Can Houseplants Impact Indoor Air Quality?

High School, Biology

Introduction

In the late 1900s, the National Air and Space Academy (NASA) had already put the first American in space, landed on the moon, and built a space shuttle. However, NASA had its sights set on sending astronauts into space for much longer periods of time, establishing a space station, or a moon base. That meant people would need safe, clean air. More safe, clean air that they could fit on board a completely sealed rocket ship.

Among other problems NASA had to solve were:

- typical ventilation systems in buildings are big and require power.
- many building materials used to build buildings and vehicles (including rockets and space stations) are also sources that emit air pollutants.

Prompt 1

NASA wanted to know whether plants could support astronaut health by removing harmful chemicals from sealed spacecraft. The following investigations test this idea at different scales and with different species of plants.

The specific air pollutant referenced in the studies below is formaldehyde. Formaldehyde (HCHO) is an air pollutant that can cause nausea, fatigue, nasal irritation, and skin irritation. Formaldehyde is considered a carcinogen, meaning it has been evaluated and determined to potentially cause cancer in humans. It is emitted by building materials such as plywood, particle board, insulation materials, and paints.

Investigation 1

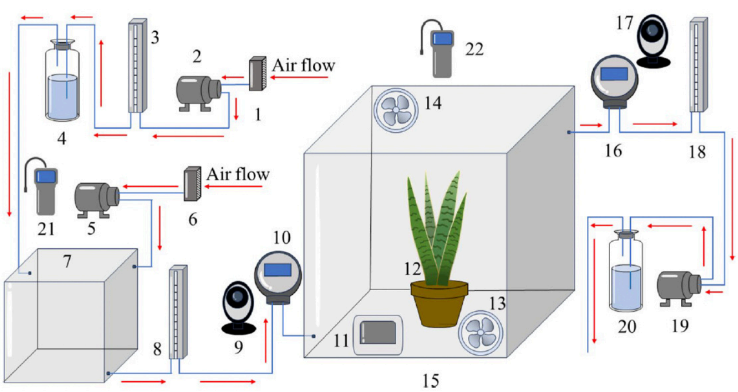
Article Title: Removal of formaldehyde from indoor air by potted Sansevieria trifasciata plants: dynamic influence of physiological traits on the process
Publish Date: 2024 Nov;31
Publication: Environ Sci Pollut Res Int.
Authors: Li J, Chen S, Zhong J, Lin S, Pang S, Tu Q, Agranovski I.
Link: doi: 10.1007/s11356-024-35366-4. Epub 2024 Oct 29. PMID: 39470907; PMCID: PMC11599484.

Overview: In the first portion of the investigation, researchers were interested in looking at the effects of prain plants' abilities to remove formaldehyde from indoor air for a longer period of time than previously tested (7 days vs 24 hours).

Materials: Plexiglass Fumigation Apparatus

- a small fan to circulate air
- two ports (each 1/4 inch in diameter):
  - 1 with tubing connected to a device for taking air samples
  - 1 with tubing connected a device to hold and pump formaldehyde into the container
- devices to measure the concentration of formaldehyde in the container
- cameras for observations
- sensory equipment for measurements

Figure 1: Plexiglas Fumigation Apparatus



Pots of plants were tightly wrapped in tin foil, ensuring only the leaves and stems were exposed to the gas. Plants were of similar height, weight, and leaf width, and all measurements were taken before and after the fumigations. The average height of the plants was about 31cm, and average width was about 6.5 cm. Grow lights were used to mimic daylight.

Methods & Data:

Plants were fumigated for 7 days using 5000 mg of formaldehyde per meter. Temperature and humidity were kept constant. Control groups (without plants) were used for comparisons. Plants were exposed to grow lights and darkness to mimic day/night.

