

Chapter

Secondary Metabolites of Plant Origin: Their Potential and Benefits for Life

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Abstract

Secondary metabolites are specialized compounds produced by certain organisms, especially higher plants, as side products of photosynthesis and not directly required for basic survival. Not every higher plant produces these substances; this ability varies by species and is influenced by environmental conditions during particular growth phases. Globally, it is estimated that around 40% of higher plant species can generate secondary metabolites. These compounds serve several functions: they help activate antioxidants that suppress radical reactions, aid in managing plant pests, attract pollinating insects, contribute to the synthesis of pheromones and allelochemicals, and provide protection against both biological and environmental stressors when growing conditions are less than ideal. Each plant species has the capacity to produce secondary metabolites through three primary biosynthetic routes: the acetic acid pathway, the shikimic acid pathway, and the mevalonate or deoxyxylulose pathway, each giving rise to a diverse array of chemical structures. These metabolites include flavonoids, prostaglandins, alkaloids, phenols, aromatic compounds, terpenoids, steroids, tannins, and related derivatives, all of which offer benefits to the plants themselves as well as to humans and other organisms. The kinds and quantities of these compounds in higher plants can differ significantly, both among different species and within the same species, influenced by factors such as the plant's developmental stage, its metabolic state when entering biosynthesis, the environmental conditions of its habitat, and the intensity of external stressors it encounters.

Keywords: flavonoid, phenolic, steroid, tannin, terpenoid

1. Introduction

A number of higher plants are able to produce one or more types of organic compounds from the secondary metabolite group, which are by-products of anabolic or photosynthetic activities. Secondary metabolite compounds are often referred to as bioactive compounds, in connection with the ability of these compounds to have high biological activity, especially antioxidant properties and certain toxicities that we can utilize for food, pharmaceutical, and agricultural industrial products.

In contrast to the role of primary metabolite compounds, which are directly involved in plant growth, development, and reproduction, secondary metabolite compounds are nonessential compounds synthesized by plants for specific purposes [1]. Secondary metabolite compounds are not always or continuously produced by a plant, but only at certain phases or under certain conditions.

The main objective of photosynthetic activity should be to form primary metabolite compounds from carbohydrates, amino acids, proteins, lipids, lactic acid, nucleic acids, ATP, DNA, and others, which are essential for plants, so that, without primary metabolite compounds [2], the plant can die. Meanwhile, if a plant is unable or fails to synthesize secondary metabolite compounds, the plant can still continue to live. When a plant grows in unfavorable environmental conditions, the plant, which has certain genetic characteristics, will synthesize secondary metabolite compounds as a defense effort for the continued growth and development of the plant.

Not all higher plant species are capable of producing secondary metabolite compounds. Until now, it has been known that approximately 40% of the world's total higher plants are capable of producing secondary metabolite compounds. Based on this percentage, it is estimated that only 40% are used by us as medicinal and cosmetic ingredients, in the food industry, or as control agents for plant pests in agricultural activities (pesticides, herbicides, insecticides). Generally, secondary metabolite compounds detected from higher plant organs are groups of phenolics, flavonoids, terpenoids, steroids, and tannins and their derivatives [2]. The diversity of chemical and physical characteristics of the types of secondary metabolite compounds and their derivatives in each species is unique, so that there are many types of secondary metabolite compounds in nature that are difficult for us to memorize, both the names and the chemical structures.

The diversity of secondary metabolite compounds from natural materials needs to be continuously studied as a special learning object [1–3]. Every year, scientists in the fields of plant science, biology, natural product chemistry, pharmacology, and other fields of science continue to expand their research to find types of higher plants, lower plants, microbes, bacteria, fungi, or animal species that are able to synthesize secondary metabolite compounds. However, in this chapter, the main topic of study will only be discussed with regard to secondary metabolite compounds originating from higher plants.

The discovery of a new type of secondary metabolite compound from a newly discovered higher plant species is very significant. The new compound will continue to be studied as a special learning object. If new structures and physical and chemical properties are found, they will be considered as to whether they have the potential to be used as raw materials for pharmaceutical and cosmetic industrial products or other downstream products that can act as natural controllers to repair damaged conditions or to maintain balanced conditions in human life and the environment. Considerations in determining the usefulness of secondary metabolite compounds from higher plants for other organisms certainly require intensive and continuous research, so that these compounds can be processed as appropriate industrial raw materials [1, 2].

