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Article

Distribution and Ecological Risk of Complex Phthalates in Soil Composition

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Abstract: Currently, there are several advanced approaches for the in-depth study and analysis of soil composition. This article provides comprehensive information on complex phthalates found in soil, along with a detailed examination of their functional role within the soil system, their influence on plant growth and development, and their level of ecological risk. Furthermore, the study presents findings on the occurrence of complex phthalates in medicinal plants and describes modern, high-precision methods for their identification, particularly the use of gas chromatography–mass spectrometry (GC–MS).

Keywords: Soil Phthalates, Ecological Risk, GC–MS Analysis

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1. Introduction

Phthalates are a group of substances that, based on their chemical nature, are united under a common name as esters of phthalic acid. Phthalic acid is a colorless crystalline compound with a melting point of about 200 °C, and upon heating it converts into phthalic anhydride[1].

Phthalates have a very wide range of applications, and today there are few fields where they are not used[2]. For example, they are found in medical products, toys, various types of packaging, plastic cards, carpets and wall coverings, hoses, pipes, automotive coatings, window frames, lubricants, cleaning agents, cosmetics, varnishes, hair sprays, shampoos, antiperspirants, and sunscreen products. According to data from the U.S[3]. Environmental Protection Agency, more than 213,000 tons of phthalates are produced annually in the United States. Globally, a single type of phthalate—di(2-ethylhexyl) phthalate (DEHP)—is produced and used in quantities exceeding 3 million tons per year. These figures clearly demonstrate that phthalates are used on a massive scale worldwide[4].

2. Materials and Methods

Complex phthalates are esters of phthalic acid, with the main representatives being di-n-butyl phthalate (DBP), di(2-ethylhexyl) phthalate (DEHP), and butyl benzyl phthalate (BBP). They are widely used in industry as plasticizers to soften plastics, increase their elasticity, and improve their mechanical properties, providing materials with flexibility, strength, and durability[5].

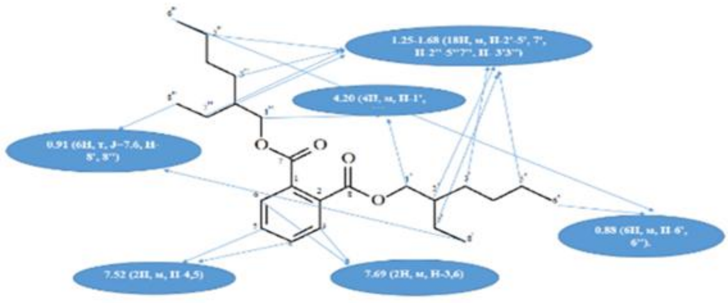

Figure 1. Di(2-ethylhexyl) phthalate

These compounds enter the environment, including soil, through industrial waste, the degradation of plastic materials, and wastewater discharge [6]. Once in the soil, phthalates exhibit low water solubility but strongly adsorb to organic matter. As a result, they tend to accumulate primarily in the upper soil layers and persist for long periods . Their biodegradation occurs very slowly, as the complex ester bonds of phthalates form structures that are resistant to microbial breakdown . For this reason, they are considered persistent organic pollutants[7].

The ecological risk of complex phthalates is associated with their biological activity. They can be absorbed from the soil through plant roots and subsequently enter the food chain [8]. In addition, phthalates are known to act as endocrine-disrupting substances in animals and humans, affecting hormonal systems . Their accumulation in soil reduces microbiological activity, negatively impacts enzymatic processes, and disrupts ecological balance [9]. In this context, the presence of phthalates in soil and plant systems may lead to adverse effects on physiological and enzymatic processes in plants. Most high–molecular-weight phthalates have low solubility in water[10].

The table below presents a list of the most commonly occurring phthalates at present:

Table 1. Most widely used phthalate esters

№	Abbreviations	phthalates	CAS №
1.	DMP	Dimethyl phthalate	131-11-3
2.	DEP	Diethyl phthalate	84-66-2
3.	DAP	Diallyl phthalate	131-17-9
4.	DPP	Dipropyl phthalate	131-16-8
5.	DnBP	Di-n-butyl phthalate	84-74-2
6.	DIBP	Diisobutyl phthalate	84-69-5
7.	BBP	Butyl benzyl phthalate	85-68-7
8.	DHP	Dihexyl phthalate	84-75-3; 68515-50-4
9.	DnOP	Di-n-octyl phthalate	117-84-0
10.	BOP	Butyl 2-ethylhexyl phthalate	85-69-8
11.	DEHP	Di(2-ethylhexyl) phthalate	117-81-7
12.	DIOP	Diisophthalate	27554-26-3
13.	DINP	Diisononyl phthalate	28553-12-0; 68515-48-0
14.	DIDP	Diisodecyl phthalate	26761-40-0; 68515-49-1
15.	D711P	Di(heptyl, nonyl, undecyl) phthalate	68515-45-7; 111381-89-6
16.	DUP	Diundecyl phthalate	3648-20-2
17.	DTDP	Ditridecyl phthalate	119-06-2; 68515-47-9
18.	DOTP, DEHT	Dioctyl terephthalate	6422-86-2

