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What is the effect of temperature on formaldehyde absorption by soil-grown and hydroponic Epipremnum aureum?

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Abstract:

Formaldehyde gas is a toxic gas and is an indoor pollutant. Phytoremediation is an effective method to remove indoor formaldehyde gas. This research aims to investigate the effect of temperature (20°C, 25°C, and 30°C) on the phytoremediation of formaldehyde by hydroponic and soil-grown Epipremnum aureum in both light and dark conditions. The experiments were conducted in a sealed acrylic box, which was tested to be airtight. Additional formaldehyde solution was added to the box to vaporize, and the concentrations of formaldehyde gas and carbon dioxide gas in the box were measured and recorded. The results showed that the formaldehyde absorption ability of both hydroponic and soil-grown Epipremnum aureum decreased as the temperature increased from 20°C to 30°C, with 20°C being the optimum temperature within the experiments. The results showed that cultivation methods (hydroponic and soil-grown) and light intensity (1100 lux and 0 lux) had no significant effect on the formaldehyde absorption capacity of Epipremnum aureum. Therefore, for greatest absorption, potted Epipremnum aureum should be kept at around 20°C.

Keywords: Phytoremediation, Epipremnum aureum, golden pothos, formaldehyde, formaldehyde removal, temperature, effect of temperature, potted plant, VOC gas removal, indoor pollutant removal.

1. Introduction

Formaldehyde is a very volatile toxic gas that is common in indoor environments [1]. In order to purify indoor air, phytoremediation of formaldehyde is a very simple method. Some studies have shown that potted plants can absorb formaldehyde through internal metabolic reactions and rhizosphere microorganisms [14,15,16,17,18]. Recently, some studies have demonstrated the ability of some plant varieties to absorb formaldehyde including the effects of light intensity [25,26] and growth media [27,28,29] on the ability of some plant species to absorb formaldehyde. This study will take the common indoor potted plant,

Epipremnum aureum, either soil-grown or hydroponic, to explore the influence of temperature on formaldehyde absorption.

2. Literature Review

2.1 Background

Formaldehyde (HCHO), is an organic compound, colorless but strongly irritant gas, readily soluble in water. Formaldehyde is widely used in industrial production, so furniture, textiles, tobacco, and electronic cigarettes can release formaldehyde gas [1,2].

0.1 mg/m3 is the indoor formaldehyde safe concentration limit provided by the World Health Organization [2,3,4]. Figure 1 shows that mobile homes, frequent smoking, and workplaces with occupational exposure can lead to indoor formaldehyde concentrations equal to or exceeding the 0.1mg/m3 limit [5]. Studies have shown that formaldehyde concentrations below the 0.1mg/m3 limit do not pose a risk of upper respiratory tract cancer in humans. However, beyond this limit, with the increase of formaldehyde concentration, people will gradually suffer from nose, eyes, throat, and skin irritation, and lung function changes [3,4,5]. Higher concentrations can cause strong lachrymation, and cause pulmonary edema, lung cancer, nasal cell cancer, etc., and at higher concentrations 60 mg/m3 cause acute harm and even endanger life (Figure 2) [5].

Table 11. Average exposure concentrations to formaldehyde and contribution of various atmospheric environments to average exposure to formaldehyde

Source	Concentration (mg/m^3)	Exposure (mg/day)
Ambient air (10% of time; 2 m^3/day)	0.001–0.02	0.002–0.04
Indoor air		
Home (65% of time; 10 m^3/day)		
– conventional	0.03–0.06	0.3–0.6
– mobile home	0.1	1.0
– environmental tobacco smoke	0.05–0.35	0.5–3.5
Workplace (25% of time; 8 m^3/day)		
– without occupational exposure [a]	0.03–0.06	0.2–0.5
– with occupational exposure	1.0	8.0
– environmental tobacco smoke	0.05–0.35	0.4–2.8
Smoking (20 cigarettes/day)	60–130	0.9–2.0[b]

[a] Assuming the normal formaldehyde concentration in conventional buildings.

[b] Total amount of formaldehyde in smoke from 20 cigarettes.

Source: World Health Organization *(2)*.

Figure 1 Average exposure concentrations to formaldehyde and contribution of various atmospheric environments to average exposure to formaldehyde. [5]

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Table 12. Effects of formaldehyde in humans after short-term exposure

Concentration range or average (mg/m^3)	Time range or average	Health effects in general population
0.03	Repeated exposure	Odour detection threshold (10th percentile) [a]
0.18	Repeated exposure	Odour detection threshold (50th percentile) [a]
0.6	Repeated exposure	Odour detection threshold (90th percentile) [a]
0.1–3.1	Single and repeated exposure	Throat and nose irritation threshold
0.6–1.2	Single and repeated exposure	Eye irritation threshold
0.5–2.0	3–5 hours	Decreased nasal mucus flow rate
2.4	40 minutes on 2 successive days with 10 minutes of moderate exercise on second day	Postexposure (up to 24 hours) headache
2.5–3.7	–[b]	Biting sensation in eyes and nose
3.7	Single and repeated exposure	Decreased pulmonary function only at heavy exercise
5–6.2	30 minutes	Tolerable for 30 minutes with lachrymation
12–25	–[b]	Strong lachrymation, lasting for 1 hour
37–60	–[b]	Pulmonary oedema, pneumonia, danger to life
60–125	–[b]	Death

[a] Frequency of effect in population.

[b] Time range or average unspecified.

Figure 2 Effects of formaldehyde in humans after short-term exposure. [5]

Before the emergence of life, formaldehyde was probably one of the most abundant organic compounds in nature, so organisms may have evolved metabolic functions capable of detoxifying formaldehyde to adapt to environmental conditions [6,36]. For example, formaldehyde can be involved as an important intermediate in the metabolic reaction of C1 compounds in Methylotrophic bacteria [6,7,36]. In Methylotrophic bacteria, C1 compounds are first oxidized to formaldehyde, and then formaldehyde is oxidized further to form carbon dioxide and release energy [6,7]. 3-hexulose-6-phosphate synthase and 6-phospho-3-hexuloisomerase are two critical enzymes in Methylotrophic bacteria for formaldehyde fixation [6,7,8].

2.2 Previous research about Phytoremediation of formaldehyde

2.2.1 Analysis of the existing literature on the mechanism of formaldehyde uptake

Plants have a great capacity for air purification. Placing potted plants indoors can beautify the environment and help clean the air. Plants can remove gaseous pollutants such as formaldehyde [9,10], benzene [11,12], and carbon dioxide [13], and increase the humidity and reduce the temperature of the indoor environment [13].

Both the metabolism of potted plants and rhizosphere microorganisms remove formaldehyde [14,15,16,17,18,50]. Plants can use formaldehyde as a carbon source by photosynthetic cells [6,7]. Carbon dioxide is produced which then joins the Calvin Cycle during the photosynthesis of

sugars [6,19,20]. One pathway is through the redox reactions of formaldehyde [14,16,21]. Formaldehyde is oxidized by oxidizing agents such as oxygen and hydrogen peroxide to produce carbon dioxide and water [16,21]. Another pathway is through enzymatic reactions which mainly involve formaldehyde dehydrogenase [6,15,22].

