PLASTICS POISON THE WORKPLACE

CHEMICAL EXPOSURES TO PLASTIC WASTE AND RECYCLING WORKERS

November 2024

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ECOLOGICAL ALERT AND RECOVERY-THAILAND (EARTH)

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PLASTICS POISON THE WORKPLACE: CHEMICAL EXPOSURES TO PLASTIC WASTE AND RECYCLING WORKERS

November 2024

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IPEN is a network of non-governmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.
www.ipen.org

Arnika is a Czech non-governmental organization established in 2001. Its mission is to protect nature and a healthy environment for future generations both at home and abroad.
www.arnika.org

EARTH is an independent non-governmental organization striving for social and environmental sustainability and justice in Thai society and promoting climate justice, good governance and accountability of governmental and international agencies. EARTH focuses on the impacts of hazardous substances on ecosystems, local communities, and workers' health.
www.earththailand.org/en

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KEY FINDINGS

Plastics are made with thousands of chemicals, mostly petrochemicals derived from fossil fuels, many of which are known to be hazardous to our health, and many more that have little or no hazard information.

Hazardous chemicals are released throughout the life cycle of plastics, including when plastic wastes are handled during waste processing or recycling.

IPEN member EARTH in Thailand coordinated with plastic recycling workers, plastic waste workers, and workers in other settings, such as office settings or other settings without occupational exposures to plastic waste to assess their exposures to chemicals in plastics.

Participants from the three groups of workers wore wristbands that capture environmental exposures to chemicals for five days. The wristbands were analyzed at an independent lab for 73 chemicals in six chemical groups: PAHs, phthalates, phthalate alternatives, OPFRs, benzotriazole UV stabilizers, and phenols and bisphenols (eg, BPA).

The study found that:.

- All workers experienced chemical exposures to all six types of chemicals. Each worker was exposed to at least 21 chemicals, and 14 chemicals were found in every wristband tested. The findings overall are consistent with previous studies showing that we are all at risk of exposure to toxic plastic chemicals.
- Plastic waste and recycling workers were exposed to more chemicals than the other workers. Plastic recycling workers were exposed to the highest number of chemicals, and for some chemicals, also the highest levels of exposures.
- Phthalates, including some that are known endocrine disrupting chemicals (EDCs), were detected at the highest concentrations of all the chemicals. All workers across the three groups were exposed to the phthalate DEHP, with plastic waste workers exposed to very high levels. DEHP is an EDC banned in certain products in the EU, US, Australia, and China but unregulated in many countries across Africa, Asia and Latin America.
- All workers across the three groups were exposed to phthalate alternatives, chemicals used to replace regulated phthalates but likely to have similar hazards. The study shows the dangers of poisonous (so-called "regrettable") substitution.
- Polycyclic aromatic hydrocarbons (PAHs) are cancer-causing chemicals found in plastics and generated when burning plastics and other materials. Both plastic recyclers and plastic waste workers were exposed to higher concentrations and higher numbers of PAHs than the office workers.
- Exposures to organophosphate flame retardants (OPFRs), chemicals linked to neurodevelopmental issues and endocrine disruption, were higher in recycling workers compared to the plastic waste workers and office workers.

Most plastic chemicals are not regulated through international agreements and would not be covered by current global Conventions. Since chemicals from plastics and plastic wastes cross national boundaries, national regulations alone cannot protect human health or the environment from their toxic hazards. Therefore, controls on hazardous chemicals should be an essential component of the Plastics Treaty.

BACKGROUND

Plastics are mixtures of various types of chemicals, most of which are produced from fossil fuels (petrochemicals). Plastic chemicals include monomers, polymers, chemical additives, and non-intentionally added substances (NIAS).

Most plastic chemicals are not regulated, and little is publicly known about the health impacts of the majority of these chemicals. Many reports and studies have provided evidence of the multitude of plastic chemicals, including highlighting the thousands of plastic chemicals of concern. For example, a recent report identified more than 16,000 chemicals potentially used or present in plastic materials and products. There is little or no information about the potential impacts on human health or the environment for over 10,000 of these plastic chemicals. More than 4,200 plastic chemicals were categorized as of concern and the report concluded that more than 400 chemicals of concern can be present in each major plastic type, such as PVC, polyurethanes, PET, polyethylene and other types (Wagner *et al.*, 2024). Chemicals present in plastics are generally not bound to the material but will be released during production, use, recycling, and disposal of the plastics (Hahladakis *et al.*, 2018).

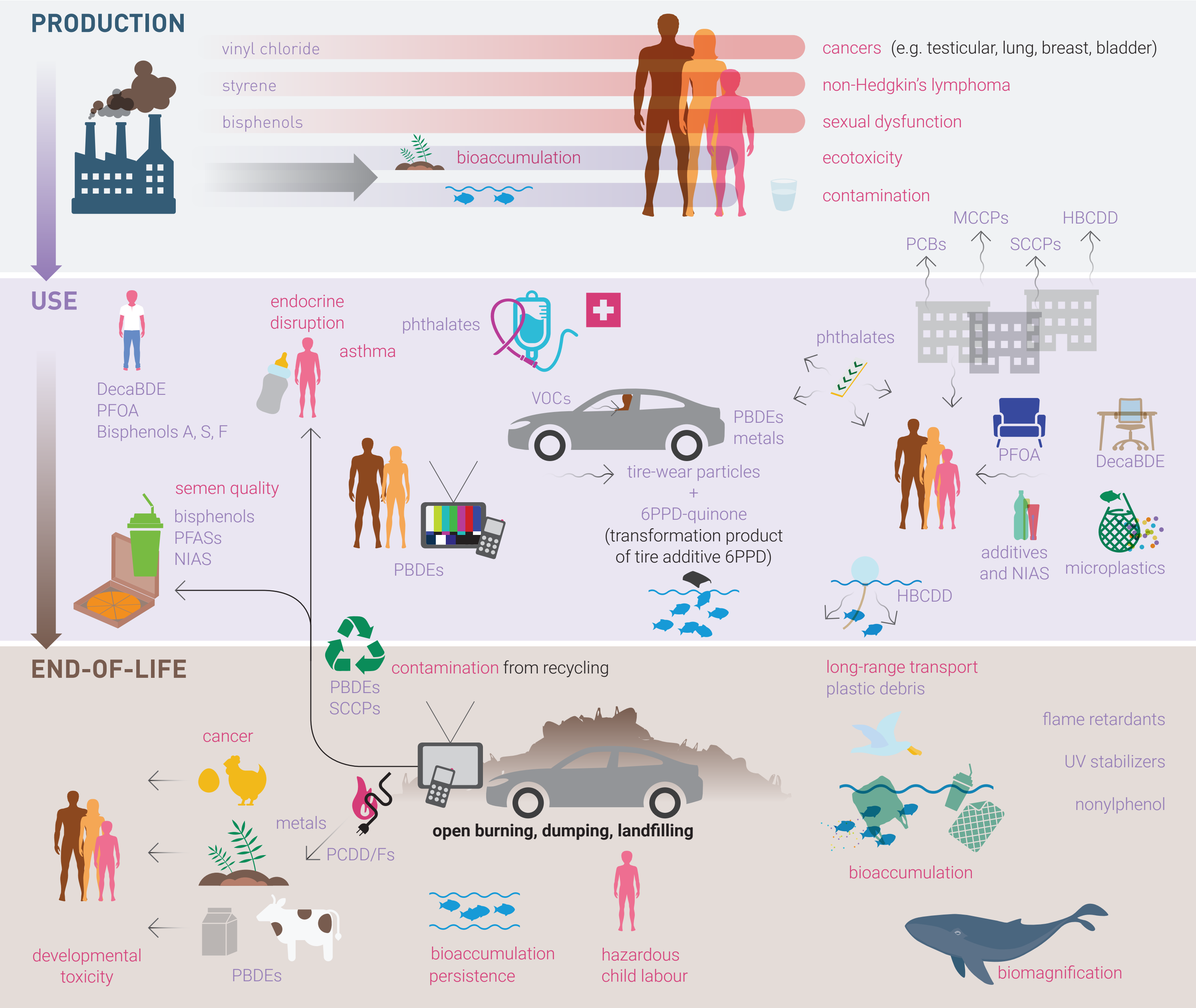
When plastics are recycled, these chemicals will be uncontrollably carried over into the new plastic material together with any new chemicals formed in the recycling process, including into consumer products made from recycled plastics. This is why highly toxic chemicals like dioxins have been found in toys and kitchenware made from recycled plastic (Petrlik, 2021). Plastic materials can also be contaminated by chemicals during use and carry these chemical contaminants into the recycling process. A study of chemicals in recycled plastic pellets detected traces of more than several hundred chemicals, including pesticides, pharmaceuticals, industrial chemicals, and plastic additives (Carmona *et al.*, 2023).

Health impacts caused by plastic chemicals include cancers, neurotoxicity, immunotoxicity, skin and respiratory conditions, and many more (Azoulay *et al.*, 2019). Many plastic chemicals are endocrine disrupting chemicals (EDCs), which means that they can interfere with our hormones natural functioning in the body, leading to disease or even death (Gore *et al.*, 2024).

Exposure to plastic chemicals is general, widespread, and occurs directly through many pathways including from extraction of fossil fuels, during production, use, recycling, and final disposal of plastics – in short, throughout the plastics life cycle. Exposure is also due to environmental contamination caused by plastics, for example, when plastic chemicals pollute soil, water, and air. This means that we can be exposed to plastic chemicals both from direct contact with the plastic and from air, food, water, dust, and other media that have been in contact with plastics (Gore *et al.*, 2024). While many chemicals are excreted from the body within days or weeks of exposure, some can be stored in fat, bone, or are attached to proteins and can remain in the body for months, years, or even decades (Wagner *et al.*, 2024). However, it is important to be aware that even though some chemicals are excreted faster from the body, that does not mean that they are safer.

Some countries have started addressing certain plastic chemicals. However, the problems related to plastic chemicals are not national but global. The plastic materials, products, and wastes that enter a country have often been traded and shipped internationally, often through complex trade routes, with no transparency, traceability, or ability for the consumer or waste worker to know what plastic chemicals they contain. Therefore, new global controls are needed to protect human health and the environment from plastic chemicals. To date, less than 1% of the chemicals used in plastics are regulated under existing international multilateral environmental agreements.

Some groups are especially impacted by plastic chemicals. These include communities living near fossil fuel extraction and processing sites and areas of plastic production, recycling, and disposal. Workers in both the formal and informal sectors engaged in these activities are also at greater risk. The International Labour Organization has identified a wide range of health impacts to workers caused by plastic chemicals, including cancers, cardiovascular disease, and respiratory conditions, and highlighted that more research is needed to provide information on exposures and impacts of plastics to workers (ILO, 2023).



