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Derleme Makale/ Review Article

Toxic Effects of Single and Mixture Polyvinyl Chloride (PVC) Microplastics on Aquatic Biota

Tek ve Karışım Polivinil Klorür (PVC) Mikroplastiklerinin Sucul Biyota Üzerindeki Toksik Etkileri

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Öz
Son yıllarda karasal ve sucul sistemlerde mikroplastik miktarındaki artış dikkat çekmektedir. Su ortamında mikroplastiklerin varlığı ve bunların su canlıları üzerindeki tehlikesi konusunda dünya çapında endişeler bulunmaktadır. Su ekosistemi, çevreye salınan ağır metaller, mikroplastikler ve pestisitler gibi kirleticilerin son noktası olabilir. Mikroplastikler çevredeki kirleticileri emer ve patojenler için vektör görevi görür. Farklı mikroplastik türlerinin sucul biyota üzerindeki etkilerine ilişkin çalışmalar hızla devam etmektedir. Bu derlemede, su ekosisteminde yaygın olarak bulunan polivinil klorür (PVC) mikroplastiklerin tek başına veya diğer çevresel kirleticilerle karışım halinde sucul organizmalar üzerindeki zararlı etkilerine odaklanan çalışmaları inceledik. Verilerimiz PVC mikroplastiğinin su ekosistemi üzerinde endişe verici etkileri olabileceğini gösteriyor. Yapılan çalışmalardan elde edilen verilerde, PVC mikroplastiğine maruz kalınması, büyüme ve üreme üzerine etkileri, kronik maruziyetlerde ölüme bağlı olarak canlıların biyokimyasal parametrelerinde değişiklikler olduğu kaydedilmiştir. İncelenen çalışmalarda PVC mikroplastiğin su ekosistemi için ciddi tehlikeler oluşturduğu ve bu etkinin gelecekte artarak endişe yaratacağı açıkça görülmektedir.
Anahtar Kelimeler: Mikroplastik, PVC, Toksik etki, Su ekosistemi, Kirlilik

Abstract
The increase in the amount of microplastics in terrestrial and aquatic systems has attracted attention in recent years. There is concern worldwide about the presence of microplastics in the aquatic environment and their danger to aquatic biota. The aquatic ecosystem can be the final point of pollutants such as heavy metals, microplastics, and pesticides released into the environment. Microplastics adsorb pollutants in the environment and serve as vectors for pathogens. Studies on the effects of different microplastics on aquatic biota continue rapidly. This review examined studies focusing on the harmful effects of polyvinyl chloride (PVC) microplastics, widely found in the aquatic ecosystem, on aquatic organisms, either alone or in mixtures with other environmental pollutants. Our data show that PVC microplastic can have worrying effects on the aquatic ecosystem. The data obtained from the studies showed changes in the biochemical parameters of living beings due to exposure to PVC microplastic exposure, effects on growth and reproduction, and death in chronic exposures. The studies examined clearly show that PVC microplastic poses severe dangers to the aquatic ecosystem and that this impact will increase in the future, which will be a cause for concern.
Key Words: Microplastic, PVC, Toxic effect, aquatic ecosystem, Pollution.

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INTRODUCTION

Wide use of plastic materials is preferred in daily life and industrial use due to their light and durable properties. Plastic production has increased since 1950 and is expected to reach 33 billion tons by 2050[1]. Plastic production in the world: 51% in Asia, 20% in Europe, 18% in North America, 7% in Africa, and 4% in South America[2]. Their large-scale use and increasing production volume bring biomagnification and accumulation risk in aquatic and terrestrial environments, further augmented by prolonged degradation time[1]. Plastic waste is classified into four groups according to their size: macroplastic (2.5 to 100 cm), mesoplastic (5 mm to 2.5 cm), microplastic (1 µm to 5 mm), and nanoplastic[3]. Although there are hundreds of polymer types available, 75% of plastic demand involves specific types: polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polyurethane (PU)[4].

Microplastics are defined as "water-insoluble synthetic solid particles or polymeric matrices with a regular or irregular shape, ranging from 1 µm to 5 mm, originating from primary or secondary production"[5]. Microplastics are released into the environment directly from daily used plastic materials, degradation of plastics, industries, and wastewater treatment plants[6]. Particle transport and retention dynamics change depending on physical properties, affecting their accumulation and bioadjustment in the environment[7]. Today, microplastics are widely distributed in atmospheric, terrestrial, and aquatic environments. Organisms are exposed through food or air and cause physical and chemical adverse effects on the digestive and respiratory systems[4].

This study focused on the toxic effect of PVC alone on organisms living in the aquatic environment and its harmful combination effect on organisms with other environmental pollutants. In the last five years, we focused on previously published articles and current studies on PVC pollution and its combined effects on organisms in freshwater and marine ecosystems.

