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Secondary Metabolites from Natural Products

Stella Omokhefe Bruce

Abstract

Natural products are substances that are confined from living organisms, they are in the form of primary or secondary metabolites. Secondary metabolites are compounds with varied chemical structures, produced by some plants and strains of microbial species. Unlike primary metabolites (nucleotides, amino acids, carbohydrates, and lipids) that are essential for growth, secondary metabolites are not. Secondary metabolites are produced or synthesized during the stationary stage. In this chapter, we will discuss secondary metabolites from natural products synthesized mainly by plants, fungi, and bacteria. Plants synthesize a large diversity of secondary metabolites; plant secondary metabolites are split into four groups namely alkaloids, phenolic compounds, terpenoids, and glucosinolates. Several classes of fungal and bacterial secondary metabolites, their sources, and pharmacological uses associated with the secondary metabolites are also discussed. Therefore, several classes of secondary metabolites are responsible for the biological and pharmacological activities of plants and herbal medicines.

Keywords: secondary metabolites, natural products, alkaloids, phenolic compounds, terpenes

1. Introduction

Secondary metabolites are natural products synthesized mainly by plants, fungi and bacteria. Secondary metabolites are molecules with low molecular weight and various biological activities and chemical structures [1]. Secondary metabolites are also called specialized metabolites; they generally mediate ecological interactions by increasing their ability to survive [2]. Secondary metabolites function as a defense against herbivores and other interspecies in plants; and it was first established by A. Kossel in 1910, and was discovered 20 years later as an end product of nitrogen metabolism by Friedrich Czapek a Botanist [3].

2. Plant secondary metabolites

Plants are capable of manufacturing diverse types of organic compounds which are grouped into primary and secondary metabolites [3]. Some secondary

metabolites are phenylpropanoids or cinnamic acids, which protect plants from UV damage [4]. Since ancient times, the plant secondary metabolite's biological effects in humans have been known. The herb *Artemisia annua* contains Artemisinin, which is widely used in herbal or traditional medicine. Plant secondary metabolites can be divided into four major classes: alkaloids, phenolic compounds, terpenes, and glucosinolates [5, 6].

2.1 Alkaloids

Plants are natural products and the oldest source of alkaloids, examples of the most widely recognized alkaloids are morphine, quinine, strychnine, and cocaine [7]. Alkaloids are present as water-soluble salts of organic acids, esters, tannins (Cinchona bark) or in plant tissues [7, 8].

Most alkaloids are isolated in the form of crystalline, non-odorous, nonvolatile and amorphous compounds, low molecular weight alkaloids, such as arecoline and pilocarpine, non-oxygen atom alkaloids such as sparteine and nicotine occur in the liquid form, these are all from plant matrices. Majority of alkaloids are colorless with a bitter taste, apart from colchicine and berberine. Alkaloids are derived from plant sources and a diverse group of nitrogen-containing basic compounds, which contain one or more nitrogen atoms. Chemically they are heterogeneous. Based on chemical structures, they are classified into two broad categories [9]:

Examples of plants with alkaloids include, *Datura stramonium*, *Atropa belladonna*, *Erythroxylum coca*, *Solanaceae* (nightshade) plant family, *Papaver somniferum*, and *Catharanthus roseus* [9].

Alkaloids (about 20,000) are isolated from plants, but it have also been found in microorganisms, marine organisms such as algae, dinoflagellates, and pufferfish, and terrestrial animals such as insects, salamanders, and toads [10].

Classification based on the botanical origin of the alkaloids, their Sources and pharmacological properties are listed below (**Table 1**). For example., *Papaver* (opium) alkaloids, *Cinchona* alkaloids, *Rauvolfia* alkaloids, *Catharanthus* alkaloids, *Strychnos* alkaloids, Ergot alkaloids, cactus alkaloids, and *Solanum* alkaloids [10], while the structures of some alkaloids are shown in **Figure 1**.

2.2 Phenolic compounds

Plant secondary metabolism produces phenolic compounds with chemical structures of one hydroxyl aromatic ring. These phenolic compounds are classified based on their carbon chain [11]. Phenolic compounds are found in plant tissues, fruits and vegetables and are also ubiquitously distributed phytochemicals. Phenolic compounds are synthesized through phenylpropanoid and shikimic acid pathways [12]. Phenolic compounds possess numerous bioactive properties and health-protective effects, although they are not nutrients, therefore postharvest treatments have been used to enhance or preserve the phenolic compounds in fruits and vegetables [12]. Phenolic compounds possess an aromatic ring with one or more hydroxyl substituents that can be divided into several classes, which are common chemical structures essential for health benefits [13].

