RESEARCH ARTICLE **Open Access**

Gema Lingkungan Kesehatan
Vol. 23, No. 3 (2025), pp 327-332
e-ISSN 2407-8948 p-ISSN 16933761
Doi: https://doi.org/10.36568/gelinkes.v23i3.318 *Journal Hompage: https://gelinkes.poltekkesdepkes-sby.ac.id/*

Pulmonary Function Impairment Associated with $PM_{2.5}$, CO, and CO_2 Exposure in Home-Based Chips Industry Workers in Indonesia: A Cross-Sectional Study

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ABSTRACT

Wood remains a traditional fuel source for many rural communities, particularly for cooking purposes. The incomplete combustion of wood, combined with prolonged heating of cooking oil at high temperatures, can release harmful carbon compounds and carcinogenic particles, posing significant risks to respiratory health. The World Health Organization (WHO) reported in 2024 that approximately 3.2 million premature deaths annually are attributable to exposure to such pollutants. This study seeks to evaluate pulmonary function impairments among workers employed in chip home industries that predominantly utilize wood as a primary energy source. The research was conducted across two chip-producing home industries located in Senduro Subdistrict, Lumajang Regency. A total of 44 respondents participated through total sampling, where all workers underwent pulmonary function examinations. The average workplace temperature, particularly near cooking pans and wood-burning stoves, was recorded at 34,7 °C. Concentrations of $PM_{2.5}$ reached 694,8 µg/m³, while CO and CO_2 levels were measured at 6 ppm and 4,460 ppm, respectively. Based on the threshold limits established by the Indonesian Ministry of Health—25 µg/m³ for PM2.5, 25 ppm for CO, and 5,000 ppm for CO_2 (Regulation No. 70 of 2016), only $PM_{2.5}$ concentrations significantly exceeded the permissible exposure levels. Although most workers reported few respiratory complaints due to perceived adaptation, field assessments revealed that 79% experienced pulmonary function impairment, either restrictive or obstructive types. Statistical analysis revealed a significant association between pulmonary impairment and age (p=0.001) as well as duration of employment (p=0.001). It is therefore recommended that home industry owners improve workplace environments, particularly by optimizing chimney systems and stove combustion processes, to safeguard workers' respiratory health over the long term.

Keywords: Lung function, Air pollution, Personal factors

INTRODUCTION

The industrial sector plays a significant role in driving economic growth. One of the industries in high demand among the people of Lumajang is the chip industry, which commonly processes cassava, taro, and banana due to strong market demand and the affordability of raw materials. However, the rapid development of this sector also brings a number of health challenges, especially for workers engaged in daily production activities.

Workers in small-scale food industries are commonly exposed to air pollutants such as fine particulate matter ($PM_{2.5}$), carbon monoxide (CO), and carbon dioxide (CO2), especially in work environments that use traditional cooking methods. One key source of these pollutants is cooking oil, which can release PM2.5 when repeatedly heated at high temperatures. The degradation of oil fats at high temperatures contributes significantly to indoor air pollution during the frying process (Pawitra, 2019).

In addition to cooking oil, incomplete combustion of traditional fuels like wood is a major contributor to indoor air pollution in small and medium enterprises (SMEs). This process generates harmful carbon compounds that may compromise workers' respiratory healthcompounds (Siegmund et al., 2024). Chronic exposure to $PM_{2.5}$, CO, and CO2 may lead to decreased lung function (Rahmaningsih & Haryanto, 2022).

The Environmental Protection Agency (2022) classifies Particulate Matter as a mixture of solid and liquid particles suspended in air, including dust, soot, and smoke. PM is categorized into PM_{10} and $PM_{2.5}$ based on their diameter size. Among these, PM2.5 is especially harmful due to its small size, which allows it to penetrate deep into the lungs and bloodstream (Kumar et al., 2020). Long-term exposure in poorly ventilated areas increases the risk of respiratory diseases, cardiovascular conditions, and even lung cancer (Sampene et al., 2024). The World Health Organization (2024) reported that 2.1 billion people, mainly in low- and middle-income rural areas, still rely on solid fuels such as wood, charcoal, and kerosene, leading to 3.2 million premature deaths annually.

