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19. LIVING PLANTS TO IMPROVE INDOOR AIR QUALITY

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ABSTRACT

Some widespread air pollutants continue to pose serious public health risks for many people. in fact nearly everyone is at risk. Many pollutants found in outdoor air are found in indoor air but at a higher concentration than outdoors, consequently it is acknowledged that inhalation of indoor air is the major determinant of human exposure to many pollutants (Krzyzanowski, 1995). There is increasing evidence that plants may be able to metabolize many potentially toxic environmental chemicals as part of their normal physiology (Sanderman 1992; Dennis et al, 1997). Work to date (Burchett et a1, 1997, Wood et al, 1997), has shown that Kentia palm as a model for indoor plant systems, has the capacity to remove several times the maximum occupational exposure levels of volatile organic compounds (V0Cs) in indoor air.

Keywords: Indoor plants, air pollution, volatile organic compounds, VOCs, Kentia palm.

INTRODUCTION

Could everyday activities in homes and offices, places we usually consider to be essentially unpolluted, expose us to the greatest contact with potentially toxic air pollutants?

Could ordinary consumer products such as air fresheners, deodorisers, cleaning compounds and various building furnishings and materials be more of a threat to our hea1th than industrial pollution? The short answer is yes.

The development of new materials and produces has substantially enhanced our standard of living. In our homes and offices, modern building materials, insulation, glues, fabrics. carpets, cleaning materials, personal care products and pesticides often expose us to high levels of a wide spectrum of chemicals. The presence of these chemicals even at very low levels is now known to influence indoor air quality with potentially adverse effects on our health. More than 300 different volatile organic compounds have been identified in office air. Exposure to these pollutants is suspected as the major cause of the headaches, lethargy, sore eyes and respiratory problems experienced by some office workers. We are realizing that the cost to our health and to the environment of these improvements is great.

We tend to take for granted the air we breathe both outdoors and indoors; particularly indoor air because it is "conditioned ", Our perception of air quality is influenced by our sense of smell and to a 1esser extent visually. This perception can be misleading; our senses may not be able to detect pollutants in trace amounts that are harmful to our health. When exposed to an odor for a period of time the perception of the odor is diminished as our olfactory cells tire very easily. Usually things that have a pleasant odor are thought of as being good and those that have an unpleasant odor are thought of as being harmful. While this is true in some cases, it is not always necessarily so. Many solvents have a sweetish odor that is not unpleasant, but will still cause serious health problems when inha1ed. Our lungs are our most important point of contact with the outside world. We may drink two liters of liquid each day. We breathe in an estimated 15,000 liters of air, approximately 6 to 10 liters every minute (American Lung Association 1996).

The perception of many people is that air pollution in cities is associated with industrialization and urbanization, and bringing outdoor air indoors for dilution purposes is no longer necessary, because of our ability for total environmental control. In practice, economic air exchange so that many pollutants found in outdoor air are found in indoor air but at a higher concentration than outdoors. Consequently it is acknowledged that inhalation of indoor air is the major determinant of human exposure to many pollutants (Krzyzanowski, 1995).

The potential hazardous natures of a multitude of substances present in indoor environments is becoming increasingly well known. Toxicology research has identified a vast range of chemicals in building materials, fittings and furnishings producing adverse health effects. Frequently, no single pollutant although having toxic potential, is present in unhealthy amounts, yet in combination and in total quantity the effects may be unhealthy.

Indoors vs. Outdoors

Recent research in the UK, Europe and the USA has shown that most people in urbanized society spend over 90% of their lives indoors, at home, work or school, (or in transit in vehicles among these locations) (Hodgson, 1997; Mann et, 1997; Cavallo et al, 1997). In Australia, where over 80% of the population lives in our major cities, the percentages can be expected to be fairly similar. The quality of the indoor environment is therefore of critical importance. to our well-being, yet it has also been shown that indoor air, particularly in situations with internal heating or cooling systems (ie. with windows shut, with or without full air-conditioning systems), may be more polluted than the air outside, except for example, along highways or directly in industrial areas (Smith, 1997). Among other contaminants. over 300 volatile organic compounds (VOC's) have been found in indoor air (Weschler and Shields 1996), as well as other gaseous toxicants such as nitrogen oxides and carbon monoxide (Ross, 1996).