Plant materials like (Tropical Root and Crops) contain two classes of phenolic compounds as hydroxybenzoic acids and hydroxycinnamic acids. Phenolic compounds are present in Nigerian *Centaurea perrottetii* DC. [family COMPOSITAE] and other related genera (*Cheirolophus*, *Rhaponticoides*, and *Volutaria*) [14].

Alkaloid	Source	Properties
Ajmaline	<i>Rauvolfia serpentina</i>	Antiarrhythmic, antihypertensive
Caffeine	<i>Coffea arabica</i>	Stimulant, insecticide
Camptothecin	<i>Camptotheca acuminata</i>	Antineoplastic
Cocaine	<i>Erythroxylon coca</i>	Analgesic, narcotic, local anesthetic
Codeine	<i>Papaver somniferum</i>	Analgesic, antitussive
Emetine	<i>Uragoga ipecacuanha</i>	Antiamoebic, expectorant, emetic
Hyoscyamine	<i>Atropa belladonna</i> and others	Anticholinergic
Morphine	<i>P. somniferum</i>	Analgesic, narcotic
Nicotine	<i>Nicotiana tabacum</i>	Stimulant
Pilocarpine	<i>Pilocarpus jaborandi</i>	Cholinergic
Quinidine	<i>Cinchona</i> spp.	Antiarrhythmic
Quinine	<i>Cinchona</i> spp.	Antimalarial
Reserpine	<i>R. serpentina</i>	Tranquilizer
Scopolamine	<i>Hyoscyamus niger</i> and others	Sedative, anticholinergic
Strychnine	<i>Strychnos nux-vomica</i>	Stimulant, poison
Taxol	<i>Taxus brevifolia</i>	Antineoplastic
Vinblastine and vincristine	<i>Catharanthus roseus</i>	Antineoplastic

Table 1.
Sources and pharmacological uses of selected plant-derived alkaloids.

The phenolic compounds found in plants are represented in **Table 2**, while the categories of phenolic compounds and their representative compounds are shown in **Figure 2**. Phenolic compounds survive in plant material, in either a soluble or a bound form [15, 16].

2.3 Terpenoids

Terpenes are a unique group of hydrocarbon-based natural products whose structures are derived from isoprene. Terpenoid secondary metabolites occur in plant tissue types often secured in secretory structures [17]. Over 30,000 members of terpenes are in an enormous class of natural products, they have been used for a broad variety of purposes including medicine, flavoring and perfume [18]. Terpenes as a broad group with ecological roles, that exhibit a range of deadly to entirely edible toxicity, which include antimicrobial properties and other properties [19, 20].

Plants and flowering plants (angiosperms) subdivisions have colonized the majority of the terrestrial surface, courtesy of rich levels of specialization and the relationships with other organisms [21].

Terpenes are important plant metabolites that include substances like floral fragrances that serve as plant hormones (gibberellic and abscisic acid), growth inhibitors, insect attractants, pine oil, and insecticides [22].

Terpenoids or isoprenoids are high in plants where many can be considered secondary metabolites and have fundamental roles in the metabolism of all organisms [23]. Terpenoid secondary metabolism in plants began with the recruitment of genes

Figure 1.

Structures of some alkaloids. Note that the structures of morphine and codeine are based on the same skeleton, but are decorated with different functional groups in the position represented by 'R'. In morphine, this group is -OH, while in codeine it is CH₂O. Similarly, vinblastine and vincristine are based on the same skeleton, but differ in the nature of the R-group, which for vinblastine is -CH₃ and for vincristine is -CHO.

from primary metabolism [24] and accelerated due to the proliferation of cytochrome P450 and terpene synthase gene families in the genomes of plants [25].

Terpenoids play various physiological and ecological functions in plant life and human through direct and indirect plant defenses, because of their enormous applications in the pharmaceutical, food and cosmetics industries [26]. Examples of terpenoids from plant species are 1). Artemisinin, present in *A. annua*, Chinese wormwood. 2). Tetrahydrocannabinol, present in *Cannabis sativa*, cannabis. 3). Azadirachtin, present in *Azadirachta indica*, the (Neem tree). 4). Saponins, glycosylated triterpenes present in *Chenopodium quinoa*, quinoa [27, 28].