For the removal by microorganisms in the rhizosphere, formaldehyde is first absorbed into plants' leaves through gas exchange through stomata, then transported to the root through the stem, then released from the root to the rhizosphere [16,17,18]. The microorganisms in the rhizosphere absorb and decompose the transferred formaldehyde [16,17,18].

The results of recent research show that the ability of Arabidopsis thaliana to absorb and detoxify formaldehyde is directly proportional to the activity of formaldehyde dehydrogenase, and the enzymes' gene expression level is similar in all organs of the plant. Therefore, most of the plant cells can process formaldehyde [15]. Glutathione-dependent formaldehyde dehydrogenase is the major enzyme involved in the metabolism of formaldehyde as well as hydrolase and formate dehydrogenase, and both glutathione and NAD need to be involved for formaldehyde dehydrogenase to be active [6,7,15,22,23]. The reactions below (Figure 3) are the general processes of how formaldehyde is decomposed [7,15,22]:

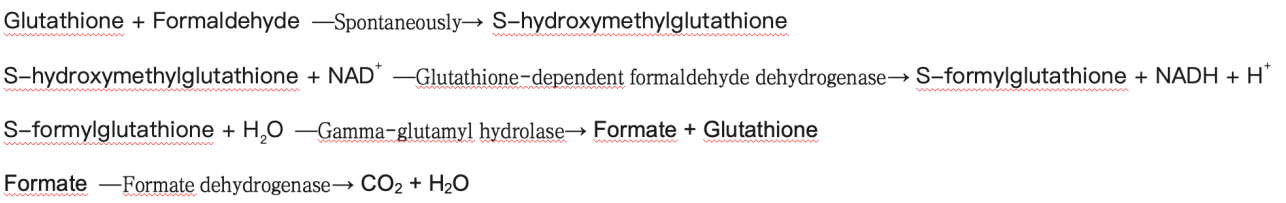

Figure 3 Reactions showing how formaldehyde is decomposed to produce CO_2.

Glutathione and formaldehyde first react to produce S-hydroxymethylglutathione spontaneously [7,15,22]. Then, S-hydroxymethylglutathione reacts with NAD to produce S-formylglutathione by glutathione-dependent formaldehyde dehydrogenase [7,15,22]. Formic acid is then produced by hydrolysis of S-formylglutathione by hydrolase [7,15,22]. Then, by formate dehydrogenase, formic acid is converted to carbon dioxide [7,15,22], which can be used in photosynthesis to produce glucose, and then can release energy by respiration. In this research, the enzymatic reaction pathway in Arabidopsis thaliana was studied but the effects of redox reactions and microorganisms on the degradation of formaldehyde were not tested and demonstrated conclusively. However, the analysis of this research about the enzymatic reactions of formaldehyde in Arabidopsis thaliana is very detailed, and it provides the necessary information for a better understanding of the process of decomposing formaldehyde in plants.

Other research looked at the ability of plant extracts and soil solutions from Plantago asiatica and Taraxacum mongolicum to decompose formaldehyde [24]. The results show that both plants can effectively absorb and remove formaldehyde mainly by metabolism [24]. Both plant species absorbed only a small amount of formaldehyde through the rhizosphere solution [24]. For Plantago asiatica, the concentrations of formaldehyde in its fresh extracts and boiled extracts are very similar, which indicates that the denaturation of enzymes does not have much effect on the decomposition of formaldehyde [24]. This result shows that Plantago asiatica mainly relies on redox reaction to degrade formaldehyde [24]. For Taraxacum mongolicum, the antioxidant enzymes (peroxidase and catalase) in its shoot are more active than the enzymes in the shoot of Plantago asiatica, which indicates that Taraxacum mongolicum has lower oxidation potential [24]. This result shows that Taraxacum mongolicum mainly relies on enzymatic reaction to degrade formaldehyde [24]. In general, the formaldehyde removal rate of Plantago asiatica is higher than that of Taraxacum mongolicum [24]. This research studied enzymatic reactions and redox reactions in two plant species and demonstrated that different plant species have different dominant mechanisms for formaldehyde removal. However, it lacks detailed analysis and explanation of the cause of the different dominant mechanisms of these two plants as well as the detailed analysis of microbial absorption and decomposition of formaldehyde in rhizosphere solution.

Furthermore, there is a recent study on the comparison of non-microbial and microbial plant systems with plant species M. cordifolium, B. pinnatum, S. Sansevieria, O. sativa, L. esculentum, and H. annuus [16]. Through the analysis of plant extracts, the results showed that the efficiency of formaldehyde removal in the experimental group with rhizosphere microorganisms was much higher than that in the control group with plants only, without microorganisms, and the removal efficiency of different combinations of plant species and microorganisms was also affected by the duration of exposure to formaldehyde [16]. Since formaldehyde needs to be transmitted from the leaves to microorganisms in the rhizosphere solution in plants, the degree of absorption and degradation of formaldehyde by microorganisms in the rhizosphere can be re-

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flected by the transmission rate [10,16]. The breakdown of formaldehyde by microorganisms in the soil reduces the concentration of formaldehyde in the rhizosphere, increasing the amount of formaldehyde transported down the concentration gradient from the leaves to the roots as well as an increase in the transport rate of formaldehyde [16]. The transfer rate and the diffusion rate of formaldehyde between plant cells determine the overall degradation rate of formaldehyde in plants [16]. This research did not identify the types of microorganisms included in the experiment and did not investigate the effect of different microbial species on the rate of absorption and purification of formaldehyde by the microbial plant system. However, it provides a detailed analysis of the differences in the rate of absorption of formaldehyde between non-microbial and microbial plant systems and a clear description of the methods for detecting formaldehyde removal rate.

2.2.2 Analysis of the existing literature on the effect of light intensity

Recently, there have been some studies on the effect of light on the rate at which plants absorb formaldehyde. One research shows that the ability of Phoenix roebelenii to remove formaldehyde increases as the light intensity increases [25]. Phoenix roebelenii photosynthesizes at about 350 lux and releases oxygen at about 700 lux [25]. Photosynthesis can increase the ability of plants to remove formaldehyde because the metabolic reaction of formaldehyde can participate in the Calvin Cycle [25]. In addition, when the light intensity is low and does not allow plants to carry out photosynthesis, the microorganisms around the plants can also absorb and purify formaldehyde, but the overall removal efficiency is lower than when the plants can carry out photosynthesis [25]. The study was limited in that it lacked control for microbial variables, but its exploration of factors affecting removal rates of Phoenix roebelenii was comprehensive. Similarly, another study conducted experiments with Epipremnum aureum, Chlorophytum comosum L., and Dieffenbachia maculate, using formaldehyde fumigation, and showed that greater light intensity increases the removal rate [26]. The study also tested the effects of carbon dioxide and showed that the concentration of carbon dioxide did not significantly affect the plant's efficiency in purifying formaldehyde [26].