Polyvinyl chloride (PVC) with the chemical formula [$(C_2H_3CI)_n$, CAS Number: 9002-86-2] is a thermoplastic[8]. Polyvinyl chloride is obtained by polymerizing vinyl chloride consisting of chlorine and ethylene. PVC is the organochlorine with the most significant production volume subject to scientific review[9]. Density is between 1.16-1.58 g/m[10]. The fact that it contains vinyl makes PVC more dangerous than other types of plastic[9]. According to PlasticsEurope 2019, PVC has been reported to be a toxic (carcinogenic) and dangerous type of plastic[2].

For this reason, their high global distribution in the last decade raises great concern as it is the most widely produced synthetic plastic polymer after polyethylene and polypropylene[9,11]. PVC is a thermoplastic and has the property of softening when heated and hardening when cooled. PVC is used in many different areas for short and long life. Sixty percent of its applications have a lifespan of more than 40 years[12]. PVC had broad application areas. It is extensively used in agriculture for various purposes such as food packaging and coating of crops[13]; insulation coatings, wire, and cabling, synthetic leather making[8]; construction materials, hand furniture[11]; medical products (endotracheal and feeding tubes, blood and plasma bags, pharmaceutical blister packs); many packaging uses such as food packaging, toys, footballs, life jackets, garden hoses; office supplies and gloves. Global level distribution of PVC microplastic in aquatic systems showed that among all microplastics, it was %7.41 in Asia, %4.65 in Europe, %9.09 in America, %4.71 in Oceania, %14.29 in Africa, and %8.33 in[14].

Polyvinyl chloride causes significant negative effects on human and environmental health. Dioctyl phthalate (DOP) used in producing PVC, dioxin, and mercury are also formed during combustion and are toxic chemical compounds. FDA approves DOP in exchange transfusion in newborns; it has been explained that exposure poses a high risk in procedures such as heart transplantation, hemolysis, and open heart surgery. Dioxin, a known human carcinogen, is released due to PVC combustion[15]. PVC has been reported to cause chronic bronchitis, cancer, skin diseases, liver dysfunction, and birth defects[16].

Effects of PVC on Biota in the Aquatic Ecosystem

The emergence of microplastics in freshwater and marine ecosystems and their harmful effects on aquatic organisms have become a major threat to biodiversity conservation. Microplastic concentrations in surface water generally exceed 300 µm particle size and approximately 1×10^{-3} to 10 particles per liter. This amount is expected to increase over time[17]. It is estimated that by 2050, plastic particles in the aquatic environment will increase to 10.000 particles per year[18]. Aquatic organisms ingest MPs as food or incidentally during feeding, resulting in harmful or fatal effects[19]. When MPs enter the digestive system of organisms, starting from phytoplankton, the smallest creatures of the aquatic system, reaching mollusks and many fish species[20], they can survive in the food chain up to humans and cause toxicity[21]. MPs can cause oxidative stress, cellular damage, DNA damage, and inflammation[22].

In recent years, PVC microplastic has been considered one of the most important pollutants emerging in the aquatic environment[8]. The long-term effects of PVC MPs intake in fish were evaluated and examined regarding enzymatic and tissue changes, oxidative stress, gene expression changes and genotoxicity[23]. It has been reported that physical and chemical damage to aquatic organisms following exposure to MP may cause fatal and sub-lethal effects on aquatic organisms[21]. In a study investigating the effect of PVC in freshwater ecosystems, negative effects on the growth of *Chlamydomonas reinhardtii* were observed after 96 hours of exposure in the range of 10-200 mg/L and caused a decrease in the chlorophyll-a level[19]. PVC studies in freshwater ecosystems and marine environments have increased in recent years. Exposure of the marine dinoflagellate Karenia mikimotoi to mPVC at different doses caused a negative effect on its chlorophyll content, growth and photosynthetic activity[24]. Based on various studies in the literature, data on organisms affected by PVC-MP in marine and freshwater ecosystems are reviewed in Table 1.

Effects of PVC Microplastic Combination with Other Environmental Pollutants on Aquatic Biota

Numerous studies reveal the interaction of toxic chemicals (organic pollutants, pesticides,

Table 1: Studies on the toxic effects of PVC microplastic on some freshwater organisms.

