PLANT CHEMISTRY

# Plant Secondary Metabolites in Ecological, Biochemical, and Agricultural Systems

Edited by Azamal Husen

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# Plant Secondary Metabolites in Ecological, Biochemical, and Agricultural Systems

Plants survive in complex and competitive environments by producing an extraordinary array of secondary metabolites that protect, signal, and strengthen them under stress. *Plant Secondary Metabolites in Ecological, Biochemical, and Agricultural Systems* offers a comprehensive exploration of these powerful natural compounds and their multifaceted roles in plant defense, ecological interactions, and sustainable crop production. Bringing together cutting-edge scientific insights from plant biochemistry, ecology, and agriculture, this volume examines major classes of secondary metabolites, their biosynthesis, stress responses, ecological roles, and applications in modern farming. With the increasing demand for environmentally safe alternatives to synthetic agrochemicals, this book highlights how natural plant compounds can support pest management, improve crop resilience, enhance soil health, and reduce environmental impact. An essential reference for researchers, advanced students, agricultural professionals, and biotechnologists, this book provides timely knowledge and practical perspectives for developing future sustainable farming strategies grounded in nature's own defense mechanisms.

Salient features:

- Provides an in-depth understanding of how plant secondary metabolites support natural defense, stress tolerance, and ecological interactions.
- Highlights eco-friendly, biologically grounded alternatives to synthetic pesticides, fertilizers, and growth regulators for sustainable agriculture.
- Integrates biochemistry, ecology, molecular biology, and agricultural science to present a holistic perspective on plant defense systems.
- Includes cutting-edge scientific advances in metabolic engineering, genomics, and biotechnology for enhancing crop protection and productivity.
- Serves as a valuable reference for researchers, postgraduate students, biotechnologists, and agricultural professionals working toward sustainable farming solutions.

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*Tahmeena Khan and Kulsum Hashmi*

### 1.1 INTRODUCTION

Natural products are used as dietary supplements and as alternative medicines (Medina et al., 1997). They have been used since ancient times for their therapeutic properties (Tsao et al., 2005). About 75% of people worldwide rely on plant-based medicines (Twaij and Hasan, 2022). Penicillin is an example of a classical natural product obtained from *Penicillium notatum* (Mulabagal and Tsay, 2004), whereas morphine was the first natural product to be extracted from *Papaver somniferum* in 1806 (Twaij and Hasan, 2022). Natural products can be obtained from plants, animals, and microbes (Bourgaud et al., 2001) and are also synthesized through primary and secondary metabolic routes. Plant-based metabolites find use in several fields, such as agriculture and pharmaceuticals, and are categorized as primary and secondary metabolites. Primary metabolites consist of carbohydrates, fats, and alcohols and are involved in growth and reproduction (Cragg and Newman, 2013). They are produced during the growth phase and are required for important processes in the body (Pawlikowski, 2010). They are directly involved in growth and development, whereas secondary metabolites are not involved in cell death, but affect the survival of the organism in the long term. Secondary metabolites contain more than 8,000 phenyl propanoids, 40,000 terpenoids, and 12,000 alkaloids. Secondary metabolites also form a basis of differentiation between plants belonging to different families (Saxena et al., 2013). Secondary metabolites play a crucial role in plant resistance, defence, and other ecological functions (Huang et al., 2009). In 1910, Albrecht Kossel first suggested the term "secondary metabolites", followed by Friedrich Czapek, a Polish botanist (Oksman-Caldentey and Inzé, 2004). They are also used to enhance the immunity of the human body against several pathogens. The methylerythritol-4-phosphate (MEP), tricarboxylic acid cycle (TCA), and shikimic acid pathways are involved. The phenylpropanoid pathway is also useful for the biosynthesis of metabolites and important compounds such as coumarins and flavonoids. Chromatographic techniques have been useful in assessing the secondary metabolites and their structures.

#### 1.1.1 Types of Secondary Metabolites

Natural products produced by plants play an important role in the development and growth of plants. Primary metabolites help in photosynthesis, translocation, and respiration, whereas secondary metabolites are obtained from primary metabolites through some biosynthetic modifications like methylation and glycosylation. The plant metabolites are categorized in three ways: (a) phenolic groups, (b) terpenes and steroids, and (c) nitrogen-containing compounds. Phenolic compounds are obtained from the phenylpropanoid pathway and are responsible for colours in fruits, vegetables, etc. Alkaloids and flavonoids have diverse biological functions like antioxidant, anticarcinogenic, and anti-inflammatory (Huang et al., 2009). Nitrogen-based compounds have a heterocyclic ring and are synthesized from the shikimic acid pathway.

##### 1.1.1.1 Classification of Plant Secondary Metabolites

Plant secondary metabolites have been known for their applications in biotechnology and plant biology. Based on their chemical structure, they are classified as terpenoids, phenolic compounds, and nitrogen-containing compounds (Sharma et al., 2022). The classification of plant secondary metabolites is given in Figure 1.1.

#### 1.1.2 Terpenes and Terpenoids

Terpenes are derived from several plants that have defensive properties. They are biosynthetic and produce terpenoids upon oxidation or rearrangement (Yang et al., 2020). Isoprene is the basic unit of terpenes, and nearly 40% of the biogenic compounds are isoprene (Hillier and Lathe, 2019). The term "terpenoid" or "isoprenoid" was coined in a broader sense to include isoprene-containing compounds, which were also called terpenic (Devarenne, 2009). Terpenes are derived from isoprene units having five carbons (Gershenzon and Croteau, 2012). They are classified based on the number of isoprene units (Figure 1.2). Monoterpenes have two isoprene units and are found in the essential oils of the family Lamiaceae, Pinaceae, and Rutaceae. Monoterpenes can be unsaturated hydrocarbons

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