The classification and selection of indoor shade-tolerant plants of indoor chemical pollution

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Abstract. It has been an urgent issue of finding a reasonable and safety methods to control the indoor benzene pollution from building materials in China. Twenty two common indoor shade-tolerant plants were tested by artificial closed fumigation to investigate their sensitivity on high concentration formaldehyde and benzene. And then sensitivity of each plant was classified according to the degree of symptoms. The results indicate that Impatiens balsamina, Begonia × aelatior and Melissa officinalis are sensitive to indoor formaldehyde and benzene pollution.

1. Introduction
With the improvement in standard of living in China, the degree of interior decoration is becoming more and more complicated, makes the phenomenon of indoor chemical pollutants increasingly serious. Modern man have entered the era of indoor chemical pollution[1]. Indoor chemical pollution has been listed by the World Health Organization as one of the five environmental factors that endanger public health. It has become an important issue to be solved urgently for a safe, effective and lasting solution[2].

Plant has a certain ability of monitoring, purifying and resisting the external pollution stress. When the stress degree of the pollutant exceeds the upper limit of the adaptability of the plant, the plant will express different degrees of harm through its growth condition or external morphological changes. According to the changes in the physiological and biochemical indicators of the plant[3,4], it can be quickly and easily screened out the plant that is more sensitive to the indoor chemical pollution[5]. The research provides scientific basis and theoretical support for the development of the ecological rehabilitation technology for indoor chemical pollution.

2. Materials and methods
2.1. Materials
Twenty-two kinds of indoor shade-tolerant plants were selected as the experimental materials the list is as follows: Zebrina pendula(X1), Hedera nepalensis(X2), Hedera helix(X3), Pelargonium hortorum(X4), Melissa officinalis(X5), Pelargonium saivia(X6), Impatiens balsamina(X7), Rieger beginia(X8), Begonia × aelatior(X9), Scindapsus aureum(X10), Chlorophytum comosum(X11), Chlorophytum capense var. Variegatum(X12), Chlorophytum capense var. Vittatum(X13), Narcissus jonquilla(X14), Asparagus setaceus(X15), Tradescantia albiflora(X16), Epipremnum aureum var. golden pothos(X17), Spathiphylhum floribundum(X18), Calathea makoyana(X19), Sansevieria trifasciata var. Laurentii(X20), Chamaedorea elegans(X21), Mentha canadensis(X22). The twenty-two kinds of plants are common in indoor environment.
2.2. Methods
The experiment sets formaldehyde concentration of 120 mg/m$^3$ and benzene concentration of 300 mg/m$^3$ with 3 replications. The indoor plants used for the study were randomly divided into 7 groups. Each group was fumigated with formaldehyde and benzene with artificial closed fumigation[6]. The plants need adapt to the environment of airtight fumigation box in advance for 2 days and then treat with formaldehyde or benzene for 1 day. The degree of plant damage and the classification of symptoms after 24 h of indoor chemical pollution, see the Table 1.

| Damage grading | Damage degree and Symptom evaluation |
|----------------|--------------------------------------|
| 1              | Plant leaf and tip withered area is less than 5%, no obvious brown spots |
| 2              | Plant leaf and tip withered area is between 5% and 30%, 10% obvious brown spots |
| 3              | Plant leaf and tip withered area is between 30% and 60%, 40% obvious brown spots |
| 4              | Plant leaf and tip withered area is above 60%, 80% obvious brown spots |
| 5              | The whole plant withered, or ulceration, most Leaf Chlorosis, about 50% of leaves off, or plant death |

3. Results and discussion
The sensitivity of plants to stress is that plants react quickly at low concentrations of chemical stress or other physical stress and exhibit varying degrees of susceptibility. Plant resistance to stress is that some plants after the stress can produce resistance reaction by adjusting its physiological activities, to reduce or avoid the damage from the adversity stress. The plant is more susceptible to the stress in the pollution stress, and its sensitivity to the stress is also higher, and the monitoring ability of the plant is stronger than that of the plant. In the same pollution stress, the disease is not obvious or the damage degree is more light, its resistance to the pollution stress is strong, the monitoring of the pollution stress is relatively weak.

3.1. Sensitivity classification of indoor formaldehyde pollution
Under formaldehyde concentration of 120 mg/m$^3$ for 24 h, the degree of injury and the symptoms of the 22 kinds of experimental plants were evaluated, as shown in Table 2.

