REVIEW / ARTÍCULO DE REVISIÓN

Secondary metabolites in plants: main classes, phytochemical analysis and pharmacological activities.

Irina Francesca González Mera[1], Daniela Estefanía González Falconí[1], Vivian Morera Córdova[1*].
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Abstract: Plants are an essential source of chemical compounds with different biological properties that man can use to his advantage. These substances are mainly produced as a result of chemical conversions of secondary metabolism. This article reviews the main classes of secondary metabolites that synthesize plants as well as their characteristics and their biological functions. Examples are provided for each of the classes. Emphasis is placed on the methods of extracting secondary metabolites and phytochemical screening, as well as on the main pharmacological activities described for the MS.

KeyWords: Secondary metabolites, extraction, phytochemical screening, pharmacological activities.

Introduction

Plants are autotrophic organisms. In addition to the primary metabolism present in all living beings, they have secondary metabolism that allows them to produce and accumulate compounds of a very diverse chemical nature. The compounds derived from secondary metabolism in plants are called secondary metabolites (SM)[1].

The SM of the plants constitute a large and varied group of organic compounds that are synthesized in small quantities; they have no direct function in essential processes such as photosynthesis, respiration, solute transport, protein synthesis, nutrient assimilation, and the differentiation or formation of carbohydrates, proteins, and lipids. They appear in plants as a result of chemical conversions and even when many of their functions are unknown, it is believed that SM are related to the defense of the plant against predators and pathogens, they also act as allelopathic agents that influence growth, survival, and reproduction of other plants, attract seed pollinators and serve to face adaptation to sudden changes in temperature, humidity, light intensity and drought[2,3,4]. The SM of the plants have a differential distribution between taxonomic groups in the Kingdom of the plants, and therefore they are useful for Systematic Botany[5].

The study of biological functions and the structure of SM are of great importance because from this knowledge, it has been possible to use them in different industries. Many SM are used as aromas, resins, gums, flavor enhancers, as insecticides and herbicides[6,7,8,9,10]. On the other hand, the majority of SM have found utility in the pharmaceutical industry, given a large number of pharmacological activities that are known about them[11]. This article summarizes the main classes of SM in plants, some techniques for their extraction from natural sources and phytochemical screening, as well as the main pharmacological activities described for fundamental classes of SM.

Classes of SM in plants

Several criteria have been considered for the classification of SM: chemical structure (presence of rings or sugars), composition (containing nitrogen or not), their solubility in organic solvents or water, and the biosynthetic pathway. Of them, the most common criterion used for grouping the SM in plants has been the biosynthetic pathway. According to this, the SM in plants can be divided into three large groups: terpenes, phenolic compounds, and alkaloids[12].

Terpenes: they constitute the largest group of SM in plants to which more than 40,000 different molecules are allocated[12]. From the chemical point of view, they are non-saponifiable lipids since fatty acids do not intervene in their formation. They are also known as isoprenoids, since the basic structural unit that forms them is the isoprene molecule[13]. They are classified according to the number of isoprene units they contain. The most straightforward class of all is hemiterpenes with a single isoprene unit and five carbons in its structure. The best-known hemiterpene is isoprene, a volatile product that emerges from photosynthetically active tissues. With two groups, the terpenes are classified in monoterpenes, with three units in sesquiterpenes, with four in diterpenes, with six in triterpenes, with eight in tetraterpenes, and with more than 10 in polyterpenes[14,15] (Table 1).

Many plants contain terpenes in their flowers and fruits as mixtures of volatile compounds with specific odors; among them, we can mention lemon, mint, eucalyptus, ginger, and great basil[24]. Terpenes have several biological functions and participate in both the primary metabolism and the secondary metabolism of plants. In the central metabolism they are photosynthetic pigments (carotenes), electron carriers (ubiquinone and plastiquinone) regulators of plant growth and development (giberilins, strigolactones, brassinosteroids), are part of cell membranes (phytosterols) and participate in protein glycosylation[25]. In secondary metabolism they participate as defense molecules, toxic compounds and food deterrents for insects. In some plants they are the responsible molecules for attracting pollinators, or they function as dispersers[26,27,28,29].

They are synthesized from primary metabolites by two pathways: that of mevalonic acid, active in the cytosol, in which three molecules of acetyl-CoA condense to form mevalonic acid that reacts to form isopentenyl diphosphate (IPP) or the pathway of methyleryritol phosphate (MEP) that functions in chloroplasts and also generates IPP[24].

