Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

Secondary Metabolites in Plants: Their Role in Modulating the Immune Response to Viral Infections in Hosts

Shahad Basil Ismael[1], Maysaa Hamid Ahmed[2], Rowshen Hani Al Nakeeb[3] and Tabarak Sabah Jassim[4]
[1]Department of Molecular and Medical Biotechnology, College of Biotechnology, Al-Nahrain University, Baghdad, IRAQ.
[2,3,4]Department of Plant Biotechnology, College of Biotechnology, Al-Nahrain University, Baghdad, IRAQ.

[1]Corresponding Author: shahad.basil@nahrainuniv.edu.iq

www.sjmars.com || Vol. 3 No. 5 (2024): October Issue

Date of Submission: 21-10-2024	**Date of Acceptance:** 31-10-2024	**Date of Publication:** 01-11-2024

ABSTRACT

In order to create biochemical defenses from herbivores, plants generate a wide variety of secondary metabolites. Plants, fungi and bacteria produce metabolites that're essential in fighting off viral infections. These active compounds, like flavonoids, alkaloids and terpenoids have effects by stopping replication blocking viral entry and regulating the immune response of the host. Moreover these secondary metabolites can work as deterrents to lower the spread of viruses through carriers. Their ranging effectiveness makes them potential options, for developing antiviral treatments and medications. Also, several phytophagous insects have developed strong adaptations to these allergens, or by detecting, integrating, as well as analyzing these phytochemicals specifically, they employ these special molecules as their individual defense compounds, particular host-finding signals, or perhaps as sexual pheromones or its precursors. Additionally, insects are pollinators and frequently directed by certain flower scents. The ecological relevance of these secondary metabolites of plants within the wide range of virus and insect-plant relationships is shown throughout this article.

Keywords- primary metabolite, virus, immunity, Pest insects; plant extracts; biological activity; secondary compounds.

I. INTRODUCTION

Many organic compounds known as secondary plant metabolites are created by plant cells via metabolism routes that branch off of core metabolic routes. The Nobel Prize laureate for physiological processes and pharmacy around 1910, Albrecht the work of Kossel, is the initial person to establish the term "secondary metabolite". Czapek defined it final products 30 years later. Researchers said that such compounds, like deamination, which are the result of "secondary modifications" in the biological breakdown of nitrogen.

The field of phytochemistry is founded with the beginning of the 20th century as a result of the increasing extraction of such compounds made possible by developments in methods of analysis like a chromatography.

The consumption of herb in conventional therapy in numerous indigenous civilizations has a factual basis thanks to the biological consequences of secondary metabolites. They are able to shield plants against infections since they have been characterized as antibiotics, anti-fungal, or antiviral. Additionally, they are significant UV-absorbing chemicals that shield leaves from harmful radiation. It has been noted that several plants used as feed vegetation, such alfalfa as well as clover, could interact with animal fertility as well as display estrogen-producing qualities.

Plants secondary metabolites are categorized within many groups based on their molecular properties. This article will explore the major groups of elements deemed as being of pharmacological interest, building on a discussion underlying the properties of secondary plant metabolites. Following an explanation of a category of secondary plant metabolites' framework, botanist transportation, as well as typical pharmacological decisions, each subsection contains numerous instances of exemplary components.

Plants secondary metabolites fall into the following categories:

- Phenolics
- Alkaloids
- Saponins
- Terpenes
- Lipids
- Carbohydrates

II. BIOLOGICAL ROLE OF ALKALOID IN MEDICINE

Although other organisms including microorganisms or mammals also create alkaloids, plants are the primary producer of these secondary metabolites. Most of them are toxic to other animals that can be eliminated using an acid-base procedure. A family of secondary metabolites having basic nitrogen atoms is called alkaloids. The alkaloids are also made up of a number of related substances that have neutral to moderately acidic properties.

This category could additionally include oxygen, sulfur, as well as, in exceptional instances, extra components like phosphorus, chlorine, or bromine, in alongside carbon, hydrogen, and nitrogen. Vegetation possessing alkaloids have been utilized by prehistoric humans, notably the people of Mesopotamia, who lived around 2000 BC, for medicinal, wellness, or creative objectives. Essentially, specific plant species—mostly blooming plants or certain animals—produce these chemicals. Secondary metabolites are a wide range of chemical substances that are created and retained by plants, including proteins, amino acids, carbohydrates, lipids, as well as alkaloids.

Amine compounds or nucleic acids are not frequently alluded to as alkaloids. Alkaloids contain a broad variety of physical properties as well as are not classified under a particular structure, in contrast to the majority of other forms of secondary metabolites. Since chemical structural knowledge was unavailable during the time, its initial categorization was determined on a shared reference. Given the similarities in the carbon skeleton, the earliest current taxonomy was created.

The primary elements that contribute to the process of biosynthesis of alkaloids include tyrosine as well as various amino acids. The production of morphine, which uses benzylisoquinoline alkaloids that includes phenolic duplication response, is an iconic instance. Alkaloids are different classes of chemicals that have similarities in structure to amines. Such names often finish in -in or -ine, for instance; epherdin.

Although the various alkaloids may be formed by alternative biochemical components like polyphenols, steroid hormones and terpenes, alkaloids may be generated through amino acids. Typically, alkaloids are spectacular substances that dissolve easily in hydroethanolic liquids. They may also form salty medium like sulphates or chlorine, as well as often from nitrogen-containing oxides in plants. Furthermore, the bulk of alkaloid substances are heterocyclic nitrogen reverberates essential alkaline forms, or ringed systems that have strong therapeutic, poisonous, and lethal effects and may have either a helpful or negative effect. Alkaloids are nitrogen-containing chemicals found in plants that have a stable physical makeup or a strong biological impact on individuals, creatures, or microorganisms. Veratrum alkaloids, such as veratrine, have a structural akin to steroids that are essential for the stimulation of voltage-sensitive sodium channels. However, excessive dosages of this alkaloid may result in cardiac capture. Furthermore, during Grecian times, extracts from plants had been utilised to execute political inmates as criminals.

Hemlock alkaloids work in two distinct manners that accomplish its effects:

These act as nondepolarizing inhibitors at the neuromuscular intersection, which results in mortality by pulmonary of respiration.

- They exhibit biphasic nicotine-like action, which includes tachycardia, saliva production, mydriasis, or brachycardia. Alkaloids that come from Aconitum sp. are classified as cardiotoxins or neurotoxins.
- Aconitine, hypaconitine, and mesaconitine—all C19-diterpenoid alkaloids—are the primary poisonous chemicals. Due to their impact on voltage-sensitive Na-channels in the membranes of plasma of certain cells, including the muscles, neurons, or the heart, these substances have both cardiotoxicity as well as neurotoxicity.
- Acute aconite toxicity may potentially result in fatal cardiac ventricular fibrillation or unconsciousness.
- To improve aconitum's pharmaceutical effects through the years to come, cytotoxicity may be reduced by a number of ways. While nicotine could be a factor on numerous individual instances of moderate serious intoxication, Nicotiana sp. alkaloids, these anabasine, are utilised for screening for teratogenicity in animals.

Atropine or scopolamine constitutes two alkaloids that were reported as being abundant within Datura species. Numerous alkaloids that are psychologically functional are found in plants. From the cellular level, alkaloids possess a variety of impacts; certain ones influence the neurological system's functioning, whereas others impact polypeptide synthesis, barrier transportation, including enzymatic function.

The names that describe the alkaloids' sources are used to determine its nomenclature. As an example, the species Atropa belldona constitutes an origin of atropine, which while belladonine originates to Atropa belldona. Traditional names for the sources as well as cultivate may also be used, such as Ergotamine from ergot as well Theine from tea. Most alkaloids originating from plants are used as drugs. Examples of these include chemotherapy drugs like vinblastine, camptothecin, or vincristine; gout reliever's colchicin, analgesic codeine or morphine, including sedatives scopolamine.

Plant-derived alkaloids are one of the major classes of secondary metabolites that are useful for treating medical conditions in both conventional and contemporary medicine. Antitumorals like vincristine or vinblastine, as well as significant instances like caffeine, nicotine, or emetine, are utilised to combat orally consumption. Because of their toxicity, alkaloids are an important instrument in plants' defence towards diseases while pests. A variety of enemies, such as viruses, fungi, germs, Nematodes, insects, or other herbivorous creatures surround plants in their native surroundings, that eventually inhibits plant expansion as well as reproduction. Any nitrogen-containing cyclic molecule in an adverse oxidation state makes up the fundamental framework of alkaloids. It belongs to more nearly 20 different categories, such as tropanes, piperidines, quinolizidine, pyrrolidines, pyrrolizidine, among others. Given its broadening hazardous or deterrent impacts, alkaloids serve as storage reservoirs for nitrogen, protective agents against predatory animals, particularly animals, vertebrates, pests, or arthropods that and growth authorities because certain during molecular structures resemble those of designated plant growth regulatory bodies. Alkaloid assisted defence of plants was a two-way mechanism that involves prompt identification of the target (herbivorous animals, pests, and bacteria), confronting ecological anxiety, signalling transmission through the plant, or boosting alkaloid synthesis. The main determinants for cytotoxicity are dose, duration of exposure, or the kind of aggressor—that is, sensibility, location of behaviour, or phase of development.

