MALAYSIAN JOURNAL OF MICROSCOPY

Journal homepage: https://malaysianjournalofmicroscopy.org

RESEARCH ARTICLE

COMPARATIVE ASSESSMENT OF PASSIVE AND PERSONAL SAMPLING FOR AIRBORNE MICROPLASTICS IN A PLASTIC MANUFACTURING FACILITY

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Abstract. The presence of microplastics (MPs) in indoor air has emerged as a pressing occupational health concern, particularly in plastic manufacturing environments, where airborne exposure is elevated due to direct handling and processing of polymeric materials. This study presents a cross-sectional assessment of inhalable MPs within a plastic manufacturing facility in the Klang Valley, Malaysia, using both passive and personal air sampling techniques. Samples were analyzed for particle size, shape, and color using a stereomicroscope statistically evaluated using chi-square tests to determine associations between these characteristics and sampling methods. The results revealed a clear dominance of fibrous, small-sized (<500 µm), and transparent MPs, with passive sampling consistently capturing 2.74 times higher counts than personal sampling. Transparent and black particles were most associated with fibers and smaller sizes, suggesting enhanced airborne mobility and prolonged suspension. Statistically significant associations ($p < 0.05$) were observed across all variable pairings. Micro-Raman spectroscopy confirmed the presence of polyethylene in the samples collected. These findings highlight the importance of targeted mitigation strategies, including engineering controls, personal protective equipment (PPE) usage, and environmental monitoring, to reduce occupational exposure and potential respiratory health risks. This study provides critical empirical data to support policy development and workplace safety interventions in the plastic manufacturing sector, particularly in developing regions.

Keywords: Microplastics, occupational exposure, micro-raman spectroscopy, inhalation risk.

Article Info

Received 6 January 2026
Accepted 19 April 2026
Published 8 June 2026

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ISSN: 1823-7010, eISSN: 2600-7444

1. INTRODUCTION

Microplastics (MPs), defined as plastic particles smaller than 5 mm, have emerged as persistent contaminants of global concern due to their widespread occurrence across various environmental matrices and their potential to harm ecosystems and human health [1]. While significant attention has been paid to their presence in aquatic environments, growing evidence indicates that MPs are also pervasive in indoor and ambient air, raising important concerns about inhalation exposure, especially in enclosed or occupational settings [2].

Indoor environments are of particular concern because individuals typically spend over 80 % of their time indoors, increasing the risk of chronic exposure [3]. The ubiquity of MPs in indoor air is largely attributed to their release from synthetic textiles, plastic-based consumer products and degradation of polymer-containing materials. Recent studies have highlighted the presence of MPs in household dust and atmospheric fallout, with the potential for these particles to be inhaled and deposited in the respiratory tract.

However, while the general population is at risk, certain occupational environments, particularly plastic manufacturing and recycling facilities, represent concentrated hotspots for MPs generation. Processes such as extrusion, cutting, heating, and molding during production can aerosolize plastic fragments and fibers, leading to elevated airborne MPs concentrations in the workplace [4]. Workers in such environments face prolonged and repeated exposure, yet empirical data quantifying these exposure levels and their associated health outcomes remain scarce [5].

Emerging evidence suggests that inhaled MPs can trigger a range of adverse health outcomes. Deposited MPs may cause respiratory inflammation, oxidative stress, and systemic toxicity because of their persistence, irregular morphologies, and adsorbed pollutants, such as heavy metals and persistent organic chemicals [6]. Particle size plays a critical role in determining deposition within the respiratory tract, where larger particles are more likely to deposit in the upper airways, whereas smaller particles can penetrate deeper into the bronchiolar and alveolar regions, potentially leading to more severe health effects. These risks are compounded in occupational settings, where MPs concentrations may far exceed background environmental levels.

Additionally, the atmospheric transport potential of MPs allows for their dispersion beyond the immediate emission source, further complicating containment and mitigation efforts [7]. Environmental contamination from such point sources can lead to downstream ecosystem impacts and human exposure through indirect pathways [8]. Despite increasing recognition of MPs pollution, there remains a critical research gap in assessing airborne occupational exposure to MPs in plastic manufacturing environments, especially in low- and middle-income countries, where regulatory frameworks may be limited [9]. The current literature largely overlooks the quantification of airborne MPs concentrations in industrial settings and their potential health implications for exposed workers in Malaysia. This study aims to address this gap by conducting a cross-sectional assessment of indoor ambient MPs exposure in a plastic manufacturing facility using microscopy and providing much-needed empirical data to inform occupational health risk evaluations and support evidence-based mitigation strategies.

2. MATERIALS AND METHODS

2.1 Study Site and Design

This study was conducted at a plastic manufacturing facility with a size of 1104 m^2 situated in the Klang Valley region of Malaysia. The facility employs over 12 workers and comprises multiple operational units, including extrusion, injection moulding, packaging and administrative departments. A cross-sectional sampling design was employed to evaluate the presence and characteristics of airborne MPs within the indoor working environment. Sampling was carried out for three weeks everyday during regular weekday operations, under standard production conditions, to ensure

representativeness of typical occupational exposure. Both personal and passive air sampling techniques were utilised across distinct functional areas within the facility to provide a comprehensive assessment of airborne MPs distribution and potential worker exposure.

2.2 Sampling Strategy

Two sampling techniques were employed in this study to assess the airborne MPs in the factory environment which is via personal sampling and passive sampling as shown in Figure 1, which was sampled for three weeks totalling up to 15 replications. Personal sampling was conducted using an Airchek XR5000 personal air sampling pump (SKC Inc., USA) equipped with a Li-ion battery. The device operated at a calibrated flow rate of 2.0 L/min and was fitted with a 25 mm mixed cellulose ester (MCE) membrane filter (pore size: 1.2 µm). A selected factory operator wore the sampler, as shown in Figure 1, throughout an 8-h work shift, allowing for the collection of inhalable airborne MPs across various operational zones, including extrusion, injection molding, and packaging sections. This mobile sampling method enabled the evaluation of MPs that may be encountered during typical occupational movements within the workspace.

