



A Correlation Between Exposure to PM₁ from Firewood Burnings in Lombok Island and Erythrocyte Deformations

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Abstract

Lombok Island is facing a big issue of emissions. These emissions are easily found in firewood burning in home industry, household, and many others. The emission can be found as PM (particulate matter), while a long-term exposure to PM has a potential to disturb respiratory system. This study aims to investigate the correlation between exposure to firewood burning emission (PM₁) and erythrocyte deformation levels. Three different firewood samples (pine, teak, and mixed firewood) were used as biomass-burning sources, with each sample burned at three different combustion speeds (fast: 1.8 m/s, medium: 1.2 m/s, and slow: 0.6 m/s). The samples were burnt inside a furnace, while the resulting PM₁ emissions were exposed to the mice (n=10 per subgroup) as the experimental animal for ten consecutive days (100 s exposure per day). All mice were sacrificed on day 11 to investigate the deformation level under a digital microscope. The results show that firewood burnings generate varied PM₁ concentrations. The PM₁ concentrations ranged from 97×10^3 to $257 \times 10^3 \mu\text{g}/\text{m}^3$ (0.97–2.57 g/m³ in the exposure chamber), depending on the firewood sample. Mixed firewood samples have the highest PM₁ concentration and erythrocyte deformation level, while teakwood has the smallest values. Linear regression analysis revealed a strong correlation between PM₁ exposure and erythrocyte deformation ($\beta = 0.082$, 95% CI: 0.064–0.100, $R^2 = 0.81$, $p < 0.001$). It can be concluded that a higher PM₁ concentration generates a higher erythrocyte deformation level. A higher combustion speed generates a smaller concentration, resulting in a lower deformation level.

Keywords: Emission; Erythrocyte deformation; Firewood burning; Lombok Island; Particulate matter

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INTRODUCTION

Biomass burning is one of the major sources of air pollution that impacts air quality. As a pollutant source, biomass burning can be classified into natural and anthropogenic activities, such as forest fire, wildfire activity, open fire, energy production or power plant, cooking, and grass fire. In some places, biomass burning is easily found in agricultural activities, such as field burning after harvesting or crop residue burning for land clearing. Biomass burning contributes to PM (particulate matter) emissions. Ultrafine particle and fine particle are the examples of PMs. Ultrafine particle (PM_{0.1}) has a diameter of $<0.1 \mu\text{m}$ (Enyoh et al., 2020; Trejos et al., 2021). Fine particle, which is known also as PM_{2.5}, has a diameter of $<2.5 \mu\text{m}$ (Tong et al., 2020). PM_{2.5} can be classified again into several submicron particulates, such as PM_{0.3}, PM₁, and PM₂. According to a previous study, 80-90% of pollutants from biomass burning are PMs in accumulation mode, with a diameter $<1 \mu\text{m}$ (categorized as PM_{0.1}-PM₁) (Suriyawong et al., 2023). The PM size distribution depends on the biomass type, combustion stage, combustion speed, air condition, and many others (Hong et al., 2023).

PM₁ is of particular concern due to its ability to penetrate deep into the alveolar region and potentially translocate into the bloodstream. PMs are known to have correlations with human health. Due to their different particle size distribution, the health impact of PM is also different (Gabdrashova et al., 2021; Rice et al., 2020). For example, a previous study shows abnormal spirometry (representing lung function) in participants who used wood biomass for cooking due to PM_{1-2.5} emissions. This study shows that using gas has lesser abnormality than using wood biomass (Stapleton et al., 2020). Another report shows that children under five years have a higher risk of acute respiratory infection symptoms when exposed to PM_{2.5} from landscape fire (Li et al., 2023). Then, the newer findings of PM_{0.1}-human health impact correlation show that PM emitted from biomass burning (for example: from wood combustion) has high deposition efficiency in lung surface area (Lepistö et al., 2023).

Despite extensive research on PM_{2.5} health effects, limited studies have specifically examined PM₁ from wood-smoke exposures and their impact on erythrocyte morphology. Previous in-vitro studies have demonstrated that particulate matter can induce oxidative stress in erythrocytes (Tian et al., 2023), but in-vivo chamber studies linking controlled PM₁ exposures from biomass burning to erythrocyte deformation remain scarce. Furthermore, most studies focus on urban particulate matter rather than biomass-derived PM₁, which may differ substantially in composition and toxicity (Suriyawong et al., 2023). This gap is particularly relevant for regions like Lombok Island, where biomass burning is prevalent and PM₁ exposures may pose significant health risks.