2.4 Glucosinolates

The pungent smell of plants (mustard, cabbage, and horseradish) is due to mustard oils produced from glucosinolates [29]. Glucosinolates are biosynthesized from amino acids, which consists of three glucosinolate subtypes (aliphatic, indole

Polyphenolic Compounds	Example	Fruit Source
Phenolic acids	<i>Hydroxycinnamic acids</i> Caffeic acid Chlorogenic acid Ferulic acid Sinapic acid Caftaric acids Neochlorogenic acid <i>p</i> -Coumaric acid	Blackberry, raspberry, strawberry, blackcurrant, blueberry, cranberry, pear, sweet cherry, apple, orange, grapefruit, lemon, and peach
	<i>Hydroxybenzoic acids</i> Ellagic acid Gallic acid	Strawberry, raspberry, grapes, longan seed, and pomegranate
Flavonoids	<i>Flavonols</i> Myricetin Quercetin Kaempferol Isorhamnetin	Apples, apricots, grapes, plums, bilberries, cranberries, olive, elderberries, currants, cherries, blackberries, and blueberries
	<i>Flavanones</i> Naringenin Hesperetin	Lemon, orange, grapefruit, and tangerine
	<i>Flavones</i> Apigenin Luteolin Tangeretin Nobiletin	Citrus fruits and pear
	<i>Flavan-3-ols</i> (+)-Catechin (-)-Epicatechin (-)-Epicatechin 3-gallate (-)-Epigallocatechin-3-gallate (+)-Gallocatechin (-)-Epigallocatechin Procyanidins Prodelphinidins	Apples, apricots, grapes, peaches, nectarines, raspberries, cherries, blackberries, blueberries, cranberries, pears, plums, and raisins
	<i>Anthocyanins</i> Cyanidin 3-galactoside Cyanidin 3-glucoside Cyanidin 3-arabinoside Cyanidin 3-xyloside Malvidin Delphinidin Pelargonidin	Blackberries, blackcurrant, blueberries, black grape, elderberries, strawberries, cherries, plums, cranberry, pomegranate, and raspberry
Stilbenes	<i>Dihydrochalcones</i> Phloretin Phloridzin	Apple
	Resveratrol <i>trans</i> -Resveratrol	Grapes
Tannins	Catechin polymers Epicatechin polymers Ellagitannins Proanthocyanidins Tannic acids	Grape seed/skin, apple juice, strawberries, raspberries, pomegranate, walnuts, peach, blackberry, and plum
Lignans	Secoisolariciresinol Matairesinol	Pear

Table 2.
Selected phenolic compounds found in plants.

Figure 2.
Categories of phenolic compounds.

and aromatic glucosinolates) that have their corresponding precursors. Aliphatic glucosinolates are derived from isoleucine, alanine, valine, methionine, and leucine. Indole and aromatic glucosinolates are obtained from phenylalanine or tyrosine and tryptophan. Examples of the three classes of glucosinolates represented by 3methylsulfinylpropyl glucosinolate; indol3ylmethyl glucosinolate; and benzyl glucosinolate in **Figure 3**.

Glucosinolates are responsible for the pungent properties present in mustard, rutcola, horseradish, cruciferous vegetables, and nasturtium and they are sulfur and nitrogen-containing glycosides, which protect against carcinogenesis [30].

The glucosinolates of sulforaphane (Glucoraphanin) present in broccoli, cabbage, and cauliflower (cruciferous vegetables) are responsible for protection against carcinogenesis. The Brown (*Brassica juncea*), white (*Brassica alba*) and black (*Brassica nigra*) mustards are examples of mustard seed with the family Brassicaceae [31, 32].

Secondary metabolites in plants (glucosinolates, isothiocyanates, S-methyl cysteine, allyl sulfurs, phytates, phytoestrogens) likely to protect against cancers, and antioxidant properties (phenolic compounds, flavonoids) [32].

Isothiocyanates are present in cruciferous vegetables, which is the product of the degradation of glucosinolates. S-methyl cysteine is a sulfur-containing phytochemicals found in all brassica vegetables [33, 34].