2.2.3 Analysis of the existing literature on the effect of growth media

There was some recent research about the effects of growing media on the removal rate of formaldehyde by plants. One study conducted experiments with Chrysanthemum morifolium, Hedera helix, Epipremnum aureum, and Dieffenbachia compacta grown in three hydroponic growth media: activated carbon, expanded clay, and grow-stone [27]. Activated carbon can be used to adsorb and remove impurities and odors from wastewater, and is a good microbial substrate [27]. The results showed that activated carbon was the fastest in absorbing formaldehyde among the three growth media, and wet expanded clay and grow-stone absorbed a greater amount of formaldehyde than dry ones [27]. This study did not control the amount of microorganisms, but it well reflects the usability and practicability of activated carbon. Two other studies also proved that activated carbon prepared from sugarcane bagasse [28] and derived from sewage sludge [29] is effective in removing formaldehyde.

2.3 Summary

Epipremnum aureum, an evergreen liana, is a very common potted plant for indoor decoration. It is cheap, easy to obtain, and easy to grow, and it generally has two methods of cultivation, soil culture and hydroponics. Epipremnum aureum has a very high consumer base in China and is the main indoor plant of choice. There was a news report that a cultivation base of Oriental Splendid Modern Agriculture Co., Ltd. in Hainan Province, China, produces and sells 5 million pots of Epipremnum aureum every year [30]. At present, studies have shown that Epipremnum aureum can absorb and purify formaldehyde gas [31,32,23], and there have been some studies on the effects of light intensity [25,26] and growth media [27,28,29] on the absorption rate of formaldehyde by plants, but there are relatively few studies about the effects of temperature on the absorption rate of formaldehyde of the common potted plant, Epipremnum aureum. In this study, several potted Epipremnum aureum were used to investigate the effects of temperature with different cultivation methods (hydroponic and soil-cultured) on formaldehyde absorption by monitoring formaldehyde concentration in real-time to analyze the most suitable common indoor temperature for Epipremnum aureum to remove formaldehyde as well as to analyze which of hydroponic and soil Epipremnum aureum is more suitable for people to put indoors in daily life to purify formaldehyde under certain temperature. In addition, the ability of Epipremnum aureum to absorb formaldehyde in light and dark conditions was compared and the possible relationship between formaldehyde and carbon dioxide concentrations was investigated.

3. Methodology

The purpose of this study was to investigate the formaldehyde absorption by hydroponic and soil-grown Epipremnum aureum under different temperatures, to compare the formaldehyde absorption by Epipremnum aureum in the

condition of light and darkness, and to explore whether carbon dioxide concentration is affected by formaldehyde absorption by Epipremnum aureum. By monitoring the change of formaldehyde concentration in the sealed environment in real-time, the absorption of formaldehyde gas by the plant was detected.

3.1 Experimental design

General overview

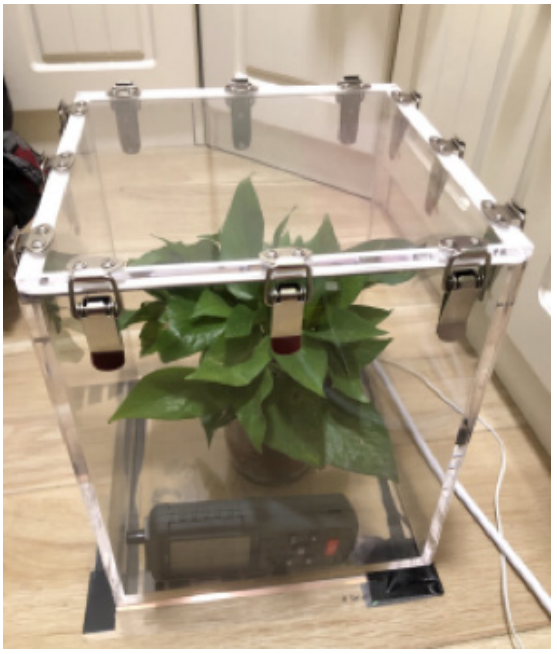

Figure 4 Experimental setup.

Figure 4 shows the experimental setup. The experiments were conducted in an airtight acrylic transparent box. Sensors in the box detected levels of carbon dioxide and formaldehyde for three hours. The temperature of the box could be adjusted to 20°C, 25°C, and 30°C, common in indoor environments. The box could be placed in light or darkness. Three trials were done under each condition.

For most experimental conditions one 15-20cm plant (Epipremnum aureum) was placed in the box at the start of the test. The plants were in either hydroponic water or soil growth medium.

Plants (Epipremnum aureum)

Figure 5 Epipremnum aureum.

6 healthy potted Epipremnum aureum (Figure 5) with about 30 leaves of the same shape and size from the same batch were purchased from the same store (both soil-grown and hydroponic). Each plantlet was weighed without soil. Specimens were selected that had the same overall mass of 55g.

Each plantlet was kept in similar conditions, receiving an equal volume of light and water. Soil-grown plants were kept in the same volume and mass of coconut husk growth medium in identical pots.

The same volume of tap water was added to the pots to make the hydroponic medium.

The test box

A sealed box made of acrylic with dimensions 25cm, 25cm, and 30cm was used for the experiment. The box was tested using formaldehyde vapour for 3 hours. The concentration remained the same during 3 trials.

Formaldehyde and Carbon Dioxide sensor

A handheld gas detector [51] is used to monitor the humidity (70%RH) [52] and concentration of formaldehyde and carbon dioxide gas in the sealed box in real time. A camera is used to record the changes in the data in real time on the display screen of the gas detector for later recording data.

Temperature Control

A graphene heating pad was used to set the temperature for each set of experiments (20°C, 25°C, and 30°C) and to control the corresponding temperature required for each set of experiments to remain constant while the experiment was being conducted.

Formaldehyde

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10ml of 10% concentration formaldehyde solution was evenly injected into the cotton cloth around the potting plant so that the formaldehyde solution was quickly and fully evaporated into gas in the sealed box. To control that the initial concentration of formaldehyde gas in the sealed box of each experiment is the same, the volume and concentration of formaldehyde solution added at the beginning of the experiments is the same (10ml of 10% concentration formaldehyde solution, which is a similar concentration to that used by other researchers [33]).

Lighting

The experiments were carried out in a closed room with no external light sources. An incandescent daylight lamp was used to provide light for Epipremnum aureum under light conditions. The light intensity in the box was 1100 lux [49]. For the experiments in dark conditions, all light sources in the room are extinguished.

3.2 Pilot and control trials.

3.2.1 Group 1 (Empty box)

In order to see if the acrylic box is airtight, the empty box was tested under 20°C, 25°C, and 30°C respectively (Table 1, Table 2, and Table 3).

Table 1 The table shows the conditions to test the airtightness of the experimental box under 20°C.

Pot	Plant	Temperature/°C	Light intensity/ lux	HCHO added/ml	Growth medium	Time/h
None	None	20	1100	0	None	3
None	None	20	1100	10	None	3

Table 2 The table shows the conditions to test the airtightness of the experimental box under 25°C.

Pot	Plant	Temperature/°C	Light intensity/ lux	HCHO added/ml	Growth medium	Time/h
None	None	25	1100	0	None	3
None	None	25	1100	10	None	3

Table 3 The table shows the conditions to test the airtightness of the experimental box under 30°C.

Pot	Plant	Temperature/°C	Light intensity/ lux	HCHO added/ml	Growth medium	Time/h
None	None	30	1100	0	None	3
None	None	30	1100	10	None	3

The results were tested to check that they had a normal distribution. Then, paired sample t-tests of the overall formaldehyde concentration and carbon dioxide concentration were carried out respectively.

