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Review

Antioxidant Potential and Known Secondary Metabolites of Rare or Underutilized Plants of Yucatan Region

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Abstract: The screening of rare plants from the Yucatan region and the known native plants in Mexico, that have been successfully introduced worldwide, has been conducted. Based on a literature analysis and a search of English and Spanish scientific information regarding botanical, plant biochemical, and antioxidant potential in databases such as Google Scholar, Scopus, Web of Knowledge, as well as the national databases of Mexico (Flora: Yucatan Peninsula (cicy.mx) and Especies endémicas | Biodiversidad Mexicana), rare or underutilized plants from the Yucatan region with antioxidant potential have been selected. The formulas of the most studied secondary metabolites of these selected rare plants are shown. Among the selected rare plants with antioxidant potential, the families *Sapidaceae* and *Anacardiaceae* had the highest number of representatives. Additionally, representatives from the families *Annonaceae*, *Moraceae*, *Malpighiaceae*, *Solanaceae*, *Ebenaceae*, *Asteraceae*, *Ranunculaceae*, and *Leguminosae* were also presented. The current scientific data analysis of selected rare plants from the Yucatan region, Mexico, provides significant background for their further use and introduction in not only the Yucatan region of Mexico, but also worldwide.

Keywords: bioactive compounds; antioxidant properties; plant natural products; Mayan medicine

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1. Introduction

In the field of plant biology, understanding the role of plant biodiversity in shaping the diverse composition of secondary metabolites across various plant species worldwide holds significant importance. Recent research has been dedicated to exploring the biochemical composition of rare, underutilized plants, and those exhibiting strong adaptive potential in response to specific stresses. Of special interest is discovering the plant biodiversity of Mayan origin and its potential implications on global plant species [1]. Climate change poses a threat to some Mayan plant species, especially those with limited distribution areas, making them particularly vulnerable [2].

The preservation of traditional medicinal knowledge in Mayan culture, especially concerning pharmacologically significant plants, can be inferred from the recognition of useful plant species used in previous centuries. The existing data on the plants used as medicines indicate that various plants in traditional Mayan medicine may impact the neuroprotective pathways of the central nervous system, as well as the serotonin and acetylcholine levels [3]. Rodríguez-García et al. [4] studied the antioxidant, antimicrobial, anti-hyperglycemic, and antihypertensive potential of water extracts from plants originating from the Yucatan coast.

However, the last literature review on rare or underutilized plants in the Mayan region did not provide detailed characteristics or information on the specific secondary metabolites that may be associated with the significant antioxidant potential of these plants. In contrast, there is extensive scientific knowledge available for pre-Columbian domesticated plants such as sunflower (*Helianthus annuus* L.) in Mexico, which has been well studied not only for its use as food, but also for its medicinal properties. While primarily grown for its seeds, which are a nutritious snack, sunflower extracts and oils are used in cosmetics and skincare products. Sunflower oil is rich in vitamin E and essential fatty acids, making it beneficial for skin and hair health [5]. Similarly, *Echinacea purpurea* L. is originally from North America, including parts of Mexico. It is now widespread worldwide, especially in Europe, and is renowned for its high antioxidant potential. Echinacea is widely used for its potential immune-boosting properties. It is believed to help reduce the severity and duration of common colds and upper respiratory infections [6]. Chili peppers (*Capsicum annuum*) are an integral part of Mexican cuisine and culture, used in dishes like salsa and mole. They have also influenced cuisines worldwide and are celebrated for their fiery flavor. Chili peppers are rich in capsaicin, a compound known for its medicinal properties [7]. Additionally, chili peppers are a good source of vitamins and antioxidants, contributing to their potential to boost metabolism and provide cardiovascular benefits. Cassava and sweet potato were among the most important plants in the Mayan region, along with mushrooms, peppers, and various herbs, all playing significant roles in human diets. Some trees were also utilized for construction purposes and herbal medicine. In the past year, there has been a screening of the antioxidant and anti-proliferative properties of underutilized Mexican plants; however, a limited description of the antioxidant compositions of these plant extracts was provided [8,9]. Interest in the antioxidant properties of plants has gained significant momentum in scientific research, owing to the growing awareness of the harmful effects of the free radicals and oxidative stress on human health. Free radicals are unstable molecules that can damage cells and contribute to inflammation, thereby underpinning the development of diseases such as cancer, diabetes, and cardiovascular disorders [8,9].

Focusing on the antioxidant properties of underutilized and rare plants is especially relevant in the context of Mayan-origin biodiversity. These plants are fundamental to the Mayan diet and traditional medicine and represent an invaluable genetic resource that could be at risk due to climate change and biodiversity loss. Moreover, identifying the specific secondary metabolites associated with the antioxidant potential of these plants could offer new avenues for drug and therapy development. Therefore, a multidisciplinary approach could reveal unexplored therapeutic applications and provide conservation strategies for these endangered species. Therefore, this literature analysis aims to describe the current or known data regarding rare or underutilized plants in the Ancient Mayan region, focusing on their phytochemical composition and antioxidant potential.

2. Plants and Plant-Derived Compounds with Antioxidant Potential from Mayan Region

González et al. [10] have described the plant families with the largest number of species of medicinal plants in the Yucatan region. These families are *Leguminosae*, *Euphobiaceae*, *Asteraceae*, *Verbenaceae*, and *Solanaceae*. In contrast, *Pinaceae*, *Rosaceae*, *Rhizophoraceae*, *Simaroubaceae*, and *Rhamnaceae* are the families with a lower number of species containing medicinal plants. On the other hand, *Pinaceae*, *Rosaceae*, *Rhizophoraceae*, *Simaroubaceae*, and *Rhamnaceae* are the families characterized by a smaller variety of species housing medicinal plants. Currently, most botanical descriptions of rare plants from the Yucatan region focus on their antioxidant potential. However, the current work aims to also select the scientific data about the presence of specific biologically active compounds that are responsible for the beneficial effects of selected rare plant species [10].

The selection of rare or underutilized plants from the Yucatan region was based on multiple criteria (Figure 1). We considered plants traditionally used in Mayan medicine and focused on plants native to the region, which are also cultivated in other parts. Hence, we included plants showing the preliminary evidence of an antioxidant potential in previous studies. The literature analysis searched both English and Spanish scientific information on botanical, plant biochemical, and antioxidant potential. The databases used for this search included Scopus, Google Scholar, Web of Knowledge, and the national databases of Mexico (Flora: Península de Yucatán (cicy.mx) and Especies endémicas | Biodiversidad Mexicana). Keywords used in the search were "Mayan plants", "Yucatan", "Mayan medicine", "Antioxidant", "Underutilized", "Metabolites", and "Compounds." The period for the literature search was from 2000 to 2023 to capture the historical context and most of the recent developments in the field.

