Experimental Investigation of the Absorption of Formaldehyde by Some Species of *Ficus* L. Genus for Application in Phytodesign

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Abstract

Absorption of formaldehyde from the gas phase by the plants of *Ficus* genus was investigated. The species promising for use in phytodesign in order to purify indoor air from formaldehyde were revealed.

Key words: Ficus genus, phytodesign, gas absorbing ability of plants, formaldehyde

INTRODUCTION

At present, the biological approach to the purification of indoor air from gaseous toxic substances with the help of decorative tropical plants is being developed. The experiments of this kind were carried out for the first time by the personnel of NASA (National Aeronautics and Space Administration) to purify the air in the inner environment of spaceships and orbital space stations. A very important discovery was made in 1980: indoor plants are able to remove volatile organics from indoor air [1]. The experiments were carried out in Plexiglas boxes with the species *Scindapsus aureus*, *Chlorophytum elatium* var. *vittatum* and *Syngonium podophyllum*. The results showed that *Chlorophytum comosum* is able to decrease the concentration of formaldehyde in the air to a substantial extent [2]. In addition, it was proven that about 30 house plant species (*Aglaonema commutatum, Azalea indica, Anthurium andreaenum, Araucaria heterophylla, Begonia semperflorens, Dracaena deremensis, Codiaeum variegatum, Maranta leuconeura etc.*) are efficient in purifying the indoor air from formaldehyde, acetaldehyde, benzaldehyde, trichloroethanol, carbon monoxide, xylene, toluene, acrolein, methyl ethyl ketone and acetone.

The authors of [3, 4] studied the ability of such house plants as *Chlorophytum comosum*, *Doritis pulcherrima* and *Epidendrum radicans* to absorb various hydrocarbons: toluene, benzene, cyclohexane, *n*-hexane. *Chlorophytum comosum* turned out to be the most efficient gas absorber among these species.

Our investigations of the indoor air in kindergartens of Novosibirsk, both with the indoor sources of carbonyl compounds (construction materials, wallpaper, paints) and with outer sources (junctions of roads with heavy traffic), with some decorative species planted in them, demonstrated that in both cases the presence of such species as *Ficus benjamina*, *Billbergia nutans*, *Chlorophytum comosum* is accompanied by a substantial decrease in the concentrations of carbonyl compounds in comparison with the rooms without plants in them. These results provide evidence that it is urgent to study the gas absorbing ability of tropical plants, including the species of *Ficus* genus [5–7].

The goal of the present work was to study the outlooks for the use of different species of the *Ficus* genus to recover the indoor air quality, in particular to decrease the concentration of formaldehyde. The problems to be solved in our investigation were: to adjust the laboratory procedure to measuring the ability of plant species to decrease the concentration of this gaseous pollutant; to examine the gas absorbing capacity of 11 *Ficus* species under laboratory conditions; examination of the gas absorbing capacity of plants depending on the concentration of formaldehyde, air humidity, exposure, duration of experiment, and the leaf area.

EXPERIMENTAL

We examined 11 species of *Ficus* genus that are most widely used in interior planting. Three tight boxes made of a transparent material (Plexiglas) were used in experiments. The dimensions of the boxes were 50 × 50 × 70 cm, volume 0.175 m^3.

Formaldehyde was chosen as the gaseous pollutant. This is a priority pollutant of indoor air [8]. Formalin was used as a source of formaldehyde under the laboratory conditions. The concentration of formaldehyde in the gas phase was determined by sampling it through its interaction with 2,4-dinitrophenylhydrazine deposited onto a sorbent. The hydrazone formed in this reaction was identified and determined quantitatively by means of high-performance liquid chromatography (HPLC) [9].

The air under investigation was passed at a flow rate of 1.5 L/min through sorption tubes filled with comminuted quartz on which the solution of 2,4-dinitrophenylhydrazine in water acidified with sulphuric acid to pH 2 was deposited. The interaction with carbonyl compounds present in the air occurs according to reaction

$$\underset{\text{carbonyl}}{R_1R_2C{=}O} + \underset{\text{2,4-DNPH}}{H_2N{-}NH{-}C_6H_3(NO_2)_2} \rightarrow \underset{\text{hydrazone}}{R_1R_2C{=}N{-}NH{-}C_6H_3(NO_2)_2} + H_2O$$

The formed hydrazones were identified by means of HPLC with a Milikhrom-1 microcolumn chromatograph; detection was performed on the basis of UV absorption at the wavelength of 354 nm. Standard KAKh-2 columns filled with reversed-phase sorbent LiChrosorb C_{18} were used. A mixture of acetonitrile with water at a ratio of 3 : 1 was used for elution. The quantitative determination was carried out with the help of calibration plots obtained in experiments with the hydrazone solutions of known concentrations (prepared using a weighed portion of specially synthesized individual hydrazones). The range of detectable concentrations of carbonyl compound was 0.1 to 390 μg/m^3.

