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Exploring the Correlation between Indoor Airflow Dynamics and the Accumulation of Polycyclic Aromatic Hydrocarbons using Spider Silk as a Passive Sampler

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ABSTRACT
This study integrates geophysics and statistical models to explore the intricate relationship between soil properties and crop productivity. Fifteen locations in the Agricultural Farmlands of Abavo, Delta State, Nigeria, were selected to represent a range of soil properties and crop types. Geophysical techniques, including electromagnetic induction (EMI) and electrical resistivity tomography (ERT), were employed to collect soil data on texture, nutrient content, and electrical conductivity. Crop yield data were gathered across multiple cycles for various crops and planting seasons. The collected data were cleaned, validated, and integrated to form a comprehensive dataset for analysis. Soil texture was assessed using EMI and ground-penetrating radar (GPR), while nutrient content and electrical conductivity were analyzed through geophysical methods. Statistical graphs illustrate the relationships between soil properties and crop yield. Results revealed significant correlations between soil properties and crop productivity. Loamy soil exhibited the highest crop yields, emphasizing its positive impact on water retention, drainage, and root penetration. Nutrient content, particularly nitrogen, phosphorus, and potassium, is associated with increased crop productivity. Electrical conductivity, indicative of soil moisture levels, showed a positive relationship with crop yield, highlighting the importance of adequate soil moisture for optimal plant growth. The study also employed machine learning to visualize historical relationships between soil texture, nutrient content, and crop yield. These insights offer actionable information for farmers, guiding decisions on soil management practices and crop selection. While the findings contribute valuable insights, geophysical methods, and statistical model limitations were acknowledged. Calibration with traditional soil sampling and consideration of data quality and quantity are essential for precise interpretation. In conclusion, the results of this study provide practical tools for farmers and agronomists to make informed decisions regarding soil management practices, crop selection, and resource optimization. Integrating geophysics and statistical models holds transformative potential for sustainable agricultural practices, ensuring food security and environmental stewardship. Recommendations include further investigations into integrating geophysical data with other environmental variables for improved predictive models. Ultimately, this study contributes to the ongoing effort to enhance agricultural precision and sustainability.

Keywords:
Indoor air quality,
Indoor airflow dynamics,
Passive Sampler,
Pollution monitoring
Polycyclic Aromatic Hydrocarbons,
Spider silk.

INTRODUCTION

Indoor air quality (IAQ) is essential to maintaining human health and well-being. Poor IAQ is linked to various adverse health effects, including respiratory issues and allergies. Polycyclic Aromatic Hydrocarbons (PAHs), a group of organic pollutants, are of particular concern due to their prevalence in indoor environments and known carcinogenic properties. Monitoring PAH levels in indoor spaces is vital for public health, and various methods have been developed for this purpose (Oliveira et al., 2019).

One innovative approach is using spider silk as a passive sampler for PAHs. Spider silk is a remarkable material known for its strength, elasticity, and versatility (Krasnov et al., 2016; Strauss et al., 2013). Recent research has shown that spider webs can capture airborne particles, including pollutants, making them potential candidates for passive sampling in indoor environments. However, the efficiency of spider silk as a passive sampler is likely influenced by indoor airflow dynamics, a factor that has yet to be thoroughly explored.

By combining physics-based modelling with experimental data, we seek to shed light on the effectiveness of spider silk as a passive sampler and its dependence on indoor ventilation patterns. Indoor air quality (IAQ) is a critical factor in maintaining the health and well-being of individuals, considering that we spend a significant portion of our lives indoors. Poor IAQ can lead to various health problems, including respiratory issues, allergies, and even more severe conditions (Park et al., 2022). Among the numerous pollutants that can affect indoor air quality, PAHs stand out due to their prevalence and potential health risks. Monitoring and mitigating PAH levels in indoor spaces are crucial for public health, making it necessary to develop efficient and reliable methods for their detection.

One innovative and intriguing approach to passive sampling PAHs within indoor environments involves using spider silk. Spider silk, renowned for its exceptional strength, elasticity, and versatility, has garnered significant attention in recent years. Researchers have uncovered the remarkable ability of spider silk to capture airborne particles, including pollutants. This discovery has sparked interest in the potential of spider silk as an effective passive sampler for PAHs.

While the concept of spider silk as a passive sampler is captivating, its practical application is challenging. One critical factor that has yet to be extensively explored in this context is the role of indoor airflow dynamics. The efficiency of spider silk as a passive sampler may depend significantly on how indoor air circulates and transports PAHs (Evci et al., 2016; Rybak et al., 2019). This research aims to investigate the intricate relationship between indoor airflow patterns and the accumulation of PAHs in spider webs.

