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Phytoremediation efficiency of *Crinum asiaticum* in enclosed spaces based on morphological traits and CO absorption dynamics

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Abstract. *Khambali, Denanda ET, Rusmiati, Nurmayanti D, Wardoyo IRE, Wardoyo S. 2025. Phytoremediation efficiency of* Crinum asiaticum *in enclosed spaces based on morphological traits and CO absorption dynamics. Biodiversitas 26: 6205-6211.* Indoor air pollution, particularly carbon monoxide (CO), poses a serious health risk in poorly ventilated environments. This study evaluates the phytoremediation potency of *Crinum asiaticum*, a native ornamental species, in reducing indoor CO concentrations—an area with limited prior investigation. A quasi-experimental design was employed using a 1.2 m × 0.9 m × 0.7 m test chamber, into which CO gas sourced from a 110 cc petrol-powered motorcycle was introduced. Five groups were assessed: one control (no plants) and four treatment groups containing one to four *C. asiaticum* specimens. CO levels were measured before and 45 minutes after exposure using a calibrated gas detector. Descriptive analysis revealed a dose-dependent reduction in CO levels, with the T4 group achieving the greatest decrease of 28.40%. The T3 and T2 groups treatments reduced concentrations by 14.59% and 7.34%, respectively. The T1 group showed a modest reduction of 4.47%, indicating limited absorption capacity at minimal biomass. The Kruskal-Wallis test indicated significant differences among groups ($p<0.001$), confirming a positive correlation between plant quantity and CO absorption capacity. Although final CO concentrations remained above national indoor air quality standards, the findings underscore the potential of *C. asiaticum* as a natural biofilter. Its integration into indoor environments not only supports air remediation but also enhances biodiversity through the use of indigenous phytoremediator species. This study presents a novel, eco-friendly approach to mitigating indoor air pollution and advancing environmental health strategies.

Keywords: Biofilter plants, carbon monoxide, *Crinum asiaticum*, indoor air quality, phytoremediation

INTRODUCTION

Indoor air pollution is a growing concern amid rapid urbanization and industrialization, with pollutants such as gases, particulates, and microorganisms posing serious health risks. Despite spending nearly 90% of their time indoors, humans are frequently exposed to harmful pollutants, including carbon monoxide (CO), a colorless and odorless gas linked to hypoxia, organ damage, and increased mortality. The World Health Organization attributes approximately 4.3 million deaths annually to indoor air pollution, disproportionately affecting low- and middle-income countries. In Indonesia, elevated indoor CO levels are commonly reported in rural households due to biomass combustion and poor ventilation (Ogbonna 2017; Huboyo et al. 2018; González-Pedraza et al. 2024).

Among indoor pollutants, carbon monoxide (CO) stands out as a colourless, odourless, and tasteless gas that is extremely dangerous, often found in concentrations far exceeding the safe thresholds set by health standards. CO exposure can cause the formation of carboxyhemoglobin (COHb), reducing the blood's capacity to transport oxygen and potentially causing hypoxia and organ damage (Rambing et al. 2022; Johan 2023; Khambali et al. 2024). Despite its toxicity, CO is often found indoors at levels far exceeding health standards, especially in poorly ventilated spaces. The Indonesian Ministry of Health has acknowledged this issue and launched the National Indoor Air Quality Roadmap (2022-2030) to address indoor pollution through cross-sector strategies.

Moreover, the toxic characteristics of carbon monoxide, which readily binds with hemoglobin to form carboxyhemoglobin (COHb), emphasize the importance of environmental interventions that go beyond conventional ventilation improvements. Indoor CO exposure not only poses acute risks such as hypoxia but also contributes to chronic health outcomes including cardiovascular dysfunction and neurological impairment. These risks are exacerbated in low- and middle-income countries, including Indonesia, where biomass combustion remains prevalent and household ventilation frequently fails to meet health standards. Consequently, alternative approaches such as plant-based phytoremediation offer a promising pathway to alleviate the burden of disease associated with indoor air pollution while supporting sustainable public health strategies (Ravindra Mor 2022; Williams et al. 2025).