The correlation between PM exposures and human health can be analyzed using many methods, including cell investigations and regression analysis under toxicology and epidemiology aspects. In the cell investigation, the observed objects were observed under a microscope or a scanning electron microscope. This method is relatively easy and low-cost in identifying the cell deformation level (Hadi et al., 2022). For this purpose, a manual calculation method in the related cell can be used to analyze a normal or abnormal (deformed) cell (Schaumann et al., 2014; Tian et al., 2023). Then, the data were statistically analyzed using a regression formula to understand the deeper correlation between particulate concentration and health level (Cabral et al., 2022).

Lombok Island, one of Indonesia's tourism regions, has a major issue with forest resources and the air environment. This island is well-known for its biomass sources, such as firewood, rice, corn, and potato (Juwita et al., 2021). However, the most trouble with this huge biomass sector is the emission. Explicitly, a previous study shows that some areas on Lombok Island have low to moderate environmental carrying capacity, including air quality control (Suhono et al., 2020). However, this study does not show the actual or real emission data, including the main emission sources. The data from UNICEF (United Nations Children's Fund) shows that Lombok Island has high tobacco drying and brick-burning activities, which correlate with health impacts, such as pneumonia. No supporting data shows the emission characteristic and air quality data in Lombok Island though there is a serious correlation with health problems. The only data that represents the air quality in Lombok Island is shown at IQAIR, with the parameter of PM_{2.5} concentration. The previous study is confirmed by our preliminary study conducted in Lombok about emission factor characterization of local biomass burning as agricultural waste. This study shows rice straw burning emits PM_{2.5} from 0.71 mg/g to 1.08 mg/g as air pollution. It means that this island has high biomass-burning activities that should be overcome in a complex system.

Based on the background above, we hypothesized that higher PM₁ concentrations from firewood burning would result in higher erythrocyte deformation levels. According to the background above, there is an urgent requirement to conduct comprehensive research concerning the health impact of biomass burning emissions on Lombok Island, especially from local firewood burnings. The use of firewood as the energy sources emit particulate matters in different size distributions, where a smaller particulate has a greater correlation with health.

Besides, Lombok Island faces big issues with the air environment and firewood burning that contributes to particulate emissions. In contrast, there is a limited study on firewood burning emissions in Lombok Island, especially for the specific firewood. Furthermore, there is no further investigation into the correlation between PM₁ emissions from local firewood burning on Lombok Island and human health. Thus, this study specifically investigates the PM₁ concentrations of firewood-burning emissions on Lombok Island and their correlation with erythrocyte deformation levels, rather than health impacts in several organs. This study's output will help researchers predict the health impact of exposure to biomass burning emissions with a better approach.

METHOD

Study Design and Overview

This experimental study employed a completely randomized design with three firewood types (pine, teak, and mixed) and three combustion speeds (fast, medium, slow), resulting in nine treatment groups plus a control group, with $n=10$ mice per group. The experimental pipeline consisted of: (1) firewood sample preparation and characterization, (2) combustion and PM₁ concentration measurement, (3) ten daily mouse exposures, (4) blood collection and smear preparation, (5) microscopic examination, and (6) statistical analysis.

Firewood Samples

This study used three firewood samples: PI (pine), TE (teak), and MI (mixed firewood). Each sample was weighed (mass = 5 grams per sample) and stored in dry packaging. They were naturally air-dried for a week to reduce the moisture content of each sample ($<10\%$). Any water content in the samples should be driven off before the combustion stage to obtain optimum combustion efficiency (Ahmad et al., 2023).

The moisture content was measured using a portable moisture meter. These samples were chosen due to the availability in Lombok Island. In detail, PI and MI samples were taken from East Lombok regency (Terara village, $8^{\circ}64'S-116^{\circ}4'E$). TE was taken from West Lombok regency (Sekotong village, $8^{\circ}78'S-116^{\circ}0'E$). The samples were classified into three classifications: fast (v_1), medium (v_2), and slow burnings (v_3) (Table 1). These classifications were related to the combustion speed variations that could influence the resulting emissions.

