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Association between Urinary BPA and BPF Levels and Inflammatory Responses in Female Waste Workers

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Keywords

BPA; BPF; waste workers; inflammation; neutrophils

Abstract

Female waste workers are at high risk of exposure to bisphenol compounds from plastic waste, which can potentially affect the immune system. This study aims to analyze the relationship between urinary Bisphenol A (BPA) and Bisphenol F (BPF) levels and inflammatory responses as measured by White Blood Cells and absolute neutrophil counts. An analytical, observational, cross-sectional study was conducted on 35 female workers in waste management facilities. BPA and BPF levels were analyzed using LC-MS/MS, while hematological parameters were examined using an automated hematology analyzer. The results showed that BPF was associated with an increase in absolute neutrophil counts as an indicator of innate inflammatory activation, while BPA did not show a similar relationship. These findings indicate that BPA replacement analogues are not necessarily safer for the immune system. Occupational health protection efforts and regular monitoring of exposure biomarkers are needed in high-risk worker groups.

INTRODUCTION

Waste workers are a profession with the potential to experience high health and safety risks (Mulya & Nasri, 2023; Phosrikham et al., 2020). This occurs because in their daily activities, they come into direct contact with plastic waste. Furthermore, in Indonesia, many waste workers are found without adequate Personal Protective Equipment (PPE) (Sarman et al., 2022; Siregar et al., 2022). This waste problem can have an impact on human health (Ompusunggu et al., 2025; Sadilla et al., 2025). In this context, plastic as anorganic waste will gradually degrade into smaller particles which are then called microplastics (Irsyad & Abidin, 2025). Consequently, workers may be exposed through inhalation, dermal contact, and oral ingestion (Roslan et al., 2024).

Compared with men, women are generally considered more susceptible to occupational health risks. This situation is partly driven by socially constructed gender roles that impose a double burden on working women, who are expected to fulfill their professional responsibilities while also undertaking unpaid domestic work, including household chores and childcare (Aronsson et al., 2023; Tongko et al., 2024). In addition, physiological differences in women who have different sex hormones than men so they have a higher tendency to experience immune system problems –(Chiaroni-Clarke et al., 2016). This statement is supported by reports that female workers are more susceptible to exposure to urban waste and biological materials from waste collection (Biswas et al., 2021). This issue has become increasingly urgent with the discovery of Bisphenol A (BPA) and Bisphenol F (BPF) in the urine of female waste workers. These chemicals, widely used in plastics, can disrupt the hormonal system and the body's immune response.

A recent study found a total of over

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13,000 chemical compounds used or present in plastics worldwide, and over 3,200 have been identified as toxic (UNEP, 2023). Among these chemicals, BPA was found in 95.7% of urine samples, while BPF was also found in high levels in 66.5% of urine samples from American adults (Yohar et al., 2021). In Malaysia, BPA was found in 100% of urine samples from plastic industry workers (Kouidhi et al., 2017). In another study, BPF, as a substitute for BPA, actually showed higher exposures. Of the 435 samples tested, BPF was detected in 96.8% of urine samples, compared to only 16.6% of BPA (Estévez-Danta et al., 2024).

Bisphenol is an industrial chemical used as a constituent of polycarbonate and epoxy resin plastics, such as in the manufacture of water bottles, gallon jugs, and the inner lining of food and beverage cans (Aulia & Mita, 2023; Faadhilah & Tiitraresmi, 2023). Bisphenols can leach from food packaging into food, particularly under prolonged storage and elevated-temperature conditions (Almeida et al., 2018). Therefore, bisphenol can enter the human body through food and beverages (Hartle et al., 2022). Bisphenol, known as an endocrine disrupting chemical (EDC), has the potential to be a biomarker for several diseases, such as obesity (Marinadhan & Calivarathan, 2023), cardiovascular disorders (Fonseca et al., 2022), kidney disease, reproductive disorders (İyİgÜndoĞdu et al., 2020) and immune system disorders (Kodila et al., 2023; Yuan et al., 2024).