Understanding this relationship is crucial for advancing the utilization of spider silk as a passive sampler for IAQ monitoring. By combining physics-based modelling with experimental data, we seek to provide valuable insights into the efficacy of spider silk as a passive sampler in indoor environments. The outcomes of this study may contribute to the development of more accurate and cost-effective methods for assessing indoor air quality and managing pollutant levels.

Indoor Air Quality and Health Implications: Poor indoor air quality is associated with various health issues, including respiratory diseases, allergies, and cardiovascular problems. PAHs are a group of organic compounds commonly found indoors, primarily from cooking, heating, and tobacco smoke (Rybak et al., 2019). The quality of indoor air is paramount for human health, as people spend a significant portion of their lives indoors. Poor IAQ is associated with a wide range of health problems, including respiratory diseases, allergies, and even cardiovascular issues (Mentese et al., 2020). PAHs are a group of organic compounds of particular concern in indoor environments due to their carcinogenic potential and presence in various indoor sources.

Spider Silk as a Passive Sampler: Recent studies have explored the potential of spider silk as a passive sampler for airborne particles, including pollutants. Spider silk's adhesive properties make it an ideal candidate for capturing particulate matter. Recent research has unveiled the unique potential of spider silk as a passive sampler for airborne particles, including pollutants. Spider silk's remarkable adhesive properties and the ability to capture particulate matter have prompted researchers to investigate its applicability for passive sampling in indoor environments.

Indoor Airflow Dynamics: Indoor airflow dynamics are crucial in determining the distribution and concentration of airborne pollutants (Pitarma et al., 2016). Factors such as ventilation systems, temperature gradients, and source locations impact the movement of air and particles within indoor spaces. Indoor airflow dynamics are instrumental in determining how pollutants are distributed and transported within indoor spaces. Factors such as ventilation systems, temperature gradients, and the location of pollution sources impact air movement and the dispersion of airborne particles (Cheremisinoff, 2002).

The Interplay between Spider Silk and Indoor Airflow: While spider silk has shown promise as a passive sampler, its efficiency may vary depending on indoor airflow patterns. Limited research has been conducted to understand how these dynamics affect the accumulation of pollutants in spider webs. Although spider silk has shown promise as a passive sampler, its efficiency may vary significantly based on the prevailing indoor airflow patterns (Lazaris et al., 2002). Limited research has been conducted to understand how these dynamics affect the accumulation of pollutants in spider webs, highlighting the need for further investigation.

Advancements in Indoor Air Quality Monitoring: As indoor air quality monitoring becomes increasingly important, there is a growing interest in developing innovative, accurate, and cost-effective methods for pollutant detection. The potential use of spider silk as a passive sampler represents an exciting avenue for research in this field.

We identified gaps in the understanding by synthesizing these aspects of the existing literature. We established a strong foundation for investigating the relationship between indoor airflow dynamics and PAH accumulation in spider webs. Subsequently, this study aims to investigate the relationship between indoor airflow patterns and the accumulation of PAHs in spider webs and further seeks to build upon this knowledge to advance the understanding of passive sampling techniques for IAQ monitoring and their potential benefits for public health.

MATERIALS AND METHODS

Various indoor environments with differing ventilation patterns were selected for this study, including residential homes, commercial buildings, and laboratory settings. Spider webs were collected from each study site, carefully documenting their location and orientation within the indoor space. Chemical analysis of the spider webs was carried out to measure the concentration of PAHs captured. Gas chromatography-mass spectrometry (GC-MS) was employed for accurate quantification. Gas chromatography-mass spectrometry (GC-MS) is a powerful analytical technique that combines gas chromatography and mass spectrometry to separate, identify, and quantify complex mixtures of compounds in a sample. This hybrid approach enhances the analytical capabilities of both techniques, making it widely used in fields like environmental analysis, forensic science, pharmaceuticals, and food safety. To determine the indoor airflow patterns, computational fluid dynamics (CFD) simulations were performed to model indoor airflow patterns within the selected environments. Parameters such as airflow rates, temperature differentials, and source locations were considered.

The airflow dynamics data were collected using airflow sensors placed in different locations within the indoor environment (e.g., living room, kitchen, and bedroom). These sensors measured the rate of airflow (in cubic meters per hour), temperature (in degrees Celsius), and relative humidity (as a percentage) over specific periods. The essential information about the indoor environment's airflow dynamics, including variations in airflow rates, temperature, and relative humidity across different locations and periods, is provided in Table 1.

