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**PLASTIC PACKAGING – IMPACT ON HUMAN HEALTH AND THE
ENVIRONMENT**

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ABSTRACT

The growing demand for plastic packaging brings increased risks to both human health and the environment. Due to its adaptability and processability, plastic is widely used in the food and beverage industry, but at the same time represents a significant source of harmful substances. Plastic products intended for the storage of food, beverages, and culinary additives, such as olive oil, can release compounds that migrate into the contents, thereby increasing the risk of developing acute and chronic diseases, and in some cases even leading to fatal outcomes. The most commonly identified hazardous substances are phthalates, bisphenol A, and heavy metals.

Keywords: plastic packaging, bisphenol A, phthalates, heavy metals

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1. INTRODUCTION

Plastic packaging has achieved extremely widespread use in everyday human life during the second half of the 20th century and the beginning of the 21st century. However, its extensive application entails potential risks for both human health and environmental preservation. It is essential to pay close attention to the composition of commonly used plastic containers, as well as to follow certain guidelines in order to make food storage, such as that of olive oil, as safe as possible, since compounds from plastic packaging can easily migrate into the product it contains. At elevated temperatures, as well as under UV radiation, harmful substances are released from the plastic and enter the product itself. These migrations occur at microscopic levels and cannot be observed with the naked eye. Prolonged exposure can cause visible changes, such as the alteration of olive oil's color from golden yellow to yellow-orange. UV radiation accelerates oxidation processes in the oil and promotes the release of compounds. Special attention should be given to the storage of plastic packaging, which should be kept in dark and cooler places. Furthermore, strong emphasis should be placed on education about harmful effects, starting from an early age.

1. PLASTIC PACKAGING

The most widely used type of packaging in the 21st century is plastic. Plastic possesses properties highly favorable for mass production, such as relatively low density and excellent insulating and thermal characteristics. Its shape, size, and color can be modified by adding various compounds during the manufacturing process. According to the classification established by the SPI (Society of the Plastics Industry), there are seven types of plastic materials, presented in Table 1. [1]

1.	PET – polietilen tereftalat	 PET
2.	HDPE – polietilen visoke gustoće	 HDPE
3.	PVC – polivinil-klorid	 PVC
4.	LDPE – polietilen niske gustoće	 LDPE
5.	PP – polipropilen	 PP
6.	PS – polistiren	 PS
7.	O – ostali polimerni materijali	 O

Table 1. Marking of plastic material

PET plastic is widely used in the production of beverage bottles, as well as in the textile industry for the manufacture of synthetic materials. In addition to PET, packaging for oils, shampoos, and cleaning agents often contains HDPE and PP, while LDPE is commonly used in the production of simple plastic bags [1].

1.1. PROBLEMS WITH PLASTIC PACKAGING

Problems associated with plastics can be divided into two groups: environmental and health-related issues. Although these categories are distinguished, they remain interconnected through the food chain of humans and animals.

The growing demand for products, whether of standard design or those with special shapes, additives, and various colors, continuously increases the production of plastic packaging, the disposal of which ultimately falls upon the final consumer. Environmental pollution begins as early as the production process itself. Due to the prevailing societal mindset, the majority of plastics are produced in less developed countries, where regulations regarding exhaust emissions and wastewater are often nearly nonexistent. Attempts to restore balance include the introduction of restrictions and the establishment of recycling facilities in many developed countries. Raising awareness about the impact of pollution is encouraged from an early age.

A major step toward environmental protection has been the phasing out of plastic straws and shopping bags, replacing them with paper and/or fabric alternatives. Plastic bags in particular have become a significant ecological problem due to their light weight, which allows them to spread across all areas of the environment, as well as their tendency to fragment under weathering conditions. Although plastic packaging breaks down into smaller particles, it does not biodegrade. Microplastic particles have been detected in the deepest parts of the oceans and on the highest mountain peaks.

The fragmentation of plastic products into microplastic particles poses a direct threat to human health. Plastic packaging contains harmful compounds such as bisphenol A, phthalates, and heavy metals. When plastic degrades into microplastic particles, these enter the soil, water, and air. Human nutrition is based on plants and animals: animals feed on plants, while plants extract

essential nutrients, such as minerals and vitamins, from soil and water. Microplastic particles enter the food chain, where they accumulate and may release toxic substances.