In contrast, passive sampling was conducted simultaneously using a static open sampling approach, in which a stainless steel collection bowl with a diameter of 30 cm was placed on a table approximately 1.2 m above ground level and centrally located within the workspace. The bowl remained undisturbed for the 8-h sampling duration to allow for gravitational settling of airborne particles.

These dual-sampling strategies enabled a comparative evaluation of stationary gravitational deposition and personal exposure levels across various zones within an industrial environment. Passive sampling, which relies on the principle of gravitational settling, represents particle deposition over time onto surfaces within the workplace. In contrast, personal sampling reflects inhalation exposure and captures airborne MPs that are likely to be directly inhaled during occupational activities.

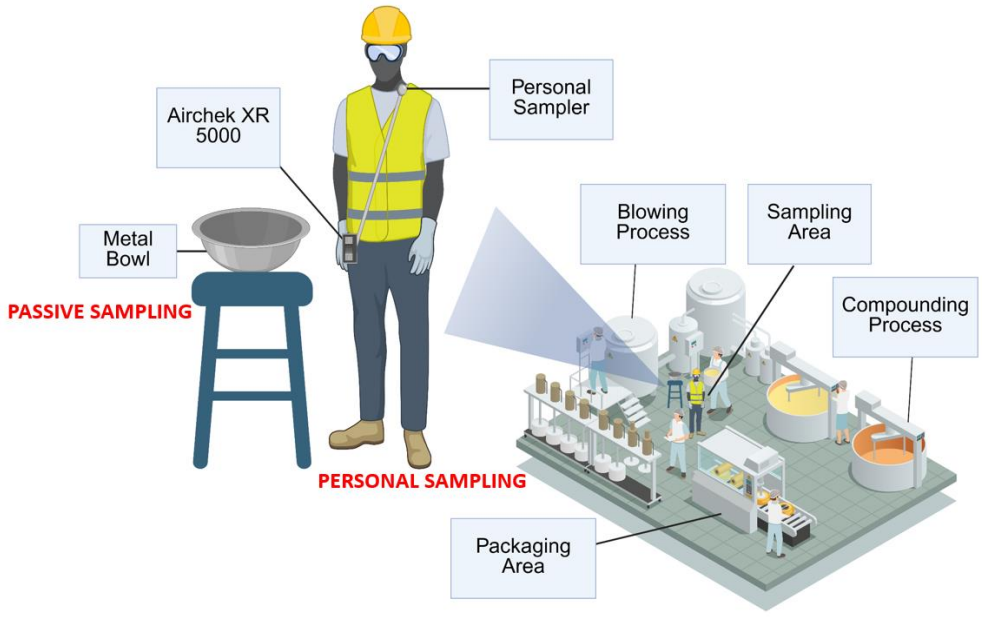

Figure 1: Schematic representation of personal and passive sampling techniques used to collect airborne MPs in a factory environment

2.3 Sample Preparation and Analysis

Collected filters were subjected to chemical digestion using 30 % hydrogen peroxide (H_2O_2) for 48 h to remove organic matter, followed by vacuum filtration through an MF-Millipore^{TM} mixed cellulose ester (MCE) filter with a diameter of 47 mm and a pore size of 0.8 µm. Then the filter paper was set to dry in the desiccator at room temperature for 48hrs. Strict contamination control protocols were implemented, including the exclusive use of metal and glass equipment, rigorous cleaning procedures, protective handling measures, and controlled storage to minimise external contamination. Blank and procedural controls were incorporated to assess and correct for potential laboratory and procedural contamination, ensuring data reliability.

2.4 Morphology Studies

After drying, the labelled MCEs were analyzed using a stereomicroscope (Nikon SMZ745T). The physical characteristics, such as shape, size, and color, were sorted and manually recorded under the microscope. The hot needle test involved inserting a heated needle into suspected samples, where melting indicated the presence of MPs, followed by microscopic examination [10]. This step enabled clear differentiation between MPs and non-MPs during the sorting process.

Micro-Raman spectroscopy was performed using a Confocal Raman Microscope (Witec alpha300 R) to characterize MPs. Particles selected for Raman analysis were based on prior stereomicroscopic identification, considering distinct morphological features (e.g., fibers, fragments, and films), color variations, and particle integrity. Only particles that were clearly distinguishable, free from overlapping debris, and representative of the dominant categories were analyzed to ensure reliable spectral acquisition. The experimental parameters optimized included the type of sample mounting substrate, laser wavelength (532 nm), grating resolution (300, 600, and 1200 lines mm^{-1}), laser power (1, 10, and 25 mW), laser exposure duration (2–20 s), and the number of spectra acquired (2–10) [11]. This method indicates that reliable spectral data can be obtained without increasing laser power to levels that risk thermal degradation of the particles. Instead, enhancing data quality by increasing the number of spectra accumulated for the same particle proved to be an effective and widely adopted approach.

2.5 Data Analysis

The data analysis phase began with an exploratory overview using a series of descriptive visualizations to identify trends and distributions within the dataset. Several bar charts were constructed to display the total count of particles based on four categorical variables: sampling method, shape, size and color. The analysis further investigates pairwise relationships between categorical variables; heatmaps were generated using pivot tables that aggregated the total counts for combinations such as sampling by shape, sampling by size, shape by size, sampling by color, shape by color, and size by color. Each heatmap used a color gradient to reflect particle count intensities across the paired dimensions, allowing for quick visual identification of high-frequency combinations.

To statistically assess whether significant associations exist between categorical variables, chi-square tests of independence were conducted with a p-value threshold of 0.05 for significance. The aim was to determine whether observed distributions of MPs particle counts differed significantly across categories. All analyses and visualizations were conducted using Python, leveraging libraries such as Pandas, Seaborn, Plotly, and SciPy.

