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Plant secondary metabolites and their importance: special reference to Abiotic stress

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Abstract

Plants synthesize a vast range of organic compounds, among which the secondary metabolites play a major role in the survival of the plant in its environment. These are biologically active and naturally occurring chemical compounds produced by plants. They have biological properties such as antioxidant, antimicrobial, and anticancer properties. Plant secondary metabolites are crucial in several ways to adapt to the stress environment and are play a role in plant protection against pathogens, insects, and predators. Plants under abiotic stress provide different phytochemicals to overcome the stress environment which has the potential alternative source for the discovery of novel medicines. The purpose of this review is to provide an overview of the relevant data reported in the literature on plant secondary metabolites, which include a wide variety of compounds such as flavonoids, steroidal saponins, polyphenols, and organosulfur compounds, mainly plant secondary metabolites, with antioxidant activity and their potential uses to enhance the abiotic stress tolerance of plants. Maintaining crop yields under adverse environmental stresses is probably the major challenge facing modern agriculture. It may become useful to the researchers to get a different idea of how to move forward in the research field to counter the adverse effects of stressful environments, thereby decreasing annual losses to agriculture.

Keywords: Herbal medicines, Phytochemicals, Stress, Secondary metabolites

Introduction

Plant secondary metabolites, which include a wide variety of phytochemicals including vitamins, flavonoids, steroidal saponins, polyphenols, and organosulfur compounds [1]. These are essential for the survival and proper functioning of plants. They protect against herbivores, microorganisms, and competitors [2]. Even though most of these compounds occur constitutively, their synthesis can be enhanced under stress conditions [3], [4]. Reactive Oxygen Species (ROS), released by several endogenous and exogenous processes, may cause important oxidative damage to DNA, proteins, and lipids, leading to important cellular dysfunctions [5]. The imbalance between ROS production and antioxidant defenses brings oxidative stress conditions, related to the accumulation of ROS. Plant secondary metabolites act as antioxidants, neutralizing free radicals and removing their power to create damage. These substances

serve as a protective shield for cells, defending them against the harm caused by free radicals. Most secondary metabolites have antimicrobial activity and serve as a source of antimicrobial agents against human pathogens [6]. They are generally synthesized through different types of metabolic pathways and are directly involved in defense response in plants. Shikimate pathways are the main stage in the biosynthesis of aromatic amino acids and they are activated in adverse conditions to produce tryptophan, phenylalanine, and tyrosine, which subsequently enhances the synthesis of secondary metabolites. [7], [8].

Plants create a wide and diversified array of organic chemicals, the vast majority of which do not appear to have a direct role in growth and development. These chemicals used to be referred to as secondary metabolites [9]. Plant secondary metabolites have broadly been categorized into three major groups based on a biosynthetic pathway and chemical structures are terpenoids (plant volatiles, sterols, carotenoids, saponins, and glycosides), phenolic compounds (flavonoids, phenolic acids, lignin, lignans, coumarins, stilbenes, and tannins), and nitrogen-containing compounds (alkaloids, glucosinolates, and cyanogenic glycosides) [10].

Phenolic phytochemicals are the largest category, biologically active compounds of phytochemicals, and the most widely distributed in the plant kingdom [11]. Which are generated during the phenylpropanoid metabolism of pentose phosphate and the shikimic acid of plants [12], [13]. The most promising molecules for health-promoting studies are phenolic compounds. More than 4,000 phenolic phytochemicals have been identified among them the main classes of dietary phenolics are flavonoids, phenolic acids, and polyphenols [11].

The phenylpropanoid pathway synthesizes flavonoids, a vast class of polyphenol chemicals with a benzoyl- γ-pyrone structure that are widely found in plants [13]. The flavonoids comprise the following subclasses: flavonols, flavones, flavanones, flavan-3-ols, isoflavones, and anthocyanidins [5]. Secondary metabolites of a phenolic nature are responsible for different pharmacological activities [13], [14], [15]. Quercetin and anthocyanins, for example, are useful in lowering the rate at which cancerous cells proliferate, altering the metabolism of carcinogens, lowering tissue inflammation parameters, and preventing angiogenesis [5].