The procedure included air sampling from the boxes after the plants and vessels with formalin (15 %) were placed in the boxes. Formalin served as a source of formaldehyde. All the experiments were carried out in a room with windows looking to the north in order to minimize the effect of sunlight. The experimental boxes contained the plants growing in pots, and the vessels with formalin, while the reference boxes contained pots with soil, artificial humidifiers (wet strips of filter paper), and a vessel with formalin. Measurements of formaldehyde concentration depending on the required exposure were made by inserting the sampling tube with the reagent into the box through a special orifice; it was tightly closed after sampling. We studied the dependence of formaldehyde concentration on the leaf area (0.14 and 0.30 m^2), exposure, and humidity because it may increase substantially in boxes for loner exposure. The humidity in experimental boxes increased as a result of transpiration of the plants with different leaf areas; humidity in the reference box increased due to artificial humidifiers. The dynamics of gas absorbing activity was studied in daytime and at night. Experiments were carried out in triple repetition. The gas absorbing activity was considered to be pronounced if formaldehyde concentration decreased by more than 10 %.

The primary goal was to determine the stability of *Ficus* species under investigation to formaldehyde and to measure the concentration at which a pronounced gas absorbing effect is observed. For this purpose, we studied the absorption of formaldehyde by plants from the gas phase in experimental boxes at the initial concentration varied within the range 200–400 μg/m^3, which exceeds the average daily maximal permissible concentration (MPC) of formaldehyde more than 100 times, and within the range 100–150 μg/m^3 (30–50 times higher than the MPC). The concentration of formaldehyde was measured after the plants were kept in experimental boxes for 3 and 22 h.

Comparative chromatographic studies of the ethanol extracts from the leaves of *F. benjamina* L. before and after the contact with gaseous formaldehyde were carried out. The chemical composition was determined using a Milikhrom-1 liquid microcolumn chromatograph.

RESULTS AND DISCUSSION

As a result of experiments, a decrease in formaldehyde concentration for its initial value within 100–150 μg/m^3 was observed for all the studied 11 species of *Ficus* genus, as shown in Table 1. In the case of the high formaldehyde concentration (>100 MPC), the ability of plants to absorb formaldehyde decreases, but all the studied species exhibit physiological stability to the action of this gas (only *F. carica* exhibited some injury of young leaves). A decrease in formaldehyde concentration in the presence of plants after 22 h reached the maximal value and accounted for 30 % of the initial level (200–400 μg/m^3); at lower concentrations the decrease reached 40 %. The highest activity in decreasing the concentration of formaldehyde within this range was exhibited by *F. benjamina*, *F. binnendijkii* (by more than 30 %), *F. retusa*, *F. lyrata*, *F. macrophyllia, F. elastica and F. rubiginosa* (by 20 %). The species *F. benghalensis, F. carica* exhibited activity only for a short time interval (see Table 1).

On the basis of the data obtained, we chose an optimal range of initial concentrations of formaldehyde for revealing the gas absorbing capacity of plants; further experiments were carried out with formaldehyde concentrations below 100 μg/m^3.

While developing the procedure, it was necessary to examine the effect of air humidity on gas absorbing capacity of the species because the humidity in boxes differs substantially from the humidity in rooms. For example, it was discovered that the rate of relative humidity changes in boxes is directly dependent on air temperature in the room, leaf area, and exposure. At the room temperature of 22–23 °C, air humidity in boxes becomes substantial after only 1 h. It reaches its maximum within the first three hours and then stays at the same level during the entire experiment (Table 2).

TABLE 1

Comparative evaluation of the gas absorbing capacity of the studied species of *Ficus* genus at different formaldehyde concentrations

Species	Initial concentration, μg/m^3			
	100–150		200–400	
	Decrease in concentration, %, after exposure, h			
	3	22	3	22
Ficus binnendijkii Mig	28±4	34±3	18±1	30±1
F. benjamina L.	39±3	43±5	25±1	35±3
F. benghalensis L.	18±2	9±3	11±2	6±1
F. carica L.	6±1	14±5	11±1	6±5
F. elastica cv. ‘Melany’ Roxb. ex Hornem.	0	20±5	3±1	12±1
F. lyrata Warb.	26±6	36±4	11±1	15±2
F. macrophylla Desf.	11±1	28±5	5±1	15±5
F. natalensis Hochst.	7±5	17±3	–	–
F. rubiginosa L.	13±3	22±6	8±5	17±4
F. retusa L. Mant.	27±5	34±2	10±2	13±1
F. pumila L.	13±4	0	–	–

**Note*. The average daily maximal permissible concentration of formaldehyde is 3 μg/m^3; this is a level safe for humans when acting during 24 h.

