土壤中典型污染物对抗生素耐药基因传播的影响

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摘要

土壤是生态系统的重要组成部分。它是物质循环和能量运输最活跃的界面，同时也是动植物赖以生存的底物和空间。土壤在整个自然界中占据着关键位置，承载着约90%的污染物。同时，也是污染物向大气、水等环境介质迁移转化的重要“源头”。本文探讨了细菌耐药机制和抗生素耐药基因的传播途径，以抗生素、重金属和有机物为代表，探讨土壤中主要污染物对耐药基因传播的影响，以期为公众健康和环境安全提供指导。

关键词

污染物，抗生素耐药基因(ARGs)

Influence of Typical Pollutants in Soil on the Spread of Antibiotic Resistance Genes

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Abstract

Soil is a key component of ecosystem. It is not only the most active interface for material circulation and energy transportation, but also the substrate and space for animals and plants to survive, and has extremely rich biodiversity. Soil occupies the central position of the key zone in the entire nature, which carries about 90% of the pollutants. At the same time, it is an important “source” for the migration and transformation of pollutants to the atmosphere, water and other environmental media. This article discussed the drug resistance mechanism of bacteria and the transmission route of antibiotic resistance genes, taking antibiotics, heavy metals and organics as representatives to discuss the impact of major pollutants in the soil on the transmission of drug resistance genes, in order to provide guidance for public health and environmental safety.

Keywords
Pollutants, Antibiotic Resistance Genes (ARGs)
影响抗性基因的转移。

本文论述了细菌的耐药机制和抗生素耐药基因的传播途径，并以抗生素、重金属和有机物为代表，探讨土壤中污染物对抗生素耐药基因传播的影响，以期为公众健康和保障环境安全提供指导，但环境污染对抗生素抗性基因的扩散机制尚不明确，希望本研究引起人们对该领域的更多关注。

2. 抗性基因的传播

细菌获得耐药基因的途径主要有两种。第一种是在环境的选择性压力下，为了继续生存，其基因发生自发突变产生抗生素耐药基因；第二种是抗生素抗性基因在细菌之间转移，耐药基因转移分为垂直转移和水平转移。前者是指亲代和子代遗传导致的耐药基因传播，后者是指耐药基因通过可移动元件(转座子、质粒和整合子)转移，并且能够在不同物种的菌株间水平传播。仅靠环境选择性压力导致的自发基因突变和 ARGs 的垂直转移并不会造成耐药基因如此广泛的传播，值得警惕的是抗生素抗性基因的水平转移可能才是导致 ARGs 污染加剧的主要因素。

一般说来，细菌水平转移的主要方式有接合、转 化和转导。

接合是指携带 ARGs 的环型 DNA 通过接触转移到其他敏感菌株的过程，细菌的接合转移通常需要借助可移动的遗传元件(质粒、转座子和整合子)。通过接合转移，ARGs 不仅可以跨属转移，而且可以从革兰氏阴性菌转移到革兰氏阳性菌[11]。通常说来，接合转移是对 ARGs 传播影响最大的转移方式[12]。

转化是指处于感受态的细菌直接从环境中摄取游离 DNA 的过程。转化成功发生的必备条件有两个：一是受体菌的细胞膜通透性增大，处于感受态(需要环境中含有较高的 Ca²⁺ 和 Mg²⁺ )，准备接受 DNA 的进入；二是需要大量的游离 DNA。这些 DNA 极易被环境中存在的 DNA 酶降解，故导致环境中自然转化的概率并不高[13][14]。

转导是指噬菌体错误的组装了携带有 ARGs 的供体菌 DNA[15]，然后将 ARGs 转移到另一个细胞的过程。供体菌由于受到了噬菌体的攻击而发生裂解，DNA 游离到周围环境中[16]。

3. 土壤中常见污染物对 ARGs 的影响

3.1. 抗生素

自 1929 年发现青霉素以来，抗生素在临床领域已得到广泛应用，为医学的发展做出了巨大贡献。然而，随着多种抗生素在临床治疗、畜禽养殖中的普及，导致的大量滥用、不规范使用，土壤中检测到越来越多的抗生素[15]。土壤中抗生素的残留提供了一种环境选择压力，使原生细菌耐受抗生素而存活，而敏感细菌则逐渐丧失生存能力。随着土壤中抗生素污染的持续严重，细菌为了适应这种抗生素压力，发生自发性基因突变，产生 ARG，且会通过垂直和水平转移传给其他敏感细菌。因此，这一系列的结果导致土壤环境中细菌的抗药性不断增加，抗药谱不断拓宽，抗药性基因的丰度也在逐步增加[16]。相关研究表明，抗生素残留与耐药基因的丰度呈正相关，并会进一步导致耐药基因的传播[17]。