Besides $PM_{2.5}$, other pollutants that degrade air quality include carbon monoxide (CO) and carbon dioxide (CO_2). CO is a colorless, odorless, and tasteless gas resulting from incomplete combustion and can cause poisoning at high concentrations (Rizaldi et al., 2021). Meanwhile, CO_2 is a byproduct of respiration and fuel combustion, which tends to accumulate indoors when ventilation is poor, making it a useful indicator of indoor air quality (Andamon et al., 2023).

Field research in Palembang by Putri et al. (2024) found that 62.07% of satay sellers were exposed to CO levels above the threshold, with a significant relationship ($p = 0.003$) between CO exposure and respiratory complaints. Similarly, Soeroso et al. (2021) revealed that food vendors using grills experienced higher levels of exhaled CO (10.56 ppm) and showed signs of restrictive and mixed-type pulmonary impairments.

In contrast, Salsabila's study (2023) on pottery workers in Sidoarjo and Girsang's research (2024) on janitors in Surabaya did not find significant relationships between pollutant levels and lung function status, highlighting the inconsistency in current findings across different occupations and environments.

While several studies have investigated respiratory outcomes among informal sector workers, there is a lack of localized evidence on how combustion-based cooking practices affect lung function in Indonesian home-based food industries.

In addition to environmental exposure, individual factors such as age, work duration, and smoking behavior also contribute to the risk of pulmonary dysfunction. Karmila et al. (2020) reported that workers aged ≥35 years had a 66% prevalence of lung disorders ($p = 0.004$), while younger workers (<35 years) showed only 29.6%. Altruisa et al. (2024) also noted higher lung impairment rates among those with longer tenure (67.5%, $p = 0.001$) and smokers (70%, $p = 0.000$), compared to 30% in non-smokers.

In the specific context of Senduro Subdistrict, Lumajang, many home-based chip industries still rely on wood as the primary fuel source and lack proper ventilation systems such as chimneys. During peak production periods, these conditions often result in high temperatures and low humidity, which can exacerbate pollutant accumulation in the indoor air.

Therefore, this study aims to analyze the relationship between $PM_{2.5}$, CO, CO_2 exposure, and the quality of physical environmental conditions with pulmonary function among chip industry workers in Lumajang. In addition, this study will evaluate the role of personal risk factors including age, tenure, and smoking habits in relation to lung health. The findings are expected to support promotive and preventive efforts to protect the respiratory health of workers in small-scale industries.

METHODS

The present study employed an analytical observational design with a cross-sectional approach, in which all variables were measured at a single point in time. Dependent variables included pulmonary function status and self-reported respiratory symptoms, while independent variables encompassed sex, age, duration of employment, daily working hours, body mass index (BMI), history of respiratory disease, and use of personal protective equipment. Workplace environmental conditions were assessed through the measurement of $PM_{2.5}$, CO, and CO_2 concentrations using a Temtop M2000C air quality monitor (accuracy ±10 μg/m³ for $PM_{2.5}$) and a Quest EVM-7 (accuracy: CO ± 2 ppm; CO_2 ± 100 ppm).

Measured values were compared against permissible exposure limits established by the Indonesian Ministry of Health: $PM_{2.5}$ = 25 μg/m³ (Permenkes No. 2/2023), CO = 25 ppm, and CO_2 = 5,000 ppm (Permenkes No. 70/2016). Physical environmental parameters—temperature, relative humidity, and lighting intensity—were also recorded across three key production zones: preparation, frying, and combustion.

Pulmonary function tests were conducted by certified medical laboratory analysts from the Public Health Laboratory of Universitas Airlangga using a MicroLab Spirometer. Spirometric procedures adhered to ATS/ERS guidelines. Interpretation of pulmonary function was classified as obstructive (FEV_1 < 80% predicted), restrictive (FVC < 80% predicted), or normal (both FEV_1 and FVC ≥ 80% predicted).