III. POTENTIALS CAPACITY OF SECONDARY METABOLITE IN REGULATING IMMUNITY TO VIRAL INFECTION

Plants and other living beings produce metabolites— compounds that aren't essential, for their growth but are crucial for defense purposes like fighting viruses and other threats to their well being such, as alkaloids and flavonoids that have antiviral effects by stopping the virus from replicating or entering host cells and regulating the immune system. For instance compounds, like quercetin have been found to inhibit the influenza and herpes simplex viruses. Similarly substances like glycyrrhizin from terpenoids exhibit properties, against hepatitis viruses and HIV. De Clercq, 2004

Additionally secondary compounds impact the regulation of the system, in hosts by boosting the generation of proteins like interferons or by reducing inflammation to prevent exaggerated immune reactions when dealing with viral illnesses (Martinez et al., 2020). Certain chemicals also help decrease the spread of viruses by acting as deterrents or blockers for carriers like mosquitoes that transmit diseases such, as dengue and Zika. Cui et al., 2020

With the range of properties they possess and their likelihood to work well together with current antiviral medications secondary metabolites are now being studied more for their natural healing abilities, in fighting viral infections (Silva et al., 2011). Their capacity to affect phases of the virus life cycle makes them options, for developing drugs especially considering the rise of new viral dangers.

IV. PHYTOALEXINS AND THEIR RELATIONSHIP IN FIGHTING HARMFUL MICROORGANISM

Phytoalexins, a class of complex secondary metabolites with antibacterial action that are synthesised de novo following anxiety, represent one among many defence mechanisms used by plants to fend off pests or diseases. The production, control, or function of camalexin in plant defence are the main topics of this review. Furthermore, Researchers describe certain phytoalexins that are generated by several agricultural plants belonging to the families Brassicaceae, Solanaceae, Fabaceae, Vitaceae, as well as Poaceae. This covers the production or control of phytoalexins generated from rice, as well as the as-yet-undiscovered kauralexins or zealexins generated from maize. Molecular techniques are assisting with the disentanglement of certain pathways or exposing the intricacy of these bioactive substances, such as the synthesis as well as metabolism of phytoalexins.

4.1 Phytoalexins: part of the plant response repertoire

Globally, crop loss as a consequence of diseases as well as pest attacks is a major issue. Numerous possible diseases assault plants on a regular basis. In response, plants produce antibacterial chemicals, activate defence genes, produce reactive oxygen species (ROS), synthesise pathogenesis-related (PR) proteins, fortify their cell walls locally, or activate defence genetics. Phytoalexins are a class of low-molecular-weight secondary metabolites which exhibit antibacterial action in response to stress. They constitute a significant component of the plant defence repertory. A diverse collection of substances known as phytoalexins (Figure 1) exhibit physiological effects against a range of parasites that are thought to be molecular indicators of disease susceptibility. The discovery that potato (Solanum tuberosum) tubers material that was earlier being with an incompatibility races of Phytophthora infestans generated resilience to a compatibility races of P. infestans led to the introduction of the notion of phytoalexins over seventy years earlier. According to a specific theory, the tuberous tissues developed phytoalexins as reaction to the incompatibility relationship, which suppressed the microbe that shielded its cells against subsequent infection by other appropriate genotypes of the pathogenic.

Following then, a great deal of progress has been made towards comprehending the functions of phytoalexins in defence towards pests or diseases as well as their potential health benefits. In particular, brassica vegetables' antioxidant, anticarcinogenic, and cardiovascular-protective properties are facilitated by indole phytoalexins. Antioxidants from peanuts (Arachis hypogea) exhibit vasodilator, cancer prevention. as antidiabetic properties.

Glyceollin is a phytoalexin found from soybeans (Glycine, also max) that has antiproliferative or anticancer properties. The phytoalexins 3-deoxyanthocyanins found in sorghum (Sorghum bicolor) may be helpful in lowering the risk of colorectal cancers. Resveratrol, the phytoalexin produced by grapevines (Vitis vinifera), has anti-aging, anticarcinogenic, anti-inflammatory, as well as anti-oxidative capabilities that may be associated with a biological lifespan or chronic illnesses. Nevertheless, little has been discovered about the majority of phytoalexins' production, the signalling pathways that mediate their generation by biotic as well as abiotic anxiety, or the molecular processes beneath their pathogenicity. With an emphasis on the simulation plant Arabidopsis (Arabidopsis thaliana) among agricultural plants from the families Brassicaceae, Fabaceae, Solanaceae, Vitaceae, and Poaceae, researchers describe several of the most current advancements in the field in this review. The initial subject to be discussed should include continuing be the significant advancements achieved lately within figuring out the biosynthesis pathways for camalexin, a phytoalexin that Arabidopsis produces, as well as the efforts to comprehend its inhibition as well as function in disease resistance. For such regard, its pharmacological identification various Arabidopsis mutations impacted in their ability to generate camelliasin following infection with pathogens (refer to to Table S1 in the web-based supplemental materials) as their use in pathogenicity assays were crucial. Plant pathogen investigation in the area of phytoalexins has also concentrated on understanding their biosynthesis routes as well as oversight in various agricultural plants through the use of diverse varieties, genetically engineered plants, as well as mutations, as well as through the application of -omics, molecular genetics, or physiological techniques in order to cultivate disease-prevention techniques. The majority of reviews that are composed using this approach until now have either concentrated on a specific category of phytoalexins and on phytoalexins that correspond to a certain species and genus. But in this review, we examine the variety of biosynthesis, oversight, buildup, or augmentation of phytoalexins following pathogen infection or elicitor therapy in certain main crop species, offering a more comprehensive view of research on these compounds.

4.2 Camalexin: the major phytoalexin in Arabidopsis

Camalexin (3-thiazol-20 -yl-indole) is a phytoalexin that was initially identified as this being obtained using a Brassicaceae group of plant camelina (Camelina sativa). This had since been identified in Arabidopsis as several other similar Brassicaceae plants. While the entire elucidation of camalexin production on Arabidopsis is pending, subsequent research have characterised a number of the pathway's stages (Box 1).

Although it was previously believed that Arabidopsis exclusively generated camalexin, the plant had recently being shown to generate additional phytoalexin, called rapalexin A.

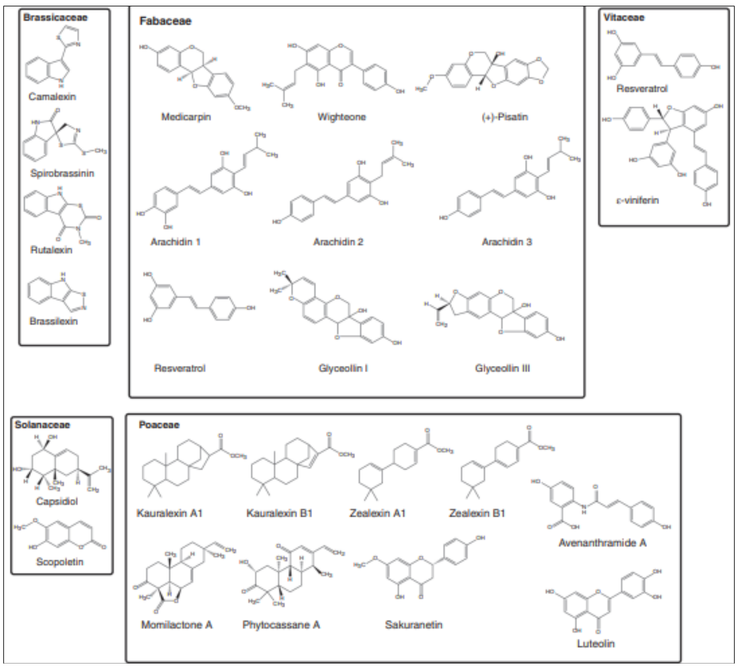


Figure 1. Structural of certain phytoalexins made by Fabaceae, Vitaceae, Solanaceae, Brassicaceae, and Poaceae species

Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

V. EFFECT OF PLANT SECONDARY METABOLITE IN PLANT MICROORGANISM INTERACTION

The manner vegetation create immediate or indirectly defence systems versus invertebrates was a major factor regulating this antagonistic connection that exists between plants with herbivorous pests (Fig 1) while insects develop indirect defence mechanisms as well as counteradaptation inside itself. The secondary metabolite-based defence compounds were a diverse range for specialised compounds that plants manufacture to fend towards pest herbivores. These substances may be continuous as well as triggered during an assault (Yactayo-Chang et al. 2020). Various nitrogen- or sulfur-containing compounds, such as alkaloids, amines, glucosinolates, cyanogenic glucosides,non-protein amino acids, organic acids, phenolics, quinones, organic terpenoids, polyacetylenes, or peptides, are contained in plant secondary metabolites (PSMs) . Herbs often create a complicated combination of secondary compounds of several architectural categories with many biological receptors at the exact same time, rather than a single defense-related chemical. This plant tactic prevents predators from adapting or becoming resistant to the biochemical defence the insects are often divided into two groups based on the variety on plants which they inhabit: generalists possess an extensive selection on devices, while specialists possess a more constrained or specialized selection of hosts. It is acknowledged that specialists are better equipped to handle their unique host defenses. Conversely, it is claimed that insects use the secondary metabolites generated by plants as a stimulant for eating. Furthermore, monophagous pests were observed to display another preference for feeding in particular genera as well as creatures categories which identical plant-derived hormones (PSMs). Over that year plant varieties have known as having insecticide qualities, and a variety in compounds created by vegetation demonstrates hazardous and protective behaviours against pests. During the evolutionary procedure, PSMs experienced numerous stages of being chosen. Among the meanwhile, insects also evolved tactics to take advantage of their victims by acquiring certain modifications in them. Furthermore, since some bugs were capable of detoxifying certain substances, such defence compounds might not consistently be efficient towards various pest insects. In order to maintain their shared existence, these occurrences give rise to the amazing plant-insect relationship. Thus, the aim of this paper is to present a general review of secondary metabolites generated by plants and an interacting element to entice or repel insects as well as cause them to develop counter-adaptations. The chemo receptor (gustatory or olfactory chemoreceptive mechanisms) on the antenna or mouth parts of insects allow them to distinguish as well as sense a broad range of plant compounds, particularly at extremely low levels. According the Swain (1977), bugs interpret signals from their sense of smell to choose either to embrace or decline the parent vegetation. The majority of bugs have a propensity to only eat one and a small number of phylogenetically connected plants for nourishment. There were also PSMs present.

