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Review

Andean Fabaceae Species with Pharmacological Potential: Exploration of Antioxidant, Anticarcinogenic, and Antimicrobial Properties

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Abstract: The objective of the present study was to explore the pharmacological potential of three Andean Fabaceae species—*Prosopis pallida* (algarrobo), *Caesalpinia spinosa* (tara), and *Inga feuilleei* (pacae)—as well as their phytochemical composition and traditional uses. A search was conducted in the Scopus database, and the bibliometric analysis was performed using VOSviewer version 1.6.20. The interventions included antioxidant, anticancer, and antimicrobial properties. Tara exhibited the highest antioxidant capacity and phenolic compounds, followed by pacae and algarrobo, with flavonoids such as quercetin, coumaric acid, and isoflavones identified as responsible for this potential. Regarding microbial activity, tara demonstrated inhibitory effects against Gram-positive and Gram-negative bacteria, while algarrobo exhibited inhibitory effects only against the latter. The considerable diversity of phenolic compounds in these species represents a broad field for research, where their cultural and nutritional reevaluation may have significant applications in the food and pharmaceutical industries, contributing to health preservation. All studies support in some way the beneficial effects of phytochemicals on human health.

Keywords: Fabaceae; pharmacology; medicinal plants; polyphenol; phytochemicals

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1. Introduction

In Peru, numerous pre-Hispanic cultures emerged, with the Mochica culture being particularly notable both nationally and internationally for its renowned ceramic pieces. These ceramics frequently depict, with remarkable realism, the most commonly cultivated crops used for consumption and ritualistic purposes. The depicted crops predominantly belong to the *Poaceae* (grasses), *Solanaceae* (nightshades), *Cucurbitaceae* (gourds), and *Fabaceae* (legumes) families [1–4].

In this last group, *Inga feuilleei* DC. (pacae), *Caesalpinia spinosa* (Molina) Kuntze (tara), and *Prosopis pallida* (Willd.) Kunth (algarrobo) are Fabaceae species characterized by their shrubs with simple or compound leaves that produce fruits commonly known as pods. In ancient times, the Mochica used these crops in purification rituals, as evidenced by excavations conducted by Castillo et al. [5] in the Huaca de La Luna, where remains of plant species such as pacae and tara were found as fillings in the purification floor, and algarrobo was specifically found in the post holes of the ritual area.

Currently, these crops have various uses: pacae provides shade for crops such as cocoa and coffee, tara is used in folk medicine to treat inflammatory problems, and algarrobo is used as a gelling and thickening agent in food. However, the agro-export of introduced species and population growth without cultural identity have led to the loss of these traditional crops. Many of them are underutilized, and very little is known about their nutritional value, productivity, and commercialization in scientific terms [6]. In 2022, Peruvian exports of *Caesalpinia spinosa* amounted to USD 22.23 million for powdered tara and USD 15.9 million for gum tara, primarily sold to countries such as China and Brazil. However, no export data were found for pacae and algarrobo [7].

Given this context, revaluing these species through sociocultural and academic lenses is necessary, highlighting their pharmacological and nutritional potential without disregarding traditional and local knowledge. Additionally, Bianco mentions that these legumes are of great economic and ecological importance due to their drought resistance and nitrogen-fixing ability, which promotes soil restoration. They also have a high content of proteins and carbohydrates, which are essential macromolecules for human metabolism [8,9].

Tara contains phenolic compounds such as gallic acid and tannins, which exhibit high antioxidant activity. When mixed with oils, these compounds can maintain oxidative stability and prolong product shelf life [10]. Various studies have shown promising results. For instance, Chambi et al. [11] demonstrated that a product with good antioxidant properties could be obtained after 4 and 9 h of chemical hydrolysis. Another study by Terán-Hilares et al. [12] showed that the thermal hydrolysis (121 °C and 103 kPa) of the gallotannins in tara pod extract enhances its antioxidant capacity, particularly in protecting *Sacha inchi* oil from oxidation.

In Peru, several studies have investigated the antimicrobial potential of the hydroalcoholic extract of tara. Guevara et al. [13] demonstrated that decoctions of three varieties of tara affected *Staphylococcus aureus*, both sensitive and resistant to oxacillin. Similarly, Aguilar-Gálvez et al. [14] found that gallotannins extracted from tara pods and their hydrolysis products had a more potent antimicrobial effect against Gram-positive bacteria than against *Pseudomonas fluorescens*. These findings support the traditional use of tara in treating skin infections, respiratory diseases, and in the prevention of foodborne illnesses. Recently, De La Cruz-Noriega et al. [15] showed that hydroalcoholic extracts of *Caesalpinia spinosa* pods inhibit β-hemolytic *Streptococcus* in vitro, with greater efficacy than erythromycin. The authors mention that this antimicrobial activity may be due to the presence of tannins, steroidal flavonoids, and alkaloids.

Some studies on the antibacterial and antioxidant activities of Peruvian algarrobo (*Prosopis pallida*) have been published. Pinto et al. [16] demonstrated that Peruvian algarrobo has a high phenolic content, which suggests that it is a potent antioxidant. Armas et al. [17], tested the antimicrobial activity of the ethanolic extract of *P. pallida* leaves against *Staphylococcus aureus* ATCC 25923, finding inhibition zones of 18.1 ± 1.2 mm and a minimum inhibitory concentration (MIC) of 1000 μg/mL. On the other hand, the antioxidant activity presented a mean inhibitory concentration (IC50) of 456.8 ± 1.5 μg/mL and 470.2 ± 2.6 μg/mL in the DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2′-azinobis (3- ethylbenzothiazoline)-6 Sulfonic acid) assays. Another study by Alvarado-Saavedra et al. [18] demonstrated the antimicrobial activity of the ethanolic extract of algarrobo leaves against *Enterococcus faecalis* ATCC 29212. Suarez-Rebaza et al. [19] recently identified nine phenolic derivatives, including vicenin II and 7-oxodehydroabietic acid, in the antioxidant activity of *P. pallida* fruits. Other studies support the antimicrobial and antioxidant activities of algarrobo, such as those conducted on the European algarrobo (*Ceratonia siliqua*) [20–23].