Figure 3.
 Glucosinolates.

Glucosinolates contain metabolites found in the plant *Arabidopsis thaliana*. The strong taste of foods (horseradish, wasabi, and mustard) is as a result of glucosinolates [35, 36].

Over 130 glucosinolate compounds have been identified in plants, and one way that they vary is by the amino acid precursor that is incorporated during glucosinolates biosynthesis [37].

3. Fungal secondary metabolites

Fungi are eukaryotic organisms that can utilize various solid substrates of their biochemical and biological evolution and are also known to inhabit almost all ecological niches of the Earth. Some of the solid substrates utilized by fungi are decaying and dead material, such as live plants (endophytic, parasitic, and mycorrhizal fungi), lichens (lichenicolous and endolichenic fungi), insects (entomopathogenic fungi) and herbivore dung (saprophytic and coprophilous fungi). A characteristic feature of many of these fungi (filamentous growth and complex morphology), is their ability to produce secondary metabolites which are useful in pharmaceutical, agrochemical industries and food with different biological activities [38, 39].

In the production of secondary metabolites which occurs after fungal growth has stopped because of nutrient limitations but an abundant carbon source available, it is then possible to manipulate their formation. Some endophytic fungi can produce secondary metabolites known from plants. Examples include production paclitaxel (Taxol®) and camptothecin, by *Taxomyces andreanae* and *Nothapodytes foetida*, respectively, and a synthetic precursor of an anticancer drug, podophyllotoxin, by *Phialocephala fortinii* [39].

The several classes of fungal secondary metabolites are polyketides (aflatoxin and fumonisins), nonribosomal peptides (sirodesmin, peramine, siderophores) and terpenes (T-2 toxin, deoxynivalenol (DON)), indole terpenes (paxiline and lolitrems) as represented in **Figure 4**. Polyketides are building blocks of natural products and are the largest group of metabolites occurring in their greatest number. They are the most sought-after molecules because of their wide spectrum of activities (clinical, industrial and economical activities). Non-ribosomal peptides are catalyzed without mRNA template by a complex enzyme called Nonribosomal peptide-synthetase (NRPS) enzymes. The peptide is modified by accessory enzymes similar to polyketides and often includes noncanonical amino acids. Nonribosomal peptide-synthetase (NRPS) enzymes include B-lactam antibiotics, cyclosporine A and echinocandin [40, 41].

The first FDA-approved secondary metabolite was Lovastatin, to lower cholesterol levels. In oyster mushrooms [42], red yeast rice [43], and Pu-erh [44], Lovastatin occurs naturally in low concentrations. Their mode of action is inhibition of HMG-CoA reductase, and it is the enzyme responsible for converting HMG-CoA to mevalonate.

Fungal secondary metabolites are dangerous to humans. The fungi *Claviceps purpurea*, a member of the ergot group, typically growing on rye, when ingested results in the death of humans. In *C. purpurea*, a build-up of poisonous alkaloids lead to spasms and seizures, Itching, diarrhea, psychosis or gangrene and paresthesias [45].

Fungi are organisms that produce a wide range of natural products often called secondary metabolites; many natural products are of agricultural, medical, and

Figure 4. Several classes of fungal secondary metabolites; a) Polyketides b) non-ribosomal peptides c) Terpenes and d) Indole terpenes.

industrial importance. Examples of natural products causing harm (mycotoxins), while others are advantageous (antibiotics) to humans [46, 47]. The biosynthesis of natural products is usually associated with cell differentiation or development, the establishment of a G-protein-mediated growth pathway in *Aspergillus nidulans* regulates both asexual sporulation and natural product biosynthesis [48].

Secondary metabolism is connected with sporulation processes in microorganisms [49, 50], including fungi [51, 52]. Secondary metabolites connected with sporulation can be classified into three groups: (i) Sporulation activated by metabolites (*A. nidulans* [53–56]), (ii) Sporulation structures from pigments (melanins [57, 58]), and (iii) toxic metabolites secreted at the time of sporulation by growing colonies (the biosynthesis of some deleterious natural products, such as mycotoxins [48, 59]). These examples of fungal secondary metabolites are shown in **Table 3**.