The main objective of this chapter is to highlight the key potential benefits of secondary metabolite compounds synthesized by higher plants, particularly for the plants themselves, their surrounding microenvironment, and human health. For the plants synthesizing them, these benefits include acting as antioxidants, pollinator

attractants, pheromones, allelochemicals affecting other organisms, and as antidotes to physiological stress. Regarding human health, these secondary metabolites serve as raw materials for medicines, cosmetics, and agricultural products such as insecticides, herbicides, and plant growth retardants.

How the biosynthesis process of secondary metabolite compounds occurs in higher plants, what forms of chemical structure diversity exist, what types of organ specifications are capable of synthesizing these compounds, how large the synthesis capacity is, and how to detect the types of secondary metabolite compounds synthesized, among other things, will be discussed in this chapter.

2. The potential of plants to synthesize secondary metabolite compounds

2.1 Secondary metabolite synthesis events

Secondary metabolites are actually types of metabolic compounds that are not essential, meaning that these compounds are not directly involved in the growth, development, and reproduction of the organisms that form them. Therefore, every higher plant that is able to synthesize secondary metabolite compounds will be found in a unique form according to the growth phase stage and the environmental conditions that suppress the growth phase, so that each organism will produce different types or chemical structures from one species to another, even within the same species, because of the different growing conditions between one and another [1–3]. The ability of each species of higher plants to synthesize secondary metabolite compounds can go through several metabolic pathways after the formation of glucose, fructose, or other sugar compounds resulting from photosynthesis, then it will meet amino acids as precursors and, with the help of enzymes as catalysts, then enter the biosynthesis pathway to be converted into metabolites until the final product is formed in the form of polyketide, terpenoid, phenolic, alkaloid, steroid, and tannin compounds along with derivatives or in the form of mixed compounds from the main framework of secondary metabolites [3]. The flowchart of secondary biosynthesis, which begins with the presence of H_2O and CO_2 compounds and then produces O_2 during the photosynthesis process, is presented in **Figure 1**.

Based on **Figure 1**, it appears that the compounds water (H_2O) and carbon dioxide gas (CO_2) are the two initial compounds in the biosynthesis of primary metabolites and then secondary metabolites. The first organic compounds formed are primary metabolites: glucose, fructose, or other monosaccharide compounds that initiate the conversion of raw materials into secondary metabolite compounds [1]. Also involved is the role of precursors, namely organic compounds that are formed after the initial raw materials but are not the final compounds. The role of biocatalysts is that enzymes work specifically to assist the chemical reaction process, thereby enabling raw material compounds to enter the secondary metabolite biosynthesis pathway [2].

Based on the biosynthesis flowchart presented in **Figure 1**, secondary metabolite compounds can be classified into the following: 1) the acetate group, with 2 carbon atoms and multiples thereof (C_{2n}); 2) the mevalonate and deoxyxylulose groups, with 5 carbon atoms and multiples thereof (C_{5n}); and 3) the shikimate group, with 7 carbon atoms and multiples thereof (C_{7n}). In addition, organic compounds can also be formed from a combination of primary and secondary metabolites [2, 3].

