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Research Paper

Bioactive compounds derived from metabolism of Solanaceae with medicinal effects

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ABSTRACT

At present, the sustainable use of biodiversity for the use of bioactive composite sources is part of the advances that chemical engineering and biochemistry have for the isolation of novel bioactive metabolites of different plant species with medicinal properties. Among them is the genus Solanum. In Mexico, 17 species of the genus have been identified. Some have antimicrobial, cytotoxic properties or act as modulators of immune response, others have not been subject to bioactivity studies, so they represent a potential source of bioactive principles. This study aims to highlight the species that have been studied and that contribute significantly as an alternative in traditional medicine. It proposed the increasing chances of success in obtaining bioactive metabolites in a rational way for the discovery of new compounds, which may be part of the development of new nutraceuticals in the short term.

Key words: Bioactivity, extracts, metabolites, plants, Solanaceae.

INTRODUCTION

Solanaceae (Solanaceae Juss) are a family of herbaceous or woody plants, they are characterized depending on the variety by presenting alternate leaves from approximately 1.5 to 20 cm long; some have villi, others have thorns on the stem and leaves, the length can go from 0.5 to 1.0 cm long. It has been reported that there are approximately 98 genera and about 1700 species (Al Sinani and Eltayeb, 2017), all of them with a great diversity of habit, morphology and ecology.

The Solanaceae family is distributed all over the world with the exception of Antarctica. The greatest diversity of these species is found in South America and Central America; in Mexico it is abundantly distributed in the southeast and to a lesser extent in the center and north of it.

This family includes species that are important food (Olivares-Tenorio et al., 2016) such as potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*) (Valdivia-Mares et al., 2016), eggplant (*Solanum melongena*) and peppers (*Capsicum*). Also within this family are ornamental plants that are well known and others little known, however, the latter are marked as weeds and usually have medicinal use in some regions of Mexico (Luna-Ramírez et al., 2014).

Currently, a large amount of research on chemical and biochemical engineering is focused on obtaining metabolites of plant origin; among them is the Solanum genus, which belongs to the Solanaceae family, whose species grow or are widely cultivated in Mexico as a source of food. These plants, as well as other species, possess two types of plant biosynthesis metabolisms: primary and secondary metabolism, both produce chemical compounds that represent a potential source of raw material for obtaining bioactive principles (Ruiz et al., 2014) with nutraceutical properties (Sakthivel and Palani, 2016). In line with its metabolism, the plants synthesize two categories of metabolites: primary and secondary.

The primary metabolites are indispensable for the physiological development of plant (Gürbüz et al., 2018), they are present in large quantities and include: peptides, proteins, lipids, carbohydrates and nucleic acids, within

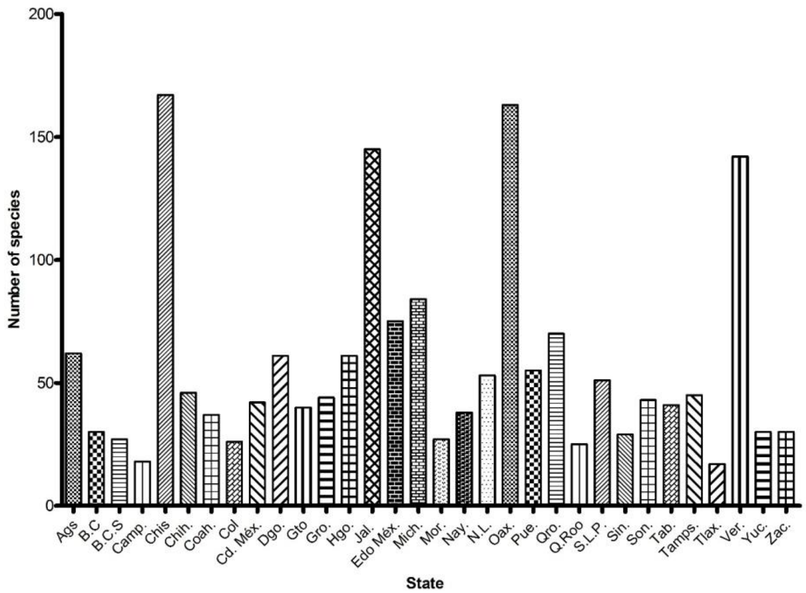

Figure 1: Distribution of Solanaceae species in Mexico.
Source: Martinez et al. (2017).

which peptides and proteins (De Coninck et al., 2013) possess greater bioactivity. While secondary metabolites include phenylpropanoids, flavonoids, alkaloids (Zhao et al., 2018), acetogenins, polyketides, terpenes, steroids and carotenoids (Nirmal et al., 2012). Such is the case of the genus Physalys, which has been reported with extensive biological properties and activities and significant pharmacological properties (Ramadan, 2011), including the ability to block antiphysiological compounds, insect repellent, hepatoprotective, immunomodulatory, antibacterial (Gurnani et al., 2016), anti-inflammatory (Zimmer et al., 2012), antitumor, cytotoxic and protection against CCl4-induced hepatotoxicity (Ramadan, 2011).