Figure 2: Experimental Data

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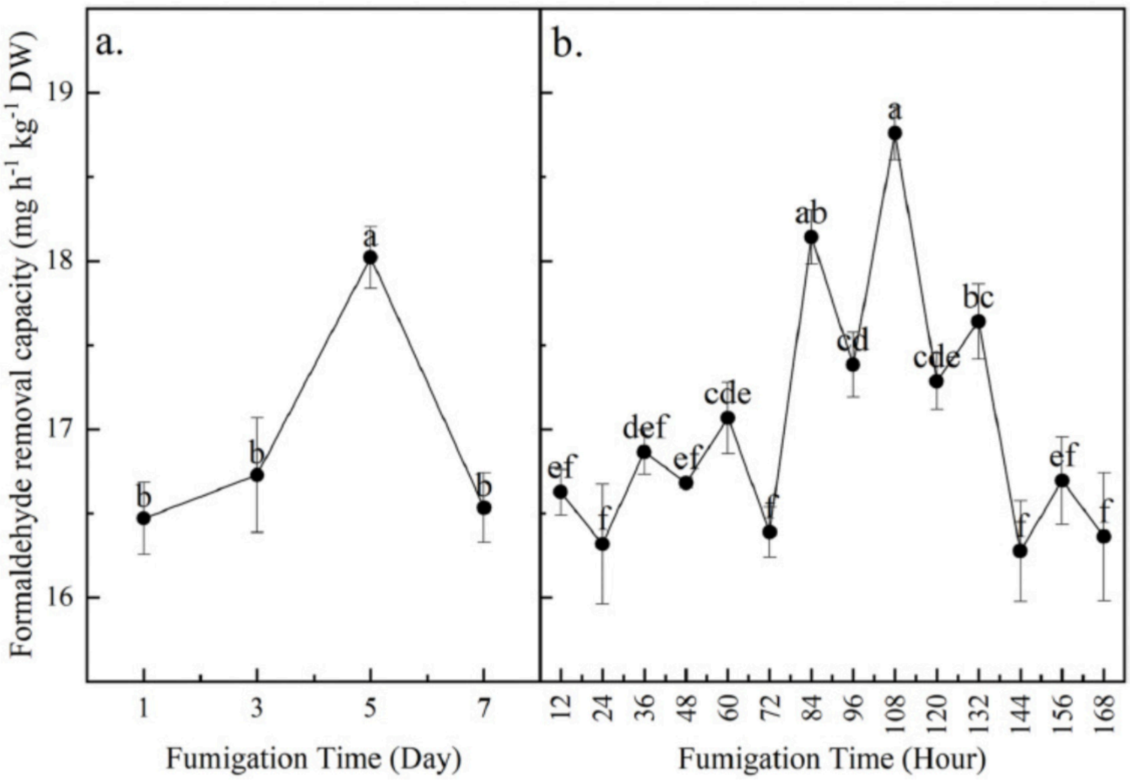


a) formaldehyde removal capability of S. trifasciata over time with fumigation variations in average daily formaldehyde removal capacity
b) fluctuation of formaldehyde removal capacity during day and night

Investigation 2

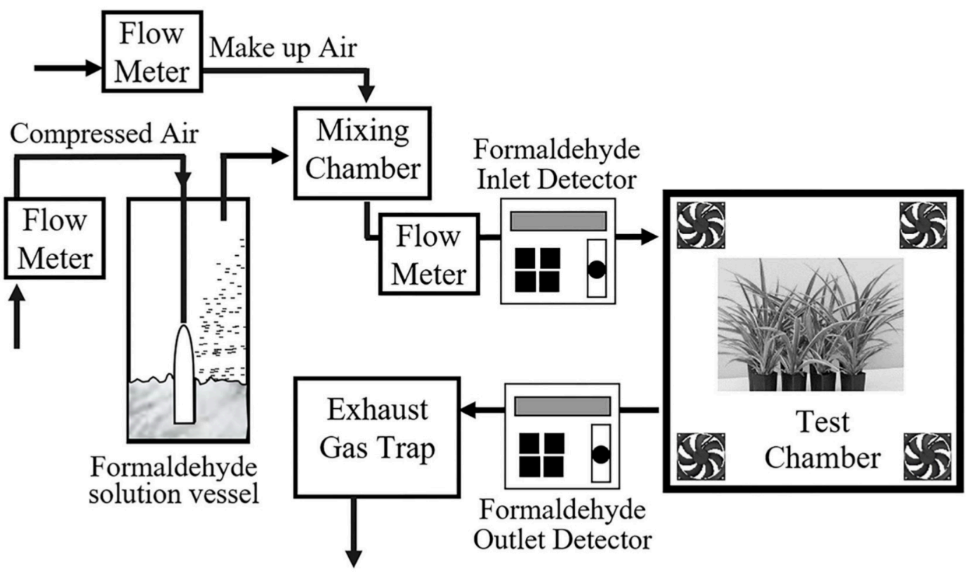
Article Title: Indoor formaldehyde removal by three species of *Chlorophytum comosum* under dynamic fumigation system: part 2—plant recovery.
Publish Date: 2021
Publication: *Environ Sci Pollut Res* **28**, 8453–8465
Authors: Li, J., Zhong, J., Liu, Q. *et al.*
Link: https://doi.org/10.1007/s11356-020-11167-3

Overview: Previous research had suggested that, comparatively, spider plants are efficient at removing pollutants, such as formaldehyde, from indoor spaces. Scientists compared three different varieties of spider plants.