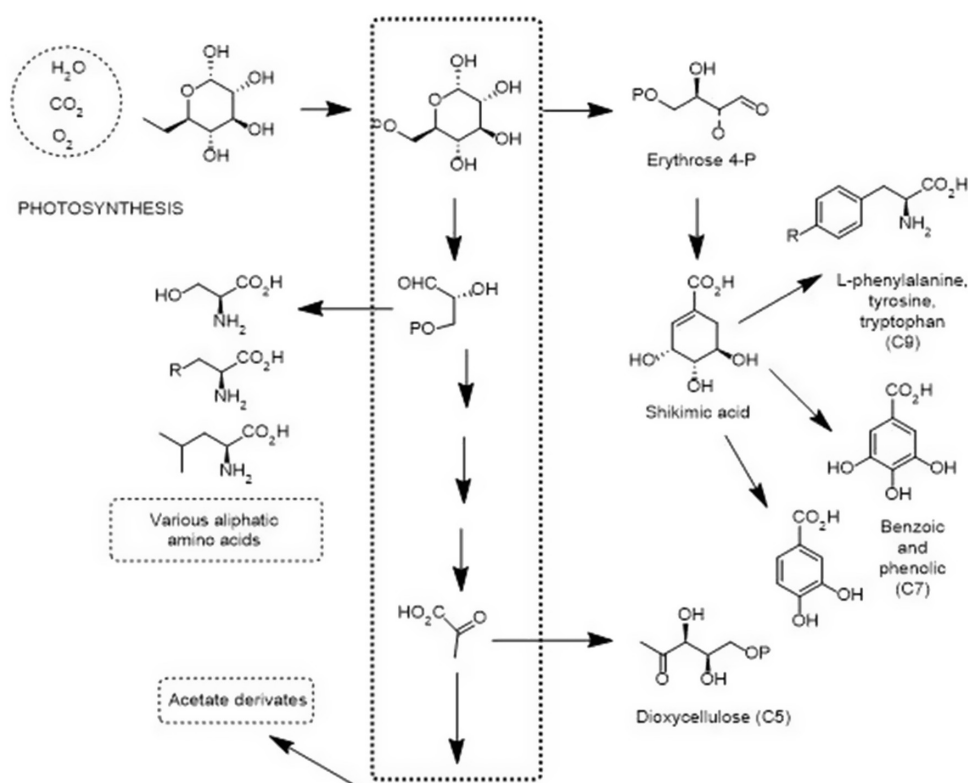


Figure 1.

The relationship between the biosynthesis of primary metabolites and secondary metabolites [2, 3].

Regarding the number of carbon atoms and their multiples in nature that form the structure of metabolite compounds, it is not always exact, but can be one less or one more; this can be tolerated, considering that the enzymatic reaction process in nature often depends on climatic factors, especially the micro-temperature of the growing region. The main characteristics of secondary metabolite compounds include: the longer the carbon chain, the more easily it dissolves in nonpolar solvents, but the more hydroxyl groups there are, the more easily the compound dissolves in polar solvents [2, 3].

2.2 Benefits of secondary metabolite compounds for plants

Secondary metabolite compounds are generally more actively synthesized as a plant response to physiological stress, especially when the plant is in unfavorable environmental conditions. There are two factors that cause plant physiological stress: nonbiotic factors (climate and soil) and biotic factors (the presence of other organisms acting as pests). The type and dominance of secondary metabolite compounds synthesized will also differ depending on the type of species and genetics, the type of stressor, the type of environmental factor that triggers it, and species responses to physiological stress [2, 3].

Higher plants have their own reasons for having to synthesize secondary metabolite compounds, namely, as self-defense due to growing conditions that do not support survival in certain growth phases. Internal plant factors (genetics) also cause the form of the physiological response displayed.

Secondary metabolite compounds of the phenolic type are synthesized by the *Ziziphus mauritiana* plant as protectors against ultraviolet B (UV-B) rays, with the aim of protecting DNA from accelerated denaturation, preventing damage and death of cells and tissues [4]. Meanwhile, phenol compounds synthesized by *Moringa oleifera* leaves act as inhibitors against free radical compounds from the atmosphere [4]. Secondary metabolite compounds of the flavonoid type produced by the bark of *Hibiscus tiliaceus* have the potential to be antibacterial through a working mechanism that damages the walls and nuclei of bacterial cells that are present as disruptors of the growth and development of the plant [4]. The Kebar grass plant (*Biophytum petersianum*) from Papua, Indonesia, is able to synthesize secondary metabolites of the saponin type, better known as the ethyl-acetic acid fraction [4]. Linalool and terpenoid compounds synthesized by sweet basil (*Ocimum basilicum*) leaves at certain concentrations are able to synergize to repel male and female imago of *Bactrocera* spp., thus failing to metamorphose into adult insects [5]. The linalool compound is also synthesized by the leaves of the *Zodia suaveolent* plant, with a distinctive aroma of essential oil, which is often used by the people of the interior village of Papua, Indonesia, as a mosquito repellent by applying chopped leaves to the surface of the skin [2, 6].

Secondary metabolite compounds of the quinone, flavonoid and tannin types produced by a plant can play a role in allelopathic events, namely killing other plants in the vicinity [7]. Terpenoid compounds from fig leaf extract (*Ficus carica* L.) have antibacterial activity against *Methicillin-resistant Staphylococcus aureus* (MRSA) [7]. *Piper betel* fruit extract contains secondary metabolite compounds of the alkaloid group, and has been shown to be effective in inhibiting the activity of *Staphylococcus epidermidis* bacteria [7]. Secondary metabolite compounds detected from Langsat fruit seed extract (*Lansium domesticum* Corr.), namely alkaloids, phenols, flavonoids, saponins, and terpenoids, are effective in inhibiting the activity of *Candida albicans* fungus [7]. Galanga rhizome extract (*Alpinia galanga* L.), which contains secondary metabolite compounds of the terpenoid type, has been shown to be effective in suppressing the fungus *Colletotrichum* spp. that attacks soybean seeds in storage warehouses [7].

