

Chapter 6

Unveiling the Anti-Inflammatory and Immunomodulatory Effects of Secondary Metabolites

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ABSTRACT

Inflammation and immune modulation are critical for the body's defense against infection, injury, and stress, but chronic inflammation underlies many diseases, including autoimmune disorders, metabolic diseases, and neurodegenerative conditions. Secondary metabolites—bioactive compounds from plants and organisms—offer promising anti-inflammatory and immunomodulatory effects. These include alkaloids, flavonoids, terpenoids, and polyphenols, which can inhibit pro-inflammatory cytokines, reduce oxidative stress, and modulate immune cell function. For example, compounds like curcumin, quercetin, and resveratrol target inflammatory pathways such as NF- κ B and COX-2. These natural agents often have fewer side effects compared to conventional drugs, making them appealing for treating inflammation-driven diseases. The growing evidence suggests secondary metabolites could provide safer, effective alternatives to traditional anti-inflammatory treatments, offering hope for more natural therapies with broad applications.

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INTRODUCTION

Metabolism is defined as the sum of all biochemical reactions occurring within an organism. Metabolites, which are intermediates and products of metabolism, are generally small molecules. In 1891, A. Kossel introduced the term “secondary” to distinguish secondary metabolites from primary ones. Unlike primary metabolites—found in every actively dividing cell and essential for basic cellular function—secondary metabolites are present only incidentally and are not crucial for the immediate survival of an organism. Although secondary metabolites are derived from primary metabolic pathways, they do not constitute the fundamental molecular structure of the organism. Their absence does not directly threaten life, unlike primary metabolites, yet their presence significantly enhances survival, especially in ecologically disadvantaged species within a phylogenetic group (Tiwari and Rana, 2015). Secondary metabolites, or natural products, are a diverse group of metabolic compounds that, while not essential for the vegetative growth of the organisms that produce them, play key roles in adaptation. Secondary metabolites represent a remarkably diverse range of natural compounds produced by plants, fungi, bacteria, algae, and animals. These metabolites, which include terpenes, phenolic compounds, and alkaloids, are typically classified according to their biosynthetic pathways. Often, specific classes of these compounds are found only within certain phylogenetic groups, reflecting their unique evolutionary roles (Roze, Chanda, and Linz, 2011). They function as differentiation compounds, supporting ecological interactions by acting as defence agents, signalling molecules, and mediators in processes like symbiosis, metal transport, and competition. Humankind harnesses the vast array of secondary metabolites to enhance health (such as antibiotics, enzyme inhibitors, immunomodulators, antitumor agents, and growth promoters for animals and plants), expand nutritional benefits (through pigments and nutraceuticals), and boost agricultural productivity (including pesticides, insecticides, ecological competitors, symbiotic effectors, and pheromones). These applications have a positive economic impact on society by supporting health, nutrition, and agricultural industries (Demain and Fang, 2000).

Inflammation is a complex physiological response driven by signalling molecules released by immune cells such as leukocytes, macrophages, and mast cells. This response, along with complement factor activation, leads to fluid and protein leakage (edema) and the accumulation of leukocytes at the site of inflammation. The inflammatory response generally serves a protective role, helping to eliminate both the cause of tissue injury and its resulting effects, thus supporting the body’s defence mechanisms (White, 1999 and Charles and Catherine, 2011). Anti-inflammatory drugs are generally divided into two main types: steroidal and non-steroidal anti-inflammatory drugs (NSAIDs). Steroidal drugs work by targeting inflammatory

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