EFFECTIVENESS OF SPECIES, THICKNESS, AND AGE OF LEAVES ON THE PERFORMANCE OF ORNAMENTAL PALM FIBER AS A CARBON MONOXIDE BIOFILTER IN FOREST FIRE SMOKE

Eva Gusmira[1*], Nissa Sukmawati[1], Reni Kartika[1], Habibillah Alva Putra[2]

[1]*Department of Physics, Science and Technology of Faculty, Universitas Islam Negeri Sulthan Thaha Saifuddin Jambi, Indonesia*

[2]*Department of Physics, Mathematics and Natural Science of Faculty, Universitas Negeri Padang, Indonesia*

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ABSTRACT

Carbon monoxide (CO) emitted from forest fire smoke requires low-cost and environmentally friendly filtration methods. This study evaluated the effects of palm species, filter thickness, and leaf age on the performance of ornamental palm leaf fiber biofilters for CO reduction. Three palm species Veitchia merrillii, Wodyetia bifurcata, and Cyrtostachys renda were tested using mature and young leaves. Palm leaf fibers were processed into filter sheets with thicknesses of 0.3, 0.5, and 0.7 mm. CO concentrations were measured before and after filtration, and filter effectiveness was calculated as the percentage reduction in CO concentration. Pore-size distribution was analyzed using a trinocular microscope and Examet software. The highest effectiveness for mature leaves was obtained from Wodyetia bifurcata at 0.5 mm thickness, with a CO reduction of 49.11%, whereas the highest effectiveness for young leaves was obtained from Veitchia merrillii at 0.7 mm thickness, with a CO reduction of 57.39%. Increasing filter thickness did not produce a uniform response; the effect varied depending on palm species and leaf age. These findings indicate the preliminary potential of ornamental palm leaf fibers as low-cost, biomass-based filter materials for laboratory-scale CO reduction. The novelty of this study lies in evaluating processed ornamental palm leaf fibers as CO biofilter media by comparing palm species, leaf age, and filter thickness. However, this study was limited by the absence of replicated measurements, adsorption-capacity testing, airflow-resistance measurement, and long-term durability evaluation.

Keywords: Carbon Monoxide; Palm Leaf Fiber; Bio-Based Filter; Smoke Filtration; Indoor Air Quality

Introduction

Forest fires are a common environmental problem worldwide, particularly in tropical and subtropical regions. These fires not only damage ecosystems but also produce air pollution that is hazardous to human health. As we know, forest fires occur almost every year, releasing various hazardous gases into the air, causing economic and health losses due to the smoke produced by the fires.[1–3] Air pollution is indicated by high concentrations of pollutant gases mixed with the air, such as Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), and other gases that exceed their normal concentrations.[4] These gases are emitted from forest fires, cigarette smoke, industrial exhaust, and motor vehicles.[5]

Furthermore, high exposure to CO from forest fire smoke can cause severe poisoning and may lead to death.[6] This gas can cause serious problems with the human respiratory system and negatively impact the environment. High concentrations of CO in the air can lead to hypoxia, a condition where the blood is unable to transport oxygen optimally throughout the body, causing symptoms such as dizziness, nausea, cognitive impairment, and even death in extreme cases.[7] CO is a toxic gas that binds

*Corresponding author.
E-Mail: evagusmira@uinjambi.ac.id

strongly to hemoglobin, thereby reducing the oxygen-carrying capacity of blood.[8]

Carbon monoxide can come from various sources, such as cigarette smoke, fuel combustion, and household appliances. In areas frequently affected by forest fires, such as Indonesia, Brazil, and Australia, elevated CO levels in the air pose a serious threat to public health, especially vulnerable groups such as children and the elderly. Forest fire smoke can affect both outdoor and indoor air quality. Indoor exposure may be particularly harmful because people often remain indoors during fire events, resulting in prolonged exposure to accumulated pollutants.[9]

Various strategies have been implemented to improve indoor air quality and reduce the impact of forest-fire-related air pollution, including fire control, emission reduction, air filtration technology, and plant-based pollutant removal.[10] Several studies have observed certain plants having the ability to effectively absorb various air pollutants,[9] including carbon monoxide (CO). Previous studies have also developed gas filters using palm-shell-based activated carbon.[11] Other plants such as Sansevieria, snake plant, and cactus have the ability to absorb significant amounts of CO.[10]