Sources of these pollutants are carpets, paint, varnish, new furniture, glues and wall coverings emitting a complex mixture of organic compounds. People also contribute to the problem; freshly dry-cleaned clothes emit a stream of tetrachloroethylene and personal shampoos, soaps and deodorants give off pleasant smelling chemicals. Virtually all fragrance chemicals are volatile compounds. Each person leaves a little bit of each of their fragranced products behind in the air wherever they go. On top of this, we contribute acetone and isoprene which our bodies produce naturally. When this use is multiplied times the number of people in an office or crowded public space the exposure is phenomenal. Couple this with inadequate air circulation of many modem buildings and the problem increases.

This cocktail of gases is now considered to be one of the main causes of building-related illness, and can exacerbate conditions such as bronchitis or asthma, of which there is now a developed-world epidemic (Norback et al, 1990; Bascom, 1997). Unfortunately most people are unaware of the ubiquity of indoor pollution or of how to reduce it

Remarkable progress has been made· in improving the quality of outdoor air by controlling motor vehicle and industrial emissions. Air quality guidelines based on National Health and Medical Research Council (NHMRC) Guidelines, World Health Organization (WHO) long term goals and US Environmental Protection Agency (US EPA) Air Quality Standards are observed.

The Commonwealth Scientific and Industrial Research Organization (CSIRO) has established an Air Quality Program to assist in developing monitoring, planning and regulatory procedures to enable government to manage air quality in the face of expanding energy, industrial and transport needs (Brown 1997). Indoor air quality is substantially different from outdoor air quality and standards for outdoor air quality do not adequately serve the goal of protecting human health (Yocom 1982, quoted in Brown, 1997). The NSW Environmental Protection Authority does not have indoor air quality within its area of responsibility. Exposure of building occupants to pollutants in workplace air, whether industrial or non-industrial falls within the requirements of occupational health and safety legislation that is set at State level in Australia.

PLANTS AND POLLUTION

During the course of evolution, plants have developed an effective defense system that enables them to survive under environmentally adverse conditions such as extremes of drought. temperature or air pollution. When plants are exposed to chemicals in the air, major damage to plant cells can be caused by "free radicals" passing into the plant through the stomata in the leaves. Stomatal numbers can be as high as 12, 000 per square centimeter. The plant leaf like the human lung can function only when it is able to exchange gases with the surrounding air. As a consequence, the leaf, like the lung is an organ that is exceedingly susceptible to air pollution.

Oxidation: essential for life.

Our metabolism is based on the chemical process of oxidation. We are all familiar with the rusting of iron. It occurs so slowly that we don't see rusting taking place, but we see the result. Rust is the product of oxidation. Without oxygen, iron won't rust and without oxygen we cannot live, because the oxidation process can't take place. However natural free radical oxygen is a by-product of oxidation processes that occur in the metabolic system, and are actually harmful to health (Halliwell and Gutteridge 1989).

Free radicals and other active derivatives of oxygen are by-products of environmental pollution. Fortunately, we have a very effective defense system of detoxifying enzymes and other antioxidants. Anti-oxidant P!9teetive mechanisms in both people and plants help to reduce and minimize the effects of c1iemical pollutants.

Anti -oxidants and free radicals

These are words we readily associate with diet and health. Probably the best known antioxidant is ascorbic acid (vitamin C). Plants and most animals can synthesize it from glucose, but humans lost the ability during their evolution, and so require ascorbic acid to be present in the diet as vitamin C. We rely on the fact that plants can still make it! Ascorbic acid is an important detoxifying element for both people and plants.

As many as a trillion hydroxyl radicals (a hydroxyl radical is one composed of one hydrogen and one oxygen atom, on which sits a lone electron that is desperate to find a partner) can be present in every cubic meter of indoor air. The hydroxyl radicals are extremely reactive with the volatile organic compounds (V0Cs) present in indoor air creating even more reactive harmful chemicals (Weschler and Shields 1996). In response, to prevent cell damage, plants produce anti-oxidants such as vitamin· C and vitamin E, and a range of protective enzymes. Ozone is one of the strongest oxidants known and reacts rapidly with many plant constituents. Recent work in Europe has shown that ascorbic acid generated in some species effectively detoxified ozone (Lee et alI984, 1988).

The chemical reactions of photochemical smog have been known for decades to cause health problems. It is now being shown that similar reactions take place indoors despite the absence of sunlight (Weschler and Shields 1996). Plants are able to metabolize many potentially toxic foreign chemicals and contain anti-oxidant enzymes that resemble by a number of criteria, two major enzymes of the human liver (Sanderman 1992). Many plant detoxifying enzymes are constitutive (Sanderman 1992), and as in animals, some enzymes that participate in altering foreign compounds are inducible, that is, response to exposure to xenobiotics produces more of the required enzyme (Sanderman 1992). There is increasing evidence that plants may be able to metabolize many potentially toxic environmental chemicals as part of their normal physiology (Sanderman 1992; Dennis et al, 1997).