Data were gathered using structured direct observation, in-person interviews, and measurement instruments. Interviews employed a questionnaire that had undergone expert validation by two occupational health specialists and demonstrated good internal consistency (Cronbach's $\alpha = 0.82$). The study population comprised all workers (N = 44) from two home-based chip industries in Senduro District, Lumajang Regency, selected through a total sampling technique after obtaining informed consent.

Collected data were organized into cross-tabulations and frequency distributions. Associations between exposure variables and pulmonary outcomes were assessed analytically using the Chi-Square test. This study was approved by the Research Ethics Committee of Universitas Airlangga (No: 0351/HRECC.FODM/III/2025).

RESULTS AND DISCUSSION

Workplace Environmental Assessment

Environmental sampling was conducted across three production zones (preparation, frying, and combustion) in two home-based chip industries in Senduro District, Lumajang Regency. A single 30-minute measurement at each location yielded the following ranges: $PM_{2.5}$ concentrations of 283–1 143 μg/m³ (mean = 558.5 μg/m³), CO levels of 1–9 ppm (mean = 4.7 ppm), and CO_2 levels of 717–1 288 ppm (mean = 962.7 ppm). These values were compared against the Indonesian

Ministry of Health thresholds (Permenkes No. 2/2023 for $PM_{2.5}$ = 25 µg/m³; Permenkes No. 70/2016 for CO = 25 ppm and CO_2 = 5.000 ppm).

Table 1
ENVIRONMENTAL CONDITION ASSESSMENT IN CHIP HOME INDUSTRIES, SENDURO DISTRICT

Pengukuran	$PM_{2.5}$ (µg/m³)	CO (ppm)	CO_2 (ppm)	Temp (°C)	RH (%)	Illum (lux)
Home Industry 1						
Area I	289	3	923	28	79	120
Area II	897	8	1132	39	57	540
Area III	400	4	945	33	59	75
Home Industry 2						
Area I	283	1	771	30	69	474
Area II	1143	9	1288	34	50	451
Area III	339	3	717	32	60	314
Min	283	1	717	28	50	75
Max	1143	9	1288	39	79	540
Average	558.5	4.67	962,67	32,67	62,3	329

Table 1 Environmental measurements showed that $PM_{2.5}$ levels in several production areas of chip home industries exceeded the WHO daily guideline of 15 µg/m³ (WHO, 2021), reaching over 1100 µg/m³ in the combustion zone. Such elevated levels are typical in informal industries with biomass combustion and limited ventilation. The relatively high temperature observed may be intentional for production purposes; however, it may also compound heat stress in the workplace. Inadequate exhaust systems and poor air circulation were reported by workers and corroborated with field observations, which is consistent with findings by Jajor et al. (2019), who noted that inefficient ventilation significantly contributes to air pollutant accumulation in home-based food industries.