Materials:

- Sealed, cube-shaped, plexiglass containers (see figure below)
    - with fans inside to circulate air and keep the concentration of formaldehyde within the container uniform throughout the container
- 2 access ports connected to formaldehyde detectors
    - 1 measuring the inlet of formaldehyde, which was connected to a mixing chamber for formaldehyde solution and a flow meter
    - a second connected to an exhaust trap for the gas removed from the container
- 3 potted spider plants: Green leaves (CG), Green/Gold leaves (CC), and Purple/White leaves (PC)
- The containers were exposed to exterior grow lights for 12 hours per day

Figure 3: Plexiglas Fumigation Apparatus



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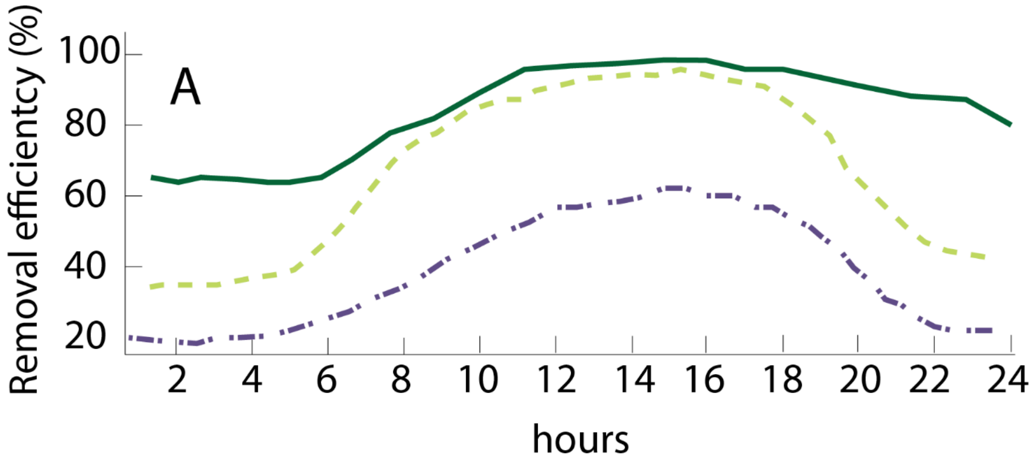
Methods & Data:

- Each variety of spider plant underwent a 7-day treatment period where it was exposed to a constant concentration of 8000 mg/m^3 of formaldehyde. Note that the data below is just representative of day 5 in the trial.
- Height, width, and leaf thickness measurements of the plants were taken before each treatment. These measurements were used to calculate the rate of formaldehyde removal per unit surface area or per gram of leaf.
- Before the experiments, the pots of all plants were wrapped in aluminum foil to focus on the interactions of the stems and leaves vs soil, soil microbes, and roots.

- Specialized methods and equipment were used to test leaf and air samples to test for the removal efficiency of the plant leaves.

Figure 4: Formaldehyde removal efficiency at the 5th day by potted plant system *(adapted)*



 GC Spider Plant: Green-Gold Leaves (solid dark green line)	 CC Spider Plant: Green Leaves (green dashed line)	 CC Spider Plant: Purple Leaves (dashed purple line)

1a. Compare and contrast the two investigations. Make note of the following:
- Identify one variable that differed between studies that might affect pollutant-removal rates.
- Is the data from each investigation consistent? If so, how or why?
- What does each study allow NASA to claim about plant effectiveness? What does it NOT tell them yet?

1b. Based on the patterns in both data sets, propose a mechanism for pollutant removal by plants, even if it is only a hypothesis.

Prompt 2

Not all plants studied were as efficient at removing indoor air pollutants. To understand which plants are best for NASA's needs, we have to look for structural patterns across species.

The image below shows photos of plants from a review of many studies that proved to be more efficient than other plants.