It can be seen from Table 2 that after 24 h of formaldehyde concentration of 120 mg/ m$^3$, the Narcissus jonquilla and the Sansevieria trifasciata var. lauritii which have a thicker layer of leaves and smoother leaves are no obvious symptoms observed. Hedera nepalensis, Chlorophytum capense var. vittatum, Spathiphyllum floribundum and Calathea makoyana only a few edge and tip of leaves wilt, or appear a small amount of brown spots. The damage of Zebrina pendula, Pelargonium hortorum, Melissa officinalis, Begonia × aelatiur and Mentha canadensis which the surface of a leaf is more coarse or the nap on the base is relatively heavy. Impatiens balsamina and Begonia × aelatiur appeared whole plant leaves wilting off, and even the phenomenon of plant death.

According to the method of symptom analysis, the sensitivity of the 22 kinds of plants under the condition of 120 mg/m$^3$ formaldehyde concentration was evaluated, and the sensitivity of the formaldehyde pollution was classified according to the symptoms and signs, and the results were shown in Table 3.

It can be seen from Table 3 that Impatiens balsamina, Begonia × aelatiur, Pelargonium hortorum, Melissa officinalis are the most sensitive to indoor formaldehyde pollution. Begonia × aelatiur, Zebrina pendula, Mentha canadensis, Pelargonium saivia, Chlorophytum comosum and Scindapsus aureun are more sensitive to indoor formaldehyde pollution. Narcissus jonquilla, Sansevieria trifasciata var. Laurentii and Spathiphyllum floribundum are the weakest sensitivity to indoor formaldehyde pollution.
Table 2. The degree of injury and symptom classification of plants under formaldehyde stress

| Plant species | Symptoms | Damage grading |
|---------------|----------|----------------|
| X1            | 60% of the leaves discolor and fester, close to the source of pollution at the obvious performance; blight after the interval of 1d | 4 |
| X2            | 10% of the leaves showed a small amount of light brown spots; no adverse reaction after the interval of 1d | 2 |
| X3            | 15% old leaves appear irregular spots; after the interval of 1d old leaves withered | 2 |
| X4            | 80% the leaves become brown, and damaged leaves dry off after the interval of 1d | 5 |
| X5            | 90% leaves appear black brown patches, blight after the interval of 1d | 5 |
| X6            | 60% of the leaves appear brown spots, the damaged leaves wilt after the interval of 1d | 4 |
| X7            | Leaves chlorosis, 50% of the leaves off; after the interval of 1d the damage increased, plant death | 5 |
| X8            | 60% leaves appeared water stains; leaves dry off after the interval of 1d | 4 |
| X9            | Leaves chlorosis, whole plant wilt; leaf abscission after the interval of 1d, plant death | 5 |
| X10           | 70% leaves appear black brown patches at the bottom; after 1 d, leaves become yellow after the interval of 1d | 4 |
| X11           | 80% of the tip and edge of leaves discolor and fester, part of the old leaves died; the damage increased after the interval of 1d | 4 |
| X12           | 20% of the tip of leaves fester, the old leaves appear brown spots; the damage increased after the interval of 1d | 2 |
| X13           | 15% of the leaves appear a small amount of spots, the tip of leaves fester; no adverse reaction after the interval of 1d | 2 |
| X14           | Plant growth is normal, no obvious symptoms were observed; no adverse reactions occurred after the interval of 1d | 1 |
| X15           | 40% of the top leaves lost green and become yellow; leaves wilt after the interval of 1d | 3 |
| X16           | 50% edge of fresh leaf lost green, water stain appeared; leaves wilt after the interval of 1d | 3 |
| X17           | 10% of leaves appear a small amount of black spots, no adverse reactions occurred after the interval of 1d | 2 |
| X18           | 3% of leaves appear irregular black or yellow spots; no adverse reactions occurred after the interval of 1d | 1 |
| X19           | 15% of the bottom leaves appear brown spots; no adverse reactions occurred after the interval of 1d | 2 |
| X20           | Plant growth is normal, no obvious symptoms were observed; no adverse reactions occurred after the interval of 1d | 1 |
| X21           | 10% of the leaves of the old leaves appear brown spots; no adverse reactions occurred after the interval of 1d | 2 |
| X22           | 80% of the leaves appear large area dark brown patches; leaves fester after the interval of 1d | 4 |