A large literature concerning plant stress responses has accumulated over the last two decades. The ability of plant leaves to absorb chemicals from the environment translocate them to other parts of the plant and biodegrade them, bas been demonstrated in many studies

One of the outstanding features of the response of plants to many of the man made pollutants in the atmosphere is the variable responses of species to both acute and chronic exposure. It is likely that plant populations are evolving in response to air pollutants (Tingey and Andersen 1991).

NASA and plants for clean air

Research carried out by Wolverton (1996), first with the National Aeronautics and Space Administration (NASA), and later with ALCA (Associated Landscape Contractors of America, Interior Plantscape Division), showed that potted plants of a number of varieties, could reduce the concentrations of volatile organic compounds (VOC's) in test chambers by 50 - 90% over a 24-hour period. Later work (Geise et al 1994) has shown that formaldehyde, one of the commonest organic compounds found in indoor atmosphere, is absorbed by leaves, and broken down by plant respiration into carbon dioxide and water, normal products which building occupants also exhale.

An investigation of the biological decontamination capabilities of plants is the object of our research at UTS. Commonly 'used 'international' indoor plant varieties, such as *Howea forsteriana* (Kentia palm), *Spathiphyllum Petite* and *Dracaena Janet Craig* are being evaluated for their ability to reduce or remove volatile chemicals including benzene and n-hexane. These chemicals are found in paints, plastics, room deodorizers, adhesives, cleaning compounds and personal care products as well as many other applications. Benzene, a known carcinogen is present in petrol and in some household products. All three of the species, tested in sealed chambers, were found to remove the individual VOC's at concentrations equal to, and 2 to 5 times higher than those recommended by WorkSafe Australia for Time- Weighted Average exposure standard (TWA), over periods ranging from 48 hours to 5 days (Burchett et al, 1997, Wood et al, 1997). In addition, it has been found in a recent British study (Ross et al, 1997) that houses containing more than six indoor plants had 30% lower levels of nitrogen dioxide than those with fewer or no plants. These findings are in line with previous work which has shown a general capacity for indoor plants to absorb trace quantities of volatile organic compounds (V0Cs) (Wolverton, 1996), and hence improve indoor air quality.

This work to date (Burchett et al, 1997 , Wood et al, 1997), has shown that Kentia palm as a model for indoor plant systems has the capacity to remove several times the maximum occupational exposure levels of volatile organic compounds (V0Cs) in indoor air (Fig. 1,2,3). We found an induction phase over the first 24 hours, followed by increased, sustainable rates of absorption, which continued uninhibited in the dark, and in the potting media alone after removal of the plant. The response suggests the switching on of an enzyme system in the micro-organisms concerned, and the subsequent metabolism of the toxicant. Since we have found little response in a new potting media which had never been used to grow a plant, it appears that in this species, as in many others, the plant plays a determining role in the development of the rhizosphere flora and its particular suite of organisms (Odham et al, 1986, Phillips and Streit, 1995, Garland, 1996, Colombo et al, 1996). The study by Giese et al, (1994) measured metabolism under hydroponic conditions so that the effects of soil microorganisms could be excluded, but in this study, hydroponic conditions gave results which highlighted the intimate association between VOC metabolizing bacteria and the roots of the Kentia.

Microorganisms are also capable of an enormous range of catabolic activity, and their enzymes for that purpose are generally specific for individual compounds (Phillips and Streit, 1995). It has been proposed that very low concentrations of many common plant products such as phytoalexins and lectins released from plant roots, may regulate genes in some. soil microorganisms (Jakoby and Zeigler, 1990). Those bacteria or fungi responding to the plant chemical signals, use carbon energy sources in the root exudate more effectively than others. There is a growing literature on the role of soil micro-organisms in detoxification or decontamination of polluted soils (see, eg, Swoboda-Colberg, 1995). It is to be expected that indoor plants and their soil microbial communities, will share the capacities of the outdoor species in the useful attributes of pollution reduction and biomonitoring.