Regarding the investigations into the biological activity of northern Peruvian pacae (*Inga feuilleei*), two studies have been registered. The research of Villacorta-Antón and Villacorta and Vásquez-Quispe [24] showed that the ethanolic extract of *I. feuilleei* shell exhibited the greatest analgesic effect at a concentration of 300 mg/kg, surpassing paracetamol 500 mg/kg and tramadol. The same extract showed a significant anti-inflammatory effect at 500 mg/kg, comparable to ibuprofen 400 mg/kg and dexamethasone 4 mg/kg. More recently, Mallqui demonstrated that pacae has potential as a base ingredient for new nutritional products rich in antioxidants [25]. Its antioxidant potential is further supported by studies on other Fabaceae species, such as *Inga edulis*, found in the Amazon region of Peru and Brazil [26–29].

Finally, this review aims to perform an exhaustive bibliographic search of scientific articles reporting on the antioxidant, anti-inflammatory, anticarcinogenic, and antimicrobial properties, as well as the phytochemical composition of three Peruvian crops: algarrobo, tara, and pacae. This study seeks to highlight the potential of these crops and their social and economic applications, representing a valuable contribution, because no existing review comprehensively covers these Fabaceae species. This is necessary for developing further research focused on the revalorization of ancestral crops.

2. Materials and Methods

In this study, bibliometric analysis was conducted using the SCOPUS database, whose coverage of thematic fields and temporal spans is excellent, as well as its rigorous quality control [30]. The analysis included original full-text articles in IMRD format (Introduction, Methodology, Results, and Discussion) available in English, Spanish, and Portuguese. Conference papers were also considered to supplement the scientific information, particularly for the Peruvian species of *Prosopis pallida* (algarrobo) and *Inga feuilleei* (pacae). The search strategy varied slightly for each type of Fabaceae due to the differing numbers of publications per year but employed similar search terms related to their pharmacological activities. All published studies on *Inga feuilleei* and *Inga edulis*, as well as *Prosopis pallida* (Willd.) Kunth, was included. For *Caesalpinia spinosa* (Molina) Kuntze (tara), only publications from the past 10 years were considered, as indicated in Table 1. The final search was conducted on 20 February 2024.

Table 1. Search strategy: Scopus database.

Type of Fabaceae	Search Equation	Period	Total Publications
Pacae	(TITLE-ABS-KEY (“Pacae” OR “Inga edulis” OR “Inga feuillei” OR “Guaba”) AND TITLE-ABS-KEY (“plant extract” OR “phytomedicine” OR “antioxidant activity” OR “anticarcinogenic activity” OR “anti-inflammatory activity” OR “Antimicrobial activities” OR “phenolic” OR “medicinal plant” OR “food”))	1995–2024	28
Tara	(TITLE-ABS-KEY (“Caesalpinia spinosa (Molina) Kuntze” OR “Tara”) AND TITLE-ABS-KEY (“Plant Extract” OR “PHYTOMEDICINE” OR “antioxidant activity” OR “anticarcinogenic activity” OR “anti-inflammatory activity” OR “Antimicrobial activities” OR “phenolic” OR “medicinal plant”)) AND PUBYEAR > 2013 AND PUBYEAR < 2025	2014–2024	61
Algarrobo	(TITLE-ABS-KEY (“*Prosopis pallida* (Willd.) Kunth” OR “Algarrobo”) AND TITLE-ABS-KEY (“PLANT EXTRACT” OR “PHYTOMEDICINE” OR “antioxidant activity” OR “anticarcinogenic activity” OR “anti-inflammatory activity” OR “Antimicrobial activities” OR “phenolic” OR “medicinal plant”))	1986–2024	21

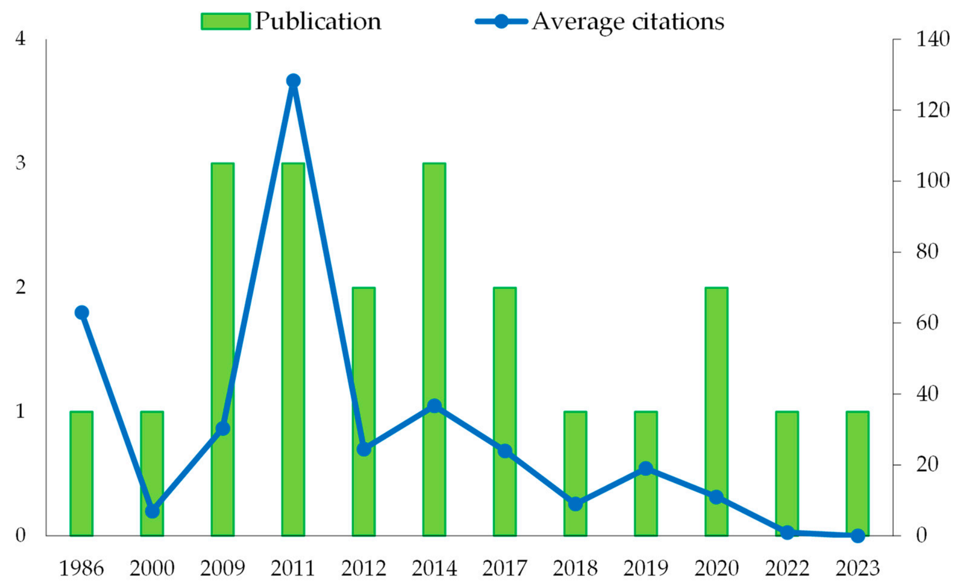
Table 1 details the search strategy employed for each Fabaceae species in the Scopus database. The data were compiled into an Excel spreadsheet for subsequent analysis. VOSviewer version 1.6.19, a free software tool created by Leiden University, Netherlands, was used to generate cooccurrence networks, facilitating the examination of associations between elements and the identification of research trends related to Fabaceae species. The analysis focused on keyword cooccurrence, country cooperation networks, and the most productive institutions in researching these ancestral crops. This methodological approach ensured a comprehensive and systematic review of the scientific literature related to the pharmacological potential, traditional uses, and phytochemical compositions of these Andean Fabaceae species.