The results showed that the formaldehyde concentration was maintained so that the acrylic box was airtight.

3.2.2 Group 2 (Pot only)

To test if growth media would absorb formaldehyde, only coconut husk and tap water were tested in the sealed box, under three different temperatures (Table 4, Table 5, and Table 6).

Table 4 The table shows the conditions to test for the growth medium under 20°C.

Pot	Plant	Temperature/°C	Light intensity/ lux	HCHO added/ml	Growth medium	Time/h
Present	None	20	1100	10	Coconut husk	3
Present	None	20	1100	10	Hydroponic water	3

Table 5 The table shows the conditions to test for the growth medium under 25°C.

Pot	Plant	Temperature/°C	Light intensity/lux	HCHO added/ml	Growth medium	Time/h
Present	None	25	1100	10	Coconut husk	3
Present	None	25	1100	10	Hydroponic water	3

Table 6 The table shows the conditions to test for the growth medium under 30°C.

Pot	Plant	Temperature/°C	Light intensity/lux	HCHO added/ml	Growth medium	Time/h
Present	None	30	1100	10	Coconut husk	3
Present	None	30	1100	10	Hydroponic water	3

The results were tested to check that they had a normal distribution. T-tests and variance analysis were used to analyze these data. These showed whether the growth media would affect the formaldehyde absorption rate of the whole water-plant system and soil-plant system and whether temperature affects the rate of absorption by growth media.

Control groups under the same conditions but with no additional formaldehyde added were conducted. The test results showed that the formaldehyde concentration was constant which showed that the pot, coconut husk, and tap water did not release formaldehyde gas. The statistical analysis of test results is shown in the Results.

3.2.3 Group 3 (Plant and pot)

Epipremnum aureum was tested in the sealed box in the light and darkness respectively, under 20°C, 25°C, and 30°C (Table 7, Table 8, and Table 9).

Table 7 The table shows the conditions to test for Epipremnum aureum under 20°C.

Pot	Plant	Temperature/°C	Light intensity/lux	HCHO added/ml	Growth medium	Time/h
Present	Present	20	1100	10	Coconut husk	3
Present	Present	20	0	10	Coconut husk	3
Present	Present	20	1100	10	Hydroponic water	3
Present	Present	20	0	10	Hydroponic water	3

Table 8 The table shows the conditions to test for Epipremnum aureum under 25°C.

Pot	Plant	Temperature/°C	Light intensity/lux	HCHO added/ml	Growth medium	Time/h
Present	Present	25	1100	10	Coconut husk	3
Present	Present	25	0	10	Coconut husk	3
Present	Present	25	1100	10	Hydroponic water	3
Present	Present	25	0	10	Hydroponic water	3

Table 9 The table shows the conditions to test for Epipremnum aureum under 30°C.

Pot	Plant	Temperature/°C	Light intensity/lux	HCHO added/ml	Growth medium	Time/h
Present	Present	30	1100	10	Coconut husk	3
Present	Present	30	0	10	Coconut husk	3
Present	Present	30	1100	10	Hydroponic water	3
Present	Present	30	0	10	Hydroponic water	3

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The results were tested to check that they had a normal distribution. T-tests were used to show the effects of illumination and growth media on the ability of plants to absorb formaldehyde. By one-way ANOVA, the trends in the effect of temperature on absorption rates were identified.

4. Results

4.1 Results from Group 1 (Empty box)

4.1.1 Summary

Table 10

Paired Sample t-test analysis showing that HCHO concentration is not changed by the empty box					
Name	Paired Data (Mean±Standard Deviation)		Difference	*t*	*p*
	1	2			
Ci-HCHO/mgm^{-3} paired with Av-HCHO/mgm^{-3}	0.08±0.07	0.08±0.07	0.00	-2.150	0.084
* p<0.05 ** p<0.01					
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.					

From the results of the paired t-test from Table 10, the paired data showed no differences (n.s.).

Table 11

Paired Sample t-test analysis showing that CO_2 concentration is not changed by the empty box					
Name	Paired Data (Mean±Standard Deviation)		Difference	*t*	*p*
	1	2			
Ci-CO_2/ppm paired with Av-CO_2/ppm	448.50±14.92	449.00±15.10	-0.50	-2.236	0.076
* p<0.05 ** p<0.01					
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.					

From the results of the paired t-test from Table 11, the paired data showed no differences (n.s.).

Formaldehyde and carbon dioxide concentrations remained constant in the empty box (n.s.). The results showed that the box is gas-tight for 3 hours, see Table 10 and Table 11.

The results showed that temperature did not affect the concentration of formaldehyde and carbon dioxide in the empty box for 3 hours (n.s.), see Table 12 and Table 13.

4.1.2 Data analysis

Table 12

One-way ANOVA analysis shows that changing the temperature makes no difference to HCHO concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-HCHO/mgm^{-3}	0.08±0.10	0.08±0.10	0.08±0.09	0.000	1.000
* p<0.05 ** p<0.01					
Av represents the mean final concentration of gases.					

From the results of one-way ANOVA in Table 12, different Temperature/°C samples did not show significant differences in Av-HCHO/mgm^{-3} (n.s.).

Table 13

One-way ANOVA analysis shows that changing the temperature makes no difference to CO_2 concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-CO_2/ppm	450.50±21.92	448.00±16.97	448.50±19.09	0.009	0.991
* $p<0.05$ ** $p<0.01$					
Av represents the mean final concentration of gases.					

From the results of one-way ANOVA in Table 13, different Temperature/°C samples did not show significant differences in Av-CO_2/ppm (n.s.).
These baseline results show that the following experimental environment can be relied upon.

Tests showed that the results from the Group 1 (Empty box) experiments were normally distributed. This is a pre-requisite for the use of t-tests and ANOVA, the statistical test used for later analysis. The tests for normal distribution are shown in Table 14.

Table 14

The normality test shows that the data from Group 1 (Empty box) are normally distributed									
Name	Number of Samples	Mean	Standard Deviation	Skewness	Kurtosis	Kolmogorov-Smirnov test		Shapiro-Wilk test	
						Statistical Magnitude D	*p*	Statistical Magnitude *W*	*p*
Ci-HCHO/mgm^{-3}	6	0.081	0.074	0.000	-3.331	0.316	0.062	0.693	0.005**
Ci-CO_2/ppm	6	448.500	14.923	0.058	-3.126	0.299	0.095	0.784	0.042*
Av-HCHO/mgm^{-3}	6	0.082	0.074	0.000	-3.332	0.317	0.060	0.691	0.005**
Av-CO_2/ppm	6	449.000	15.100	0.066	-3.124	0.305	0.084	0.770	0.031*
* $p<0.05$ ** $p<0.01$									
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.									

A normality test was performed for Ci-HCHO/mgm^{-3}, Ci-CO_2/ppm, Av-HCHO/mgm^{-3}, and Av-CO_2/ppm, and the results in Table 14 showed that the data are approximately normally distributed.

4.2 Results from Group 2 (Pot only)

4.2.1 Summary

The effect of temperature and cultivation method

The results showed that temperature did not affect formaldehyde and carbon dioxide levels in the box when there was only pot and growth media in the box (n.s.), see Table 17 and Table 18.
The results showed that the cultivation method affected formaldehyde and carbon dioxide levels in the box when there was only pot and growth media in the box (*), see Table 19 and Table 20.