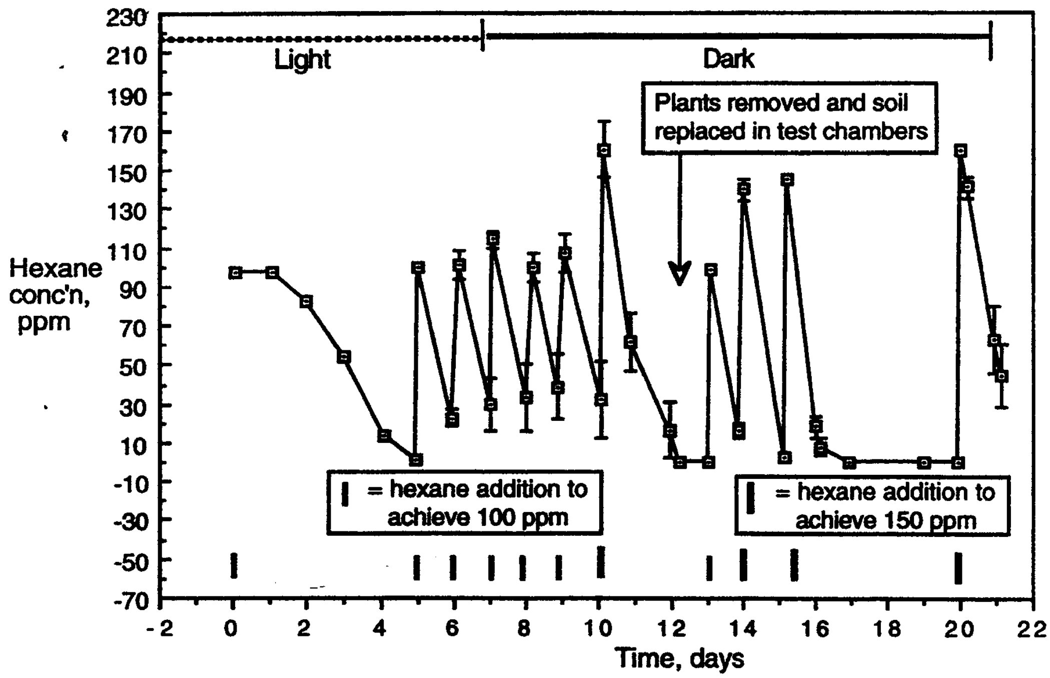

Fig.1. Hexane levels in test chambers containing Howea forsteriana (Kentia palm) Each point is the mean of 4 experiments (Mean ± SEM).

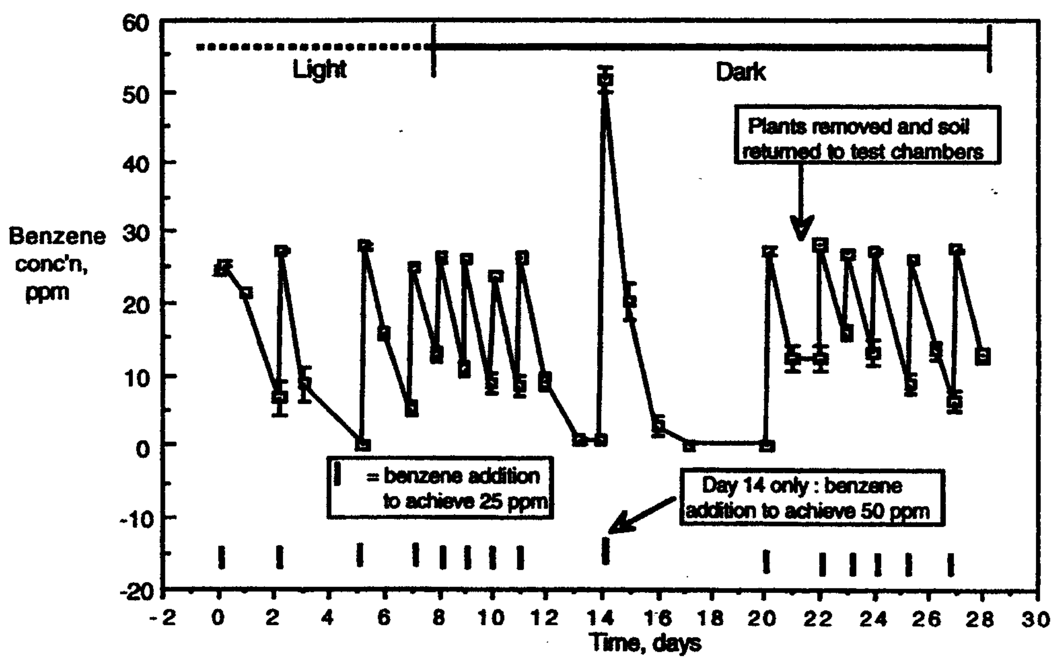

Fig.2. Benzene levels in test chambers containing Howea forsteriana (Kentia palm). Each point is the mean of 4 experiments (Mean ± SEM).