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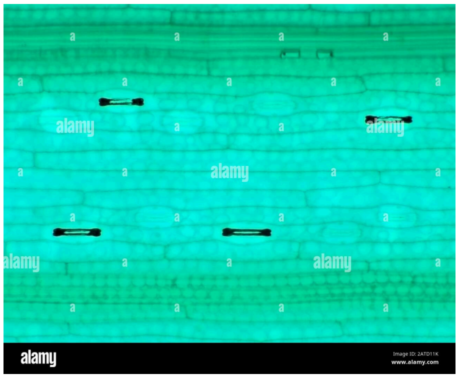
Figure 5. Recommended Plants for Indoor Air Pollutants

Mushahary R, Nath A, Chutia S, Deka P. A systematic review on phytoremediation of indoor air pollution. JAPH. 2024;9(2):255-278.

Below are two photos of two plants, hyacinth and wheat. Wheat plants are not known for being efficient in removing formaldehyde from the air. The hyacinth is a plant similar to those seen in the image of the house plants, which have been shown to be effective in removing air pollutants, such as formaldehyde. The microscopic images of both plants were taken at a 100X magnification.

Plant	**Macroscopic Plant Images**	**Microscopic Plant Images**

Hyacinth		
Wheat		
Image Sources Alamy: #2J9JX7W, #2ATD11K Adobe Stock: #466397878, #33126497		

2a. Observe evidence from the images. How do the macroscopic level features of the two plants compare? How might these differences affect gas exchange or pollutant removal?

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2b. Observe evidence from images. How do the microscopic features of each plant differ in:
- Cell shape/density
- Presence/density of darker spots

2c. How do the differences in both macroscopic and microscopic features of each plant contribute to gas exchange or pollutant movement? Be sure to link each observed structure to its possible function.

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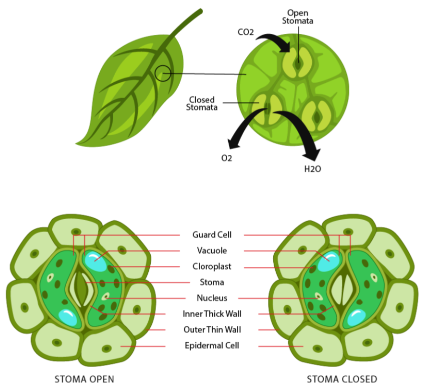
Prompt 3

Now that we have some structural clues, we can explore the mechanisms that control the uptake of pollutants. Below are three new sources of information related to our question: *Can houseplants improve air quality?*

Source 1 - Figure 6: Diagram of Structure and General Function of Stomata



Source 2: Investigation of VOC Uptake

Article Title: A systematic review on mitigation of common indoor air pollutants using plant-based methods: a phytoremediation approach
Publish Date: 2023 Mar
Publication: Air Qual Atmos Health. 11:1-27
Authors: Kumar R, Verma V, Thakur M, Singh G, Bhargava B.
Link: doi: 10.1007/s11869-023-01326-z. Epub ahead of print. PMID: 37359395; PMCID: PMC10005924.

Note: VOC stands for volatile organic compound. Formaldehyde is considered a VOC.

Excerpt

The stomatal conductance determines VOC uptake by leaves. Previous studies have shown that the rate of VOC removal by the leaf stomata is directly proportional to its conductance (Tani et al. 2007). The stomatal conductance can be measured by measuring the transpiration rate. Therefore, by monitoring the rate of transpiration, VOC concentration in intercellular spaces can be predicted, which indirectly suggests the contribution of stomatal regulation on VOC uptake (Tani et al. 2007). Studies performed with the aerial parts of plants under light conditions reported efficient removal of VOCs like formaldehyde, benzene, and toluene from the indoor air. As a result, the role of stomata in VOC uptake was demonstrated, as stomata remain open under light conditions (Yoo et al. 2006).

Source 3: What are Guard Cells?

Guard cells are roughly the shape of a kidney bean. Each stoma has two guard cells that face each other to surround the pore. The most notable thing about guard cells is the thick bands (represented in the drawing by the black) along their cell wall. The thick bands are clustered at the inside of the stoma and radiate out, leaving some space (represented by the white area in the drawing) between bands along the outer edges. As water pressure increases inside the guard cells, the outside end of the cell bulges and the inner side goes concave.

Figure 7: Guard Cells of Stoma

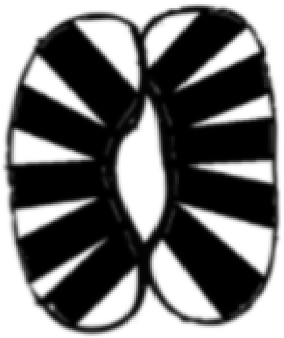


Image from: Vojtech.dostal (public domain)

Figure 8: Example of mechanisms of opening and closing stoma by guard cells.