The eugenol compound released by clove flowers and leaves that are still in bud is attractive to pollinators, so that the pollination process of the plant is assisted [8]. Several species of orchid plants are also able to synthesize eugenol compounds, which are derivatives of phenylpropanoid organic compounds, with different ratios for each species among eugenol, linalool, and geraniol, so that certain insects will choose certain types of flowers that they like; if they are not suitable, then the secondary metabolite compounds produced will be enemies to certain insects. Tobacco plants (*Nicotiana tabacum*) and citronella grass (*Cymbopogon nardus*) are examples of two species that are able to synthesize unique types of secondary metabolite compounds, namely nicotine and citronellal, as an effort to defend themselves from attacks by plant-disturbing organisms [5, 8].

From several types of compounds with descriptions of metabolite functions as examples from several species of higher plants that have been described above, it can be concluded that secondary metabolite compounds are beneficial for the plants themselves, including: 1) antioxidant activity (inhibiting free radical reactions), 2) controlling plant pests, 3) allelopathy for other plants, 4) overcoming abiotic stress,

especially –UV-B rays, 5) preventing biotic stress, 6) pheromones as a host-finding tool for insects, and 7) attracting pollinating insects [1, 2, 3, 5].

3. Biosynthesis of secondary metabolite compounds by plant organs

Based on the building blocks, the biosynthetic pathways of secondary metabolites in photosynthetic plants can be divided into three main pathways [1–3], namely:

1. Acetate pathway
2. Shikimic acid pathway
3. Mevalonic acid and deoxyxylulose pathway

With various known secondary metabolite biosynthesis pathways, it is not surprising that many types and chemical structures of secondary metabolite compounds are found, but in one species, usually no more than five types of secondary metabolite compounds are found. The main characteristics of the chemical properties of secondary metabolite compounds include having a small molecular weight (between 500 and 1500 Daltons), being semi-polar, and being insoluble in water, with very diverse chemical structures [3, 4].

3.1 Biosynthesis of the acetic acid pathway

Biosynthesis of secondary metabolites via the acetic acid pathway begins with the oxidative decarboxylation reaction of the acetyl coenzyme-A compound in the glycolytic process, with pyruvic acid as a precursor to secondary metabolites. The final results of secondary metabolite biosynthesis via the acetic acid pathway include types of flavonoid compounds, prostaglandins, and various nonessential derivatives. Then, the deoxyxylulose compound is synthesized from a combination of two intermediate compounds in the glycolytic process, pyruvic acid and glyceraldehyde-3-phosphate [2, 3].

The diversity of chemical structures resulting from the biosynthesis of secondary metabolite compounds via the acetic acid pathway can be seen as derivatives of the poly- β -keto chain, formed by coupling acetic acid units (C2) through a condensation reaction. The formation of poly- β -keto chains can be described in terms of a series of Claisen reactions, including structural diversity involving the β -oxidation sequence in fatty acid metabolism.

Figure 2 shows a series of chemical reactions that can occur during the biosynthesis of secondary metabolite compounds via the acetic acid pathway. Based on **Figure 2**, it appears that the biosynthesis of secondary metabolite compounds through the acetic acid pathway is a straight chain with a simple ring structure, with even carbon elements (C2, C4, C6, C8, etc.), with many OH groups and does not contain nitrogen elements [3]. Often, secondary metabolites synthesized through this pathway act as pigments, for example, the curcumin compound found in the rhizome of the turmeric plant (*Curcuma longa*), which produces a yellow color and provides a fairly strong antiinflammatory effect [9]; however, the leaves contain very few secondary metabolites so they are not efficient if used as raw materials for medicine [10].