Although the presence of microplastics and bisphenol compounds in human blood and urine has been widely reported in recent years (Estévez-Danta et al., 2024; Kouidhi et al., 2017; Yohar et al., 2021), most research has focused on the general population or plastics industry workers. Research specifically examining BPA and BPF exposure in waste workers is still very limited, particularly in female workers who have different biological and social vulnerabilities. This makes this study novel in its focus on waste workers. This group of workers has a high potential for bisphenol compound exposure due to direct contact with various types of household and industrial plastic waste, but it has rarely been scientifically studied. By focusing on waste workers, this study is expected to provide a more specific picture of bisphenol compound exposure levels in high-risk occupational groups that have not received much research attention.

This study aims to analyze the relationship between BPA and BPF levels in urine with immune responses as measured by White Blood Cells and absolute Neutrophil parameters in female waste workers. The results of the study are expected to provide an initial overview of the impact of plastic waste exposure on the immune system and serve as a scientific basis for developing health protection efforts for waste workers. However, this study has several limitations. The cross-sectional design allows for the assessment of associations but does not establish causal relationships. Furthermore, potential confounding factors, including dietary habits, lifestyle factors, and other environmental exposures, were not fully accounted for. Further research is warranted to overcome these limitations and elucidate the observed associations more comprehensively.

RESEARCH METHOD

This is an observational, analytical, cross-sectional study aimed to analyze the relationship between BPA and BPF in urine and inflammatory responses indicated by white blood cells and absolute neutrophil counts in female waste workers. The study was conducted on female waste workers, a population exposed to the waste management facility. Sampling was conducted from March to November 2025. Hematological analyses were conducted at a local healthcare facility laboratory, whereas BPA and BPF concentrations were determined at the Wonjin Laboratory, South Korea, following standardized human biomonitoring protocols.

The study population consisted of women of reproductive age in the study area who work as female waste pickers. The study sample consisted of 35 respondents, all of whom were female waste pickers. Subjects were categorized based on the duration of occupational exposure into several categories: <1 year, 1–5 years, >5–10 years, >10–15 years, and >15 years. The sampling technique used was purposive sampling, with the inclusion criteria being women aged 15–49 years, actively working as scavengers, willing to participate, and signing informed consent. The independent variables in this study were the levels of Bisphenol A (BPA) and Bisphenol F (BPF) in urine as biomarkers of chemical exposure, while the dependent variables were the inflammatory response indicated by white blood cells and absolute neutrophil counts.

Urine samples were collected at the end of the workday using polypropylene containers, then centrifuged and stored at -20°C until sample analysis. BPA and BPF metabolite levels were determined using Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS). Hematology tests were performed to obtain white blood cell and absolute neutrophil counts as indicators of the innate inflammatory response using an automated hematology analyzer in accordance with standard laboratory procedures.

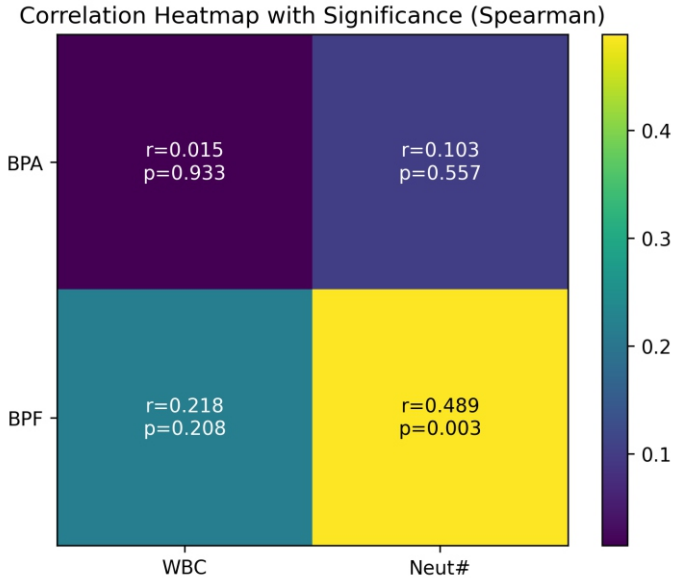
Data were analyzed using IBM SPSS Statistics. Descriptive statistics were used to summarize BPA and BPF concentrations, white blood cell (WBC) counts, and absolute neutrophil counts. Data normality was assessed using the Shapiro–Wilk test. As the data were not normally distributed, Spearman's rank correlation test was employed to examine the associations between BPA and BPF concentrations and WBC and absolute neutrophil counts.