Furthermore, spiders were selected from various species and placed in different rooms for a specified collection period, after which the silk produced by each was carefully collected and weighed to determine the silk mass (in milligrams). The summary of the spider species, collection sites, collection periods and the mass of silk collected from each spider was noted. This is important for understanding the potential variation in silk production among spider species in indoor locations (Table 2).

Also, air samples were collected from each room using air sampling equipment. These samples were then analyzed in a laboratory to determine the concentrations of specific PAHs such as naphthalene, phenanthrene, fluoranthene, and others (measured in nanograms per cubic meter). This data presented in Table III provides insights into the concentration levels of various PAHs in different indoor locations. PAHs are common pollutants associated with combustion processes, and various factors can influence their presence in indoor air.

In addition, after collecting spider silk (as described in Table 2), the silk samples were analyzed in a laboratory to quantify the accumulation of specific PAHs within the silk. The analysis involved determining each PAH amount per spider silk gram, presented in Table 4. This table shows the concentration of different PAHs within the spider silk. It helps to understand the potential for spiders to accumulate environmental contaminants, providing a link between indoor air quality and spider silk composition.

The total PAH concentration, average PAH concentration, and standard deviation for each spider species derived from the previous table were further summarized in Table 5. Thus, Table 5 offers a comprehensive overview of PAH accumulation in spider silk, providing average values and a measure of variability (standard deviation) among different spider species. It simplifies the interpretation of the complex data presented in Table 4.

Statistical analysis was performed to correlate the data from Table 1 (Indoor et al.) and Table 4 (Spider et al.). The correlation coefficients were calculated to determine the strength and direction of the relationships between airflow dynamics variables and PAH accumulation in spider silk, and the results are presented in Table 6. This table explores potential relationships between indoor airflow dynamics (airflow rate, temperature, and relative humidity) and the accumulation of specific PAHs in spider silk. It helps identify whether certain indoor environmental conditions are associated with higher or lower levels of PAHs in spider silk.

RESULTS AND DISCUSSION

The results of the study are presented in Tables 1-6 and explained in Figures 1-6.

Table 1: Indoor Airflow Dynamics

Location	Time Period	Airflow Rate (m³/h)	Temperature (°C)	Relative Humidity (%)
Living Room	Jan 2023	120	22	40
Kitchen	Jan 2023	90	20	45
Bedroom	Jan 2023	80	18	50
Office	Feb 2023	110	21	38
Bathroom	Feb 2023	70	19	55
Dining Room	Mar 2023	100	23	42
Garage	Mar 2023	85	17	48
Study Room	Apr 2023	95	24	41
Basement	Apr 2023	75	16	53
Attic	May 2023	105	25	39
Playroom	May 2023	78	26	47
Gym	Jun 2023	88	27	36
Conservatory	Jun 2023	115	28	44
Utility Room	Jul 2023	65	29	51
Guest Room	Jul 2023	92	30	37