4.2.2 Data analysis

Table 15

Paired Sample t-test analysis showing that HCHO concentration is changed by the pot or the growth medium					
Name	Paired Data (Mean±Standard Deviation)		Difference	*t*	*p*
	1	2			
Ci-HCHO/mgm^{-3} paired with Av-HCHO/mgm^{-3}	0.15±0.00	0.15±0.00	0.00	4.385	0.007**
* $p<0.05$ ** $p<0.01$					
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.					

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From the results of the paired t-test from Table 15, Ci-HCHO/mgm^{-3} and Av-HCHO/mgm^{-3} showed a 0.01 level of significance (t=4.385, p=0.007). The mean value of Ci-HCHO/mgm^{-3} (0.15) was significantly higher than the average value of Av-HCHO/mgm^{-3} (0.15). All the paired data showed differences (*).

Table 16

Paired Sample t-test analysis showing that CO_2 concentration is changed by the pot and the growth medium					
Name	Paired Data (Mean±Standard Deviation)		Difference	*t*	*p*
	1	2			
Ci-CO_2/ppm paired with Av-CO_2/ppm	459.33±4.89	542.83±24.32	-83.50	-8.662	0.000**
* p<0.05 ** p<0.01					
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.					

From the results of the paired t-test from Table 16, Ci-CO_2/ppm and Av-CO_2/ppm showed a 0.01 level of significance (t=-8.662, p=0.000). The average value of Ci-CO_2/ppm (459.33) was significantly lower than the average Av-CO_2/ppm (542.83). All the paired data showed differences (*).

Table 17

One-way ANOVA analysis shows that changing the temperature makes no difference to HCHO concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-HCHO/mgm^{-3}	0.15±0.00	0.15±0.00	0.15±0.00	0.111	0.898
* p<0.05 ** p<0.01					
Av represents the mean final concentration of gases.					

From the results of one-way ANOVA in Table 17, different Temperature/°C samples did not show significant differences in Av-HCHO/mgm^{-3} (n.s.).

Table 18

One-way ANOVA analysis shows that changing the temperature makes no difference to CO_2 concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-CO_2/ppm	542.00±29.70	542.50±31.82	544.00±32.53	0.002	0.998
* p<0.05 ** p<0.01					
Av represents the mean final concentration of gases.					

From the results of one-way ANOVA in Table 18, different Temperature/°C samples did not show significant differences in Av-CO_2/ppm (n.s.).

Table 19

Independent sample t-test shows that changing the growth medium makes a significant difference to HCHO concentration in the box				
	Cultivation method (Mean±Standard Deviation)		*t*	*p*
	Hydroponic	Soil-grown		
Av-HCHO/mgm^{-3}	0.15±0.00	0.14±0.00	5.000	0.007**
* p<0.05 ** p<0.01				
Av represents the mean final concentration of gases.				

From Table 19, the Cultivation method for Av-HCHO/mgm^{-3} showed a 0.01 level of significance (t=5.000, p=0.007). The average value of Hydroponic (0.15) was significantly higher than the average value of Soil-grown (0.14). Therefore, there were significant differences in Av-HCHO/mgm^{-3} among different Cultivation methods (*).

Table 20

Independent sample t-test shows that changing the growth medium makes a significant difference in CO_2 concentration in the box				
	Cultivation method (Mean±Standard Deviation)		*t*	*p*
	Hydroponic	Soil-grown		
Av-CO_2/ppm	520.67±0.58	565.00±2.00	-36.888	0.000**
* p<0.05 ** p<0.01				
Av represents the mean final concentration of gases.				

From Table 20, the Cultivation method showed a 0.01 level of significance for Av-CO_2/ppm (t=-36.888, p=0.000). The average value of Hydroponic (520.67) was significantly lower than the average value of Soil grown (565.00). All the samples with different Cultivation methods showed significant differences in Av-CO_2/ppm (*).

Tests showed that the results from the Group 2 (Pot only) experiments were normally distributed. This is a pre-requisite for the use of t-tests and ANOVA, the statistical test used for later analysis. The tests for normal distribution are shown in Table 21.

Table 21

The normality test shows that the data from Group 2 (Pot only) are normally distributed									
Name	Number of Samples	Mean	Standard Deviation	Skewness	Kurtosis	Kolmogorov-Smirnov test		Shapiro-Wilk test	
						Statistical Magnitude D	*p*	Statistical Magnitude *W*	*p*
Ci-HCHO/mgm^{-3}	12	0.081	0.072	0.000	-2.443	0.325	0.001**	0.665	0.000**
Ci-CO_2/ppm	12	448.083	12.391	0.130	-1.873	0.216	0.126	0.881	0.091
Av-HCHO/mgm^{-3}	12	0.078	0.071	-0.002	-2.437	0.322	0.001**	0.681	0.001**
Av-CO_2/ppm	12	494.750	53.363	0.242	-1.792	0.243	0.050*	0.848	0.035*
* p<0.05 ** p<0.01									
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.									

A normality test was performed for Ci-HCHO/mgm^{-3}, Ci-CO_2/ppm, Av-HCHO/mgm^{-3}, and Av-CO_2/ppm, and the results in Table 21 showed that the data are approximately normally distributed.

4.3 Results from Group 3 (Plant and pot)

4.3.1 Summary

The effect of temperature on formaldehyde and CO_2 levels with the plant and pot present

As the temperature increased from 20°C to 30°C Epipremnum aureum was less able to metabolise formaldehyde (*), see Table 24, Table 26, and Table 28.

As the temperature increased there was no effect on carbon dioxide concentration in the box (n.s.), see Table 25, Table 27, and Table 29.

The effect of cultivation methods on formaldehyde and CO_2 levels with the plant and pot present

Results showed there is no difference in final formaldehyde concentration between hydroponic and soil-grown plants, (n.s.) see Table 30.

Results showed there is no difference in final carbon dioxide concentration between hydroponic and soil-grown plants, (n.s.) see Table 31.

The effect of light intensity on formaldehyde and CO_2 levels with the plant and pot present

Results showed light intensity did not affect plants' ability to metabolise formaldehyde (n.s.), see Table 32.

Results showed carbon dioxide concentration is lower under 1100 lux than in darkness (*), see Table 33.

4.3.2 Data analysis

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Table 22

Paired Sample t-test analysis showing that HCHO concentration is changed by Epipremnum aureum					
Name	Paired Data (Mean±Standard Deviation)		Difference	*t*	*p*
	1	2			
Ci-HCHO/mgm^{-3} paired with Av-HCHO/mgm^{-3}	0.15±0.00	0.02±0.01	0.13	84.559	0.000**
* p<0.05 ** p<0.01					
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.					

From the results of the paired t-test from Table 22, Ci-HCHO/mgm^{-3} and Av-HCHO/mgm^{-3} showed a 0.01 level of significance (t=84.559, p=0.000). The average value of Ci-HCHO/mgm^{-3} (0.15), was significantly higher than the average value of Av-HCHO/mgm^{-3} (0.02). Therefore, there were differences in paired data (*).