TABLE 2

Changes in air humidity in experimental boxes depending on exposure (in experimental boxes with *F. benjamina*)

Exposure, h	Humidity, %			
	in reference boxes		in experimental boxes	
	without humidifiers	with humidifiers (S_1 = 0.30 m^2)	S_1 = 0.14 m^2	S_1 = 0.30 m^2
1	77±3	85±3	88±3	93±3
2	86±2	89±2	92±2	96±0.5
3	90±2	91±2	95±2	97±2
4	91±1	92±1	95±2	98±2
5	91±3	93±3	96±2	100±0.5
6	91±2	95±2	96±2	97±3
7	91±1	96±0.5	96±2	97±2
8	95±0.5	96±0.5	96±0.5	97±2
9	95±0.5	96±0.5	98±2	98±2

Note. Here and in Tables 3, 5: S_1 is the leaf area.

One of the goals of the investigation was to determine the humidity of air on changes in formaldehyde concentration in boxes. This is connected with the fact that formaldehyde forms a hydrate when the humidity of the air is high; this hydrate is less toxic for plants than the anhydrous form which is prevailing at low humidity [9]. The data on changes in formaldehyde concentration in the experimental boxes with plants and in the boxes with artificial humidifiers are shown in Table 3. One can see that an increase in humidity in boxes alone has no effect on the decrease in formaldehyde concentration.

To reveal the mechanism of formaldehyde binding in plants, we carried out a comparative chromatographic investigation of the extracts from *F. benjamina* L. before and after contact with gaseous formaldehyde in the concentration of 150 μg/m^3 (Fig. 1). One can see that a new peak appears after the contact; its retention time is about 4.5 min. Formaldehyde is likely to enter a chemical reaction in the leaves; the substance detected as a new peak is formed as a result of the reaction.

At the next stage of work, we studied changes inn formaldehyde concentration depending on exposure. Formaldehyde concentration in boxes was measured in daytime and at night (Table 4).

Studies of the dynamics of formaldehyde absorption with sampling every hour during a

TABLE 3

Changes in formaldehyde concentration in experimental boxes with *F. benjamina* and in the reference box depending on exposure

Time of day, h	Exposure, h	Formaldehyde concentration, μg/m^3		Decrease in concentration (*A*), %	
		Reference*	Experiment (S_1 = 0.30 m^2)	Reference (with humidifiers)	Experiment (with plants)
10-00	1	54±4/51±4	41±5	5±4	27±7
11-00	2	52±5/53±7	39±5	0	37±7
12-00	3	56±6/55±7	34±5	0	34±3
13-00	4	57±7/54±5	34±5	0	38±5
14-00	5	53±7/54±7	32±5	0	37±4
15-00	6	54±8/55±7	32±3	0	44±2

* The first value: without humidifiers; the second value: with humidifiers.

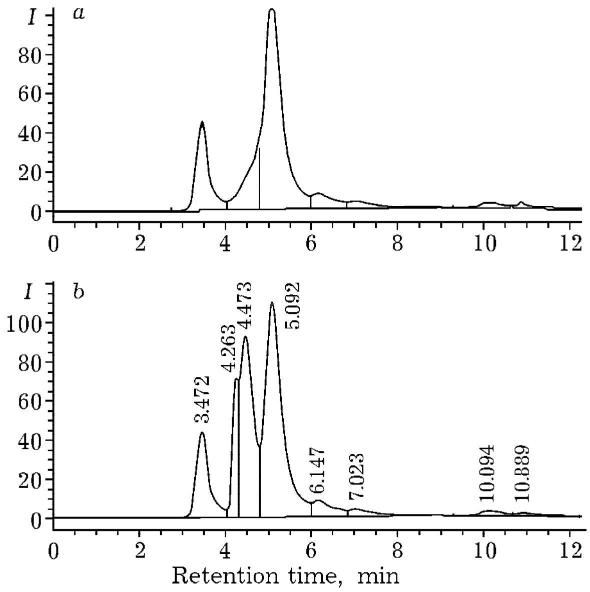

Fig. 1. Chromatograms of the ethanol extract from *F. benjamina* before (*a*) and after contact with formaldehyde (*b*).

6-hour period in daylight and at night showed that a substantial decrease in the pollutant concentration is observed within the first 3–4 h of experiments, after that absorption takes place uniformly during the whole experiment. The data obtained provide evidence that *F. benjamina* absorbs formaldehyde at night with almost the same efficiency as during the day.

We studied the dependence of gas absorbing capacity on the plant leaf area. The data on changes of formaldehyde absorption by the plants of *F. benjamina* and *F. binnendijkii* species depending on leaf area for exposure 3, 6 and 9 h are presented in Table 5.