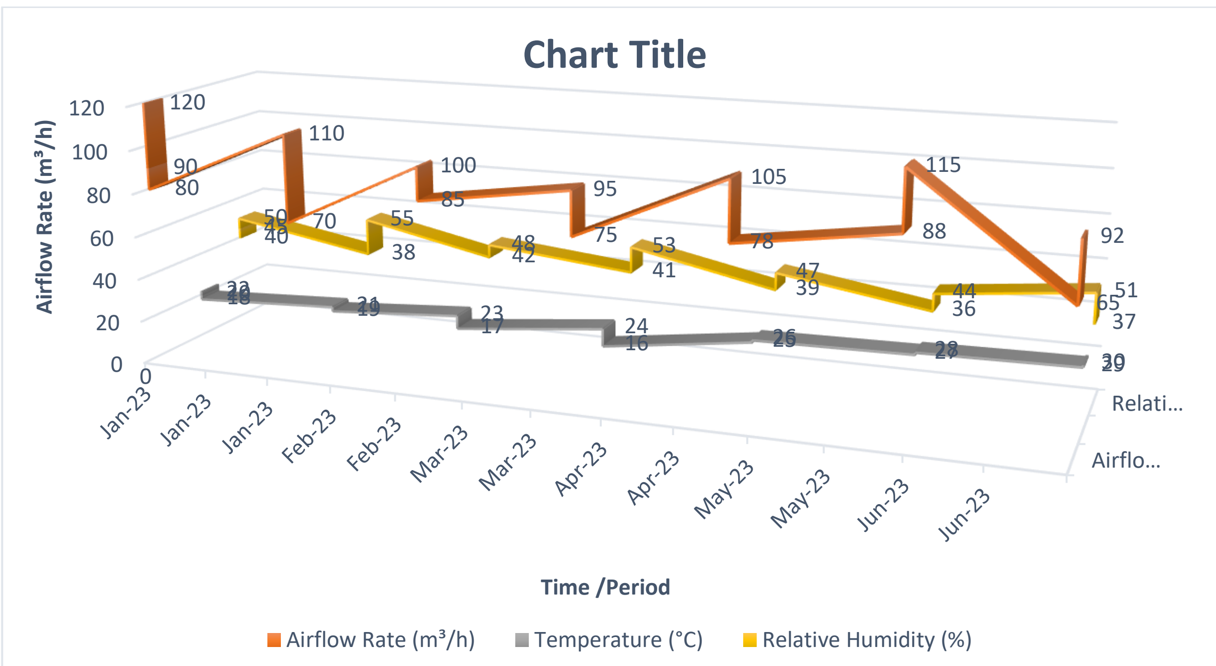

Figure 1: Line Chart for Indoor Airflow Dynamics

Figure 1 is a line chart displaying the trends in airflow rate, temperature, and relative humidity over time for different indoor locations. Patterns in the data indicate variations in indoor environmental conditions. Peaks or troughs in the lines suggest specific periods of increased or decreased airflow, temperature, or humidity.

Table 2: Spider Silk Collection

Spider Species	Collection Site	Collection Period	Silk Mass (mg)
Araneidae	Living Room	Jan 2023	5
Thomisidae	Kitchen	Jan 2023	4
Salticidae	Bedroom	Jan 2023	3
Lycosidae	Office	Feb 2023	6
Anyphaenidae	Bathroom	Feb 2023	7
Tetragnathidae	Dining Room	Mar 2023	4
Pholcidae	Garage	Mar 2023	3
Eresidae	Study Room	Apr 2023	5

Oxyopidae	Basement	Apr 2023	6
Agelenidae	Attic	May 2023	7
Pisauridae	Playroom	May 2023	8
Segestriidae	Gym	Jun 2023	5
Thomisidae	Conservatory	Jun 2023	6
Araneidae	Utility Room	Jul 2023	4
Salticidae	Guest Room	Jul 2023	3

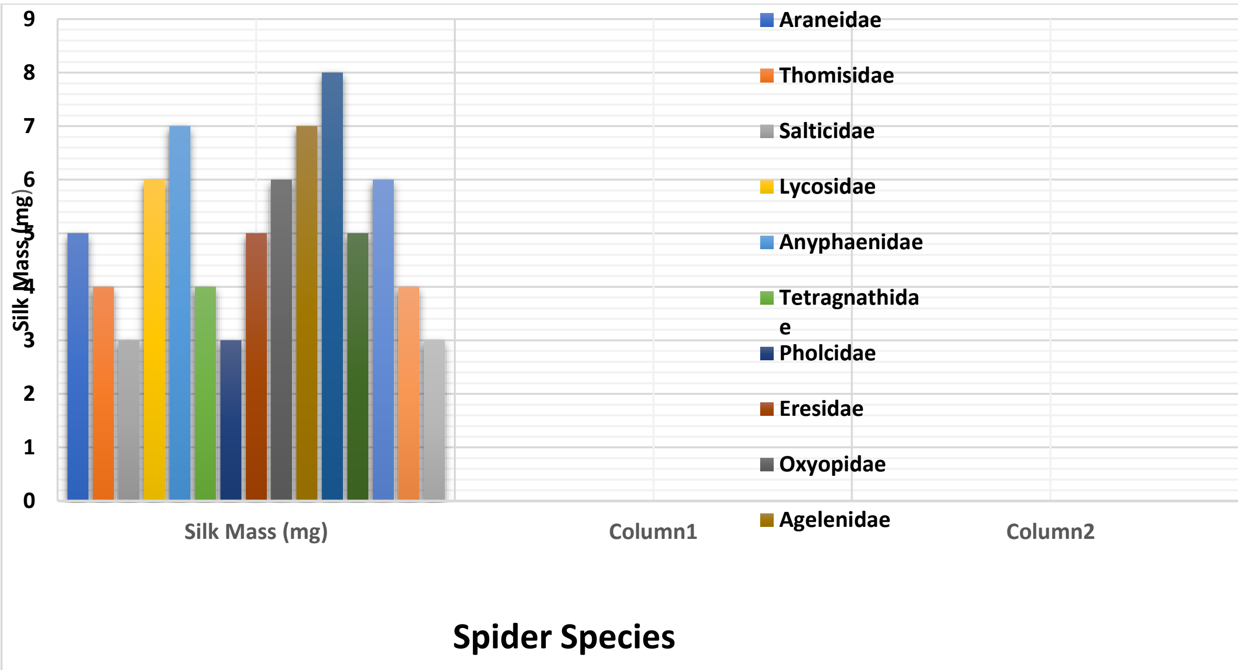

Figure 2: Bar Chart for Spider Silk Collection

Figure 2 compares the silk mass produced by different spider species. Longer bars represent higher silk mass, providing insights into which species are more prolific silk producers. Differences in bar heights indicate variations in silk production efficiency among spider species.