Table 3. Sensitivity classification of indoor formaldehyde pollution

| Plant sensitivity level | Plant species |
|-------------------------|---------------|
| I                       | Impatiens balsamina, Begonia × aelior, Pelargonium hortorum, Melissa officinalis |
| II                      | Begonia × aelior, Zebrina pendula, Mentha canadensis, Pelargonium saivia, Chlorophytum comosum, Scindapsus aureun |
| III                     | Asparagus setaceus, Tradescantia albiflora |
| IV                      | Hedera nepalensis, Hedra helix, Chlorophytum capense var. Vittatum, Chlorophytum capense var. Variegatum, Chamaedorea elegans, Epipremnum aureum var. golden pothos, Calathea makoyana |
| V                       | Narcissus jonquilla, Sansevieria trifasciata var. Laurentii, Spathiphyllum floribundum |
3.2. Sensitivity classification of indoor benzene pollution

Under benzene concentration of 300 mg/m$^3$ for 24 h, the degree of injury and the symptoms of the 22 kinds of experimental plants were evaluated, as shown in Table 4.

**Table 4.** The degree of injury and symptom classification of plants under benzene stress

| Plant species | Symptoms                                                                 | Damage grading |
|---------------|--------------------------------------------------------------------------|----------------|
| X1            | 60% of the leaves discolor and fester, blight after the interval of 1d    | 4              |
| X2            | no adverse reactions occurred                                            | 1              |
| X3            | no adverse reactions occurred                                            | 1              |
| X4            | 70% leaves fester and 80% leaves become brown, blight after the interval of 1d | 4              |
| X5            | 80% leaves appear black brown spots, blight after the interval of 1d      | 5              |
| X6            | Leaves appear black brown patches at the bottom and 50% tips of leaves lost green, leaves wilt after the interval of 1d | 3              |
| X7            | Plant wilt, leaf abscission after the interval of 1d, plant death        | 5              |
| X8            | 40% fresh leaves become brown, and damaged leaves dry off after the interval of 1d | 3              |
| X9            | 80% of the edge of old leaves and fresh leaves fester, leaves die after the interval of 1d | 5              |
| X10           | leaves appear black brown patches, the damage increased after the interval of 1d | 4              |
| X11           | 70% of the tip and edge of leaves discolor and fester, part of the old leaves died; the damage increased after the interval of 1d | 4              |
| X12           | 60% of the tip and edge of leaves discolor and fester, 70% old leaves appear black brown patches, old leaves died after the interval of 1d | 4              |
| X13           | 50% of the tip and edge of leaves discolor and fester, the damage increased after the interval of 1d | 3              |
| X14           | 40% of the tip and edge of leaves discolor and fester, the damage increased after the interval of 1d | 3              |
| X15           | 20% of the tip of fresh leaves discolor, tip of leaves fester after the interval of 1d | 2              |
| X16           | 30% leaves appeared water stains; leaves dry off after the interval of 1d | 2              |
| X17           | 30% of the tip of fresh leaves discolor, the damage increased after the interval of 1d | 3              |
| X18           | 10% mature leaves and calyx show a small amount of black spots, no adverse reactions occurred after the interval of 1d | 2              |
| X19           | 15% leaves at the bottom show brown spots, no adverse reactions occurred after the interval of 1d | 2              |
| X20           | no adverse reactions occurred after the interval of 1d                  | 1              |
| X21           | part of tip of leaves fester and show a small amount of brown spots, no adverse reactions occurred after the interval of 1d | 3              |
| X22           | 80% fresh leaves lost green, leaves become yellow after the interval of 1d | 4              |

It can be seen from Table 4 that after 24 h of benzene concentration of 300 mg/m$^3$, the *Sansevieria trifasciata* var. *laurentii*, *Narcissus jonquilla*, *Hedera nepalensis* and *Hedra helix* the which have a thicker layer of leaves and smoother leaves are no obvious symptoms observed. *Spathiphyllum floribundum*, *Tradescantia albiflora*, *Asparagus setaceus* and *Calathea makoyana* only a few fresh leaves appear a small amount of brown spots. The damage to *Impatiens balsamina*, *Melissa officinalis*, *Pelargonium hortorum*, and *Mentha canadensis* which the surface of a leaf is more coarse or base with a nap are relatively heavy.
According to the method of symptom analysis, the sensitivity of the 22 kinds of plants under the condition of 300 mg/m$^3$ benzene concentration was evaluated, and the sensitivity of the formaldehyde pollution was classified according to the symptoms and signs, and the results were shown in Table 5.