It was established that the simultaneous involvement of two plants causes a faster and stronger decrease in formaldehyde concentration than in the case when only one plant is used; however, the effect is not linear (the concentration decreases not by a factor of 2 but by a factor of 1.4–1.6 times).

A comparative analysis of the degree of gas absorbing capacity for different plant species and different exposure, and the absorbing capacity depending on the total time during which a plant was used in experiment (Fig. 2) showed that the total time does not affect the gas absorbing capacity of *F. benjamina* and *F. retusa*. For the *F. benjamina* species, permanently high (40–50 %) absorbing capacity is observed. The species *F. lyrata* and *F. pumila* are characterized by a sharp decrease in the gas absorbing capacity when they are frequently used in experiments.

On the basis of the data obtained, it may be concluded that it is reasonable to use some species of Ficus genus possessing pronounced gas absorbing capacity to improve the indoor ecological situation. Among the studied species, the most promising ones for use in phytodesign turned out to be *F. benjamina*, *F. retusa*, *F. lyrata*, *F. binnendijkii*. The plants of these spe-

TABLE 4

Changes of formaldehyde concentration in the experimental boxes with *F. benjamina* in daytime and at night depending on exposure

Exposure, h	Time of day, h	Initial concentration, μg/m^3		*A*, %
		Reference	Experiment	
1	10-00	45±4	41±5	27±7
2	11-00	46±2	39±5	37±7
3	12-00	44±4	34±5	34±3
4	13-00	43±3	34±5	38±3
5	14-00	46±2	32±5	37±4
6	15-00	46±3	32±3	44±2
1	21-00	54±4	41±5	25±4
2	22-00	52±5	37±9	26±4
3	23-00	56±6	34±6	40±6
4	24-00	57±7	34±5	41±1
5	1-00	53±7	33±5	39±2
6	2-00	54±8	32±3	39±4

TABLE 5

Changes of formaldehyde concentration in experimental boxes with *F. benjamina* and *F. binnendijkii* depending on the leaf area at different exposures

Species	Exposure, h	Formaldehyde concentration, mg/m^3			A, %	
		Reference	S_l, m^2		S_l, m^2	
			0.14	0.30	0.14	0.30
F. benjamina	3	142±17	102±17	88±14	28	37
	6	133±17	94±18	86±13	29	42
	9	139±18	92±15	80±14	34	47
F. binnendijkii	3	155±4	132±4	111±3	15	28
	6	153±4	127±4	103±3	17	33
	9	159±4	118±4	105±3	26	34

Note. For designations, see Table 2.

cies possess the ability to decrease the concentration of formaldehyde in the air substantially (by 30–40 %), and *F. benjamina* is a universal biological twenty-four-hour filter.

CONCLUSIONS

1. All the 11 studied species of *Ficus* genus turned out to be physiologically stable to the action of formaldehyde within the concentration range 100 to 300 μg/m^3.

2. The highest activity in formaldehyde absorption was exhibited by the species: *F. benjamina*, *F. binnendijkii, F. retusa* (30 to 40 %). They turned out to be the most stable species against the action of the high formaldehyde concentrations. The efficiency of formaldehyde absorption by these plants is almost the same for different concentrations.

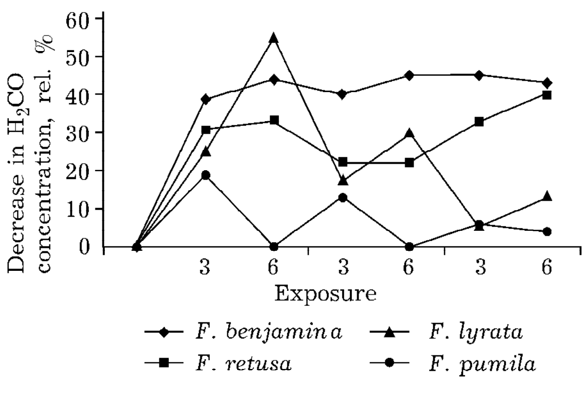

Fig. 2. Dependence of the gas absorbing capacity of plants on the total time of use in experiment. Experiments were carried out for three days from 10 to 16 h.

A substantial decrease in formaldehyde concentration under the action of the studied *Ficus* species occurs mainly within the first 3–4 h. *F. benjamina* absorbs formaldehyde uniformly during day and night.

With an increase in the leaf area, a faster and more substantial decrease in formaldehyde concentration is observed, though the effect is not linear.

F. benjamina and *F. retusa* conserve the ability to absorb formaldehyde during the whole experiment, while the gas absorbing capacity of *F. lyrata* and *F. pumila* decreases sharply in the case of frequent use in experiments.

3. *F. benjamina* is the most promising species for use in phytodesign as a biological filter because this species possesses the ability to decrease formaldehyde concentration in the air substantially.

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