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Identification of Microplastic Polymers in Packaged Sugar-Sweetened Beverages and Associations with Children's Diabetes Mellitus Risk

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ABSTRAK

Microplastics are known to be composed of many chemical compounds, and there are compounds that act as hormone disruptors that can trigger insulin resistance. Children are the highest consumers of sugar-sweetened beverages in packaging (SSBs), which generally have plastic packaging. The study aimed to identify the presence of microplastics and polymer types of SSBs that are widely consumed in Indonesia, and evaluate their potential impact on health, especially the risk of diabetes mellitus in children. SSBs samples were taken from several brands in traditional and modern stores in Gresik Regency. The analysis was conducted by FT-IR test with the control variable being the water source from Beji Spring, Wonosalam. Furthermore, a literature review was conducted on the relationship between microplastics and diabetes mellitus in children. The results showed that the microplastics detected were filaments and fibers with polymers PET, PP, POM, EVOH and others. Microplastics are known to affect the performance of the pancreas so that it will cause diabetes mellitus in children. Reflecting on this condition, the government is expected to make quality standards for microplastics because of their harmful impact on the human body, especially children.

Keywords: SSBs, Microplastics, Children, Diabetes Melitus Risk

PENDAHULUAN

Children are the biggest consumers of packaged sugar-sweetened beverages (SSBs). According to Riskesdas (Basic Health Research) data by the Indonesia Ministry of Health (2018), 61.3% of respondents consume sugary drinks more than 1 time per day, 30.2% 1-6 times per week and only 8.5% consume them less than 3 times per month. Based on data from the Indonesia Ministry of Health (2023) shows that more than 50% of children aged 3-14 years consume sugary drinks more than once a day. Further revealed by YLKI (2023) that 1 in 4 or 25.9% of children aged less than 17 years consume SSBs every day, even 1 in 3 (31.6%) children consume SSBs 2-6 times a week. The packaging used by SSBs is plastic.

Most of the plastic consumption in Indonesia is used for packaging (including single-use plastic bottles) at 34.88%, for plastic bags 33.26%, for automotive and construction 22.09%, 5.35% for buildings and 4.42% for electronics (DRI's Pulse Check, 2023). The increase in the amount of plastic production since 1970 has made many developed and also developing countries experience the problem of increasing the amount of plastic waste (Ritchie et al., 2023).

Plastics are composed of 16,000 chemical compounds and of these only a small number have been studied for their effects. One of the common plastic chemicals that are most harmful to human health are BPA (*bisphenol A*), phthalates (*plasticizers*), PCBs (*polychlorinated biphenyls*) and PBDEs (*Polybrominated Diphenyl Ethers*) and additional plasticizers, fillers, stabilizers, dyes, and flame insulators (Gündoğdu et al., 2024; Hahladakis, 2020) . Through the polymerization process, the extracted petroleum is converted into Poly(*ethene*), and then additives are added to form

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plastic pellets that can be formed into various types of plastics, such as *polyvinyl chloride* (PVC), *polyethylene* (PE), *polystyrene* (PS) (Sarker et al., 2012). One of the main functions of phthalates is for *plastisizer* agents that aim to increase the flexibility and ductility of plastics while BPA serves as a stabilizer to prevent plastic degradation due to heat, light, or oxidation (Mondal et al., 2022; Rubin, 2011).

Most polymers used in plastic packaging materials are subject to certain changes due to external conditions that cause the release of chemical components. Specific physico-chemical changes of polymers occur after exposure to high temperatures, UV light and changes in pH. The migration of plastic components depends not only on the quality of the plastic material but also the characteristics of the food and the time of contact or exposure. Plastic products, have additives that are not covalently bound to the polymer and easily migrate to the food or beverage they come in contact with (Aprilianti, 2023). There was an increase in the migration of some components of PET bottles into water at 60ºC and there was a release of 11.6 billion microplastics and 3.1 billion nanoplastics from plastic tea bags soaked in water at 95ºC (Bach et al., 2013; Cortés et al., 2020). Physical processes such as repeated friction and displacement can accelerate plastic degradation, particularly when bottles are exposed to mechanical stress or high temperatures which then trigger the release of microplastics (Mason et al., 2018).

Besides being composed of hazardous chemical compounds, microplastics have the ability to absorb and bind hazardous pollutants in the environment. Microplastics and their chemical compounds have the ability to bioaccumulate and biomagnify so that they accumulate in the body and spread in the food chain. Microplastics and their chemical compounds cause negative impacts on human health, such as gastrointestinal disorders and lung toxicity, oxidative stress, inflammatory reactions, and metabolic disorders, reduce growth rates, inhibit enzyme production, reduce steroid hormone levels, affect reproduction, and can cause greater exposure to plastic additives toxic properties (Akhbarizadeh et al., 2019; Tuhumury & Ritonga, 2020) . In addition, plastic toxic compounds can affect endocrine health, including the hormone insulin, which plays an important role in the regulation of glucose metabolism. Children who frequently consume SSBs are higher risk of exposure to microplastics and the harmful chemical compounds dissolved in them. Exposure to toxic plastic compounds can lead to insulin resistance, which is a major risk factor for the development of type 2 diabetes. When children consume SSBs contaminated with microplastics, they not only get a high sugar intake but are also exposed to compounds that can interfere with the normal function of the hormone insulin (Belmaker et al., 2024).