Table 1. Firewood Sample Classification

Groups	Mass (g)	Moisture Content (%)
PI (pine)	5 (v_1)	9.7 $\pm$ 0.1
	5 (v_2)	
	5 (v_3)	
TE (teak)	5 (v_1)	9.1 $\pm$ 0.2
	5 (v_2)	
	5 (v_3)	
MI (mixed)	5 (v_1)	9.9 $\pm$ 0.2
	5 (v_2)	
	5 (v_3)	

Combustion speed was measured using a hot-wire anemometer (model: Testo 425, accuracy: ± 0.03 m/s) positioned 10 cm above the burning sample surface within the furnace. The three speed levels (1.8, 1.2, and 0.6 m/s) were selected to represent the range of combustion conditions typically observed in household firewood burning practices in Lombok, based on preliminary observations and literature (Ahmad et al., 2023). Faster combustion speeds generally indicate more complete combustion with higher temperatures, potentially reducing particulate emissions, while slower speeds suggest smoldering conditions that may produce higher particulate yields.

Experimental Animals and Ethics

There were 100 male mice (12 weeks old, weighing 21 - 23 g) used as the experimental animals. All mice were treated humanely, provided with water and foods ad libitum, and kept under controlled light (12:12 dark-light cycle) and room temperature (27.4 – 28.1°C) (Wardoyo et al., 2021). All animal treatment procedures were approved by the Animal Care and Use Committee of Brawijaya University, Indonesia (Approval No. 245/KEP-UB/2024, dated January 15, 2024). The mice were acclimatized for seven consecutive days inside an exposure chamber (volume $V = 12$ L) before exposure to PM₁. Mice were randomly assigned to groups using a computer-generated random number sequence. The researcher performing microscopic examinations was blinded to the treatment groups to prevent observer bias. They were divided into groups (Table 2) related to their exposure treatments.

Table 2. Experimental Animal Grouping

Groups	Mice (<i>n</i>)	Population (<i>N</i>)
CT (control)	10	10
PI (pine)	10 (<i>v</i> ₁)	30
	10 (<i>v</i> ₂)	
	10 (<i>v</i> ₃)	
TE (teak)	10 (<i>v</i> ₁)	30
	10 (<i>v</i> ₂)	
	10 (<i>v</i> ₃)	
MI (mixed)	10 (<i>v</i> ₁)	30
	10 (<i>v</i> ₂)	
	10 (<i>v</i> ₃)	

PM₁ Generation and Measurement

The next step was PM₁ concentration measurement. Each sample was burned inside a furnace. For example, PI-*v*₁ sample ($m_b = 5$ grams) was placed inside a metal furnace. This sample was burned using a heating torch with a fast combustion speed ($v_f = 1.8$ m/s) for 60 s ($t = 60$ s). The emission flowed into a measurement chamber using a suction pump (flowrate $v = 2$ m/s) to generate PM₁. The chamber has a particulate filter (Whatman GF/C glass microfiber filter, pore size 1.2 µm) to block other emissions (Budianto et al., 2023). The filtered emission was connected to a Laser Dust Particle Counter (ATECH, CLJ-2803) for the PM₁ concentration measurement (Figure 1).

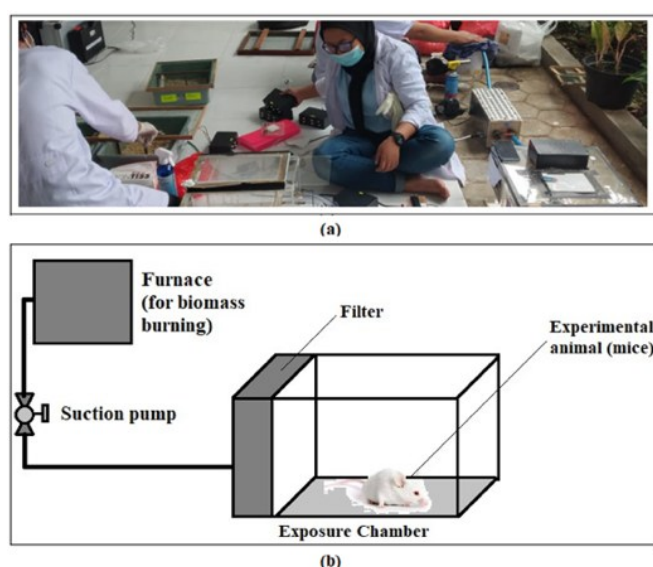


Figure 1. Schematic of PM₁ Concentrations Measurements

The particle counter was calibrated using standard polystyrene latex particles (0.3, 0.5, 1.0, and 2.5 µm) prior to measurements. Zero checks were performed daily using particle-free

air. The PM₁ cut-point was achieved using a cyclone pre-separator with a 1.0 µm aerodynamic cut-point (flow rate: 2.0 L/min).