Source: United Nations Environment Programme and Secretariat of the Basel, Rotterdam and Stockholm Conventions (2023). Chemicals in plastics: a technical report. Geneva

The use of silicone wristbands as passive samplers has become a common tool for assessing exposure to chemicals that people are exposed to via dermal contact or inhalation. The wristbands adsorb the same chemicals that the participant's skin comes in contact with and can therefore be used to determine the complex mixture of chemicals study participants are exposed to during a certain amount of time when the wristband is worn.

Previous studies have shown that such wristbands provide reliable information about which type of chemicals participants were exposed to from their environments. This includes both occupational exposure studies, but also studies of everyday exposures outside the workplace. While the wristbands cannot predict the exact concentration of the chemicals in the body, previous studies have demonstrated that they accurately show that the same chemicals or their breakdown products are present in the body for a wide range of chemicals such as flame retardants, pesticides, phthalates, polycyclic aromatic hydrocarbons (PAHs), and others (Dixon *et al.*, 2022; Hammel *et al.*, 2016; Hamzai *et al.*, 2022; Levasseur *et al.*, 2021; Samon *et al.*, 2022).

AIM

Plastic waste workers who are engaged in collection, sorting, handling, shredding, recycling, and final disposal of plastics are believed to be more highly exposed to plastic chemicals than the general population. Therefore, the purpose of this study was to assess exposures of plastic waste workers to plastic chemicals and to compare these exposures with others who do not face such occupational exposures.

OVERVIEW OF STUDY SET-UP AND APPROACH

Silicone wristbands, precleaned as described in Annex II at an accredited laboratory of the University of Chemistry and Technology, Prague (Czechia), were shipped to the NGO Ecological Alert and Recovery in Thailand (EARTH). Until their use, the wristbands were contained in tin cans, which were stored in sealed bags.

In preparation for the study, EARTH met with groups of potential study participants to explain the aim and procedure of the wristband study, the intended use of the data, and the voluntary nature of the study. Individuals who agreed to participate in the study were asked to sign an informed consent form, ensuring the anonymous use of their wristband data and noting that all participants had the right to withdraw from the study at any point. This approach was approved in ethics approval for the study by the ethical Committee of University of Chemistry and Technology, Prague (Czechia).

18
Sample label: TH - WB - PR - 08
Date on: 14.5/2024 Time on: 9.08 am/~~pm~~
Date off: Time off: am/pm
Notes:

Three groups of participants were included in the study, identified by the type of work they do:

- People engaged in plastic waste work:
    - 10 people (6 women + 4 men)
- People engaged in the plastic recycling industry:
    - 10 people (7 women + 3 men)

People in a control group with no occupational exposure to plastics:

- (6 women + 4 men)

At the start of the study, each of the participants was given a wristband in a tin can with an assigned sample code to ensure that their data remained anonymous. The participants put on the wristbands, noted the time and day, and wore wristbands for 5 days (120 hours). The first day, each participant filled in a questionnaire about their lifestyle, working environment, and working conditions to provide information about possible exposure sources. At the end of each study day, participants filled in daily logs about their activities during the day to enable identification of potential sources of exposures that might impact the results. After the five days, participants took off their wristbands, put them back in the tin can and put the can back into their original bag. All the bags were then shipped to the NGO Arnika Association in Czechia, who delivered them unopened to the lab.

A field blank was also included in the study to capture any contamination during the handling of the wristbands before or after the start of the study. This was opened for a brief time at the start of the study when the wristbands were handed out. It was then put back into its tin, the tin put back in its original bag, and it was shipped to the lab together with the other wristbands at the end of the five days.

Lab protocols and other information are provided in Annex II

PLASTIC WASTE AND RECYCLING WORK IN THAILAND

In rural Thailand, small-scale, informal recycling operations process plastic and electronic waste. Typically family-run, these operations take place within household-based workshops, where locals engage in tasks like sorting, dismantling, and shredding waste materials to extract valuable components, such as metals. Recycling has become a crucial source of income, with a significant portion of the population in some villages involved in this type of work.

Waste pickers typically work in local waste management centers associated with sub-district municipalities, where they collect plastic waste from various sources, compress plastic bags into compact lumps, and prepare the materials for recycling processes.

Plastic recyclers generally work in local collection and processing centers, where they handle and sort various plastic materials, with occasional tasks in dismantling and use of shredding equipment. While these activities provide economic benefits, they also bring environmental and health challenges due to the lack of regulated waste management practices. Non-valuable plastic waste is often openly burned or dumped, leading to significant pollution of the surrounding land, air, and food sources. Additionally, some communities run small shredding enterprises, grinding down plastic waste for further processing or sale. The use of basic, often unsafe equipment and personal equipment combined with limited awareness of potential hazards exposes workers and their families to toxic substances. Manually handling waste without protective measures releases hazardous materials, including persistent organic pollutants (POPs) and heavy metals, which can accumulate in the environment and increase health risks, particularly respiratory and endocrine issues.

This situation highlights the urgent need for safer waste processing practices and regulatory oversight to reduce chemical exposure in Thailand's recycling communities.

PLASTIC E-WASTE POSES HEALTH THREATS TO RECYCLING WORKERS IN THAILAND

Dechlorane Plus is a highly toxic flame retardant used in plastics. A previous study by EARTH and IPEN showed that recycling workers in Thailand have high levels of this toxic chemical in their bodies and in their food and surroundings. Compared to the average levels of the chemical found in samples from a group of organic farm workers and agriculturalists, who had trace levels of Dechlorane Plus in their blood, the Thai recycling workers on average had nearly 40 times higher levels of the harmful substance in their blood, with the highest level in one worker at nearly 280 times the trace levels found in the organic farm workers and agriculturalists.

The study also found that environmental and food contamination can be a source of Dechlorane Plus in humans. Dechlorane Plus was detected in 78% of the environmental and food samples taken from Thai e-waste recycling communities, but in only 20% of samples from Thai organic farms that served as reference areas. The results of sampling around Thai e-waste recycling workshops suggest that transport, storage of e-waste, and the shredding of plastic waste is a source of environmental contamination by Dechlorane Plus, with implications for waste workers throughout the plastics recycling chain.

CHEMICALS INCLUDED IN THE STUDY

Six types of chemicals were included in the study. These chemicals were selected due their association with plastics, concerns about their health impacts, and the lack of global, legally binding instruments to address these chemicals.

A total of 73 chemicals were included:

1. Phthalates: 12 chemicals;
2. Other plasticizers (phthalate alternatives): 2 chemicals;
3. Polycyclic aromatic hydrocarbons (PAHs): 24 chemicals;
4. Benzotriazole UV-stabilizers: 8 chemicals;
5. Phenols and bisphenols: 6 chemicals; and
6. Organophosphate flame retardants (OPFRs): 21 chemicals.

PHTHALATES

Uses: Phthalates are a large group of chemicals that are most commonly used in PVC plastics to make them flexible and durable. PVC is used for a wide range of plastic products such as consumer products, food packaging, children's products, and medical plastics. Some phthalates also have additional uses in personal care products, cosmetics, and other non-plastic consumer products.

Exposures: Due to their extensive use, people are widely exposed to phthalates from use of products and also, for example, from contaminated house dust, food, and water.

Health impacts: Many phthalates are confirmed or suspected endocrine disrupting chemicals (EDCs), leading to a multitude of health impacts. They are toxic for reproduction, lower testosterone and estrogen levels, and can affect fertility across multiple generations. They are also associated with elevated blood pressure, obesity, anemia, and higher miscarriage rates (Flaws *et al.*, 2020).

Regulations: In Thailand, the phthalates DEHP, DBP, DEP, BBP, DINP, DIDP, and DNOP are not allowed in toys above a threshold of 0.1% (weight). Similar restrictions for use in toys are in place in many other Asian countries, including Indonesia, Vietnam, China, the Philippines, as well as in countries in other regions such as the US, EU, and Australia. In the EU, some phthalates require authorization before use in any product.

OTHER PLASTICIZERS

Uses: Trioctyl trimellitate (ToTM) and bis(2-ethylhexyl) adipate (DEHA) are used instead of phthalates to make plastics softer and more flexible. Plastics containing DEHA and ToTM are used in a wide variety of products, including food packaging, toys, electronics, fabrics, personal care products, and many more.

Exposures: Because of their widespread use, ToTM and DEHA have been widely detected in household dust and found to contaminate soil and sediment. People are exposed to these substances from the use of products containing them, but also, for example, from contaminated house dust, food, and water.

Health impacts: ToTM has been reported to cause endocrine and reproductive toxicity and cell damage (cytotoxicity), and DEHA has been linked to harmful effects on the brain, heart, and liver tissues due to oxidative stress, inflammation, and apoptosis (cell death) (Tan *et al.*, 2023).

Regulations: The use of ToTM and DEHA are not regulated in Thailand or banned in any other country. ToTM is under evaluation in the EU to assess the need for regulatory controls.

POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Uses: Polycyclic aromatic hydrocarbons (PAHs) comprise a group of more than 100 chemicals that are generally not intentionally used in plastics but occur naturally in fossil fuels and can also be generated when, for example, coal, oil, gas, wood, plastics, and tobacco are burned.

Exposures: Most people are exposed to PAHs in their everyday lives from contaminated air, water, soil, and food sources. Occupational exposure to PAHs is common and widespread, for example, among firefighters, road workers, steel industry workers, workers in rubber and other plastics industries, and many other industries and occupations

Health impacts: Exposure to PAHs causes a wide range of health impacts, including cancer, reproductive- and endocrine-disrupting effects, immunotoxicity, and neurotoxicity (Sun *et al.*, 2021).

Regulations: In Thailand, PAHs are not regulated. Many other countries have also established thresholds for occupational exposures, food, and environmental contamination, and have restricted levels of PAHs in children´s products and other consumer products.

BENZOTRIAZOLE UV-STABILIZERS

Uses: Benzotriazole UV stabilizers (BUVs) are a group of chemicals that are widely used in plastics to prevent the plastics from degrading when exposed to UV radiation from sunlight. Some of the chemicals in this group are also used in sunscreen and skincare products to prevent damage to skin from UV radiation.

Exposures: Because of their widespread use, BUVs have been shown to contaminate all environmental media, including soil, air, and water and have been detected in human breast milk. UV stabilizers can also leach from packaging materials into our food. Exposure to BUVs occurs during use of products containing them and from contaminated house dust, food, and water.

Health impacts: BUVs have been linked to harm to human health, including endocrine disruption, damage to liver and kidney functions, and impacts on the immune system. (Khare *et al.*, 2023; Zhou *et al.*, 2023).