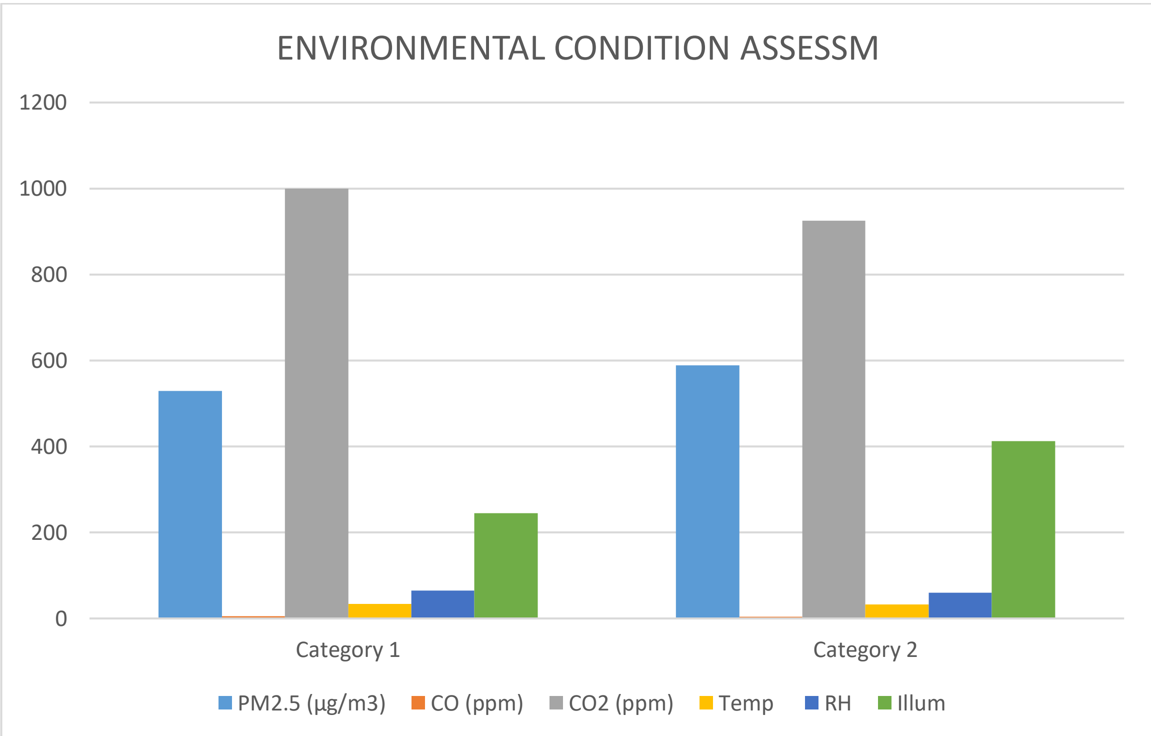

Figure 1. Identification of Pulmonary Function Impairment

Each respondent underwent a pulmonary function test using a spirometer equipped with a pre-attached mouthpiece. During the procedure, a laboratory technician provided guidance to ensure that the respondent performed the breathing maneuver in accordance with the established protocol.

In Table 2 forty-four workers underwent spirometric assessment using a MicroLab Spirometer (ATS/ERS guidelines). Pulmonary function was classified as normal (both FEV_1 and FVC ≥ 80% predicted), obstructive (FEV_1 < 80% predicted), or restrictive (FVC < 80% predicted). Results showed: normal = 11 (25.0 %), obstructive = 5 (11.4 %), and restrictive = 28 (63.6 %).

Table 2
Distribution of Pulmonary Function Impairments Among Home Industry Chips Workers

Pulmonary Function	Frequency (n)	Percent (%)
Normal	11	25.0
Obstructive	5	11.4
Restrictive	28	63.6
Total	44	100.0

Analysis of Statistical Test Results

The statistical test in this study was conducted to examine the relationship between pulmonary function impairment and several determinant factors among the respondents. A more detailed presentation of the results is provided in Table 3.

Table 3 demonstrates that all independent variables are significantly associated with the occurrence of pulmonary function impairment among the respondents (p=0,001). Short measurement duration may not fully reflect daily average pollutant exposure; thus, findings should be interpreted with caution.

Table 3
Chi-Square Analysis of Research Variables in Chip Home Industries Workers, Senduro District

Independent Variable	Pulmonary Function						*p*
	Normal		Obstructive		Restrictive		
	n	%	n	%	n	%	
Age							
17-27	3	6.8	1	2.3	0	0.0	
28-39	7	15.9	1	2.3	0	0.0	
40-50	0	0.0	0	00	10	22.7	0.001
51-61	1	2.3	1	2.3	12	27.3	
62-73	0	0.0	2	4.5	4	9.1	
74-84	0	0.0	0	0.0	2	4.5	
Total	11	25.0	5	11.4	28	63.3	
Duration of Employment (months)	9	20.5	1	2.3	0	0.0	
3-32	1	2.3	1	2.3	9	20.5	
33-63	0	0.0	0	0.0	10	22.7	
64-93	1	2.3	3	6.8	4	9.1	0.001
94-123	0	0.0	0	0.0	3	6.8	
124-154	0	0.0	0	0.0	2	4.5	
155-184	11	25,0	5	11.4	28	63.6	
Total							

The findings of this study reveal a statistically significant association between pulmonary function impairment and the independent variables of age and employment duration among chip home industry workers in Senduro District, Lumajang Regency. This result is consistent with Tran et al. (2024), who observed that prolonged exposure to airborne pollutants in small-scale industrial settings has a cumulative effect on pulmonary health. In the present study, although most respondents did not report subjective respiratory complaints, spirometry results revealed both restrictive and obstructive impairments. This suggests the presence of subclinical pulmonary dysfunction, a phenomenon also observed in previous research by Sidebang (2023), where workers with more than five years of exposure had a higher prevalence of pulmonary abnormalities.