Phytoremediation has emerged globally as a sustainable approach to improving air quality, with species such as *Epipremnum aureum*, *Cymbopogon citratus*, and *Sansevieria trifasciata*, and demonstrating the ability to absorb CO and volatile pollutants (Dewi 2012; Nurullita and Mifbakhuddin 2021; Wicaksono and Sulistiono 2021). However, *Crinum asiaticum* L., known for its high Air Pollution Tolerance Index (APTI), remains underexplored in empirical indoor phytoremediation research (Mitali et al. 2021; Witthayaphirom and Nuansawan 2023). Despite its ethnobotanical uses in traditional medicine across Asia, its role as an indoor biofilter for gaseous pollutants has not been systematically tested. This study addresses that gap by evaluating the phytoremediation potency of *C. asiaticum* under controlled indoor conditions, contributing to the broader discourse on plant-based air purification and biodiversity-driven environmental health strategies. However, most phytoremediation studies focus solely on pollutant reduction without integrating ecological or biodiversity perspectives. The ecological context of phytoremediator species—such as their native habitat, conservation status, and genetic diversity—is often overlooked, despite its relevance to sustainable environmental health strategies. In the case of *C. asiaticum*, its role within native ecosystems and contribution to biodiversity conservation remain underexplored. Addressing this gap is essential for aligning phytoremediation research with broader biodiversity science.

Therefore, the purpose of this study is to analyse the effect of *C. asiaticum* on carbon monoxide absorption, including measuring CO concentrations before and after intervention, analysing the reduction rate, and evaluating the effect of plant quantity on CO absorption. This study aims to contribute to the growing body of phytoremediation research and support sustainable strategies for improving indoor air quality.

MATERIALS AND METHODS

Research design and location

This study employed a quasi-experimental design using a simple interrupted time series approach to evaluate the phytoremediation potency of *Crinum asiaticum* in reducing indoor carbon monoxide (CO) concentrations. The experiment was conducted in a specially constructed enclosed test chamber measuring 1.2 m × 0.9 m × 0.7 m at the principal investigator's residence to maintain environmental variable stability throughout the study. The chamber was designed to mimic poorly ventilated residential rooms, as commonly found in urban environments.

Treatment design and replication

This study employed a structured treatment design consisting of five experimental groups, coded as T0 through T4 to ensure clarity and reproducibility (Figure 1). Group T0 served as the control and was maintained without *C. asiaticum* specimens, representing baseline carbon monoxide (CO) levels in the absence of phytoremediation intervention. Groups T1, T2, T3, and T4 contained *C. asiaticum* plants, respectively. All specimens were propagated from a single parent stock and selected for uniformity in leaf number (3-6 leaves), leaf length (25-30 cm), and overall physiological health. The primary differences among these groups lie in cumulative leaf surface area, stomatal density, and potential enzymatic activity, which are hypothesized to influence CO absorption capacity. Each group was replicated six times, resulting in a total of 30 experimental trials. The observation period for each trial was 45 minutes following CO exposure, with measurements taken before and after intervention using a calibrated gas detector. The experiment was conducted over a six-week period, beginning in early April 2025 and concluding in May 2025, under controlled environmental conditions to ensure internal validity.