Table 5. Sensitivity classification of indoor benzene pollution

| Plant sensitivity level | Plant species                                                                 |
|------------------------|-------------------------------------------------------------------------------|
| I                      | Impatiens balsamina, Begonia × aelatior, Melissa officinalis                  |
| II                     | Zebrina pendula, Pelargonium hortorum, Mentha Canadensis, Chlorophytum comosum, Scindapsus aureun |
| III                    | Chlorophytum capense var. variegatum, Chlorophytum capense var. vittatum, Pelargonium saivia, Rieger begonia, Chamaedorea elegans, Epipremnum aureum var. golden pothos |
| IV                     | Asparagus setaceus, Tradescantia albiflora, Spathiphyllum floribundum, Calathea makoyana |
| V                      | Hedera nepalensis, Hedra helix, Narcissus jonquilla, Sansevieria trifasciata var. laurentii |

From Table 5 we can see that Impatiens balsamina, Begonia × aelatior, Melissa officinalis are the most sensitive to indoor formaldehyde pollution. Zebrina pendula, Pelargonium hortorum, Mentha Canadensis, Chlorophytum comosum and Scindapsus aureun are more sensitive to indoor formaldehyde pollution. Hedera nepalensis, Hedra helix, Narcissus jonquilla and Sansevieria trifasciata var. laurentii are the weakest sensitivity to indoor formaldehyde pollution.

3.3. Sensitivity classification of indoor formaldehyde and benzene pollution
Based on the sensitivity of plants to indoor formaldehyde and benzene pollution, the sensitivity of 22 kinds of experimental plants to indoor formaldehyde and benzene pollution was summed up according to the method of symptom, as shown in Table 6.

Table 6. Sensitivity classification of indoor formaldehyde and benzene pollution

| Plant sensitivity level | Plant species                                                                 |
|------------------------|-------------------------------------------------------------------------------|
| I                      | Impatiens balsamina, Begonia × aelatior, Melissa officinalis                  |
| II                     | Zebrina pendula, Pelargonium hortorum, Mentha Canadensis, Chlorophytum comosum, Scindapsus aureun |
| III                    | Rieger begonia, Tradescantia albiflora, Pelargonium saivia, Asparagus setaceus, Chlorophytum capense var. variegatum |
| IV                     | Epipremnum aureum var. golden pothos, Chlorophytum capense var. vittatum, Chamaedorea elegans, Calathea makoyana |
| V                      | Narcissus jonquilla, Sansevieria trifasciata var. laurentii, Spathiphyllum floribundum, Hedera nepalensis, Hedra helix |

4. Conclusions
The results show:
- The plants most sensitive to the indoor formaldehyde pollution are *Impatiens balsamina, Begonia × aelatior, Melissa Officinalis, Pelargonium hortorum*.
- The plants most sensitive to the indoor benzene pollution are *Impatiens balsamina, Begonia × aelatior, Melissa Officinalis*.
- The plants with strong comprehensive sensitivity to indoor formaldehyde and benzene pollution sensitivity are *Impatiens balsamina, Begonia × aelatior, Pelargonium hortorum, Zebrina pendula,*
Scindapsus aureun, Mentha Canadensis, Chlorophytum comosum, Pelargonium hortorum. The appearance of the symptoms of these plants can serve as an indicator of indoor chemical pollution. However, the purification amount and reaction mechanism of plants to indoor benzene and formaldehyde pollution need further in-depth study.

References
[1] Xue A, Xia L, Huitang P, Jingnan L, Qixiang Z The purifying effect of 16 indoor ornamental plants on formaldehyde and changes in plant physiology and biochemistry 2010 Ecol. Environ. Sci. 19 379-384
[2] Baozhen C, Hexian J, Wei X 2011 Progress of Research on the Purification of Formaldehyde by Plants Chin. Agric. Sci. Bull. 27 30
[3] Cruz M D, Christensen J H, Thomsen J D, Muller U 2014 Can ornamental potted plants remove volatile organic compounds from indoor air? — a review Environ. Sci. Pollution Res. 21 13909
[4] Xue W, Guohui K, Changlian P, Guizhu L, Kena X, Yaodong L 2003 Plant monitoring of air pollution and its resistance J. Trop. and Subtrop. Bot. 11 348
[5] Yumei X, Jianming W, Junming G, Keyong C 2006 Study on the Sensitivity of 42 Garden Plants to SO₂ Damage J. Shanxi Agric. U. (Nat. Sci. Ed.) 26 32
[6] Wolverton B C, Wolverton J D 1993 Plants and soil microorganisms: removal of formaldehyde, xylene, and ammonia from the indoor environment J. Mississippi Acad. Sci. 38 11