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Antibiotic from the Earth: Soil Microbes and the Future of Infection Control

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The first antibiotic, salvarsan, was deployed in 1910. In just over 100 years antibiotics have drastically changed modern medicine and extended the average human lifespan by 23 years (Hutchings et al., 2019). Antibiotics into clinical use was arguably the greatest medical breakthrough of the 20th century. In addition to treating infectious diseases, antibiotics made many modern medical procedures possible, including cancer treatment, organ transplants and open-heart surgery. The antibiotics discovered between 1945 and 1978, 55% came from the genus Streptomyces the most likely explanation is that they have multiple functions, acting as chemical weapons to kill competitors in the soil either as protection (defensive) or predation (offensive), as signal ling molecules to close relatives or to mediate interactions with eukaryotic hosts such as insects and plants. Antibiotics encompass a chemically heterogeneous group of organic, low-molecular weight compounds produced by microorganisms. At low concentrations, antibiotics are deleterious to the growth or metabolic activities of other microorganisms. there are several reasons for the abundance of studies on antibiotics produced by Pseudomonas spp.: they are common inhabitants of rhizosphere and physllosphere environments, are isolated easily from natural environments, utilize a wide range of substrates, are easy to culture and manipulate genetically, making them more amendable to experimentation. The soil ecosystem harbours an immense diversity of microorganisms, many of which possess the remarkable ability to produce bioactive compounds with therapeutic and agricultural significance. Among these, antibiotics produced by bacterial biocontrol agents have emerged as critical tools in sustainable agriculture, particularly in the biological suppression of soilborne plant pathogens. As conventional chemical pesticides raise ecological and health concerns, microbial antagonism offers a compelling alternative rooted in nature's own defence mechanisms (Raaijmakers et al., 2002). Recent advances in molecular microbiology and bioanalytical techniques have illuminated the pivotal role of soil bacteria especially genera such as *Pseudomonas*, *Bacillus*, and *Burkholderia* in producing structurally diverse antibiotics with broad-spectrum antifungal, antibacterial, and nematicidal properties. These compounds not only disrupt pathogen metabolism but also contribute to the ecological competitiveness and survival of the producing microbes in complex rhizosphere environments (Raaijmakers et al., 2002).

Soil Microorganisms as Natural Drug Factories

The bacteria found in soil can be rods, (bacilli) cocci (spherical), and spirilla (spirals) of which, bacillus is more numerous than others. They are one of the major groups of soil bacteria and are widely distributed (Sandhya et al., 2012). While many antibiotics are known to exist, efforts to discover new antibiotics continue. Therefore, many species such as Streptomyces, Bacillus and Penicillium have been studied continuously for their ability to produce antibiotics. these microorganisms are preferable for commercial production (Sandhya et al., 2012).

Bacillus species dominate the soil microbiota and are known for generating polypeptide antibiotics such as bacitracin, polymyxin, and subtilin. These bacteria naturally produce antibiotics to outcompete other microbes and defend their ecological niche. Due to increasing antibiotic resistance among pathogens, the search for novel soil-derived antibiotics is urgent and ongoing (Sandhya et al., 2012).

Soil as a Source of Antibiotics

Soil hosts diverse microbial communities, including bacteria, fungi and actinomycetes many of which naturally produce antibiotics. These microorganisms generate antibiotics to compete for resources or defend themselves within complex soil ecosystems (Cycoń et al., 2019). many clinically important antibiotics (e.g., *tetracyclines, streptomycin, penicillins*) were discovered from soil-derived microbes. Soil acts as a reservoir for antibiotic resistance genes, including those for resistance to tetracycline, sulfonamides, and β-lactams (Cycoń et al., 2019).

Antibiotics Discovered from Soil

The discovery of penicillin (1928) and streptomycin (1943) revolutionized infection control. Early soil microorganisms, particularly Streptomyces, provided the foundation for over 70% of frontline antibiotics (Quinn et al., 2019). Antibiotics are the products of secondary metabolism whereby microorganisms can repurpose their metabolites from primary metabolism to generate often quite complex organic compounds using a dedicated set of enzymes for each secondary metabolite they produce. The specific enzymes required for antibiotic biosynthesis of any given secondary metabolite are encoded on a set of genes organised in a biosynthetic gene cluster (BGC), permitting coordination of their expression (Quinn et al., 2019).