Phenolic compounds: they are chemical compounds containing a hydroxyl group directly attached to an aromatic hydrocarbon. Chemically, phenolic compounds are a very diverse group of SM. The simplest representative of this class is phenol[30,31,32,33]. The most important criterion for classifying

[1] Yachay Experimental Technology Research University. School of Chemical Sciences and Engineering. San Miguel de Urcuquí. Hacienda San José s/n. Imbabura, Ecuador.

Corresponding author: vmorera@yachaytech.edu.ec

Class	Number of isoprene units	Number of carbon atoms in the structure	Examples	Usages	Isolated from	References
Hemiterpene	1	5	Isovaleramide	Anticonvulsant	*Valeriana povonii*	16
Monoterpenes	2	10	Geraniol	Fragrance material	*Palmarose oil*	17, 18
Sesquiterpenes	3	15	Farnesol	Source of perfume	*Citrus aurantium*	19
Diterpenes	4	20	Vitamin E	Antioxidant	*Corylus avellana L.*	20
Triterpenes	6	30	Squalene	UV protector	*Olive oil*	21
Tetraterpenes	8	40	Carotene	Antioxidant	*Rhodotorula glutinis*	22
Polyterpenes	>9	>40	Rubber	Restorative material (endodontics)	*Palaquium gutta*	23

Table 1. Classes of terpenes according to the number of isoprene units.

phenolic compounds is the number of carbons present in the molecule. According to this criterion, the phenolic compounds are classified into simple phenols, acidic phenols, acetophenones, and phenylacetic acids, hydroxycinnamic acids, coumarins, flavonoids, biflavonyls, benzophenones, xhantones, stilbenes, quinones and betacyanins (Table 2). Lignans, neolignans, tannins, and phlobaphenes also belong to this group. The latter are polymers and have more complex structures[34,35].

Phenolic compounds are synthesized in plant cells by the shikimic acid pathway or the malonate/acetate pathway (or both, for example, flavonoids)[36]. The shikimic acid pathway provides the synthesis of phenylalanine and cinnamic acids and their derivatives (simple phenols, phenolic acids, coumarins, lignans, and phenyl propane derivatives)[37,38]. The polyacetate pathway provides quinones and xanthones. The mixed pathways combine precursors of both the shikimic acid pathway and the polyacetate pathway. This is the case of flavonoids[39,40].

Phenolic compounds fulfill various functions in plants: they oxidize quickly and act as antioxidants[41,42,43], they act as plant growth inhibitors[44], seeds accumulate significant amounts of phenols that act as filter so that oxygen does not reach the embryo and inhibit its germination[45]. Phenols also accumulate on surfaces of leaves, capturing up to 90% of UV radiation[46]. Phenols confer aromas and colors to the fruits making them appetizing for herbivores, which favors the dispersion of seeds through feces[47]. Plants compete with each other to preserve their territories, and in this process (allelopathy) the phenols participate[48]. Plants also defend themselves against the attack of pathogens by synthesizing phytoalexins that are toxic to microorganisms and their presence prevents infections[49]. Phenols also protect plants by generating bitter flavors or textures that are unpleasant for herbivores[50].

Alkaloids: alkaloids constitute another large and diverse group of SM that includes molecules isolated primarily from vascular plants[51]. Plants generally produce a complex mixture of alkaloids, in which a significant constituent dominates[51]. In a given plant the biosynthetic origin of the alkaloids present is common, even if their structures are slightly different[51]. Another interesting observation is that the concentration of alkaloids varies considerably from one part to another of the same plant, and even in some parts it may not contain those at all[52]. Alkaloids are also found in fungi, bacteria, and animals[53]. They include an atom of nitrogen in their structure, are toxic compounds and respond to common precipitation reactions[54,55].