Regulations: Thailand is a Party to the Stockholm Convention, where the BUV UV-328 is listed for global elimination. No other BUV is regulated in Thailand, similar to most other countries in the world. However, in the EU, the use of three additional BUVs (UV-327, UV-350, and UV-320) require authorization.

PHENOLS AND BISPHENOLS

Uses: The two alkylphenols (octylphenol and nonylphenol) included in the study are used as antioxidants in plastics. Other uses include latex paints, pesticides, and industrial cleaners. Bisphenols are used as chemical building blocks in polycarbonate plastics and epoxy resins and also, for example, in the linings of food cans and thermal paper receipts.

Exposures: Sources of exposure to phenols and bisphenols are contamination of household dust, food, water, and other beverages. The sources of dietary exposure to bisphenol A have been extensively studied, and shown to be caused by leaching from carbonate plastics food and drink containers and food can liners.

Health impacts: Alkylphenols are linked to male infertility, low sperm count, and disrupted prostate development. Studies of occupational exposures have shown that exposures are associated with heightened risk of male and female breast cancers. One of the most well studied EDCs is bisphenol A (BPA), a chemical that causes a wide range of health impacts. These include impacts on brain development, adverse reproductive outcomes, reduced fertility, increased risk of diabetes, and associations with breast, prostate, ovarian, and endometrial cancers. Scientific studies show that other bisphenols have similar effects (Gore *et al*., 2024).

Regulations: BPA is banned for use in infant food containers in Thailand and infant and children's tableware containing BPA must carry a warning label. Many other countries have also banned the use of BPA in baby bottles and food contact materials for children.

ORGANOPHOSPHATE FLAME RETARDANTS

Uses: Organophosphate flame retardants (OPFRs) include more than 130 chemicals that are increasingly used as replacements for brominated flame retardants, for example, in furniture, textiles, building materials, and electronics. They can also be used as plasticizers to make plastics softer and more flexible.

Exposures: The main source of human exposure to OPFRs is through contaminated indoor air and dust, since they are used widely in consumer products. They have also been shown to pollute water, biota, sediment, and soil.

Health impacts: Growing scientific evidence shows that OPFRs are toxic replacements for brominated flame retardants and have similar health impacts, such as endocrine disruption and developmental and neurodevelopmental toxicity (Blum *et al*., 2019). Individual OPFRs have also been linked to reproductive toxicity, neurotoxicity, respiratory effects, and eczema (Chupeau *et al*., 2020).

Regulations: Similar to most countries, Thailand does not have any regulations to control the use of organophosphate flame retardants. In the EU, several OPFRs are restricted for use in toys.

THE STUDY: MOST SIGNIFICANT RESULTS

Concentrations of the different chemicals detected in the wristbands varied within the three participant groups, where levels in individual wristbands in some instances were far higher than the levels in other wristbands in the same group. Given the small sample size, comparisons between groups were therefore primarily based on median values, i.e., the middle value rather than averages. Also, to facilitate readability and make results easier to compare, results are rounded in the text but provided in detail in Annex I.

1. ALL PARTICIPANTS WERE EXPOSED TO ALL TYPES OF CHEMICALS

All six types of chemicals were detected in all wristbands. Of the 73 chemicals included in the chemical analysis in total, 14 were detected in all wristbands, and each wristband contained between 21 – 41 chemicals (see Fig. 2).

Similar to other studies, no two wristbands contained the exact same set of chemicals (Dixon *et al.*, 2022). In addition, even in the control group, the wristbands from some individuals contained very high levels of some chemicals. For example, the wristband of one individual from the control group contained 107,000 ng/g of di-isobutyl phthalate (DiBP), whereas the wristband with the second highest levels contained 2,400 ng/g. The wristband of one of the plastic waste worker contained a total of 1,500 ng/g of PAHs, whereas the second highest concentration detected was 700 ng/g. Two wristbands of the plastic waste workers contained 129,000 and 157,000 ng/g of bis(2-ethylhexyl) phthalate (DEHP), whereas the third highest concentration was 74,000 ng/g.

2. PHTHALATES WERE DETECTED AT THE HIGHEST CONCENTRATIONS IN ALL WRISTBANDS

Six out of the twelve phthalates included in the chemical analysis were detected in the wristbands (see Tab 1), and three phthalates were detected in all the wristbands: diethyl phthalate (DEP), di-n-butyl phthalate (DBP), and bis(2-ethylhexyl) phthalate (DEHP) (see Fig. 1a-c). DEHP, DiBP, and DPB were detected at the highest levels of all chemicals, 157,000 ng/g, 107,000 ng/g, and 24,000 ng/g respectively. A low level (38 ng/g) of DBP was detected in the field blank.

	DMP	DEP	DIBP	DBP	BBP	DEHP
Control group	11 (range: 6.9–2,300)	1,800 (range: 140–9,200)	450 (range: 140–107,000)	2,200 (range: 750–24,000)	69 (range: BLQ –580)	8,400 (range: 3,500–65,000)
Plastic recyclers	30*	920 (range: 72–2,100)	370 (range: BLQ –800)	2,300 (range: 460 –8,000)	41 (range: 7.8 –1,547)	13,500 (range: 5,500–73,900)
Plastic Waste workers	BLQ	1,600 (range: 79–10,200)	470 (range: 300–2,400)	3,300 (range: 1,200–16,000)	110 (range: 72– 2,200)	46,600 (range: 9,800–157,000)

Table 1 Median concentrations of the six phthalates detected in the wristbands of each participant group (ng/g, rounded numbers).
BLQ = Below limit of quantification *only detected in one wristband

Dimethyl phthalate (DMP) was detected in all the wristbands of the participants of the control group, but only in one other wristband. Since DMP is also used in cosmetics, skin care products, and insect repellants, it could be hypothesized that the measured levels came from such uses rather than from plastics.

When comparing median concentrations of phthalates detected in the wristbands, plastic waste workers were exposed to higher levels of DBP and DEHP, and slightly higher levels of BBP, but not to DEP and DiBP.

The range of levels of DEHP, DEP, and DBP that were detected in all wristbands was wide, sometimes spanning more than one order of magnitude. The levels and the wide variance were similar to results from other studies of phthalate exposure using silicone wristbands.

A wristband study of exposures in office workers in the US, UK, China and India found the following concentrations (ng/g-wristband) of these three phthalates after 32 hours of exposure (Young *et al.*, 2021).

	DEHP	DEP	DBP
US	466 – 69,100 (median 6,910)	<MDL – 218,000 (median 168)	73.3 – 5,340 (median 403)
UK	911 – 27,700 (median 4,780)	<MDL – 12,800 (median 198)	194 – 3,060 (median 689)
CHINA	1,840 – 348,000 (median 27,300)	<MDL – 11,900 (median 395)	194 – 3,060 (median 689)
INDIA	<MDL – 218,000 (median 47,000)	<MDL – 57400 (median 3,290)	<MDL – 31,500 (median 2,680)

Table 2 Levels of three phthalates detected in wristbands of office workers
<MDL = Below the Minimum Detection Level

In a study of wristbands worn by around 150 undergraduate students at the University of California for 5 days, a wide range of exposures to these three phthalates were detected (minimum – maximum levels): DBP 188 – 30,600 ng/g; DEP 113 – 12,980 ng/g; and DEHP 991 – 233,200 ng/g (Reddam *et al.*, 2024).

Even in rural communities in Peru, DEHP and DBP were detected in all wristbands and DEP in 92% of the wristbands. These wristbands were worn for a month, which means the levels cannot be compared (Bergmann *et al.*, 2017).

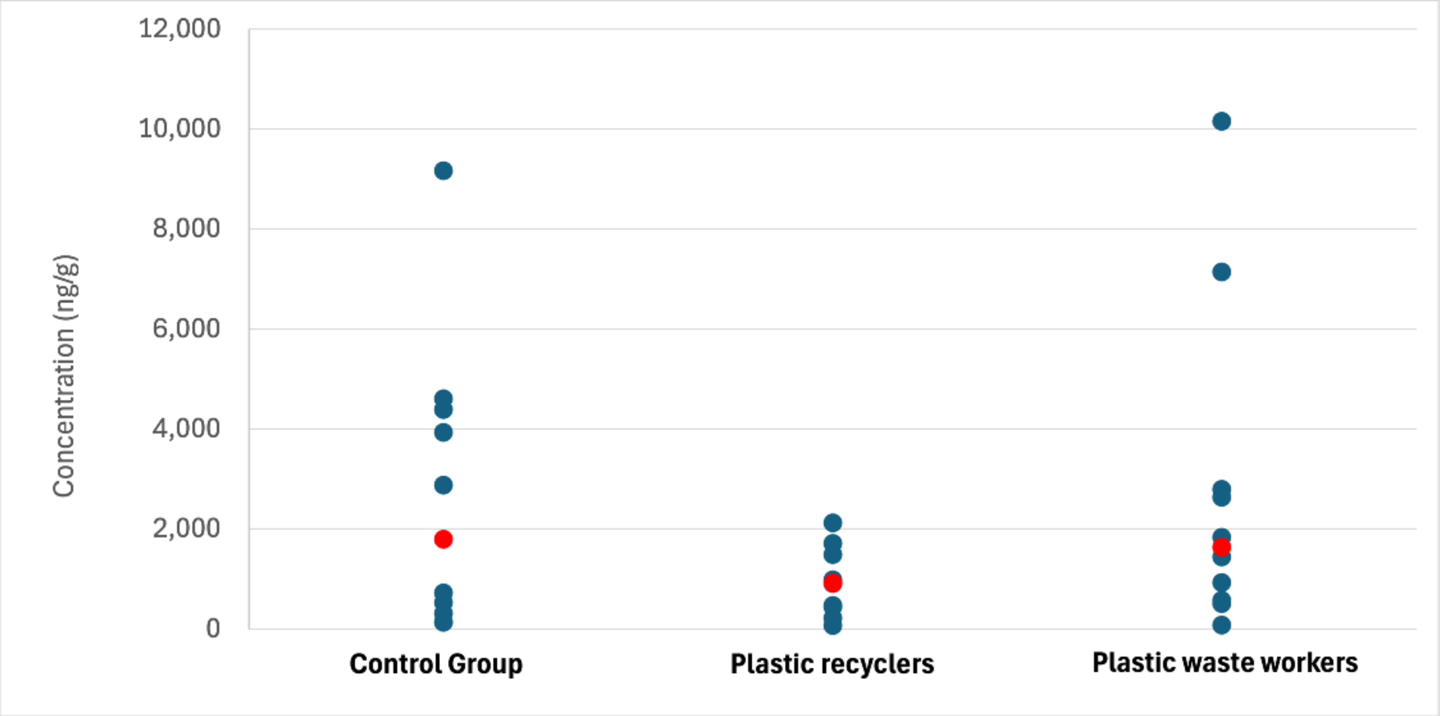


Figure 1a. Concentrations detected of diethyl phthalate (DEP) (ng/g). Median values for each participant group in red.