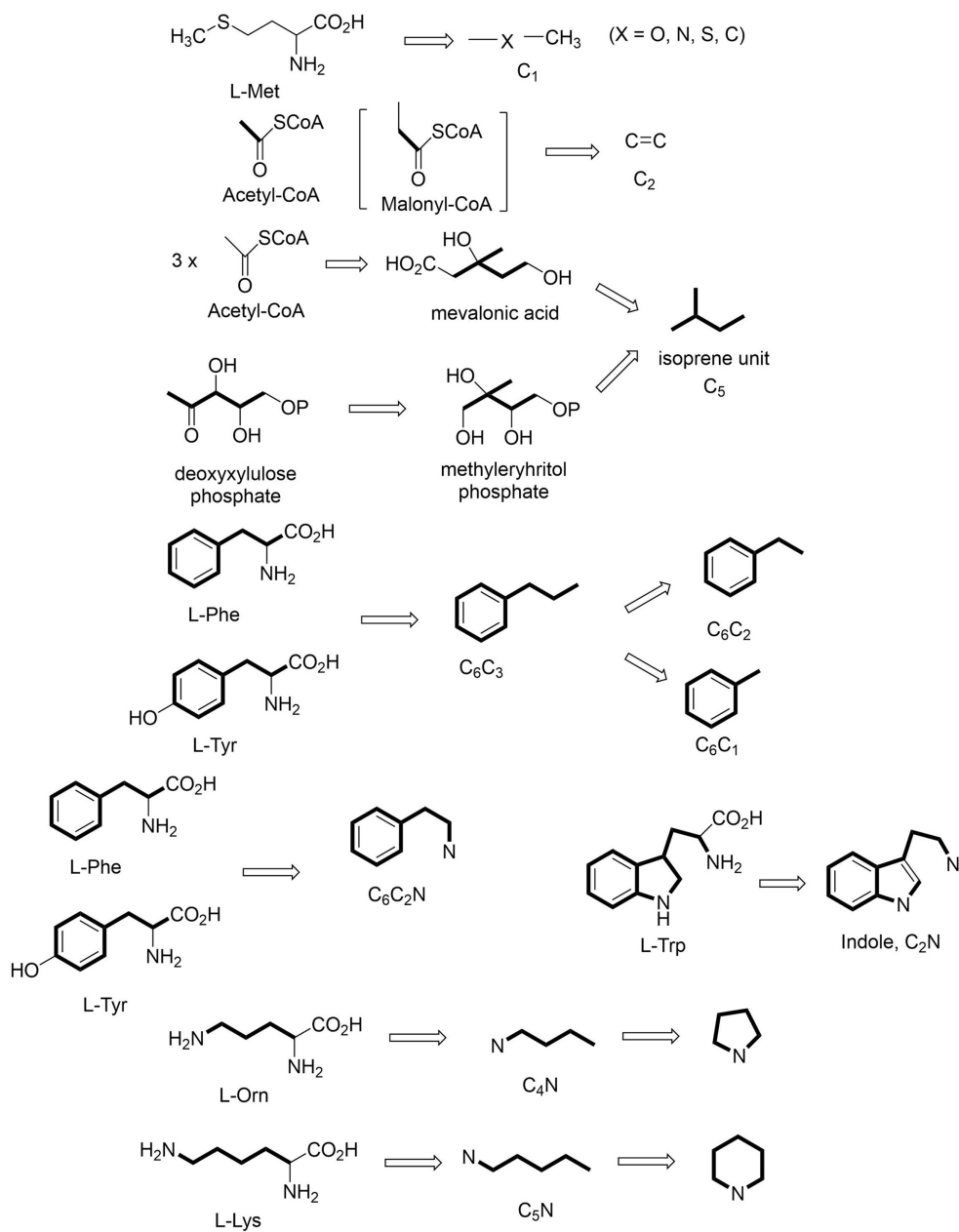


Figure 2.
Biosynthesis of the acetic acid pathway [2].

3.2 Biosynthesis of the shikimic acid pathway

Biosynthesis of secondary metabolites through the shikimic acid pathway involves a combination of phospho-enol-pyruvate compounds in the glycolytic process and erythrose 4-phosphate compounds in the pentose phosphate cycle [2, 3]. The chemical reactions occurring in the pentose phosphate cycle can be utilized to

degrade glucose produced by photosynthesis. The biosynthesis of secondary metabolites via the shikimic acid pathway leads to various types of phenolic compounds, cinnamic acid (and its derivatives), lignans, and alkaloids [2]. Generally, these types of organic compounds – aromatic amino acids and phenylpropanoids – play an important role in biological and ecological processes. Nitrogen is often bound to aromatic rings, especially if the final product is an alkaloid. Examples include caffeine from the coffee plant, which is characterized by its bitter taste, produced as a secondary metabolite via the shikimic acid pathway [11].

It is known that there are three types of natural aromatic amino acids from plants, including phenylalanine, tyrosine, and tryptophan. Humans and animals are unable to synthesize aromatic amino acids, which are essential compounds, so they must be obtained through the diet.

Figures 3 and 4 below present the reactions of secondary metabolite synthesis via the shikimic acid pathway.