Figure 1. Selected rare or underutilized plants of Yucatan region. Reproduced with permission from [11].

In Table 1, we have attempted to present plants originally from the Yucatan region that are widespread all over the world, as well as rare Yucatan plants and their plant-derived metabolites with antioxidant potential. It is evident that flavonol quercetin and its isomers are present in all the described selected plant species originating from Yucatan. Furthermore, certain secondary metabolites are unique to specific plant species. For instance, bell pepper (*Capsicum annuum*) contains the terpenoid capsidiol, purple coneflower (*Echinacea purpurea*) possesses cyclic monoterpene α-phellandrene, and *Helianthus annuus* yields the sesquiterpene α-copaene. Notably, copaene has demonstrated antioxidant activity, as well as cytotoxic and genotoxic/antigenotoxic effects on human lymphocyte cultures, as observed in [12].

Among the chosen specific plant-derived compounds presented in the selected plant species of the Yucatan region, we would like to highlight the high presence of phenolic acids, terpenes, and terpenoids. β-eudesmol, a sesquiterpenoid found in *Annona purpurea* Moc. & Sessé ex Dunal, is of special scientific interest [13]. *p*-Hydroxybenzoic acid, a phenolic acid from *Brosimum alicastrum*, is known for its antioxidant and anti-inflammatory potential [14,15]. The selected specific metabolites, along with their formula specifications, are presented in Figure 2.

Table 1. Plants and plant-derived compounds with antioxidant potential from East North America region origin.

Plant Species	Family	Plant Part	Terpenes Terpenoids	Phenolic Acids	Alkaloids	Flavonoids Flavones	Coumarins	References
Achras sapota (Sapodilla)	*Sapidaceae*	stem, leaves, fruit	present (not specified)	present (not specified)	present (not specified)	dihydromyricetin, quercitrin, myricitrin, catechin, epicatechin, gallocatechin	present (not specified)	[16–19]
Annona purpurea Moc. & Sessé ex Dunal (Sancoya)	*Annonaceae*	leaves, pulp, seeds	β-eudesmol, α-eudesmol	present (not specified)	Norpurpureine 7-formyl-dehydrothalicsimidine 8-7-hydroxy-dehydrothalicsimidine N-methyllaurotetanine N-methylasimilobine Lirinidine Thalicsimidine Purpureine 3-hydroxyglaucine Annomontine Annopurpuricins A-D	present (not specified)	present (not specified)	[20–22]
Astronium graveolens (Gateado)	*Anacardiaceae*	leaves	lupeol	3-*O*-caffeoylquinic, 5-sinapoylquinic, 1,2,3,4,6-Penta-*O*-galloyl-D-glucopyranose		quercetin 3-*O*-glucoside, quercetin 3-*O*-rhamnoside	-	[23]
Brosimum alicastrum swartz (Ramon)	*Moraceae*	leaves, seeds, bark	-	Gallic, chloro genic, vanillic, sinapic, ferulic, *t*-cinnamic, coumaric, caffeic acid, *p*-hydroxibenzoic, *m*-hydroxybenzoic acids	-	Quercetin, catechin, epicatechin, catechin gallate, syringetin, Kaempferol−*O*−dihexoside, Isoquercetin	Xanthyletin, luvangetin, 8-hydroxyxanthyletin	[24–26]
Byrsonima bucidaefolia (Sak Pah)	*Malpighiaceae*	leaves	-	Methyl gallate, methyl-*m*-trigallate	-	-	-	[27]
Capsicum annuum (Bell pepper)	*Solanaceae*	fruit	capsidiol	cinnamic acid	capsaicinoids	quercetin, luteolin, caffeoyl, cinnamoyl glycosides, apigenin	coumaric acid coumaroyl	[28–30]

Table 1. *Cont.*

Plant Species	Family	Plant Part	Terpenes Terpenoids	Phenolic Acids	Alkaloids	Flavonoids Flavones	Coumarins	References
Cnidosfolus aconitifolius IM. Jonst (Chaya)		leaves	α y β amyrin, borneol, hederaginin, oleanolic acid, squalene, lupeol acetate	ellagic, ferulic, *p*-coumaric, caffeic, protocacheuic, vainillic, chlorogenic, caftaric, *p*-hidroxibenzoico, coutaric, syringic, synaptic acids	choline, trigonelline, nicotinic acid, palmatine, sitsirikine, Dihydrositsirikine, vinblastine, vindoline, catharanthine, vinleurosine	kaempferol, quercetin, rutin, catechin, hesperidin, narigenin, kaempferol, procuanidin B1, catechin, procyanidin B2, rutin, gallocatechin gallate, epigallocatechin gallate, epicatechin-3-*O*-gallate, quercetin-3-*O*-galactoside, quercetin-3-*O*-glycoside, quercetin-3-*O*-rhamnoside, trans-resveratrol	-	[31–34]
Cordia dodecandra DC. (Circote)	*Sapidaceae*	fruit	-	caffeic acid, rosmarinic acid, caffeoyl hexoside	-	Rutin, Quercetin 3-*O*-rutinoside, lutein	-	[35–37]
Diospyros digyna Jacq. (Black sapote)	*Ebenaceae*	fruit, pulp, peel, seeds	-	Cinnamic, *p*-hydroxybenzoic, Caffeic, Sinapic, Ferulic, *O*-Coumaric, Protocatechuic, Chlorogenic, Isochlorogenic	-	Catechin Epicatechin Myricetin Gallocatechol Epigallocatechin, rutin, Myricetrin, Isohermetin, Kaempherol-4′-glucoside, Quercetin, Dihydromyricetin, Cynaroside	-	[38,39]
Echinacea purpurea (Purple coneflower)	*Asteraceae*	whole plant	α-phellandrene, camphene, limonene	present (not specified)	pyrrolizidine alkaloids tussilagine and isotussilagine	quercetin, kaempferol, isorhamnetin	Coumaric acid	[40–44]
Helianthus annuus (Common sunflower)	*Asteraceae*	seeds	α-copaene, bornyl acetate, β-elemene, β-selinene, germacrene-D	present (not specified)	present (not specified)	kaempferol, apigenin, dihydroflavonol, daidzein, biochanin A, formononetin, luteolin, quercetin	*p*-coumaroyl	[45–47]