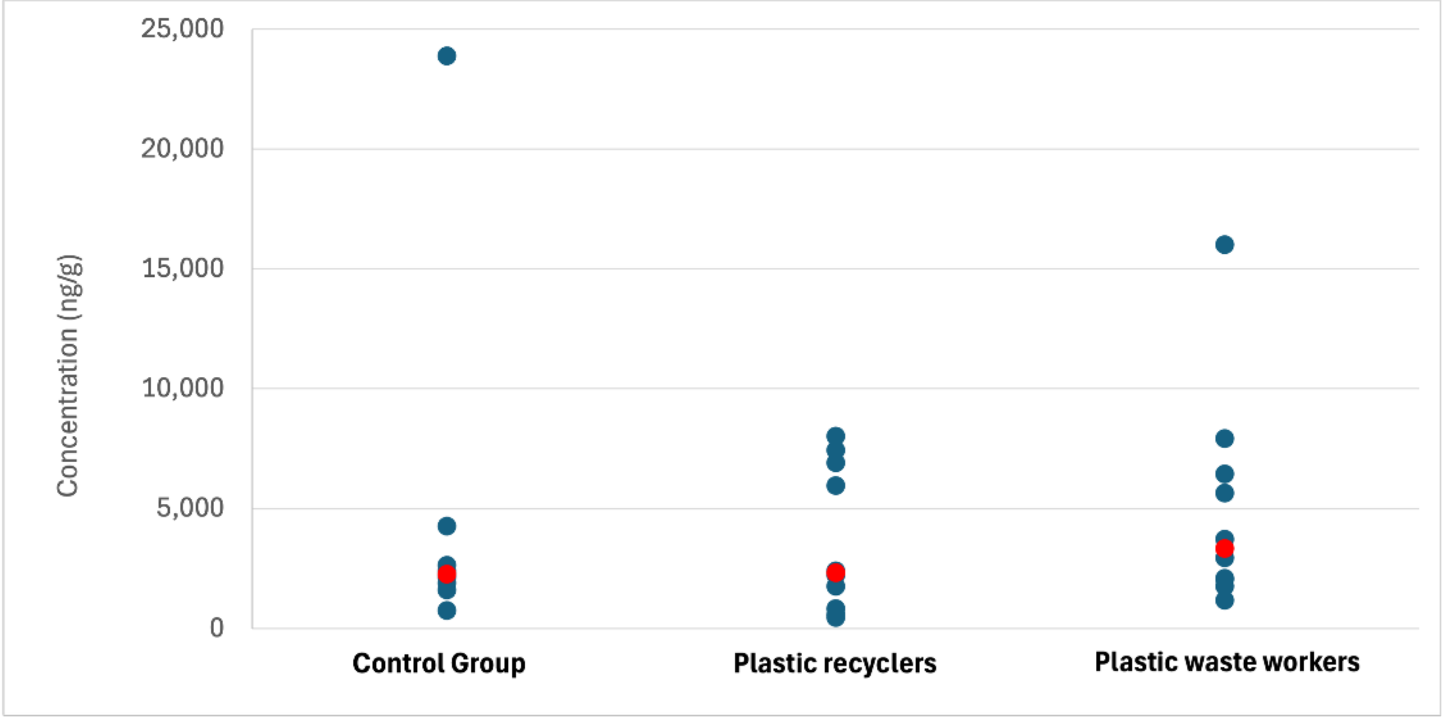


Figure 1b. Concentrations detected of di-n-butyl phthalate (DBP) (ng/g). Median values for each participant group in red.

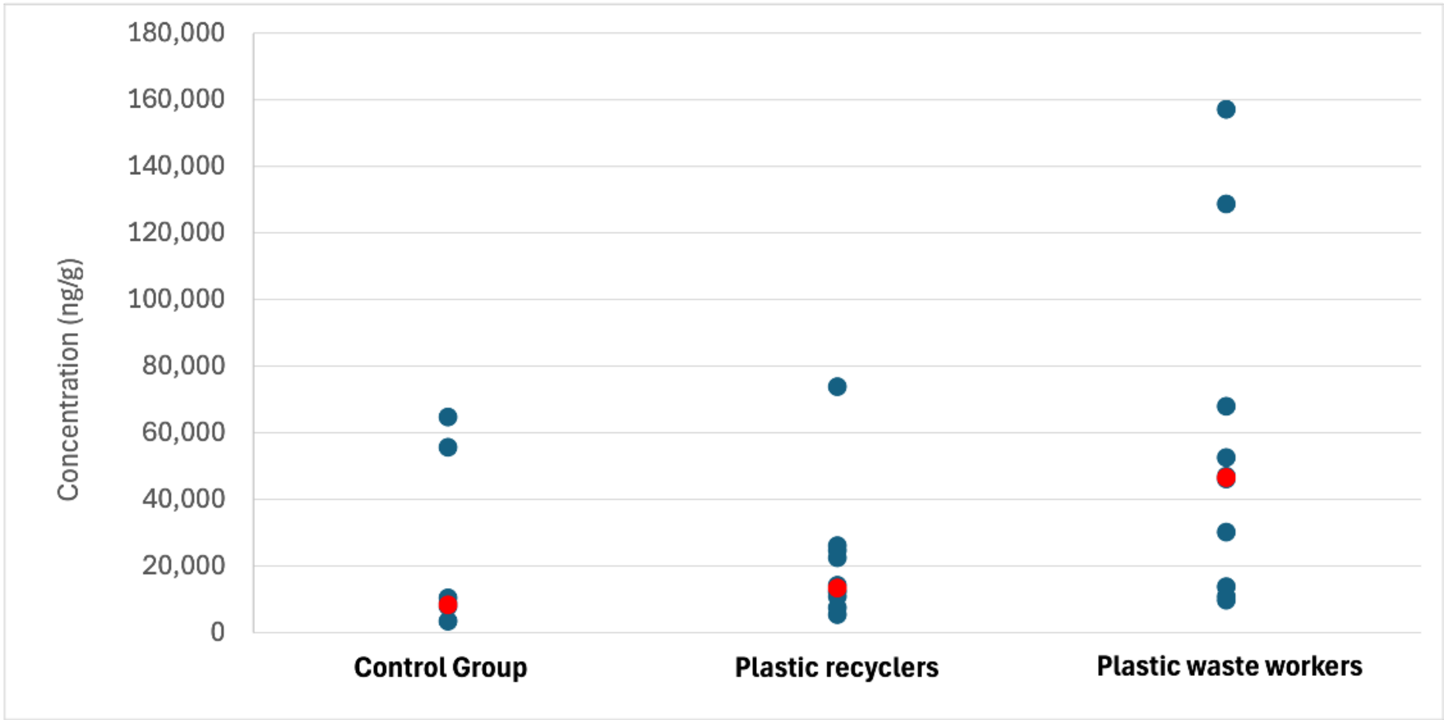


Figure 1c. Concentrations detected of bis(2-ethylhexyl) phthalate (DEHP) (ng/g). Median values for each participant group in red.

3. THE PLASTIC WASTE WORKERS WERE EXPOSED TO A HIGHER NUMBER OF CHEMICALS

The participants in the control group were in general exposed to fewer chemicals than the plastics waste workers and recycling workers (see Fig. 2): between 21-33 chemicals in the control group wristbands compared to 23-40 chemicals in the wristbands of the plastic recyclers and 27 – 38 chemicals in the wristbands of the plastic waste workers. The median number of detected chemicals for each group were 26.5, 37, and 33.5 chemicals respectively.

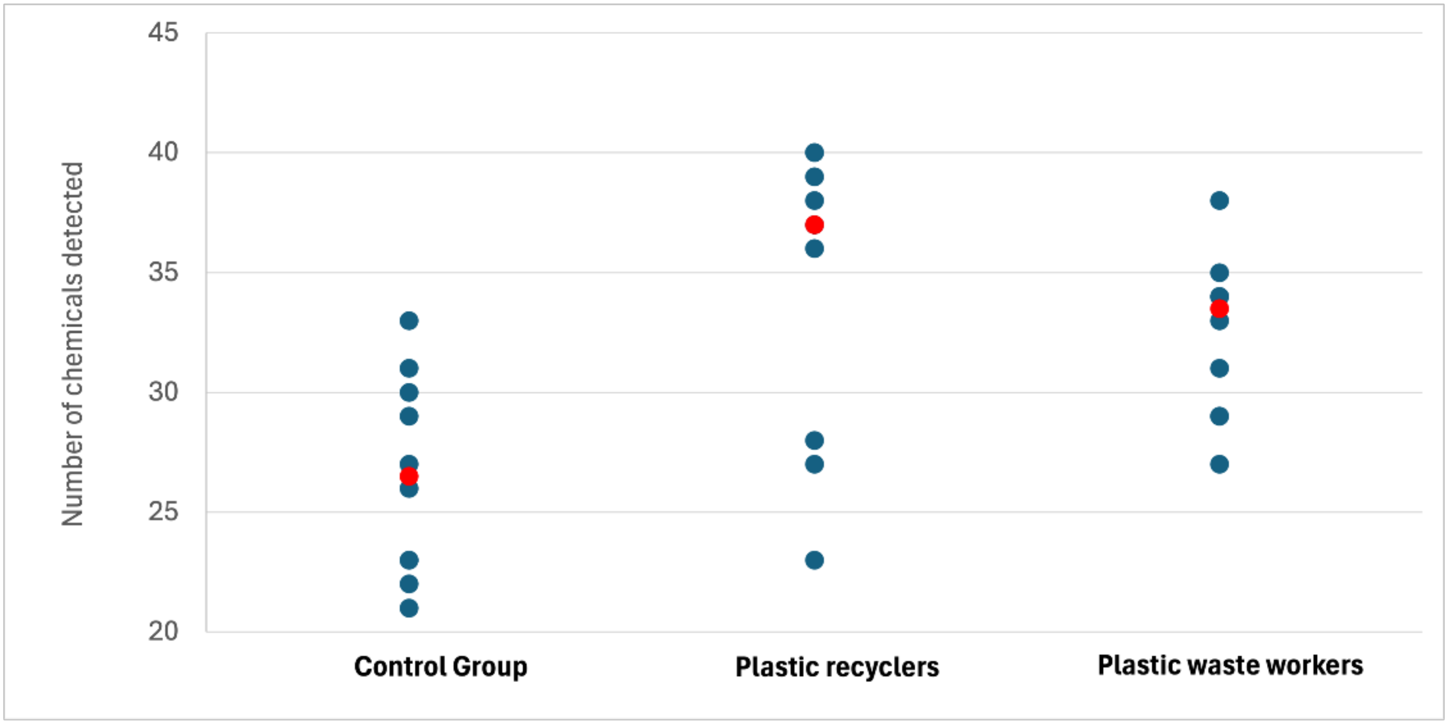


Figure 2. Number of chemicals detected in each wristband. Median values for each participant group in red.