Figure 1. Microplastics in the food chain

2. BISPHENOL A

Bisphenol A is a synthetic molecule with diverse applications. The systematic name of the compound is 2,2-bis-(4-hydroxyphenyl)propane. Its molecular formula is $C_{15}H_{16}O_2$, with a relative molecular mass of 228.31 g/mol. At room temperature, it is a solid substance. The free form of the molecule is lipophilic and is found in adipose tissue and breast milk, whereas its hydrophilic form is excreted in urine and feces [2].

2.1. SYNTHESIS

Bisphenol A is produced through the condensation reaction of two phenol groups with one molecule of acetone in an acidic medium, as shown in Figure 2.

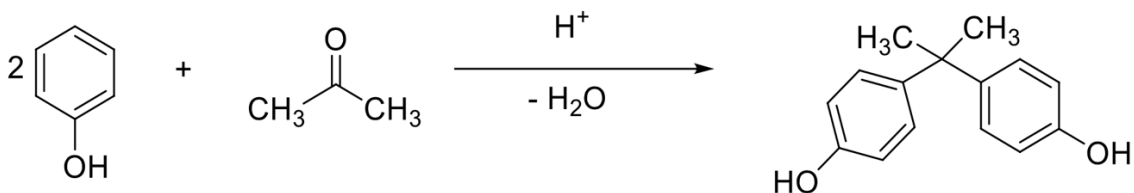


Figure 2. Synthesis of Bisphenol A [2]

2.2. APPLICATION

Bisphenol A is widely used across various industries. It is employed in the production of epoxy resins and polycarbonate plastics. The compound can be found in plastic bottles, canned food, mobile phones, and laptops. In the synthesis of tetrabromobisphenol A (TBBPA), it serves as a reactant [2]. TBBPA is further used in the manufacture of tires, cables, and thermal paper, such as that used for printing receipts.

2.3. HAZARDS TO HEALTH AND THE ENVIRONMENT

From its production to the use of end products, exposure to bisphenol A is continuous. The main sources of human exposure are water bottles, plastic packaging, and canned foods. Dietary intake represents the greatest health risk, as it affects all age groups, with newborns being a particularly vulnerable population.

Greater exposure and more serious risks occur during the handling of the compound for the production of resins and polycarbonate plastics than during the synthesis of the compound itself. Bisphenol A migrates into the human body in two ways: through direct diffusion of the compound and through polymer hydrolysis. When polycarbonate plastic is exposed to boiling water (100 °C), the migration of bisphenol A is 55 times higher than when exposed to water at 20 °C [2]. Over time, polymer hydrolysis further increases the migration of bisphenol A.

Depending on the concentration of bisphenol A that has migrated into the body or has been released into the environment during the production of epoxy resins and/or polycarbonate plastics, negative effects on both the organism and the environment will eventually occur.

Bisphenol A adversely affects embryonic development, body growth, and reproductive maturation. Due to its action as an endocrine disruptor, elevated concentrations of bisphenol A in women have been linked to polycystic ovary syndrome and breast cancer, while in men it has been associated with prostate cancer and reduced sperm quality and motility. Its harmful effects on plant growth and development have also been investigated and confirmed.

2.4. ANALYSIS OF BISPHENOL A

Given the aforementioned negative effects, health agencies worldwide place increasing emphasis on the analysis of bisphenol A. Numerous methods have been developed to detect its presence, including chromatography and mass spectrometry. However, due to the high costs of sample transportation and processing with such methods, which require expensive equipment and trained personnel, newer approaches such as chemical sensors and biosensors are being developed.

3. PHTHALATES

Phthalates are synthetic compounds widely used in industry. Their application is particularly significant in the production and processing of plastics, where they are employed to improve material properties. Their high molar mass, fluidity, and stability make them ideal for use in the plastics industry. At room temperature, they are clear, oily liquids [3].

Figure 3 shows the structure of phthalates. Phthalates are esters of phthalic acid and are well soluble in other organic solvents.

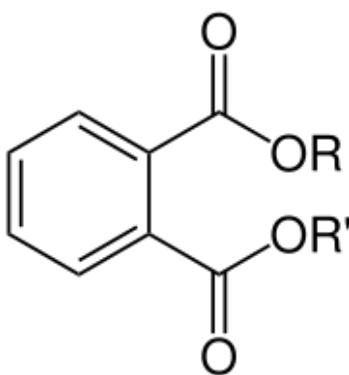


Figure 3. Structure of phthalates [4]

3.1. SYNTHESIS

The starting reactants for the synthesis of phthalates are phthalic anhydride and monovalent alcohols (ROH) [3].