3. Results

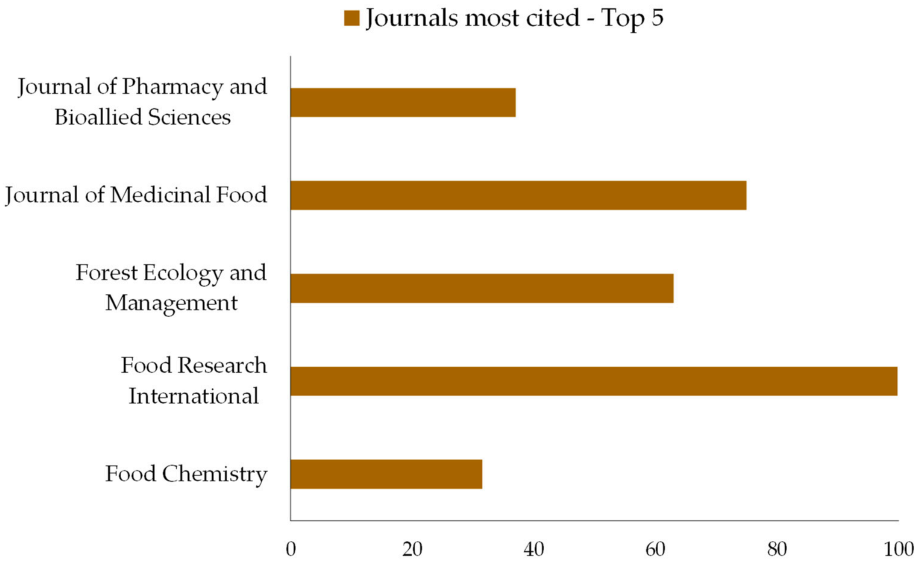
3.1. Bibliometric Networks of Publications

The publication count revealed that the first publication indexed in Scopus regarding *Prosopis pallida* (algarrobo) (Figure 1a) and *Inga feuilleei* (pacae) (Figure 2a) was in 1986 and 2005, respectively. An increase in publications for each species was evident in 2011 and 2007. In contrast, publications on *Caesalpinia spinosa* (tara) began in 1987; however, for this review, only the last 10 years were considered, with 2014 being the year of highest scientific productivity (Figure 3a). Between 2014 and 2018, there was a decrease in the number of publications on *Prosopis pallida* and *Inga feuilleei*. The average number of citations per publication also decreased more noticeably in 2014 for *Prosopis pallida* (Figure 1b) and *Inga feuilleei* (Figure 2b), and in 2019 for *Caesalpinia spinosa* (Figure 3b). Although the COVID-19 pandemic may have influenced the research output on these Fabaceae species, the reality is that, being underutilized crops, research and development funding is minimal and often influenced by conventional export-oriented policies and monoculture practices [31].

The main journals that published studies on these Fabaceae species and were most cited in the scientific community (more than 100 citations) included *Food Research International*, *Spectrochimica Acta—Part A: Molecular and Biomolecular Spectroscopy*, and *Separation and Purification Technology*.

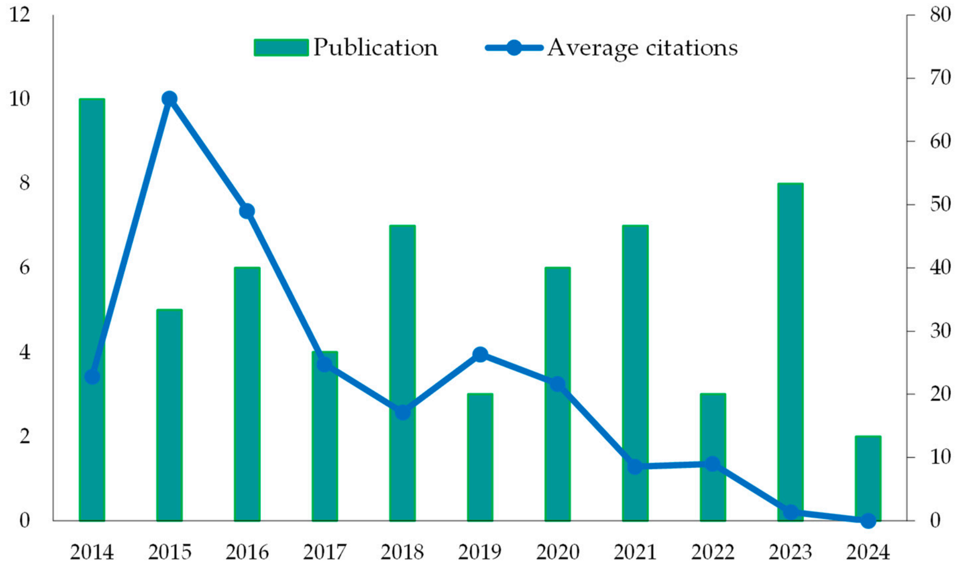


(a)