Table 1. *Cont.*

Plant Species	Family	Plant Part	Terpenes Terpenoids	Phenolic Acids	Alkaloids	Flavonoids Flavones	Coumarins	References
Parmentiera aculeata (H.B. & K.) Seeman (Cucumber kat)	*Bignoniaceae*	fruit	Lactucin-8-*O*-methylacrylate	present (not specified)	present (not specified)	-	present (not specified)	[48,49]
Pouteria campechiana (H.B. & K) Baehni (Canisté)	*Sapidaceae*	fruit, leaves, seeds, bark	Corsolic acid, euscaphic acid, fatty acid ester of betulinic acid, fatty acid ester of oleanolic acid, maslinic acid, ursolic acid, lucumic acid A, lucimic acid B, 4(R),23-epoxy-2α,3α,19α-trihydroxy-24-norurs-12-en-28-oic acid, 2α,3α,19α,23-tetrahydroxy-13α,27-cyclours-11-en-28-oic acid, 2α, 3α, 19α, 23 tetrahydroxyursolic acid, 2α,3*β*,19α-trihydroxy-24-norursa-4(23),12-dien-28-*O*-ic acid, 3*β*, 28-dihydroxy-olean-12-enyl fatty acid ester	Caffeic, ferulic, gallic, protocatechuic, vanillic, *p*-coumaric acid	-	Apigenin, catechin, epicatechin, gallocatechin, kaempferol, luteolon, myricetin, myricitin, myricetin-3-*O*-α-L-rhamnoside, myricetin-3-*O*-*β*-galactoside, quercetin, rutin, myricetin 3-*O*-α-rhamnopyranoside, quercetin 3-*O*-α-rhamnopyranoside, quercetin 3-*O*-*β*-rhamnopyranoside, quercetin 3-*O*-*β*-arabinopyranoside, taxifolin 3-*O*-arabinofuranoside, taxifolin 3-*O*-α, rhamnopyranoside	-	[50]

Table 1. *Cont.*

Plant Species	Family	Plant Part	Terpenes Terpenoids	Phenolic Acids	Alkaloids	Flavonoids Flavones	Coumarins	References
Pithecellobium dulce (Roxb) Benth (Dziuche)	*Leguminosae*	seeds	(−)-19*β*-D-glucopyranosyl-6,7-dihydroxykaurenoate	Caffeic acid, chlorogenic acid, ferulic acid, gallic acid, *p*-coumaric acid, protocatechuic acid,	-	apigenin, catechin, daidzein, kaemferol, luteolin, quercetin, myricetin, naringin and rutin	-	[51,52]
Spondias purpurea L.	*Anacardiaceae*	leaves	spathulenol, linolenic acid, *t*-caryophyllene, *α*-muurolene	caffeic acid	-	epigallocatechin	-	[53,54]

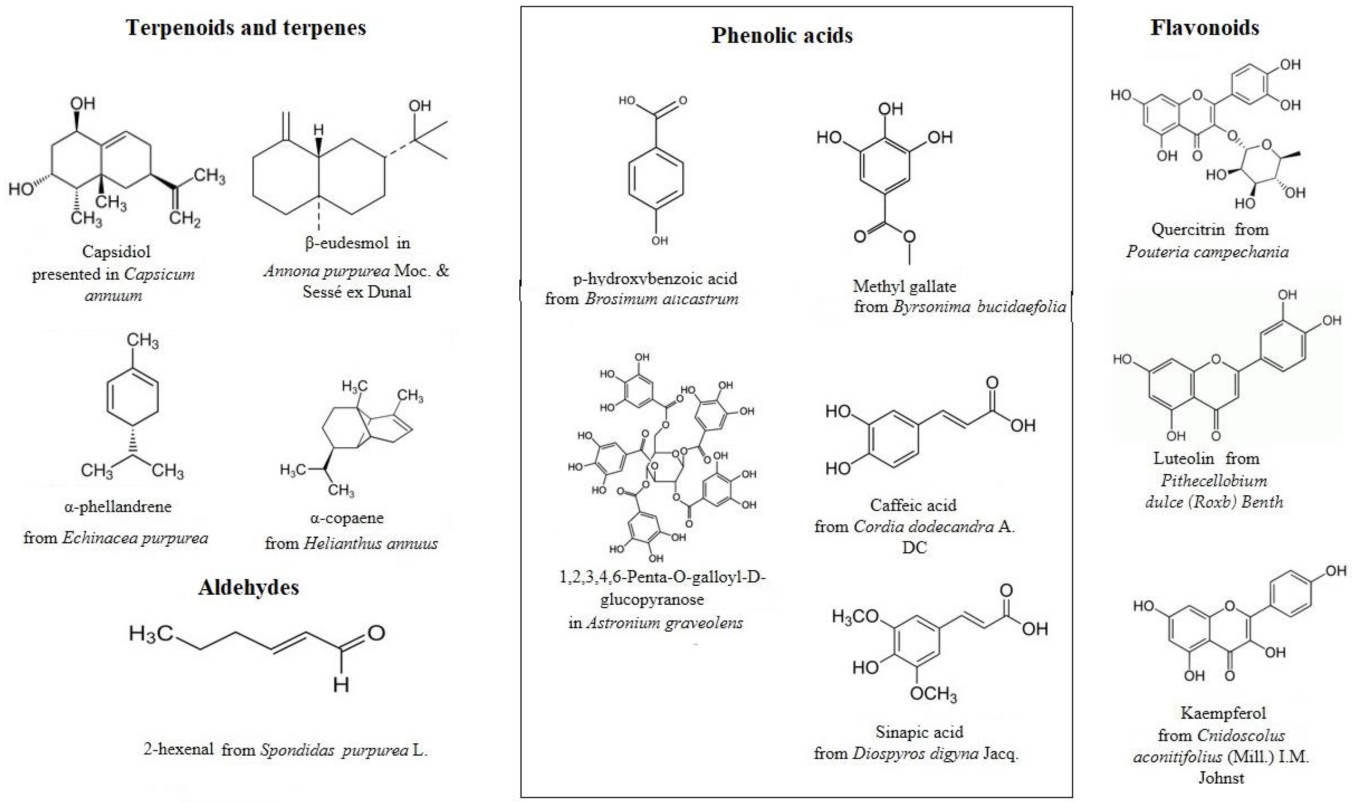

Figure 2. Some specific secondary metabolites of the selected plant species of Yucatan region.

Figure 2 presents the secondary metabolites that were identified; however, there is a need for a more comprehensive investigation of the other known classes of natural products. Particularly noteworthy among the phenolic acids identified in the selected plant species from the Yucatan region is the significant content of sinapic acid found in *Diospyros digyna* Jacq. Sinapic acid is known for its various beneficial properties, including antioxidant, anti-inflammatory, anticancer, neuroprotective, antimutagenic, anti-glycemic, and antibacterial functions [55]. Another phenolic acid known for its antioxidant potential is echinacoside, derived from *Echinacea purpurea.* Additionally, a significant level of caffeic acid from *Cordia dodecandra* has been confirmed, which has demonstrated anticarcinogenic properties [56] and antioxidant potentials [37].