The Solanaceae are important in human diet due to their nutritional properties (Ordóñez-Santos et al., 2017; Puente et al., 2011) which have been reported in tomato species grown in Mexico. The content of protein or enzymes (Bravo and Osorio, 2016) fluctuates from 0.04 to 1.02% in the genus Physalis (Valdivia-Mares et al., 2016).

The Solanaceae family is characterized by its use in traditional medicine in the form of an infusion, which is administered orally for the treatment of diseases such as diabetes and biliary problems, among others.

In the Mexican Republic, it has been found plants of the Solanaceae family with biological activity: *Solanum americanum* Mill., *Solanum bulbocastanum* Dunal, *Solanum corymbosum* Jacq., *Solanum elaeagnifolium* Cav., *Solanum erianthum* D., *Solanum fructutecto* Cav., *Solanum heterodoxum* Dunal, *Solanum tridynamum* Dunal, *Solanum lanceolatum* Cav., *Lycopersicon esculentum* P. Mill., *Solanum marginatum* L., *Solanum myriacanthum* Dunal, *Solanum nigrescens* Mart and Gal, *Solanum pseudocapsicum* L., *Solanum rostratum* Dunal, *Solanum stoloniferum* Schltdl and Bouché and *Solanum torvum* Sw (Rzedowski, 2006). These species represent a source of compounds that have health benefits (Luna-Ramírez et al., 2014), which provides an opportunity for the development of new nutraceuticals with specific biological activities (having beneficial effects on diseases of the system biliary), such as hypoglycemic, antimicrobial (Dias et al., 2013), antihypertensive, antineoplastic and antioxidant (Vioque et al., 2006;Al-Fatimi et al., 2007; Moreno et al., 2013; Möller et al., 2008).

At present, research on the activity of both groups of compounds has focused mainly on evaluating their bioactivity, due to the fact that there is little scientific information that validates their proper use. Therefore, the objective of this study is to present an analysis of the primary and secondary metabolites of Solanaceae species, as well as the properties they possess, the scope of current research and their potential use as a source of raw material for the development of new nutraceuticals.

Geographical distribution of Solanacea species in the mexican republic

Mexico is home to a significant number of Solanaceae species and is considered a center of diversity for this family. There are other centers of diversification in the American continent, that is, Central and South America, and the rest of North America. The genera with wide distributions, cultivated species and with more than 300 years of dispersal of plants by humans have complicated the nomenclature of the relative (Martínez et al., 2017).

Figure 1 shows the distribution of Solanaceae species in each of the states that make up the Mexican Republic. There

Table 1: Bioactive proteins of Solanaceae and other plant sources.

Source	Property/function
Nicotiana. Tabacum	Antifungal
N. tabacum	β-1,3-glucanases
N. tabacum	Class I, II, IV, V, VI, VII Chitinases
N. tabacum	Class I, II Chitinases
N. tabacum	Thaumatin-like proteins
Solanum lycopersicum	Proteinase inhibitor
S. lycopersicum	Endoproteinase
Cucumis sativus	Class III Chitinase
N. tabacum	Peroxidase
Petroselinum crispum	Ribonuclease-like proteins
N. tabacum	Class I Chitinase
Raphanus raphanistrum	Defensin
Arabidopsis thaliana	Thionin
Hordeum vulgare	Lipid-transfer protein
Hordeum vulgare	Oxalate oxidase
H. vulgare	Oxidase-like
N. tabacum	Antifungal and antiviral

Source: Ali et al., 2018.

are three states in the south of Mexico which constitute a species of sanctuary with greater diversity; by state there are between 20 to 170 different species. Figure 1 shows the great diversity of Solanaceae species that exist in the mexican republic.

Some species that have been identified in Mexico, are used in a traditional manner, given that medicinal properties are attributed to them. For example flowers are boiled and used to combat overweight. They are also used as ornamental and sanitizer after childbirth and even, other species have an abortive effect, since they have been identified in them alkaloids, such as diosgenin, and steroidal saponins. However, some of them are used as coagulant of milk for cheese making and even as fodder for animal feed. While other uses this species, it is antifungal, hypoglycemic and for the treatment of cancer ("CONABIO www.biodiversidad.gob.mx," 2018).

Nutraceutical properties of Solanaceae

Nutraceuticals are considered as alternative therapeutic agents, used for the prevention and treatment of various diseases, specifically degenerative diseases such as cancer (Gulati et al., 2016). Nutraceuticals with anticancer potential include curcumin, propolis, silymarin and capazine. However, despite the extraordinary anticancer activity of many nutraceuticals, their clinical use is very limited due to their low solubility and chemical stability (Olivares-Tenorio et al., 2017).