Palm trees belong to the Arecaceae family and are widely used as ornamental plants. Palms have been reported to contribute to air purification by absorbing several harmful gases, including carbon monoxide.[9,12] Palm trees are also known to filter harmful toxins such as formaldehyde and xylene.[13] Previous studies have shown that indoor plants can act as effective biofiltration agents, which are excellent for the environment.[14] Several ornamental plant species have been reported to contribute to indoor air purification, although their effectiveness depends on plant type, pollutant type, and exposure conditions.[9,14] Air filters use plants that have been tested to filter gases and air particles.[5] Palm leaf fiber may also be suitable as a filter material because natural fibers generally possess mechanical properties that support their use in porous filter structures.[15] However, limited studies have evaluated processed ornamental palm leaf fibers as passive CO filter media for forest fire smoke, particularly by comparing palm species, leaf age, and filter thickness.

Therefore, this study aimed to evaluate the effects of palm species, leaf age, and filter thickness on CO reduction efficiency in forest fire smoke filtration. These three variables were expected to affect the biofilter's CO reduction performance. A better understanding of the filtration performance of palm leaf fibers may support the development of low-cost, biomass-based filter materials for reducing CO exposure during forest fire events.

Methods

The research began with a survey and sampling of ornamental palm plants in Jambi City and Muaro Jambi Regency, observing the types of ornamental palms commonly found in the community. Experiments on leaf preparation, filter manufacturing, and filter effectiveness testing were conducted in the Physics Laboratory of the Faculty of Science and Technology, Sultan Thaha Saifuddin State Islamic University, Jambi. The ornamental palm species used were Veitchia merrillii (princess palm), Wodyetia bifurcata (foxtail palm), and Cyrtostachys renda (red palm). The plant part used for filter preparation was the leaf, with leaf age classified into mature leaves, indicated by yellow and dry characteristics, and young leaves, indicated by fresh green characteristics. The leaves were then processed into biofilter sheets and installed in a simple suction device to filter smoke-contaminated air.

The equipment used in this study included a filter-testing chamber, a trinocular microscope, and a blender. The filter-testing instrument consisted of an acrylic simulation chamber equipped with a smoke extraction system controlled by an Arduino Uno, a fan for airflow generation, and an MQ-7 sensor for CO detection (Figure 1). The MQ-7 sensor was calibrated using a standard CO measuring instrument before testing. However, the calibration equation, calibration range,

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standard instrument model, and measurement uncertainty should be reported to improve reproducibility. The pore test used a trinocular microscope and was analyzed using Examet metallurgical particle analysis. A blender was used to smooth the palm leaves. Other materials used in this study were tapioca flour and water as binders for the leaf fibers.

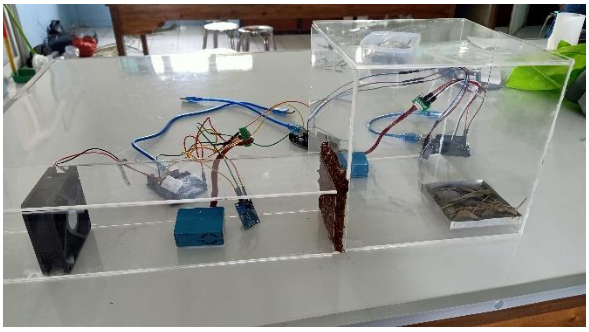

Figure 1. Filter Testing Instrument

The CO smoke filters were prepared from palm leaves cut into small pieces of approximately 1–2 cm. Before cutting, the leaf veins were removed from the palm leaves. The leaf pieces were then blended to obtain palm leaf powder. The palm leaf powder was mixed with tapioca flour and water to form a fiber slurry. The composition ratio of palm leaf powder, tapioca flour, and water was 5:1:2. The filter sheets were molded using a 9 cm × 9 cm mold with different thicknesses. Water and tapioca flour serve to bind the palm leaf fibers. The filter sheets were prepared at three thicknesses: 0.3, 0.5, and 0.7 mm. The molded filters were dried until solid and dry. The drying duration and conditions should be reported to ensure reproducibility. The dried filter sheet was placed between the smoke source and the suction fan during filtration testing.

The data collection process involved placing filters of varying thicknesses on an automatic smoke extractor. The sensor recorded CO concentrations before and after filtration. Filter effectiveness was tested for each combination of palm species, filter thickness, and leaf age. In addition to testing the filter's effectiveness in reducing CO using a smoke extractor, porosity testing was also performed using a trinocular microscope. The resulting microscope images were analyzed using Examet metallurgical particle analysis.