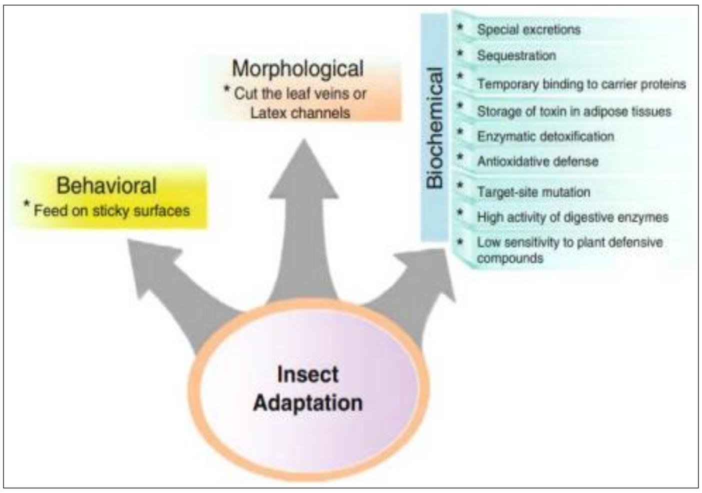


Fig 2: Plant defense characteristics that influence predator adaption techniques.

VI. RESPONSE OF PLANTS TO PRODUCE SECONDARY METABOLITES

This synthesis of secondary metabolites within plants induced by insects varies or is contingent upon the particular plant-insect relationship; nonetheless, Fig. 2 lists a few typical defence compounds along with certain situations. The apparent grazing deterrence activity of insect-inducible PSMs against herbivores has one of its main advantages. There are a number of known processes by that plants recognise an insect assault or build defences against it. The plants are able to detect a produced the saliva from pests during consuming as well as the ovipositional liquid generated during egg-laying in order to adhesive eggs for the plant's exterior and discourage pests from attacking. The salivary secretions of Spodoptera exigua are the source of the initial insects elicitor ever documented.

Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

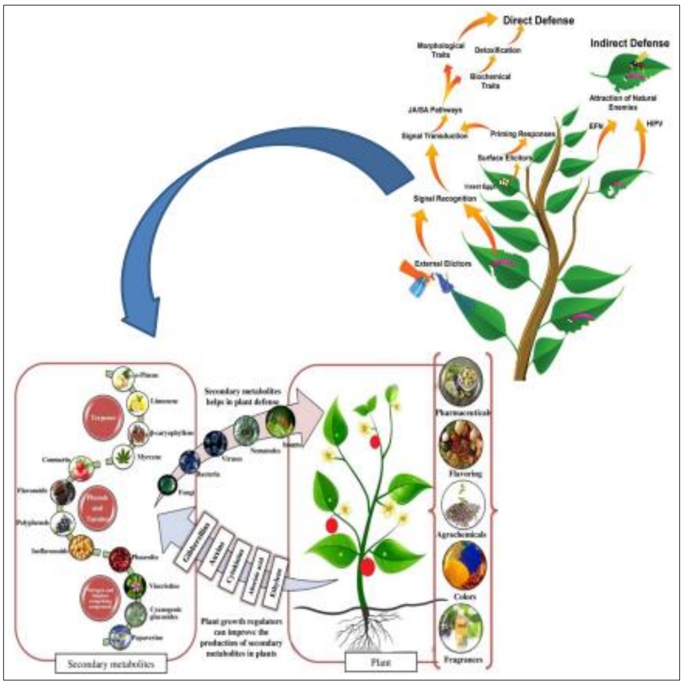


Fig 3: A theme diagram that illustrates how plants defend themselves against insect infestations. (HIPV = herbivore induced plant volatiles; JA = jasmonic acid; SA = salicylic acid; EPF = extrafloral nectar)

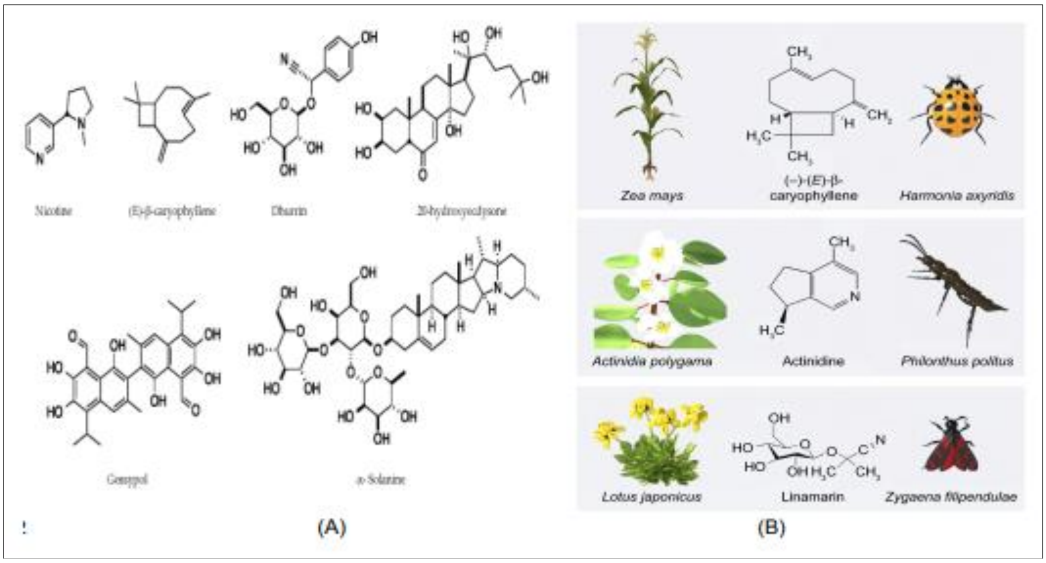


Fig 4 Plants defence molecule characteristic chemical arrangements are depicted in (A) together with instances in (B)

A range of hazardous compounds, such as thiocyanates, isothiocyanates, nitriles, with epithionitriles, are produced by them. While dhurrinase, the indigenous β-glucosidase, its cyanogenic glucoside dhurrin, develops within its cytoplasm, its stimulating enzymes stays inside the mitochondria of the plant. Its stimulating enzymes stay inside the mitochondria of the plant.

When cyanogenic glucosides are subjected to their activation hydrolases after herbivory, they burst their cells and produce poisonous cyanohydrin aglycones. Certain routes use a mixed strategy in which the final activation phase is stimulated while the route to create the chemicals is repressive. For instance, crop inherently produces large quantities of the Cglycosyl the flavone maysin within its silk, so this has been linked with enhanced defence against insect pests, such as maize's earworm. Maysin isn't immediately anti-insect; rather, it is triggered when polyphenol oxidases produced after harm to tissue convert. Because the quinones bind to the -SH or -NH2 bonds to enzymes and amino acids, these reduce the accessible level of these nutrients for larval insects, making crops less nourishing. Quinones are generated by maysin or similar chemicals.

VII. PATHWAY OF SECONDARY METABOLITE ON MICROORGANISM TOXICITY

Organic products are synthetic compounds that often have positive effects on the well-being of people, as stated in the article. However, identical microorganisms also generate harmful substances. Secondary metabolites are thought to be biosynthesised as wastes or detoxifying byproducts. Additionally, it has been proposed that secondary metabolites have useful metabolic functions. Presently widely recognized theory is that the production for secondary metabolites serves a biological purpose, including protecting a creature from competitors and assisting during the acquisition of prey.

Excessive toxicity thus constitutes a fundamental feature of this objective. It's fascinating to note who these chemicals are hazardous to. Throughout millennia, the lethal properties of plants, animals, or microbes have fascinated or terrified mankind. The investigation of harmful chemicals (toxins) generated by cells and tissues is so popular as a discipline that it has its own scientific branch called toxicology. It is important to understand the distinction between poison as well as venom. Venoms are animal discharges produced by specialised organs or administered by specialised systems. They include mixes of various poisons, digestive enzymes, and additional substances.