On the other hand, the products of plant origin (Septembre-Malaterre et al., 2017) used as food source are rich in bioactive principles (Malaguti et al., 2014; Maestri et al., 2016) with nutraceutical properties (Elekofehinti et al., 2013; Rizzello et al., 2016) and therefore reduce the risk of chronic diseases, such as heart disease, cancer, stroke, diabetes, Alzheimer's disease and cataracts (Ruiz et al., 2014).

The Solanaceae family has different nutraceutical properties, among them the antimicrobial (Singh et al., 2015), the cytotoxic (Muñoz et al., 2010), the immunomodulatory, the antioxidant (Riahi and Hdider, 2013)(Fiorito et al., 2018), the antineoplastic (Al Sinani and Eltayeb, 2017), the antihypertensive(Mäkinen et al., 2016), the hepatoprotective, etc. The plants of the Solanaceae family are used in traditional Mexican medicine and in the world for their antimicrobial properties, which is why they are used as antidiarrheals, although they also have antifungal and anti-inflammatory effects in Ramsay Hunt syndrome (Hormaza et al., 2011).

Recent research indicates that proteins and peptides of plant origin are sometimes part of the defense mechanism in the plant, and that they are induced by phytopathogenic agents. Therefore, they have become key components of the innate immune system; Chitinase, glucanase, thaumatin, defensin and thionin have been reported as part of it (Ali et al., 2018). As reported of these molecules, when they are isolated from some plant species and are subjected to a purification process, they show the ability to present antimicrobial activity at concentrations between 13 µg/mL and 15 µg/mL (Sakthivel and Palani, 2016). In addition to the molecules mentioned previously, there are others with different functions and different origin, such as those shown in Table 1.

Peptides and proteins are synthesized from the biosynthesis of amino acids in plants (Lay and Anderson, 2005).

The main amino acids that have been identified in some species of Solanaceae (*Solanum melongena* L. and *Solanum phureja*) are alanine, [neurotransmitter (serotonin) synthesized from tryptophan], 5-hydroxytryptamine, arginine, glycine, leucine, serine (Choi et al., 2011) as well as carboxylic acids: alpha-linoleic, arachidonic, ascorbic, aspartic, glutamic, oxalic, palmitic and amines such as: phenylalanine and tryptamine. While from *Solanum nigrum* L., a glycoprotein having a molecular weight of 4.8 to 150 kDa (Jin Boo et al., 2010) has been isolated, which possesses 69.74% carbohydrates, 30.26% protein, and more than 50% hydrophobic amino acids such as glycine and proline. It has also been observed that peptides of *Solanum tuberosum* contain tyrosine residues (Cheng et al., 2010).

The StAPs are isolated peptides of *S. tuberosum*, whose amino acid sequence is deposited in the GeneBank accession number AY672651, in which the presence of a region of approximately 100 amino acids located between the amino and carboxyl-terminal regions, is described which is called "Plant Specific Insert" (PSI), and corresponds to a domain that has structural homology with proteins of the saponin family, specifically granulysin and NK-lysine(Muñoz et al., 2014).

It has also been pointed out that lunasin is used to obtain peptides from *S. nigrum* (Erdmann et al., 2013), while in other Solanaceae species the presence of alanine analogues has been reported, as well as a hexapeptide that has been obtained from casein (Mcclean et al., 2014).

Peptides and proteins with antioxidant properties of Solanaceae

S. tuberosum is one of the food sources richest in antioxidants(Perla at al., 2012). Therefore, there are therapeutic alternatives used traditionally by the population to counteract problems of gastric mucosa (acidity), the juice is used to reduce oxidative stress to a dose of 5 mL/kg, while with higher doses, it produces cytoprotective effect on the gastric mucosa (Sandoval and Loli-Ponce, 2010).

In addition to other biologic effects, it has been demonstrated that there is an antioxidant effect on the part of the peptides, which is a function of the composition, structure and sequence of amino acids. In the genus Solanum, antioxidant activity of the peptides obtained from hydrolyzed protein of *S. tuberosum* L., which inhibit the oxidation of linoleic acid and repress lipid oxidation in 26% 59, has been found (Kudo et al., 2009). Lunasin is a peptide with antioxidant effect on isolated DNA of *S. nigrum*, which inhibits the oxidative process in 11, 37, 69 and 85% at the concentrations of 0.5, 1, 5 and 10 mM, respectively. This is why its efficacy in the protection of DNA damage is generated by free radicals (Erdmann et al., 2013).

Peptides and antimicrobial proteins of Solanaceae

In what corresponds to the nutraceutical properties of plant peptides, there is scarce information about their different biological activities (Arenas et al., 2009;Rogozhin et al., 2011), because research is focused on their antimicrobial effect (Marcus et al., 2008) since it is known that plant peptides are part of the compounds involved with the innate immunity of the plant (Nawrot et al., 2014). So they are commonly called AMP (Antimicrobial Peptides), due to the antimicrobial effect that they have (Lopes et al., 2014) (Pribylova et al., 2008) against the pathogens that attack them. Among the peptides described are the defensins and/or thionins (Berrocal-Lobo et al., 2009). One example is the StAPs (AMP's isolated from *S. tuberosum*), which interact directly on infective structures such as cells, spores and hyphae of phytopathogenic fungi (Mendieta et al., 2006), a domain very similar to that of saponins, to which the antimicrobial activity of the monomeric AMPs of plants is attributed (Muñoz et al., 2011).