Even when there is no uniform classification of alkaloids, several criteria have been used in order to classify them: biosynthetic origin, presence of basic heterocyclic nucleus in the structure, pharmacological properties, and distribution in plant families[56]. Among these criteria, the biosynthetic origin of the alkaloids has been used quite frequently. According to this criterion the alkaloids are classified as true alkaloids, protoalkaloids, and pseudoalkaloids[57]. Pure alkaloids strictly comply with the fundamental characteristics of the alkaloids. The majority of the alkaloids found in plants belong to this group. They contain an intracyclic nitrogen, have basic character and are compounds of high reactivity, even in small quantities. In plants, they can be found free, although they predominate as salts. The precursor compounds of the true alkaloids are amino acids (L-ornithine, L-lysine, L-tyrosine, L-tryptophan, L-histidine, and L-arginine). Some pure alkaloids have been derived from anthranilic and nicotinic acids[57,58]. The protoalcaloides constitute a smaller class in number. In this group, the nitrogen atom is not part of the heterocycle, and they derive from L-thyroid, L-tryptophan, and L-ornithine. They can also be considered aromatic amines[55]. The pseudoalkaloids contain heterocyclic rings with nitrogen but are not derived from amino acids. They are formed by subsequent incorporation of nitrogen into compounds originally free of this element. To this group belong terpenic alkaloids[58].

Although the presence of alkaloids is not vital for the plant, there is evidence that indicates the roles that these substances play in vegetables. As for the functions they fulfill, at first, they were considered waste products of nitrogen metabolism, nitrogen reservoirs in the plant, and were even mentioned as growth regulators. Today it is accepted that the role they play is to defend the plant against insects and herbivores due to its toxicity and deterrent capacity. While some serve to protect the plant from predators or microorganisms (toxic or repellent substances), others do so to compete with other plant species in a given habitat (allelopathic substances)[59,60].

Alkaloids have remarkable physiological properties and toxicological that are exerted primarily on the nervous system central, with predominance in some of its levels (Table 3). For these reasons, they can be used as drugs. Prolonged use of any of these compounds produced in man accustoming, which constitute true drug addictions, with physical and psychic dependence and an increase in the tolerance 57,59. To date, around 15,000 alkaloids have been isolated from plants. If it is considered to have been examined less than 25% of the upper plant species of the planet, it is clear that there is still

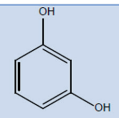
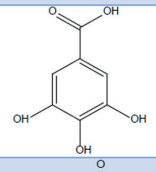
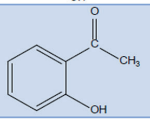
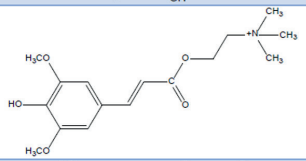
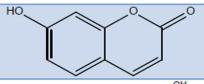
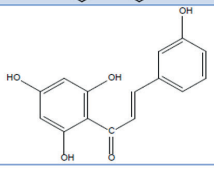
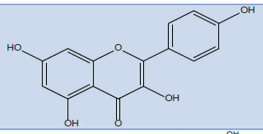
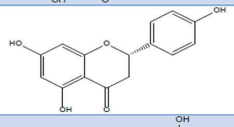
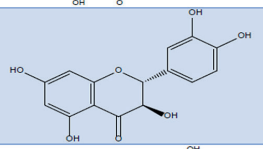
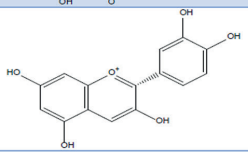
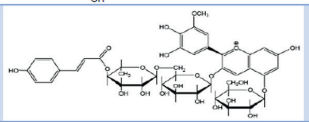
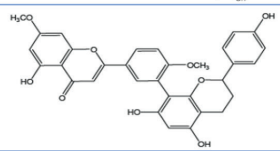
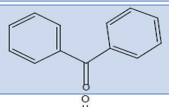
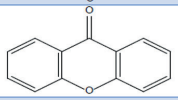
Skeleton structure	Class	Characteristics	Examples	Structure
C6	Simple phenolics	Substituted phenols	Resorcinol	
C6 - C1	Phenolic acids and related compounds	A carboxyl group substituted on a phenol	Gallic acid	
C6 - C2	Acetophenones and phenylacetic acids	Are rarely found in nature	2-hydroxyacetophenone	
C6 - C3	Cinnamic acids, cinnamyl aldehydes, cinnamyl alcohols	Are commonly found in plants as esters of quinic acid, shikimic acid, and tartaric acid or as sugar esters	Sinapoyl choline	
C6 - C3	Coumarins, isocoumarins, and chromones	They possess an oxygen heterocycle as part of the C3-unit	Umbelliferone	
C6-C3-C6 (C15) Flavonoids	Chalcones, aurones, dihydrochalcones	Two benzene rings are linked together by a group of three carbons	Butein	
	Flavones	Contains a ketone group, and an unsaturated C-C bond	Kaemferol	
	Flavanones	Contains a ketone group	Naringenin	
	Flavanonols	Occur in association with tannins	Taxifolin	
	Anthocyanidins	The heterocycle is a pyrilium kation	Cyanidin	
	Anthocyanins	Are water-soluble glycosides of anthocyanidins	Pentanin	
C30	Biflavonyls	Are dimers of flavones or methylated derivatives	Ginkgetin	
C6-C1-C6	Benzophenones	Are aromatic ketones	Benzophenone	
	Xanthones	Are yellow pigments in flowers	Xanthone	