Table 23

Paired Sample t-test analysis showing that CO_2 concentration is changed by Epipremnum aureum					
Name	Paired Data (Mean±Standard Deviation)		Difference	t	p
	1	2			
Ci-CO_2/ppm paired with Av-CO_2/ppm	462.17±2.55	569.50±71.89	-107.33	-5.222	0.000**
* p<0.05 ** p<0.01					
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.					

From the results of the paired t-test from Table 23, Ci-CO_2/ppm and Av-CO_2/ppm showed a 0.01 level of significance (t=-5.222, p=0.000). The average value of Ci-CO_2/ppm (462.17) was significantly lower than the average value of Av-CO_2/ppm (569.50). Therefore, there were differences in paired data (*).

Table 24

One-way ANOVA analysis shows that changing the temperature makes a significant difference in HCHO concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			F	p
	20.0	25.0	30.0		
Av-HCHO/mgm^{-3}	0.01±0.00	0.02±0.00	0.02±0.00	12.990	0.002**
* p<0.05 ** p<0.01					
Av represents the mean final concentration of gases.					

From the results of one-way ANOVA in Table 24, Temperature/°C for Av-HCHO/mgm^{-3} showed 0.01 level significance (F=12.990, p=0.002). The average values of the groups with more significant differences were "25.0>20.0; 30.0>20.0; 30.0>25.0". All samples at different Temperature/°C showed significant differences for Av-HCHO/mgm^{-3} (*).

Table 25

One-way ANOVA analysis shows that changing the temperature makes no difference to CO_2 concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			F	p
	20.0	25.0	30.0		
Av-CO_2/ppm	588.25±77.08	568.75±77.65	551.50±77.96	0.225	0.803
* p<0.05 ** p<0.01					
Av represents the mean final concentration of gases.					

From the results of one-way ANOVA in Table 25, different Temperature/°C samples did not show significant differences in Av-CO_2/ppm (n.s.).

Table 26 and Table 27 show the results of one-way ANOVA of temperature for soil-grown Epipremnum aureum.

Table 26

One-way ANOVA analysis shows that changing the temperature makes a significant difference in HCHO concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			F	p
	20.0	25.0	30.0		
Av-HCHO/mgm^{-3}	0.01±0.00	0.01±0.00	0.02±0.00	26.214	0.013*
* p<0.05 ** p<0.01					
Av represents the mean final concentration of gases.					

From Table 26, Temperature/°C for Av-HCHO/mgm^{-3} showed 0.05 level significance (F=26.214, p=0.013). The average values of the groups with more significant differences were "25.0>20.0; 30.0>20.0". All samples at different Temperature/°C showed significant differences for Av-HCHO/mgm^{-3} (*).

Table 27

One-way ANOVA analysis shows that changing the temperature makes no difference to CO_2 concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-CO_2/ppm	588.00±94.75	568.50±95.46	553.00±96.17	0.068	0.936
* *p*<0.05 ** *p*<0.01					
Av represents the mean final concentration of gases.					

From Table 27, different Temperature/°C samples did not show significant differences in Av-CO_2/ppm (n.s.).

Table 28 and Table 29 show the results of one-way ANOVA of temperature for hydroponic Epipremnum aureum.

Table 28

One-way ANOVA analysis shows that changing the temperature makes a significant difference in HCHO concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-HCHO/mgm^{-3}	0.01±0.00	0.02±0.00	0.02±0.00	10.140	0.046*
* *p*<0.05 ** *p*<0.01					
Av represents the mean final concentration of gases.					

From Table 28, Temperature/°C for Av-HCHO/mgm^{-3} showed 0.05 level significance (F=10.140, p=0.046). The average values of the groups with more significant differences were "30.0>20.0". All samples at different Temperature/°C showed significant differences for Av-HCHO/mgm^{-3} (*).

Table 29

One-way ANOVA analysis shows that changing the temperature makes no difference to CO_2 concentration in the box					
	Temperature/°C (Mean±Standard Deviation)			*F*	*p*
	20.0	25.0	30.0		
Av-CO_2/ppm	588.50±94.05	569.00±94.75	550.00±94.75	0.083	0.922
* *p*<0.05 ** *p*<0.01					
Av represents the mean final concentration of gases.					

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From Table 29, different Temperature/°C samples did not show significant differences in Av-CO_2/ppm (n.s.).

Table 30

Independent sample t-test shows that changing the growth medium makes no difference to the HCHO concentration in the box				
	Cultivation method (Mean±Standard Deviation)		t	p
	Hydroponic	Soil-grown		
Av-HCHO/mgm^{-3}	0.02±0.01	0.01±0.01	1.421	0.186
* p<0.05 ** p<0.01				
Av represents the mean final concentration of gases.				

From the results of the Independent sample t-test in Table 30, different samples of the Cultivation method did not show significant differences in Av-HCHO/mgm^{-3} (n.s.).

Table 31

Independent sample t-test shows that changing the growth medium makes no difference to the CO_2 concentration in the box				
	Cultivation method (Mean±Standard Deviation)		t	p
	Hydroponic	Soil-grown		
Av-CO_2/ppm	569.17±75.21	569.83±75.59	-0.015	0.988
* p<0.05 ** p<0.01				
Av represents the mean final concentration of gases.				

From the results in Table 31, samples of the Cultivation method did not show significant differences in Av-CO_2/ppm (n.s.).

Table 32

Independent sample t-test shows that changing the light intensity makes no difference to the HCHO concentration in the box				
	Light intensity/lux (Mean±Standard Deviation)		t	p
	0	1100		
Av-HCHO/mgm^{-3}	0.02±0.01	0.01±0.01	0.864	0.408
* p<0.05 ** p<0.01				
Av represents the mean final concentration of gases.				

From the results in Table 32, different Light intensity/lux samples did not show significant differences for Av-HCHO/mgm^{-3} (n.s.).

Table 33

Independent sample t-test shows that changing the light intensity makes a significant difference to the CO_2 concentration in the box				
	Light intensity/lux (Mean±Standard Deviation)		t	p
	0	1100		
Av-CO_2/ppm	636.67±16.16	502.33±16.80	14.116	0.000**
* p<0.05 ** p<0.01				
Av represents the mean final concentration of gases.				

From Table 33, Light intensity/lux for Av-CO_2/ppm showed 0.01 level significance (t=14.116, p=0.000). The average value of 0 (636.67) was significantly higher than that of 1100 (502.33). Different Light intensity/lux samples all showed significant differences for Av-CO_2/ppm (*). Tests showed that the results from the Group 3 experi-

ments were normally distributed. This is a pre-requisite for the use of t-tests and one-way ANOVA, the statistical test used for later analysis. The tests for normal distribution are shown in Table 34.

Table 34

The normality test shows that the data from Group 3 (Plant and pot) are normally distributed									
Name	Number of Samples	Mean	Standard Deviation	Skewness	Kurtosis	Kolmogorov-Smirnov test		Shapiro-Wilk test	
						Statistical Magnitude D	*p*	Statistical Magnitude *W*	*p*
Ci-HCHO/mgm^{-3}	12	0.149	0.001	-0.630	-0.344	0.264	0.020*	0.903	0.172
Ci-CO_2/ppm	12	462.167	2.552	0.171	-0.133	0.128	0.848	0.983	0.993
Av-HCHO/mgm^{-3}	12	0.016	0.006	0.287	-0.367	0.100	0.984	0.975	0.952
Av-CO_2/ppm	12	569.500	71.892	-0.006	-2.155	0.246	0.044*	0.819	0.015*
* p<0.05 ** p<0.01									
Ci represents the initial concentration of gases; Av represents the mean final concentration of gases.									