$$C = \sum_{t=0}^t C_t \quad (1)$$

where C_t represents the PM₁ concentration at each time point during the 60-second combustion period, measured in µg/m³. The calculated C was used as the benchmark value in determining the exposed PM₁ concentrations in the experimental animal for each firewood sample. These all treatments were applied also to other groups in accordance with the velocity variations: medium ($v_2 = 1.2$ m/s) and slow speeds ($v_3 = 0.6$ m/s). Similar treatments were applied to TE and MI groups using the specific firewood sample. Concentrations reported in Table 3 represent time-averaged values over the 100-second exposure period for each daily session, with mean ± SD calculated from ten daily measurements (n=10 days per subgroup).

PM₁ Exposures in Experimental Animals

The next step was exposing PM₁ in mice as experimental animals. For the PI- v_1 group, all mice from its subgroups were placed inside the exposure chamber. At the same time, the PI- v_1 sample was burned inside a furnace, while the emission was filtered (PM₁) and injected into the chamber containing the mice for 100 s. The 12-L exposure chamber had an air exchange rate of 2.0 L/min, ensuring that the injected PM₁ concentrations remained relatively stable during the 100-second exposure period. After that, the mice were placed back into their cages. Mice in the control group were placed in an identical chamber but exposed to filtered air only. Similar treatments were applied to TE and MI groups using the specific firewood samples. All exposures were conducted for ten consecutive days (days 1–10).

Blood Collection and Microscopy

On the 11th day, all mice were sacrificed using a cervical vertebra dislocation to take the blood samples. Blood was collected via cardiac puncture using EDTA-coated tubes to prevent hemolysis. The blood samples were prepared on object glasses, dried, and fixed using a methanol solution (70%). Then, all object glasses were colored using a Giemsa-Buffer Pro Giemsa coloring, dried, and washed using clean water. Smear thickness was controlled by using a fixed volume of blood (10 µL) and a consistent spreading technique.

All ready-prepared samples were observed under a digital microscope (Olympus CX23 with integrated camera, magnification = 400×) to identify the number of cells (N), including the deformed (DC) and normal cells (NC). The observation was conducted under five random fields of view (Figure 2).

	1st view	
2nd view	3rd view	4th view
	5th view	magnification: 400x

Figure 2. Fields of View for the Microscope Observations

For each mouse, five fields were examined, and the average percentage of deformed cells was calculated to obtain a single value per mouse (n=10 mice per subgroup). The collected number was calculated to find the deformation level (%Def) using Equation (2). The deformed cell has a different shape than a normal erythrocyte (biconcave). The deformed cells are shown as helmet-shaped cell, teardrop-shaped cell, and sickle cell (Pretorius et al., 2016).

$$\%Def = \frac{DC}{N} \times 100\% \quad (2)$$

Morphological assessment was performed by two independent observers blinded to treatment groups, with inter-rater reliability assessed using Cohen's kappa coefficient ($\kappa = 0.89$, indicating excellent agreement).

Statistical Analysis

The data are interpreted as the mean and SD (standard deviation). All statistical analyses were performed at the mouse level ($n=10$ per subgroup), with each mouse's %Def value derived from averaging five microscopic fields, to avoid pseudo-replication. The data are plotted in a graph and analyzed using simple linear regression (performed using SPSS version 26.0 and Microsoft Excel 2013). The regression model examined the relationship between PM₁ concentration (independent variable, X) and erythrocyte deformation percentage (dependent variable, Y). The statistical analysis result is shown as regression coefficient (β), 95% confidence interval (CI), coefficient of determination (R^2), and p -value. Statistically, $p < 0.05$ shows the significant influence, or the data error is about 5%. Model assumptions (normality of residuals, homoscedasticity, and linearity) were checked using residual plots and Shapiro-Wilk tests. The linear regression statistical method was used because it represents a simple linear regression approach. This method can be implemented to predict the value of dependent parameters (Y-axis, as the deformation level) and independent parameters (X-axis, as the concentration) with a simple equation (Dong et al., 2020). For group comparisons (wood type $\times$ combustion speed), two-way ANOVA was performed with post-hoc Tukey's HSD tests.