According to Crawford & Quinn (2016), microplastics are generally defined as pieces of plastic that based on size and length dimensions can be categorized as macroplastics (≥25 mm), mesoplastics (<25 mm -5 mm), microplastics (<5 mm -1 μm), and finally nanoplastics (<1 μm). Microplastics in bottled drinking water (AMDK) 93% of 259 bottles from 11 brands sold in several countries including Indonesia with an average of 10.4 particles /L of microplastics measuring >100 μm, 335 particles / L measuring (6.5- 100 μm) with fragments and polymer type Polypropylene (PP) (Masson *et al*, 2018). Microplastics were also found in 23 brands (bottled water) as many as 215 particles in China, mostly in the form of fibers and fragments with polymer types Polystyrene (PS), Polyethylene-terephthalate (PET) and Polyethylene (PE) with sizes of 0.025-5.000 mm and abundances ranging from 2 to 23 particles / bottle (Zhou et al., 2021) . Microplastics were also found in refill drinking water (AMIU) in Gunung Anyar Subdistrict Surabaya as many as 25 samples of *High Density Polyethylene* (HDPE) type, 13 samples containing

Polyvinyl Chloride (PVC) type microplastics and 11 samples containing *Polyethylene* (PE) type microplastics, fiber-shaped with 159 blue particles, 130 red particles, 67 clear particles and 35 yellow particles (Abdulloh, 2020).

Many studies on microplastic contamination in bottled drinking water have been conducted and shown positive results with different concentrations of microplastics. However, examinations of microplastic contamination in SSBs are still limited. Considering the high consumption of various flavors of bottled drinking water among Indonesians, especially children and adolescents, this research is very important to do. The study aims to identify microplastics and their polymers in SSBs and determine the relationship between microplastics and diabetes mellitus cases in children. The results of this study are expected to provide an early warning regarding the potential dangers of microplastic contamination, especially for children and adolescents who are in the developmental phase.

RESEARCH METHODS

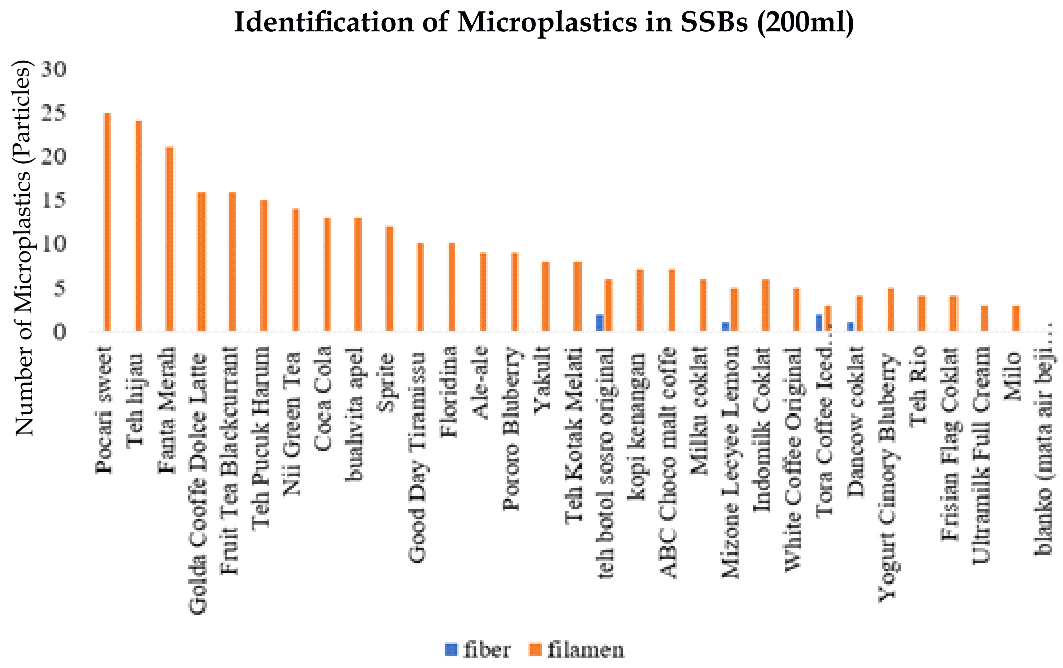
This research was conducted in June-November 2024 in Gresik Regency, East Java. This is because Gresik Regency is the 4th district in East Java which has the largest number of mini markets after Sidoarjo, Malang, and Surabaya (BPS East Java, 2018). This will affect the number of sales of several products, one of which is BMDK products.

This study used mixed methods, namely quantitative and qualitative. The quantitative method was used to identify MBDK microplastics and their polymers using FT-IR. Then it will be explained with descriptive quantitative. Meanwhile, the qualitative method was used to link the consumption of MBDK and the risk of diabetes mellitus in children. This method uses literature review from several sources, namely Scopus and Google Scholar.

SSBs samples in this study were taken from 3 traditional stores and 2 modern stores with a total sample of 30 brands and 3 replicates of each brand. The type of sampling method used is convenience sampling. Because it selects stores randomly and adjusts to the availability of samples, which reflects the ease of access and conditions that exist in the field. Although there is an element of randomization in store selection, the sample availability factor remains the main consideration. In this study, control samples were taken from Beji Village, Wonosalam Subdistrict, Jombang Regency spring water source for comparison of plastic bottled drinking water samples.

Preparation and identification of microplastic types were carried out at the ECOTON Foundation microplastics and water quality testing laboratory. All equipment to be used in this study was cleaned and rinsed using 10% nitric acid and secondly using aqubidest to avoid any contaminants originating from the external environment. For the test samples, 200 ml of each replicate of each brand was prepared. Each replicate of each brand was filtered using a 0.45 micrometer pore size cellulose nitrate filter with the help of a vacuum pump to speed up the filtering process. After completion of filtration, take the cellulose nitrate filter and place it on a cleaned peteri cup, then the sample can be identified based on the type, color, size of microplastics with a magnification of 100x to 400x using a stereo microscope. Meanwhile, to measure microplastic particles using the optilab application and J raster image.