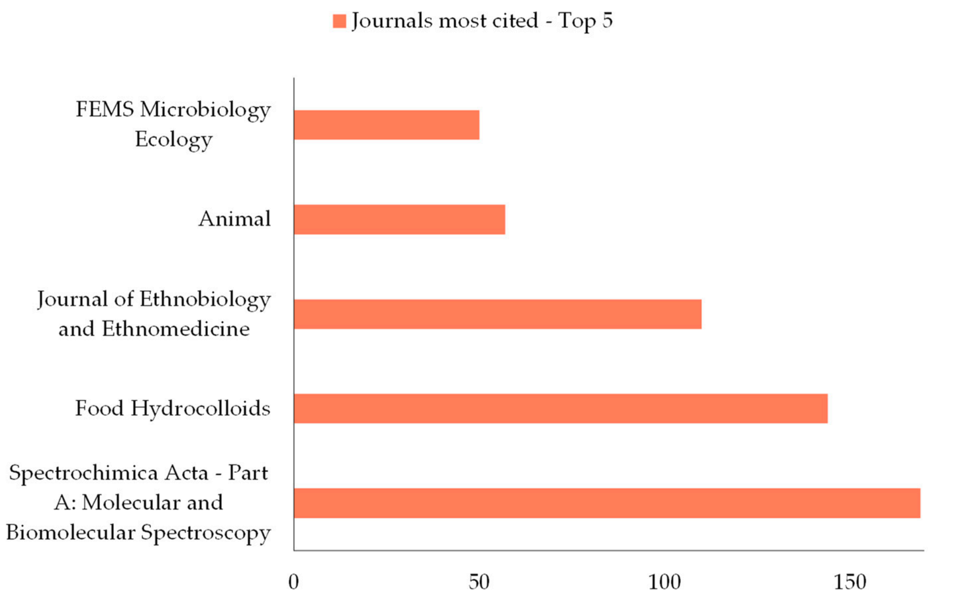


(b)

Figure 1. (**a**) Evolution by year of the frequency of publications on *Prosopis pallida* (Willd.) Kunth by author in the database. The blue line represents the average number of citations per year. (**b**) Top 5 most predominant journals on *Prosopis pallida* studies.



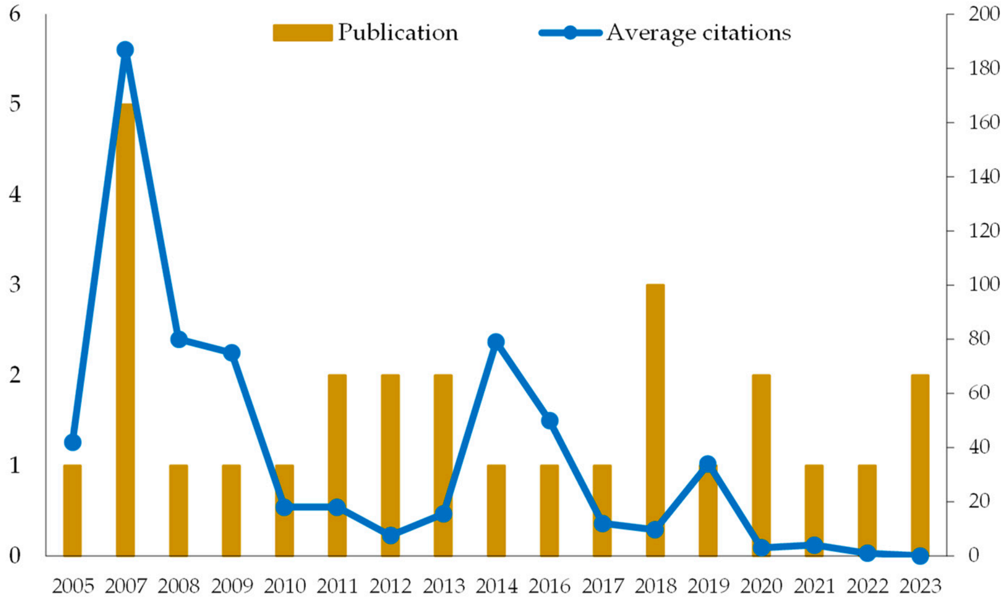
(a)



(b)

Figure 2. (**a**) Evolution by year of the frequency of publications on *Inga* sp. (*Inga edulis* and *Inga feuilleei*) by author in the database. The blue line represents the average number of citations per year. (**b**) Top 5 most predominant journals on *Inga feuilleei* studies.

Keyword cooccurrence (Figure 4a–c) and country cooperation networks were analyzed to identify the most influential institutions in research on *Prosopis pallida*, *Caesalpinia spinosa*, and *Inga feuilleei* (Figure 5). The term "Prosopis" had a relatively larger node size, indicating its frequent appearance in the literature, followed by terms such as "antioxidant activity", "chemistry", and "phenols". Four color clusters were identified, representing groups of keywords based on their interrelation within the network. For example, the red cluster primarily comprised studies focused on the chemical composition of *Prosopis pallida*, evaluating functional properties, antioxidant capacity, and flavonoid identification through chromatographic techniques. The green cluster included studies evaluating antioxidant activity via the DPPH (1,1-diphenyl-2-picryl-hydrazyl) technique. Similar clustering was observed for *Caesalpinia spinosa* and *Inga feuilleei*, with keywords like "tannins", "chemistry", and "plant extracts" being predominant. According to the green cluster originated in the bibliometric analysis on tara, it is suggested that research is related to the study of extracts through in vivo and in vitro assays. A similar trend was observed for pacae, where terms like "anti-proliferative activity" appeared in the same cluster.