The action mechanism of the Solanaceae AMPs is mainly based on the interaction capacity they have with the plasma membrane of the pathogens, where they cause permeabilization alterations due to irreversible changes in the flow of ions which causes the death of the phytopathogen, which some authors refer to as microbial cytotoxicity (García et al., 2013). It has also been found that hexapeptide analogous to that obtained from casein (Mcclean et al., 2014), inhibits the growth of *E. coli* and *Micrococcus luteus* with efficacy equal to ampicillin.

In *S. tuberosum*, two aspartyl proteases have been identified that show an increase in their expression before the infection by the phytopathogen *Phytophthora infestans*, so there is a much higher increase in potato crops with a high degree of resistance to the pathogen. It has been determined that these proteins exert direct cytotoxic activity on other potato pathogens, such as *Fusarium solani*, *Streptomyces scabies* and *Erwinia carotovora* (Mendieta et al., 2006; Jami et al., 2007; Bittara et al., 2013) (Table 2) and antibacterial effect on pathogens of animals and humans such as *Staphylococcus aureus, Salmonella cholereaesuis, Salmonella gallinarum* and *E. coli* at concentrations ranging from 100 to 150 ppm, as well as an effect on its growth and microbial population in the stools of the large intestine of weaned pigs (Zhao et al., 2012; Kang et al., 2012).

Proteins of Solanaceae as antineoplastics

There are few reports on the antineoplastic effect of Solanaceae proteins in the world. However, it has been demonstrated that aspartyl proteases derived from *S. tuberosum* induce apoptosis in a dose-dependent manner in the Jurkat cell line (acute lymphocytic leukemia) (Muñoz et al., 2014; Mendieta et al., 2010), which is why the researchers suggest that they could be used in the treatment of this type of cancer.

It has also been observed that the glycoprotein isolated from *S. nigrum* L. has a cytotoxic effect by inducing

Table 2: Antimicrobial activity of aspartyl proteases isolated from *Solanum tuberosum*.

Microorganisms	CL_{50} µM		
Phytopathogens	***St*AP1**	***St*AP2**	***St*Asp-PSI**
Phytophthora infestans	0.005	0.37	0.20
Fusarium solani	0.80	2.95	2.50
Streptomyces scabies	1.50	1.20	-
Erwinia carotovora	3.70	3.75	-
Human pathogens			
Bacillus cereus	3.20	1.73	0.24
Escherichia coli	4.25	2.87	0.30
Staphylococcus aureus	1.01	3.85	2.67

CL_{50}= Concentration that kills 50% of microorganisms.
- = undetermined.
Source: Mendieta et al., 2006.

apoptosis on the HCT-116 cell line at a concentration of 40 µg/mL; which is based on the use of the plant species in traditional medicine as an anticancer agent (Surh, 2002).

Secondary metabolitos with nutraceutical properties of Solanaceae

In Solanaceae species, a large variety of compounds derived from secondary metabolism has been identified, including coumarins, alkaloids, terpenes, flavonoids, and polyphenols (Gupta et al., 2014; Pardhi et al., 2010). However, the thermal treatment of *S. tuberosum* destroys a large number of bioactive compounds such as phenols, flavonoids, flavonols, lutein and anthocyanins (Yao et al., 2013; Pérez Colmenares et al., 2013), which are largely responsible for the antioxidant power; however, a proportion of these compounds retains the effect (Perla et al., 2012).

One of the compounds widely studied in Solanaceaes are the glycoalkaloids. The main characteristics of these substances is their toxicity at certain levels, but with beneficial effects. For example, solamargina and solasonina are distinguished because they have chemical structures that are very similar to hormones steroids and consequently they have been proposed to be used as a substantial source for the production of drugs with properties such as contraceptives and steroidal anti-inflammatory drugs. These glycoalkaloids have been studied and proposed for their antiglicémica, antifúngicas, antiparacetica, antibiotic, antimicrobial, antiviral and especially for anticancer properties. Biological investigations since 2009 to date indicate that solamargine and solasonin have significant cytotoxicity against several human cancer cell lines (Al Sinani et al., 2016).

Antineoplastic and antioxidant effect

There is a very close relationship between the antioxidant effect and the anticancer (Aguilera et al., 2011), so that a potential source of phenolic antioxidants and agents against Solanaceae cancer is the use of different tomato genotypes, as well as the residues of their agro-industrial process, since it has been demonstrated that the extracts obtained from tomato residues have the capacity to eliminate hydroxyl radicals and superoxide anion radicals with IC_{50} from 0.03 to 0.45 mg/mL. It has also been shown that polyphenols have an effect on cancer cells at concentrations of 6.3 to 13.7 mg/mL, so that Solanaceae can be considered as a potential low-cost nutraceutical source.