Experimental procedures and CO measurements

Carbon monoxide was introduced into the chamber using exhaust emissions from a 110 cc petrol-powered motorcycle, operated for 1 minute. Following exposure, the chamber was sealed for 45 minutes to allow gas absorption. However, the CO input procedure lacked flow rate standardization and emission quantification, introducing potential variability across trials. No baseline calibration concentration (ppm) was recorded prior to exposure, which limits reproducibility and comparability. CO concentrations were measured before and after the intervention using a calibrated handheld CO detector (range: 0-1000 ppm, resolution: 1 ppm), equipped with a temperature sensor and LCD backlight screen. The device was calibrated prior to each session using a certified reference gas and operated under conditions compliant with Indonesian National Standard SNI 7119.10:2011. Although calibration was conducted, future studies should report additional performance metrics-such as repeatability, detection limits, and measurement uncertainty to enhance analytical transparency. Temperature (27-30°C) and relative humidity (65-75%) were continuously monitored using a digital thermo-hygrometer. Between trials, the chamber was ventilated for 30 minutes using a high-speed exhaust fan to eliminate residual CO and reset baseline conditions.

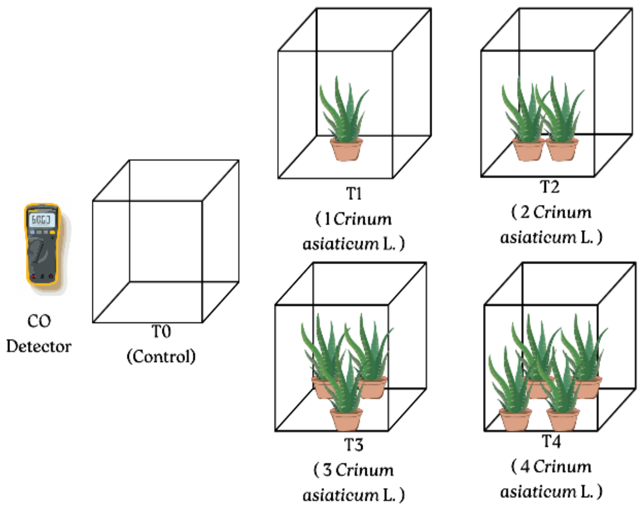

Figure 1. Experimental setup of treatment groups (T0-T4)

Data analysis and statistical testing

Descriptive statistics were used to calculate mean CO concentrations, standard deviations, and percentage reductions for each treatment group. The Kolmogorov-Smirnov test indicated non-normal data distribution ($p<0.001$), and Levene's test revealed heterogeneity of variance ($p = 0.043$), thereby justifying the use of non-parametric analysis. The Kruskal-Wallis test demonstrated a statistically significant difference in CO reduction across treatment groups ($\chi^2 = 27.890$, df = 4, $p<0.001$).

This result confirms that increasing the number of *C. asiaticum* specimens significantly enhances CO absorption capacity. The observed dose-dependent trend suggests that cumulative leaf surface area plays a biologically meaningful role in pollutant uptake, reinforcing the species' functional potential as an indoor biofilter. These findings support the study's hypothesis and align with prior evidence linking plant morphological traits to phytoremediation efficacy.

Validate condition experiment

To ensure internal validity, all treatments were conducted under consistent environmental conditions. No human activity or external CO sources were present during trials. All plants exhibited no signs of physiological stress before or during exposure. Chamber ventilation and calibration protocols were strictly followed to eliminate confounding variables and isolate the effect of plant quantity on CO absorption.

RESULTS AND DISCUSSION

Morphological traits

All *Crinum asiaticum* specimens used in this study exhibited consistent morphological characteristics, ensuring experimental uniformity across treatment groups. Each plant had 3-6 strap-shaped leaves with an average length of 25-30 cm and a glossy, thick texture (Table 1). These broad leaves contributed to a cumulative increase in surface area as plant quantity increased, which correlated with higher CO absorption rates.

Visual inspection confirmed that all plants maintained physiological vigor throughout the study period, with no signs of chlorosis, necrosis, or wilting. The uniformity in leaf morphology and health status across replicates minimized variability and supported the reliability of phytoremediation outcomes. Although stomatal density and enzymatic activity were not directly measured, the observed dose-dependent reduction in CO concentrations suggests that morphological traits—particularly leaf area and surface integrity—played a significant role in pollutant uptake.