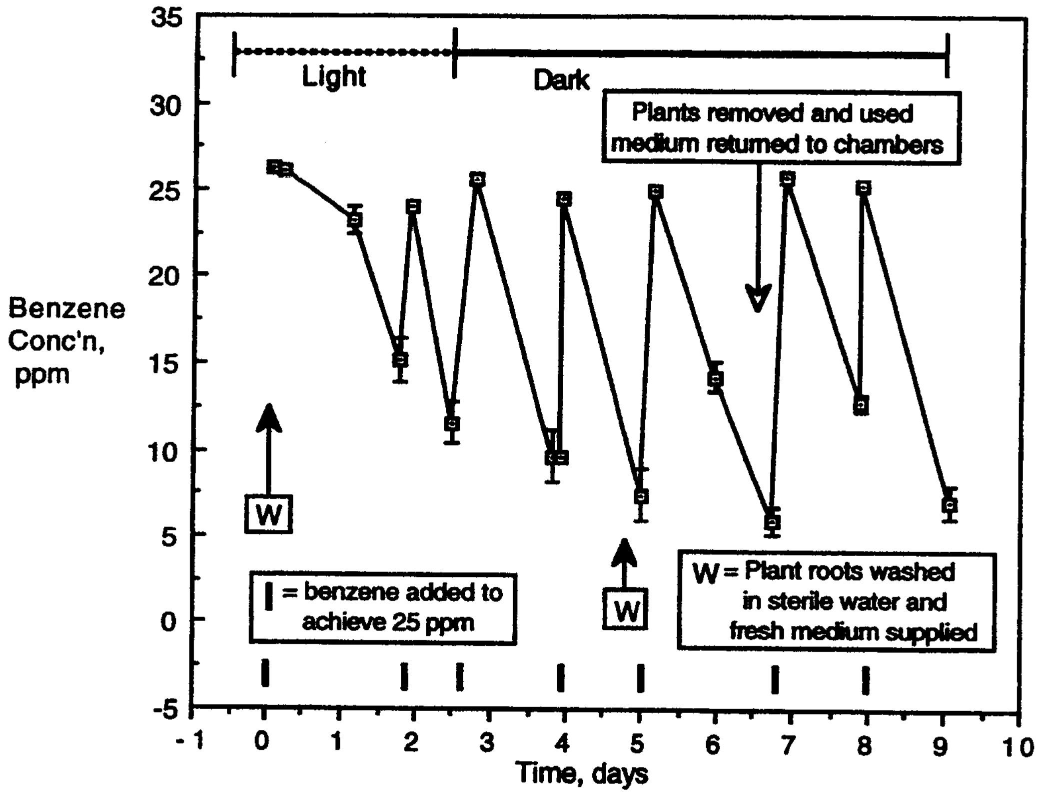

Fig.3. Benzene levels in test chambers containing Howea forsteriana (Kentia palm) : Bare plants under hydroponic conditions. Each point is the mean of 4 experiments (Mean ± SEM).

SUMMARY

1. These results show that the plant-soil complex can directly reduce concentrations of air pollution, and again, selection, breeding and planting programs are needed to maximize their potential. use for this purpose. (Funding support: NSW Agric. /Comm. Hort. Research and Devpt. Corp.)

2. Plants are four or five times more sensitive to air pollution than humans, and so can act as biomonitors of air pollution, and early-warning systems of any deterioration in air quality, (Singh, 1993; Mousine and Aliev, 1994; Burchett et al., 1997a).

Future work is needed to extend the range of plants, potting mixes and chemicals tested, to achieve a better evaluation of the capacity of indoor plants to detoxify VOCS in the indoor environment. Industrial chemicals and pesticides were initially introduced into the environment without any knowledge of their environmental fate. Millions of tons of chemicals are released into the air each year. Large scale environmental contamination may have been prevented or at least reduced by the metabolic sink activity of plants. The effect of air quality on human well being depends on both outdoor air quality and indoor air quality. Indoor air and outdoor air are intrinsically connected. We need green plants outdoors for oxygen generation and as carbon sinks and indoors for the improvement of air quality. Green plants have the capacity to assist in the goal of improving air quality in several unique ways, which urgently need targeted research and development:

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