Similar evidence of widespread exposure to a variety of chemicals has also been seen in other studies using wristbands as passive samplers, including widespread exposure to phthalates, organophosphate flame retardants, and PAHs.

While many wristband studies focus on the United States (US), some studies provide insights from other regions. Since exposure levels and patterns may be different in different countries and regions depending on consumer habits, population density, and regulatory controls, the results from this study were primarily compared to studies with a broader geographical spread.

For example, one study assessed exposures to 1,530 chemicals in the general population from rural and urban communities in Senegal, South Africa, United States, and Peru. The number of chemicals detected per wristband ranged from 4 (in rural communities in Africa) to 43 (in the US). The same 14 chemicals were detected in over half of the wristbands, including six phthalates and one organophosphate flame retardant. Of these 14 chemicals, 13 were defined as potential endocrine disrupting chemicals (EDCs). Overall, the number of potential EDCs ranged from 4 to 30 per wristband, and of the 191 chemicals detected in one or more wristbands, 96 were classified as potential EDCs (Dixon *et al.*, 2019).

In the study evaluating exposures to office workers in the USA, UK, China, and India, 94 of the 99 measured targeted chemicals were present in at least one of the wristbands and most samples had detectable levels of at least one chemical within each chemical class (Young *et al.*, 2021). All wristbands contained at least one organophosphate flame retardant and one or more phthalate. Most of the samples (98%) contained one or more PAH. In addition, 793 unknown chemicals were present on average in each wristband. When a piece of each wristband was screened for endocrine disrupting properties in different bioassays, they all exhibited hormonal activity (Young *et al.*, 2023).

Finally, in a study of exposures in students in Italy and France, 74 of the 92 targeted chemicals were detected in at least one wristband. As further discussed below, organophosphate flame retardants and PAHs were extensively detected in this study (Wang *et al.*, 2020).

4. PLASTIC RECYCLERS WERE MORE EXTENSIVELY EXPOSED TO ORGANOPHOSPHATE FLAME RETARDANTS.

Sixteen of the 21 OPFRs included in the analysis were detected in one or more wristbands and four were detected in all wristbands: tri-isobutyl phosphate (TiBP), tri-n-butyl phosphate (TnBP), tris(2-ethylhexyl) phosphate (TEHP), and triphenyl phosphate (TPhP). TnBP was detected at the highest levels in 20 of the wristbands (range 2.4 ng/g – 36 ng/g). The highest concentrations detected of any OPFR was of tris(2-chloropropyl) phosphate, only detected in two wristbands belonging to plastic recyclers at 62 ng/g and 61 ng/g.

The median concentrations for TiBP and TnBP were higher for plastic recyclers than for the other two groups. The median concentration for TiBP was 9.6 ng/g in the recycler wristbands compared to 3.1 ng/g and 3.0 ng/g for the waste workers and controls, respectively. For TnBP, the median concentration in the recyclers' wristbands was 23 ng/g compared to 7.9 ng/g and 9.8 ng/g for the waste workers and controls, respectively.

The total concentrations and the number detected of organophosphate flame retardants (OPFRs) were higher in the plastic recycling workers compared to the plastic waste workers and the control group (see Fig. 3a and 3b). The median sum concentrations were 18 ng/g (range 6 – 82 ng/g) in the wristbands of the control group, 71 ng/g (range 23 – 176 ng/g) in the wristbands of the plastic recyclers, and 20 ng/g (range 10 – 55 ng/g) in the wristbands of the plastic waste workers. Trace amounts (0.12 ng/g) of tri-n-butyl phosphate (TnBP) was detected in the field blank.

These levels were lower than the sum concentration of 25 OPFRs in wristbands worn for five days in a study of exposure in students in Italy and France. There, the median sum of concentrations detected in the group of students in France was 495 ng/g, and in Italy 387 ng/g (Wang *et al.*, 2020). They were also lower than the sum of median levels of 31 OPFRs in wristbands worn for 32 hours by office workers in the US (241 ng/g), UK (2,206 ng/g), China (138 ng/g) and India (95 ng/g) (Young *et al.*, 2021). Finally, the levels in the present study were lower than medium sum concentrations of 22 OPFRs measured in wristbands in a 7-day study from Vietnam after worn by a control group in Hanoi (58 ng/g), e-waste recycling workers in Bui Dau Village (230 ng/g), and End-of-Life Vehicle (ELV) recycling workers in Thuyen Village (170 ng/g) (Matsukami *et al.*, 2022).

One likely explanation for why the concentrations in Thailand were lower than in other countries is that OPFRs are less widely used.

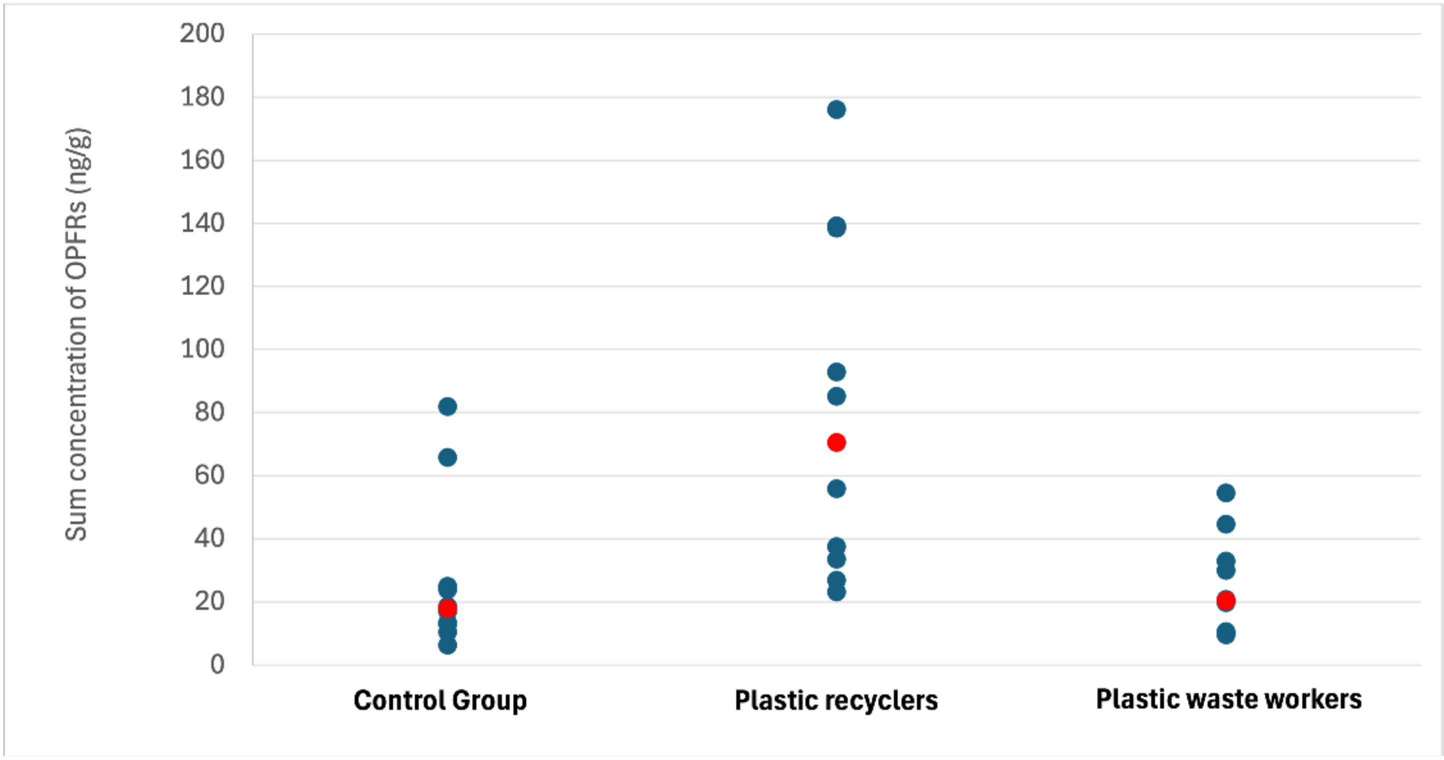


Figure 3a. Sum of concentrations detected of organophosphate flame retardants (ng/g). Median values for each participant group in red.

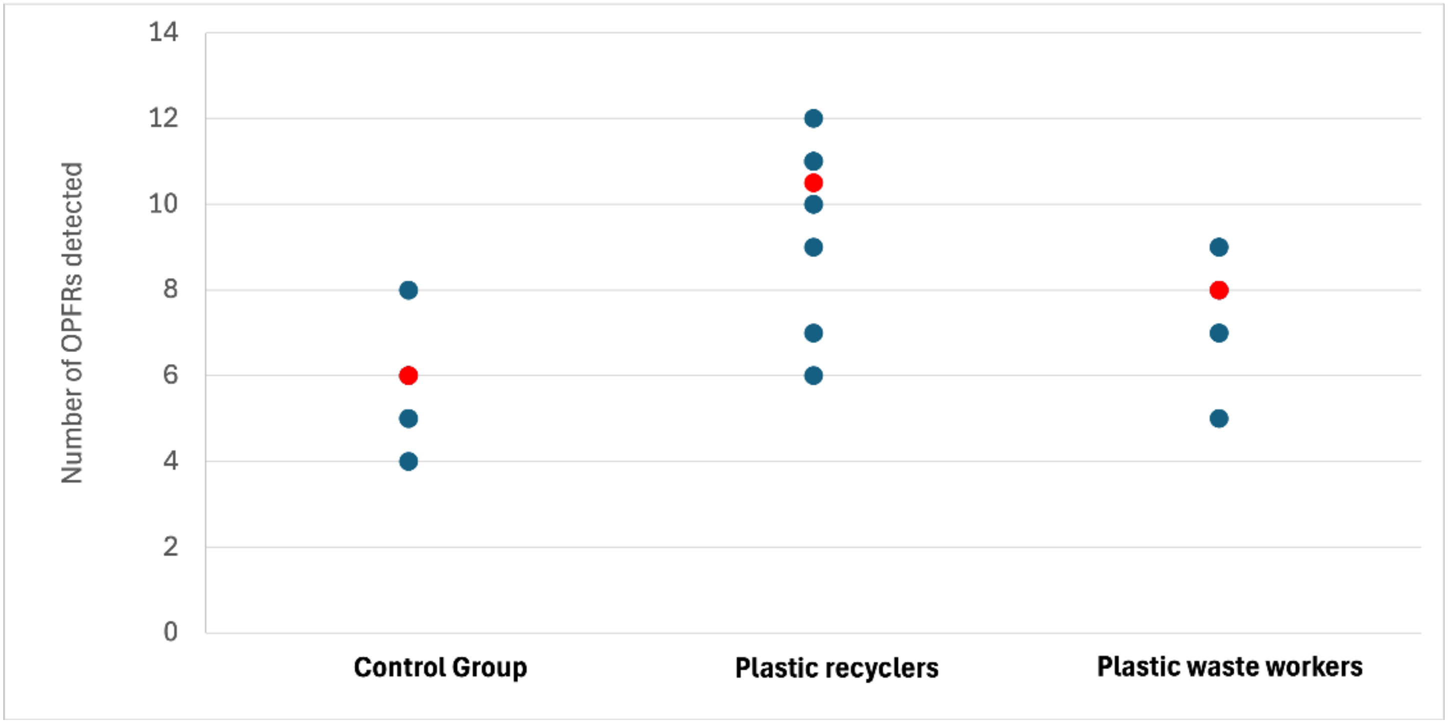


Figure 3b. Number of organophosphate flame retardants detected per wristband. Median values for each participant group in red.