Among the flavonoids found in substantial levels in the selected plants of the Yucatan region, we have kaempferol from *Cnidoscolus aconitifolius* (Mill.) I.M. Johnst, quercitrin from *Pouteria campechania*, and luteolin from *Pithecellobium dulce* (Roxb) Benth. Notably, luteolin, a flavonoid, is of special interest due to its multiple cardioprotective effects [57], as well as its antioxidant, anticancer, and anti-inflammatory effects [58].

3. Description of Rare or Underutilized Plants of Mayan Region

3.1. Achras sapota L.

The *Sapotaceae* family includes a plant known as sapota, scientifically named *Achras sapota* L. (also known as *Manilkara achras* or *Manilkara zapota*). *A. sapota* is renowned for its delightful and nutritious attributes, characterized by a soft, sweet pulp with a granulated texture and an enticing aroma [58–61]. Originally from southern Mexico, *A. sapota* has spread beyond its country of origin to the other nations with tropical and subtropical climates. The fruit of *A. sapota* is classified as a succulent berry, displaying various shapes such as ellipsoidal, conical, and oval, and it typically contains one or two glistening black seeds. The pulp, concealed beneath the skin, exhibits an array of colors, ranging from yellowish and light brown to red hues [59,60,62].

Apart from being a nutritious food, *A. sapota* holds high regard in traditional medicine. Moreover, an infusion of young fruits is believed to relieve respiratory ailments, and consuming the fruit soaked in melted butter is thought to ward off biliousness and fever. Furthermore, *A. sapota* is rich in diverse bioactive compounds, predominantly including ellagitannins, gallotannins, phenolic acids, and flavonoids (such as anthocyanins and flavanols), making it a great natural laxative [59].

A. sapota is abundant in sugars, comprising 12–18% of the fruit, and contains dietary fiber (2.6%) and protein (0.7%). It is a fantastic source of ascorbic acid (6 mg/100 g) and is laden with minerals like calcium, phosphorus, and iron, with 28, 27, and 2 mg/100 g, respectively [63]. This rich phytochemical makeup, present in both its edible and non-edible parts, positions *A. sapota* as a fruit with immense potential for pharmacological applications through various biological activities [62].

A. sapota naturally possesses a high concentration of antioxidants present in its various parts, including flavonoids, phenolic compounds, and polyphenols, particularly the fruit, peel, and leaves [60,64]. Aguirre Crespo et al. [65] discovered that *A. sapota* methanolic extracts exhibited the most potent antioxidant effect among various medicinal plants in Mexico. Similarly, Rodríguez-García et al. [4] confirmed the superior free radical scavenging activity of *A. sapota* leaves compared to the other native plants in Yucatan, Mexico.

The antioxidant properties of *A. sapota* fruit are influenced by its ripeness, with mature fruits showing the highest levels of antioxidant enzymes such as SOD (superoxide dismutase), ascorbate peroxidase, glutathione reductase, and peroxidase, especially in the peel [66]. *A. sapota* leaves also possess significant antioxidant activity, as noted by Islam et al. [61], who reported IC_{50} values of 7.93 and 72.85 μg/mL for the DPPH and ABTS scavenging activities, respectively. *A. sapota* leaf extract exhibited a 49.94% β-carotene bleaching inhibition and a 93.61% DPPH radical scavenging ability. Karle and Dhawale [59] highlighted the efficacy of *A. sapota* fruit peel extract in scavenging the DPPH and H_2O_2 radicals. The ethanolic extract of *A. sapota* peel exhibited an 88.42% inhibition at 1 mg/mL for the H_2O_2 radicals, while the acetone extract showed even better results.

Upon analysis, *A. sapota* peel was found to contain a significant amount of quercetin, reaching 49.1 mg per 100 g, along with gallic acid (27.5 mg/100 g), catechin (43.3 mg/100 g), and kaempferol (51.2 mg/100 g) [67]. What is particularly noteworthy is that compared to other vegetables and fruits, *A. sapota* peel stands out as having the highest level of quercetin, surpassing even banana peel. This highlights the importance of *A. sapota* peel as a rich source of quercetin ($C_{15}H_{10}O_7$) [68].

3.2. Annona purpurea Moc. & Sessé ex Dunal

Annona purpurea Moc. & Sessé ex Dunal, also called "Soncoya", is a tiny tree species that is indigenous to the tropical and subtropical parts of the Americas and is a member of the *Annonaceae* family. Its distribution spans from southern Mexico to northern Argentina and includes Central America, the Caribbean Islands, and northern South America [69,70]. This bushy tree's fruits are highly valued for their rich taste and significant nutritional content, including a good source of fiber (11.91%) and protein (7.32%). In addition to its edible fruits, the other parts of the tree are employed in traditional medicine, and the wood is used in paper manufacturing.

For instance, fever, chills, and jaundice can all be treated with fruit juice, while a decoction of the inner bark is prescribed for dysentery and edema [71]. This traditional use is supported by its high content of bioactive secondary metabolites such as acetogenins, flavonoids, terpenes, and benzylisoquinoline alkaloids, which confer anti-inflammatory and antispasmodic properties to the plant. The principal compounds identified in *A. purpurea* were alkaloids such as aporphine, anonamine, isomuricarpin, isoannonacin, and liriodenine. These compounds have effects such as anxiolytic or antiplaque actions [21]. However, Munoz-Acevedo et al. [20] reported that the essential oil of seed extract from *A. purpurea*, which is mainly composed of β-eudesmol ($C_{15}H_{26}O$) (68.9%), exhibited antioxidant activity via the ATBS method (165 mmol Trolox/kg).

3.3. *Astronium graveolens Jacq.*

Astronium graveolens Jacq is a tropical dioecious tree belonging to the *Anacardiaceae* family, commonly known as "Gateado", "ron ron", "palo culebro", or "jobillo." It naturally grows in riparian habitats from Mexico through Central America and South America [72]. The small unisexual flowers have five green-yellow petals and are grouped in 10–25 cm long panicles. Female trees produce single-seed fruits that are drupe-like wind-dispersed nuts. The roots and bark of *Astronium* species are used in folk medicine to treat allergies, inflammation, diarrhea, and ulcers [23].

Antioxidant activity was demonstrated in the extracts of *A. graveolens* leaves, prepared via successive extraction using solvents of increasing polarity (n-hexane, chloroform, and methanol). The methanol extract showed significant activity ($p < 0.05$) in the concentration-dependent, free radical scavenging (DPPH). Among the six isolated compounds, 1,2,3,4,6-penta-*O*-galloyl-D-glucopyranose ($C_{41}H_{32}O_{26}$) was found to be the most active, exhibiting high efficiency in the DPPH radical scavenging (EC_{50} = 2.16 μg/mL). Additionally, a methanol extract of *A. graveolens* at 3 mg/mL showed an 85% inhibition of the free radicals via the DPPH method [73].