In Mexico, antineoplastic activity has been reported of compounds obtained from *Capsicum annuum* (green chilepoblano), from *Physalis philadelphica* Lam. (Tomatillo) of *S. tuberosum* (potato) and *Solanum pinnatisectum* (Wang et al., 2011).

In the east, *S. nigrum* L. has been used in traditional Chinese medicine to counteract the effects of cancer of the digestive system and its anti-tumor effect on cell lines has been demonstrated: HepG2 (human liver hepatoprotective carcinoma cell line), SGC- 7901 (human gastric cancer cell line) (Choi et al., 2011), and LS-174 (colon carcinoma cell line) (Milner et al., 2011).

The antitumor potential of withaferin A, present in the fruits of *Physalis longifolia* Nutt, has also been highlighted (Solanaceae), this steroid was delivered on an experimental mouse model, where the treatment with a probe has the capacity to reduce the triple breast carcinoma by 60% (MDA-MB-468LN), so that the dried fruit of this species can be used as a dietary supplement, given that this compound is a promising chemotherapeutic agent for antitumor therapies (Gallagher et al., 2015).

On the other hand, the antiproliferative effect of aqueous extract, ethyl acetate and hexane of *C. annuum* L. (20 µg/mL) against the gastric cancer cell SNU-1 has been studied; these extracts have minimal inhibition effects at the evaluated concentration, although with effects of TRAP-PCR inhibitory reaction and telomerase inhibitory

Table 3: Bioactive secondary metabolites present in Solanaceae.

Specie	Identified compounds	Bioactivity reported	Reference
Solanum lycopersicum	Lycopene	Antioxidant and anticancer and immunomodulator (mitochondrial protective effect)	Reshmitha et al., 2017;Lee et al., 2013; Conlon et al., 2015; Arathi et al., 2016; ,Ilic y Misso, 2012; Li et al., 2014.
Solanum nigrum	Solanine	Anticancer and immunomodulator	Al Sinani and Eltayeb, 2017a
Solanum torvum	Solasodin	Hypotensive, antirheumatic, antidiarrheal, antitussive, antimicrobial, wound healing and ulcers	Arthan et al., 2006; Pérez etal., 2013.
Solanum tuberosum	Solasonina	Antioxidant	Rodríguez-Pérez et al., 2018;López-Cobo et al., 2014.
Capsicum annuum	Solamargina	Analgesic, Antioxidant. anti-inflammatory, chemopreventive effects	Li et al., 2013.
Solanum coagulans	Phenolic acids Anthocyanins and glycoalkaloids	Antibacterial and antifungal	Qin et al., 2016

activity(Xu and Sung, 2015).

In Table 3, bioactive compounds identified in Solanacea and their biological effects are indicated, which represents an alternative for the treatment of diseases that affect the quality of life of human beings.

In addition to the aforementioned species, there are others that have been widely studied, such as *Lycium barbarum*, which by the specificity of their studies showed the phytochemical compounds that may have nutraceutical effects, such as polyphenolic compounds, varying their content in the fruit, leaves, flowers and stem, as shown in Table 3. This is attributed to antioxidant and anti-inflammatory activity (Lopatriello et al., 2017).

In addition to the reports on the entire Solanaceaes plant, the bioactive effect of extracts of different Solanaceaes species has been reported. It was demonstrated their potential in pharmaceutical area, given that their content of polyphenolic compounds has the ability to exert antioxidant activity and to inhibit to a certain extent the activity of enzymes involved in the aging process of the skin. As shown in Table 4, it is the physiologically immature species that present the highest contents of total polyphenolic compounds which, in turn, have the highest antioxidant activity (Bravo et al., 2016).

On the other hand, it has also been reported that the flower of Petunia x hybrida belonging to the Solanaceaes, has an antioxidant effect attributed to the anthocyanin content, which fluctuates from 2.5 to 14.4 mg cyn3-glu Eq/100 g FW, depending on the color of the flower. Therefore, its antioxidant activity is approximately 5.40 to 10.22 mmol $FeSO_4$/100 g FW. Other species used as alternative medicine and with antioxidant properties are *Datura fastuosa* L., *Solanum forskalii* Dunal, *Solanum surattense* Burm. F. and *Withania sominifera* (L.) Dunal, whose antioxidant activity is attributed to the total polyphenolic compounds found as 24.42 ± 2.02, 7.21 ± 0.59, 22.29 ± 2.56 and 4.79 ± 0.22 mg GAE/g of plant, with respective values of minimum amount of antioxidant (IC50) by the DPPH method of 289.65 ± 11.87, 825.32 ± 21.01, 305.15 ± 16.59 and 711.45 ± 21.90 μg/mL, and by the FRAP method of 3.56 ± 0.21, 1.85 ± 0.04, 3.57 ± 0.3 and 1.72 ± 0.03, mM Fe^{+2}/g, respectively (Qasim et al., 2017).