Conversely, compounds which produce toxic consequences in creatures are referred to as toxins, and they are not limited to sources found in nature. Since animal-derived poisons may permeate every part of an animal's body or are generated by specialised biological processes, the lethal impact in this instance happens when the attacking creature comes into contact with the deadly creature. Table 1 is a collection of specific instances of naturally occurring substances having established hazardous action.

Table 1: A few representative instances of known-toxic secondary metabolites are shown together with their fatal dosage (LD50) estimates.

Source	Molecule	Toxicological effect	LD_{50}*, mg/kg (animal model, route of administration)	Reference
Clostridium tetani	Botulinum Toxin**	Neurotoxic	0.0000004–0.0000025 (mus, IP)	[28]
Shigelladysenteriae	Shiga toxin	Enterotoxic	0.02 (mus, ip)	[29]
Catharanthusroseus	Vincristine	Cytotoxic	1.9 (rat, ip)	[30]
Colchicum autumnale	Colchicine	Cytotoxic	6.1 (rat, ip)	[30]
Taxusbrevifolia	Paclitaxel	Cytotoxic	32.5 (rat, ip)	[31]
Amanita muscaria	Muscimol	Neurotoxic	45 (rat, oral)	[32]
Nicotiniana spp.	Nicotine	Neurotoxic	50 (rat, oral)	[33]
Psilocybe spp.	Psilocybins	Neurotoxic	280 (rat, iv)	[30]
Gyromitra esculenta	Gyromitrin	Hepatotoxic	320 (rat, oral)	[34]
Cinchona spp.	Quinine	Antimalarial	115 (mus, ip)	[30]
Atropabelladona	Atropine	Neurotoxic	500 (rat, oral)	[29]
Prunus spp.	Amygdalin	Cyanogenic	880 (rat, oral)	[35]

*LD50 is the maximum dosage of a substance that, when administered simultaneously, results in the demise of 50% of test animals.*Botulinum toxin ranges for A, B, C1, C2, D, E, or F.

Toxic secondary metabolites had arguably two significant sectors that mankind are discovering useful applications: medication creation or the agrochemical business. Considering the vast majority of contenders to be a major pharmaceutical success fail because of perhaps its intrinsic poison to mammalian bodies with tissues as well as their absence of the bioavailability it has become imperative for the variables contributing to such cytotoxicity be examined in pharmaceutical development. Conversely, if substances with remarkable pesticidal properties are hazardous additionally to the intended organisms (plants, fungus, insects, etcetera.), typically fall short in the latter stage of the pesticide manufacturing process, and not just to individuals. Determining toxicological goals early on in the creation of novel compounds is thus advised. Researchers address the importance of cytotoxicity in agrochemistry or pharmaceutical development throughout the next articles.

VIII. ECOLOGICAL EFFICIENCY OF PLANT SECONDARY METABOLITE IN MICROORGANISM CONTROL

Around the globe, pesticides are used extensively. Various crops or nations employ various amounts or kinds of pesticides. The total amount of distinct insecticides used for various plants is summarised in Figure 1. This information came from an investigation of the Pesticides are toxic Particles Records (PPDB), which is created by the University of Hertfordshire's Agriculture & Environment Research Unit (AERU). Particularly, a wide range of pesticides are used in the production of vegetables, fruits, or grains. Subsequently is obvious that numerous pesticides are used in contemporary agriculture; thus, adhering to ethical standards or ethical procedures is crucial.

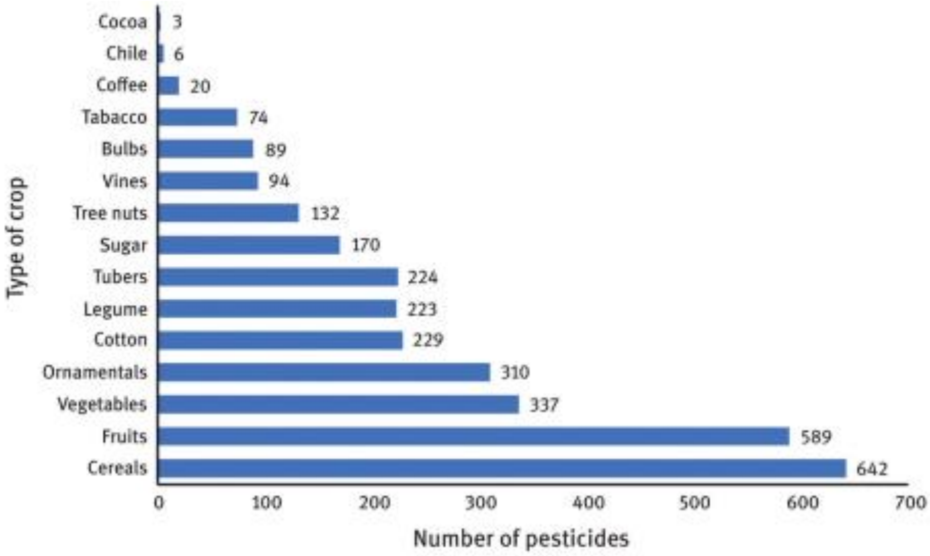


Figure 5: The variety of pesticides that are administered to various crops.

The hazardous nature of the insecticides is a clear need. It goes without saying that pesticides ought to be as innocuous to non-target creatures as feasible, including individuals and the surroundings, while being as discriminating as possible towards the pest under control. In a recent research, researchers examined the various methods of exposure, pharmacological mechanisms or actions, as well as toxicity estimates among several species.

This would be predicted, the spectrum of toxicities determined for an identical endpoints were a single order of magnitude higher for delicate creatures (like birds) compared for bigger and less susceptible species (like mammals). The majority of pesticides are man-made substances. A small number of pesticides derived from organic compounds, by overall opposing hand, demonstrate very favourable toxicological characteristics; they tend to be less hazardous towards individuals, creatures, as well as the surroundings, and more discriminating towards pests. As new pesticides are being developed, emphasis ought to be placed on those that have healthier toxicological characteristics as well as more friendly ecological features.

Certain natural compounds meet such prerequisites, allowing for the creation of novel pesticides with unique molecular targets that set them apart from synthetic pesticides. Instances of certain secondary metabolites utilised at controlling pests are shown below Table 2.

Table 2: Selected examples of toxic compounds used in agrochemical industry

Classification	Molecule name	Reference
Weed control	Glufosinate	[49]
	AAL-toxin	[50]
	Leptospermone	[51]
Insect control	Spinosad	[52]
	Avermectins	[53]
	Rotenone	[54]
Mollusc control	Vulgarone B	[55]
	Phytolacca dodecandra	[56]
Algae control	9,10-anthraquinone	[57]
	Menadione sodium bisulfite	[58]
Plant pathogens control	Azoxystrobin	[59]
	Cinnamaldehyde	[60]
	Flindersine	[61]

Interestingly, a large portion of pesticides, contained in PPDB (one of the most comprehensive pesticide database), are classified as metabolites [46]. In this database, those classified as metabolites correspond to chemical degradation substances and might retain pesticidal activity. This highlights the relevance of metabolic products, in addition to those naturally occurring in nature.

IX. STRATEGIES USED TO IMPROVE PLANT SECONDARY METABOLITE IN BIOLOGICAL INSECT

This propensity of plants as well as other solitary creatures to synthesize a vast array of tiny molecules, as "supplementary metabolites of it," is a defining attribute. These creatures lack a system of antibodies to fight diseases or are unable to flee from danger. Over 100,000 nanostructures have been characterized so far . A mechanism for development fueled by selecting for the development of increased protection against microbiological assault and animal/insect predators was partially responsible for this wide range. These substances are by necessity necessary for vegetation to interact using its surroundings despite being necessary to the growth of maintenance in their own.

While among a number of organisms the manufacture of numerous secondary metabolites was the foundation, biologically stressful situations like wounding or infections may promote or accelerate it. The most basic physiological definitions identify phytoanticipins as pre-formed inflectional antagonists and antioxidants to be substances that have been synthesized from scratch (this is in contrast having been granted liberty, for instance via hydrolyzing action). The difference between phytoalexin as well as phytoanticipin isn't frequently apparent since such names depends upon the processes of the molecule's creation rather than their biochemical composition. Certain chemicals are known to be phytoanticipins for particular plants or phytoalexins in another. One such instance is the methylation flavanone sakuranetin, that's a significant stimulated antibacterial metabolite in rice (Oryza sativa L.) foliage however that continuously increases within the leaves glands on cassis (Ribes nigrum L.). A inherent metabolite's classification as a phytoalexin in circumstances whereby it is formed within greater quantities immediately following contamination would rely on the possibility that its constitutive levels were high enough to have antibacterial properties.

Utilising the understanding of the plant's molecular structure being the main emphasis, traditional biochemistry has been applied to the investigation of secondary metabolites. Plant secondary metabolites frequently go by the name plant natural products, which means that they're having negative impacts on other living things. Terpenes or terpenoids (~25,000 kinds, 55%), alkaloids (~12,000 types, 27%), or phenolic molecules (~8,000 kinds, 18%) were the three main groups of botanical metabolites that function considered typical substances. While certain chemical groups have been employed for protection throughout taxa, such as phenylpropanoid swaps, identical groups of plants often employ comparable chemical arrangements over protection (such as these substances among the Fabaceae, sesquiterpenes in the Solanaceae). The names info chemicals and semi chemicals, which are frequently employed in biochemical ecological research for these compounds, serve to describe secondary metabolites if their involvement on naturally occurring relationships among species is taken into account. Semi chemicals are defined by the Organization for Economic Cooperation and Development (OECD), as substances released by plants, animals, and other kinds of living things that cause a biological as well as behavioral reaction in members of identical as well as other species. Pheromones as well as allele chemicals are two among them.

Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

Besides plant-insect coevolution, secondary metabolites have significant impact on the environment. At furtherance for drawing within aggressive organisms within the event of a herbivores approach, such biological substances might also function as biological transmitters, affecting the functioning of mutations related to defense processes in vegetation or even influencing gene expression of nearby plants. Organic compounds, such as phytoalexins, have been employed to unintentionally defend plants against diseases by inducing systemic acquired resistance (SAR), as a consequence of other research's developments. Researchers refer to these substances along with mixes that cause SAR as elicitors.

These substances are ideal prospects in comprehensive treatment of diseases as the infectious agent cannot effectively develop susceptibility to the elicitor due to the indirect nature of their action. Inducing agents of seedlings have a wide range of effects upon bacterial or pathogenic viruses and on plants, while the extent to which they are effective depends on a number in factors, including agricultural dietary habits, their genotype, environmental variables, including the physiological condition of the untreated vegetation.

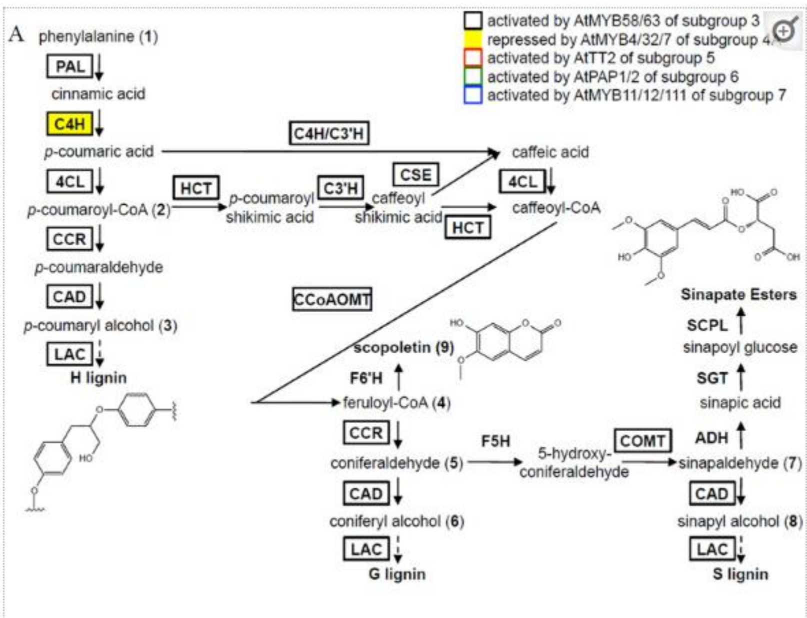
Plants generate a vast array of chemicals that are thought to play a crucial role in regulating the interactions between vegetation as well as its surroundings, making the realm of plants a vast pool of undiscovered molecules. Numerous scientific and ethnobotanical works exist that identify plants with established pest-control capabilities. It has been estimated that around 2000 plant species have pesticidal qualities; producers throughout underdeveloped nations employ many of these plants.

Fortunately only around 20–30% of higher plants are thought to have undergone research to far. Five thousand to twenty thousand distinct primary or secondary chemicals could be formed within a given organisms, majority of them in tiny levels that are often missed in a phytochemical examination. Only a tiny proportion of plants having undergone testing tested for pesticidal effectiveness; however, numerous of these research efforts are incomplete, as the bioassay techniques used are frequently insufficient or unsuitable. From this store about plant-based matter, possibly significant biological chemicals are yet unidentified, unexplored, underutilised, and underdeveloped.

X. REGULATORY AND SAFETY CONCERN OF PLANT SECONDARY METABOLITE

This heterocyclic protein L-phenylalanine is a primary source with a compound called a family with polyphenol primary with secondary functions which are widely distributed throughout terrestrial vegetation along with other eukaryotic. The majority of the plant-derived phenylpropanoids that have been identified consist of the lignin together with lignans that flavonoids (such as flavonols, anthocyanins, or proanthocyanidins), stilbenoids, coumarins, or hydroxycinnamic acid and its a combination. These compounds are produced through each broad as well as particular routes in phenylpropanoid metabolic processes.

The production of activating hydroxycinnamic acids, or p-coumaroyl-CoA, is typically the result of three processes that are catalysed through enzymes including phenylalanine ammonia-lyase (PAL), cinnamate 4-hydroxylase (C4H), as well as p-coumarate:co enzyme A ligase (4CL) (2) as shown in Figures 6 as well as 7). The additional processes in phenylpropanoid biosynthesis include the lignin, flavonoid, as well as several species- or clade-specific processes. Such above reaction chain was referred as the overall phenylpropanoid pathway.



ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

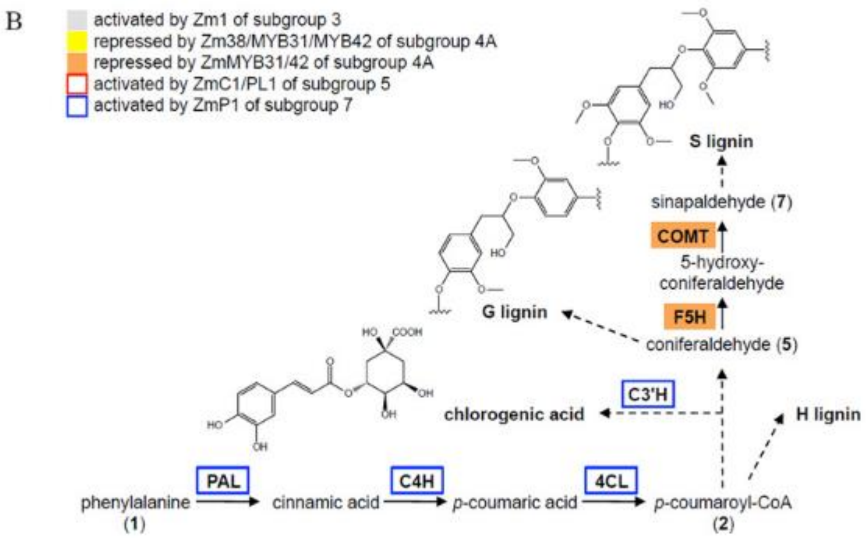
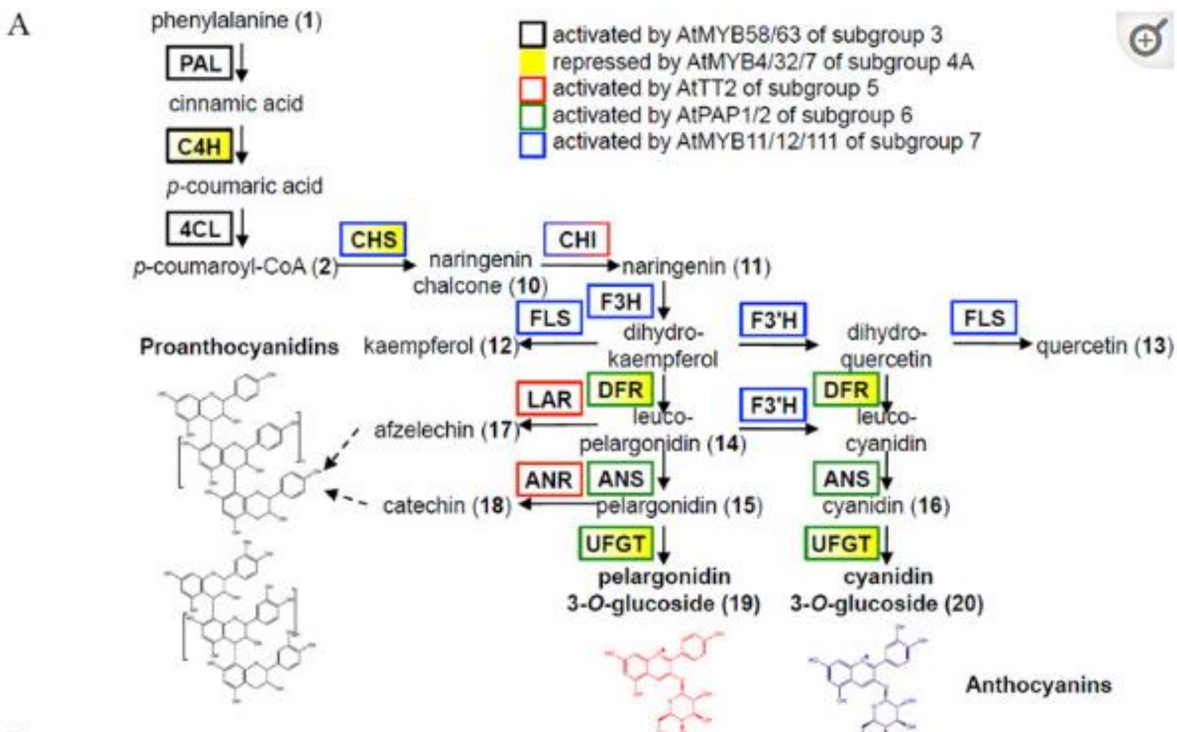