3. RESULTS AND DISCUSSION

3.1 Airborne and Deposited MPs Concentrations

The distribution of sampling methods employed in this study is presented in Figure 2, where passive sampling recorded the highest particle count (3,331 particles/m^2), followed by personal

sampling (1,213 particles/m^3). The predominance of passive sampling is consistent with findings from previous studies, which have demonstrated the presence of high MPs concentrations in indoor ambient air due to indoor sources, such as synthetic textiles, household materials and personal care products [2, 3]. In the context of the plastic manufacturing facility studied here, elevated concentrations of MPs in the indoor atmosphere were expected, given the nature of polymer-handling processes and the potential for direct emission of particulate plastics into the working environment. Similar to other studies, passive sampling generally yielded higher MPs counts than active or personal sampling methods [12]. This difference reflects the nature of the sampling approaches, where passive sampling captures particle deposition over time, while personal sampling provides a closer approximation of inhalable exposure. This is likely attributed to the passive method's capacity to continuously collect gravity-settling particulate matter over an 8h period without requiring active airflow or a human interface. Bowl based passive samplers accumulate particles that settle naturally from the air column, offering an integrated snapshot of deposition over time.

Conversely, the lower counts observed in personal sampling can be explained by the operational characteristics of this method. Personal sampling involves wearable devices that collect MPs via a specific inlet nozzle, and the efficiency of collection is influenced by wearer movements, breathing patterns, and environmental air turbulence. Moreover, such sampling captures only a fraction of suspended MPs that enter the device's intake volume during active usage, making it more sensitive to transient activity and spatial dynamics. These particles, particularly those within the respirable size fraction (≤10 µm, and more critically ≤2.5 µm), can penetrate deep into the respiratory system, potentially leading to respiratory issues and other health problems [13].

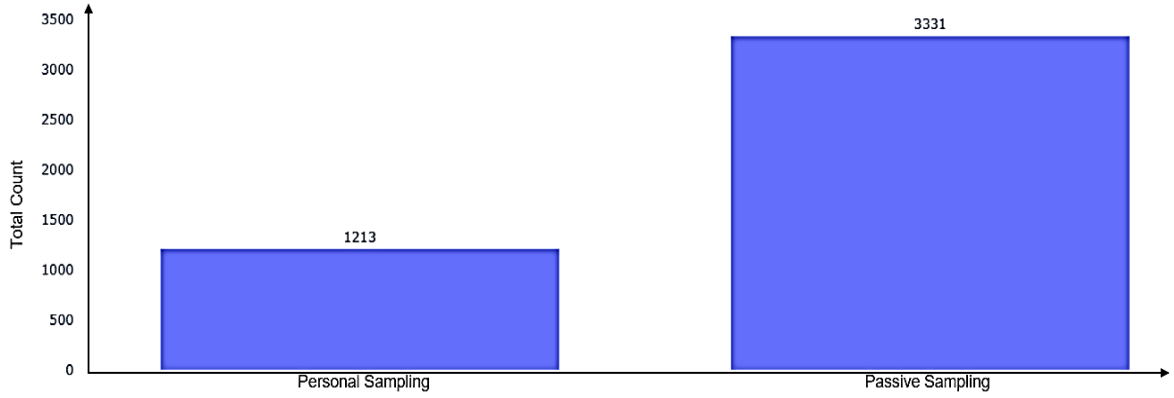

Figure 2: Total MPs counts according to sampling method

Figure 3 depicts the count and distribution of MPs for both sampling methods, with the characteristics categorized by shape, size, and color using a stereomicroscope. Among the shapes, fiber was the most dominant type, with 2,844 (≈62 %) occurrences, followed by fragment (1,262, ≈28 %) and film (415, ≈9 %), while pellet was the least common at 23, <1 %). In terms of size, particles were classified into non-overlapping ranges of <50 µm, 50–100 µm, 100–500 µm, and >500 µm. The <50 µm category recorded 1,152 counts (≈25 %), followed by 50–100 µm (1,257; ≈28 %) and 100–500 µm (1,271; ≈28 %), indicating a predominance of smaller-sized particles. Larger particles (>500 µm) accounted for 864 instances (≈17 %). For color, transparent MPs were the most frequently observed, with 2,765 counts (≈60 %), followed by black (665; ≈14 %) and brown (373; ≈8 %). Other colors, such as red (191; ≈4 %), orange (159; ≈3 %), yellow (135; ≈2 %), and blue (114; ≈2 %), appeared in moderate quantities, whereas green (44; ≈1 %), purple (79; ≈2 %), and pink (28; <1 %) were the least common. Overall, the data indicate a strong dominance of fibrous, small-sized, and transparent MPs in the analyzed samples.

This trend aligns with findings from various indoor environments, including offices and residential homes, where fibrous, small-sized and transparent MPs have been predominantly reported

[14]. Numerous studies have demonstrated that the frequency of MPs generally decreases with increasing particle size, suggesting a higher prevalence of smaller particles due to their greater potential to remain suspended in the air [3]. The dominance of small MPs can be attributed to the fragmentation of larger plastic items and the shedding of fine fibers from both raw materials and finished products in plastic manufacturing settings. One reason for the high number of transparent MPs found in the samples could be the bleaching effect of hydrogen peroxide, which is used in the sample digestion process to remove organic material. This bleaching is a known, yet unavoidable, consequence of this analytical technique [15]. These findings collectively underscore the influence of both indoor activities and analytical procedures on the characteristics and composition of MPs detected in enclosed environments similar to all other studies of indoor ambient MPs.