3.4. *Brosimum alicastrum Swartz*

Brosimum alicastrum, an evergreen tree species in the *Moraceae* family, is also known as "ramon". It is native to the Americas, stretching from southern Mexico to Brazil and Peru [74]. The fruit of *B. alicastrum* has a sweet taste and contains a seed referred to as a Mayan nut, which was historically used as a subsistence food by the ancient Maya. Traditionally, this tree has been used to treat diabetes, asthma, and bronchitis [75].

The seeds of *B. alicastrum* contain 10.49% fat, 5.21% crude fiber, and 2.02% crude protein, as well as minerals such as copper, potassium, iron, zinc, and sodium [75]. Several phenolic compounds, including gallic acid, *p*-hydroxybenzoic acid, vanillic acid, caffeic acid, and *p*-coumaric acid, have been identified for their antioxidant activity [75–77].

Previous studies have reported high antioxidant activity in *B. alicastrum* seeds with values of 2.04, 68.18, and 10.95 μM TEAC/g, according to the DPPH, ABTS, and FRAP methods, respectively [78]. Gullian and Terrats [79] conducted a study to optimize the content of bioactive compounds in *B. alicastrum* leaves by varying parameters such as the temperature and sonication power. They found that the highest antioxidant activity occurred at low temperatures (28 °C), with the extraction times being less than 20 min and a higher sonication power being exhibited (74 W/cm^2). Under these conditions, DPPH activity reached 65.74 μmol TEAC/g, which was twice the ABTS activity (38.79 μmol TE/g) measured at the point of maximum desirability.

Subria-Cueto et al. [75] reported antioxidant activity values of *B. alicastrum* seed meal with values of 0.9, 14.3, and 0.41 mmol TEAC/100 g for DPPH, ABTS, and FRAP, respectively. Ozer [77] found that the percentages of the DPPH and ABTS scavenging activity were 79% and 92.55%, respectively, at 400 μg/mL, and the FRAP value was 22.64 mmol Fe^{2+}/100 g per sample. The authors suggested that *p*-hydroxybenzoic acid ($C_7H_6O_3$) (326.2 μg/g) could be the main contributor to the antioxidant activity.

3.5. *Byrsonima bucidaefolia Standl*

Byrsonima bucidaefolia Standl, known as "sakpah" and "sak bo'ob" in the Yucatan Peninsula, is a native plant belonging to the *Malpighiaceae* family. In traditional medicine, this species is used to treat asthma, fever, and skin infections [27]. *Byrsonima* species have been found to produce bioactive compounds such as saponins, flavonoids, tannins, and triterpenes, which exhibit various biological properties, including fungicidal, antibacterial, and cytotoxic activities [80]. An ethanolic extract (50%) of *B. bucidifolia* fruits has been shown to possess antioxidant activity of 0.159 (mg Trolox/g DW) for FRAP and an EC_{50} value > 0.60 mg/mL for DPPH [81]. Notably, *B. bucidifolia* contains active metabolites like methyl gallate ($C_8H_8O_5$), which significantly contributes to the DPPH free radical scavenging. Both compounds exhibited more potent antioxidant activity than vitamin C (6.5 μg/mL), with an EC_{50} of 0.9 μg/mL [27].

3.6. *Capsicum annuum*

Capsicum annuum L., commonly known as bell peppers, holds a prominent position within the *Capsicum* genus, which is part of the economically significant *Solanaceae* family. Native to Mexico and Northern Central America, *C. annuum* is notably versatile as an annual or biennial herbaceous plant, allowing it to adapt to various growing seasons and conditions [82,83]. The bell pepper, the fruit of *C. annuum*, is notably large and fleshy, with a distinct quadrangular shape. Its size and weight can vary, typically ranging from 100 to 500 g. One captivating feature of *C. annuum* is its diverse spectrum of colors, including red, green, orange, and yellow. This variation in hue is due to the different stages of ripeness and the fruit's ability to synthesize pigments such as chlorophylls and carotenoids [82,83]. The nutritional composition of *C. annuum* predominantly comprises water and carbohydrates, with low levels of proteins (1.30%) and fat (0.30%). Moreover, its substantial dietary fiber content (2.10%) categorizes it as a high-fiber food. *C. annuum* is also a rich source of vitamins, including A (300 mg), C (128 mg), B_{12} (0.45 mg), and others. In terms of minerals, *C. annuum* is endowed with potassium (234 mg), sodium (58 mg), magnesium (12 mg), and phosphorus (26 mg) [84].

Studies have demonstrated the various beneficial properties of *C. annuum*, such as antidiabetic, anti-inflammatory, immunomodulatory, antibacterial, and antioxidant effects. The antioxidant activity is influenced by the bioactive substances present in *C. annuum* [84, 85]. For instance, Park et al. [86] reported that methanolic extracts from orange peppers showed the greatest antioxidant effect via the ABTS test (880 μmol TE/g). Green peppers exhibited the most potent antioxidant capacity according to the DPPH assay (1153 μg/mL) and its SOD-like activity (IC_{50} = 1472 μg/mL). Thupairo et al. [85] studied the effect of solvent extraction on antioxidant qualities and found that aqueous–ethanol extraction yielded the greatest antioxidant activity of 25.15, 30.15, and 61.96 μmol TE/g via the DPPH, FRAP, and ORAC tests, respectively. Green peppers displayed the highest activity due to the higher phenolic content and ascorbic acid.

Chávez-Mendoza et al. [86] demonstrated that the ethanolic extracts of grafted *C. annuum* have antioxidant activities dependent on the cultivar, color, concentration, and type of bioactive compound. Red *C. annuum* exhibited the highest activity (79.65%) according to the DPPH test due to its higher phenolic and β-carotene content. Yellow *C. annuum* extract exhibited the highest antioxidant effect (IC_{50} of 3267 μg/mL) via the DPPH assay [87]. However, yellow *C. annuum* had the highest antioxidant activity (80% via the DPPH assay) [88]. Phenolic fractions of *C. annuum* exhibited higher antioxidant activities using the ABTS and DPPH tests compared to the oily fractions [89].