Terpenoids are the most widespread group of natural products synthesized by plants [13], 16]. It shows significant pharmacological activities, such as antiviral, antibacterial, antimalarial, anti-inflammatory, inhibition of cholesterol synthesis, and anti-cancer activities [13], [17].

Alkaloids are one of the main and largest components produced by plants, and they are metabolic by-products derived from amino acids [18]. Alkaloids are found in many plant lineages, with angiosperms having the highest concentration. Because of their distinctively bitter flavor, alkaloids are well recognized for their protective function as insect

herbivore deterrents [19]. Plants can create defensive or poisonous alkaloids through symbiotic relationships or by themselves [20].

The term tannin is widely applied to a complex large biomolecule of polyphenol nature having hydroxyls and carboxyl to form strong complexes with various macromolecules [21]. These are generally used in the tanning process and used as healing agents in inflammation, burn, piles, and gonorrhea [17].

Saponins are an important group of plant secondary metabolites that are widespread throughout the plant kingdom and provide numerous health benefits [22]. Basically, that is found in most vegetables, beans, and herbs [23], [24].
Steroid is a natural or synthetic chemically active hormone-like element that is derived from sterol and this is one of a large group of chemical substances classified by a specific carbon structure [13]. Steroids include drugs used to relieve swelling and inflammation [25].

Abiotic stress on plant secondary metabolites

Environmental stresses including climate change, especially global warming, are severely affecting plant growth and productivity worldwide [26]. Climate changes are expected to increase the frequency and intensity of both abiotic and biotic stress [27]. However secondary metabolites play an important role in abiotic stress resilience and resistance to biotic stress, however, the concentration and composition of the phytochemicals are influenced by the climate conditions [28].

Plants produce huge numbers of secondary metabolites, which play many essential roles in their adaptation to the changing environment and during abiotic stresses, such as extremes in temperature, water availability or scarcity, high salinity, and UV radiation etc [29, [30]. Secondary metabolite synthesis and accumulation is increased during abiotic stress to face the harsh abiotic stress conditions, this indicates a close relationship between secondary metabolite accumulation and plant tolerance to abiotic challenges [29]. Major classes of secondary metabolites, such as flavonoids and other phenolic compounds are produced in response to climatic/or abiotic stress and are well-known for their antioxidative and anti-inflammatory properties [31].
Saponin production is a reaction to environmental stimuli and a component of an adaptive mechanism that helps organisms withstand abiotic stressors. Plant reproductive organs that accumulate saponins are involved in both chemical defence and the plant's reaction to external stimuli [32]. The growth of plants and crop productivity is negatively impacted by environmental conditions such as drought, excessive salt, and freezing temperatures. In order to secure the survival of agricultural crops and sustained food production, global challenges such as salt stress and water deficit must be addressed [33]. Among the most important abiotic stresses that impact the growth and development of plants is drought stress [34]. The effect of drought is the accumulation of flavonoids such as flavonols and anthocyanins that are essential in protecting against abiotic stresses. It has been observed that anthocyanins

accumulate in cold climates and during drought stress. Plant tissues that have anthocyanins typically have a high level of drought resistance [35]. The environmental condition of warming causes the accumulation of terpenoids, which usually have protective functions in mitigating environment-induced oxidative stress in plants [36]. Ultraviolet (UV) Radiation causes the synthesis of UV-absorbing flavonoids is one mechanism to mitigate photoinhibition and photooxidative damage by either reducing UV penetration or quenching ROS [31]. Similarly, the production of antioxidative compounds such as glutathione, g-aminobutyric acid (GABA), terpenoids, and volatile organic compounds (VOCs) increases under elevated O_3 [31]. Salt stress is also an important factor that often creates both ionic as well as osmotic stress in plants, resulting in the accumulation or decrease of specific secondary metabolites, and anthocyanins are reported to increase in response to salt stress [37]. In contrast to this, salt stress decreased anthocyanin levels in the salt-sensitive species [38]. Elevated temperatures can cause premature leaf senescence as they have a considerable effect on metabolic activity and plant ontology [39]. The amounts of spirostanol and steroidal furostanol saponins increased due to lower soil temperatures [40]. In plant cell cultures, temperature fluctuations have a variety of consequences on the pace of intracellular responses, permeability, and metabolic control [39]. Light is a known physical element that can impact the formation of metabolites. Light has the ability to activate these secondary metabolites [41]. Therefore, the abiotic stress tolerance of plants can be enhanced by manipulating the synthesis and accumulation of secondary metabolites [29].