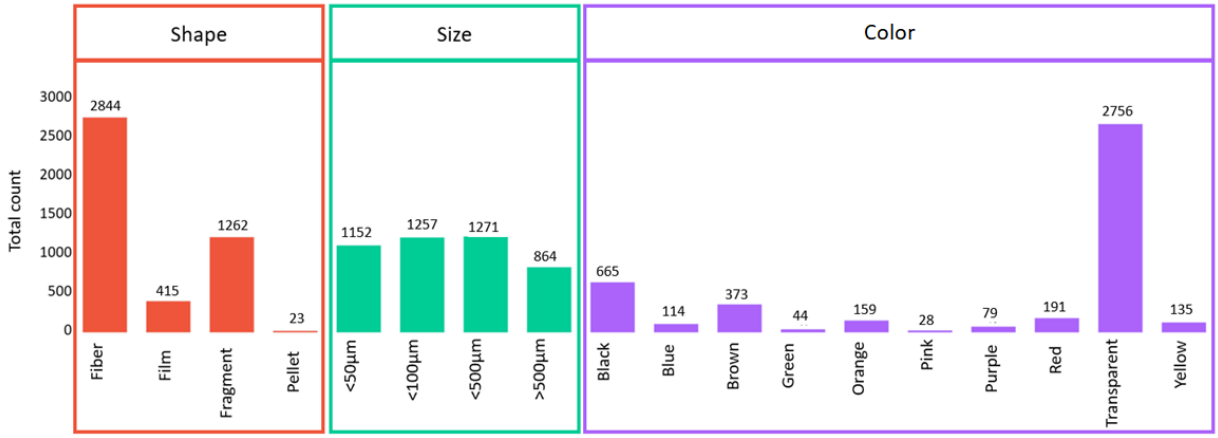

Figure 3: Total distribution of MPs according to shape, size, and color

Figure 4 presents a series of heatmaps illustrating the distribution patterns of MPs characteristics under various sampling conditions. Figures 4(A-C) represent the relationships between sampling method and (A) color, (B) size, and (C) shape, respectively. In Figure 4(A), transparent and black MPs are predominantly observed under passive sampling, suggesting a higher deposition rate of these visually distinguishable particles. Figure 4(B) indicates that MPs smaller than 100 and 500 µm dominate, particularly under passive sampling, reinforcing the susceptibility of MPs to gravitational settling. Figure 4(C) shows that fibers are overwhelmingly dominant under the passive sampling method, reflecting their morphological advantage in airborne suspension and eventual deposition.

Figures 4(D-F) provide further insights into the interrelationships between the shape, size, and color of both sampling methods. Figure 4(D) (shape vs. size) shows that fibers are mostly detected in particles <500 µm. In Figure 4(E) (shape vs. color), fibers are primarily transparent, with a smaller proportion identified as green and orange. Finally, Figure 4(F) (size vs. color) confirms that smaller MPs, particularly those <500 µm, are predominantly transparent, indicating a potential link between particle size and visual attributes.

Meanwhile, Table 1 displays the summary of Chi-square test results for all the combinations have a statistically significant association except the sampling method and size. The Chi-square statistic was 5.17 with a degree of freedom of three and a p-value of 0.1597 (>0.05), indicating no significant association between them. For the combination of sampling and color, the Chi-square statistic was 41.35 with a degree of freedom of nine and a p-value of 0.0000 ($p<0.05$). When comparing shape and sampling, the Chi-square statistic was 37.87 with a degree of freedom of three, yielding a p-value of 0.0000 ($p<0.05$). Observing the dependencies between size, color, and shape, both p-values were 0.000 ($p<0.05$) with chi-square statistics of 1149.71 (degree of freedom = 27) and 1767.10 (degree of freedom = 9), respectively. Lastly, for shape and color, a Chi-square statistic of 1756.45 (degree of freedom = 27) confirmed that the p-value was 0.000 ($p<0.05$). Thus, referring to the p-values indicates that only

sampling method and size were not significant, while the rest of the pairings strongly indicate a significant association.