3.3 Biosynthesis of mevalonic acid and the deoxyxylulose pathway

The biosynthesis of secondary metabolites through the mevalonate acid and deoxyxylulose pathways is preceded by the formation of three acetyl coenzyme-A molecules, but they then separate, and each combines with another compound in the acetic acid pathway [2, 3]. Then, the deoxyxylulose compound is synthesized from the combination of two intermediate compounds in the glycolytic process that form pyruvic acid and glyceraldehyde-3-phosphate compounds. The biosynthesis of secondary metabolites through the mevalonate acid and deoxyxylulose pathways is responsible for the formation of both terpenoid and steroid compounds [3].

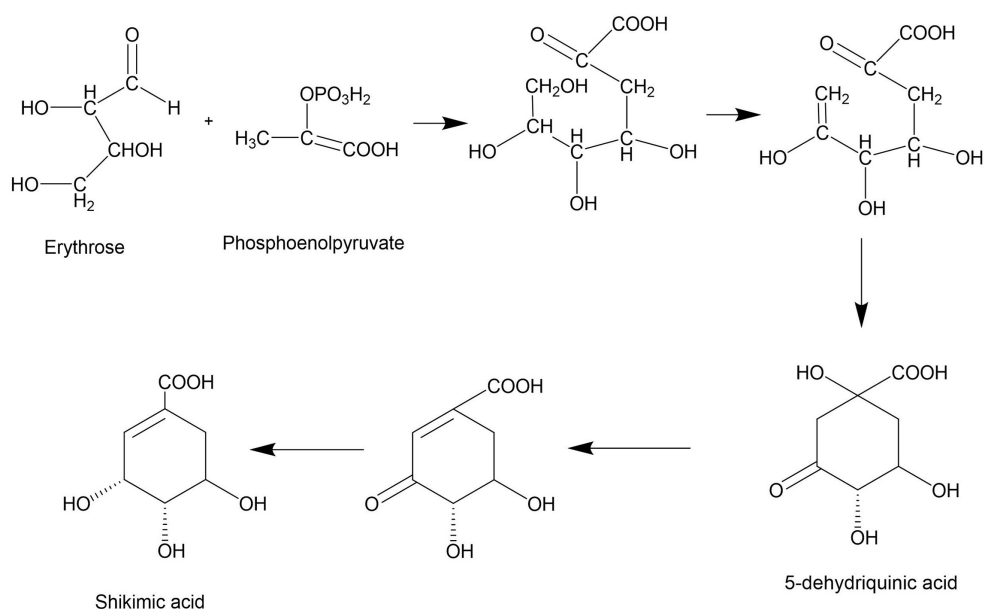


Figure 3.
Biosynthesis of shikimic acid pathway [2].

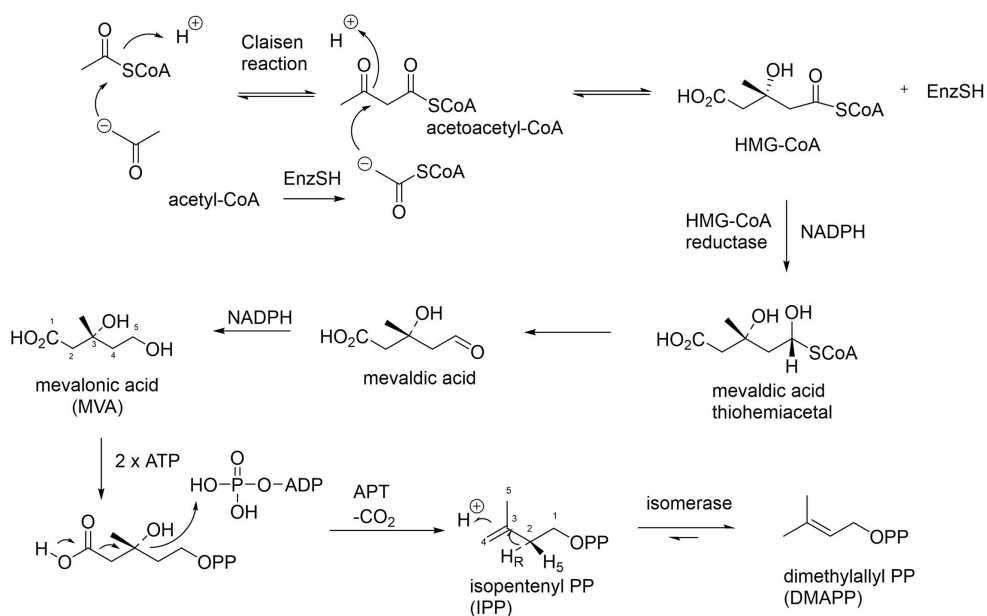


Figure 4.
 Biosynthesis of mevalonate acid and deoxyxylulose pathway [2].