Natural products are essential for sporulation, examples of fungal strains that are sporulated and deficient in secondary metabolite production are *Penicillium urticae* patulin mutants [52] and *A. nidulans* sterigmatocystin mutants [67]. Secondary metabolites such as brevianamides A and B produced by *Penicillium brevicompactum* [60], some natural products have subtle effects on sporulation, as recent studies of *A. nidulans* sterigmatocystin mutants suggest that they display a decrease in asexual spore production [61, 62].

Secondary metabolites have easily visible effects on morphological differentiation in fungi, mycelium excretes compounds that can prompt sexual and asexual sporulation in other fungi [63–65], these compounds have not been identified but are assumed to be natural products produced as the mycelia ages. Other natural product such as *Fusarium graminearum* enhances perithecial production in *F. graminearum* and produces an estrogenic mycotoxin called zearalenone, an inhibitor of zearalenone synthesis, which inhibits the sexual development of this fungus [66].

Butyrolactone I, produced by the fungus *Aspergillus terreus*, is an inhibitor of eukaryotic cyclin-dependent kinases, which increases sporulation [68]. Some secondary metabolites trigger sporulation and influence the development of the

Secondary metabolite	Producing fungus	Association with development	References
Linoleic-acid derived psi factor	<i>Aspergillus nidulans</i>	Induces sporulation; affects ratio of asexual to sexual spore development	[54–57]
Zearalenone	<i>Fusarium graminearum</i>	Induces sporulation; enhances perithecial formation	[60]
Butyrolactone I	<i>Aspergillus terreus</i>	Induces sporulation and lovastatin production	[61]
Melanin	<i>Colletotrichum lagenarium</i>	Associated with appressorial formation	[62]
Melanin	<i>Alternaria alternata</i>	UV protection of spore	[62]
Melanin	<i>Cochliobolus heterotrophus</i>	Required for spore survival	[63]
Spore pigment	<i>Aspergillus fumigatus</i>	Required for virulence	[64]
Mycotoxins	<i>Aspergillus</i> spp.	Produced after sporulation	[65, 66]
Patulin	<i>Penicillium urticae</i>	Antibiotic; produced after sporulation	[53]

Table 3.
Fungal secondary metabolites.

producing organism and neighboring members of the same species. Natural product biosynthetic gene clusters can be conserved between organisms, for example, the sterigmatocystin-aflatoxin biosynthetic gene cluster in several *Aspergillus* spp. [69].

4. Bacterial secondary metabolites

The bacterial secondary metabolites are natural products source of anticholesterol agents, immune suppressants, antibiotics, antitumor agents, and other medicines; secondary metabolite-producing microorganisms synthesize these bioactive and complex molecules at the late phase and stationary phase of their growth [70–72] as shown in **Figure 5a**. In bacteria, the actinomycetes (streptomycetes) produce a significant number of chemically distinct secondary metabolites [73–76]. Other major sources include soil pseudomonas, bacilli, and myxococci [77–80]. An example of a bacterial secondary metabolite is botulinum toxin synthesized by *Clostridium botulinum*, with a positive and negative effect on humans. However, botulinum toxin has multiple medical uses for the treatment of muscle spasticity, migraine and cosmetics use [81].

Bacterial production of secondary metabolites starts in the stationary phase in response to environmental stress and lack of nutrients. Secondary metabolite synthesis in bacteria, allow them to better interact with their ecological niche and it is not essential for their growth. The b-lactam, shikimate, polyketide and non-ribosomal are the synthetic pathways for secondary metabolite production [82] as shown in **Figure 5b**. B-lactam family of cephalosporins antibiotics have been used to treat bacterial infections for 40 years and above. Gram-positive bacteria, Gram-negative bacteria, and fungi are the major sources of b-lactam antibiotics. The shikimate pathway contributes to the basic building blocks for aromatic metabolites and amino acids, which can serve as antibacterial agents. In the bacterial secondary metabolite, two enzymes can transfer a complete enolpyruvoyl moiety to a metabolic pathway, 5-enolpyruvoyl shikimate 3-phosphate synthase and chorismate synthase that require a reduced cofactor, flavin mononucleotide, for its activation. When secreted those found in the prokaryotic cell wall are endotoxins, while those poisonous compounds are known as exotoxins. Other examples of bacterial secondary metabolites are phenazine, polyketides, nonribosomal peptides, ribosomal peptides, glucosides, and alkaloids.