For characterization needs with FTIR-AIM 9000 Shimadzu, the identified samples were sent to the Center for Food and Agriculture laboratory, Faculty of Food Technology, Unika Soegijapranata Semarang. The samples sent were 10 MBDK samples with the highest microplastic content with 50% being samples with multinational brands and the remaining 50% being local brands. FT-IR is a chemical analysis method used to identify the characteristics of compounds in the samples with



Source: Primary Data Processed, (2024)

Figure 1

Lokasi Pengambilan Sampel

infrared light (Dutta, 2017). The identity of the compound can be recognized by its functional groups, which are the types of bonds between different atoms, which is the part that distinguishes one compound from another. FTIR is used to analyze chemical changes on the surface of plastics caused by UV exposure.

RESULTS AND DISCUSSION

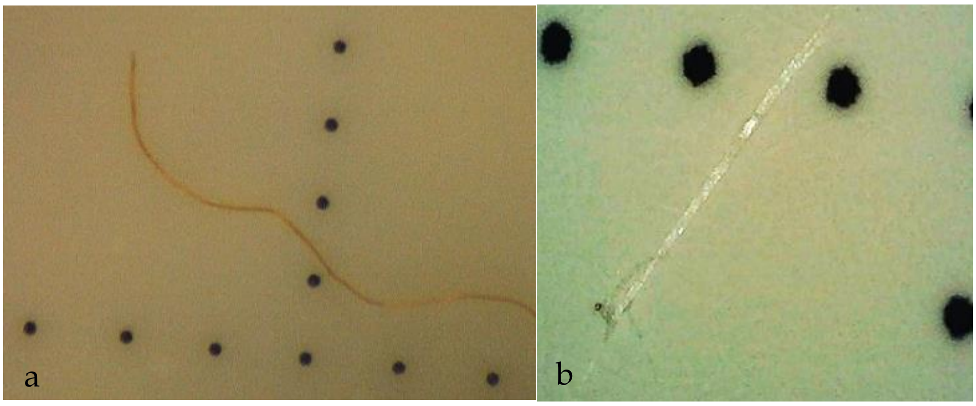
Identification of Microplastic Polymers in SSBs

Based on the identification results using a microscope, the presence of microplastics was found in all SSBs and was not found in the control sample taken from Beji spring water source in Wonosalam, Jombang (Figure 1).

Based on Figure 1, the highest number of microplastics found in MBDK was 25 particles. The lowest number of MBDK microplastics was 3 particles. The number of filament microplastics is more than fiber because all MBDKs are plastic packaged, either in the form of bottles, cups, sachets, or multilayered boxes packaging. The average abundance of microplastics in the 30 samples of packaged SSBs was 0.0495 particles/ml. The average particle size of microplastics found in the samples was 0.11-3.72 mm.

The SSBs containing the the highest levels of microplastics is packaged in plastic bottles with code 1 or PET. This type of plastic classified as a single-use plastic that will be harmful when reused for beverage containers. Meanwhile, the brand's plastic bottle packaging tends to be thick compared to other brands and bottled bottled water. This means that the thickness of the plastic does not affect the bonding strength of the plastic content itself. The MBDK with the second highest microplastic content was obtained from a grocery store that placed the product in direct sunlight. This means that errors in the placement of plastic-packaged SSBs will affect the amount of microplastics released.

Microplastics in bottled drinking water can potentially enter the human body through ingestion, specifically via consumption. Emenike et al.(2023) explained that the process of entry of microplastics into the human body can occur through several main pathways



Source: Primary Data Processed, (2024)

Figure 2.

Microplastics in SSBs (a. Microplastic Fiber, b. Microplastic Film)

through inhalation, ingestion (digestion), and skin contact. The largest proportion among the three pathways is inhalation (digestion) with sources include drinking water and food in plastic packaging, seafood, salt and other foods that are contaminated during production or serving.

This study is in line with Singh & Talpade's (2024) which states that plastic bottled drinking water in the Mumbai Market contains an average of 15 ± 20 microplastics per 30 ml of water with an average size of 82 ± 22 micrometers. The most commonly found polymers are polyethylene terephthalate (PET) and polypropylene (PP), which originate from packaging materials and microplastic bottle caps that are commonly found in disposable plastic bottled drinking water. The presence of microplastics in drinking water is due to the microplastic migration process occurring during the production and packaging stages, where friction between caps and bottles and contact with the surrounding environment can cause microplastics to be released into the water. Additionally, contamination can also arise from the water filling process and the degradation of packaging materials.

Plastics in bottled water can degrade into microplastics due to several external and internal factors. Exposure to sunlight (photodegradation) and high temperatures during storage and distribution can trigger the degradation of plastic polymer chains into small particles. In addition, chemical contamination from substances that come into contact with the plastic, including from contaminated water, can also accelerate the chemical process that breaks down the plastic into microplastics. Friction and abrasion during transportation and handling of water bottles also contribute to the release of small particles from the bottle surface. The longer the plastic is stored, the more likely it is to degrade as older plastics are more brittle and break down easily. The type of plastic used, such as PET (Polyethylene Terephthalate), and its chemical composition also affect the plastic's resistance to external factors such as heat, UV light and friction, which in turn affects how readily it degrades into microplastics (Geyer et al., 2017; Lambert & Wagner, 2017) .