Among Solanaceae, *S. tuberosum* L. is the most widely cultivated crop in the world and forms a fundamental part of the diet of man. There are reports that the shell of this tuber is a potential source of polyphenols (1.2 to 2.5 mg/g dry skin), emphasizing mainly the caffeic acid and the chlorogenic acid (0.4 to 1.1 mg/g dry skin) depending on the variety and storage conditions. These compounds, in addition to being in greater proportion, are those that favor antioxidant activity (Al-Weshahy et al., 2013). Table 5 shows the polyphenolic compounds identified in leaf, fruit, leaf, stem and flowers of *L. barbarum*, suggesting that the active compounds are not located in certain part of a plant.

Another investigation from shell of *S. tuberosum,* such as agroindustrial waste, indicates that it possesses bioactive components with possible antioxidant properties. The

Table 4: Effect of the methanolic extracts of Solanaceae fruits on the enzymes related to skin aging and antioxidant properties.

Species Solanaceae	Maturation state	Anti-collagenase	Anti-elastase	Anti-hyaluronidase	Anti-tyrosinase	TPC (mg EAG/g)	ORAC (µmol ET/g)	TEAC (µmol T/g)
Cestrum nocturnum L.	S3	0.7 ± 1.2	15.0 ± 3.3	0.0 ± 0.0	64.5 ± 1.9	88.3 ± 2.4	364.2 ± 10.0	93.7 ± 3.5
	S1	0.0 ± 0.0	12.0 ± 4.6	1.4 ± 2.8	19.1 ± 1.4	57.8 ± 5.9	352.8 ± 4.2	95.2 ± 2.5
Solanum betaceum Cav., (Purple)	S1	1.2 ± 1.2	6.6 ± 3.1	2.8 ± 0.7	40.8 ± 1.0	116.8 ± 2.2	408.3 ± 10.6	385.8 ± 3.7
	S2	5.7 ± 2.9	7.3 ± 3.5	0.0 ± 0.0	29.5 ± 5.2	79.1 ± 2.5	353.0 ± 13.3	158.7 ± 3.7
	S3	1.6 ± 1.5	4.0 ± 1.3	0.0 ± 0.0	23.0 ± 1.3	79.8 ± 1.5	382.9 ± 13.8	126.5 ± 2.9
Solanum betaceum Cav., (Yellow)	S1	5.0 ± 2.4	5.3 ± 3.7	0.0 ± 0.0	41.4 ± 2.0	105.4 ± 5.2	449.0 ± 17.4	204.4 ± 2.9
	S2	0.7 ± 1.3	0.0 ± 0.0	0.0 ± 0.0	17.6 ± 5.2	32.5 ± 1.4	109.8 ± 4.8	58.5 ± 0.8
	S3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	14.9 ± 9.1	31.6 ± 1.8	121.3 ± 2.3	48.9 ± 1.6
Lycianthes radiata (Sendtn.) Bitter	S1, S2, S3	17.0 ± 2.3	2,0 ± 3,5	8.3 ± 2.7	27.3 ± 0.4	227.7 ± 8.2	434.8 ± 21.1	418.6 ± 4.3
Physalis peruviana L.	S1	20.4 ± 8.7	0.0 ± 0.0	1.9 ± 0.4	20.2 ± 2.2	40.8 ± 0.6	93.0 ± 1.8	57.9 ± 1.4
	S2	4.7 ± 3.7	2.7 ± 2.5	0.9 ± 1.9	20.4 ± 1.3	19.3 ± 0.2	39.0 ± 0.7	19.9 ± 0.2
	S3	8.4 ± 3.1	11.2 ± 2.8	0.0 ± 0.0	6.6 ± 5.6	18.1 ± 0.5	39.5 ± 3.0	15.7 ± 0.0
Solanum nigrescens M. Martens and Galeotti.	S1	0.0 ± 0.0	0.0 ± 0.0	7.2 ± 0.4	34.4 ± 1.8	82.0 ± 1.1	379.7 ± 5.7	153.8 ± 11.4
Solanum nutans Ruiz y Pav.	S3	1.5 ± 1.3	6.5 ± 3.7	0.0 ± 0.0	3.2 ± 3.0	12.6 ± 0.8	38.2 ± 0.9	5.1 ± 1.6
Solanum ovalifolium Dunal.	S1	0.0 ± 0.0	0.0 ± 0.0	4.1 ± 0.4	93.6 ± 0.5	133.2 ± 6.0	401.0 ± 8.4	276.7 ± 6.9
	S3	2.6 ± 4.0	6.1 ± 3.7	15.2 ± 1.2	28.3 ± 0.3	51.4 ± 2.8	86.6 ± 1.9	117.7 ± 15.2

Source: Bravo et al., 2016.
Immature (S1), intermediate (S2) and mature (S3).