In the first step of the synthesis, the reaction between the anhydride and the alcohol occurs, leading to the opening of the anhydride ring. The $-OR$ group of the monovalent alcohol attaches to one part of the anhydride, while the hydrogen atom binds to the other, forming a monoester. In the second step, the monoester is converted into a diester with the release of a water molecule.

The first step begins at elevated temperatures. Water formed in the second step is removed by distillation, which drives the equilibrium toward the formation of the diester. The synthesis process is shown in Figure 4.

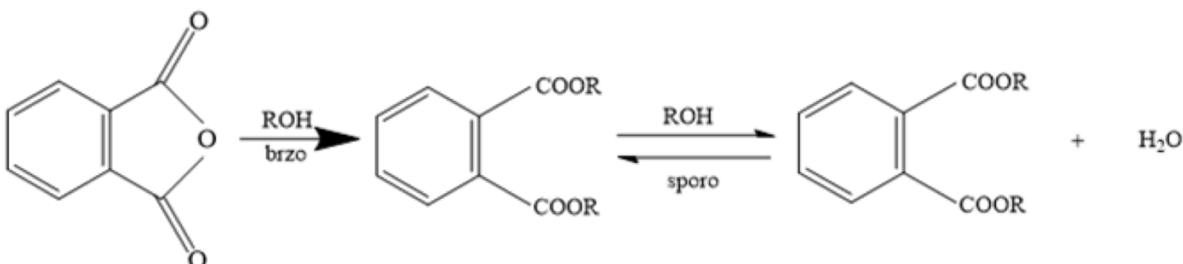


Figure 4. Reaction of phthalate ester formation [3]

The reaction rate can be increased by the addition of catalysts such as H₂SO₄, p-toluenesulfonic acid, sodium bisulfate, or by the addition of the monoester itself.

3.2. CLASSIFICATION

Phthalates represent an extremely widespread group of compounds. The development of different types of phthalates was primarily influenced by the availability of monovalent alcohols in the early 20th century. At that time, the availability of alcohols was limited to those with carbon chains up to four atoms long. This availability resulted in the production of three main types of phthalates: dimethyl phthalate – DMP (C₁₀H₁₀O₄), diethyl phthalate – DEP (C₁₂H₁₄O₄), and dibutyl phthalate – DBP (C₁₆H₂₂O₄). Iso-phthalates also exist, such as diisobutyl phthalate – DIBP (C₁₆H₂₂O₄) [3].

3.3. APPLICATION

Phthalates account for 87% of the annual consumption of plasticizers in the plastics industry. Long-chain phthalates are found in adhesives, medical supplies, food packaging, automotive parts, footwear, and children's toys. Short-chain phthalates are used in cosmetics, perfumes, and household fragrances due to their excellent solubility, as well as in hair sprays and nail polishes.

3.4. HAZARDS TO HEALTH AND THE ENVIRONMENT

The increased use of phthalates in products has led to a corresponding rise in their concentration in the environment. Because phthalates are not chemically bound within materials, they migrate easily.

The release of phthalates occurs at all stages—from production and packaging to purchase and use of the product. Once released, phthalates accumulate in soil, water, and air. Studies have shown that their concentrations are higher indoors, as a result of emissions from household sources such as flooring, windows, paints, and cosmetics. Although air is the most favorable medium for the transfer of phthalates, the highest concentrations are usually detected in wastewater. Modern wastewater treatment systems from households and/or industrial plants are not sufficiently effective in removing phthalates, leading to their accumulation in water systems.

The most common adverse health effects of phthalate exposure are linked to obesity and the reproductive system. Exposure to phthalates may lead to: damage to male reproductive cells (sperm), reduced female fertility, disorders of the female reproductive system, precocious puberty, asthma, and impaired thyroid function. Phthalates also accumulate in adipose tissue and disrupt lipid homeostasis, making them a contributing factor to obesity and thereby increasing the risk of diabetes and cardiovascular diseases.

Phthalates can be detected through laboratory analyses of blood, urine, saliva, and breast milk. The measured concentration depends on the type of phthalate, the duration of exposure, and the proportion present.

4. HEAVY METALS (Cd, Pb, Hg)

Cadmium (Cd) is an element of group 12 in the periodic table, with a relative atomic mass of 112.41. It is a soft, silver-white metal that can be cut. It is stable at room temperature, but oxidizes when heated [5]. It is used for coating other metals, producing low-melting alloys, and rechargeable Ni-Cd batteries.