This study received ethical approval from the Health Research Ethics Committee of the Muhammadiyah University of Lamongan under No. 133/EC/KEPK–S3/04/2025 on April 15, 2025. This study was deemed ethical and conducted in accordance with ethical principles of health research. All respondents were explained the purpose and procedures of the study and signed an informed consent form before sampling. The confidentiality of respondents' identities was maintained, and the data obtained were used only for research purposes.

RESULTS AND DISCUSSION

To investigate the relationship between exposure to synthetic phenols and inflammatory responses among female waste workers, quantitative analysis is required to assess the strength and direction of associations between exposure biomarkers and hematological parameters. Correlation analysis was used to evaluate the association between urinary bisphenol levels and indicators of inflammatory immune responses. Therefore, a visualization of the Spearman correlation is presented in Figure 1 as an initial illustration of the statistical relationship between exposure variables and biological responses.

Based on Figure 1, the results of the Spearman correlation analysis indicate that BPA levels in urine do not have a statistically significant correlation. This can be seen from the very weak correlation figures with the total leukocyte count (WBC) ($r = 0.015$; $p = 0.933$) and the absolute neutrophil count (Neut#) ($r = 0.103$; $p = 0.557$), so it can be said to be far from being related. In contrast, BPF levels showed a moderate and significant positive correlation with the absolute neutrophil count ($r = 0.489$; $p = 0.003$), although the correlation with total WBC was still weak and insignificant ($r = 0.218$; $p = 0.208$). This suggests that BPF exposure may be more specifically associated with the activation of the innate inflammatory response through neutrophils than BPA in this study population. The results showed that BPF had a significant association with neutrophil count, while BPA showed no



Source: Processed Primary Data, (2026)

Figure 1
Correlation between BPA, BPF with WBC and NEUT#

significant association with the measured inflammatory parameters. This finding is interesting because BPA has historically been studied more than its substitute analogues.

Theoretically, bisphenol is known to act as an endocrine-disrupting chemical that can trigger oxidative stress and activate inflammatory pathways. Review studies show that bisphenol can increase the production of reactive oxygen species (ROS) and activate inflammatory pathways such as NF-κB, which increases the production of pro-inflammatory cytokines like IL-6 and TNF-α (Bazany et al., 2025). Furthermore, bisphenol exposure is also associated with increased oxidative stress biomarkers in humans, including 8-OHdG and isoprostanes (Steffensen et al., 2020).

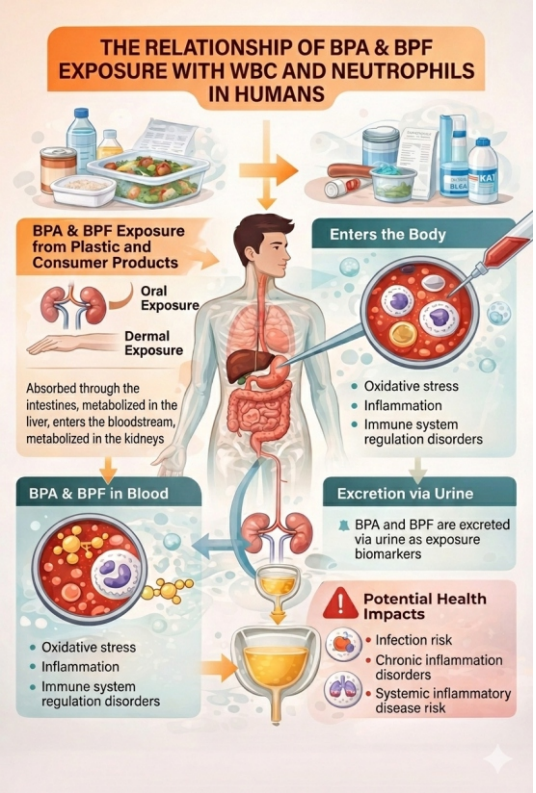
Empirically, experimental studies have shown that BPA can modify the immunophenotype of neutrophils and potentially cause immune cell dysfunction (Ratajczak-Wrona et al., 2020). However, the findings of this study indicate a stronger association between BPF exposure and neutrophil levels than between BPA exposure and neutrophil levels. This is supported by other studies showing that BPF can cause oxidative stress and significant changes in the antioxidant system, potentially triggering the activation of a systemic inflammatory response (Li et al., 2023).