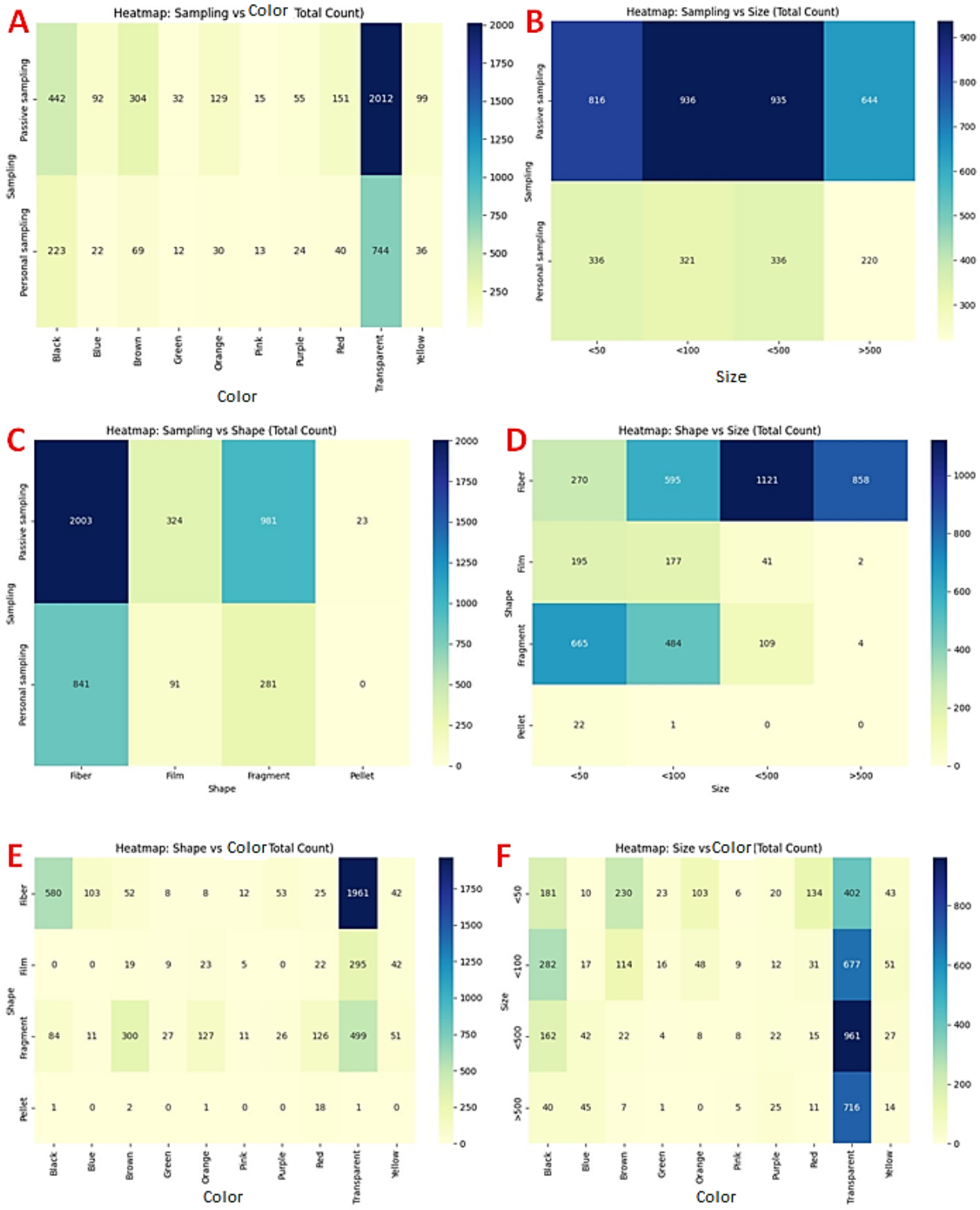

Figure 4: Heatmaps displaying the distribution and associations of MPs characteristics (color, size, and shape) across different sampling methods

Table 1: The Chi-square test for the combination

Pairing	Chi-square statistic	Degree of freedom	p-value
Sampling method and size	5.17	3	0.1597
Sampling method and colour	46.35	9	0.0000*
Sampling method and shape	37.87	3	0.0000*
Size and colour	1149.71	27	0.0000*
Size and shape	1767.10	9	0.0000*
Shape and colour	1756.45	27	0.0000*

*Significant at 0.05

The observed distributions in the heatmaps were further validated by the results of the chi-square tests (Table 1), confirming that only one pairing, namely, sampling method and size, was insignificant, whereas the remaining pairings were statistically significant ($p < 0.05$). The dominance of transparent and black MPs in passive sampling may reflect the high prevalence of such particles in indoor environments, particularly from polymeric materials commonly used in the raw material and final product of the factory. Transparent MPs could be associated with photobleaching [16].

The prevalence of particles smaller than 500 µm, especially within the <100 µm range, can be attributed to their aerodynamic properties, which facilitate prolonged suspension in indoor air and an increased likelihood of deposition into passive samplers. Fiber particles were consistently associated with both passive sampling and smaller size ranges, suggesting that these are the most mobile and abundant forms of airborne MPs in the factory environment. These patterns are consistent with previously reported indoor MPs profiles [3, 7, 17] and further emphasize the critical role of material fragmentation, occupational activities and airflow dynamics in shaping the airborne MPs landscape in enclosed industrial settings.

3.2 Morphology Examinations

Figure 5 presents the commonly observed characteristics of MPs in terms of shape, size, and color, as visualized under a stereomicroscope. The predominant morphologies identified included fibers, fragments, films, and granules, with size distributions typically falling below 500 µm [18] and colors largely dominated by transparent, black, and brown hues. These findings are consistent with previous studies on indoor MPs contamination, wherein similar morphologies and color profiles were reported across various indoor environments, including residential homes, offices, and classrooms [19].

Figure 6 presents the Raman spectral profiles of representative predetermined raw materials used and sample MPs in the factory. The selection of particles for Raman analysis was based on visual identification under stereomicroscopy, considering distinct morphological characteristics (e.g., fibers, fragments, and films), color variations, and particle integrity. Particles that were clearly distinguishable, free from overlapping debris, and representative of the dominant categories observed in the samples were prioritized to ensure reliable spectral acquisition and accurate polymer identification.