A normality test was performed for Ci-HCHO/mgm^{-3}, Ci-CO_2/ppm, Av-HCHO/mgm^{-3}, and Av-CO_2/ppm, and the results in Table 34 showed that the data are approximately normally distributed.

5. Discussion

5.1 Results analysis for Group 2 (Pot only)

5.1.1 Absorption of growth media

The paired sample t-tests showed that the growth media absorbed some formaldehyde during the experiments. This is because some formaldehyde gas might be removed by the moist coconut husk. This result is consistent with previous research which showed coconut husk can filter TVOC gases [34,37]. The difference is that the previous research also mixed some activated carbon in the coconut husk-based substrate so those results showed a greater rate of absorption of TVOC gases [34]. In addition, the microorganisms in the growth media might absorb formaldehyde. Other previous research showed consistent results that microorganisms in the potted plant soil are effective in degrading formaldehyde [18, 35]. In one study the ability of formaldehyde absorption of the microbe-plant system was better than plant-only system so microorganisms were active in absorbing formaldehyde [35]. Moreover, some formaldehyde gas might also dissolve in hydroponic water because formaldehyde is soluble in water. Therefore, the formaldehyde concentration decreased.

The paired sample t-tests showed the carbon dioxide concentration increased. This result is consistent with previous research [6,7,36]. Carbon dioxide was probably exhaled through microbial respiration or produced through the metabolism of formaldehyde.

5.1.2 Differences between growth media

The results from independent sample t-tests showed that the coconut husk absorbed greater amount of formaldehyde gas than hydroponic water, because there was greater microbial population in moist coconut husk so greater rate of formaldehyde absorption and degradation than in tap water. This is similar to other studies [17,34,35,37]. Therefore, the rate of formaldehyde absorption by coconut husk was faster than the rate of formaldehyde gas dissolution in water.

Similarly, the final carbon dioxide concentration of coconut husk was greater than hydroponic water, probably because there was a greater population of microorganisms in moist coconut husk so more carbon dioxide was exhaled through microbial respiration and through the metabolism of formaldehyde [6,7,36]. Therefore, coconut husk had a greater final carbon dioxide concentration.

5.1.3 Effect of temperature

For group 2 (Pot only), one-way ANOVA showed that there were no differences between the final concentration of formaldehyde under 20°C, 25°C, and 30°C because the activity of enzymes in microorganisms in the growth media was similar in this temperature range so the microorganisms had similar rate of formaldehyde metabolism at all three temperatures. This is consistent with previous research [38]. Additionally, the adsorbability of coconut husk might be similar between 20°C and 30°C. This is a different trend as described in other previous research which showed that the absorbability decreased as temperature increased [37]. The different conclusions might be due to the fact that the study used activated carbon prepared from coconut husk [37]. Since the adsorption capac-

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ity of activated carbon is greater, the resulting trend might be more obvious. Therefore, the small adsorption capacity of coconut husk might cause a similar formaldehyde concentration as temperature increases.

There were no differences between the final concentration of carbon dioxide gas at all three temperatures, probably because the microorganisms had similar metabolic rates under 20°C, 25°C, and 30°C. This is consistent with previous research [39]. Therefore, they produced and exhaled a similar amount of carbon dioxide gas in three hours.

5.2 Results analysis for Group 3 (Plant and pot)

5.2.1 Absorption of Epipremnum aureum

The results of paired sample t-tests showed that formaldehyde concentration decreased significantly after three hours. This result is consistent with other research that tested for formaldehyde absorption by plant-microbe system, by the plant only, or by the leaves and stems of the plant respectively using Epipremnum aureum [17,23,27,31,35]. Therefore, formaldehyde was absorbed by Epipremnum aureum mostly and rhizosphere microorganisms.

The results showed that the carbon dioxide concentration increased after three hours. This result is consistent with previous research that tested with Rohdea japonica and Epipremnum aureum [31]. It suggested that the concentration of carbon dioxide increased as formaldehyde concentration decreased so the degree of formaldehyde uptake by plants can be judged by the increase in carbon dioxide concentration [31]. This is because carbon dioxide gas is produced through the metabolism of formaldehyde by plants and through respiration [7,15,22]. Therefore, the final carbon dioxide concentration was greater than before.

5.2.2 Effect of temperature

The results of one-way ANOVA showed that Epipremnum aureum was more able to metabolise formaldehyde at 20°C in the experimental range, showing that the enzyme activity could be higher at 20°C than 25°C and 30°C. From 20°C to 30°C, the ability of both soil-grown and hydroponic Epipremnum aureum to absorb formaldehyde decreased as temperature increased, see Table 35 (for soil-grown) and Table 36 (for hydroponics, which is linear). The result is consistent with previous research which tested for ability of Epipremnum aureum to absorb formaldehyde [40]. Its results showed the same trend that the absorption capacity of hydroponic Epipremnum aureum decreases from 12°C to 25°C linearly, and the absorption ability of soil-grown Epipremnum aureum was the greatest at 21°C, and 21°C is the optimal for Epipremnum aureum to grow [40]. The difference in findings between the optimum temperature may be due to the different measurement intervals between the set temperatures. A more precise temperature could be obtained when setting more temperatures between 20°C and 30°C.

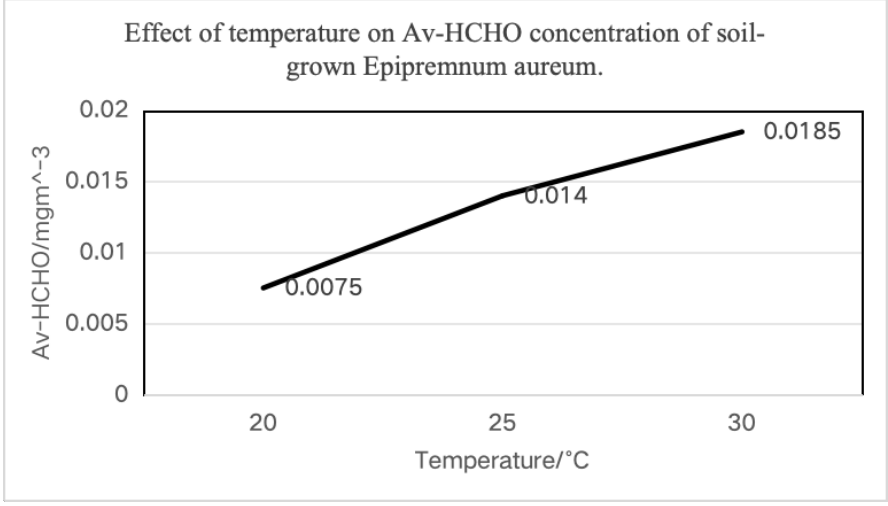

Table 35 Shows the tendency for temperature to affect HCHO uptake by soil-grown Epipremnum aureum. Av represents the mean final concentration of gases.