Seed extracts of *C. annuum* exhibited a higher antioxidant activity than the pulp extracts, which is associated with a higher total phenolic content. They reported that the seed extracts showed the highest antioxidant capacity (11.32, 89.25, and 9.94 μmol TE/g via the DPPH, ABTS, and FRAP methods, respectively) compared to the pulp extracts (2.28, 17.17, and 3.99 μmol TE/g, respectively) [90]. Yellow *C. annuum* displayed the highest antioxidant activity in the DPPH and ABTS methods, while green *C. annuum* excelled in the FRAP method [91]. The lipophilic fraction of orange *C. annuum* exhibited the greatest antioxidant activity using the ABTS test compared to the red and yellow ones [92]. In *C. annuum* fruits, several compounds, such as capsidiol ($C_{15}H_{24}O_2$), a bicyclic sesquiterpene produced by *Solanaceae* in response to fungal pathogens, have been shown to decrease the NO levels induced by IFN-γ and IL-6, regulating oxidative stress and inflammation [93].

3.7. *Cnidoscolus aconitifolius (Mill.) I.M. Johnst*

Cnidoscolus aconitifolius (Mill.) I.M. Johnst, commonly known as "chaya", is a large, fast-growing evergreen shrub belonging to the *Euphorbiaceae* family. This family comprises trees, shrubs, and herbs of pantropical distribution and contains 317 genera and approximately 8000 species. Some of these species are included in the genus *Cnidoscolus*, which encompasses about 70 species [94–96]. In Mesoamerica, *C. aconitifolius* was extensively cultivated and used by the Mayan culture as a daily vegetable. Although it is still used as an ingredient in traditional dishes, its consumption in its simple form is negligible, and it is more appreciated for its herbal remedy properties [94–96].

C. aconitifolius is rich in nutrients, containing high levels of minerals such as calcium, iron, potassium, ascorbic acid, and β-carotene. In addition to its high nutritional content, *C. aconitifolius* has a diverse phytochemical composition, with compounds such as flavonoids, cyanogenic glycosides, saponins, anthraquinone steroids, tannins, phenols, alkaloids, and oxalates [95,97]. These compounds are biologically active and can prevent or treat diseases. Several studies in animal models have evaluated their biological effects against various conditions, revealing antidiabetic [98], antithrombotic [99], hepatoprotective [100], nephroprotective [100], anti-inflammatory [101], and antioxidant [101] effects.

The antioxidant potential of *C. aconitifolius* has been investigated in several studies using various techniques and extract types. An ethyl acetate extract of *C. aconitifolius* reported an 11.6% inhibition of the DPPH radicals and 387.1 µmol Fe/L via FRAP [102]. Valenzuela et al. [103] infused *C. aconitifolius* and determined that the antioxidant capacity was 5.9 mM Trolox equivalents per mL of infusion. Ramos-Gómez et al. [32] used an aqueous extract and observed 25.5, 44.3, and 38.5 µg/mL antioxidant capacities via the DPPH, ABTS, and NO (nitric oxide) methods, respectively. Additionally, *C. aconitifolius* leaves exhibited a 45.5% inhibition in the DPPH test and 95% in the ABTS test [104]. An amount of 34.38 µmol of Trolox equivalents per gram of the methanolic extract of *C. aconitifolius* was obtained [94].

3.8. *Cordia dodecandra*

The "ciricote" tree, scientifically known as *Cordia dodecandra* A. DC., is native to the Yucatan Peninsula. It is cultivated as a shade and decorative plant in the medium-sized jungles of Southeast Mexico, as well as in green metropolitan neighborhoods and rural villages. The primary product derived from this species is its highly prized wood [105]. On a small scale, the fruit of *C. dodecandra* is prepared and consumed as an artisanal treat. The pulp of *C. dodecandra* is rich in nutrients, with 76.96% carbohydrates, 8.08% fiber, 7.28% protein, 5.06% ash, and 2.62% fat. It also contains significant levels of potassium (58,926.1 mg/kg) and calcium (11,302.2 mg/kg). Carotenoids such as lutein and β-carotene can also be found in *C. dodecandra* [37]. The bark is used as a decoction for the treatment of diarrhea and dysentery, while the leaves or a combination of leaves and bark are used for treating asthma, bronchitis, and cough [35]. However, traditional native fruits like *C. dodecandra* are currently facing a loss in biological variety due to neglect, resulting in their underutilization [106].

Reports indicate that both the fruits and peels of *C. dodecandra* contain promising amounts of bioactive substances and exhibit antioxidant qualities. In a research study, phenolic compounds were extracted from *C. dodecandra* fruit at various stages of maturity and from different regions of the fruit using ultrasound-assisted extraction. Semi-ripe *C. dodecandra* peels showed the highest antioxidant activity (122.09 µTrolox/g, via the DPPH method) and the highest content of phenolic compounds (19.93 mg GAE/g DW). On the other hand, an aqueous–ethanolic extract exhibited higher DPPH (50.04 mM TE/g) and ABTS (31.84 mM TE/g) activity [37]. The main phenolic compounds in *C. dodecandra*, identified via UPLC-DAD-ESI-MS/MS, were quantified as caffeic acid, rutin, and rosmarinic acid and distributed as 45.82%, 41.45%, and 12.72%, respectively. The antioxidant effects were mainly associated with caffeic ($C_9H_8O_4$) and rosmarinic acids [36].

3.9. *Diospyros digyna Jacq.*

Diospyros digyna Jacq., commonly known as the "black sapote" or "tauch", is a tropical fruit native to Mexico and Central America. It has long been prized for its nutritional properties. Rich in vitamins A and C, *D. digyna* also contains dietary fiber, calcium, phosphorus, magnesium, and potassium [39]. Despite its numerous health benefits, some people may find the texture and taste of *D. digyna* unappealing. It has a soft, custard-like consistency and a mild flavor that is often compared to chocolate pudding or pumpkin pie filling. However, others enjoy the unique taste and use it in various culinary applications [39,107–109].

The ethanolic extracts of different *D. digyna* parts (pulp, peel, and seeds) showed antioxidant activity with a means of 3.64, 7.88, and 4.26 mmol TE/100 g FW in the ABTS, DPPH, and FRAP tests. Also, the effect of *D. digyna* on antioxidant enzymes such as SOD (superoxide dismutase), GPx (glutathione peroxidase), and CAT (catalase) acting on the superoxide radicals and hydrogen peroxide was evaluated. *D. digyna* extracts in HepG2 cells showed a 47% inhibition of MnSOD, 27% of CuZnSOD, 49% of GPx, and 62% of CAT. These findings suggest that black sapote phytochemicals may participate in cellular antioxidant protection by eliminating ROS (reactive oxygen species) and stimulating the activation of the adaptive response in which antioxidant enzymes are involved [109].

The pulp of this fruit is a rich source of polyphenols; in particular, sinapic acid and proanthocyanidins. On the other hand, the peel and seeds, considered waste products, also showed an interesting phytochemical composition, thanks to fumaric and sinapic acids. The most representative compound in black sapote extracts was sinapic acid ($C_{11}H_{12}O_5$), reaching 17%, 22%, and 11% of the total compounds identified in the peel, pulp, and seeds, respectively. This compound showed several biological properties, including antioxidant, anti-inflammatory, anticancer, and antibacterial activity [110].