Sang et al.(2020) explained that at temperatures around 20 °C, all PET products degrade at a much slower rate. The degradation rate showed in increase significantly with increasing temperature. Ruoko(2012) proved that the length of UV exposure is directly proportional to the degradation rate of the plastic, which is detected as an increase in carbonyl absorption in the IR spectrum. The longer the UV exposure, the more the plastic structure is damaged due to the formation of carbonyl groups, which is an indicator of oxidative degradation. Petroody et al. (2023) explained that a wide variety of plastics present in the environment absorb ultraviolet (UV) radiation and undergo

Table 1
FT-IR Test Results of 10 SSBs Brands

SSBs Brand	Types of Polymers
Yakult	Thermal-Damaged Plastics - 87 PP(10)_350-2h , Thermal-Damaged Plastics - 45 PE(07)_350-2h
Fantasy	Thermal-Damaged Plastics - PET(02)_250-2h
Mizone	Thermal-Damaged Plastics- 49 PET (02)_2 50-2h
Sprite	UV-Damaged plastics PS 500h , HardPVC_150h
Pocari Sweat	UV Damaged plastics-88 HardPVC_150h
Fruit Tea	UV-Damaged Plastics - 303 POM_27h , UV-Damaged Plastics - 308 POM_50h
Pororo	UV-Damaged Plastics- 260 PU_125h , UV-Damaged Plastics – 278 PBT_25h
Dancow	Thermal-Damaged Plastics - 87 PP(10)_350-2h , UV-Damaged Plastics - 278 PBT_25h , T-Polymer2 36 EVOH , UV-Damaged Plastics - 345 PMP_550h , UV-Damaged Plastics - 152 ABS_400h
Golda Coffee	Thermal-Damaged Plastics - 87 PP(10)_350-2h , Thermal-Damaged Plastics - 49 PET(02)_250-2h
The Green	Thermal-Damaged Plastics - 87 PP(10)_350-2h , UV-Damaged Plastics - 46 PP_550h, 550h

Source: Primary Data Processed, (2024)

photolytic, photo-oxidation, and thermal oxidation reactions that cause their degradation. Polymer photodegradation involves physical and chemical changes, leading to a decrease in molecular weight and loss of flexibility and mechanical integrity. Photodegradation can occur in the presence of oxygen (photooxidation). The photooxidation of polymers usually involves reactions caused by free radicals that lead to chain cleavage, cross-linking, and eventual formation of functional groups (degradation of plastic polymers).

Based on Table 1, it is known that Fruitea Blaccurant detected UV-Damaged Plastics - 303 POM_27h and UV-Damaged Plastics - 308 POM_50h, UV exposure to polyoxymethylene (POM) plastics causes degradation through photochemical and oxidation reactions. UV exposure of POM results in changes to its chemical structure, which are often identified by the appearance of carbonyl (C=O) and hydroxyl (O-H) groups in FTIR results. POM_27h and POM_50h can be interpreted to mean that the exposure duration of 27 hours and 50 hours indicates the length of time these samples were exposed to UV. The presence of POM content in the sample correlates with the type of fruitea blaccurant sachet plastic, namely "other", one of the constituents of which is POM polymer. Based on the research of Liu et al. (2023), POM can be used as an inner layer due to its moisture resistance and good airtightness. In certain cases, POM can also be utilized in components such as closures or seals that interact directly with the product.

Dancow carton box packaging detected plastic polymers include Thermal-Damaged Plastics - 87 PP(10)_350-2h, 350-2h indicates heating process for 2 hours. Thermal-Damaged Plastics that have deteriorated due to exposure to high temperatures. UV-Damaged Plastics - 278 PBT_25h, indicating that this PBT was exposed to UV light for 25 hours. T-Polymer2 is a code or name for a specific type of plastic, and 36 EVOH indicates that the polymer is composed of ethylene-vinyl alcohol. UV-Damaged Plastics - 345 PMP_550h, 550h means that this material underwent 550 hours of UV exposure. UV-Damaged Plastics - 152 ABS_400h, ABS is widely used for durable products, but is susceptible to UV light which can cause color fading, brittleness, and surface cracking over time. Exposure for 400 hours simulates extensive wear conditions.

Milk carton packaging generally consists of more than 70% paper, but also contains polymers that serve to ensure the paper remains bonded to the aluminum layer and provide additional protection against moisture. Polymers used include polypropylene, polyethylene, ABS and others (Tice, 2002) . EVOH (ethylene-vinyl alcohol) is one of the materials used in carton packaging for liquid products, including milk. EVOH is usually arranged in a multilayer structure, where a layer of EVOH is placed between layers of other materials, EVOH is responsible for blocking gases (Gaucher-Miri et al., 2002).

Liquid milk carton box packaging generally consists of several layers of material, including plastic polymers that act as a protective barrier and leak barrier. One type of polymer often used in this packaging is POM (Polyoxymethylene), also known as formaldehyde. When POM packaging comes into contact with beverage products, molecules from the polymer can begin to move into the liquid. This process is affected by temperature, contact time, and the chemical properties of the beverage product. Higher temperatures can increase the diffusion rate as the kinetic energy of the molecules increases (Kadac-Czapska et al., 2023) . Liquid milk carton packaging usually consists of three main layers: an outer layer made of cardboard to provide strength and stability, a middle layer made of aluminum material that serves as a barrier against light and oxygen, and an inner layer made of plastic polymers such as PS (Apt & Tu, 2013) . PBT (Polybutylene Terephthalate) plastic polymer is one type of plastic that is often used in various industrial applications, including as a component in liquid milk carton packaging (Kaseke et al., 2023) .

In the polymer test results of Golda Coffee samples, PP and PET polymers were detected. The Golda Coffee bottle packaging is PET plastic and the bottle cap is PP plastic. Thermal-Damaged Plastics - 87 PP(10)_350-2h, **350-2h** indicates that this PP sample has been exposed to 350°C for 2 hours. Thermal-Damaged Plastics - 49 PET(02)_250-2h, **250-2h** means that this PET has been exposed to 250°C for 2 hours.

The polymer test results of the green tea sample, which was packaged in PP plastic, detected the polymer Thermal-Damaged Plastics - 87 PP(10)_350-2h, 350-2h, indicating that this PP plastic had been exposed to high temperatures for 2 hours. This exposure caused thermal damage to the PP structure, which may affect stability and increase the release of certain compounds. Additionally detected UV-Damaged Plastics - 46 PP_550h, 550h indicates that this plastic has been exposed to ultraviolet light for 550 hours, resulting in UV damage (photo-oxidative degradation). This damage can cause the plastic to become more brittle, discolored.