Figure 6: Both Brassica or a grain Several R2R3-type MYB Subgroups of Control the Lignin Biosynthesis Routes

Solitary enzymatic transformations are shown by uninterrupted bows, while numerous catalytic transformations are indicated by broken arrows. (A) Lignin routes in Arabidopsis. Taken from Vanholme and colleagues. (B) Lignin routes in maize. At the meeting point of the G/S lignin or coumarin biosynthesis processes is feruloyl-CoA . The biosynthetic routes for S lignin or sinapate esters converge at sinapaldehyde. P-coumaryl (3), coniferyl (6), and sinapyl (8) alcohols, which are monolignols, form polymers to create H, G, or S lignin, in that order. Alcohol dehydrogenase, or ADH; C3'H stands for p-coumaroyl ester 3'-hydroxylase; C4H for cinnamonate 4-hydroxylase; CAD for cinnamoyl-alcohol dehydrogenase; 4CL for 4-coumarate:CoA ligase; CCoAOMT for caffeoyl-CoA O-methyltransferase; CCR for cinnamoyl-CoA reductase; COMT for caffeic acid O-methyltransferase; CSE for caffeoyl shikimate esterase; F5H for ferulate 5-hydroxylase; F6'H for feruloyl-CoA 6'-hydroxylase; HCT for hydroxycinnamoyl-CoA:shikimate/quinate hydroxycinnamoyltransferase; LAC for laccase; PAL for serine carboxypeptidase-like; SGT for sinapate UDP-glucose sinapoyltransferase.



B

Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

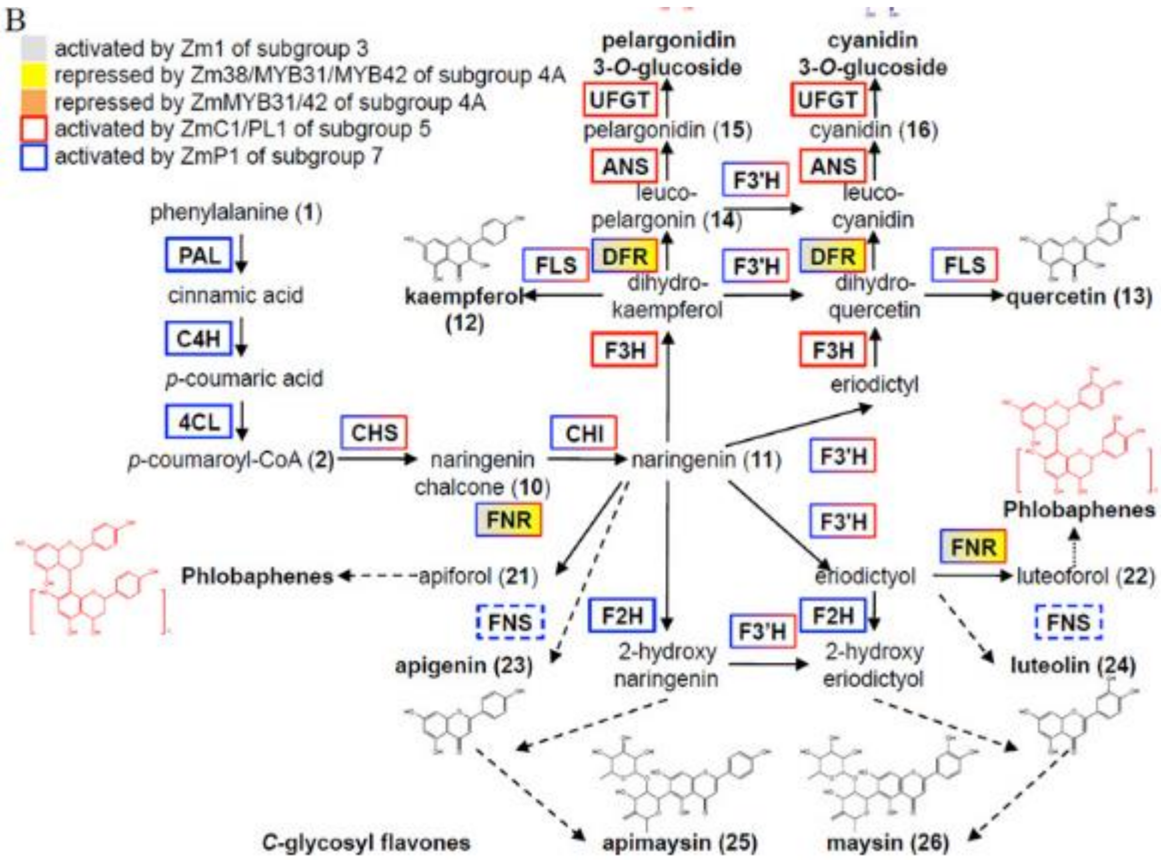


Figure: 7 Maize and Arabidopsis Flavonoid Biosynthesis Routes Are Regulated by Several R2R3-type MYB Sub groups
A) Flavonoid pathway in arabidopsis.
(B) Flavonoid routes in maize. Revised from Morohashi and colleagues (2012). The junction of the 3-hydroxyflavonoid or 3-deoxyflavonoid routes was occupied by naringenin (11). Solitary enzymatic conversions are shown by uninterrupted arrows, while numerous catalytic transformations are indicated by broken arrows. Proanthocyanidins are created when the flavan-3-ols catechin (16) as well as afzelechin (17) polymerize. The flavonols kaempferol (12) as quercetin (13), as well as the anthocyanins pelargonin 3-glucoside (19) with cyanidin 3-glycoside (20) are examples of 3-hydroxyflavonoids.

The flavones apigenin (23) or luteolin (24), their flavan-4-ols apiforol (21) or luteoforol (22), with the C-glycosyl flavones apimaysin (25) as well as maysin (26), are examples of 3-deoxyflavonoids. Phlobaphene pigments are formed via the polymerization of flavan-4-ols. Single enzymatic transformations are shown by unbreakable arrows, while numerous enzyme transformations are indicated by broken arrows. Anthocyanidin synthase (ANS); anthocyanidin reductase (ANR); Chalcone isomerase (CHI), chalcone synthase (CHS), p-coumaroyl ester 3'-hydroxylase (C4H), and chalcone isomerase (C3'H) The enzymes that are involved in this process are 4CL, 4-coumarate-CoA ligase; COMT, caffeic acid O-methyltransferase; DFR, dihydroflavonol 4-reductase; F2H, flavanone 2-hydroxylase; F3H, flavanone 3-hydroxylase; F3’H, flavonoid 3’-hydroxylase; FLS, flavonol synthase; FNR, flavanone 4-reductase; FNS, Type I flavone synthase; LAR, leucoanthocyanidin reductase; PAL, phenylalanine ammonia-lyase; UFGT, UDP-glucose flavonoid 3-O-glucosyltransferase.

XI. CONCLUSION

Plants generate a diverse range of secondary plant metabolites that provide defence towards infections and predators. Additionally, antioxidants strengthen defences against biotic or abiotic stressors. Numerous pests are deterred from eating by the several classes of secondary metabolites that include phenolic substances, terpenes, nitrogen- or sulfur-containing chemicals. It serve as a collection of pollinators' or seed-dispersing organisms' lures (colour, odour, or taste). They play a role in both plant-microbe cooperation and plant-plant interaction conflict. Secondary metabolites play an important role in a plant's capacity for warfare or live. The synthesis by primary plants molecules was a complex process

ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

that involves contemporary microbiological techniques; tests conducted assays vitro support the proactive functions in secondary plant metabolites.

The establishment of a distinct field of inquiry known as ecological chemistry is made possible by substances combining environmental, chemical in nature, or defence functions. Consequently, given this particular situation, more investigation within the actual process of creating organic pesticides was essential. Longer forward, it will become conceivable to produce genes that might be utilised to metabolically modify crops and produce beneficial protective secondary metabolites within bioreactors. Their tolerance to infections, herbivorous creatures or other ecological obstacles is going to get strengthened as a result. The main features of plant secondary metabolites as their significance for providing vegetation with defensive mechanisms or environmental adaptability are covered throughout this section of the paper. Numerous, widely dispersed SPS compounds are found in plants. Therefore, studies should concentrate on secondary metabolites or their use in agricultural protection strategies.

