have less damage.

Key words: formaldehyde; indoor potted plants; Marantaceae; Pteridophytes; purification

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竹芋科和蕨类室内盆栽植物对甲醛净化作用的研究

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摘　要：以竹芋科和蕨类室内盆栽植物各 10 种为试验材料，分别置于体积为 1.0 m×1.0 m×0.8 m 密封玻璃箱内，甲醛起始浓度均设置为 15 mg/m^3，连续观察 7 d。结果表明：卷叶巢蕨(*Neottopteris nidus* cv. Volulum)、矩叶肖竹芋(*Calathea lubbersiana*)对甲醛抗性最强(Ⅰ级)；银线竹芋(*C. ornata*)、银羽斑竹芋(*C. setosa*)、翠叶竹芋(*C. freddy*)和彩虹竹芋(*C. roseo*-picta)抗性较强(Ⅱ级)；巢蕨(*N. nidus*)、傅氏凤尾蕨(*Pteris fauriei*)、银脉凤尾蕨(*P. ensiformis* cv. Victoriae)、银心大叶凤尾蕨(*P. cretica* cv. Albolineata)、肾蕨(*Nephrolepis cordifolia*)、华南毛蕨(*Cyclosorus parasiticus*)、乌毛蕨(*Blechnum orientale*)、花叶竹芋(*Maranta bicolor*)和天鹅绒竹芋(*C. zebrina*)抗性最差(Ⅳ级)。甲醛处理后，密封玻璃箱内甲醛浓度均呈递减变化，递减最快都集中在试验后 1～3 d 之间。吸收甲醛最快的植物是天鹅绒竹芋和星蕨(*Microsorum punctatum*)，最慢的是华南毛蕨、银脉凤尾蕨、卷叶巢蕨和

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银羽斑竹芋。对甲醛处理产生伤害反应少或较少，而吸收能力强的前 8 种植物是：巢蕨、青苹果竹芋(*C. rotundifolia*)、银心大叶凤尾蕨、银线竹芋、二歧鹿角蕨(*Platycerium bifurcatum*)、卷叶巢蕨、彩虹竹芋和翠叶竹芋，可作为甲醛净化专用植物应用推广。

关键词：甲醛；盆栽植物；竹芋科；蕨类；净化作用

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, especialy steadily releasing from indoor decoration materials for three to fifteen years. FDH like other chemicals such as benzene causes serious hazards to human health and is classfied 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 & 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. The adoption of energy-saving proposals to reduce the release of indoor pollutants has led inefficiency in improvement of indoor air quality and consequently makes potential health hazards remaining. It is one of today's hottest research subjects how to use indoor plants to absorb and remove the indoor air pollutants. 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 eliminating 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*, *D. marginata*, *D. 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*. Recent years, many researchers and scientists in China 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 & Su, 2009; Wu 2006). Plants such as *Monstera deliciosa*, *Ficus elastic*, *Chlorophytum comosum*, and Opuntia strictia have proved capable of absorbing FDH in the 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, culture media and microorganisms in the media also showed ability of absorbing FDH to some extent. However, the purification effects of the tested plants, such as *Chlorophytum comosum* and *Scindapsus aureun*, were inconsistent in different researches. Although ten species of the plants such as *Scindapsus aureun*, *Asparagus setaceus*, *Sansevieria trifasciata* cv. Hahnii, *Chlorophytum 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 were recommended for FDH purification (Zhou *et al.*, 2011). But there is still much work to seek for more plants not only with good performance to remove air pollutants, but also with less or no damage to human beings. 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, in order to provide reference to the utilization of plants for indoor air purification.

1 Materials and Methods

Twenty potted plants from the Marantaceae and Pteridophytes were used as experimental materials(Table 1).

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*

1.1 Experimental treatments

The tested potted plant was placed in a glass chamber with a wall 0.8 mm thick and inside volume of 0.8 m^3(1.0 m×1.0 m×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 diameter. 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) ℃. Three treatments were designed as followed: (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; (3) the chamber only filled with 15 mg·m^{-3} FDH as control.

1.2 Measurement of chlorophyll

0.2 g fresh diachyma was obtained from the middle part of one leaf without venation before treatment and in the 7th day after being treated for measurement of chlorophyll, respectively. Leaf chlorophyll was extracted by 95% ethanol(Wang, 2006). The concentration of the extracted chlorophyll was measured at 665 nm 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(CB) 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 nm and 649 nm, respectively.

1.3 Measurement of leaf cell membrane permeability

The fresh diachyma was measued for cell membrane permeability before treatment and in the 7th day after being treated, respectively. The diachyma 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 $L_C(\%) = 100 \times (C_1/C_2)$.

1.4 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 determination(Yu *et al.*, 2007). The damage of the tested plants in the formaldehyde air was scored from 0 to 4 degrees with the hurt increasing.

2 Results and Analysis

2.1 Plant response caused by formaldehyde

The ranking for hurt response of potted plants to formaldehyde(FDH) pollution was made shown in Table 2 according to(Zhou *et al.*, 2011). It was suggested that species like *N. nidus* 'Volulum' and *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

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

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

Species	Day after being treated						
	1 d	2 d	3 d	4 d	5 d	6 d	7 d
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
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
CK	14.87	13.40	13.40	9.26	4.62	2.81	1.11

(right in the frame) subjected to FDH pollution are shown in Fig. 1. The concentration of formaldehyde in the chamber was decreased fast in 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, *C. setosa*, and *N. cordifolia* (Table 3).