RESULTS AND DISCUSSION

PM₁ Concentration Measurements

Table 3 interprets the resulting PM₁ concentration measurements under different firewood samples.

Table 3. PM₁ Concentrations

Groups	Combustion Speed (m/s)	PM ₁ ($\times 10^3$ $\mu\text{g}/\text{m}^3$)
PI (pine)	1.8 (v_1)	152 $\pm$ 4
	1.2 (v_2)	167 $\pm$ 5
	0.6 (v_3)	188 $\pm$ 5
TE (teak)	1.8 (v_1)	97 $\pm$ 2
	1.2 (v_2)	134 $\pm$ 7
	0.6 (v_3)	137 $\pm$ 6
MI (mixed)	1.8 (v_1)	215 $\pm$ 7
	1.2 (v_2)	248 $\pm$ 5
	0.6 (v_3)	257 $\pm$ 8

Table 3 confirms that each firewood sample has different PM₁ concentration under different combustion speed. MI sample, as the mixed firewood, has the highest PM₁ concentration. These samples were purchased as standard timbers processed in order to be burnt on a fire. As seen in Table 3, MI samples have 215×10^3 to 257×10^3 $\mu\text{g}/\text{m}^3$ of PM₁. Compared to PI and TE samples, these concentrations are much higher. The influence of the combustion speed is also confirmed in this study, where a faster speed decreases the emissions. At each sample, the highest emission is found at the lowest combustion speed. All concentrations represent time-averaged values across the 100-second exposure period, with $n=10$ daily measurements per subgroup.

Erythrocyte Deformation Levels

Figure 3 interprets the resulting histological examination under a microscope for five fields of view. It can be seen that a normal erythrocyte has a different form compared to abnormal cells. The form of a biconcave cell is identified as a normal cell. The deformed cells are found as teardrop-shaped cells and helmet-shaped cells.

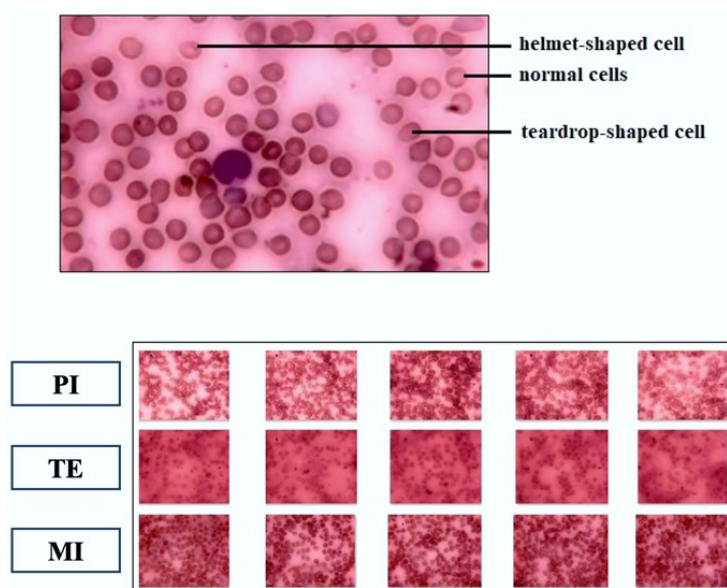


Figure 3. Histological Examinations under a Microscope

According to the calculation of the histological examinations, the deformation levels are varied from 5% to 24% (Table 4). The mixed firewood samples have the most deformed cells. These groups have the deformation levels of 21-24%. These percentages are 16-19% higher than the control group. These group become the higher deformation level contributor since they have mixed biomass samples with varying heating value. Physically, the slow combustion speed, 0.6 m/s, generates a higher PM₁ emission (than faster speeds) and may related to the higher deformation level, representing a non-perfect combustion stage. Interestingly, TE groups have similar pattern with the MI groups. A faster speed has a lower deformation level, representing a good combustion stage. The faster speed of the TE group has the deformation levels of 11-14%. These deformation levels are also higher than the control group. Besides, the PI groups still have higher deformation levels than the control group (14-17%). Two-way ANOVA revealed significant effects of wood type ($F(2,81) = 156.7, p < 0.001$), combustion speed ($F(2,81) = 38.2, p < 0.001$), and their interaction ($F(4,81) = 6.8, p < 0.001$) on deformation levels.