Table 5: Profile of bioactive compounds identified in *Lycium barbarum.*

Compound	Matrices			
	Fruit (90.0 g)	Sheets (35.0 g)	Flowers (4.2 g)	Stems (500.0 g)
caffeic acid	0.6 mg			
Chlorogenic acid	0.2 mg	9.3 mg	3.0 mg	
p- cumaric acid	0.3 mg			
5-hydroxyferulic acid	0.5 mg			
Kaempeferol	0.8 mg			
Myricetin	0.2 mg			
N, N-dicafeolespermidines			2.0 mg	
Quercetin	0.2 mg			
Routine		780.0 mg	40.0 mg	
Scopoletin		7.4 mg		20.0 mg

Table 5 Contd: Profile of bioactive compounds identified in *Lycium barbarum.*

Compound	Matrices			
	Fruit (90.0 g)	**Sheets (35.0 g)**	**Flowers (4.2 g)**	**Stems (500.0 g)**
3, 4,5-trihydroxycinnamic acid	0.5 mg			
dihydro-N-caffeoyltyramine				50.0 mg
trans -N-feruloyltyramine				100.0 mg

Source: Lopatriello et al., 2017

results showed that the antioxidant potential of the potato husk is a function of the degree of physiological maturity and also of the extraction solvent. Therefore, when extracts are obtained with ethyl acetate and regardless of the degree of physiological maturation, they have a greater antioxidant potential (Arun et al., 2015).

Organic compounds derived from secondary metabolism of Solanaceae with antimicrobial property

In recent years, a large amount of research has been carried out which focused on the search for secondary metabolites with antimicrobial potential (AL-Janabi and AL-Rubeey, 2010). The Solanaceae are not excluded from the group of plants studied, an example is the effect of the hexane, dichloromethane and ethanolic extracts of *Solanum trilobactum on Bacillus subtilis, Micrococcus luteus, Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa* and *Candida albicans* (Al-Oqail et al., 2012). In addition, bioactive compounds affect *Klebseillla pneumoniae* and *S. aureus* when concentrations of 0.06 to 0.5 mg/mL are applied (Geetha et al., 2011; Qi and Kim, 2017). Antimicrobial activity has also been observed from the aqueous hydroethanolic and ethanolic extracts of *Solanum xanthocarpum*, which have an effect on *S. aureus* and *E. coli* at a minimum inhibitory concentration (MIC) of 50 μg/mL (Pardhi et al., 2010). Whereas extracts of leaf, flower and fruit of *Solanum malongena* L. showed effect on the growth of *S. aureus, E. coli, K. pneumoniae, B. subtilis,* and *Proteus vulgaris* at MIC of 6 to 50 mg/mL (Berrocal-Lobo et al., 2009).

It has been reported that some of the compounds identified from extracts with antimicrobial activity on *E. coli, K. pneumoniae* and *Proteus mirabilis* include acids: caffeic, ferulic, cinnamic, p-coumaric-O-β-D- glucoside and kaemferol, which have been identified in *Solanum esculentum* and *S. trilobactum* (Geetha et al., 2011; Yende et al., 2014). Other compounds present in this family of plants are polyphenols, mainly anthocyanins.

The synergistic antimicrobial action of polyphenolic compounds of *Solanum panduriforme* has been evaluated with those obtained from different plant species, as well as their combined effect with antibiotics (ampicillin, cefotaxime, chloramphenicol and penicillin) against gram-negative strains (*E. coli* and *K. pneumoniae*), where it has been shown that the minimum action of inhibition is 313 to 625 μg/mL. This confirms that Solanácea polyphenolic compounds can be used as therapeutic agents (Vambe et al., 2018).

Analgesic and anti-inflammatory properties of Solanaceae

The analgesic and anti-inflammatory properties of a large number of active compounds have a close relationship because they inactivate some compounds involved in the inflammatory process, such as cytokines and intraperitoneal prostaglandins (Erdmann et al., 2013).

Much of the Mexican population uses plants as an alternative therapy for the treatment of their illnesses, some of them are used to counteract stomach and body pain. According to studies carried out in recent years on the ethnopharmacological use of medicinal plants in Mexico, it was shown that Solanaceae species are traditionally used as an analgesic and anti-febrifuge, mainly in the state of Yucatán 60,108. An example of traditional use as an analgesic of Solanaceae is the use of *Cestrum dumetorum* (Orcajuda) and *Cestrum nocturnum* (black orcajuda), for the treatment of body aches and bronchitis (Yende et al., 2014).