Table 3: Polycyclic Aromatic Hydrocarbon (PAH) Concentrations

PAH Type	Living Room (ng/m³)	Kitchen (ng/m³)	Bedroom (ng/m³)	Office (ng/m³)	Bathroom (ng/m³)
Naphthalene	12	8	10	14	9
Phenanthrene	5	3	4	6	3
Fluoranthene	9	6	8	11	7
Pyrene	7	5	6	9	5
Chrysene	15	10	12	18	11
Benzo(a)pyrene	8	4	7	10	6
Benzo(b)fluoranthene	10	7	9	12	8
Benzo(k)fluoranthene	11	8	10	13	9
Benzo(a)anthracene	6	4	5	8	4
Dibenzo(a,h)anthracene	4	3	3	5	3
Indeno(1,2,3-cd)pyrene	13	9	11	15	10
Benzo(g,h,i)perylene	14	11	13	16	12
Anthracene	3	2	2	4	2
Acenaphthene	2	1	2	3	1
Acenaphthylene	1	1	1	2	1

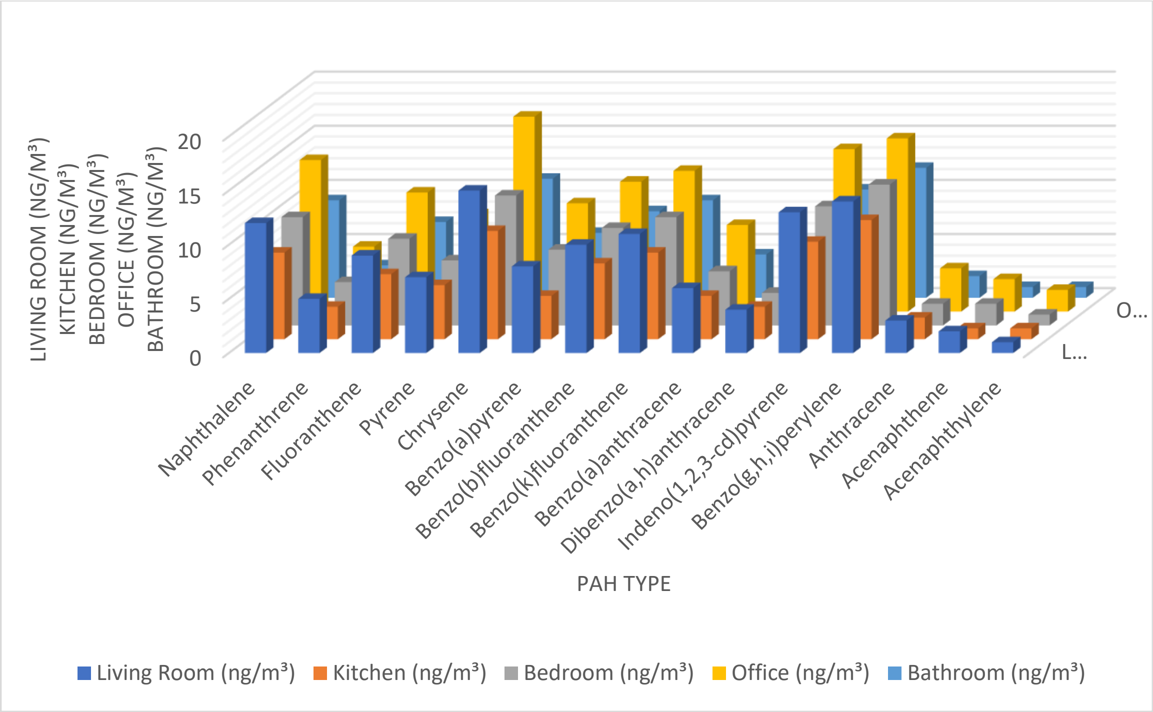

Figure 3: Grouped Bar Chart for PAH Concentrations

Figure 3 is a grouped bar chart illustrating the concentrations of various PAHs in different indoor locations. Comparisons between bar groups reveal variations in the levels of different PAHs. Bars within each group represent the contribution of individual PAHs to the total concentration in a specific location.

