Chapter 10
Nature's Cure: Harnessing the Therapeutic Power of Secondary Metabolites in Medicine

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ABSTRACT

Secondary metabolites are organic compounds produced by microorganisms, higher plants, and fungi, with significant ecological and human health relevance. This chapter explores their biological activities, types, and biosynthesis, emphasizing their applications in disease prevention and control. It highlights the pharmacological properties of key compounds, including phenolics, alkaloids, flavonoids, terpenoids, glycosides, and polyketides, in treating and preventing cancer, diabetes, heart diseases, infections, mental disorders, and immune system dysfunctions. Their roles in combating aging, inflammation, oxidative stress, neurodegeneration, malaria, and modulating immunity are also discussed.

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1. INTRODUCTION: THE HIDDEN POWER OF SECONDARY METABOLITES

The story of secondary metabolites began in 1891 when A. Kossel introduced the term, recognizing their significance beyond the primary processes of life. Nearly two decades later, in 1910, his groundbreaking work earned him the Nobel Prize in Medicine or Physiology. Secondary metabolites, though not essential for the immediate survival of an organism, are indispensable for long-term success. Their absence may not curtail life but can severely impair an organism's ability to thrive, (Thirumurugan *et al.,* 2018a).

Derived from primary metabolic pathways, secondary metabolites are found across diverse life forms—plants, bacteria, fungi, and marine organisms like sponges, tunicates, and corals. Unlike primary metabolites, which are fundamental to cellular functions and energy production, secondary metabolites excel in specialized roles. They bolster defense against biotic and abiotic stresses, paint the vibrant hues of fruits and flowers, and aid in pollination, (Andryukov, Mikhailov, & Besednova, 2019).

Scientists have cataloged approximately 2.14 million secondary metabolites, classified based on their structure, function, and synthesis. Intriguingly, about 80% of these compounds are derived from plants, with the rest originating from microbes and marine life. Secondary metabolites in plants and microorganisms are classified into six major groups, showcasing their diversity and complexity. These include alkaloids (e.g., morphine and nicotine), terpenoids (e.g., menthol and carotenoids), phenolics (e.g., flavonoids and lignin), polyketides (e.g., erythromycin), glycosides (e.g., digitoxin), and non-protein amino acids (e.g., canavanine). Each class plays unique roles in ecological interactions, defense mechanisms, and has significant applications in medicine and industry **(Figure 1)**. This remarkable diversity has allowed secondary metabolites to find extensive use in pharmaceuticals, agriculture, and beyond, (Demain, 1999).

The versatility of secondary metabolites makes them invaluable to humankind. In medicine, they serve as antimicrobial agents, enzyme inhibitors, immunomodulators, and anti-tumor compounds. In agriculture, their properties such as insecticides, pesticides, and pheromones enhance crop productivity while maintaining ecological balance, (Microbial Secondary Metabolites, 2021). These compounds also play vital ecological roles, fostering symbiotic relationships between plants and other organisms and aiding in sporulation and germination, (Griesbach, 2010).

Plants dominate the production of secondary metabolites, contributing approximately 80% of the known compounds. This dominance stems from their evolutionary need to interact dynamically with their environment. The remaining metabolites come from other natural sources such as bacteria, fungi, and marine organisms, underscoring the collaborative ingenuity of nature, (Thirumurugan *et al.,* 2018a).