Terpenoid compounds synthesized through the mevalonic acid pathway generally contain only carbon and hydrogen elements, without nitrogen elements; for example, monoterpene, diterpene, triterpene, sesquiterpene, and terpene polymers. These types of compounds, in their use for pharmacology, include influencing the neurotransmission system, ion transport, inhibiting oxidative phosphorylation, anesthesia, and toxicity. Higher plants that have an odor are characterized by containing terpenoid compounds, which, if distilled, will produce essential oils. Strong fragrant odor is associated with the C₅ ring or multiples thereof and without binding N. Examples are α -pinene and β -pinene volatile compounds in pine plants (*Pinus merkusii*) [3].

Figure 3 below presents the reactions of secondary metabolite synthesis via the mevalonic acid and deoxyxylulose pathways. Based on the differences in the biosynthesis pathways of secondary metabolites, we can obtain information on the types of secondary metabolites that will be produced, and then we can create a pattern of thinking regarding the selectivity of utilizing each type of secondary metabolite as a natural raw material for pharmaceutical products, the food industry, or the agricultural industry.

Which type of plant organ is the site of biosynthesis of secondary metabolite compounds? This question will be easily answered if we carry out phytochemical screening of each organ of the plant species in which we want to study the secondary metabolite content. It has been discussed previously that not all species of higher-plant groups have the ability to synthesize secondary metabolite compounds. Generally, people use certain plant organs based on their experience and have proven that they can treat certain types of diseases. This experience continues to be developed by pharmacologists as a precursor to drugs, antibiotics, or cosmetic ingredients.

Similarly, plant scientists are experimenting with the application of certain plant extracts to control pests, diseases, and other organisms. The effectiveness of these extracts in preventing and eradicating other organisms that interfere with plant growth and reproduction is then being studied for their use as control agents for plant pests.

The following explains several types of higher plant organs that are capable of synthesizing secondary metabolite compounds and have been used as raw materials for medicines, food, and cosmetics for human needs, as well as for control drugs for plant pests.

3.3.1 Leaves

Most higher plants synthesize secondary metabolite compounds in leaf organs because plant-disturbing organisms more easily attack the leaves; therefore, these plants synthesize compounds that can provide protection (as a protective effort against biotic stress). In addition, the photosynthesis process occurs in the leaf organs. If the plant receives excessive ultraviolet-B rays, secondary metabolite compounds will be synthesized to protect the DNA from immediate damage (as a protective measure against abiotic stress) [12].

For example, the leaves of the cabbage plant (*Brassica oleracea*) synthesize 90% of the saponin and steroid compounds from the terpenoid group [13], which emit a spicy odor to repel microbes or pests (antimicrobial). Kelor leaves (*Moringa oleifera*) are able to synthesize secondary metabolite compounds of the monoterpene type to protect themselves from caterpillar attacks [12]. Ingu leaf extract (*Ruta angustifolia* L.), which is believed by the public to be an anticancer agent, contains flavonoids of the quercetin type of 1.67%, saponins of 2.13%, and tannins of 7.04% [14].

3.3.2 Flowers

Flower organs are an important part of plants for synthesizing secondary metabolite compounds of the volatile group at quite high levels, emitting a fragrant aroma that is offered to pollinators; for example, jasmine and rose flowers. Flavonoid and glycoflavonoid derivatives in orchid flowers, for example, apigenin and luteolin, in the form of glycoside compounds, are flower pigments that act as Ultra Violet protectors, so they can maintain bright colors in several orchid species [8].

3.3.3 Bark

The secondary metabolite compound quinine is synthesized at the highest levels in the bark of the Cinchona plant (*Cinchona spp.*) [15]. The levels of alkaloid and terpenoid compounds are higher in the bark than in the leaves of bidara (*Ziziphus mauritiana*), which can be used as antimicrobials [4].

3.3.4 Root

Secondary metabolite synthesis in roots is relatively low compared to other plant organs. Roots typically synthesize secondary metabolites to combat attacks by soil fungi and nematodes. The roots are directly connected to the growing medium, so to

defend themselves, they synthesize secondary metabolites as a self-defense effort. For example, the roots of the *Eurycoma longifolia* plant synthesize secondary metabolite compounds of the quassinoid and eurycomanone types, which can be used as antimalarials and are believed to be aphrodisiacs [16].