3.10. *Echinacea purpurea (Purple coneflower)*

Echinacea purpurea, commonly known as Purple Coneflower, is a species of flowering plant in the *Asteraceae* family native to North America. Native Americans in eastern North America recognized its medicinal properties [111]. Later, *E. purpurea* was introduced to Europe and other parts of the world. Around 1880, the premier *E. purpurea* drug establishment known as Meyers Blood Purifier entered the pharmaceutical market. This product was known for its effects against rheumatism and neuralgia. In the early 20th century, *E. purpurea* was one of the most popular plants used for pharmaceutical drug preparation in the USA. The commercial cultivation of *E. purpurea* began in Germany around 1939, focusing on *E. purpurea* [111].

Biochemists and pharmacologists became interested in *E. purpurea* extracts due to the presence of specific polysaccharides, ketoalkenes, and alkylamides [41]. The major compounds identified included caffeic acid, caftaric acid, cichoric acid, echinacoside, and alkylamides [112]. Echinacoside ($C_{35}H_{46}O_{20}$) was found to have various pharmacologically important benefits on human health, particularly in terms of neuroprotective and cardiovascular impacts [113]. Echinacoside is a caffeic acid derivative found at a concentration of 1.45% in the flower of *E. purpurea* [114]. In addition to these substances, *E. purpurea* species also contain flavonoids, terpenoids, polyacetylenes, and alkaloids [112,115]. Among the flavonoids identified were quercetin, kaempferol, and isorhamnetin [41]. Specifically, the alkaloids require further detailed study.

3.11. *Helianthus annuus*

Helianthus annuus, commonly known as sunflower, is believed to have originated in North America, covering the US and southern Canada. Research has revealed evidence of the domesticated sunflower as early as 2600 cal. BC, in the archaeological region of Tabasco, Mexico. Notably, wild sunflower seeds discovered in Tabasco are much larger compared to those found in other North American archaeological sites [5]. In the last century, the large-scale production of wild sunflowers shifted to Eastern Europe, particularly in Russia and Ukraine. By 2020, these two countries collectively contributed to more than half of the global sunflower seed production, as reported in reference [116]. Although sunflowers are not native to the Yucatan region and are not classified as rare plants, we have opted to include them as an illustrative example of a successful introduction and cultivation on a global scale.

The seeds of the common sunflower have been found to contain flavonoids, alkaloids, terpenoids, phenolic acids, and *p*-coumaroyl. Among the identified flavonoids are kaempferol, apigenin, dihydroflavonol, daidzein, biochanin A, formononetin, luteolin, and quercetin [45–47]. The terpenoids present include α-copaene ($C_{15}H_{24}$), bornyl acetate, β-elemene, β-selinene, and germacrene-D [45,47].

3.12. *Parmentiera aculeata*

Parmentiera aculeata, commonly known as "cucumber kat" or "cuajilote", belongs to the genus *Parmentiera* in the *Bignoniaceae* family. This genus includes various plants native to Central America, particularly Mexico, Guatemala, Honduras, Costa Rica, Belize, El Salvador, and Nicaragua; it has also naturalized in northern Australia [41]. *P. aculeata* is a small- to medium-sized evergreen tree, growing taller than 10 m, with a short, thick trunk. Its fruit is subcylindrical, sail-shaped, short, and plump, measuring 10–12 cm in length. The fruit is indehiscent, ribbed, and often pointed, slightly curved, greenish-yellow to dull yellow, and waxy [41]. Additionally, the fruit of *P. aculeata* contains a high percentage of protein (6.5%) and crude fiber (3.9%), which may be beneficial for human health [116].

In traditional Mexican medicine, the fruit, root, and bark of *P. aculeata* are recognized as treatments for diabetes and kidney diseases, as well as for headaches, gallstones, deafness, and diarrhea [117]. Studies have confirmed the plant's hypoglycemic activity using the chloroform extracts from *P. aculeata* on alloxan-induced diabetic mice, leading to decreased blood glucose levels [118]. Aqueous and methanol extracts of *P. aculeata* have shown antioxidant effects on the DPPH and ABTS radicals, with values up to 70.09% and 67.60%, respectively [116]. Moreover, the ethanolic extracts of mature pulp have exhibited the highest antioxidant activity via ABTS (0.087 µg TE/mL) compared to seeds and pulps of the other ripening stages of *P. aculeata* [119]. In another study, a guaianolide compound, lactucin 8-*O*-methyl acrylate ($C_{19}H_{20}O_6$), was isolated from the chloroform extract of the dried fruits of *P. aculeata* [49].

3.13. *Pouteria campechiana (H.B. & K) Baehni*

Pouteria campechiana, also known as "canisté", is an evergreen tree native to and cultivated in southern Mexico, Guatemala, El Salvador, and Belize. Growing up to 10 m tall, it produces yellow-orange fruits that are raw edible and sometimes referred to as a yellow sapote, measuring up to 7 cm in length. The flesh of *P. campechiana* fruit has a delicious texture reminiscent of a hard-boiled egg yolk. The fruit is a rich source of nutrients, including fat (4.97%), dietary fiber (2.12%), protein (1.16%), and vitamins C (105.82 mg) and A (51.15 mg) [50,120,121]. The methanolic extract of *P. campechiana* fruit exhibited antioxidant activity with 0.43 mM and a 73.32% scavenging activity, as determined via the FRAP and DPPH analysis, respectively [122]. In the DPPH test, *P. campechiana* fruit showed a 92.15% inhibition [122]. Additionally, *P. campechiana* extract demonstrated an antioxidant capacity of 87.21 mg AEAC/100 g, as determined via DPPH [123].

Studies have looked at various parts of *P. campechiana* fruit, and some have found no significant difference in the antioxidant capacity between the pulp, peel, and seed extracts when extracted with 70% ethanol [124]. However, another study reported that the seeds exhibited the highest antioxidant potency, followed by the leaf, peel, and pulp [125]. The bark extract of *P. campechiana* showed high antiradical activity in several antioxidant assays, including ABTS, DPPH, hydroxyl radical scavenging, and superoxide radical scavenging [126]. The antioxidant potential and total phenolic and flavonoid contents in *P. campechiana* fruit correlated significantly.

The main phytochemical constituents isolated from *P. campechiana* include flavonoids, carotenoids, stilbenes, phenolic acids, triterpenes, glycosides, sterols, alkanes, and volatiles. In total, 189 compounds have been identified in the plant, with volatile compounds and essential oils being the most prominent [50]. Phenolic compounds, such as flavonoids, phenolic acids, stilbenes, coumarins, and tannins, are known for their role as free radical scavengers, reducing agents, and singlet oxygen scavengers. Among these compounds, quercitrin ($C_{21}H_{20}O_{11}$) may be particularly relevant to the antioxidant properties of *P. campechiana*, as it has been reported in higher proportions compared to other compounds [126].