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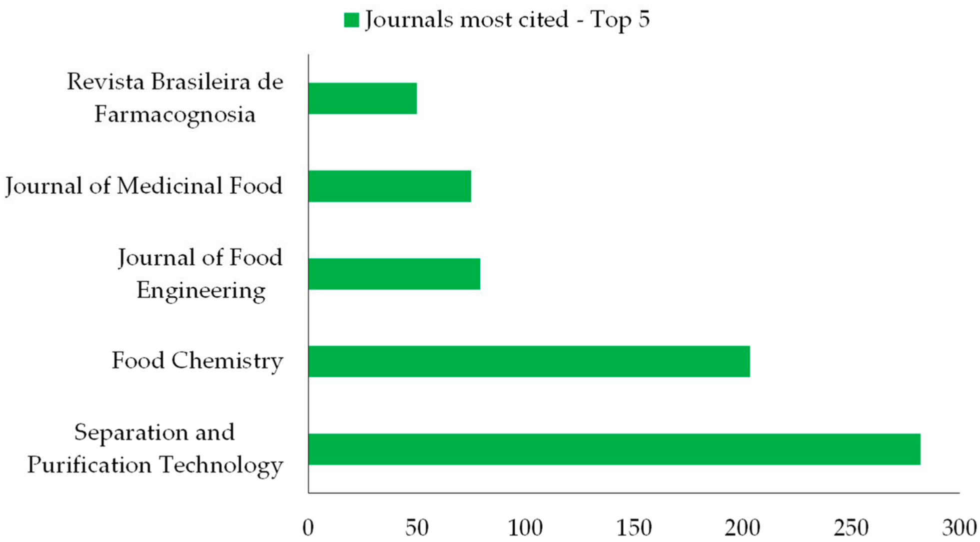
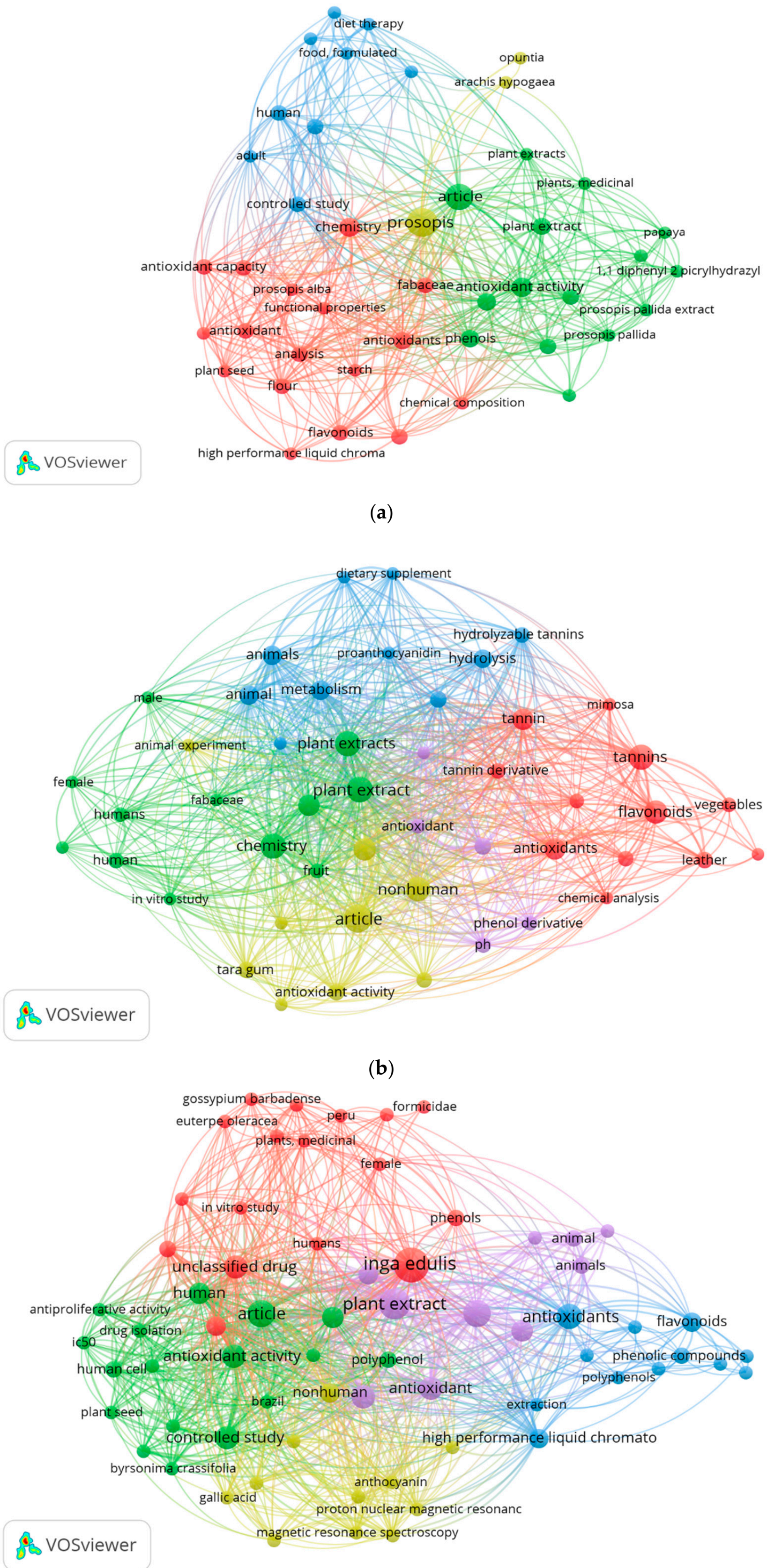


(b)

Figure 3. (**a**) Evolution by year of the frequency of publications on *Caesalpinia spinosa* (Molina) Kuntze by author in the database. The blue line represents the average number of citations per year. (**b**) Top 5 most predominant journals on *Caesalpinia spinosa* studies.