2.2 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

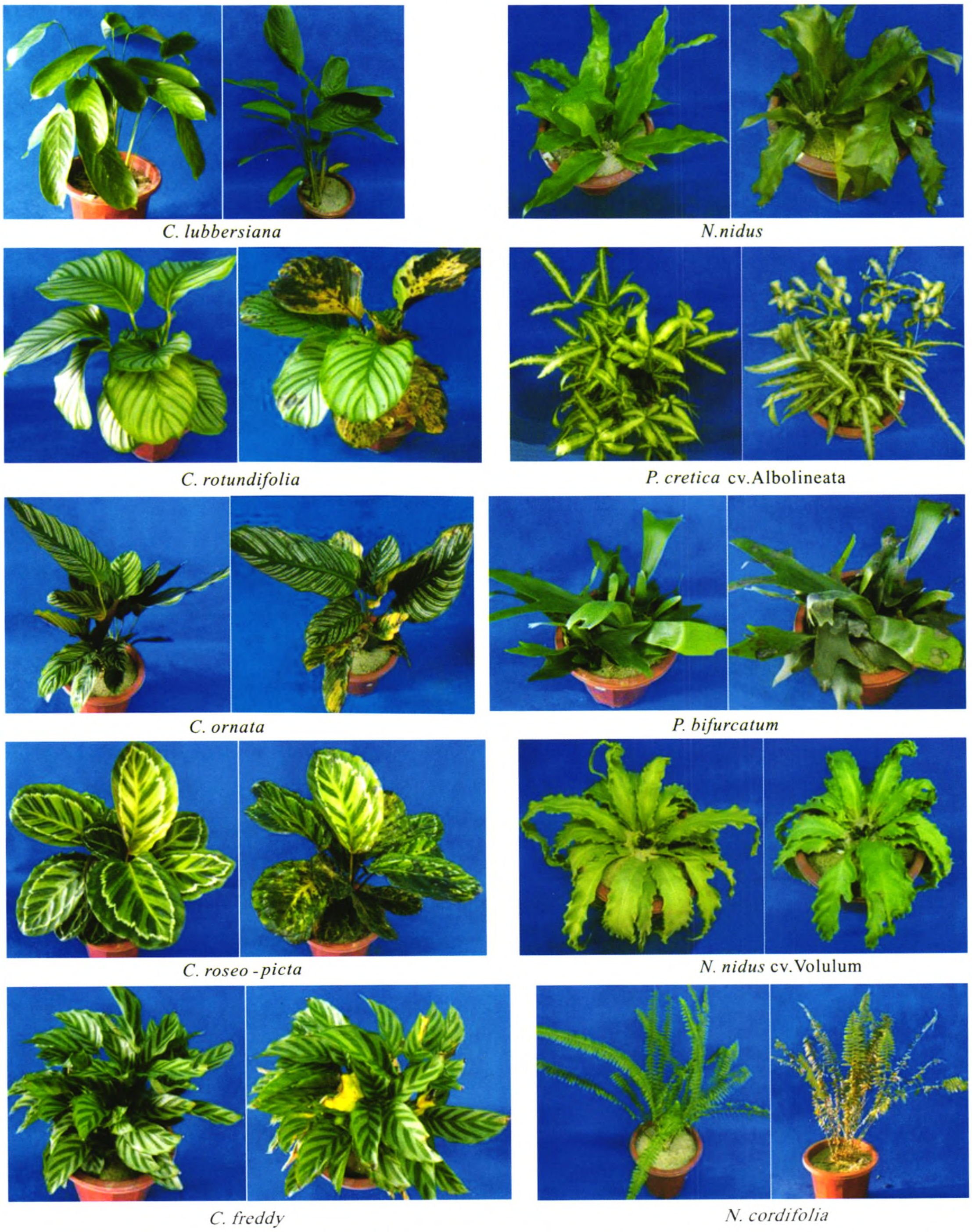

Fig. 1　Photos of some potted plants before (left in the frame) and after (right in the frame) subjected to FDH pollution

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 were 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.

2.3 Changes in total chlorophyll concentration and cell membrane permeability

According to changes in cell membrane permeability (CMP), plants were divided into three groups. The

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

Species	Plant DM (g)	Decr in FDH (mg · m^{-3})	FDH abso (g)	FDHAB per DM (mg · g^{-1})
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; Decr in FDH, decrease in FDH; FDH abso, actual FDH absorption; FDHAB per DM, actual FDH absorption per dry mass.

Table 5 Integrated evaluation for the purification effects 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 contents 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.

first group, with change of more than 10%, included 11 species such as *P. ensiformis* cv. Victoriae, *P. fauriei*, *P. cretica* cv. Albolineata, *C. parasiticus C. makoyana*, *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% included 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% included 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. It maybe suggested that the lower the change in cell membrane permeability was, the stronger the FDH absorption ability was.

3 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*, *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 (Zhou *et al.*, 2006; Li 2006; Wang *et al.*, 2007; Huang *et al.*, 2008; Cao *et al.*, 2009; Xiong & Su., 2009; 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 problems 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, showed obvious hurt morphology, for example, in plants such as *N. cordifolia*, *P. fauriei*, *C. parasiticus* and *P. ensiformis* cv. Victoriae. The second showed 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 showed absorpation and transforming ability with more or less hurt responses, included plants such as *C. rotundifolia*, *C. setosa*, and *C. roseo*-picta. It was perplexed that some plants had higher absorption ability for FDH, but had lower cell membrane permeability, vice versa. This mechenism may be need further studies in future.

4 Conclusions

In conclusion, 8 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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竹芋科和蕨类室内盆栽植物对甲醛净化作用的研究

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