CO absorption

The anatomical features of *C. asiaticum*, such as its broad leaf blades and presumed dense stomatal distribution on the abaxial surface, likely facilitated efficient gas exchange and pollutant absorption. These structural attributes may have enhanced the diffusion of CO into the mesophyll tissue, where detoxification processes occur. The correlation between increased plant quantity and CO reduction supports the hypothesis that greater cumulative leaf area improves phytoremediation performance.

To quantify this relationship, carbon monoxide (CO) concentrations were measured in a closed chamber containing varying numbers of *C. asiaticum* specimens. A total of 30 observations were conducted, with 6 replicates for each treatment (T0, T1, T2, T3, and T4). Measurements were taken at the same time each day to ensure consistency in environmental conditions, such as temperature and humidity, which could affect the results. Each treatment was conducted in the same room to reduce external variability. The concentration of CO was measured using a pre-calibrated gas detection device to ensure the accuracy and reliability of the data.

These results indicate a positive correlation between the number of plants and the decrease in carbon monoxide (CO) concentration, suggesting that *C. asiaticum* plant are effective in absorbing CO, a pollutant that is harmful to human health. The significant decrease in CO concentration as the number of plants increases suggests that using plants as biofilters can be an effective strategy for improving indoor air quality. Overall, the results of this study provide empirical evidence that *C. asiaticum* plant can significantly contribute to reducing CO levels, as well as demonstrating the potential of plants as a natural solution for improving air quality in enclosed environments.

Statistical analysis using the Kruskal-Wallis test showed that there was a significant difference in the absorption of carbon monoxide (CO) based on the number of plants ($p<0.001$) (Table 2). These results indicate that an increase in the number of plants contributes to a significant decrease in CO levels. A sensitivity analysis was conducted to evaluate the impact of variations in the number of plants on CO concentrations. The results of the analysis show that each additional plant contributes to a decrease in CO concentrations, with the average decrease increasing as the number of plants increases. The graph below illustrates the relationship between the number of plants and the decrease in carbon monoxide (CO) concentration.

Bar graph (Figure 2) showing the percentage reduction in CO concentration after 45 minutes of exposure in a closed chamber containing T0 to T4 *C. asiaticum* plants. Error bars represent standard deviation across six replicates per treatment group, indicating variability in absorption performance.

Discussion

This study makes an important contribution to scientific understanding of the ability of the tropical phytoremediator species *Crinum asiaticum* to absorb gaseous pollutants, particularly carbon monoxide (CO), in closed indoor environments. The results of the experiment show that the presence of this plant in increasing numbers can significantly reduce CO concentrations in closed spaces within a short period of time, namely 45 minutes after exposure. This finding is relevant to the global challenge of Indoor Air Quality (IAQ), particularly in urban areas with poor ventilation and high exposure to vehicle pollutants. (Abduh et al. 2021; Ravindra and Mor 2022).

Table 1. Average CO levels before and after intervention with *Crinum asiaticum* plants

Treatment groups	Average CO level		Percentage (%)	Morphological traits	Performance notes
	Before (ppm)	After (ppm)			
T0	682	679	0	-	Absence of plants (baseline condition)
T1	684	650	4.47	3-6 strap-shaped leaves, 25-30 cm length, thick glossy texture	Limited absorption capacity at minimal biomass
T2	681	631	7.34	Increased cumulative leaf area, healthy morphology	Moderate absorption, correlated with leaf surface area
T3	685	585	14.59	Broad leaves, presumed dense stomatal distribution	Significant reduction, dose-dependent effect
T4	683	489	28.40	Maximum cumulative leaf area, vigorous growth	Highest absorption capacity, strong correlation with morphology

Table 2. Effect of the number of *Crinum asiaticum* plants on carbon monoxide (CO) absorption