The cooperation network analysis identified 13 countries with the highest total tie strength in research on these Fabaceae species (Figure 2). The highest cooperation intensity was between Italy, Brazil, and the United States, which occupied the top three positions. Research on *Prosopis pallida*, *Caesalpinia spinosa*, and *Inga feuilleei* was concentrated in countries like Chile, the United States, and Brazil, respectively.



(c)

Figure 4. Cooccurrence network map of keywords in the world scientific literature on (**a**) *Prosopis pallida* (Willd.) Kunth, (**b**) *Caesalpinia spinosa* (Molina) Kuntze and (**c**) *Inga feuilleei* DC and *Inga edulis*.

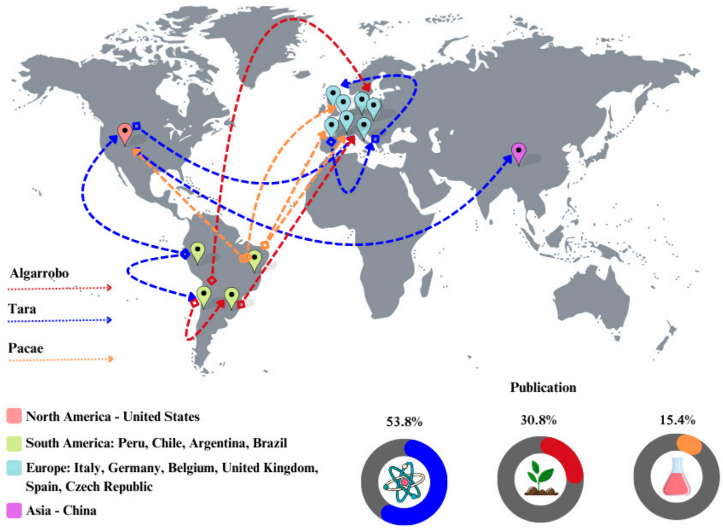


Figure 5. Map of the cooperation network between countries extracted from the scientific literature on *Prosopis pallida* (Willd.) Kunth, *Caesalpinia spinosa* (Molina) Kuntze, *Inga feuilleei* DC, and *Inga edulis*.

3.2. Traditional Use

These Fabaceae species have been used since pre-Hispanic times as crops for consumption, utilitarian, and medicinal purposes. According to Fernandez [32], ancient civilizations used the wood of the algarrobo tree as charcoal and to make utensils and stakes; tara for tanning leather; and pacae was cultivated like potatoes, corn, and lima beans for consumption, although some report that the wood of the tree was also used as firewood [33]. Medically, Algarrobo was employed to treat respiratory infections, stomach pain, and severe wounds, while tara had similar uses but was also applied to inflammations and skin infections. On the other hand, the seeds and fruit of pacae were used as laxatives and to strengthen hair [34,35]. Today, these species continue to be used in traditional medicine in certain cities and communities of Peru.

Algarrobo is consumed in the form of flour and algarrobina (algarrobo syrup), which can be used in juices, milk, and desserts. These products can be found in local markets or supermarkets, with prices ranging from 3 to 6 US dollars for 300 g and 4 to 7 US dollars for 800 g. Tara is marketed as gum, a thickener used in the food industry, and as a powder utilized in the chemical industry for leather tanning and the extraction of organic acids, which are employed in the pharmaceutical and textile industries. Both products are exported by Peru and their prices are between 10 US dollars per kg and 23.69 US dollars per kg. Pacae is consumed fresh and is rarely found in supermarkets; it is mostly used by farmers as a shade tree for coffee or cocoa cultivation [36].

Of these three species, only reports of tara exports have been found in the foreign trade system (SIICEX-Peru), with no records for algarrobo or pacae; however, it is worth noting that exports of tara gum and powder have declined in recent years (2022–2023) by 8% and 5%, respectively [37]. Despite the ancestral significance of these legumes, their consumption and use have diminished due to the expansion of introduced crops and industrialization, which has overlooked the value of agro-diversity.

3.3. Antioxidant Properties of Tara, Algarrobo, and Pacae

Plants contain phytoconstituents such as flavonoids, polyphenols, and terpenes that have diverse bioactive properties. Currently, several studies have shown their pharmacological potential as antimicrobial, antioxidant, anti-inflammatory, and antimutagenic in experimental models in vitro and in vivo [38,39].

Phenolic compounds are bioactive substances that contain one or more phenol groups in their structure. They are formed during the secondary metabolism of plants as part of their physiological processes and serve as a defense mechanism against external stress. The most well-known are flavonoids, polyphenols, and phenolic acids, which are differentiated by the position of their hydroxyl groups, phenol groups, and carbon unsaturations [40]. Like polyphenols, terpenes are also secondary metabolites that have nitrogen atoms in their structure and are synthesized when the interaction between plants and the environment is adverse. Terpenes are typically responsible for sensory attributes such as aroma, smell, and taste, and they are a key component of the essential oils derived from plants.