5. RECYCLERS AND WASTE WORKERS WERE MORE EXPOSED TO POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Out of the 24 PAHs included in the study, 16 were detected in one or more wristband and three PAHS were present in all wristbands: phenanthrene, fluoranthene, and pyrene. Plastic recyclers and plastic waste workers were exposed to higher median and minimum concentrations of these than the control group, and waste workers had the highest maximum concentrations (see Tab 3).

	MEDIAN			MIN			MAX		
	CONTROL	RECYCLERS	WASTE WORKERS	CONTROL	RECYCLERS	WASTE WORKERS	CONTROL	RECYCLERS	WASTE WORKERS
Phenanthrene	28	48	42	17	34	28	190	140	460
Fluoranthene	10	33	30	4	24	12	160	79	290
Pyrene	7	38	28	2	20	12	160	75	270

Table 3 Median, maximum and minimum concentrations of the three PAHs detected in all the wristbands (ng/g).

The three individual PAHs detected at the highest concentrations were all in the same wristband of a plastic waste worker: phenanthrene at 460 ng/g, fluoranthene at 290 ng/g, and pyrene at 270 ng/g. The same wristband had the highest sum of PAHs detected at 1,545 ng/g. Trace amounts (1 – 2 ng/g) of fluorene, fluoranthene, and anthracene were detected in the field blank.

Both plastic recyclers and plastic waste workers were exposed to higher concentrations and higher numbers of PAHs than the control group (see Fig. 4a and 4b). The median sum of PAHs was 60 ng/g (range 36 – 679 ng/g) in the control group, 190 ng/g (range 87 – 356 ng/g) in the group of plastic recyclers, and 150 ng/g (range 68 – 1,545 ng/g) in the plastic waste workers.

When assessing exposures of 18 PAHs (16 of which were the same as in this study) to a group of students in France, a similar median total PAH concentration of 50 ng/g was found, whereas the median level was lower in wristbands worn by students in Italy, at 21 ng/g (Wang *et al.*, 2020).

In the study of office workers, exposures to 20 PAHs were included, 15 of which were the same as in this study. When summarizing the median levels detected of each of the PAHs in their study, total median levels in the US and UK were slightly lower (29 and 34 ng/g, respectively) that the levels in the control group in this study, whereas levels in China and India were higher (118 and 149 ng/g, respectively). The study authors note that China and India have previously been shown to have the highest inventoried PAH emissions across the world, due to air pollution from denser populations, traffic, and industrial activities (Young *et al.*, 2021).

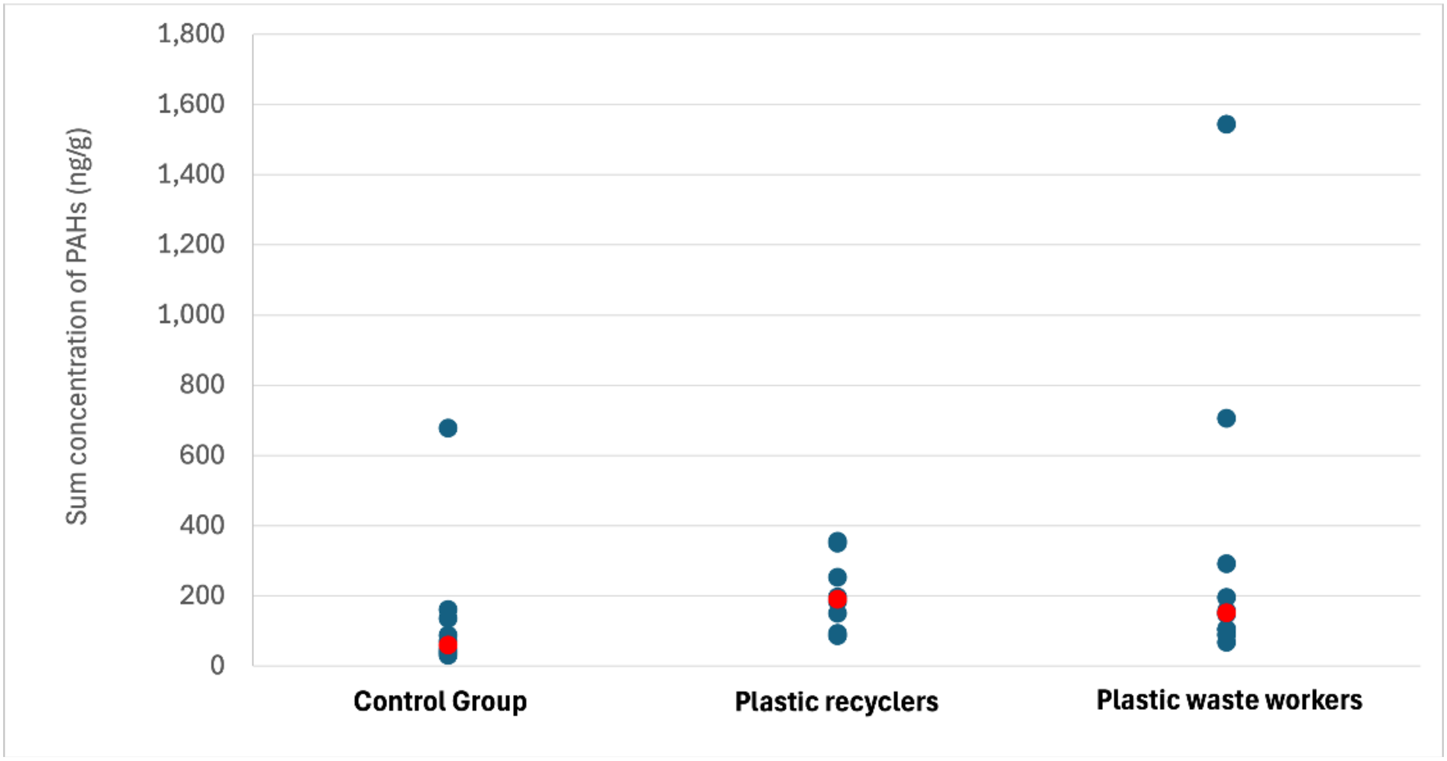


Figure 4a. Sum of concentrations detected of polycyclic aromatic hydrocarbons (PAHs) (ng/g). Median values for each participant group in red.

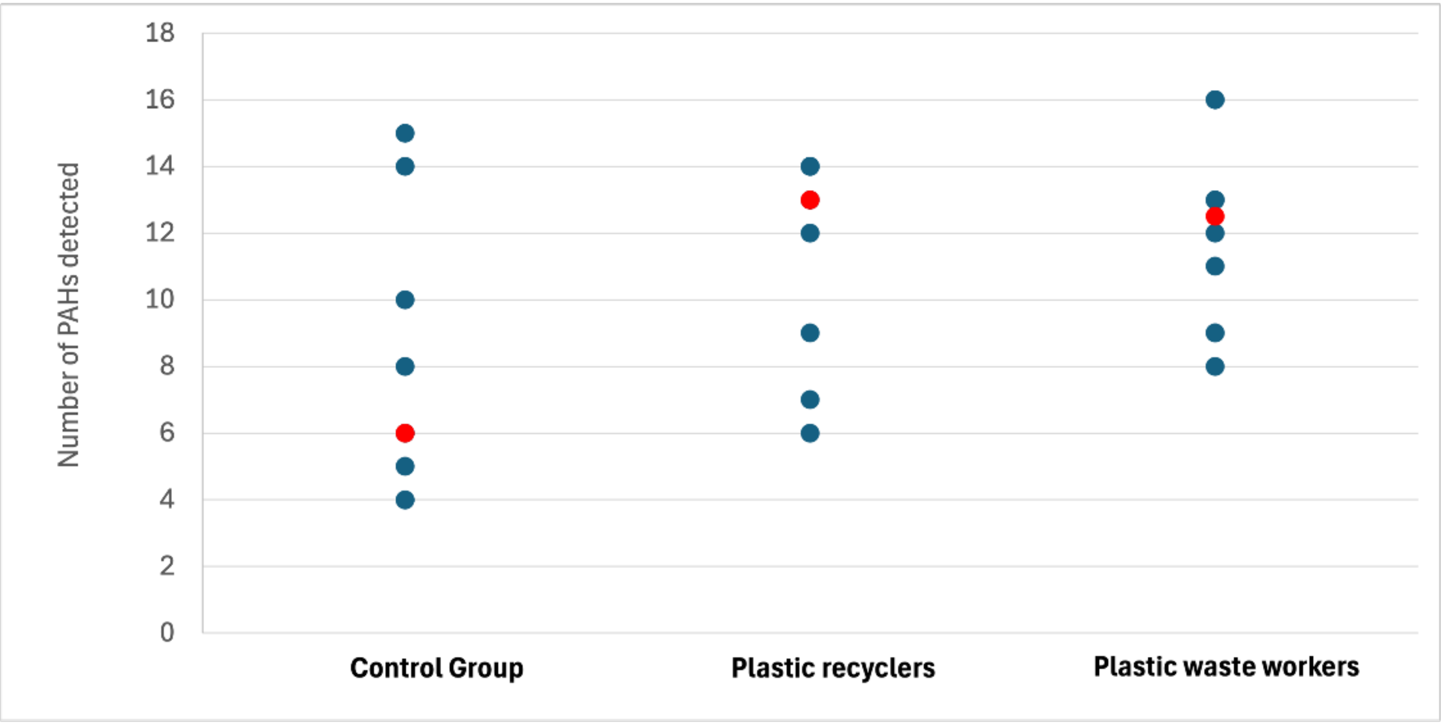


Figure 4b. Number of polycyclic aromatic hydrocarbons (PAHs) detected per wristband. Median values for each participant group in red.