3.2. 重金属

重金属污染不同于抗生素污染，由于其二者的化学结构不同，抗生素可以在环境中被水解，从而削弱对耐药基因传播的影响。然而，重金属不仅是广泛存在于环境中，而且其能够持久的存在于土壤中难以降解，长期积累使其持续维持在毒性水平[18]。研究表明，自然环境中的重金属污染会致抗性基因耐药基因的传播，这也是导致耐药基因不断传播的重要原因之一[19]。

值得注意的是，重金属与抗生素具有协同作用，并会进一步影响耐药基因的传播。Yang 等人研究了中国武汉一个城市湖泊中磺胺类、四环素类以及喹诺酮类抗生素耐药基因的分布及其相关影响因素因素
的分析，结果表明抗生素和重金属的共同驱动力是 ARGs 在 6 个城市湖泊中传播的主要因素[20]。

一般认为抗生素残留是 ARGs 传播的关键选择压力。Ji 等人对养殖场的畜禽粪便和周围土壤进行了分析，发现抗生素残留量与 ARGs 丰度之间只有微弱的相关性。相反，一些 ARGs 的丰度与典型的重金属浓度之间存在显著的正相关性[21]，此项研究强调了重金属对 ARGs 迁移和扩散中的潜在作用。

3.3. 有机物

持久性有机污染物在环境中有很多的半衰期，它可以与污染链对生态系统、动植物甚至人类健康产生不利影响。多环芳烃、多氯联苯和杀虫剂是众所周知的有机污染物。现有的研究表明，有机污染物会对 ARGs 产生明显的选择压力，从而极大地加速 ARGs 的水平转移扩散的速度[22][23][24]。研究发现，萘、菲、芘等有机化合物通过筛选可以增加 I 类整合子的丰度，促进 sul 基因的横向迁移速率[23][25]。多种农药的复合污染环境大大增加了 IncP-1b 质粒的丰度，加速了 ARGs 在细菌间的传播[23][24]。此外，Sun 研究发现，ARGs 的丰度与有机污染物的生物有效性浓度之间的相关性明显高于总有机污染物的浓度[26]。

4. 环境中抗生素常见去除方式

传统消毒工艺：目前，对于水环境中抗性基因最常用的处理方式是人工湿地法，人为建造的湿地能够对针对水域抗性基因的污染情况进行有针对性的设计，比如植物类型、环境喂养和填料种类等[27]。有研究表明，温度对人工湿地的抗性基因去除效果有一定的影响，Li 等人的研究表明，冬季去除效果优于冬季，这可能是由于温度变化对微生物的繁殖，导致抗性基因的水平传播比较明显。除此之外，氯消毒、紫外线消毒以及臭氧消毒也是比较常见的方法[29]。

电离辐射技术：这种方法主要是利用射线或高能电子束破坏细菌细胞内的 DNA 从而破坏抗性基因，并杀死细胞。电离辐射作用分为直接和间接两种，直接作用是指作用在 DNA 上，而间接作用则是对细胞内的水分子由于电离作用产生的羟基自由基，进而对 DNA 进行破坏。两种方式的最终结果都是作用于 DNA[30]。

好氧堆肥和厌氧堆肥：该种方式是通过提高温度对微生物作用进一步去除耐药菌株以及抗性基因，传统的好氧堆肥和厌氧消化温度通常控制在 55℃[31]，但是该方法对温度要求过高，并不能快速有效地减少 ARGs 以及一些可移动元件，且长时间的高温胁迫可能会导致嗜热耐药菌株的产生[32]。

5. 结论

抗生素、重金属和有机污染物都是影响 ARGs 扩散的重要因素，本文综述了这三种环境中常见污染物对抗性基因传播的影响，但值得注意的是，各种因素并不是单独起作用的，而是表现为复杂的影响。除此之外，列举了目前较为常见的传统消毒方法、电离辐射方法、好氧堆肥以及厌氧消化技术这 4 种去除抗性基因的方法，每种方法都有其一定的优势，抗性基因对环境的污染不可忽视，且因其广泛的传播性迫切需要找到恰当的去除方法，因此，迫切需要运用多学科的研究方法，在宏观和微观环境中进行多重选择压力下的 ARGs 传播机制研究，以更好地评估和控制复杂环境下 ARGs 的转移和传播风险，并采用有效的手段对环境中的抗性基因进行去除，从而削减其对环境造成的不良影响。

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