Table 2. Classes of phenolic compounds according to the number of carbons in the structure.

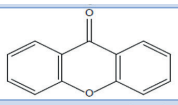
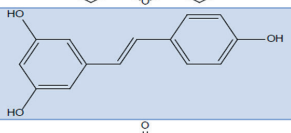
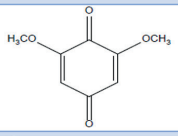
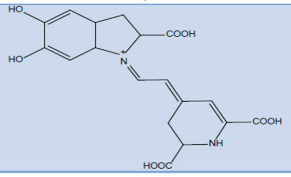
	Xanthones	Are yellow pigments in flowers	Xanthone	
C6-C2-C6	Stilbenes	Two benzene rings are linked together by a group of two carbons	Resveratrol	
C6, C10, C14	Quinones	Oxidizing agents	2,6-dimethoxybenzoquinone	
C18	Betacyanins	Are red pigments and contain nitrogen	Betanidin	

Table 2. Classes of phenolic compounds according to the number of carbons in the structure.

Class	Name	Biological properties	Plant family
True alkaloids	Atropine	Anticholinergic drug	Solanaceae
	Nicotine	Potent poison that at low doses is stimulating	Solanaceae
	Morphine	Narcotic and anesthetic properties	Papaveraceae
Protoalkaloids	Mescaline	Hallucinogen	Cactaceae
	Hordenine	Stimulant of the central nervous system	Cactaceae
	Ephedrine	Sympathetic nervous system stimulant	Ephedraceae
Pseudoalkaloids	Aconitine	Highly poisonous	Ranunculaceae
	Theobromine	Stimulating the central nervous system	Malvaceae
	Coniine	Highly poisonous	Apiaceae Sarraceniaceae

Table 3. Some biologically relevant plant-derived alkaloids.

a wide field for his research. Because of its pharmacological and medicinal importance there is an excellent motivation to continue with the chemical-biological study of the alkaloids. This is one of the most important secondary metabolites of plants with therapeutic interest[60].

Phytochemical analysis

Phytochemical studies generally are based on previous ethnobotanical and ethnopharmacological knowledge about plants and often constitute hypothesis-driven studies. The general methodology for studying SM from plants comprises several stages: extraction from natural sources, the phytochemical screening of extracts to determine qualitatively the main chemical classes of SM present in the plant, the purification of individual components and elucidation of their chemical structures, the biological activity studies through *in vitro*/*in vivo* assays and the toxicity-cytotoxicity studies on organisms or cells. The methodology involves a combination of different analytical techniques (Figure 1). In this methodology, the method of extracting secondary metabolites and their identification in phytochemical gait is crucial. These two aspects are reviewed below.

Extraction

The initial step during extraction is the preparation of plant tissues. The extraction can be done on clean and ground leaves, barks, roots, fruits, and flowers, from fresh or dried plant material. In order to maintain the freshness of the samples and avoid possible chemical damage, it is recommended that the interval between harvest and the initiation of extraction does not exceed 3 hours since the plant tissue is fragile and tends to deteriorate faster than dry tissue[61]. Otherwise it is preferable to dry the plant by air-drying, microwave-drying, oven-drying or lyophilization. Each of these methods has advantages and disadvantages that the researcher should consider[62,63,64,65]. Another critical point to view during pre-treatment of the plant is the particle size of plant material. The smaller the particle size, the higher the area of contact between the plant material and the solvent, and consequently the more effective the extraction of the chemicals[66].