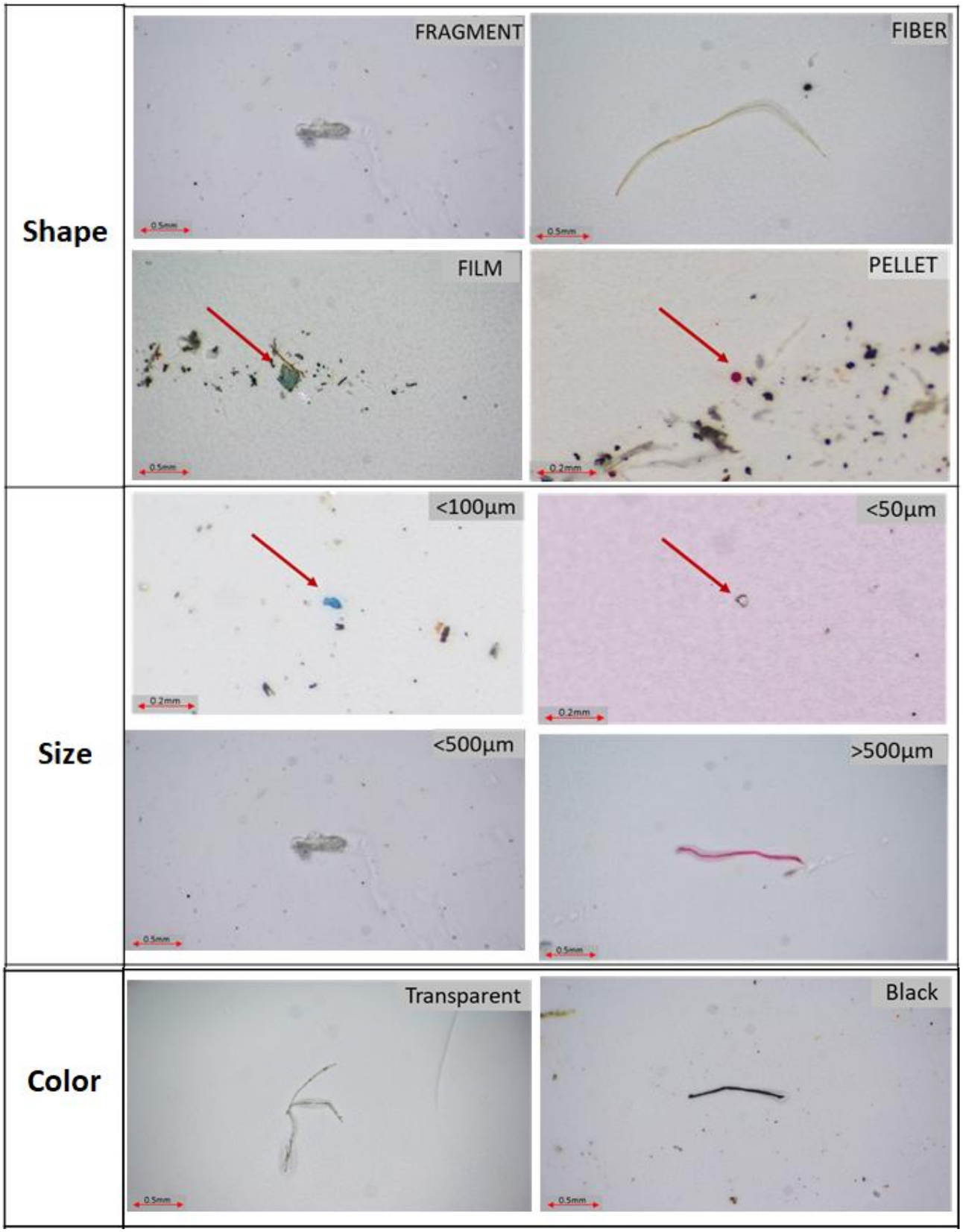

Figure 5: Typical shapes, sizes, and colors of MPs identified using a stereomicroscope

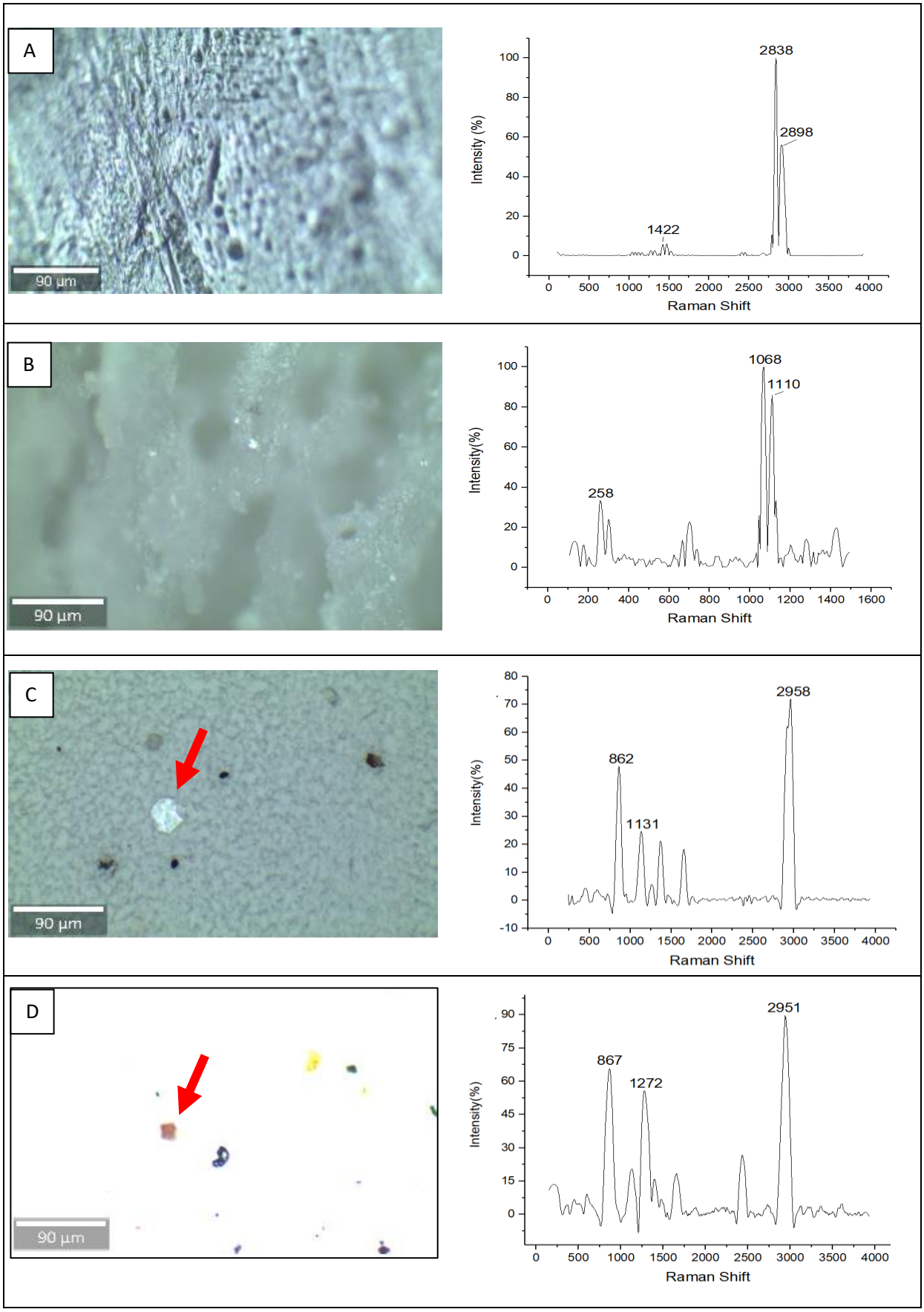

Figure 6: Raman peaks of MPs (A) Raw Polyethylene, (B) Raw $CaCO_3$, (C) Transparent Fragment from sample (Shifted Polyethylene) and (D) Red Fragment from sample (Shifted Polyethylene)