Lead (Pb) is an element of group 14 in the periodic table, with a relative atomic mass of 207.2. It is a shiny, gray, soft metal, highly malleable. In nature, it occurs in sulfide and oxide ores. It is obtained by oxidizing sulfides and reducing oxides. It is slightly soluble in acids due to the presence of a protective layer [5]. Lead is the cheapest technical metal and therefore has a wide range of applications in everyday products such as chemical apparatus, electrical fuses, cables, and sculptures.

Mercury (Hg) is an element of group 12 in the periodic table, with a relative atomic mass of 200.59. In its elemental form, it is the only liquid metal. It dissolves in oxidizing acids and aqua regia (a mixture of HCl + HNO₃ in a 3:1 ratio) [5,6]. It is used as a filling in thermometers, barometers, and clinical thermometers, as a catalyst in reactions, in mercury lamps and rectifiers, and in the production of explosives.

4.1. COMPOUNDS

Cadmium sulfide (CdS) is the main source of cadmium for all market needs. Its most well-known use is as a pigment—cadmium yellow. Although it occurs naturally in crystalline structures and as an impurity in zinc ores, it does not have pigment properties naturally. The pigment is produced synthetically. It has significant covering power, and dried coatings in oil paint are strong and durable, making it suitable for use in the plastics industry. Another cadmium compound used in plastics is cadmium selenide (CdSe). It has crystalline (cubic or hexagonal) structures, and its color ranges from red to yellow depending on particle size [6]. It is used in television and radar systems and in the semiconductor industry.

The most important lead compounds are salts—halides, nitrates, sulfates, and carbonates—in which lead is in the Pb²⁺ oxidation state. Lead in compounds can also be in the Pb⁴⁺ state, but this form is significantly less stable than Pb²⁺ [5].

In the plastics industry, the following lead compounds were used: lead(II) carbonate – PbCO_3 , lead(II) oxide – PbO , lead(II) stearate – $\text{Pb}(\text{C}_{17}\text{H}_{35}\text{COO})_2$, as stabilizers for polyvinyl chloride (PVC) because they prevent degradation of PVC at elevated temperatures. They improve the resistance of plastics to UV radiation and have been used as additional pigments.

In the plastics industry, mercury was primarily used as a fungicide and antimicrobial additive. Used compounds include phenylmercury acetate – $\text{C}_8\text{H}_8\text{HgO}_2$, phenylmercury nitrate – $\text{C}_6\text{H}_5\text{HgNO}_3$, and methylmercury chloride – CH_3HgCl . Their main role was to prevent the growth of mold, fungi, and bacteria in plastics, especially plastic bottles and containers. They also served to extend the durability of plastics under various weather conditions.

4.2. ABSORPTION AND STORAGE IN THE BODY

Lead is absorbed in the body through the digestive system (5–10%) and via the lungs, where 50–70% of inhaled amounts are absorbed [7]. After absorption, lead is stored in various parts of the body such as erythrocytes, kidneys, liver, brain, hair, and bone marrow, where it easily enters but is difficult to remove.

Elemental mercury is well absorbed through the lungs, while absorption through the digestive system is present but significantly lower. Its lipophilic properties allow easier passage through barriers. It is stored in the brain, liver, kidneys, and heart. Mercury salts are best absorbed through the digestive system, while absorption through skin and lungs is negligible. They are stored in the kidneys and poorly pass through barriers, which is the main difference between elemental mercury and mercury salts. Organometallic mercury is well absorbed by all routes, especially orally due to accumulation in marine organisms such as fish and shellfish. In the body, it is stored in the brain, kidneys, liver, and muscle and fat tissue. Its high lipophilicity allows it to cross the placenta and accumulate in the fetus.

Cadmium enters the body primarily through inhalation but also via the digestive system. Absorption through the lungs is more efficient. Cadmium is stored in the kidneys, liver, brain, and bones, where it can replace calcium. A deficiency of iron and calcium increases cadmium absorption from the digestive system.

4.3. EFFECTS IN THE BODY

Mercurialism represents mercury poisoning, which can be acute (short-term) or chronic (long-term) depending on the concentration. Mercury has an extremely negative impact on health, primarily on the nervous system due to its high neurotoxicity [8]. Exposure to elevated mercury levels during prenatal development is particularly important because of the risk of permanent effects.