In addition, phthalates pose the following risks to plant and soil ecosystems:

-complex phthalates may slow down or completely inhibit seed germination;

-phthalates in soil restrict root development, reducing root length and biomass, which in turn limits the plant’s ability to absorb water and nutrients;

-they can reduce chlorophyll synthesis, leading to leaf yellowing (chlorosis) and a decline in photosynthetic efficiency;

-these compounds increase the production of reactive oxygen species (free radicals) in plant cells, causing membrane damage, disruption of enzyme activity, and ultimately cell death;

-phthalates can disturb the balance of phytohormones such as auxins and gibberellins, resulting in overall growth inhibition;

-plants grown in phthalate-contaminated soil often show reduced dry matter content and lower overall yield[11].

3. Results and Discussion

In the course of our research, the chemical composition of the hexane and cyclohexane extracts of the resin of the medicinal plant Ferula tadshikorum was investigated using GC–MS analysis. As a result, complex phthalates such as dioctyl phthalate and di(2-ethylhexyl) phthalate were identified[12]. When these detected phthalates were compared with the GC–MS analysis of the soil from the same sampling site, it was found that phthalates of the same composition were also present in the soil[13]. This indicates a close correlation between soil contamination and the chemical profile of the plant resin, suggesting possible environmental uptake or shared sources of phthalate pollution[14].

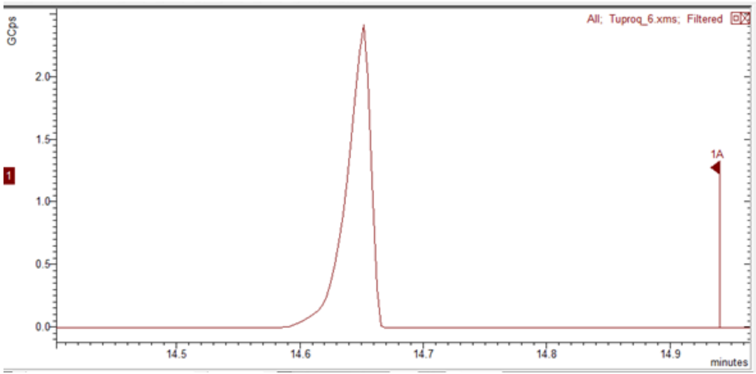

Figure 2. Di(2-ethylhexyl) phthalate identified in soil composition

Table 2. Chemical composition of the hexane extract of Ferula tadshikorum resin identified by GC–MS analysis

№	Compound	CAS №	%	Emperical formula	Mr
1	Dioctyl phthalate	000117-84-0	90	$C_{24}H_{38}O_4$	390.55

Table 3. Chemical composition of the cyclohexane extract of Ferula tadshikorum resin identified by GC–MS analysis[15].

№	Compound	CAS №	RI	content, %
1	Di(2-ethylhexyl) phthalate	117-81-7	3071	1.0

4. Conclusion

In conclusion, complex phthalates exhibit high environmental persistence and therefore remain in soil ecosystems for extended periods, creating a continuous ecological burden. Their strong adsorption to soil organic matter and slow biodegradation increase their potential for bioaccumulation and biomagnification within biological systems. As a result, phthalates not only negatively affect soil microbial activity but also disrupt the physiological and biochemical balance of the soil–plant system.

In this regard, a comprehensive understanding of the migration, transformation, and degradation kinetics of complex phthalates in soil, as well as the assessment of their spatial distribution and ecological risk, represents one of the key priorities in modern environmental chemistry and pollution studies. The application of highly sensitive analytical techniques such as gas chromatography–mass spectrometry (GC–MS) is essential for accurate detection and reliable risk evaluation.

Overall, research aimed at preventing phthalate contamination, reducing their environmental load, and enhancing their biodegradation is of significant scientific and practical importance for maintaining ecosystem stability and preserving biodiversity.

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