Target organism	Concentration	Experimental duration	Effects	References
Chlorella pyrenoidosa	5-10-50-100-250-500 mg/L	11 days	Altered chlorophyll-a syntesis	Wu et al. (2019)
Chlamydomonas reinhardtii	1-10-20-30-40-50 mg/L	24-48-72-96 hours	Decreased chlorophyll-a concentrations. Reduced growth and population density. Increased MDA and SOD activity.	Wang et al. (2020)
Daphnia magna	10-20-40-80-160 mg/L	4-7-14-21 days	Reproductive rate, CAT activity and MDA level varied depending on MP particle size. SOD activity, GSH levels and vtg gene regulation decreased	Liu et al. (2022)
Barbodes gonionotus	0.2-0.5-1.0 mg/L	96 hours	PVC were found in the intestine. Trypsin and chymotrypsin activities increased. Localized thickening of the mucosal epithelium was seen.	Romano et al. (2018)
Cyprinus carpio	45.55-91.1- 136.65 µg/L (10%-20%-30%)	30-60 days	MDA levels decreased. SOD, CAT and GST activities decreased. Transcription of CYP1A and GSTa was reduced at high microplastic concentration.	Xia et al. (2020)
Clarias gariepinus	0.5% 1.5% 3.0%	45 days	Hb, MCH, RBC and LPO levels increased. Neutrophil count, MCV and WBC counts decreased. GPx, SOD, AChE and CAT activities decreased. No changes in monocyte and lymphocyte counts.	Iheanacho and Odo., (2020)
Cyprinus carpio	1-10-100-1000 µg/L	10 days	Mortality observed. Abnormal swimming behavior, irregular movements. Mucus secretions increased. Structural abnormality in the intestinal wall and lesions in villi, liver and stomach inflammation.	Darabi et al. (2021)
Karenia mikimotoi	0, 5, 25, 50 and 100 mg/L	0, 24, 48, 72 and 96 h	Reduced algal growth, chlorophyll content, and photosynthetic efficiency	Zhao et al. (2019)
Dicentrarchus labrax	0.1% (w/w)	30-60-90 days	Morphological changes and hyperplasia observed	Pedà et al. (2016)
Dicentrarchus labrax	0.1 % (w/w)	90 days	Histopathological effects were observed. Induced expression of peroxisome proliferator-activated receptors (PPARs) and Estrogen receptor alpha (ER-α) genes.	Pedà et al. (2022)
Perna viridis	0 mg/L, 21.6 mg/L, 216 mg/L, 2160 mg/L	44 day-91 day	After 44 dyas, mussel filtration, respiration rates, and byssus production were observed to be negative. Within 91 days, the survival rate of mussels decreased.	Rist et al.(2016)
Etroplus suratensis	31.43 to 38.30 mg/L	10 day	Behavior changes, Hematological indices decreased,	Vijayaraghavan et al. (2022)
Skeletonema costatum	1-5-10-50 mg/L	96 hours	Growth decreased. Photosynthesis rate and chlorophyll conc. decreased.	Zhang et al. (2017)
Sparus aurata	100 and 500 mg/kg	15 and 30 days	Creatine kinase, aspartate aminotransferase, albumin and globulin conc. in serum decreased. IgM conc. in the skin mucosa increased. prdx5 gene expression decreased, prdx1 and prdx3 genes	Espinosa et al. (2017)

metals, emerging contaminants) with MPs. Plastic accumulation in aquatic ecosystems serve as vectors that attract metal pollutants[21]. Considering that global PVC production has reached 37 million tons per year[25], it can be said that it will pose a serious danger to the ecosystem and other environmental pollutants. Multiple types of chemicals are mixed with polymers to produce plastics[26] thus, toxic additives found in plastic manufacturing are known to leak into the environment[27]. Toxic substances such as heavy metals (Pb, Cu, Cd), phthalates, and bisphenol A (BPA) are used to produce plastics[28]. Plastic polymers such as PVC may contain chemical additives such as lead (Pb) and release them into the aqueous solution.

The study conducted with Danio rerio (zebrafish) caused an increase in mt2 due to Pb leakage from PVC to water[18]. Organic compounds have strong toxicity and persistence and are widely found in aquatic environments[29]. Among the POPs (persistent organic pollutants), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides are toxic compounds, and there is concern that they may be absorbed on the MP surface and accumulate in living things[30]. By focusing on various studies in the literature, the data about organisms affected in the aquatic ecosystem due to the combined effects of PVC-MP with environmental pollutants are reviewed in Table 2.