Lead is a systemic poison that inhibits heme biosynthesis. It causes symptoms such as nausea, cramps, loss of appetite, insomnia, headaches, dizziness, weakness, and nerve paralysis [9]. It leads to kidney damage and affects teeth due to accumulation in dental deposits. Lead blocks proteins important for brain development, leading to concentration, learning, attention, and behavioral disorders.

Cadmium primarily affects the kidneys and liver, causing damage. It causes nausea, through which a portion of ingested cadmium is excreted, and rarely leads to death [8]. The rest accumulates in the body and can remain for several decades. Cadmium affects the skeletal system by replacing calcium in bones and interfering with phosphate metabolism, leading to osteoporosis or bone weakening.

All the mentioned heavy metals have carcinogenic properties and are especially linked to lung and urinary system cancers, primarily kidney cancer.

4.4. LIMITATIONS

Regulation 2023/915 sets maximum allowable amounts of cadmium, lead, and mercury in food in the European Union [10]. The allowable amount of a specific metal in food depends on the type of food.

Allowed cadmium levels range from 0.005 mg/kg in liquid baby food made from cow's milk to 3.00 mg/kg for dietary supplements produced from at least 80% dried seaweed.

For lead, allowable levels range from 0.010 mg/kg in liquid food for infants and special medical food for children and infants to 2.00 mg/kg in spices obtained from fruit peel.

For mercury, allowable levels in food range from 0.10 mg/kg for salt and dietary supplements to 1.0 mg/kg for meat of most fish species, including tuna, shark, and cod.

According to these regulations and new knowledge, many compounds have been completely removed from production or reduced to minimal levels, especially in developed countries. Some risk and exposure remain due to lack of enforcement in developing countries and accumulation from past use.

4.5. IMPACT OF HEAVY METAL POLLUTION

Industry is the largest polluter in terms of type and number of pollutants. The problem is difficult to control due to pollutant diversity. Industrial pollution consequences often appear later.

Minamata Bay – a bay surrounded by heavy industry facilities. From 1932 to 1968, a factory discharged significant amounts of methylmercury into the bay [11]. Due to mercury's accumulation in marine organisms such as shellfish and fish, local residents relying on seafood from the bay suffered severe neurological damage. In spring 1956, a hospital in Minamata admitted a child with speech difficulties, convulsions, and impaired walking [11]. Initially, the source of symptoms was unknown. Soon, the number of affected people increased, and symptoms were initially attributed to an infectious disease. In 1968, the factory ceased production under public pressure and lawsuits from victims [11]. Authorities finally confirmed methylmercury as the cause.

Kaštela Bay – local industry discharged mercury-rich wastewater into the sea for decades, leading to long-term pollution. Marine organisms are not suitable for consumption, although mercury levels are below allowed limits. Mercury is still found in sediments. This is the largest pollution of the Adriatic Sea, even though elemental mercury discharged here is less harmful than methylmercury released in Japan.

Itai-Itai disease – disease caused by exposure to high cadmium concentrations. The epidemic began in 1912 in Toyama, Japan [12]. The disease is named after the Japanese words for “it hurts, it hurts,” as cadmium caused bone damage, leading to bone deformation and fractures among the local population. The high exposure was caused by the discharge of cadmium into the river by a nearby mine.

5. CONCLUSION

A review of the literature and analysis of conducted research show that plastic packaging has more negative than positive aspects. The positive aspects include consumer adaptability and easy availability, while the negative aspects involve the release of harmful substances from production to final use, adverse effects on human health from the products themselves, and from consuming food contaminated with microplastic particles. The entry of harmful substances into the body is easy, and increased migration occurs with improper storage of plastic packaging.

Heavy metals accumulate in various organs, causing a range of acute or chronic diseases. Bisphenol A and phthalates primarily affect the reproductive system, growth, and development, raising questions about the extent to which plastic use contributes to infertility. Numerous studies have been conducted or are ongoing to definitively establish the connection between plastic packaging use and reproductive or developmental disorders.

Education from early childhood through kindergarten contributes to raising awareness about the harmful effects of environmental pollution from various pollutants. Significant changes can only be observed when the majority adhere to guidelines and choose alternative food storage methods, such as replacing plastic packaging for storing olive oil with glass or stainless steel containers.

The ideal packaging for short-term storage is glass bottles made from dark, green, or brown glass that blocks light, while for long-term storage, stainless steel (inox) is preferable. Stainless steel packaging is desirable due to its exceptional durability, long lifespan, and excellent protection from light.

6.LITERATURE

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