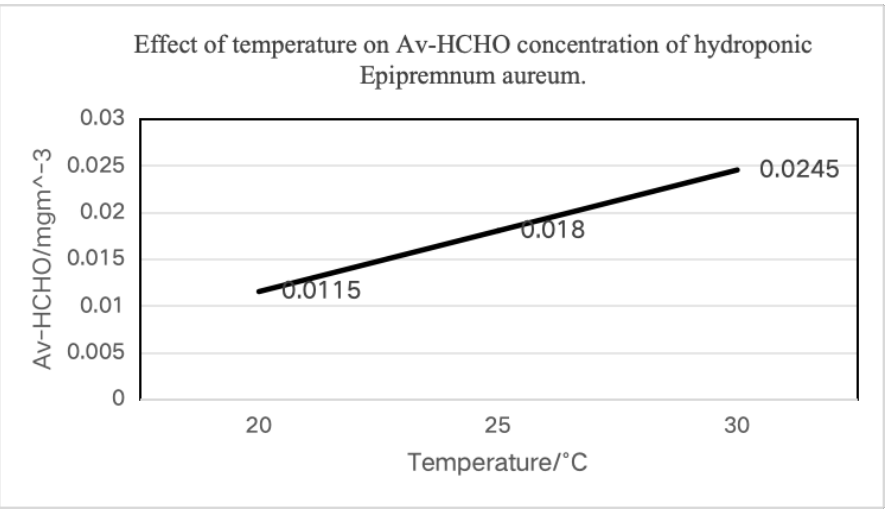

Table 36 Shows the tendency for temperature to affect HCHO uptake by hydroponic Epipremnum aureum. Av represents the mean final concentration of gases.

The results showed that carbon dioxide concentration only slightly decreased as temperature increased. This is because the metabolic rate of formaldehyde decreased as temperature increased, so the carbon dioxide level produced from the metabolism of formaldehyde decreased as temperature increased [7,15,22]. Carbon dioxide concentration only slightly decreased because photosynthetic uptake is roughly balanced by formaldehyde metabolism at all temperatures.

5.2.3 Differences between cultivation methods

The independent sample t-tests showed that there was no difference in final formaldehyde concentration between soil-grown and hydroponic Epipremnum aureum. This result is different from previous research about other plant species which showed that plant-soil systems with microorganisms had a greater ability of absorption than plant-water systems with fewer microorganisms [35,43]. The difference might be due to the plant Epipremnum aureum having a very great formaldehyde absorption capacity as shown in previous research [21,32], and the microbial population could be smaller or of different species which had less absorptive capacity [6,36]. Therefore, in contrast, the effect of the growth media (coconut husk and tap water) on the overall formaldehyde absorption rate of the potted Epipremnum aureum was relatively small so the final formaldehyde concentrations were similar.

The results showed no difference in the final carbon dioxide concentration. This is because the carbon dioxide gas produced through both respiration and the metabolism of formaldehyde by Epipremnum aureum and microorganisms could be absorbed by Epipremnum aureum for photosynthesis [7,22,41,42]. Moreover, previous research showed that humidity could affect the rate of photosynthesis [44,45], so due to the experiment was conducted under similar humidity, and the potted Epipremnum aureum used for each set of experiments were treated the same before the experiments, the soil-grown and hydroponic Epipremnum aureum could have metabolised and photosynthesized at a similar rate.

5.2.4 Effect of light intensity

The independent t-tests showed that the formaldehyde concentration between Epipremnum aureum under light conditions (1100 lux) and dark conditions had no difference. This is consistent with previous research which showed that light intensity did not affect formaldehyde absorption rate by plant species such as Epipremnum aureum [27]. Light intensity affects the photosynthetic rate of plants which affects carbon dioxide concentration, hence the similar absorption capacity of formaldehyde in the light and the dark showed that carbon dioxide concentration did not affect the absorption rate of formaldehyde. This is consistent with previous research which showed that carbon dioxide concentration had no significant effect on the formaldehyde absorption capacity of Epipremnum aureum [26]. Therefore, light intensity did not significantly affect the absorption capacity of formaldehyde by Epipremnum aureum.

The results showed that the carbon dioxide concentration measured in the dark condition is higher than that in the light condition because Epipremnum aureum photosynthesizes and absorbs carbon dioxide gas in the light but not in the dark. This is consistent with a considerable body of previous research that greater light intensity increased the photosynthetic rate of plants [46, 47]. This helps to validate the methodology used in this study.

5.3 Summary

The results of the experiments showed that the growth media could remove formaldehyde, and coconut soil had

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better absorption capacity than hydroponic water. There were no change in the absorption rate of formaldehyde gas by growth media under 20°C to 30°C.

The results showed that Epipremnum aureum was effective in absorbing formaldehyde gas. The absorption capacity of both soil-grown and hydroponic Epipremnum aureum decreased as temperature increased from 20°C to 30°C, and they both had the greatest formaldehyde absorption capacity at 20°C. The cultivation method and light intensity had no significant impact on the formaldehyde absorption capacity of Epipremnum aureum. The results also showed the correlation that carbon dioxide concentration increased as formaldehyde concentration decreased.

6. Conclusion

This research aimed to find out the optimum temperature for potted Epipremnum aureum to absorb formaldehyde to purify the indoor environment, and to find out which common cultivation method, soil-grown or hydroponic Epipremnum aureum, is more effective in removing formaldehyde from indoor air, moreover, to find out if formaldehyde absorption by Epipremnum aureum affects carbon dioxide concentration.

The results from the experiments of soil-grown and hydroponic Epipremnum aureum showed that the absorption ability decreased as temperature increased from 20°C to 30°C. The formaldehyde absorption capacity at 20°C was the greatest which showed that 20°C was the most appropriate temperature for Epipremnum aureum. Therefore, keeping potted Epipremnum aureum at 20°C is the most effective to absorb formaldehyde gas from indoor air.

The effects of cultivation methods and light intensity were also studied and the results showed that they had no significant effects on the formaldehyde absorption capacity of Epipremnum aureum. Therefore, keeping soil-grown and hydroponic Epipremnum aureum indoors are both similarly effective to remove formaldehyde gas.

Evaluation

This research is valuable because clean indoor ambient air is important to people's health. Phytoremediation is a very convenient and cheap way to remove indoor pollution gases such as formaldehyde. It can keep people away from some serious diseases.

In this research, the effect of temperature on formaldehyde absorption by soil-grown and hydroponic Epipremnum aureum was discovered successfully, and the optimum temperature for soil-grown and hydroponic Epipremnum aureum to absorb formaldehyde was found. In addition, this study considered a comprehensive set of factors to investigate the optimal condition for Epipremnum aureum to absorb formaldehyde. However, there were a few limitations. For example, the species and the amount of microorganisms were not controlled.

For future research, The optimal condition of formaldehyde absorption by more species of common potted plants can be investigated, such as their optimum temperature, light intensity, and growth media, so that people can keep them in their optimal condition for the greatest efficacy in absorbing indoor formaldehyde.

Recommendation

Formaldehyde gas is a toxic substance found in many indoor environments. Epipremnum aureum is an attractive indoor plant that can significantly lower formaldehyde levels and therefore provide health benefits. For the greatest effect, it should be kept at around 20°C.

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