CONCLUSIONS

Plastic pollution due to microplastica and nanoplastics, formed by the breakdown of plastics in various ways, continues to pose significant health risks and is expected to increase in the future. The widespread use of plastics, the inability to manage waste generation, and the fact that microplastic particles serve as vectors market their environmental pollutant even more dangerous. Microplastics, present as a wide variety of polymer types, are gradually increasing both in freshwater and marine ecosystems. The fact that PVC-MP is one of the most widely used polymer types causes it to be encountered frequently in environmental and aquatic life. Predictably, the use of product-based PVC will increase further in terrestrial and aquatic environments due to increasing market demand. It is conceivable that the increase in these pollutants through aquatic biodiversity and the food web will reach alarming levels. In this study, we examined the effects of PVC-MP on aquatic biota, focusing on physiological, reproductive, biochemical, and cellular level biomarkers under realistic environmental and simulated/laboratory conditions. It can be predicted that more studies on the potential risks of PVC-MP pollution will be included in the literature as proven effects in the future perspective.

Table 2: Studies examining the effect of PVC microplastic in combination with other environmental pollutants on aquatic organisms

Target organism	Pollution type	Concentration	Experimental duration	Effects	References
Artemia salina	PVC, Chlorpyrifos, Triclosan, Simvastatin, Carbamazepine	PVC: 0.26, 0.69 ve 1.6 mg/dm3 Chlorpyrifos: 0.0156, 0.0078, 0.0039 and 0.00195 mg/dm3, Triclosan: 12, 6,3,1.5, 0.75 and 0.0312 mg/dm3, Simvastatin: 12.03, 10.03, 8.35, 6.96, 5.80 and 52.08 mg/dm3, Carbamazepine: 43.40, 36.17, 30.14 and 25.16 mg/dm3.	48 hour	LC50; Chlorpyrifos+ PVC= 0.012 mg/dm3, Triclosan+ PVC= 4,957 mg/dm3, Simvastatin+PVC= 10.29 mg/dm3, Carbamazepine+PVC = 46,50 mg/dm3 Chlorpyrifos and Carbamazepine, both alone and associated with microplastics, showed a decline in cholinesterase activity.	Albendin et all. (2021)
Zebrafish Medeka	Virgin PE-MP, Spiked PE MPs, Virgin PVC-MP, Spiked PVC MPs, PFOS, BaP BP3	200 g/L PVC, 200 mg/L PFOS, BaP, BP3 125 g/L PVC 5000 µg/L BaP, 20 µg/L BP3 respectively	4 month	There was a reduction in growth at 2 months of exposure. This decline was much stronger for females. MPs with added PFOS and benzophenone-3 appeared to be more reproductive toxic than PVC, PE compared to MPs with added B[a]P. Additionally, PVC-benzophenone-3 caused behavioral disorders in juvenile larvae.	Cormier et all. (2021)
Dicentrarchus labrax L.	PVC-PE	0-100-500 mg/kg PVC , 0-100-500 mg/kg-1 PE	3 weeks	PE and PVC Decreased the activity of antioxidant enzymes, PVC-MP intake increased the phagocytic and repiratory activities. PE-MP increased skin mucus and immunoglobulin M	Espinosa et all. (2019)
Danio rerio	50% PE 25% PP 15% PS 10% PVC	5-100 mg/L	21 days	AChE activity decreased. Behavioral changes observed.	Hanslik et al. (2022)
Chlorella sp.	PP, PE, PET, PVC	10-1000 mg/L	3 days	Microplastic internalization, retarded growth	Miloloza et al. (2021)
Potamorpyrgus antipodarum	polyamide, polyethylene terephthalate, polycarbonate, polystyrene, polyvinylchloride	30%-70%	8 weeks	Mortality observed, number of juveniles did not change.	Imhof and Laforsch. (2016)
Zebrafish (*Danio rerio*)	PVC, (2-etylhexyl) phthalate	0.1 ppm PVC-MP, 71 µg/L DEHP	9 days	PVC-MPs slowed down the hatching rate of zebrafish embryos, PVC-MPs/DEHP induced ROS. Antagonistic effect of combination exposure, Inhibition of gene expression related to cardiac development	Wang et all. (2022)
Microcystis aeruginosa	PVC, PFOA	PFOA: 0 mg/L, 100.0 ng/L, 10.0 µg/L, 1.0 mg/L, 20.0 mg/L, and 100.0 mg/L PVC: 50.0 mg/L PFOA+PVC: 50.0 mg/L of PVC + 100.0 ng/L, 10.0 µg/L, 1.0 mg/L, 20.0 mg/L, and 100.0 mg/L of PFOA	15 day	PVC+PFOA inhibited growth and promoted Microcystin-LR synthesis and release. PFOA 20 mg/L > CAT activity increased, 100.0 mg/L>MDA increased PVC and PFOA exposure physical damage to algal cells	Zhang et all. (2023)
Chlorella vulgaris	aged mPVC, Copper	aged mPVC: 10 mg/L , Copper:0.5 mg/L	10 day	Caused serious cell damage, SOD and MDA levels increased	Fu, et all. (2019)

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