The data analysis method in this study used quantitative descriptive analysis techniques with a percentage method. Quantitative descriptive analysis was used to describe the air quality results produced. The CO concentration in the chamber was recorded before and after filtration using the MQ-7 sensor. Filter effectiveness was calculated using the following formula (1).[16]

$$\text{Effectiveness } (\%) = \frac{(X_2 - X_1)}{X_1} \, x \, 100 \qquad (1)$$

Where X_1 is the CO concentration before filtration and X_2 is the CO concentration after filtration. This formula was used to determine the effectiveness of ornamental palm leaf fibers in reducing CO concentration at different filter thicknesses and leaf ages. The values shown are based on a single measurement for each condition; therefore, the results should be interpreted as preliminary observations rather than statistically confirmed effects. The microscopy results were analyzed to determine the pore-size distribution of the filter samples. The results of the porosity test were analyzed using statistics to see the average size of the pores in the filter samples.

Result and Discussion

Three palm species were used in this study: Cyrtostachys renda (red palm), Veitchia merrillii (princess palm), and Wodyetia bifurcata (foxtail palm). The samples were prepared based on three variables: palm species, filter thickness, and leaf age, resulting in 18 treatment combinations. The research samples were subjected to the same treatment, separating the leaves from their veins. After obtaining clean leaves, they were cut into small pieces and ground using a blender. The ground leaf material was mixed with water and tapioca flour to bind the fiber particles and form a slurry. The mixture was then molded using a 9 cm x 9 cm mold with varying thicknesses. The sample thicknesses were 0.3 mm, 0.5 mm, and 0.7 mm (Figure 2).

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Microscopy-based pore size analysis showed that 99.06% of the observed pores were within the smallest size interval, up to 0.002939147 mm (Table 1). This result indicates that the filter surface contained predominantly small pores, which may contribute to smoke filtration performance.[17] Previous studies have reported that plant fibers generally possess tensile strength and elasticity, supporting their potential use in filter materials[18].

Figure 2. Filter Sample After Drying

Table 1. Pore size distribution of ornamental palm leaf fiber filters

Interval		Frequency	Percentage
0.000000000	0.002939147	3050	99.058
0.002939148	0.005878296	18	0.585
0.005878297	0.008817444	4	0.130
0.008817445	0.011756593	4	0.130
0.011756594	0.014695741	1	0.032
0.014695742	0.017634890	0	0.000
0.017634891	0.020574038	0	0.000
0.020574039	0.023513186	0	0.000
0.023513187	0.026452335	0	0.000
0.026452336	0.029391483	0	0.000
0.029391484	0.032330632	1	0.032
0.032330633	0.035269780	0	0.000
0.035269781	0.038208929	1	0.032

Table 2. CO reduction effectiveness of ornamental palm leaf fiber biofilters

Palm Type	Leaf Age	0.3 mm (%)	0.5 mm (%)	0.7 mm (%)
Wodyetia Bifurcata (squirrel tail palm)	Old	48.00	49.11	25.71
	Young	40.83	34.65	37.86
Cyrtostachys renda (red palm)	Old	31.18	35.92	17.05
	Young	43.66	38.03	33.61
Veitchia Merrillii (princess palm)	Old	29.00	25.89	21.43
	Young	45.83	53.66	57.39

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Effect of Filter Thickness on CO Reduction Effectiveness

The CO reduction effectiveness of filters with different thicknesses is shown in Table 2. Smoke containing CO was drawn by a fan and passed through the filter sheet. Data collection was carried out on each sample with three thickness variations. Table 2 presents the CO reduction effectiveness of each palm species and leaf age at filter thicknesses of 0.3, 0.5, and 0.7 mm.

Table 2 shows that filter thickness was associated with differences in CO reduction effectiveness across the tested palm species. In mature leaf samples, increasing thickness from 0.3 to 0.5 mm tended to improve CO reduction, whereas effectiveness decreased at 0.7 mm for most species. This pattern is shown in Figure 3a, where the effectiveness of mature Wodyetia bifurcata peaked at 0.5 mm with a CO reduction of 49.11% and then declined at 0.7 mm.