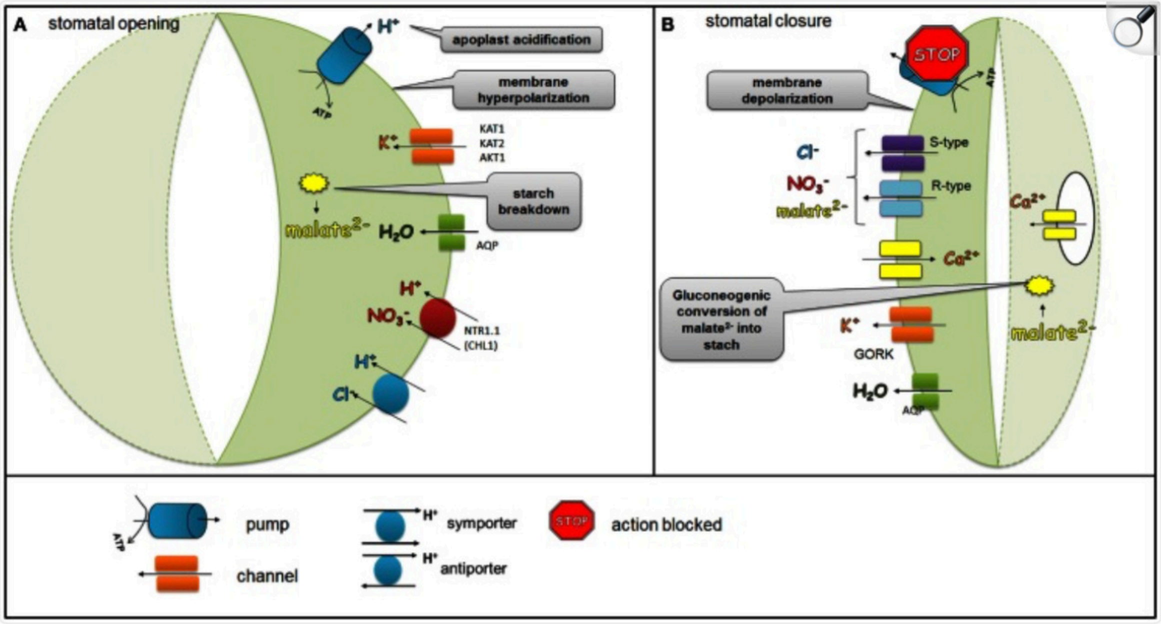


Image from:
Daszkowska-Golec A, Szarejko I. Open or close the gate - stomata action under the control of phytohormones in drought stress conditions. Front Plant Sci. 2013 May 13;4:138. doi: 10.3389/fpls.2013.00138. PMID: 23717320; PMCID: PMC3652521.

The water pressure in guard cells changes based on the concentration differences of ions inside the cell. Ions are allowed to pass or are pumped through specialized channels located in the cell membrane of the guard cells. Different kinds of signals open or close them. Water follows the ions into or out of the cell membrane to attempt to keep the concentration of ions/water even both inside and outside of the guard cells. When more ions are in the cell, the water pressure inside the cell increases. The opposite occurs when ions leave or are pumped out of the cell.

What triggers the permeability of the ion channels?

Multiple mechanisms trigger the ion channels/pumps along the cell membranes of guard cells to pump ions into or out of the guard cells. Below are the two most common:

- The first is sunlight. Phototropins, proteins present in plants, detect the presence of sunlight. In turn, the phototropins trigger a series of events that increase the permeability of the membrane channels and allow water/fluid into the cell
- When cells in the plant sense stress (lack of water, dangerous pathogens), a hormone called ABA is released. When ABA reaches the membrane of the guard cells, it triggers the release of ions out of the guard cells. This increase in concentration of ions outside of the guard cells triggers the cell membrane to allow water to pass out of the cell.

3a. Describe one claim that all three sources support to explain the physical characteristics of guard cells. List at least one piece of information that is unique to each source to: ○ Explain how these characteristics create changes in the size of the stoma. ○ Use your new understanding of the structure and function of guard cells to explain possible reasoning for the patterns seen in the data.

3b. Using what you've learned from the data, images, and information about stomata and guard cells, construct an explanation that recommends how plants could be used to improve indoor air quality.

In your explanation, be sure to:

- Use evidence from the task to support your ideas.
- Identify relevant patterns in plant structure or performance that relate to pollutant removal.
- Apply your understanding of plant structures and mechanisms (such as stomata and guard cells) to justify why your recommendations would be effective.

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