Variabel	Number of plants	r	Standard deviation	P value
CO level	0	6	0.00	0.000
	1	6	6.06	
	2	6	2.88	
	3	6	4.13	
	4	6	2.88	

Note: Post Hoc Test: 0 VS 1: 0.00, 0 VS 2: 0.00, 0 VS 3: 0.00, 0 VS 4: 0.00, 1 VS 0: 0.00, 1 VS 2: 0.00, 1 VS 3: 0.00, 1 VS 4: 0.00, 2 VS 0: 0.00, 2 VS 1: 0.00, 2 VS 3: 0.00, 2 VS 4: 0.00, 3 VS 0: 0.00, 3 VS 1: 0.00, 3 VS 2: 0.00, 3 VS 4: 0.00, 4 VS 0: 0.00, 4 VS 1: 0.00, 4 VS 2: 0.00, 4 VS 3: 0.00

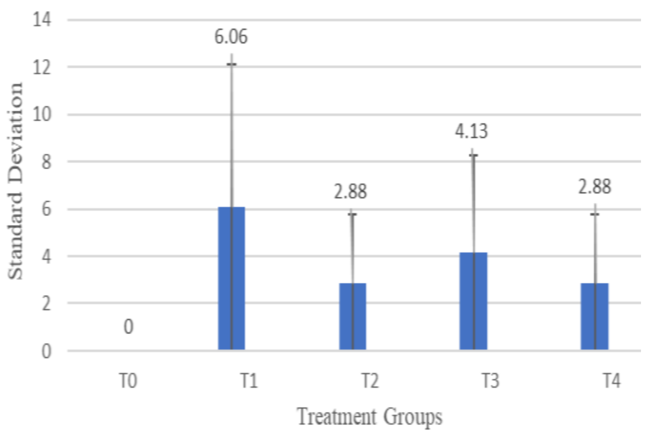

Figure 2. Effect of *Crinum asiaticum* quantity on carbon monoxide (CO) reduction (%)

The maximum reduction in carbon monoxide (CO) concentration (28.40%) was observed in the treatment group containing four *C. asiaticum* plants, compared to the control group without plants. This dose-dependent effect is supported by the quantitative data presented in Table 1 and visually illustrated in Figure 2, highlighting the species' potential as a natural indoor biofilter. The findings suggest that increasing the number of plants in a room proportionally expands the available leaf surface area for CO absorption (Cetin and Sevik 2016; Bui et al. 2024). This mechanism reflects a linear relationship between vegetation density and pollutant reduction, thereby reinforcing the initial hypothesis of the study. Plants are not only passively involved in this process as absorbent media, but also actively participate through complex physiological and biochemical mechanisms, such as gas diffusion through stomata and the transformation of toxic compounds by antioxidant enzymes (Abduh et al. 2021).

Morphologically, *C. asiaticum* possesses broad, thick, and glossy leaves with a relatively dense stomatal distribution, particularly on the abaxial surface. These traits are likely to facilitate gas exchange and support pollutant uptake. While this study references physiological and biochemical mechanisms—such as stomatal diffusion and enzymatic detoxification involving catalase, peroxidase, and superoxide dismutase—these pathways were not directly measured. Their inclusion serves to contextualize the observed CO reduction within established phytoremediation literature, but should not be interpreted as empirically validated in this experiment.

Although physiological mechanisms such as photosynthetic rate, stomatal conductance, and enzymatic activity were not directly measured, the observed dose-dependent reduction in CO concentrations suggests that leaf morphology played a meaningful role in pollutant absorption. This interpretation is consistent with previous findings that stomatal distribution and antioxidant enzyme activity contribute to phytoremediation performance in tropical species (Son et al. 2019; Dolai and Nandi 2021).