During the review, it has been observed that authors such as Picariello et al. [41], Terán et al. [12], and Chen et al. [42] highlighted the presence of flavonoids (vicenin II, catechin, quercetin) and tannins (gallotannin and ellagitannin) in tara and algarrobo, with traces of triterpenoids also found in the latter. According to Quispe et al. [43], the species *Prosopis pallida* follows a chemo-taxonomic trend with other tropical species of the Fabaceae family, specifically with *Mimosa pudica* and *Cassia occidentalis*, sharing the presence of 5-hydroxymethyl furfural, a phenolic that can be easily degraded by temperature or acid hydrolysis, and which presents a high antioxidant activity similar to that of a quinoa seed extract. On the other hand, 5-hydroxymethyl furfural is known to have cytotoxic effects on human health. Extracts of Peruvian algarrobo pods have been found to contain cinnamic acid (28 μg/g dry extract), a phenolic acid not reported in *Inga edulis* and *Prosopis alba* containing ferulic and coumaric acid, and terpenes such as α and β tocopherol. On the other hand, flavonoids such as kaempferol and some anthocyanins (cyanidin, peonidin, and malvidin) are found in *Prosopis nigra* extracts [44,45].

Peruvian algarrobo derivatives, such as flour, contain Vicenina (1864 μm/g extract), Isoschaftósido (879 μm/g extract), and Schaftósido (479 μm/g extract) [45]. Flavonoids similar to those obtained by Rodriguez et al. [46] in Argentine algarrobo flour contain Isovitexina (1.12 μg/mg dry extract), followed by Vicenina II (1.07 μg/mg dry extract), Vitexina (0.91 μg/mg dry extract), and Schaftoside (0.42 μg/mg dry extract). Algarrobina, another algarrobo derivative, also presents these compounds, along with quercetin and kaempferol. Nevertheless, it is worth mentioning that in the case of flour, the granulometry is essential for the preservation of these phytochemicals, since in particle sizes greater than 500 μm, Schaftoside can completely disappear [43,46]. Likewise, products derived from Peruvian algarrobo may contain fatty acids such as palmitic, oleic, and linoleic, substances that are important for immune system function and possess hypocholesterolemic effects—although these will not be explored in depth in this review.

Like algarrobo, tara also contains phytochemicals, mainly reflected in hydrolyzable tannins (gallotannins and ellagitannins). Polyphenols are found in greater proportion in the pod and range between 44% and 63% [47]. Dos Santos et al. [48] found that Peruvian tara extract contains 64.15% of total polyphenols and 55.75% of tannins, which are lower than the values observed in *Mimosa pudica*, with 80.04% and 77%, respectively. Using in vitro colorimetric methods, the content of gallotannins, free gallic acid, and catechin in the extract of *Caesalpinia spinosa* (Molina) Kuntze was determined, which reported values of 34.4 mg/mL and 2.4 mg/mL and 2.93 mg/g dry weight, respectively [10,14]. Chromatographic identification also revealed the presence of homoisoflavans, coumarin, and bonduelin [49].

Different phenolic acids from those found in algarrobo have been reported by Tauchen et al. [50] for pacae from the Peruvian Amazon (*Inga edulis*). Chlorogenic and salicylic acids have been detected in the fruit, pericarp, and seed, while only caffeic acid has been identified in the leaves, with no detection of chlorogenic acid. The edible part of the fruit contains the lowest levels of these phytochemicals; however, it presents approximately 250% more phenolic compounds than the pulp of *Inga feuilleei* found in the northern region. Few studies have identified the phytoconstituents of Peruvian pacae; however, research on *Inga edulis* from the Brazilian Amazon has evidenced the presence of terpenes, phenolic acids, flavonoids, and anthocyanins [51,52]. In all these studies, the Folin–Ciocalteu colorimetric method has been used to determine polyphenol content (Table 2).

Table 2. Phenolic compound content and antioxidant capacity of Fabaceae.

Sample	Extraction Method	Phenolic Compound Content	Antioxidant Activity	Reference
Algarrobina 	• Walter solvent • Material/solvent ratio of 500:125 (*w*/*v*) • 200 g of sugar was added • Boiling for 1 h, cooled and ground	118 ± 1.63 mg GAE/g dry weight	Inhibition DPPH IC50: 85.27%, final concentration of 100 mg/mL extract	[53]
Pacae Pulp *Inga feuilleei* 	• Walter solvent • Material/solvent ratio of 1/20 (*w*/*v*) • Reflux 95 °C for 30 min	Between 4 and 6 mg GAE/g dry weight	Inhibition DPPH IC50: 9% aqueous extract	[16]
Algarrobo flour 	• Water solvent • Material/solvent ratio of 1/20 (*w*/*v*) • Reflux 95 °C for 30 min	Between 8 and 12 mg GAE/g dry weight	Inhibition DPPH IC50: 11% aqueous extract	[16]
Pacae seed *Inga edulis* 	• EtOH solvent 70% • Material/solvent ratio of 1/20 (*w*/*v*) • Soxhlet extractor at 130 °C • Concentrated at 50 °C	17.2 ± 3.3 ug GAE/mg extract	DPPH: 7.9 g Trolox (TE)/mg extract	[50]
Algarrobo pods 	• EtOH solvent 45% • Material/solvent ratio of 1/10 (*w*/*v*) • Evaporation and Lyophilization (−80 °C)	70.77 ± 0.64 mg GAE/g dry weight	DPPH: 29.49 mg TE/g	[19]
Pacae peel *Inga edulis* 	• EtOH solvent 70% • Material/solvent ratio of 1/20 (*w*/*v*) • Soxhlet extractor at 130 °C • Concentrated at 50 °C	207.2 ± 13.8 ug GAE/mg extract	DPPH: 288 mg TE/g	[50]