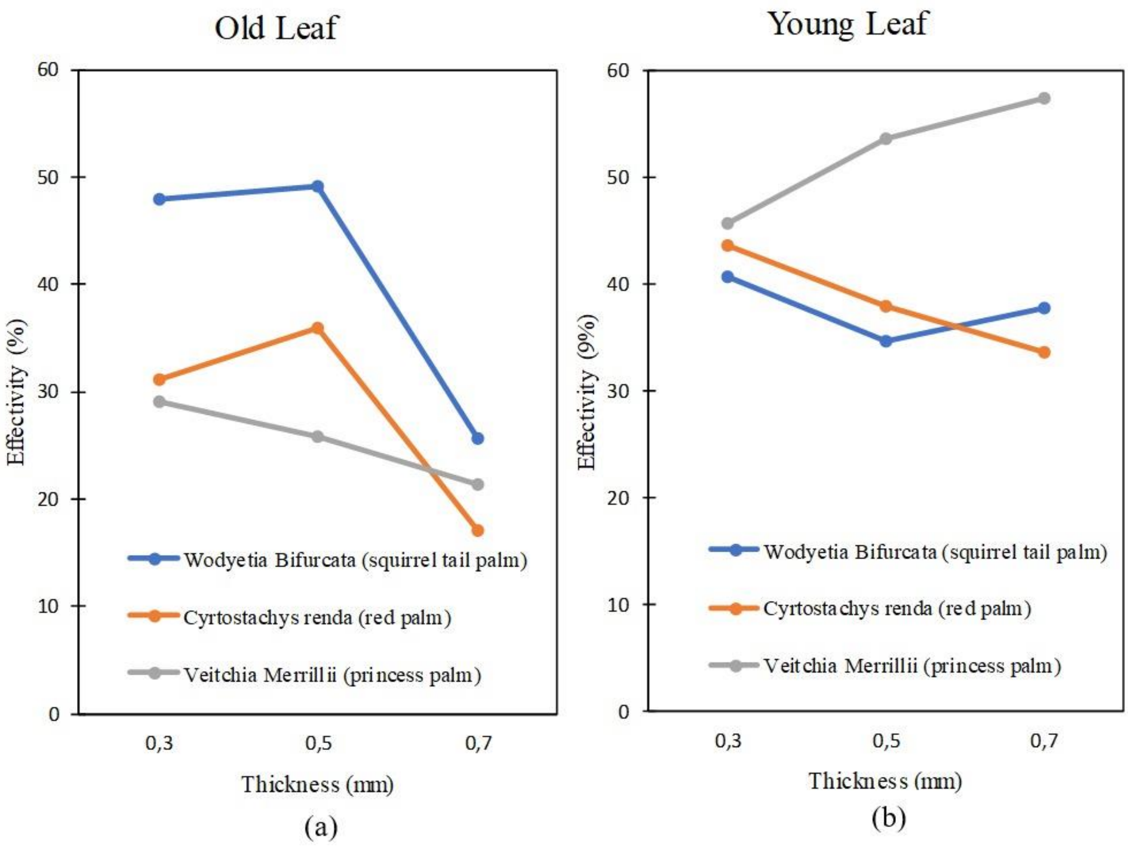

Figure 3. Effectiveness of ornamental palm leaf fiber filters in reducing CO at different filter thicknesses: (a) mature leaves and (b) young leaves.

These findings suggest the possible presence of an optimum filter thickness, where the available surface area and airflow permeability may be balanced. Increasing filter thickness may increase the contact area between CO gas and biomass fibers, thereby improving the potential interaction between gas molecules and the filter surface. However, excessive thickness may increase airflow resistance and reduce gas diffusion through the filter pores. This phenomenon is consistent with modern biofiltration studies that emphasize the importance of the balance between surface area and airflow resistance in determining filter performance[15]. In young leaves, a different trend was observed in Figure 2b, where increasing thickness up to 0.7 mm improved effectiveness, particularly in Veitchia merrillii, which reached the highest CO reduction value of 57.39%. This may indicate that young leaf fibers have a structure that allows better gas penetration;

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however, further pore-structure and airflow-resistance measurements are required to confirm this explanation. Thus, the internal characteristics of the biomass may influence the relationship between filter thickness and filtration performance.

From a possible mechanistic perspective, CO reduction by palm leaf fibers may involve physical adsorption and diffusion into small pores, although this mechanism was not directly confirmed in the present study. The lignocellulosic structure of the leaves may provide surface sites that interact with gas molecules. Recent studies have shown that natural fiber-based biomass has an adsorption capacity that is influenced by pore size, pore distribution, and specific surface area.[19]

Thus, the results of this study indicate that filter thickness is an important design parameter, but its effect depends on the properties of the material used. The optimum thickness is not universal, but rather depends on the combination of palm species and leaf age. Therefore, optimization of biomass-based biofilter design should consider the interaction between filter thickness, material characteristics, and airflow behavior to improve CO reduction efficiency.