Challenges in Antibiotic Discovery

The Waksman soil-based screening method was hugely successful during the “golden age,” but over time it led to rediscovery of known compounds. Abandoning this method resulted in fewer novel antibiotics. Abandoning this method resulted in fewer novel antibiotics (Boyd et al., 2021). AMR is evolving rapidly and is designated as a global health priority. Though resistant bacteria cause ~1.3 million deaths annually, over 8.9 million die from antibiotic-sensitive infections due to limited access and ineffective treatments (Bergkessel et al., 2023).

Role of Biotechnology

Biotechnology plays a transformative role in enhancing the discovery, activation, and production of antibiotics, particularly from actinomycetes, which are prolific producers of secondary metabolites (Buyuklyan et al., 2023). High-throughput sequencing has revealed that actinomycetes contain dozens of biosynthetic gene clusters (BGCs) with hidden potential. Traditional screening recovers less than 5% of this metabolic capability, many antibiotics remain undiscovered due to silent or low-expression clusters (Buyuklyan et al., 2023). Suppress known antibiotics, minimizing redundancy and rediscovery. Activate silent genes to promote the synthesis of novel compounds. Introduce mutations via tools like CRISPR/Cas, I-SceI meganuclease, and recombination systems Cre-loxP, pSAM2 (Buyuklyan et al., 2023).

Antibiotic effectiveness

Since their introduction into modern medicine in 1941, antibiotics have saved millions of lives. Although access to antibiotics remains a problem more than a million children with untreated pneumonia and sepsis die each year the effectiveness of these drugs is declining globally, driven by ever-higher rates of antibiotic use and selection pressure for resistance (Ramanan Laxminarayan, 2014). For example, gonorrhoea, which was entirely susceptible to penicillin in the 1970s, is now becoming increasingly resistant to third generation oral cephalosporins and is reemerging as a threat. Resistance elements, such as extended-spectrum b-lactamase (ESBL), NDM-1, and *Klebsiella pneumoniae carbapenemase* (KPC) producing

Enterobacteriaceae, have made many Gram-negative infections untreatable globally (Ramanan Laxminarayan, 2014).

Antibiotic Conservation

Antibiotic use by humans is a significant driver of resistance. Global sales of antibiotics for human consumption increased 36% between 2000 and 2011, with Brazil, Russia, India, China, and South Africa accounting for 76% of the increase. Newer antibiotics tend to be more expensive but also used less frequently, Reducing the need for antibiotics and reducing unnecessary antibiotic use will help keep existing antibiotics working. Reducing need is best achieved by reducing the burden of infections. Reducing antibiotic overuse is the other part of conservation. In many low- and middle-income countries, nonprescription antibiotic use contributes to resistance (Laxminarayan, 2014).

Future of Infection Control

Antibiotics have long been the cornerstone of modern medicine, but their future role in infection control is being reshaped by both innovation and urgency. Antimicrobial resistance (AMR) is rising dramatically. In the U.S. alone, resistance increased by 20% between 2019 and 2022, partly due to high antibiotic use during the COVID-19 pandemic. Misuse and **b** of antibiotics continue to fuel resistance, making once-treatable infections harder to manage. Rapid diagnostics like nanopore sequencing and biosensors are helping clinicians identify resistant strains faster, enabling targeted therapy. CRISPR-Cas systems and aptamer-based biosensors are showing promise for ultra-specific detection of resistance genes. Experts are calling for large-scale incentives like the PASTEUR Act to support antibiotic development and ensure access to new drugs. There's a push toward point of care testing in resource-limited settings, using affordable biosensors and microfluidic platforms (Yamin et al., 2023).

Conclusion

The antibiotics produced showed broad-spectrum activity, making these strains promising candidates for further characterization and potential therapeutic development (Sandhya et al., 2012). Future work should focus on chemical characterization of the antibiotics (e.g., via HPLC, NMR) and determining the genetic basis of their biosynthesis and resistance traits (Sandhya et al., 2012).

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