The concentration of airborne particulate matter ($PM_{2.5}$) in several sampled areas exceeded 1000 µg/m³, which is significantly above the 24-hour exposure threshold of 25 µg/m³ as set by the World Health Organization (WHO, 2021). These excessive levels, especially in poorly ventilated spaces or facilities with malfunctioning chimneys, likely contribute to chronic respiratory inflammation and oxidative stress. Ayuso-Álvarez et al. (2019) emphasized that sustained exposure to high concentrations of $PM_{2.5}$ in confined work environments leads to a decline in pulmonary function due to persistent oxidative and inflammatory responses.

Age is also a determining factor in the deterioration of pulmonary capacity. Physiological aging naturally reduces lung elasticity, alveolar surface area, and respiratory muscle strength (Schneider et al., 2021). When combined with long-term exposure to hazardous substances such as $PM_{2.5}$, CO, and CO_2, this condition accelerates the decline in lung function. This finding is corroborated by Ye et al. (2023), who reported that long-term exposure to fine particulate matter significantly reduces FEV1 and FVC, two primary indicators of pulmonary impairment.

While these results provide valuable insights into occupational respiratory risks, several potential biases must be acknowledged. Firstly, the use of a cross-sectional design limits causal inference; it only provides a snapshot in time without tracking longitudinal changes. Secondly, the reliance on self-reported symptoms may underestimate the true prevalence of respiratory issues, especially when workers are unaware of or reluctant to disclose health concerns. Thirdly, environmental measurements were taken at a single time point, which may not fully capture daily or seasonal variability in air quality.

From a practical standpoint, the implications of these findings are significant. There is an urgent need for occupational health interventions targeting informal industrial sectors. These should include the installation of proper ventilation systems and functional chimneys, as well as the mandatory use of personal protective equipment such as certified respirator masks. In addition, workers should undergo regular pulmonary function testing to enable early detection of respiratory disorders. Training programs aimed at increasing workers' awareness regarding the risks of pollutant exposure and proper protective practices are equally essential to ensure sustainable workplace safety.

CONCLUSIONS

This study underscores the significant occupational health risks associated with prolonged exposure to indoor air pollutants among workers in chip home industries in the Senduro District, Lumajang Regency. Elevated levels of $PM_{2.5}$, CO, and CO_2 were recorded, especially in combustion and frying areas, aggravated by inadequate ventilation and poorly functioning exhaust systems. These environmental conditions were found to contribute substantially to compromised respiratory health.

Spirometry assessments revealed a high prevalence of pulmonary function impairment among the workers, with restrictive patterns being the most common. Statistical analysis identified age and duration of employment as significant determinants of reduced lung function, suggesting a cumulative impact of aging and long-term pollutant exposure on respiratory outcomes.

This study relied on short-duration pollutant measurements and cross-sectional data, which may not fully capture the chronic effects of long-term exposure. Moreover, the use of a single-time-point spirometric assessment and reliance on self-reported occupational histories may introduce measurement and recall biases.

Future research should employ longitudinal designs with repeated exposure assessments to better evaluate the long-term respiratory consequences of occupational pollutant exposure in informal industrial settings.

SUGGESTION

To mitigate respiratory health risks, it is strongly recommended that chip home industries implement improved ventilation systems, ensure the routine use of appropriate personal protective equipment (PPE), and conduct regular pulmonary health screenings for workers. Local governments should establish targeted environmental health policies for small-scale industries, including guidelines on pollutant thresholds and mandatory health monitoring protocols.Furthermore, occupational health education programs should be introduced to raise awareness among workers about the risks of air pollutant exposure and the importance of personal safety practices. Future interventions should also prioritize training on the correct use of PPE and promote structural improvements in work environments to reduce the accumulation of airborne contaminants.

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