The polymer test results of the Yakult sample detected PP polymer Thermal-Damaged Plastics - 87 PP(10)_350-2h, 350-2h indicates that this PP plastic has been exposed for 2 hours. This damage may have occurred due to excessive heating during production or in the packaging recycling process, resulting in deterioration of the plastic. This sample also detected PE Thermal-Damaged Plastics - 45 PE(07)_350-2h, 350-2h signifying that this PE has been exposed for 2 hours, causing thermal degradation. This correlates with the packaging type of the Yakult bottle which is a type of PP plastic. Based on the research of Gall et al. (2020), some lids made of aluminum foil have a polyethylene layer on the inside to improve airtightness and prevent contamination.

The polymer test results of Fanta Red and Mizone samples, detected PET polymer Thermal-Damaged Plastics - 49 PET(02)_250-2h, 2h indicates the duration of exposure to such high temperatures for 2 hours. Thermally damaged PET can release compounds such as antimony (commonly used in PET manufacturing catalysts) or other chemical compounds that can dissolve in beverages or liquids. The structure of damaged PET tends to break down more easily into small particles (microplastics). This correlates with the type of plastic bottle packaging, which includes PET.

The polymer test results of pororo samples, detected UV-Damaged Plastics-260 PU_125h, and UV-Damaged Plastics - 278 PBT_25h. 25h and 125h indicate the duration of exposure to such high temperatures for 25 and 125 hours. The pororo plastic packaging type is plastic labeled "other". Polyurethane (PU) plastic polymers serve as elastomers, adhesives and coating materials (Cinelli et al., 2013) . PBT is used in the packaging of food and other products due to its thermal stability and chemical resistance. PBT is often used in lamination applications and as an adhesive material in various industries (Vyavahare et al., 2024).

The polymer test results of sprite samples, detected UV-damaged plastics PS 500h and HardPVC_150h. 500h and 150h indicate the duration of exposure to high temperatures for 500 and 150 hours, respectively. Gupta *et al.,* (2024) Some additives used in the bottle or packaging manufacturing process can be derived from polystyrene and PVC. For example, if emulsifiers or stabilizers based on PS and PVC are used, this could contribute to the detection of polystyrene and PVC.

The polymer test result of Pocari sweat sample detected UV Damaged plastics-88 HardPVC_150h. 150h indicates the duration of exposure to such high temperatures for 150 hours. Barone *et al* (2015) explained that PVC is often used in several types of packaging and bottle caps. If the bottle or cap is made of or contains PVC, it is possible that the material can migrate into the liquid, especially if the bottle is exposed to high temperatures or stored for a long time.

Relationship between Plastic Packaging and Pediatric Diabetes Mellitus

Many studies have shown that the presence of new pollutants including plastic compounds (microplastics) in the environment increases the risk of diabetes in exposed populations and accelerates the onset and progression of the disease. In addition, it is known that the mechanisms of type I diabetes and type II diabetes are different. Type I diabetes is mostly related to genetic factors, while for type II diabetes, lifestyle factors and exposure to new contaminants. Microplastics induce the production of large amounts of ROS in Caco-2 cells, thereby increasing cytotoxicity (Cortés et al., 2020) . Gut microbiota dysbiosis, inflammatory reactions, oxidative stress, and altered innate immune responses, all resulting from microplastic exposure are major pathophysiological factors for insulin resistance. There is potentially a strong link between microplastic exposure and insulin resistance (Xu et al., 2024).

Once accumulated in tissues, microplastics irritate local cells and trigger an immune system response. Immune cells, such as macrophages, detect microplastics as foreign bodies. This triggers the release of pro-inflammatory cytokines including TNF-α (*Tumor Necrosis Factor-alpha*), IL-1β (Interleukin-1 beta), IL-6 n (AL et al., 2013) . At the same time, microplastics can also cause dysbiosis of the gut microbiota, which is a change in the composition of gut bacteria that exacerbates the inflammatory response. Microplastics increase the number of Gram-negative bacteria, which produce lipopolysaccharides (LPS). These LPS then enter the bloodstream and amplify the inflammatory process by further activating macrophages to produce pro-inflammatory cytokines (Cani et al., 2008) . Research by Zhang et al.(2024)) states that microplastics activate inflammatory responses and oxidative stress through the elevation of hepatic lipopolysaccharide (LPS) which inhibits the hepatic SIRT1/IRS1/PI3K pathway, ultimately leading to insulin resistance, impaired glucose metabolism , and poor pregnancy outcomes.

Pro-inflammatory cytokines such as TNF-α and IL-1β that increase due to inflammation interfere with the insulin signaling pathway in the following ways, firstly Inhibition of IRS-1 (Insulin Receptor Substrate-1) i.e. Pro-inflammatory cytokines inhibit the phosphorylation of IRS-1, which is a key molecule in the insulin signaling pathway. IRS-1 plays a role in transmitting signals from the insulin receptor to the PI3K/Akt pathway, which is required to regulate glucose uptake into cells. Both Disruptions in PI3K/Akt, i.e. Disruptions in IRS-1 lead to reduced activation of the PI3K/Akt pathway, which is important in getting glucose from the blood into body cells (such as muscle and liver cells) (Cseh et al., 2000; Hançer et al., 2014) . As the insulin signaling pathway is disrupted, the body cells become less responsive to insulin, this condition is known as insulin resistance. As a result, even though there is sufficient insulin in the blood, the body cells are unable to absorb glucose effectively. This leads to increased blood glucose levels (Huang et al., 2022) . Prolonged insulin resistance due to chronic inflammation leads to a continuous increase in blood glucose levels. The body responds by producing more insulin in the early stages, but over time, the pancreas becomes exhausted and unable to produce enough insulin. This contributes to chronic hyperglycemia, which is characteristic of type 2 diabetes mellitus (Huang et al., 2022) .