Extraction is the process that allows separating SM from the plant by using solvents of different polarity. As a result of the extraction remains two phases: a liquid phase containing solubilized metabolites and a solid containing the insoluble cell debris. Conditions as temperature and time are important factors to achieve high-quality extracts[67]. The most common extraction methods are maceration, infusion, percolation, decoction, Soxhlet or continuous extraction, microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), accelerated solvent extraction (ASE), and supercritical fluid extraction (SFE)[68].

Maceration is a solid-liquid extraction technique[69]. The

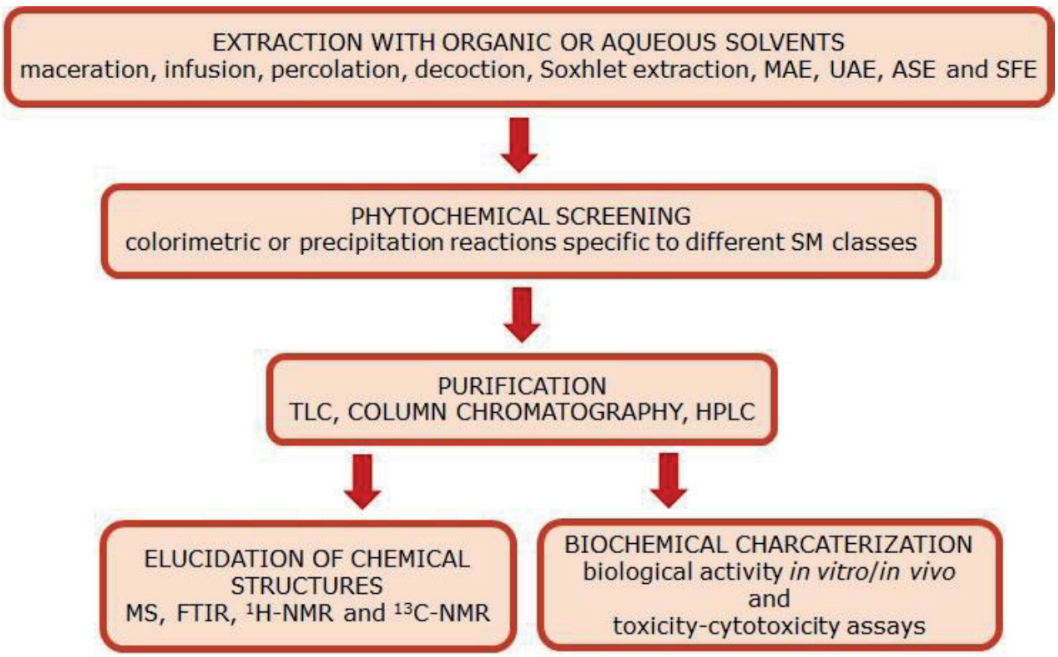


Figure 1. A brief summary of the general methodology for studying bioactive compounds from plants. SM-SM, MAE-Microwave Assisted Extraction, UAE-Ultrasound Assisted Extraction, ASE- Accelerated Solvent Extraction, SFE-Supercritical Fluid Extraction, TLC-Thin Layer Chromatography, HPLC-High Performance Liquid Chromatography, MS-Mass Spectrometry, FTIR-Fourier Transform Infrared Spectroscopy, 1H-NMR-proton Nuclear Magnetic Resonance and 13C-NMR-carbon Nuclear Magnetic Resonance.

method consists of using a solvent or a mixture of solvents having different polarities and a particular affinity with compounds that are going to be extracted. The mixture (plant-solvent) is placed in a container with lid and let it rest for two or three days until the compounds could be transferred from vegetal tissues to the solvent. This method is widely used with soft vegetal material[70]. The infusion is a maceration process too but uses shorter extraction times and the solvent usually is cold or boiling water. This method is used to obtain a diluted solution of compounds that are easily extracted[67]. The decoction is a more convenient method for extracting water-soluble compounds from roots and barks that are stable at high temperatures and usually results in oil-soluble compounds compared to maceration and infusion[71]. The decoction method is carried out boiling the vegetal material in water by 15 minutes, then cooling, filtering and adding water until it reaches the desired volume[67]. Finally, percolation is an extraction method that shares similar fundamentals. The method uses a conical filtration camera open on both sides where the material is placed with the solvent. The camera is connected to a flask and once the material is inside the camera, the system is opened to let it strain. The solvent can be used several times to rinse the material until the saturation point[68]. Another way to conduct the extraction of SM is using a Soxhlet apparatus. In this method, a Soxhlet extractor, a condenser, and a round bottom flask are used. The finely ground vegetal material is loaded into the thimble of a strong paper of cellulose and then placed in the Soxhlet extractor. The solvent goes in the round bottom flask, and it needs to be heated. The solvent vapors go into the thimble and then return to the flask after being condensed. The system is left, at least for sixteen hours[72]. The main advantage of Soxhlet extractor is the use of smaller quantity of solvent compared to maceration. However, the exposure to hazardous and flammable organic solvents, with potential toxic emissions is high[68].