REFERENCES

[1] Al Aboody MS, Micky Maray S (2020) Antifungal efficacy and mechanisms of flavonoids. Antibiotics 9:1–42
[2] Aprile AM, Coppola M, Turrà D, Vitale S, cone P, Diretto G, Fiore A, taldi V, Romanelli A, Avitabile C, Guerrieri E (2022) Combination of the Systemin peptide with the beneficial fungus *Trichoderma afroharzianum* T22 improves plant defense responses against pests and diseases. J Plant Interact 17:569–579
[3] Arrázola G, Grane N, Dicenta F (2021) Quantification of cyanogenic compounds, amygdalin, prunasin, and hydrocyanic acid in almonds (*Prunus dulcis* Miller) for industrial uses. Rev Colomb Cienc Hortic 15:1–13
[4] Badmi R, Gogoi A, Doyle Prestwich B (2023) Secondary metabolites and their role in strawberry defense. Plants 12:3240
[5] Bezhuashvili M, Tskhvedadze L, Surguladze M, Shoshiashvili G, Elanidze L, Vashakidze P (2020) Change of phytoalexins-stilbenoids of vine leave Tsitska variety (*Vitis vinifera* L.) in condition Downy mildew. EurAsian J. Biosci. 14:167–171
[6] Bhattarai B, Steffensen SK, Staerk D, Laursen BB, Fomsgaard IS (2022) Data-dependent acquisition-mass spectrometry guided isolation of new benzoxazinoids from the roots of *Acanthus mollis* L. Int J Mass Spectrom 474:116815
[7] Birkenbihl RP, Kracher B, Roccaro M, Somssich IE (2017) Induced genome-wide binding of three arabidopsis wrky transcription factors during early mamp-triggered immunity. Plant Cell 29:20–38
[8] Chen CY, Liu YQ, Song WM et al (2019) An effector from cotton bollworm oral secretion impairs host plant defense signaling. Proc Natl Acad Sci USA 116:14331–14338
[9] Chen D, Mubeen B, Hasnain A, Rizwan M, Adrees M, Naqvi SAH, Iqbal S, Kamran M, El-Sabrout AM, Elansary HO, Mahmoud EA, Alaklabi A, Sathish M, Din GMU (2022) Corrigendum: role of promising secondary metabolites to confer resistance against environmental stresses in crop plants: current scenario and future perspectives. Front Plant Sci 13:881032
[10] Cuny MA et al (2019) Role of cyanogenic glycosides in the seeds of wild lima bean, *Phaseolus lunatus*: defense, plant nutrition or both? Planta 250:1281–1292
[11] Deng Y, Lu S (2017) Biosynthesis and regulation of phenylpropanoids in plants. CRC Crit Rev Plant Sci 36:257–290
[12] Egamberdieva D et al (2017) Phytohormones and beneficial microbes: essential components for plants to balance stress and fitness. Front Microbiol 8:1–14
[13] El Khawand T, Gabaston J, Taillis D, Iglesias M-L, Pedrot E, Palos Pinto A, Valls Fonayet J, Merillon JM, Decendit A, Cluzet S, Richard T (2020) A dimeric stilbene extract produced by oxidative coupling of resveratrol active against *Plasmopara viticola* and *Botrytis cinerea* for vine treatments. OENO One 54:157–164
[14] El-Maraghy SS, Tohamy TA, Hussein KA (2020) Role of plant-growth promoting fungi (PGPF) in defensive genes expression of *Triticum aestivum* against wilt disease. Rhizosphere 15:1–8
[15] Fernandes KR, Bittercourt PS, Souza AD, Souza AQ, Silva FM, Lima ES, Acho LD, Nunomura RD, Teixeira AF, Koolen HH (2019) Phenolic compounds from Virola venosa (*Myristicaceae*) and evaluation of their antioxidant and enzyme inhibition potential. Acta Amazon 49:48–53
[16] Florean M, Luck K, Hong B, Nakamura Y, Oconnor SE, Köllner TG (2023) Reinventing metabolic pathways: independent evolution of benzoxazinoids in flowering plants. Proc Natl Acad Sci USA 120:e2307981120
[17] Gaikar N, Raval M, Patel S, Patel P, Hingorani L (2021) Isolation, characterization and estimation of benzoxazinoid glycoside from seeds of *Blepharis persica* (Burm.f) O. Kuntze. Sep Sci plus 4:163–173
[18] Gleńsk M, Gajda B, Franiczek R, Krzyżanowska B, Biskup I, Włodarczyk M (2016) In vitro evaluation of the antioxidant and antimicrobial activity of DIMBOA [2,4-dihydroxy-7-methoxy-2H-1,4-benzoxazin-3(4H)-one]. Nat Prod Res 30:1305–1308

ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

[19] González-Hernández AI, Scalschi L, Vicedo B, Marcos-Barbero EL, Morcuende R, Camañes G (2022) Putrescine: a key metabolite involved in plant development, tolerance and resistance responses to stress. Int J Mol Sci 23:2971–3023
[20] Habash SS, Könen PP, Loeschcke A, Wüst M, Jaeger K-E, Drepper T, Grundler FMW, Schleker ASS (2020) the plant sesquiterpene nootkatone efficiently reduces *Heterodera schachtii* parasitism by activating plant defense. Int J Mol Sci 21:9627
[21] Handrick V, Robert CAM, Ahern KR, Zhou S, Machado RAR, Maag D, Glauser G, Fernandez-Penny FE, Chandran JN, Rodgers-Melnick E, Schneider B, Buckler ES, Boland W, Gershenzon J, Jander G, Erb M, Köllner TG (2016) Biosynthesis of 8-O-methylated benzoxazinoid defense compounds in maize. Plant Cell 00065:2016
[22] Hano CF, Dinkova-Kostova AT, Davin LB, Cort JR, Lewis NG (2021) Editorial: lignans: insights into their biosynthesis, metabolic engineering, analytical methods and health benefits. Front Plant Sci 11:630327
[23] Harun-Or-Rashid M, Kim HJ, Yeom SI, Yu HA, Manir MM, Moon SS, Kang YJ, Chung YR (2018) Bacillus velezensis YC7010 enhances plant defenses against brown plant hopper through transcriptomic and metabolic changes in rice. Front Plant Sci 9:1904–1915
[24] Hazrati H, Fomsgaard IS, Kudsk P (2020) Root-exuded benzoxazinoids: uptake and translocation in neighboring plants. J Agri Food Chem 68:10609–10617
[25] He X, Jiang Y, Chen S, Chen F, Chen F (2023) Terpenoids and their possible role in defense against a fungal pathogen *Alternaria tenuissima* in *Chrysanthemum morifolium* cultivars. J Plant Growth Regul 42:1144–1157
[26] Helfrich EJ, Lin GM, Voigt CA, Clardy J (2019) Bacterial terpene biosynthesis: challenges and opportunities for pathway engineering. Beilstein J Org Chem 15:2889–2906
[27] Huang LQ, Li PP, Yin J, Li YK, Chen DK, Bao HN, Fan RY, Liu HZ, Yao N (2022) The *Arabidopsis* alkaline ceramidase ACER functions in defense against insect herbivory. J Exp Bot 73:4954–4967
[28] Islam MT, Lee BR, Lee H, Jung WJ, Bae DW, Kim TH (2019) p-Coumaric acid induces jasmonic acid-mediated phenolic accumulation and resistance to black rot disease in *Brassica napus*. Physiol Mol Plant Pathol 106:270–275
[29] Jeschke V, Kearney EE, Schramm K, Kunert G, Shekhov A, Gershenzon J, Vassão DG (2017) How glucosinolates affect generalist lepidopteran larvae: growth, development and glucosinolate metabolism. Front Plant Sci 8:310911
[30] Kandaswamy R, Ramasamy MK, Palanivel R, Balasundaram U (2019) Impact of *Pseudomonas putida* RRF3 on the root transcriptome of rice plants: insights into defense response, secondary metabolism and root exudation. J Biosci 44:1–3
[31] Kapoor S, Handa A (2018) Role of total phenolic compounds in inducing hypersensitive reaction against PNRSV in peach. J Pharmacogn Phytochem 7:766–776
[32] Karssemeijer PN, Reichelt M, Gershenzon J, van Loon J, Dicke M (2020) Foliar herbivory by caterpillars and aphids differentially affects phytohormonal signalling in roots and plant defence to a root herbivore. Plant Cell Environ 43:775–786
[33] Khare S, Singh NB, Singh A, Hussain I, Niharika K, Yadav V, Bano C, Yadav RK, Amist N (2020) Plant secondary metabolites synthesis and their regulations under biotic and abiotic constraints. J Plant Biol 63:203–216
[34] Kiyama H, Matsunaga A, Suzuki G, Gomi K (2021) Monoterpene geraniol produced by rice terpene synthase 21 suppresses the expression of cell-division-related genes in the rice bacterial pathogen, *Xanthomonas oryzae* pv. *oryzae*. Physiol Mol Plant Pathol 115:1–6
[35] Kumar S, Abedin MM, Singh AK, Das S (2020) Role of phenolic compounds in plant-defensive mechanisms. Plant Phenol Sustain Agri 1:517–532
[36] Lefevere H, Bauters L, Gheysen G (2020) Salicylic acid biosynthesis in plants. Front Plant Sci 11:1–7
[37] Leybourne DJ, Valentine TA, Binnie K, Taylor A, Karley AJ, Bos JI (2022) Drought stress increases the expression of barley defence genes with negative consequences for infesting cereal aphids. J Exp Bot 73:2238–2250
[38] Li J, Huang H-C, Zuo Y-Q, Zhang M-Y, He M-L, Xia K-F (2024) PatWRKY71 transcription factor regulates patchoulol biosynthesis and plant defense response. BMC Plant Biol 24(1):8
[39] Liu G, Yang M, Fu J (2020) Identification and characterization of two sesquiterpene synthase genes involved in volatile-mediated defense in tea plant (*Camellia sinensis*). Plant Physiol Biochem 155:650–657
[40] Liu S, Ziegler J, Zeier J, Birkenbihl RP, Somssich IE (2017) Botrytis cinerea B05.10 promotes disease development in Arabidopsis by suppressing WRKY33-mediated host immunity. Plant Cell Environ 40:2189–2206
[41] Luo HZ, Jiang H, Huang XS, Jia AQ (2022) New sesquiterpenoids from plant-associated Irpex lacteus. Front Chem 10:1–6
[42] Masyita A, Sari RM, Astuti AD, Yasir B, Rumata NR, Emran TB, Nainu F, Simal-Gandara J (2022) Terpenes and terpenoids as main bioactive compounds of essential oils, their roles in human health and potential application as natural food preservatives. Food Chem X 13:100217–100314