To achieve the validation of the adequate use of Solanaceae species, some research studies have indicated that *Capsicum annum* (chileguajillo, which is used as food in Mexico), has analgesic and anti-inflammatory activity. Previously, by means of the evaluation with a biological model, it was determined the inhibition of the formation of edema, with a dose of extract of 20 to 80 mg/kg, whose effect has been compared with the indomethacin (conventional anti-inflammatory used as positive control), evidencing a significant analgesic and anti-inflammatory action that the authors attribute to the presence of carotenoids (Hernández-Ledesma et al., 2011).

Another species of Solanaceae in which anesthetic properties have been observed is *Datura stramonium* (toloache), an effect that has focused attention on dental problems. On the other hand, according to what was reported in a study carried out in the highland region of Mexico and other studies in southeast and central Mexico, it was shown that sordid *Physalis* has an anti-inflammatory effect that is comparable with indomethacin (conventional anti-inflammatory drug) (Pérez et al., 2013). Similarly, this effect has been observed with the methanolic extract of *Solanum lanceolatum* compounds (a medicinal plant used in some communities of Chiapas, Mexico) (Aguilar-Santamaría et al., 2013).

Solanum betaceum, is a species which studies on some of its structural components (Osorio et al., 2012; Hurtado et al., 2009) have been carried out. The analgesic and anti-inflammatory effects have been demonstrated, given in animals intraperitoneally (Do Nascimento et al., 2013). In addition, the analgesic effect of the fruit extract has been confirmed, the resin and capsaicin of *C. annuum* and *Capsicum frutescens* at doses of 80 mg/kg in mice. It has also been observed that capsaicin potentiates the penetration of anti-inflammatory agents through human skin.

Regarding the anti-inflammatory effect of secondary metabolites of the genus *Solanum*, there are studies on the molecular mechanism underlying the effect shown by the chloroform fraction of the epicarp of *S. tuberosum* L. (FCESt). Based on the above, in animal models of mice with colitis induced by macrophages RAW 264.7 and with sodium dextran sulfate, the results showed that FCESt has anti-inflammatory potential and there is the possibility of using it as a therapeutic agent in the treatment of colitis.

This is because it inhibits the expression of nitric oxide synthase and cyclooxygenase-2 enzymes at the level of transcription, so that it attenuates transcriptional activity (Lee et al., 2014).

Properties antihypertensive and hepatoprotector of some compounds of Solanaceae

With the aim of obtaining bioactive compounds, recent investigations are directed to the search of peptides with antihypertensive activity from the hydrolysis of proteins extracted from potatoes (*Solanum tuverosum*). As a result, researchers have used Goldblatt mice as an *in vivo* model and verified that effectively when there is a sequence of Glu, Gly, Leu and Ser, they exert antihypertensive effect. The results provide important information for future applications in vascular health, since these peptides can be incorporated as ingredients in the formulation of functional foods (Mäkinen et al., 2016).

In some studies on *S. torvum*, it has been shown that the aqueous extract of the fruit reduces blood pressure and does not cause toxicity, however there is an evident decrease in body weight when administered in animals without causing death ((Muñoz et al., 2010)). In addition, hepatoprotective effect has been observed in mice, by means of the reduction of acute hepatic lesions by 50%, when treated with the methanolic extract of *S. xanthocarpum* leaves at concentrations of 200 and 400 mg/kg (Gupta et al., 2014).

The use in traditional Mexican medicine of the genus *Solanum* for the treatment of skin and mucosal infections is known, and evidence of therapeutic effects has been found in superficial mycosis caused by fungi and yeast (Otte et al., 2003). Scientific studies have also been carried out regarding the toxic activity of aqueous extract, hydroalcoholic and methanol saponins of *Solanum chrysotrichum*, which have been provided in healthy mice to evaluate the genotoxic and cytotoxic effects, causing amyloidosis and moderate necrosis, steatosis and inflammation in the liver and at kidney level cause focal swelling (Mertz et al., 2010). On the other hand, the antiviral effect of *S. nigrum* seed extract on cells with hepatitis C has been investigated, and it has been demonstrated that chloroform and methanol extracts at non-toxic concentrations inhibit pathologically affected cells (Javed et al., 2011).

Conclusion

The great biodiversity of plants of the Solanaceae family present in Mexico constitute an alternative for the implementation of technological advances, within which the search for methodologies that allow obtaining products with nutraceutical potential, useful in the prevention and/or treatment of human diseases is contemplated. This contributes to the reduction of side effects caused by conventional treatments.

The search for new sources of peptides and proteins, as well as secondary metabolites with potential nutraceuticals, is currently one of the alternatives that will allow the strengthening of human health, at low cost, with high yields because they are substances that have an effect at minimum doses. This represents an area of opportunity for researchers to study this group of plants, and it is of great scientific interest to use agroindustrial residues that are derived from crops for human consumption as a source ofood, which provides an advantage for the care of the environment.

The different peptides and proteins reported in the literature have advantages over conventional treatments to counteract different diseases at once, and can be used in the formulation of products with different biological activities such as antioxidant, antiparasitic, antineoplastic, antidepressant, antifungal, analgesic and anti-inflammatory.

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