In children, organ and metabolic system are still developing, especially the pancreas which produces insulin. Exposure to microplastics, which contain chemicals such as phthalates and BPA (bisphenol A), can disrupt the body's hormonal and metabolic functions. Because children have organs that are not fully mature, they are more sensitive to endocrine disruption than adults. (Gore et al., 2015). These disruptions can lead to changes in the hormones that regulate sugar metabolism, increasing the risk of insulin resistance that triggers type 2 diabetes. Excess sugar consumption forces the pancreas to produce more insulin, which over time can lead to insulin resistance. When combined with exposure to microplastic compounds, this risk of insulin resistance increases further (Cao et al., 2010). In children, this insulin resistance is more prone to develop into diabetes due to an unstable metabolic system (Swan et al., 2015). In children, the gut microbiota is not fully developed, making them more susceptible to these changes. Damage to the gut microbiota can disrupt blood sugar regulation, increase the risk of obesity, and cause insulin resistance, all of which are major risk factors for diabetes mellitus (Saal & Myers, 2008) . Some chemical compounds in microplastics, such as phthalates and BPA, are known endocrine disruptors. They can increase the levels of reactive oxygen species (ROS) in the body, leading to oxidative stress and chronic inflammation. In children, who have a lower capacity to withstand oxidative stress, this increase in ROS can cause a greater inflammatory response, disrupt insulin signaling and trigger insulin resistance. These conditions worsen glucose metabolism and increase the risk of diabetes (Lang et al., 2008).

CONCLUSION

Based on the results of the study, it is known that microplastics were found in all SSBs. The microplastics found were dominated by filament types. Polymer tests using FTIR identified various types of plastics in the packaging, including PET, PP, and POM. Microplastics in SSBs originate from the production and packaging process, where friction between caps and bottles and exposure to sunlight can cause degradation of the plastic into small particles. One of the problems caused by microplastics is insulin resistance, which is associated with diabetes mellitus. Microplastics stimulate an inflammatory response in the body, which disrupts insulin signaling pathways, causing cells to become less responsive to insulin and increasing blood glucose levels. This is particularly risky for children whose metabolic and pancreatic systems are still developing, increasing the likelihood of hormonal and metabolic disturbances due to the chemicals contained in microplastics. Therefore, solutions are needed to reduce the consumption of flavored packaged beverages, especially among children and adolescents, in order to protect future health.

REFERENCES

Abdulloh, M. N. (2020). *Identifikasi Kandungan Mikroplastik pada Air Minum Isi Ulang di Kecamatan Gunung*

Anyar Surabaya [Skripsi, UPN Veteran Jawa Timur]. http://repository.upnjatim.ac.id/1099/5/5.PDF

Akhbarizadeh, R., Moore, F., & Keshavarzi, B. (2019). Investigating Microplastics Bioaccumulation and Biomagnification in Seafood from the Persian Gulf: A Threat to Human Health? *Food Additives & Contaminants: Part A*, *36*(11), 1696–1708.https://www.tandfonline.com/doi/abs/10.1080/19440049.2019.1649473

AL, N., J, C., Couto L, L.-M. A., & Jr, R.-A. R. (2013). Metabolic Endotoxemia: A Molecular Link between Obesity and Cardiovascular Risk. *Journal of Molecular Endocrinology*, *51*(2), R51-64.https://europepmc.org/article/med/23943858

Aprilianti, R. (2023). *Rekam Jejak Mikroplastik*. Surabaya: Global Aksara.

Apt, A., & Tu, C.-M. (2013). *Light Barrier Properties of Paperboard, Packages and Plastic Caps in Packages*. Tesis, Lunds Universitet.

Bach, C., Dauchy, X., Severin, I., Munoz, J.-F., Etienne, S., & Chagnon, M.-C. (2013). Effect of Temperature on the Release of Intentionally and Non-Intentionally Added Substances from Polyethylene Terephthalate (Pet) Bottles into Water: Chemical Analysis and Potential Toxicity. *Food Chemistry*, *139*(1–4), 672–680. https://doi.org/10.1016/j.foodchem.2013.01.046

Belmaker, I., Anca, E. D., Rubin, L. P., Magen-Molho, H., Miodovnik, A., & Hal, N. van der. (2024). Adverse Health Effects of Exposure to Plastic, Microplastics and Their Additives: Environmental, Legal and Policy Implications for Israel. *Israel Journal of Health Policy Research*, *13*(1), 44. https://link.springer.com/article/10.1186/s13584-024-00628-6

BPS East Java. (2018). *Banyaknya Desa/Kelurahan Menurut Sarana Perdagangan dan Akomodasi*. Badan Pusat Statistik Provinsi Jawa Timur. https://jatim.bps.go.id/id/statistics-table/1/MTc1NSMx/banyaknya-desa-kelurahan-menurut-sarana-perdagangan-dan-akomodasi--2018.html

Cani, P. D., Bibiloni, R., Knauf, C., Neyrinck, A. M., & Delzenne, N. M. (2008). Changes in Gut Microbiota Control Metabolic Endotoxemia-Induced Inflammation in High-Fat Diet–Induced Obesity and Diabetes in Mice. *Diabetes*, *57*(6), 1470–1481. https://doi.org/10.2337/db07-1403.Additional

Cao, W., Liu, H. Y., Hong, T., & Liu, Z. (2010). Excess Exposure to Insulin may be the Primary Cause of Insulin Resistance. *American Journal of Physiology - Endocrinology and Metabolism*, *298*(2), E372. https://doi.org/10.1152/ajpendo.00677.2009

Cinelli, P., Anguillesi, I., & Lazzeri, A. (2013). Green Synthesis of Flexible Polyurethane Foams from Liquefied Lignin. *European Polymer Journal*, *49*(6),1174–1184.https://www.sciencedirect.com/science/article/pii/S0014305713001742

Cortés, C., Domenech, J., Salazar, M., Pastor, S., Marcos, R., & Hernández, A. (2020). Nanoplastics as a Potential Environmental Health Factor: Effects of Polystyrene Nanoparticles on Human Intestinal Epithelial Caco-2 Cells. *Environmental Science: Nano*, *7*(1),272–285.https://pubs.rsc.org/en/content/articlehtml/2020/en/c9en00523d

Crawford, C. B., & Quinn, B. (2016). *Microplastic Pollutants*. London: Elsevier Limited.