The microwave-assisted extraction (MAE) is another popular and easy technique in which the sample is heated using electromagnetic radiation. This method improves the extraction of intracellular compounds due to the rupture of the cellular wall. Increasing temperature, the humidity inside the cell is transformed into vapor; as a result the intracellular pressure increases and the lysis is provoked. This factor comes together with other effects in the solution that benefit the interaction of the compounds to be extracted with the solvent. The main disadvantage is the possible thermal degradation[73,74]. The ultrasound-assisted extraction (UAE) facilitates partition of analytes with the occurrence the fragmentation of cell wall provoked by the collisions between the electromagnetic waves and the particles. There are two forms of applying it: in direct contact with the sample or using an ultrasound bath, where the contact is given through the walls of the bottle. In the first case the efficacy is 100 times higher than the second one. The procedure is simple, low cost and can be used in both small and larger-scale extraction[75].

In the method called accelerated solvent extraction (ASE), high temperatures and high pressures are applied to the samples. The time required to achieve the extraction is reduced to one hour, which is an advantage in comparison with other methods (48h or 72h). This is a method that separates efficiently analytes from the matrix. Since the nature of the solvent is an important fact in each method of extraction, the solvents used in this method determine the efficiency of the results. The solvents system, temperature, and time of action are determinants in accelerated solvent extraction. In the case of extraction of bixin the most efficient mixture of solvent was cyclohexane: acetone (6:4) at 50°C for 5 minutes[76].

The supercritical fluid extraction (SFE) involve a supercritical fluid. It is a substance that has both physical properties of gas and liquid in its critical point. Pressure and temperature are determinant factors to reach this critical point. The utility of the supercritical fluid is their gas behavior and solvating capacity of liquids. The most used solvent is CO_2

due to its capacity to dissolve nonpolar analytes, it has low cost and low toxicity[77,78]. This method is very selective, very fast, has a high yield percentage and the resultant product has high quality. It has been used in the coffee industry to decaffeinate coffee, or in other industries to extract essential oils[78].

Phytochemical screening

The phytochemical screening is a fast and cheap procedure to determine the main classes of SM or groups of substances that a plant contains. Since each class or group of SM is related to specific biological activities, based on the results obtained in the preliminary phytochemical screening it is possible to guide further research to determine the biological activity of the species in question and the active principles involved. The phytochemical screening consists in executing chemical reactions on aliquots of the plant extracts. The reactions can be based on liquid-liquid partition with solvents, in chemical reactions that produce colorimetric changes, fluorescence, or precipitates of a specific color. Among the SM to be analyzed are alkaloids, anthraquinones, flavonoids, phenols, saponins, sterols, tannins, quinones, coumarins and terpenoids. There are numerous reviews summarizing the principles of chemical reactions and the qualitative changes that can be are observed[68,79,80,81]. A summary of the experimental protocols for the phytochemical screening methods is shown in Table 4.