Furthermore, BPF is known to be metabolized and excreted in the urine as sulfate and glucuronide conjugates, making urine a valid exposure biomarker for assessing internal exposure levels (Akash et al., 2023). Human biomonitoring studies have also shown that urinary levels of BPA, BPF, and BPS are associated with biomarkers of oxidative stress, strengthening the link between bisphenol exposure and inflammatory responses (Wang et al., 2019).

The novelty of this research finding lies in the identification that BPF, often considered a "safer" substitute for BPA, actually showed a more significant association with innate inflammatory parameters in a group of female waste workers. This is important because this group is potentially exposed to chronic exposure through environmental contact and plastic waste products. This finding adds to the empirical evidence that substituting BPA with analogues like BPF does not necessarily reduce the biological risk to the human immune system.

In addition to statistical analysis, understanding the biological mechanisms by which bisphenol exposure affects the

inflammatory response is also crucial to elucidating causal relationships. Therefore, Figure 2 presents a conceptual overview of the pathways through which BPA and BPF enter the body and their impact on the immune system and inflammatory processes.



Source: Author's Own Illustration, (2026)

Figure 2.
Research infographic on the relationship between BPA and BPF levels with white blood cells and neutrophils

Based on Figure 2, BPA and BPF exposure occurs through the oral and dermal routes from plastic and consumer products. After entering the body, these compounds are absorbed through the gastrointestinal tract, metabolized in the liver, then enter the bloodstream and are finally excreted through the kidneys and urine. While in the body, BPA and BPF can trigger oxidative stress, inflammation, and impaired immune system regulation. Urine is the primary biomarker for assessing internal bisphenol exposure. Potential health impacts include increased risk of infection, chronic inflammation, and systemic inflammation.

Theoretically, bisphenol acts as a xenoestrogen that can bind to estrogen receptors and trigger changes in gene expression, oxidative stress, and immune system dysregulation (Bazany et al., 2025). The main mechanisms of bisphenol-induced inflammation involve ROS production, DNA damage, and the activation of pro-inflammatory cytokines.

Empirically, research shows that exposure to BPA and BPF can increase oxidative stress by disrupting the balance of antioxidant enzymes such as catalase and superoxide dismutase (Li et al., 2023). Furthermore, experimental studies have shown that BPF exposure can cause immune system changes, including changes in the number of peripheral immune cells (Kaptaner et al., 2026).

The fact that BPA and BPF are primarily excreted in the urine makes urinary biomarkers reliable indicators for assessing internal exposure, particularly in at-risk populations such as waste workers (Akash et al., 2023). This is relevant to the study design, which uses urine as a biomonitoring matrix.

The novelty of this study lies in the integration of urinary biomarker data with hematological inflammatory parameters in a population of female waste workers, a practice rarely reported in the literature. Most previous research has focused on the general population or experimental studies, making this study an important contribution to understanding the impact of real-world environmental exposures on the human immune system.

CONCLUSION

This study shows that in female waste workers there is an association between exposure to Bisphenol F (BPF) in urine and an increase in the innate inflammatory response as reflected by absolute neutrophil counts, while Bisphenol A (BPA) does not show a significant association with the measured immune parameters. These findings answer the

research question that not all bisphenol analogs have the same biological impact, and BPF as an alternative to BPA, may contribute to inflammatory responses in populations experiencing high levels of environmental exposure, such as waste sorting workers. These results emphasize the importance of vigilance regarding the use of bisphenol analogs in plastic products and the need to strengthen occupational health protection policies, including increased use of personal protective equipment, education on chemical exposure, and regular biomarker monitoring to prevent the risk of chronic inflammation in vulnerable worker groups.

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