Cseh, K., Winkler, G., Melczer, Z., & Baranyi, E. (2000). The Role of Tumour Necrosis Factor (Tnf)- A Resistance in Obesity and Insulin Resistance. *Diabetologia*, *43*(4), 525.

DRI's Pulse Check. (2023). *Tren Produksi Dan Konsumsi Plastik Di Indonesia*. Jakarta: Danareksa Research Institute.

Dutta, A. (2017). Fourier Transform Infrared Spectroscopy. *Spectroscopic Methods for Nanomaterials Characterization*, 73–93. https://www.sciencedirect.com/science/article/pii/B9780323461405000042

Emenike, E. C., Okorie, C. J., Ojeyemi, T., Egbemhenghe, A., Iwuozor, K. O., Saliu, O. D., Okoro, H. K., & Adeniyi, A. G. (2023). From Oceans to Dinner Plates: The Impact of Microplastics on Human Health. *Heliyon*, *9*(10). https://www.cell.com/heliyon/fulltext/S2405-8440(23)07648-X

Gall, M., Schweighuber, A., Buchberger, W., & Lang, R. W. (2020). Plastic Bottle Cap Recycling — Characterization of Recyclate Composition and Opportunities for Design for Circularity. *Sustainability (Switzerland)*, *12*(24), 1–21. https://doi.org/10.3390/su12241037 8

Gaucher-Miri, V., Jones, G. K., Kaas, R., Hiltner, A., & Baer, E. (2002). Plastic Deformation of EVA, EVOH and Their Multilayers. *Journal of Materials Science*, *37*, 2635–2644. https://link.springer.com/article/10.1023/A:1015872129472

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, Use, and Fate of All Plastics Ever Made. *Science Advances*, *3*(7). https://www.science.org/doi/abs/10.1126/sciadv.1700782

Gore, A. C., Chappell, V. A., Fenton, S. E., Flaws, J. A., Nadal, A., Prins, G. S., Toppari, J., & Zoeller, R. T. (2015). Edc-2: The Endocrine Society's Second Scientific Statement on Endocrine-Disrupting Chemicals. *Endocrine Reviews*, *36*(6), E1–E150. https://academic.oup.com/edrv/article/36/6/E1/2354691

Gündoğdu, S., Bour, A., Köşker, A. R., Walther, B. A., Napierska, D., Mihai, F.-C., Syberg, K., Hansen, S. F., & Walker, T. R. (2024). Review of Microplastics and Chemical Risk Posed by Plastic Packaging on the Marine Environment to Inform the Global Plastics Treaty. *The Science of the Total Environment*, *946*. https://pubmed.ncbi.nlm.nih.gov/38901589/

Hahladakis, J. N. (2020). Delineating the Global Plastic Marine Litter Challenge: Clarifying the Misconceptions. *Environmental Monitoring and Assessment*, *192*(5). https://doi.org/10.1007/s10661-020-8202-9

Hançer, N. J., Qiu, W., Cherella, C., Li, Y., Copps, K. D., & White, M. F. (2014). Insulin and Metabolic Stress Stimulate Multisite Serine/Threonine Phosphorylation of Insulin Receptor Substrate 1 and Inhibit Tyrosine Phosphorylation. *Journal of Biological Chemistry*, *289*(18), 12467–12484.https://www.jbc.org/article/S0021-9258(20)41436-X/fulltext

Huang, D., Zhang, Y., Long, J., Yang, X., Bao, L., Yang, Z., Wu, B., Si, R., Zhao, W., Peng, C., Wang, A., & Yan, D. (2022). Polystyrene Microplastic Exposure Induces Insulin Resistance in Mice Via Dysbacteriosis and Pro-Inflammation. *Science of the Total Environment*,*838*.https://www.sciencedirect.com/science/article/pii/S0048969722030340

Indonesia Ministry of Health. (2018). *Laporan Nasional Riskesdas 2018*. https://repository.badankebijakan.kemkes.go.id/3514/1/Laporan Riskesdas 2018 Nasional.pdf

Indonesia Ministry of Health. (2023). *Survey Kesehatan Indonesia Dalam Angka: Data Akurat Kebijakan Tepat*. https://www.badankebijakan.kemkes.go.id/ski-2023-dalam-angka/

Kadac-Czapska, K., Knez, E., Gierszewska, M., Olewnik-Kruszkowska, E., & Grembecka, M. (2023). Microplastics Derived from Food Packaging Waste—Their Origin and Health Risks. *Materials*, *16*(2), 674. https://pubmed.ncbi.nlm.nih.gov/36676406/

Kaseke, T., Lujic, T., & Velickovic, T. C.