Panel A displays the Raman spectrum of raw polyethylene, characterized by prominent peaks at 2838 and 2898 cm^{-1}, associated with C–H stretching vibrations, and a smaller peak at 1422 cm^{-1}, corresponding to CH_2 bending, confirming its polymeric identity. Panel B illustrates the spectrum of raw calcium carbonate ($CaCO_3$), with distinctive peaks at 258 cm^{-1}, 1068 cm^{-1} and 1110 cm^{-1}, indicative of carbonate vibrational modes [20]. Panel C shows a transparent fragment retrieved from the indoor sample, exhibiting spectral features at 862 cm^{-1}, 1131 cm^{-1}, and 2958 cm^{-1}, suggestive of common polymer structures likely linked to polyethylene derivatives, which could possibly be from the final end product of the production line, a combination of the aforementioned raw materials. Panel D corresponds to a red particle from the same sample, showing peaks at 867 cm^{-1}, 1272 cm^{-1} and 2951 cm^{-1}, potentially attributed to pigment-loaded polymers or colored synthetic materials. The spectral overlap between the environmental MPs and the predetermined raw materials indicates a plausible linkage, yet the presence of additives, processing by-products, or pigment compounds may obscure direct identification of a single polymer type. This highlights the complexity of MPs identification in industrial settings, where material blends and formulation heterogeneity can alter spectral signatures.

3.3 Mitigation Strategies

Given the observed concentrations of airborne MPs in operational zones, such as extrusion and molding sections, the implementation of targeted mitigation strategies is essential to reduce occupational exposure and associated health risks. These strategies should be holistic and address engineering controls, operational practices, worker behavior, and policy alignment to ensure a comprehensive risk reduction framework.

First, enhancing engineering controls and ventilation systems is critical for minimizing airborne MPs. Upgrading general ventilation to include high-efficiency particulate air filtration and installing local exhaust ventilation at point sources, such as cutting, heating, and molding stations, can significantly reduce the concentration of MPs in the air. Enclosing processing units and maintaining negative pressure zones in high-emission workspaces can further help to contain particle dispersion and prevent contamination of adjacent areas. Second, process optimization and improved material handling practices can substantially decrease the generation of MPs during production. This includes minimizing mechanical abrasion and thermal degradation of plastic materials by automating material transfer, employing enclosed conveyance systems and reducing unnecessary manual handling. Where feasible, the use of low-dust plastic formulations or pelletized raw materials should be prioritized to reduce friability and airborne release.

Third, the provision and mandatory use of appropriate PPE is vital. Workers operating in high-exposure zones should be equipped with certified respiratory protection, such as N95 or P100 respirators. However, the effectiveness of PPE depends on proper usage, which necessitates regular training sessions and compliance monitoring to ensure correct and consistent application. Fourth, environmental hygiene and housekeeping practices must be improved to prevent the resuspension and redistribution of settled MPs. Dry sweeping should be replaced with vacuum cleaning systems fitted with HEPA filters, which are more effective in capturing fine particles. High-exposure areas should be cleaned frequently, and the installation of anti-static flooring may reduce particle adhesion and secondary mobilization.

Fifth, raising awareness among workers is a key behavioral intervention. Occupational health and safety programs should incorporate MPs-specific training modules that explain the associated health risks, emphasize the importance of PPE and reinforce good hygiene practices such as washing hands before meals and after shifts. These training programs should be conducted regularly to maintain a high level of vigilance and safety culture. Sixth, long-term environmental monitoring and health surveillance systems should be established within plastic manufacturing facilities. Air quality should be routinely assessed using gravimetric and spectroscopic techniques to detect changes in MPs concentrations. Concurrently, periodic health screening for workers, such as pulmonary function tests, can enable early identification of respiratory conditions linked to MPs inhalation.

Finally, policy alignment is essential to institutionalize these practices and ensure regulatory compliance. Although occupational exposure to MPs is still an emerging concern, existing particulate matter exposure standards, such as those from the Occupational Safety and Health Administration and World Health Organization, can serve as interim benchmarks. Engagement with national regulatory authorities and occupational health agencies is recommended to support the development of specific occupational exposure limits for MPs.

4. CONCLUSIONS

This study provides one of the first empirical assessments of airborne MPs exposure within an operational plastic manufacturing facility in Malaysia, highlighting the number of inhalable MPs in industrial indoor environments. The findings indicate that MPs within the size range of <50–>500 µm were detected, with a predominance of smaller particles (<500 µm), particularly in the respirable fraction. The results clearly demonstrate the dominance of fibrous, small-sized, and transparent MPs, particularly in passive sampling, reflecting both material characteristics and airborne behavior. Statistically significant associations between sampling methods, particle size, shape and color further validate the influence of production activities and environmental dynamics on MPs distribution. Although this study provides important insights, it is limited to a single industrial setting and specific sampling duration, which may not fully capture temporal variability and broader exposure scenarios. Future research should focus on long-term monitoring, multi-site comparisons, and advanced characterization techniques to better understand exposure pathways and health implications. The findings reinforce the urgent need for integrated workplace interventions, including ventilation upgrades, process optimization, personal protective equipment and ongoing monitoring. In light of increasing global attention to MPs pollution, this study adds valuable insights into a largely overlooked exposure route and provides foundational evidence to support regulatory development and occupational health protections in high-risk industrial sectors.