Table 4. Erythrocytes Deformation Levels

Groups	Deformation (%)
CT (control)	5±1
PI (pine)	14±1 (v_1)
	16±1 (v_2)
	17±2 (v_3)
TE (teak)	11±1 (v_1)
	12±2 (v_2)
	14±1 (v_3)
MI (mixed)	21±1 (v_1)
	22±2 (v_2)
	24±2 (v_3)

Correlation Between PM₁ Exposures and Deformation Levels

Figure 4 depicts the correlation between PM₁ exposures and the deformation levels. At the mouse level ($n=90$ mice across all exposure groups, excluding controls), linear regression analysis revealed a significant positive correlation: %Def = $4.52 + 0.082 \times (\text{PM}_1 \text{ concentration in } \times 10^3 \mu\text{g}/\text{m}^3)$ ($\beta = 0.082, 95\% \text{ CI: } 0.064\text{--}0.100, R^2 = 0.81, p < 0.001$). This R^2 value confirms a strong correlation between PM₁ concentrations and the erythrocyte deformation levels. A higher PM₁ concentration, a higher erythrocyte deformation level. Residual analysis confirmed

that model assumptions were met (Shapiro-Wilk test for normality: $p = 0.21$; Breusch-Pagan test for homoscedasticity: $p = 0.34$).

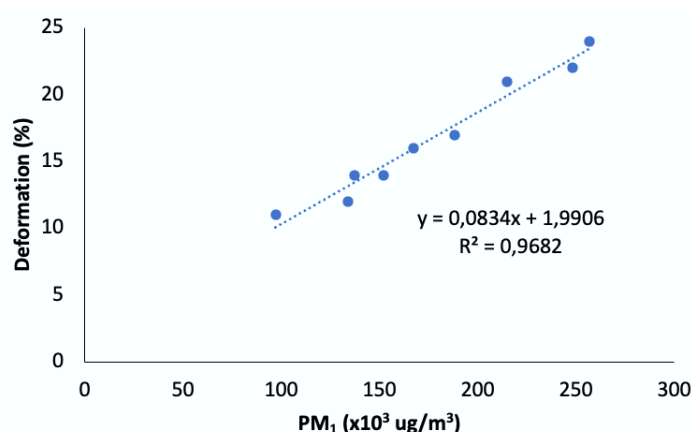


Figure 4. Correlation Between PM₁ Exposures and Deformation Levels

The research results indicate that exposure to PM₁ emitted from firewood burning has a correlation with the deformed erythrocytes. Physically, due to the small size of PM₁ (0.01-0.3 μm in diameter), PM₁ is easily inhaled, deposited, and transported in human body. The first interaction should be found in the breath system, where the lung has a large surface area that makes PM₁ easy to be inhaled. After being accumulated, PM₁ may pass through the lung area as the reactive substances. Then, PM₁ may trigger inflammation in the alveolar cells (Schraufnagel, 2020). As a chain reaction, the interaction in the alveolar cells leads to cell deformation, generates ROS (reactive oxygen species) and may cause oxidative stress (Debnath et al., 2019). Consequently, abnormalities in the alveolar cells (such as emphysema and edema) happen and penetrate to other organs by following the blood stream (as the second deposition area of PM₁ after being inhaled by the respiratory system). In this case, PM₁ may be deposited into the erythrocytes and disturb the mechanical properties, membrane-cytoskeletal interactions, and other biological reactions (Khojah et al., 2016). Moreover, a defect in such biological-physical reaction and interaction is due to the weakening or unwinding of anastomosis (at lipid and protein levels), resulting in crenation of the cell membrane, microcytosis, or spherocytosis (Bongaerts et al., 2020).