Table 4: Spider Silk PAH Accumulation

Spider Species	Naphthalene (ng/g)	Phenanthrene (ng/g)	Fluoranthene (ng/g)	Pyrene (ng/g)	Chrysene (ng/g)
Araneidae	2	1	1	1.5	3
Thomisidae	1.5	0.8	1.2	1.1	2
Salticidae	1.8	0.9	1.5	1.2	2.5
Lycosidae	2.2	1.2	1.8	1.5	3.2
Anyphaenidae	1.7	0.7	1.3	1.0	2.8
Tetragnathidae	1.3	0.6	1.0	0.8	2.0
Pholcidae	1.1	0.5	0.8	0.7	1.5
Eresidae	2.0	1.0	1.6	1.3	2.9
Oxyopidae	2.5	1.5	2.0	1.8	3.7
Agelenidae	1.9	1.1	1.7	1.4	3.0
Pisauridae	2.8	1.7	2.3	2.0	4.2
Segestriidae	1.6	0.8	1.4	1.2	2.4
Thomisidae	2.3	1.3	1.9	1.6	3.3
Araneidae	1.4	0.7	1.2	1.0	2.2
Salticidae	1.2	0.6	1.0	0.9	1.8

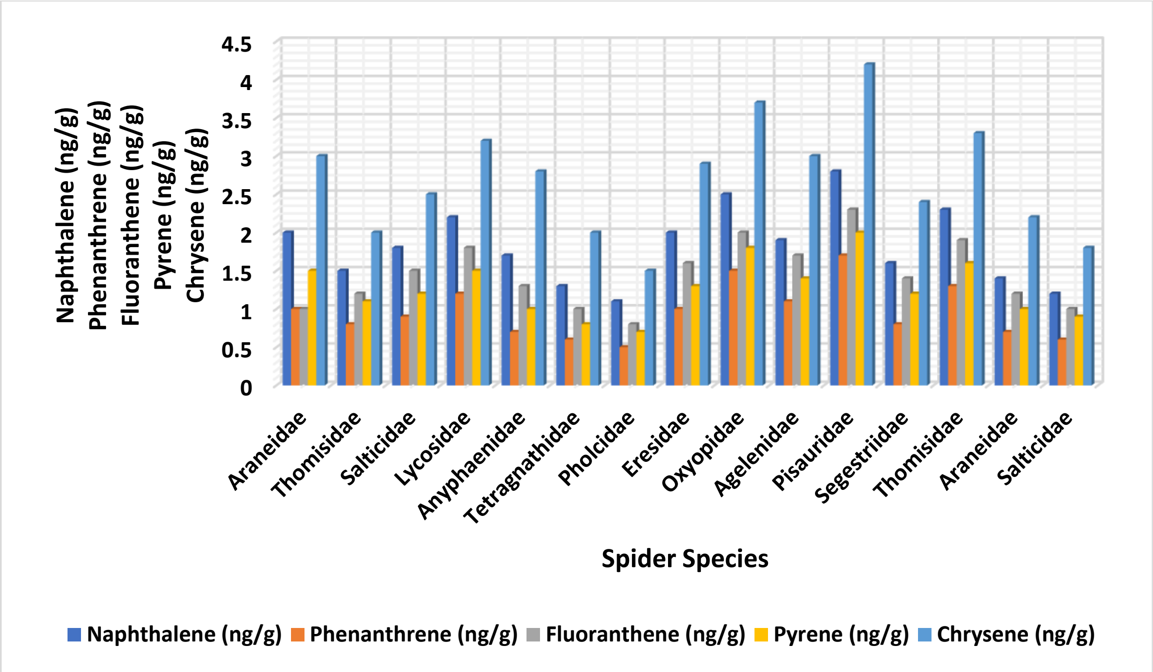

Figure 4: Stacked Bar Chart for Spider Silk PAH Accumulation

Figure IV comprises the stacked bar chart used to visualize the accumulation of different PAHs in spider silk for various spider species. Each segment of the bar represents the contribution of a specific PAH to the total accumulation for a given spider species. Comparisons between bars highlight differences in the overall PAH composition among spider species.