ISSN (Online): 2583-3340
Volume-3 Issue-5 || October 2024 || PP. 32-47 https://doi.org/10.55544/sjmars.3.5.5

[43] Motallebi P, Niknam V, Ebrahimzadeh H, Hashemi M, Enferadi ST (2017) Exogenous methyl jasmonate treatment induces defense response against *Fusarium culmorum* in wheat seedlings. J Plant Growth Regul 36:71–82
[44] Narnoliya LK, Sangwan N, Jadaun JS, Bansal S, Sangwan RS (2021) Defining the role of a caffeic acid 3-O-methyltransferase from *Azadirachta indica* fruits in the biosynthesis of ferulic acid through heterologous over-expression in Ocimum species and *Withania somnifera*. Planta 253:1–13
[45] Ninkuu V, Yan J, Fu Z, Yang T, Ziemah J, Ullrich MS, Kuhnert N, Zeng H (2022) Lignin and its pathway-associated phytoalexins modulate plant defense against fungi. J Fungi 9:52
[46] Niu Y, Zhao X, Chao W, Lu P, Bai X, Mao T (2023) Genetic variation, DIMBOA accumulation, and candidate gene identification in maize multiple insect-resistance. Int J Mol Sci 24(3):2138
[47] Pant SR, Irigoyen S, Liu J, Bedre R, Christensen SA, Schmelz EA, Sedbrook JC, Scholthof K-BG, Mandadi KK (2021) *Brachypodium* phenylalanine ammonia lyase (PAL) promotes antiviral defenses against *Panicum mosaic virus* and its satellites. Mbio 12(1):10–1128
[48] Pazouki L, Niinemets Ü (2016) Multi-substrate terpene synthases: their occurrence and physiological significance. Front Plant Sci 7:1–16
[49] Rice CP, Otte BA, Kramer M, Schomberg HH, Mirsky SB, Tully KL (2022) Benzoxazinoids in roots and shoots of cereal rye (*Secale cereale*) and their fates in soil after cover crop termination. Chemoecology 32:117–128
[50] Shahrokhi M, Yali MP, Bozorg-Amirkalaee M (2022) Role of exogenous elicitors in canola plant defense against cabbage aphid by regulating physiological balance and secondary metabolite biosynthesis. Res Sq. https://doi.org/10.21203/rs.3.rs-1575991/v1
[51] Shu P, Li Y, Wang X, Yao L, Sheng J, Shen L (2021) Exogenous ferulic acid treatment increases resistance against Botrytis cinerea in tomato fruit by regulating nitric oxide signaling pathway. Postharvest Biol Technol 182:111678–111679
[52] Singh AP, Mani B, Giri J (2021) OsJAZ9 is involved in water-deficit stress tolerance by regulating leaf width and stomatal density in rice. Plant Physiol Biochem 162:161–170
[53] Singh S, Fatima Z, Hameed S (2016) Insights into the mode of action of anticandidal herbal monoterpenoid geraniol reveal disruption of multiple MDR mechanisms and virulence attributes in Candida albicans. Arch Microbiol 198:459–472
[54] Srinivasa C, Umesha S, Pradeep S, Ramu R, Gopinath SM, Ansari MA, Alomary MN, Ali A, Ahmad W, Kollur SP, Shivamallu C (2022) Salicylic acid-mediated enhancement of resistance in tomato plants against *Xanthomonas perforans*. Saud J Biol Sci 29:2253–2261
[55] Su LH, Geng CA, Li TZ, Ma YB, Huang XY, Zhang XM, Chen JJ (2020) Artatrovirenols A and B: two cagelike sesquiterpenoids from *Artemisia atrovirens*. J Org Chem 85:13466–13471
[56] Su Y, Huang Y, Dong X, Wang R, Tang M, Cai J, Chen J, Zhang X, Nie G (2021) Exogenous methyl jasmonate improves heat tolerance of perennial ryegrass through alteration of osmotic adjustment, antioxidant defense, and expression of jasmonic acid-responsive genes. Front Plant Sci 12:664519
[57] Tamiru A, Bruce TJ, Richter A, Woodcock CM, Midega CA, Degenhardt J, Kelemu S, Pickett JA, Khan ZR (2017) A maize landrace that emits defense volatiles in response to herbivore eggs possesses a strongly inducible terpene synthase gene. Ecol Evol 7:2835–2845
[58] Tan J, Wang M, Shi Z, Miao X (2018) OsEXPA10 mediates the balance between growth and resistance to biotic stress in rice. Plant Cell Rep 37:993–1002
[59] Tzin V, Hojo Y, Strickler SR, Bartsch LJ, Archer CM, Ahern KR, Zhou S, Christensen SA, Galis I, Mueller LA, Jander G (2017) Rapid defense responses in maize leaves induced by *Spodoptera exigua* caterpillar feeding. J Exp Bot 68:4709–4723
[60] Valletta A, Iozia LM, Leonelli F (2021) Impact of environmental factors on stilbene biosynthesis. Plants 10:90
[61] Vergnes S, Gayrard D, Veyssière M, Toulotte J, Martinez Y, Dumont V, Bouchez O, Rey T, Dumas B (2020) Phyllosphere colonization by a soil *Streptomyces* sp. promotes plant defense responses against fungal infection. Mol Plant-Microbe Interact 33:223–234
[62] Wang D, Jiang C, Liu W, Wang Y (2020) The WRKY53 transcription factor enhances stilbene synthesis and disease resistance by interacting with MYB14 and MYB15 in Chinese wild grape. J Exp Bot 71:3211–3226
[63] Wang H, Hao Z, Zhang X, Xie W, Chen B (2022) Arbuscular mycorrhizal fungi induced plant resistance against Fusarium wilt in jasmonate biosynthesis defective mutant and wild type of tomato. J Fungi 8:422–514
[64] Wouters FC, Blanchette B, Gershenzon J, Vassão DG (2016) Plant defense and herbivore counter-defense: benzoxazinoids and insect herbivores. Phytochem Rev 15:1127–1151
[65] Xing Q, Liao J, Cao S, Li M, Lv T, Qi H (2020) CmLOX10 positively regulates drought tolerance through jasmonic acid-mediated stomatal closure in oriental melon (*Cucumis melo* var. makuwa Makino). Sci Rep 10:17452

[66] Xu J, Wang X, Zu H, Zeng X, Baldwin IT, Lou Y, Li R (2021) Molecular dissection of rice phytohormone signaling involved in resistance to a piercing-sucking herbivore. New Phytol 230:1639–1652

[67] Yadav V, Wang Z, Wei C, Amo A, Ahmed B, Yang X, Zhang X (2020) Phenylpropanoid pathway engineering: an emerging approach towards plant defense. Pathogens 9:312

[68] Yang J, Fei K, Chen J, Wang Z, Zhang W, Zhang J (2020) Jasmonates alleviate spikelet-opening impairment caused by high temperature stress during anthesis of photo-thermo-sensitive genic male sterile rice lines. Food Energy Secur 9:233

[69] Yang L, Wen KS, Ruan X, Zhao YX, Wei F, Wang Q (2018) Response of plant secondary metabolites to environmental factors. Molecules 23:762

[70] Yu S, Yang F, Zou Y, Yang Y, Li T, Chen S, Wang Y, Xu K, Xia H, Luo L (2022) Overexpressing PpBURP2 in Rice increases plant defense to abiotic stress and bacterial leaf blight. Front Plant Sci 13:1–15

[71] Zhang M, Yu Z, Zeng D, Si C, Zhao C, Wang H, Li C, He C, Duan J (2021) Transcriptome and metabolome reveal salt-stress responses of leaf tissues from *Dendrobium officinale*. Biomolecules 11:736

[72] Zhang X, Ran W, Li X, Zhang J, Ye M, Lin S, Liu M, Sun X (2022) Exogenous application of gallic acid induces the direct defense of tea plant against *Ectropis obliqua* Caterpillars. Front Plant Sci 13:1–8

[73] Zhao G, Song Y, Wang Q, Yao D, Li D, Qin W, Ge X, Yang Z, Xu W, Su Z, Zhang X, Li F, Wu J (2020) Gossypium hirsutum salt tolerance is enhanced by overexpression of *G. arboreum* JAZ1. Front Bioeng Biotechnol 8:157

[74] Ziegler T (2021) Identification and characterization of genes involved in stilbene biosynthesis and modification in Vitis Vinifera. https://archiv.ub.uni-heidelberg.de/volltextserver/30000

[75] Zorrilla JG, Giovannini O, Nadalini S, Zanini A, Russo MT, Masi M, Puopolo G, Cimmino A (2024) Suppressive Activity of Glechoma hederacea extracts against the phytopathogenic oomycete *Plasmopara viticola*, and first screening of the active metabolites. Agriculture 14:58