3.3.5 Tuber

Stem tubers generally synthesize metabolites that act as nutrient reserve compounds, for self-defense, can be toxic, and are used as natural pesticides. For example, garlic bulbs (*Allium sativum*) synthesize the compound allicin, which acts as an antimicrobial; diosgenin, a saponin compound, is synthesized by the tubers of the gadung plant (*Dioscorea hispida*), which is poisonous if consumed raw [17].

3.3.6 Rhizoma

Rhizomes are horizontal roots that grow below the surface of the soil, generally rich in volatile terpenoid and phenylpropanoid compounds. For example, the rhizome of the Javanese red ginger plant synthesizes dominant secondary metabolite compounds of the curcuminoid type [18] which can act as antimicrobials and hepatoprotectors. Rhizome extract of white galangal (*Alpinia galanga* L.) contains five types of secondary metabolites, namely flavonoids, alkaloids, tannins, terpenoids, and saponins [19].

3.3.7 Seed

Seeds are a place to store food reserves and genetic defenses, thus, many secondary metabolites are stored in seeds, with types of compounds that are beneficial to us as well as toxic to animals and humans. Types of secondary metabolite compounds that are safe for consumption and beneficial for us include those from the phenolic, lignan, and glucosinolate groups. For example, the isoflavone compound contained in soybeans (*Glycine max*) is beneficial if consumed raw or after cooking, while the trypsin compound, which acts as an inhibitor, will be removed or lost after cooking. The linamarin compounds and cyanogenic glycosides contained in cassava seeds (*Manihot esculenta*) are toxic if consumed raw, but the toxins disappear if they are soaked and boiled. Pangi fruit seeds (*Pangium edule* Reinw.) contain secondary metabolite compounds of the phenolic, saponin, tannin, and triterpenoid types, which are effective as antibacterial agents [20].

3.3.8 Fruit

Fruit organs are attractive to herbivores because the secondary metabolite content is dominated by color pigments, aroma, taste, and antioxidants. The types of secondary metabolite compounds that fruit contains include: 1) flavonoids and anthocyanins, which produce red, purple, and blue colors; 2) carotenoids, which produce yellow, orange, and red colors; 3) volatile terpenoids, which produce the characteristic aroma of fruit; 4) phenolics and tannins, which produce an astringent and bitter taste as a defense measure before the fruit is ripe, but the bitter taste disappears after the fruit is ripe; 5) alkaloids, which produce a bitter and toxic taste; 6) organic acids, which produce a sour taste that can be used as preservatives;

and 7) furanocoumarins, which have an active synergistic or antagonistic role when collaborating with other metabolite compounds [6].

Apart from that, the fruit skin can also produce secondary metabolite compounds; even in certain species, the fruit skin produces more secondary metabolites than the fruit flesh. An example of a tropical fruit is mangosteen (*Garcinia mangostana*); the skin of the fruit contains more xanthone antioxidant compounds, which are useful as antiinflammatory, antiallergic, and anticancer agents. The secondary metabolites that dominate in mangosteen peel are flavonoid compounds, saponins, alkaloids, triterpenoids, tannins, and polyphenols [21]. In contrast, the Bali orange peel extract (*Citrus maxima* Merr.) was detected to contain a phenolic value of 4.96% and weak antioxidant activity with a value of 0.06 [22].

4. Conclusion

Secondary metabolite compounds are by-products of photosynthesis in higher plants, and these compounds are not synthesized continuously, but rather when the plant is experiencing physiological stress due to unfavorable growing environmental conditions at that time. The diversity of types and chemical structures of secondary metabolite compounds is so great that it is difficult for us to memorize them; however, we can group them based on the biosynthetic pathway, namely the acetic acid pathway, the shikimic pathway, the mevalonate pathway, and the deoxyxylulose pathway and its derivatives. Every time researchers in biology, agriculture, and pharmacology try to find new types of secondary metabolites from natural materials, it is to be used as special objects of study and to study the potential of these compounds for living organisms. Phenolic compounds, flavonoids, terpenoids, steroids, and tannins are the types of secondary metabolite compounds most frequently found in higher plants. The reasons why plants synthesize secondary metabolite compounds include acting as an attractant for pollinating insects, an allelochemical for other plants, a pheromone, a controller of pest organisms, an inhibitor of free radical reactions, and to overcome biotic and abiotic stress. Meanwhile, humans utilize antioxidant compounds resulting from secondary metabolites from higher plants as raw materials for the pharmaceutical and cosmetics industries, as well as the agricultural industry.

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