6. ALL PARTICIPANTS WERE EXPOSED TO THE PHTHALATE PLASTICIZER ALTERNATIVES

In the EU, the use of alternative plasticizers has become more common than the use of phthalates due to increasing regulations of phthalates. The alternatives are therefore commonly detected in, for example, household dust (Jung *et al.*, 2024).

Two alternative plasticizers were included in the study, Bis(2-ethylhexyl) adipate (DEHA) and Trioctyl trimellitate (TOTM). Both were detected in all wristbands (see Fig 5a and 5b). While median exposure levels to ToTM was slightly lower in the control group compared to the plastic waste workers (500 ng/g vs 740 ng/g in the group of plastic recyclers and 750 ng/g in the group of plastic waste workers), median levels of DEHA were much higher in the control group (3,900 ng/g) compared to the plastic recyclers (1,600 ng/g) and plastic waste workers (2,700 ng/g). Traces of ToTM (12 ng/g) and a comparatively low level of DEHA (217 ng/g) were detected in the field blank.

These median levels were all higher than the median levels detected in office workers (Young *et al.*, 2021), where median levels were:

- US: DEHA 669 ng/g and ToTM 228 ng/g
- UK: DEHA 427 ng/g and ToTM 260 ng/g
- China: DEHA 242 ng/g and ToTM 91.9 ng/g
- India: DEHA 753 ng/g and ToTM 485 ng/g

In a study of wristbands worn by three groups of university students in California for five days, these two chemicals were detected in all the wristbands. The range of median levels detected of DEHA in the three groups were 643.3 – 2,336 ng/g, and for ToTM 25.92 – 246.4 ng/g (Reddam *et al.*, 2024). So, while the DEHA median levels were higher than in the study by Young, they were not as high as in the control group of the present study

However, the range of levels detected in this study are within the same range of concentrations detected in individual wristbands in both the study by Young and Reddam.

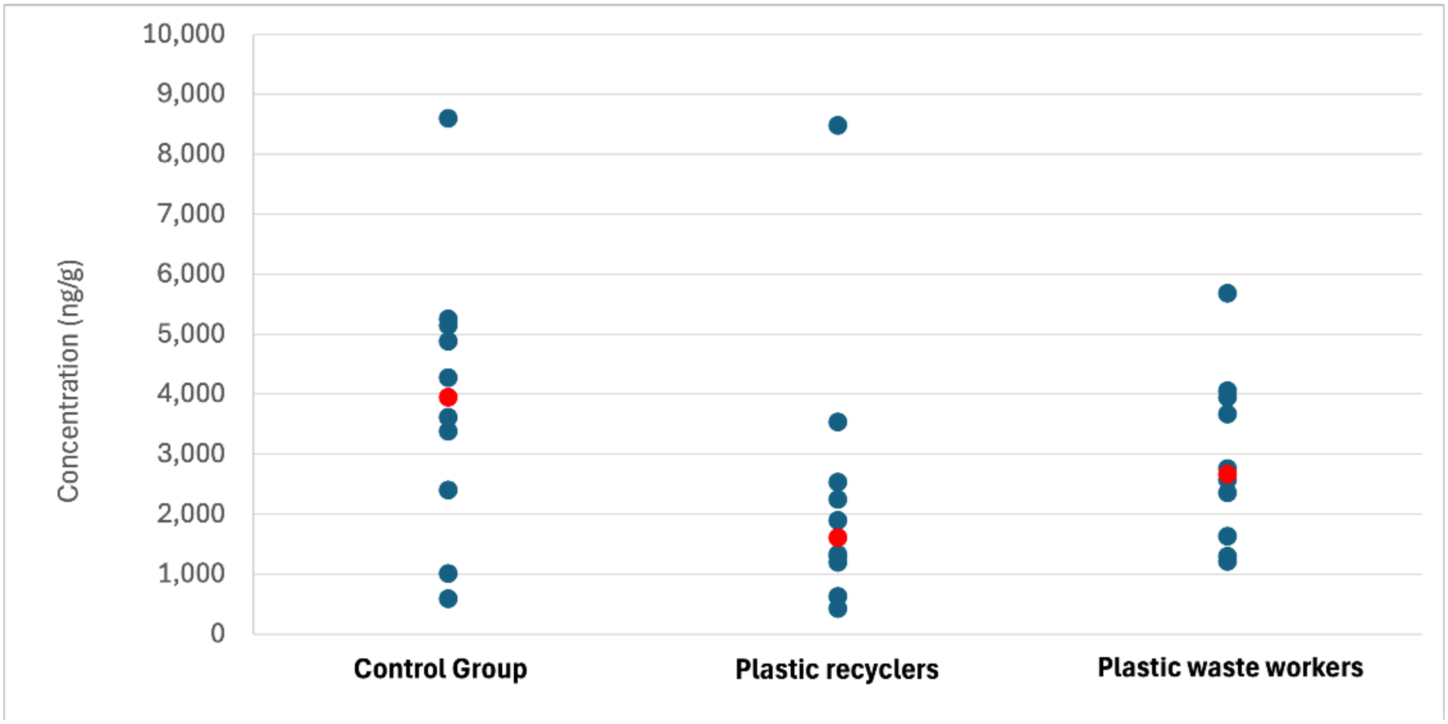


Figure 5a. Concentrations detected of Bis(2-ethylhexyl) adipate (DEHA) (ng/g). Median values for each participant group in red.

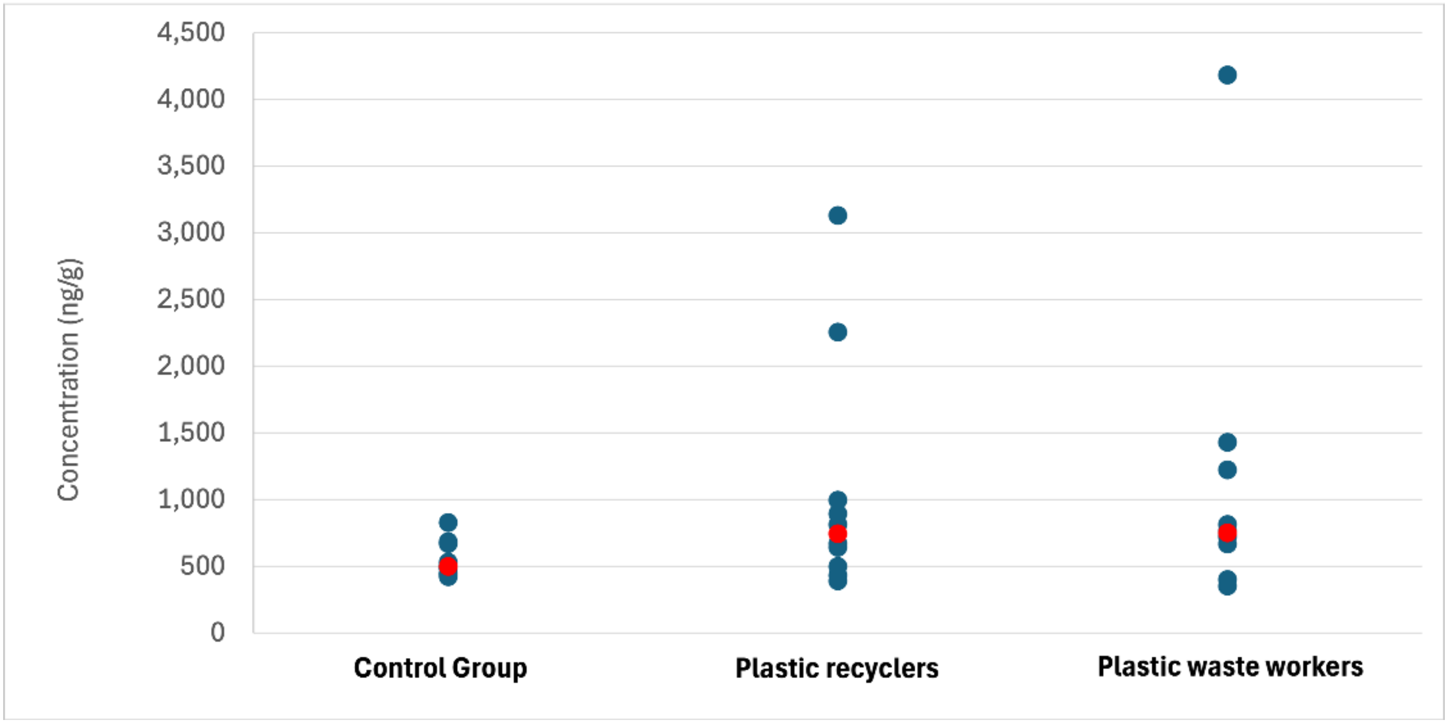


Figure 5B. Concentrations detected of Trioctyl trimellitate (TOTM) (ng/g). Median values for each participant group in red.

CONCLUSIONS AND RECOMMENDATIONS

The results from this study show that all participants were exposed to a wide range of plastic chemicals, all of which have associated health concerns. These included many chemicals that are confirmed or suspected endocrine disrupting chemicals. It is very concerning that the highest concentrations detected in the wristbands were of the phthalates DEHP, DiBP, and DPB, all chemicals that have been strictly regulated in the EU because of their harm to human health.

In addition, the number of chemicals detected in each wristband raises concerns of combined effects, since mixture effects can be higher than the effects of each individual chemical. It should also be noted that this study did not include other widely used chemicals of concern such as pesticides, parabens, brominated flame retardants, and others. It is therefore very likely that participants in this study, as well as everyone else, are exposed to a higher number of hazardous chemicals in our everyday lives.

Plastic waste recyclers and plastic waste workers were exposed to a higher number and higher concentrations of some of the plastic chemicals included in the study. This supports the hypothesis that their work makes them more highly exposed to plastic chemicals than the general population and therefore they must be considered a group in an especially vulnerable situation.

Everyone has the right to a clean, healthy, and sustainable environment, including a safe and healthy working environment. However, not even the wealthiest country has the capacity by its own to protect its people from toxic plastic chemicals, and low- and middle-income countries are the most impacted, even though most are not major plastic producers.