Secondary metabolite	Name of test	Reactants	Expected result if positive
Alkaloid	Dragendorff's test	Solution of potassium bismuth iodide	A red precipitate
	Wagner´s test	Iodine in potassium iodide	A brown/reddish precipitate
	Mayers test	Potassium mercuric iodide	A yellow coloured precipitate
	Hager ´s test	Saturated picric acid solution	A yellow coloured precipitate
Saponins	Froth test	Water	Formation of 1 cm layer of foam
	Foam test	Water	Produced foam persists for ten minutes
Phytosterols	Salkowski's test	Chloroform, concentrated sulphuric acid,	Appearance of golden yellow color
	Libermann Burchard's test	Chloroform, acetic anhydride, concentrated sulphuric acid	Formation of brown ring at the junction
Phenols	Ferric chloride test	Ferric chloride solution	Formation of bluish black color
Tannins	Gelatin test	1% gelatin solution, sodium chloride	Formation of white precipitate
Flavonoids	Alkaline reagent test	Sodium hydroxide solution	Formation of intense yellow color, which becomes colorless on the addition of dilute acid
	Lead acetate test	Lead acetate solution	Formation of a yellow color precipitate
Diterpenes	Copper acetate test	Copper acetate solution	Formation of emerald green color
Glycosides	Modified Borntrager's test	Ferric chloride, benzene, ammonia solution	Formation of rose-pink color in the ammonical layer
Cardiac glycosides	Legal's test	Sodium nitroprusside in pyridine, sodium hydroxide	Formation of pink to blood-red color
Carbohydrates	Molisch's test	Alcoholic α-naphthol solution	Formation of the violet ring at the junction
	Benedict's test	Benedict's reagent	Orange-red precipitate
	Fehling's test	Fehling's A & B solutions	Formation of red precipitate
Proteins and amino acids	Xanthoproteic test	Concentrated nitric acid	Formation of yellow color
	Ninhydrin test	Ninhydrin reagent	Formation of blue color

Table 4. A summary of the phytochemical screening methods.

Pharmacological activities of secondary metabolites

Plants have the ability to synthesize a vast and diverse group of SM. Many of them constitute bioactive substances that plants use as defense molecules. These molecules interact with specific targets in microorganisms or animal cells to exert some biological activity that neutralizes them. On the other hand, the diversity of metabolic pathways that plants use in the production of SM guarantees the existence in these defense molecules of specific structures useful to develop new drugs and medicinal products. That is why plants constitute an important source of substances that can be used for improving health and/or curing diseases. Among the beneficial pharmacological activities of the plants stand out antitumor, antioxidant, and antibacterial and activities[82,83].

Special attention has been devoted to the antitumor activity of SM. According to the World Health Organization, among the causes of death that most affect humanity today cancer is found[84]. Even when there are numerous alternatives for cancer treatment, research is continuing today to find new molecules from natural sources with better treatment effectiveness or able to alleviate the toxic effects of treatments[85]. Examples of isolated metabolites of plants with antitumor activity are lupeol, asiatic acid, celastrol, aurapten, ursolic acid, saidmanetin and indole-3-carbinol and hypericin. These substances have been shown to affect signaling to control cell growth and apoptosis, immune response and stromal microenvironment[85-95].

Another health problem that has been in focus on the action of medicinal plants is the antimicrobial resistance. It is estimated that around 25 thousand patients die per year in the European Union, due to infections caused by resistant bacteria[96]. In the United States, it is estimated that resistant bacteria cause around 77 thousand deaths per year[97]. These estimates give a clear idea that the search for new molecules with antimicrobial activity is a priority in basic research and necessity of the pharmaceutical industry. The antimicrobial activity of many plant extracts has demonstrated to be effective against Gram-positive and Gram-negative[98,99]. Besides, several authors have pointed out the possible synergy between antibiotics and plant extracts[100]. In the case of polyphenols, the antibacterial activity is based on the ability of these compounds to inhibit growth, reproduction, respiration, and any other vital function of microorganisms. This action is performed by the oxidation of specific enzymes, which inhibit some critical functions, such as breathing. It is also reported that polyphenols bind to DNA chains disrupting protein synthesis in microorganisms. Other authors suggest that some polyphenols can break the cell membranes of microorganisms, producing cell apoptosis[101,102]. It is also known that monoterpenes can interact with the phospholipids of cell membranes of many microorganisms due to their lipophilic nature. As a result, the ordered structure of the membranes is interrupted, thus causing cell lysis[103,104].

The antioxidant activity has also been studied from plant extracts. It is mainly related to the presence of polyphenols or phenolic compounds. Flavonoids act primarily as buffers and capture free radicals to generate the flavinic radical, much less reactive since in their structure the missing electrons are more delocalized. Also, flavonols such as quercetin can chelate transition metal ions such as iron or copper, preventing the formation of reactive oxygen species[105,106].

Conclusions

Currently, phytochemical research is aimed at isolating and identifying compounds synthesized by plants with pharmacological activities of importance for the treatment of human diseases. The development of efficient methods of extraction and the battery of methods that exist for the scrutiny of the extracts of these medicinal plants allow more profound studies on the pharmacological activities of metabolites and their potential application in human health.

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