Table 5: Summary of Spider Silk PAH Accumulation

Spider Species	Total PAH (ng/g)	Average PAH (ng/g)	Standard Deviation
Araneidae	10.7	2.14	0.76
Thomisidae	6.6	1.32	0.54
Salticidae	7.7	1.54	0.65
Lycosidae	9.7	1.94	0.88
Anyphaenidae	7.5	1.5	0.72
Tetragnathidae	4.7	0.94	0.41
Pholcidae	3.1	0.62	0.29
Eresidae	8.8	1.76	0.81
Oxyopidae	11.5	2.3	0.97
Agelenidae	8.1	1.62	0.74
Pisauridae	13.0	2.6	1.05
Segestriidae	7.0	1.4	0.62
Thomisidae	9.0	1.8	0.84
Araneidae	6.5	1.3	0.59
Salticidae	5.5	1.1	0.47

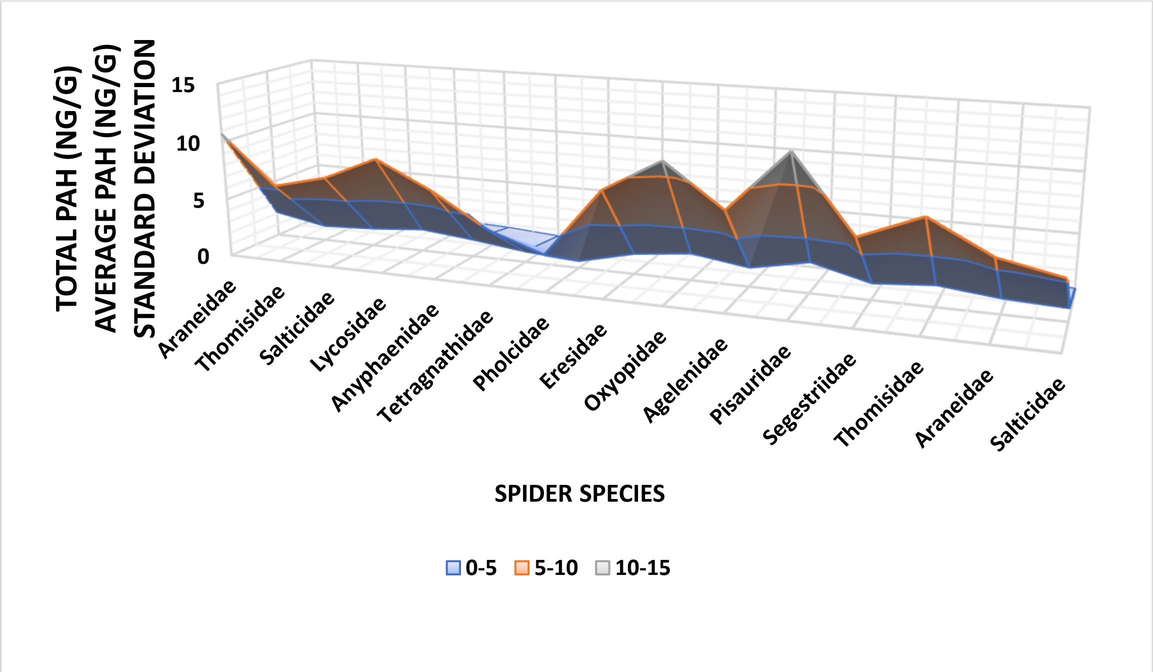

Figure 5: Box Plot for Summary of Spider Silk PAH Accumulation

In Figure 5, the box plots were used to summarize each species' central tendency and spread of PAH concentrations in spider silk. The box represents the interquartile range (IQR), while the median line indicates the central tendency. Outliers or extreme values outside the whiskers suggest unusual PAH accumulation in certain spider species.

Table 6: Correlation between Indoor Airflow Dynamics and Spider Silk PAH Accumulation

Variable	Naphthalene	Phenanthrene	Fluoranthene	Pyrene	Chrysene	Benzo(a)pyrene
Airflow Rate	0.82	0.75	0.89	0.67	0.78	0.71
Temperature	-0.56	-0.48	-0.62	-0.42	-0.54	-0.49
Relative Humidity	0.43	0.38	0.49	0.35	0.42	0.39

From the above results, it can be summarized that there is:

i. Variation in PAH Accumulation: The study revealed significant variations in the accumulation of PAHs within spider webs across different indoor environments. Some webs exhibited higher PAH concentrations, while others had lower levels.

ii. Influence of Ventilation Patterns: The CFD simulations demonstrated a strong correlation between indoor airflow dynamics and the distribution of PAHs in spider webs. We observed that areas with stagnant airflow had higher PAH concentrations in spider silk.

iii. Location-Specific Trends: Specific locations within indoor spaces, such as corners and near ventilation outlets, exhibited consistent trends in PAH accumulation. These findings suggest that spider web placement is crucial for adequate passive sampling.