IPEN recommends:

- Legally binding, global controls on plastic chemicals throughout their full life cycle and across sectors must be established in the new Plastics Treaty.
- Replacing one toxic plastic chemical with a similar chemical, so-called regrettable substitution, must be prevented by regulating groups of chemicals.
- Recycling of plastics containing or generating toxic chemicals must be prohibited. These plastics should instead be destroyed using non-combustion technologies.
- Producers must be required to disclose the chemicals in their plastics and plastic products and ensure that the information is publicly available throughout the full product life cycle.
- Employers must fulfill their obligations to protect their workers from harm from plastic chemicals, prioritizing elimination, and where this is not possible, substitution of toxic plastic chemicals as established in the occupational safety and health hierarchy of controls.
- The overproduction of plastics leads to higher exposures to toxic plastic chemicals. Therefore, plastic production and use must be reduced.

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ANNEX I - RESULTS FROM THE CHEMICAL ANALYSIS

Minimum, maximum and median concentrations of the chemicals detected in wristbands of the three groups of participants, and concentrations detected in the field blank (ng/g).

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Dimethyl phthalate	DMP	6.89	2,254	10.8	30.4*	30.4*	30.4*	BLQ	BLQ	BLQ	BLQ
Diethyl phthalate	DEP	140	9,170	1,804	72.1	2,130	924	78.7	10,159	1,641	BLQ
Di-n-propyl phthalate	DnPrP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-isobutyl phthalate	DiBP	144	107,107	453	114	817	366	300	2,433	474	BLQ
Di-n-butyl phthalate	DnBP	746	23,880	2,266	457	8,035	2,321	1,191	16,017	3,346	37.8
Di-isopentyl phthalate	DiPeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
N-pentyl-isopentyl phthalate	nPiPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-n-pentyl phthalate	DnPeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-n-hexyl phthalate	DnHP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dicyklohexyl phthalate	DcHP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Butyl benzyl phthalate	BBzP	9.52	577	69.4	7.79	1,547	41.4	71.8	2,152	113	BLQ
Bis(2-ethylhexyl) phthalate	DEHP	3,486	64,748	8,365	5,466	73,945	13,457	9,759	157,142	46,594	BLQ
Trioctyl trimellitate	ToTM	423	828	501	391	3,132	744	353	4,187	751	12.4
Bis(2-ethylhexyl) adipate	DEHA	586	8,601	3,946	424	8,482	1,611	1,215	5,682	2,664	217
4-n-octylphenol	4-OP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
4-n-nonylphenol	4-NP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Naphthalene	NA	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Acenaphthylene	ACY	1.20	18.0	3.75	1.31	15.0	3.47	2.63	99.8	3.24	BLQ
Acenaphthene	ACE	3.21	48.7	35.3	46.3*	46.3*	46.3*	31.6	93.3	56.7	BLQ
Fluorene	FLN	6.92	18.5	12.7	8.97	21.7	15.3	3.39	67.9	13.3	1.32
Phenanthrene	PHE	16.9	192	27.7	34.1	139	47.7	27.6	456	41.7	BLQ
Anthracene	AN	3.95	36.9	7.41	4.60	78.5	14.0	7.57	102	12.3	2.23
Fluoranthene	FLT	4.33	155	9.85	24.4	79.1	32.7	12.1	290	30.1	1.57
Pyrene	PY	2.24	156	6.84	19.7	75.3	38.5	12.2	274	28.3	BLQ
Benzo[c]fluorene	BcFl	0.79	9.75	1.34	0.94	5.17	1.86	0.73	14.3	2.22	BLQ
Benzo[a]anthracene	BaA	1.84	12.7	2.98	2.25	12.5	5.80	0.64	23.1	3.07	BLQ
Cyklopenta[cd]pyrene	CPP	2.56	17.8	10.2	1.67	23.5	7.49	0.97	53.7	6.99	BLQ
Chrysene	CHR	0.51	15.0	1.47	1.23	18.2	4.17	0.92	31.8	4.55	BLQ
5-methylchrysene	5MC	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Benzo[b]fluoranthene	BbFA	0.64	3.58	1.72	0.77	18.6	6.85	0.59	10.3	3.02	BLQ
Benzo[k]fluoranthene	BkFA	0.72	1.31	1.02	0.63	8.51	2.98	1.14	5.59	2.29	BLQ
Benzo[k]fluoranthene	BjFA	0.51	2.36	1.31	1.39	11.3	4.38	3.04	8.13	5.39	BLQ
Benzo[a]pyrene	BaP	0.66	1.24	0.83	0.70	7.59	2.58	1.18	8.66	2.52	BLQ
Indeno[1,2,3-cd]pyrene	IP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ah]anthracene	DBahA	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Benzo[ghi]perylene	BghiP	0.00	0.00	BLQ	1.31	7.58	5.39	0.82	5.28	2.97	BLQ
Dibenzo[al]pyrene	DBalP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ae]pyrene	DBaeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ai]pyrene	DBaiP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ah]pyrene	DBahP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Drometrizole	UV-P	32.2	80.2	46.6	18.0	36.3	25.6	16.3	17.0	16.7	BLQ
Tinuvin 234	UV-234	1.10	17.4	2.30	1.20	31.9	3.18	1.30	21.4	3.05	BLQ
Tinuvin 320	UV-320	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bumetrizole	UV-326	8.33	53.2	20.1	7.33	92.4	48.6	9.33	547	20.2	5.23
Tinuvin 327	UV-327	12.3	14.1	13.2	0.70	4.75	2.20	1.10	2.70	2.20	BLQ
Tinuvin 328	UV-328	3.40	24.8	10.4	3.10	17.9	8.65	3.00	8.80	4.50	BLQ
Octrizole	UV-329	1.80	8.40	4.00	0.80	7.80	1.55	0.70	24.0	0.90	BLQ
Tinuvin 350	UV-350	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol A	BPA	0.85	25.4	2.01	0.94	12.4	6.49	2.23	15.3	4.75	0.93
Bisphenol B	BPB	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol F	BPF	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol S	BPS	0.05	1.47	0.12	0.06	1.59	0.17	0.09	2.23	0.36	BLQ
Triethyl phosphate	TEP	0.52	0.52	0.52	0.70	2.31	1.09	0.52	1.07	0.70	BLQ
Tri-n-propyl phosphate	TPrP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tri-isobutyl phosphate	TiBP	0.76	30.9	2.96	0.91	36.4	9.61	0.60	19.0	3.05	BLQ
Tri-n-butyl phosphate	TnBP	3.76	30.2	9.84	5.70	35.8	23.3	2.40	23.3	7.93	0.12
Tris(2-butoxyethyl) phosphate	TBOEP	0.26	6.54	1.26	0.25	6.48	0.55	0.52	3.31	1.98	BLQ
Tris(2-ethylhexyl) phosphate	TEHP	0.11	8.89	0.44	0.10	1.69	0.69	0.16	6.27	0.66	BLQ
Triphenyl phosphate	TPhP	0.44	2.03	1.08	1.29	8.33	5.73	0.29	3.36	1.28	BLQ
Cresyl diphenyl phosphate	CDPP	0.45	0.57	0.48	0.64	18.4	6.96	0.78	1.80	1.03	BLQ
Tricresyl phosphate (sum of isomers)	¼TCP	0.18	0.35	0.27	0.84	41.9	3.83	0.18	13.1	0.50	BLQ

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	**ACRONYM**	**MIN**	**MAX**	**MEDIAN**	**MIN**	**MAX**	**MEDIAN**	**MIN**	**MAX**	**MEDIAN**	
Ethylhexyl diphenyl phosphate	EHDPhP	3.21	3.92	3.56	3.70	31.07	6.93	3.53	8.80	3.73	BLQ
Isodecyl diphenyl phosphate	iDDPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tris(2-isopropylphenyl) phosphate	TIPPP	BLQ	BLQ	BLQ	0.73	2.10	1.14	0.22	0.39	0.39	BLQ
Tris(p-tertbutylphenyl) phosphate	TtBPP	BLQ	BLQ	BLQ	0.09	0.38	0.14	BLQ	BLQ	BLQ	BLQ
Trixylenyl phosphate	TXP	BLQ	BLQ	BLQ	13.7*	13.7*	13.7*	BLQ	BLQ	BLQ	BLQ
Tris(2-chloroethyl) phosphate	TCEP	BLQ	BLQ	BLQ	0.68*	0.68*	0.68*	BLQ	BLQ	BLQ	BLQ
Tris(2-chloropropyl) phosphate	TClPP	BLQ	BLQ	BLQ	61.1	61.9	61.5	BLQ	BLQ	BLQ	BLQ
Tris(1,3-dichloroiso-propyl) phosphate	TDClPP	0.49	3.76	0.61	0.32	1.53	0.67	0.26	0.86	0.37	BLQ
Tris(tribromopentyl) phosphate	TTBNPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tetrakis(2-chlorethyl) dichloroisopentyl diphosphate	V6	BLQ	BLQ	BLQ	0.05	0.10	0.07	BLQ	BLQ	BLQ	<0.05
Resorcinol-bis(diphenyl) phosphate	RDP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol A-bis(diphenyl) phosphate	BPA-BDPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ

BLQ = Below limit of quantification
*only detected in one wristband in the participant group

ANNEX II – DETAILS OF THE PRECLEANING AND ANALYSIS OF THE WRISTBANDS

A. Method of preparing silicone wristbands for sampling

Before sampling, the silicone wristbands (SWs) were pre-cleaned with solvent mixtures ethyl acetate:hexane (1:1, v/v) for 3x2 hours ethyl acetate:methanol (1:1, v/v) for 2x2 hours. The SWs were then placed in pre-baked aluminium foil (450 °C, 5 h) and dried for 2 hours (450 °C). The SWs were then stored in prepared aluminium boxes.

B. Method for isolating target polar analytes from SWs (organophosphate flame retardants and bisphenols)

The target analytes were extracted from the SWs with basic methanol (1% NH4OH in methanol) by ultrasound-assisted extraction (3x30 min). The combined extract was evaporated to dryness and redissolved in methanol with internal standards and analysed by UHPLC-MS/MS after filtration.

C. Method for isolating target non-polar analytes from SWs (phthalates, polycyclic aromatic hydrocarbons, UV stabilisers)

The target analytes were extracted from SW with the solvent mixture hexane:dichloromethane (1:1, v/v) by ultrasound-assisted extraction (3x30 min). The combined extract was redissolved in hexane.

A half aliquot was used for the analysis of UV stabilisers after the solvent was change to methanol containing internal standards and analysed by UHPLC-MS/MS after filtration.

The second part of the extract was purified with silica SPE. The purified extract was evaporated and redissolved in isooctane with internal standards and analysed by GC-MS/MS.

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