3.14. *Pithecellobium dulce (Roxb) Benth*

Pithecellobium dulce (Roxb) Benth, originally from the tropical regions of the Americas, is a tree species belonging to the *Leguminosae* family and is widely present in Mexico. In rural areas, it is commonly known as "guamuchil", and it has also been found in various parts of Asia, especially in India [52]. The tree is characterized by its evergreen leaflets, usually in pairs, and its bark, which has a rough texture and a grayish color. One of the remarkable features of *P. dulce* is its pods, which are green and red with a twisted shape. Inside these pods, there are 5 to 12 white and pink arils, each enclosing black seeds. The seeds can be ground into flour, which is rich in proteins (32.9%), and essential minerals such as copper, iron, magnesium, phosphorus, potassium, and zinc [127]. Due to its pharmacological benefits, *P. dulce* is known for its analgesic, antidiarrheal, anti-inflammatory, antiulcer, antibacterial, hypoglycemic, antioxidant, and hepatoprotective actions, making it a potent treatment for gastrointestinal and cardiovascular conditions [128].

In the studies on *P. dulce*, Nagmoti et al. [129] analyzed the antioxidant capacity of an aqueous seed extract and observed the inhibitions of 81.9% for DPPH and 82.1% for the superoxide radicals. Katekhaye and Kale [130] used acetone to extract the antioxidants from *P. dulce* leaves, reporting an 83.2% DPPH inhibition and a 78.3% for hydrogen peroxide elimination, among others. Kumari [131] employed acetone for the leaf extraction and found antioxidant capacities, including 49.9 IC_{50} g/mL for DPPH. Pío-Leon et al. [132] studied the methanolic extracts of white and red arils, reporting 155.9 mg vitamin C equivalents (VCE)/100 g FW (ABTS) and 170.9 $\pm$ 14 mg VCE/100 g FW (DPPH) for white arils, with notably higher values for red arils. Similarly, luteolin ($C_{15}H_{10}O_6$), a flavonoid, is the compound that has been quantified in the highest proportion in *P. dulce*, with 120.8 mg/g dw.

3.15. *Spondias purpurea L.*

The "ovo" fruit (*Spondias purpurea* L.), belonging to the *Anacardiaceae* family, stands out among others like apricot, peach, mango, plum, and cherry due to its higher caloric density, providing 74 kcal per 100 g of the edible portion, compared to the 39 to 58 kcal of the others. This increased energy content is mainly attributed to the ovo's higher total carbohydrate content of 19.1%, with glucose, fructose, and sucrose constituting 65% of the soluble content. Differing from the rest, the ovo fruit contains a considerable amount of starch in its mesocarp. Its nutritional value also includes being a good source of potassium, providing 250 mg per 100 g of the edible part, and an impressive source of vitamin C, contributing 49 mg per 100 g. The main flavor compound detected during the analysis of its volatile flavor substances was 2-hexenal [133].

2-hexenal belongs to the class of compounds known as medium-chain aldehydes and is recognized as the principal antimicrobial agent found in cashew, apples, and olive oil, where it is proposed as an antimicrobial agent [133]. The leaf extract of *S. purpurea* has shown antioxidant potential along with a high presence of caffeic acid and epigallocatechin [53].

4. Perspectives

As the field of plant biology continues to advance rapidly and the significance of plant biodiversity grows, exploring the potential benefits of Mayan-origin plant species becomes increasingly important. While this review has highlighted the antioxidant properties of certain Mayan plants, future research should focus on several key areas to fully harness the potential of these plants, particularly regarding the secondary metabolites of these rare or underutilized Mayan plants. Future research endeavors should prioritize detailed phytochemical analyses to identify and quantify the bioactive compounds responsible for the therapeutic effects of these plants.

The global distribution of some of these plants necessitates international cooperation for a well-rounded understanding of their benefits and challenges. However, several challenges must be acknowledged. Climate change looms as a significant threat to these plants' sustainability, affecting their natural habitats and potentially altering their medicinal properties. Ethical considerations, such as the rights of indigenous communities and concerns over biopiracy, must be carefully navigated. Regulatory hurdles also exist, including the rigorous clinical trials needed to transform the research findings into marketable drugs that are both effective and safe.

Considering the impact of climate change on Mayan plant species, it is crucial to explore sustainable cultivation practices. Developing strategies for preserving the germplasm via seed banks or tissue culture could also prove invaluable. By cultivating these plants under different environmental conditions, we can gain insights into their adaptability and resilience to the changing climatic conditions.

Since some of these plants are now distributed worldwide, fostering global collaboration in research would facilitate the sharing of knowledge and resources. Establishing collaborative frameworks with researchers from different parts of the world can lead to a more comprehensive investigation into the global relevance of these plants. Extensive pharmacological and clinical studies are necessary to translate the findings into practical applications. This entails analyzing the efficacy, safety, and optimal dosage of plant extracts and compounds for treating various ailments.

Regularly updating the databases with the latest information on plant species, their bioactive compounds, and potential medicinal uses is essential to promote further research and innovation in the field. The rich plant biodiversity in the ancient Mayan region presents an invaluable reservoir for discovering novel bioactive compounds with potential medicinal properties. Adopting a sustainable and integrative approach that combines traditional knowledge with modern scientific research and technological innovations can open new avenues for developing drugs and therapies related to oxidative stress.

5. Conclusions

A screening was conducted to explore the antioxidant potential of rare or underutilized plants in the Yucatan region. The work consisted of analyzing the information available in the scientific literature on the biochemical composition and the presence of secondary metabolites in plant extracts, which could be responsible for their antioxidant effects. The research identified a significant number of plants with antioxidant potential from the *Sapidaceae* and *Anacardiaceae* families. Additionally, representatives from the *Annonaceae*, *Moraceae*, *Malpighiaceae*, *Solanaceae*, *Ebenaceae*, *Asteraceae*, *Ranunculaceae*, and *Leguminosae* families were also presented.

Detailed specifications of major terpenes (terpenoids), phenolic acids, and flavonoids found in these selected plant species were provided. The scientific data analysis of plant-derived compounds from these selected plants with potential antioxidant properties can serve as a foundation for future applied studies. These studies could focus on introducing and utilizing these rare plant species not only in the Yucatan region of Mexico but also in Europe and other regions. By further exploring the antioxidant potential of these plants, we can unlock their benefits and possibly develop new applications and uses for them in various industries and fields.

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