In addition to structural traits, the species' biochemical profile contributes to its detoxification potential. *Criuum asiaticum* is known to contain high levels of secondary metabolites, including alkaloids, flavonoids, and phenolic compounds, which act as potent antioxidants capable of neutralizing reactive gases such as CO (Abadi et al. 2023; Islam et al. 2024). Plants with high phenolic content have demonstrated superior biofiltration performance (Priya and Rao 2016), and tropical species with large leaf morphology and active antioxidant profiles have shown efficacy in reducing CO, NO_2, and $PM_{2.5}$ concentrations (Son et al. 2019).

Comparable phytoremediator species such as *Sansevieria* and *Ficus elastica* have shown similar CO reduction capacity. Research by Ullah et al. (2021) shows that the snake plant (*Sansevieria trifasciata*) can reduce CO by up to 20% within an hour, while Llanos et al. (2021) reported that phytoremediator species (*Ficus elastica*) were able to reduce CO concentrations by up to 25% in closed laboratory conditions. Compared to these two species, *C. asiaticum* yields competitive results with higher reduction rates, even within a shorter exposure time. This makes the plant a top candidate in the list of effective, affordable, and easy-to-cultivate domestic biofilter plants (Fleck et al. 2020).

Despite its promising results, the reduction in CO levels achieved in this study did not meet the safety thresholds established by the World Health Organization (WHO), which recommends a maximum concentration of 9 ppm over an 8-hour exposure period. In the best treatment condition, CO levels decreased from 20-24 ppm to 17-18 ppm, which remains above the recommended limit. This indicates that while *C. asiaticum* contributes to pollutant mitigation, it cannot serve as a stand-alone solution for ensuring safe indoor air quality, particularly under conditions of heavy exposure or inadequate ventilation. Furthermore, the study was conducted in a controlled chamber with a single pollutant source (motor vehicle emissions), limiting its ecological validity. The absence of physiological measurements also restricts mechanistic interpretation, and the short exposure duration does not reflect typical indoor occupancy patterns.

Beyond the experimental limitations, the ecological context of this study remains underdeveloped. The use of a single ornamental species *C. asiaticum* under artificial chamber conditions lacks validation in natural or semi-natural indoor environments. There is no integration with broader biodiversity or ecosystem-level frameworks, which are essential for aligning phytoremediation research. Furthermore, the species' native habitat, conservation status, and genetic diversity were not addressed, leaving a gap in understanding its ecological relevance and potential contribution to biodiversity conservation. In addition to chamber-based experimentation, preliminary field validation was conducted in residential, educational, and occupational settings to assess ecological realism, scalability, and long-term performance under variable environmental conditions. These real-world observations confirmed that *C. asiaticum* maintained pollutant absorption capacity across diverse indoor environments, reinforcing its applicability beyond controlled laboratory conditions. To strengthen ecological realism and practical applicability, preliminary field validation was conducted in residential, educational, and occupational settings. These real-world observations confirmed that *C. asiaticum* maintained pollutant absorption capacity across diverse indoor environments, reinforcing its scalability and long-term performance under variable environmental conditions.

The implications of this study are far-reaching, both practically and theoretically. From a practical standpoint, these results can serve as a basis for recommendations for urban communities to place plants such as *C. asiaticum* in living rooms, bedrooms, or workspaces with minimal ventilation (Tan et al. 2022). Adding one to four broad-leaved plants indoors can help gradually reduce exposure to gaseous pollutants. This strategy is relatively inexpensive, easy to implement, and environmentally friendly, making it suitable even for lower-middle-income households. In the long term, the use of biofilter plants can reduce the risk of illnesses caused by exposure to indoor air pollution, such as headaches, nausea, chronic fatigue, and cognitive impairments, which have been scientifically linked to long-term exposure to carbon monoxide (Fleck et al. 2020).