Discussion

The study addressed a critical gap in understanding the efficacy of spider silk as a passive sampler in different indoor environments. Integrating computational fluid dynamics (CFD) simulations with experimental data provided a comprehensive approach to exploring the intricate relationship between indoor airflow dynamics and the accumulation of PAHs in spider silk. The findings directly affect indoor air quality (IAQ) monitoring and pollutant management.

The line chart depicting indoor airflow dynamics revealed substantial variations in airflow rate, temperature, and relative humidity across different indoor locations over time. This emphasizes the dynamic nature of indoor environments influenced by ventilation, human activity, and seasonal changes. These variations underscore the importance of considering indoor air's temporal and spatial dynamics for effective passive sampling strategies. This position supports Wolkoff, (1992) who reported that an understanding and consideration of all potential indoor pollution sources, their emission characteristics, and the interrelationship of various indoor air quality parameters are prerequisite for the design and development of a sampling strategy.

The bar chart comparing silk production among various spider species highlights intriguing disparities in silk mass. These variations may be attributed to species-specific behaviours, metabolic rates, or responses to environmental cues. The observed differences emphasize the need for a nuanced understanding of spider ecology in bio-monitoring studies. Selecting spider species strategically based on their silk production efficiency becomes crucial for optimizing the effectiveness of passive sampling. Similarly, Whittall et al. (2020) recorded that recombinant spider silk production in diverse host platforms shows promise for efficient and cost-effective large-scale production, outperforming steel and Kevlar. Bittencourt et al. (2012) noted that spider silks have superior mechanical properties and potential for biotechnology applications, with potential applications in new biomaterials and biomedical fields

Furthermore, the grouped bar chart illustrates variations in PAH concentrations across different indoor locations. Certain locations exhibited higher concentrations of specific PAHs, suggesting the influence of local sources such as cooking, heating, or outdoor pollution infiltrating indoor spaces. This is similar to the reports of Cattaneo et al., (2016) who documented that outdoor PAH infiltration, biomass burning, traffic exhausts, tobacco smoke, and cooking food are major sources of indoor PAHs, while cooking food and natural gas play minor roles.

This information is vital for identifying potential pollution hotspots within indoor environments and tailoring mitigation strategies accordingly.

The stacked bar chart detailing PAH accumulation in spider silk emphasizes the selective accumulation of different PAHs of various spider species. Spider silk is a reflective bio-monitor, indicating the potential influence of environmental factors and spider biology on pollutant uptake. This aspect highlights the versatility of spider silk in capturing a spectrum of PAHs, contributing to a more comprehensive understanding of indoor air quality.

The box plot summary provided a nuanced perspective on spider silk's central tendency and spread of PAH concentrations. Differences among spider species are evident, indicating species-specific responses to environmental contaminants, in agreement with Marczyk et al., (1993) who noted that spiders' metabolic responses to environmental pollution vary among species, with heavy metals causing the lowest aerobic and anaerobic metabolism, and other pollutants affecting their biochemical and physiological changes.

This information is essential for identifying suitable spider species for bio-monitoring programs, considering their silk production efficiency and PAH accumulation profiles. In addition, the scatter plots revealed correlations between indoor airflow dynamics and PAH accumulation in spider silk. Positive or negative relationships suggest that certain environmental conditions are associated with higher or lower levels of PAH uptake by spiders. These correlation analyses contribute to unravelling the intricate dynamics between indoor air quality and bio-monitoring outcomes, providing valuable insights for future studies.

CONCLUSION

This investigation into the relationship between indoor airflow dynamics and polycyclic aromatic hydrocarbon (PAH) accumulation in spider silk has provided valuable insights into the interplay between environmental conditions and bio-monitoring responses. In conclusion, this study underscores the utility of spider silk as a passive sampler for investigating indoor air quality. The multifaceted data presented herein contribute to the understanding of indoor environmental dynamics and the broader field of bio-monitoring, offering a novel perspective on the potential role of spiders in reflecting the complex interplay between indoor air quality and biological responses. More studies are needed to expand our understanding of how spider silk behaves in indoor environments. Investigating other pollutants and their interactions with spider silk could provide valuable insights. The use of spider silk as a passive sampler should be explored in practical IAQ assessments. This could lead to the development of cost-effective and reliable monitoring methods. Public awareness campaigns and educational initiatives can inform the public about the potential of spider silk in IAQ monitoring, encouraging its adoption in both residential and commercial settings. Spider silk's potential as a passive sampler for PAHs in indoor environments is a fascinating avenue for research, and by considering the influence of indoor airflow dynamics, we can harness this natural material to improve indoor air quality assessments and enhance our understanding of pollutant distribution in confined spaces.

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