(2023). Nano-and Microplastics Migration from Plastic Food Packaging into Dairy Products: Impact on Nutrient Digestion, Absorption, and Metabolism. *Foods, 12*(16),3043.https://doi.org/10.3390/foods12163043

Lambert, S., & Wagner, M. (2017). Environmental Performance of Bio-Based and Biodegradable Plastics: The Road Ahead. *Chemical Society Reviews*, *46*(22), 6855–6871. https://pubs.rsc.org/en/content/articlehtml/2017/cs/c7cs00149e

Lang, I. A., Galloway, T. S., Scarlett, A., Henley, W. E., Depledge, M., Wallace, R. B., & Melzer, D. (2008). Association of Urinary Bisphenol A Concentration with Medical Disorders and Laboratory Abnormalities in Adults. *Jama, 300*(11),1303–1310.https://jamanetwork.com/journals/jama/fullarticle/182571

Liu, P., Wei, W., Zhao, Q., Shi, J., Bai, B., & Jin, H. (2023). Visualization of Polyoxymethylene (POM) Particle Decomposition Behavior in Hydrothermal Condition. *Thermal Science and Engineering Progress*, *41*(1), 101825.https://doi.org/10.1016/j.tsep.2023.101825

Mason, S. A., Welch, V. G., & Neratko, J. (2018). Synthetic Polymer Contamination in Bottled Water. *Frontiers in Chemistry*, *6*. https://www.frontiersin.org/articles/10.3389/fchem.2018.00407/full?here's_what_to_expect

Mondal, T., Mondal, S., Ghosh, S. K., Pal, P., Soren, T., Pandey, S., & Maiti, T. K. (2022). Phthalates - A Family of Plasticizers, Their Health Risks, Phytotoxic Effects, and Microbial Bioaugmentation Approaches. *Environmental Research*, *214*(P3), 1–13. https://doi.org/10.1016/j.envres.2022.114059

Petroody, S. S. A., Hashemi, S. H., Škrlep, L., Mušič, B., Gestel, C. A. M. van, & Škapin, A. S. (2023). UV Light Causes Structural Changes in Microplastics Exposed in Bio-Solids. *Polymers*, *15*(21),4322.https://www.mdpi.com/2073-4360/15/21/4322

Ritchie, H., Samborska, V., & Roser, M. (2023). *Plastic Pollution*. Our World in Data.https://ourworldindata.org/plastic-pollution

Rubin, B. S. (2011). Bisphenol A: A Developmental Endocrine Disruptor with Widespread Exposure and Multiple Effects. *Journal of Steroid Biochemistry and Molecular Biology*, *127*(1–2),27–34.https://www.sciencedirect.com/science/article/pii/S0960076011001063

Ruoko, T.-P. J. (2012). *UV-light Induced Degradation of Polypropylene and Polystyrene–A Spectroscopic and DSC Study*.https://trepo.tuni.fi/handle/123456789/21157

Saal, F. S. vom, & Myers, J. P. (2008). Bisphenol A and Risk of Metabolic Disorders. *Jama*, *300*(11), 1353–1355. https://jamanetwork.com/journals/jama/article-abstract/182555

Sang, T., Wallis, C. J., Hill, G., & Britovsek, G. J. P. (2020). Polyethylene Terephthalate Degradation under Natural and Accelerated Weathering Conditions. *European Polymer Journal*, *136*,109873.https://doi.org/10.1016/j.eurpolymj.2020.109873

Sarker, M., Rashid, M. M., Rahman, M. S., & Moll, M. (2012). Environmentally Harmful Low Density Waste Plastic Conversion into Kerosene Grade Fuel. *Journal of Environmental Protection*, *3*(8), 700–708. https://www.scirp.org/journal/paperinformation?paperid=21756&

Singh, A., & Talpade, M. B. (2024). Presence of Microplastic in Bottled Water from Mumbai Market. *Uttar Pradesh Journal of Zoology*, *45*(14), 340–348.http://ebooks.keeplibrary.com/id/eprint/1738/

Swan, S. H., Sathyanarayana, S., Barrett, E. S., Janssen, S., Liu, F., Nguyen, R. H. N., & Redmon, J. B. (2015). First Trimester Phthalate Exposure and Anogenital Distance in Newborns. *Human Reproduction*, *30*(4), 963–972.

https://academic.oup.com/humrep/article/30/4/963/613595#google_vignette

Tice, P. (2002). *Polypropylene as a Packaging Material for Foods and Beverages*. Brussels: International Life Sciences Institute.

Tuhumury, N., & Ritonga, A. (2020). Identifikasi Keberadaan dan Jenis Mikroplastik pada Kerang Darah (Anadara granosa) di Perairan Tanjung Tiram, Teluk Ambon. *TRITON: Jurnal Manajemen Sumberdaya Perairan*, *16*(1), 1–7. https://ojs3.unpatti.ac.id/index.php/triton/article/view/3052

Vyavahare, S. A., Kharat, B. M., & More, A. P. (2024). Polybutylene Terephthalate (PBT) Blends and Composites: A Review. *Vietnam Journal of Chemistry*. https://onlinelibrary.wiley.com/doi/abs/10.1002/vjch.202300177

Xu, M., Niu, H., Wu, L., Xing, M., Mo, Z., Chen, Z., Li, X., & Lou, X. (2024). Impact of Microplastic Exposure on Blood Glucose Levels and Gut Microbiota: Differential Effects under Normal or High-Fat Diet Conditions. *Metabolities*, *14*(9), 504. https://www.mdpi.com/2218-1989/14/9/504

YLKI. (2023). *Survei YLKI: Minuman Berpemanis dalam Kemasan*. Yayasan Lembaga Konsumen Indonesia.

Zhang, R., Feng, Y., Nie, P., Wang, W., Wu, H., Wan, X., Xu, H., & Fu, F. (2024). Polystyrene Microplastics Disturb Maternal Glucose Homeostasis and Induce Adverse Pregnancy Outcomes. *Ecotoxicology and Environmental Safety*, *279*(1), 1–10. https://doi.org/10.1016/j.ecoenv.2024.116492

Zhou, X., Wang, J., Li, H., Zhang, H., Zhang, H.-J., & Lei, D. (2021). Microplastic Pollution of Bottled Water in China. *Journal of Water Process Engineering*, *40*(April). https://www.sciencedirect.com/science/article/abs/pii/S2214714420307613