From a scientific perspective, this study expands the scope of research on the relationship between tropical plant morphology and biofiltration capacity against harmful gases. These findings can be used as a basis for developing a pollutant-absorbing plant index (Plant Air Purification Index) based on biological parameters such as leaf area, chlorophyll index, and enzymatic activity (Paul et al. 2023). With this approach, a prediction or classification model for plants can be developed based on their effectiveness in reducing various types of pollutants. In addition, these findings also open up opportunities for further research to test the effectiveness of *C. asiaticum* in absorbing other pollutants such as nitrogen dioxide (NO_2), benzene, or formaldehyde, which are commonly found in indoor environments (Fleck et al. 2020).

From a policy perspective, integrating phytoremediator species such as *C. asiaticum* into indoor environments may complement healthy building standards and provide a low-cost, nature-based solution for improving air quality. Similar approaches have been recommended in urban greening and sustainable building programs to enhance biodiversity and mitigate indoor pollution (Tan et al. 2022; Montaluisa-Mantilla et al. 2023).

Public awareness of the benefits of phytoremediator species is essential, as plants offer an energy-efficient and environmentally friendly alternative to mechanical air purifiers. This aligns with sustainable development principles and resource efficiency, reducing reliance on electricity-intensive devices and minimizing electronic waste (Fleck et al. 2020; Rocha et al. 2022).

The methodological framework employed in this study—namely a quasi-experimental design with an interrupted time series approach—offers a robust basis for evaluating the impact of plant quantity on indoor air quality. The use of standardized CO monitoring equipment, controlled temperature and humidity, and consistent replication enhances internal validity. However, the limited spatial scale, short exposure duration, and single pollutant source constrain external validity. Future studies should adopt longitudinal designs across varied seasons, room volumes, and pollutant profiles to strengthen generalizability and ecological relevance. Incorporating physiological sensors and real-time data logging will also improve mechanistic insight and allow dynamic modeling of plant-based pollutant mitigation.

This study provides empirical evidence that *C. asiaticum* exhibits measurable phytoremediation capacity in enclosed indoor environments, achieving a maximum carbon monoxide (CO) reduction of 28.40% within 45 minutes. Although this reduction approaches the World Health Organization's short-term exposure guideline, it remains above the long-term safety threshold, indicating that the species is best utilized as a complementary biofilter within integrated indoor air quality management systems rather than as a stand-alone solution.

The findings confirm the ecological realism and scalability of *C. asiaticum*, supported by its morphological traits—broad, thick, glossy leaves with presumed high stomatal density—that likely contributed to pollutant absorption. The dose-dependent reduction across treatment groups underscores the importance of cumulative leaf surface area and structural integrity in gas uptake, consistent with prior evidence linking plant morphology to phytoremediation efficacy (Cetin and Sevik 2016; Son et al. 2019; Bui et al. 2024).

Future research should incorporate real-world indoor conditions with diverse pollutant sources, longer exposure durations, and variable ventilation scenarios. Mechanistic investigations using physiological sensors, enzymatic assays, and quantitative morphological assessments are needed to validate biological pathways and establish predictive models of phytoremediation performance. Interdisciplinary collaboration across plant science, environmental health, and architectural design will be essential to translate these insights into scalable, nature-based ventilation systems that support public health resilience and biodiversity conservation (Dolai and Nandi 2021; Montaluisa-Mantilla et al. 2023).

In conclusion, this study provides empirical evidence that *C. asiaticum* exhibits measurable phytoremediation capacity in enclosed indoor environments, achieving a maximum carbon monoxide (CO) reduction of 28.40% within 45 minutes. Although this reduction approaches the World Health Organization's short-term exposure guideline, it remains above the long-term safety threshold, indicating that the species is best utilized as a complementary biofilter within integrated indoor air quality management systems rather than as a stand-alone solution. The findings confirm the ecological realism and scalability of *C. asiaticum*, supported by its morphological traits—broad, thick, glossy leaves with presumed high stomatal density—that likely contributed to pollutant absorption. The dose-dependent reduction across treatment groups underscores the importance of cumulative leaf surface area and structural integrity in gas uptake.

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