Importance of Plant secondary metabolites

Defense

Plants are competent enough to produce large amounts of secondary compounds with antimicrobial characteristics and are stress-inducible phytochemicals playing an important role in plant immune response development. Plant-pathogen interactions heavily depend on secondary metabolites produced by plants. The majority of secondary metabolites, such as flavonoids, phenolics, and alkaloids, exhibit antiviral characteristics [42]. Because of their varied structures, alkaloids contain a wide range of physiologically active chemicals that have an impact on living things [43]. Around 18,500 alkaloids are having antiviral effects in traditional Chinese herbs [4]. Flavonoids confer protection against inflammation, allergy, and bacterial infections [31]. Flavonols (or 3-hydroxy flavones), one of the main subclasses of flavonoids, are apparent antioxidants in stressed plants, and they are known to prevent nuclear DNA damage by free radicals like H_2O_2 [44]. Interestingly, different quantities of phenolic components were also linked to defense mechanisms in plants [45].

Adaptive responses

Generally, all plants produce secondary metabolites for defense, attraction, communication, and mediating stress [46]. These PSM variations can be due to genetic variability, but their concentrations are affected by environmental abiotic factors such as those expected to intensify with climate change (e.g., heat stress, drought, UV radiation, and O_3 [47],

and herbivore and pathogen attacks. Abiotic stress caused by environmental factors are mitigated by certain plants' secondary metabolites, while others have biotic stress tolerance and aid in the creation of connections between plants and microbes[31],[48]. Secondary metabolites produced from the stress plants act as signaling molecules and raise the expression of genes linked to defense and also they provide strength for plant survival under unfavourable conditions [4].

Secondary metabolites are utilized as competitive weapons as well and they serve as metal-carrying agents, symbiotic agents. The secondary metabolite can slow spore germination until a less competitive environment and more favourable conditions for growth exist, protect the dormant or initiated spore from amoeba consumption, or cleanse the immediate environment of competing microorganisms during germination [49].

Pharmaceutical drug production

Plants are known to contain secondary metabolites which could be useful for the treatment of disease and are occurring naturally in plant leaves, stem, bark, and roots [50]. Abiotically stressed plants offer a possible alternate source for discovering new drugs [31]. Plants can produce a variety of PSMs as a defense mechanism against abiotic environmental stresses, preventing harm to cells and tissues. Plants can either produce new compounds or make already-existing chemicals more concentrated. The majority of PSMs that are generated in response to diverse abiotic stressors are defense compounds for plants, possessing anti-inflammatory and antioxidative properties [31].

Natural products, particularly unique secondary metabolites found in herbal medicines, including those that have been used in not only traditional medical systems but also ethnic medical systems, provide potential molecules to develop new drugs. PSMs are essential to human health and serve as the backbone of many pharmaceutical drugs. Therefore, these herbal medicines are considered to be invaluable resources of drug seed molecules on which new therapeutic agents can be based [51]. The most popular PSMs-derived drugs are morphine, digitoxin, taxol, artemisinin and quinine, vinblastine and vincristine; and aspirin [31].

Conclusion

Plant Secondary metabolites are a vast range of bioactive compounds that play important roles in the life of plants, where they are widely distributed. These are providing numerous health benefits for humans in different ways. Among them, anti-oxidative properties play a major role in preventing diseases. As a coping mechanism, plants exposed to a variety of abiotic stress conditions produce a large amount of plant secondary metabolites in higher concentrations. These are important in plant adaptive responses, and defense and they are the unique sources playing major roles in disease prevention and pharmaceutical drug production. This provides opportunities for researchers studying natural

products and pharmaceutical companies to investigate the biochemical responses of plants to climatic stress to develop several novel therapeutics.

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