The strong dose-response relationship observed in this study ($R^2 = 0.81$) supports the biological plausibility of PM₁-induced erythrocyte damage, consistent with previous findings on particulate matter toxicity (Tian et al., 2023). The higher deformation levels observed with mixed firewood samples may be attributed to their heterogeneous composition, potentially containing higher concentrations of toxic compounds compared to single-species wood (Suriyawong et al., 2023). The inverse relationship between combustion speed and deformation levels suggests that incomplete combustion (smoldering conditions) produces more toxic particulate emissions, likely due to higher organic carbon content and polycyclic aromatic hydrocarbon (PAH) formation (Hong et al., 2023).

However, several limitations should be acknowledged. First, the chamber concentrations (0.97–2.57 g/m^3) were significantly higher than typical ambient air levels (which range from 10–100 $\mu\text{g}/\text{m}^3$), as this study modeled high-dose occupational or household exposure scenarios. While this limits direct extrapolation to ambient exposures, it provides valuable information on the toxicity potential of PM₁ at elevated concentrations relevant to indoor biomass burning settings (Stapleton et al., 2020). Second, co-pollutants (gaseous compounds, volatile organic compounds, and other particulate size fractions) were not characterized, making it impossible to attribute the observed effects solely to PM₁ mass. Third, particle composition (metals, organics, oxidative potential) was not assessed, limiting mechanistic interpretation. Fourth, the study examined acute effects only (10-day exposure), with no assessment of recovery or

chronic effects. Fifth, while microscopic examination provided morphological data, more quantitative measures such as ektacytometry or microfluidics would strengthen the deformability assessment.

Despite these limitations, the study has several strengths. The controlled experimental design, randomization, blinding, and mouse-level statistical analysis enhance internal validity. The use of local firewood samples relevant to Lombok Island improves the translational relevance for this region. The clear dose-response relationship provides strong evidence for PM₁-induced erythrocyte deformation.

Future research should include: (1) particle composition analysis using ICP-MS and GC-MS to identify toxic components; (2) measurement of oxidative stress biomarkers (malondialdehyde, glutathione, catalase) to confirm the mechanistic pathway; (3) ektacytometry or microfluidic deformability assays for quantitative assessment; (4) dose-response studies at lower, more environmentally relevant concentrations; (5) chronic exposure studies to assess reversibility; and (6) inflammatory marker assays (TNF- α , IL-6, IL-1 β) to evaluate systemic effects.

CONCLUSION

Firewood burnings generate varied PM₁ concentrations. The PM₁ concentrations are 97×10^3 to 257×10^3 $\mu\text{g}/\text{m}^3$ (0.97 – 2.57 g/m^3 in the exposure chamber), depending on the firewood sample (emission factor dependance). Mixed firewood samples have the highest PM₁ concentration and erythrocyte deformation level, while teakwood has the smallest values. There is a strong correlation between exposure to PM₁ concentrations and erythrocyte deformation levels as evidenced by linear regression ($\% \text{Def} = 4.52 + 0.082 \times \text{PM}_1$, $R^2 = 0.81$, $p < 0.001$). A higher PM₁ concentration generates a higher erythrocyte deformation level. Moreover, a higher combustion speed can generate a smaller PM₁ concentration, resulting in a lower deformation level.

RECOMMENDATION

Future research should examine the relationship between PM₁ exposure from firewood burning and erythrocyte deformation under environmentally relevant exposure conditions. Further investigations should characterize particle size distributions, chemical compositions, and co-emitted pollutants to clarify the specific contribution of PM₁ to erythrocyte abnormalities. Incorporating oxidative stress biomarkers, inflammatory indicators, and quantitative erythrocyte deformability assessments is recommended to strengthen mechanistic explanations. Additionally, longer exposure durations, independent experimental replication, and appropriate statistical analyses are needed to improve the reliability and generalizability of findings. Such investigations may inform evidence-based strategies for reducing health risks associated with firewood combustion in Lombok Island and similar settings.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Kasnawi Al Hadi	✓	✓		✓	✓				✓	✓		✓		
Arif Budianto		✓	✓	✓	✓	✓		✓	✓		✓			
Alfina Taurida Alaydrus	✓	✓				✓	✓			✓			✓	
Dian Wijaya Kurniawidi					✓				✓			✓		
Palaivia Harman Wardi		✓	✓				✓					✓		

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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