Acknowledgements

The authors would like to express their sincere gratitude for the financial support provided under Universitas Indonesia & Sunway University Bilateral Strategic Alliance (UI-SU Bisa) Matching Fund (GRTIN-UI-DADTP-06-2024), which made this research possible.

Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

References

[1] Bucci, K. & Rochman, C. M. (2022). Microplastics: a multidimensional contaminant requires a multidimensional framework for assessing risk. *Microplastics and Nanoplastics,* 2(7), 1-9.

[2] Salthammer, T. (2022). Microplastics and their additives in the indoor environment. *Angewandte Chemie International Edition*, 61(32), e202205713.

[3] Torres-Agullo, A., Karanasiou, A., Moreno, T. & Lacorte, S. (2022). Airborne microplastic particle concentrations and characterization in indoor urban microenvironments. *Environmental Pollution*. 308(12), 119707.

[4] Kallenbach, E. M. F., Rødland, E. S., Buenaventura, N. T. & Hurley, R. (2022). Microplastics in Terrestrial and Freshwater Environments. In *Microplastic in the Environment: Pattern and Process,* Ed. Bank, M. S. (Springer International Publishing, MA, USA), pp. 87–130.

[5] Cheng, F., Wu, Y., Yao, M., Wang, X. & Li, L. (2024). Exploring the relationship between adverse working environments and poor psychological states of Chinese workers: A comprehensive study. *Journal of Affective Disorders*, 351(1), 442–448.

[6] Wright, S. & Borm, P. J. A. (2022). Applying existing particle paradigms to inhaled microplastic particles. *Frontiers in Public Health*, 10, 868822.

[7] Ziani, K., Ioniță-Mîndrican, C-B, Mititelu, M., Neacșu, S. M., Negrei, C., Moroșan, E., Drăgănescu, D. & Preda, O-T. (2023). Microplastics: a real global threat for environment and food safety: a state of the art review. *Nutrients*, 15(3), 617.

[8] Lopez-Lorenzo, X., Hueting, D., Bosshard, E. & Syrén, P-O. (2023). Degradation of PET microplastic particles to monomers in human serum by designer enzymes. *Faraday Discussions*. 252(0), 387–402.

[9] Vaseashta, A., Ivanov, V., Stabnikov, V. & Marinin, A. (2021). Environmental safety and security investigations of neustonic microplastic aggregates near water-air interphase. *Polish Journal of Environmental Studies,* 30(4), 3457–3469.

[10] Deme, G. G., Ewusi-Mensah, D., Olagbaju, O. A., Okeke, E. S., Okoye, C. O., Odii, E. C., Ejeromedoghene, O., Igun, E., Onyekwere, J. O., Oderinde, O. K. & Sanganyado, E. (2022). Macro problems from microplastics: Toward a sustainable policy framework for managing microplastic waste in Africa. *Science of The Total Environment*, 804, 150170.

[11] Beckingham, B., Apintiloaiei, A., Moore, C. & Brandes, J. (2023). Hot or not: systematic review and laboratory evaluation of the hot needle test for microplastic identification. *Microplastics and Nanoplastics,* 3(8), 1-13.

[12] Unnimaya, S., Mithun, N., Lukose, J., Nair, M. P., Gopinath, A. & Chidangil, S. (2023). Identification of microplastics using a custom built Micro-Raman spectrometer. *Journal of Physics: Conference Series,* 2426(1), 012007.

[13] Perera, K., Ziajahromi, S., Nash, S. B., Manage, P. M. & Leusch, F. D. L. (2022). Airborne microplastics in indoor and outdoor environments of a developing country in south asia: abundance, distribution, morphology, and possible sources. *Environmental Science & Technology*, 56(23), 16676–16685.

[14] Dewika, M., Markandan, K., Nagaratnam, S., Irfan, N. A., Abdah, M. A. A. M., Ruwaida, J. N., Sara, Y. Y. & Khalid, M. (2025). Assessing the concentration, distribution and characteristics of suspended microplastics in the Malaysian indoor environment. *Science of The Total Environment,* 959, 178049.

[15] Dris, R., Gasperi, J., Saad, M., Mirande, C. & Tassin, B. (2016). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment?. *Marine Pollution Bulletin*. 104(1–2), 290–293.
[16] Gasperi, J., Wright, S. L., Dris, R., Collard, F., Mandin, C., Guerrouache, M., Langlois, V., Kelly, F. J. & Tassin, B. (2018). Microplastics in air: Are we breathing it in?. *Current Opinion in Environmental Science & Health*, 1, 1–5.

[17] Mendiratta, S., Gulia, S., Goyal, P. & Goyal, S. K. (2021). Evaluation of Particulate Matter Pollution in Micro-Environments of Office Buildings—A Case Study of Delhi, India. In *Environmental Sustainability - Preparing for Tomorrow*. Ed. Khan, S. A. R. (IntechOpen, London, UK), pp. 912-1132.

[18] Dewika, M., Markandan, K., Irfan, N. A., Abdah, M. A. A. M., Ruwaida, J. N., Sara, Y. Y. & Khalid, M. (2023). Review of microplastics in the indoor environment: Distribution, human exposure and potential health impacts. *Chemosphere,* 324, 138270.

[19] Uddin, S., Fowler, S. W., Habibi, N., Sajid, S., Dupont, S. & Behbehani, M. (2022). A preliminary assessment of size-fractionated microplastics in indoor aerosol—Kuwait's baseline. *Toxics,* 10(2), 71.

[20] Sullivan, K. D. & Gugliada, V. (2018). Fluorescence photobleaching of microplastics: A cautionary tale. *Marine Pollution Bulletin*, 133, 622–625.