4.1 Phenazine

Bacteria are natural phenazines, phenazines are heterocyclic, nitrogenous compounds that differ in their physical and chemical properties. Phenazines are significant for their potential impact on bacterial interactions and biotechnological processes. It exhibits a wide range of biological activities, Pyocyanin, from *Pseudomonas aeruginosa*. Other phenazines from *Pseudomonas* sp. and *Streptomyces* sp. (Natural Products of Actinobacteria Derived from Marine Organisms) [83].

Phenazines produced by various bacteria species and excrete them in high quantities in the environment in a visible form to the naked eye, they are nitrogen-containing colored aromatic secondary metabolites. The main use of phenazines is to

Figure 5.
a) the secondary metabolite-producing microorganisms synthesize these bioactive and complex molecules at the late phase and stationary phase of their growth. b) Secondary metabolite pathway reactions are conducted by an individual enzyme or multienzyme complexes. Intermediate or end-products of primary metabolic pathways are channeled from their systematic metabolic pathways that lead to the synthesis of secondary metabolites.

protect plants (biocontrol field), because of their antimicrobial properties. Examples of bacteria species able to produce phenazines are *Pseudomonas* spp. (including *P. aeruginosa*, *P. fluorescens*, and *Pseudomonas chlororaphis*) [84].

4.2 Polyketides

Polyketides from plants, bacteria, fungi, and animals, are a large group of secondary metabolites known to possess remarkable properties [85, 86]. Polyketides possess some bioactivities such as antibacterial (e.g., tetracycline), antifungal (e.g., amphotericin B), immune-suppressing (e.g., rapamycin), anti-cholesterol (e.g., lovastatin), anti-inflammatory activity (e.g., flavonoids), antiviral (e.g., balticolid), and anti-cancer (e.g., doxorubicin) [87–93]. Some organisms that can produce polyketides are plants (e.g., emodin from *Rheum palmatum*), fungi (e.g., lovastatin from *Phomopsis vexans*), bacteria (e.g., tetracycline from *Streptomyces aureofaciens*), protists (e.g., maitotoxin-1 from *Gambierdiscus australes*), mollusks (e.g., elysione from *Elysia viridis*), and insects (e.g., stegobinone from *Stegobium paniceum*) [94–99]. These organisms can use the polyketides they produce for pheromonal communication in the case of insects and also as protective compounds.

Polyketides are a family of natural products which are synthesized by polyketide synthase (PKS) enzymes with different biological activities and pharmacological properties. They are divided into three types: type I polyketides (macrolides produced by multimodular megasynthases), type II polyketides (aromatic molecules produced by the iterative action of dissociated enzymes), and type III polyketides (small aromatic molecules produced by fungal species) [100]. Polyketides are also found in bacteria, fungi, plants, mollusks, protists, sponges, and insects. They have notable variety in their structure and function. Some examples of polyketides antibiotics are Erythromycin, Avermectin, Nystatin, and Rifamycin [100].

4.3 Nonribosomal peptides

Nonribosomal peptides (NRPs) are peptide secondary metabolites that are synthesized by nonribosomal peptide synthetases (NRPSs) (multidomain mega-enzymes), without messenger RNAs and cell ribosomal machinery [101]. Nonribosomal peptides are naturally synthesized by bacteria, fungi, and higher eukaryotes [101]. Nonribosomal peptides are also synthesized by indigoidine (pigment). Some examples of nonribosomal peptide antibiotics are; Vancomycin, bacterium, Ramoplanin, Teicoplanins, Gramicidin, Bacitracin, Polymyxin [102].

4.4 Ribosomal peptides

Streptomyces azureus is produced from several strains of streptomycetes (Thiostrepton), *Escherichia coli* produced from Microcins and Bacteriocins [82].

4.5 Glucosides

Streptomyces species produced from Nojirimycin [82].

4.6 Alkaloids

Pseudoalteromonas produced by Tetrodotoxin, a neurotoxin [82].

5. Conclusion

Natural products originate as secondary metabolites. Plants possess different indigenous defensive mechanisms to cope with certain environmental stresses. Secondary metabolites are natural tools used by plants to combat biotic and abiotic stresses. Microorganisms can produce several antibiotics and other pharmaceutically important drugs to treat bacterial and fungal infections. The secondary metabolites from natural products help us to understand their classes, sources, pharmacological importance and examples associated with the secondary metabolites derived from plants, fungi, and bacteria.

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