Effect of Leaf Age on Biofilter Effectiveness

The comparison between mature and young leaves in Table 2 shows different CO reduction patterns, which are also illustrated in Figure 2. In mature leaves, Wodyetia bifurcata showed the highest effectiveness, particularly at a thickness of 0.5 mm. In young leaves, Veitchia merrillii showed the best performance, with effectiveness increasing up to a thickness of 0.7 mm.

These differences may be related to variations in leaf anatomical characteristics and chemical composition. Mature leaves may have denser tissue structures and thicker cell walls, although these characteristics were not directly measured in this study. These characteristics may increase the number of available surface sites for gas interaction, but further chemical and structural analyses are required to confirm this mechanism. Previous research suggests that lignocellulosic composition may influence adsorption behavior by providing functional groups that interact with pollutants.[20]

In contrast, young leaves may have softer and more open tissue structures, although this should be confirmed through additional characterization. Such structures may facilitate gas diffusion into the fiber network, especially at greater filter thicknesses. For Veitchia merrillii, the high effectiveness of young leaves may be associated with the interaction between filter thickness and fiber structure, which could increase contact between CO and the filter surface.

In addition, differences between species indicate that biofilter effectiveness is not only influenced by leaf age but also by plant-specific characteristics, such as fiber structure, leaf surface area, and chemical composition. Variations in plant species may result in different gas adsorption behaviors due to differences in morphology and biopolymer composition.[21]

The tabular and graphical data suggest a possible interaction between filter thickness and leaf age. In older leaves, increasing thickness tends to be limited by diffusion barriers, while in younger leaves, increasing thickness still provides benefits to some extent. This indicates that biofilter performance may be influenced by multiple interacting parameters rather than by a single factor.

Overall, the results indicate that leaf age is an important factor to consider in the design of biomass-based biofilters. Mature leaves appeared to perform better in some species, whereas young leaves showed higher performance in other species, suggesting that leaf age interacts with species and thickness. Further optimization of leaf age, species, and thickness may support the development of more efficient biofilter materials for reducing CO exposure from forest fire smoke. This is consistent with the properties of palm leaves, which can filter air pollution.[22] The highest CO reduction observed in this study was higher than the 46% air filtration efficiency reported for a hemp-fiber-based filter,[23] However, this comparison should be interpreted cautiously because pollutant type,

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test conditions, and filter design may differ. Previous studies have also reported the potential of ornamental plants for reducing certain airborne pollutants.[24]

Conclusion

This study shows that ornamental palm leaf fiber has preliminary potential as a biomass-based filter material for reducing CO from forest fire smoke under laboratory conditions. The results indicate that filter thickness, palm species, and leaf age influence CO reduction performance in different ways. For mature leaves, the best performance was obtained from Wodyetia bifurcata at a thickness of 0.5 mm, with a CO reduction effectiveness of 49.11%. At a thickness of 0.7 mm, effectiveness tended to decrease in mature leaves, possibly due to increased airflow resistance and reduced gas diffusion efficiency. For young leaves, the best performance was obtained from Veitchia merrillii at a thickness of 0.7 mm, with the highest CO reduction effectiveness of 57.39%. This suggests that the effect of filter thickness may depend on the physical characteristics of the biomass material.

In terms of leaf age, mature leaves showed higher effectiveness in some species, but further analysis is required to confirm whether this is related to tissue density, lignin content, or other structural factors. Meanwhile, young leaves showed higher effectiveness in Veitchia merrillii, possibly because their fiber structure allowed better gas penetration at greater thickness. Overall, CO reduction by palm leaf fibers may involve physical adsorption, diffusion, and surface interactions, but these mechanisms require further confirmation through additional characterization tests. The interaction between thickness, palm species, and leaf age suggests that no single filter configuration is universally optimal; therefore, optimization based on material characteristics is necessary.

The novelty of this research lies in evaluating processed ornamental palm leaf fibers as CO biofilter media by integrating variations in palm species, leaf age, and filter thickness. These findings provide preliminary information for the development of environmentally friendly and low-cost biomass-based filter materials for CO reduction. However, this study has several limitations, including the absence of replicated measurements for inferential statistical analysis and the lack of evaluation of adsorption capacity, airflow resistance, pressure drop, reusability, and material durability. Therefore, further research should include replicated experiments, statistical analysis, adsorption-capacity testing, airflow-resistance measurement, durability evaluation, and field-scale validation.

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