Table 2. *Cont.*

Sample	Extraction Method	Phenolic Compound Content	Antioxidant Activity	Reference
Pacae leaf *Inga edulis* 	• EtOH solvent 70% • Material/solvent ratio of 1/20 (*w*/*v*) • Soxhlet extractor at 130 °C • Concentrated at 50 °C	262.3 ± 11.8 ug GAE/mg extract	DPPH: 337 mg TE/mg extract	[50]
Tara pods 	• Methanol solvent 50% • Material/solvent ratio of 1/30 (*w*/*v*) • Centrifuged at 10,000× *g* for 15 min • Concentrated at 38 °C	468.2 ± 12.2 gallic acid equivalents/L extract	FRAP: 3.89 mmol L^{-1} TE g^{-1} DW	[10]
Tara powder 	• Material/solvent ratio of 0.005:100 (*w*/*v*) • Dissolved in 100 mL Acetate buffer (200 mM, pH 6.8) • Incubated at 37 °C for 90 min	510.63 mg GAE/g dry weight	ND	[54]

EtOH = ethanol-water, mg GAE = milligrams gallic acid, DW= Dry weight, DPPH IC50 = sample concentration required to scavenge 50% of DPPH free radicals, ND = not determined.

The antioxidant activity of these species has been determined through in vitro assays such as DPPH, ABTS, and FRAP (ferric-reducing antioxidant power). Pacae leaves exhibit a greater chelating and free radical inhibitory capacity compared to algarrobo syrup and leaves, with DPPH IC50 values of 42 µg/mL and 456.8 µg/mL, respectively. This is attributed to the presence of flavonoids, specifically C-glucosides and quercetin glucosides, within the species. These compounds, due to their polyphenolic structure (two phenyl rings and one heterocyclic pyran ring), possess greater antioxidant capacity than phenolic acids, lignans, and stilbenes. The correlation between phenolic compounds and antioxidant activity has been reported in various studies; however, the solvent typically plays a predominant role in this association. This is evidenced by the lack of correlation in aqueous extracts of pacae and algarrobo, contrasted with the significant correlation in ethanolic extracts ($r \geq 0.7$). Conversely, tara leaves exhibit a DPPH IC50 value of 30.8 µg/mL, surpassing the other two species, primarily due to the presence of isoflavones, a subgroup of flavonoids with estrogenic action [17,38,39,49].

3.4. Anticarcinogenic Properties of Tara, Algarrobo, and Pacae

Plants contain phytoconstituents or phytochemicals, which are non-nutritive bioactive compounds abundant in medicinal plants. The intake of these compounds provides health benefits by protecting against various diseases [55,56]. These phytochemicals have garnered increasing interest in the pharmaceutical and food industries due to their antioxidant activity and other beneficial properties [57]. The Fabaceae family, in particular, is rich in phytochemicals such as flavonoids, lectins, saponins, alkaloids, carotenoids, and phenolic acids [58,59], many of which exhibit pharmacological properties. However, few human trials have been conducted using standardized extracts of tara (P2Et). The available results indicate that the oral administration of P2Et is safe at a maximum dose of 600 mg/day, as reported by Duran et al. [60]. Similarly, studies in animal models show that doses of 500, 1000, and 2000 mg/kg of body weight in mice do not produce mutagenic or genotoxic effects [61].

In pacae, particularly the species *I. feuilleei*, no trials have been conducted to analyze its carcinogenic activity. However, another species, *I. laurina*, has recently been investigated for its anticancer properties [62,63]. In 2022, a study by Lima et al. [51] evidenced the antitumor activity of *I. laurina*, analyzing extracts from the seed and fruit peel. The seed extracts were found to contain a bioactive fraction with high cytotoxicity against human colon cancer cells HT-29 (IC50 = 4.0 μg/mL). This fraction contained a mixture of p-hydroxybenzoic acid and 4-vinylphenol. Additionally, the fruit peel and seed extract exhibited cytotoxic activity against the T98G cell line, with a chemical composition showing a variety of phenolic compounds. The antitumor activity can be attributed to the high polyphenol content in the extracts. Another study by Ferro et al. [64] investigated active compounds of *Inga edulis* and their inhibitory activity against multiple myeloma cells. The extracts were found to contain saponins, which exhibited antiproliferative activity against myeloma cells.

Regarding tara (*Caesalpinia spinosa*), various studies have demonstrated the potential of its standardized extract (P2Et) against breast cancer, leukemia, and melanoma. Tests have been conducted on different tumor cell lines, as well as in humans and animals (Table 3). This extract is rich in polyphenols, which have been proven to exhibit antitumor activity in breast cancer and melanoma models by modulating tumor cell metabolism or inducing immune response development [65]. Similarly, P2Et has shown effectiveness in reducing primary tumors and metastases in animal models, involving mechanisms such as increased intracellular Ca^+, endoplasmic reticulum stress, autophagy induction, and subsequent activation of the immune system [66]. Recent research by Ballesteros-Ramírez et al. [61] showed encouraging results regarding the consumption of P2Et in Wistar rats and New Zealand rabbits, because it does not present cytotoxicity in the animals tested.

Similarly to pacae, no studies have been reported on the anticancer activity of *Prosopis pallida* (algarrobo). However, recent research has been conducted on other species, such as *Prosopis farcta*, an African species, which has been analyzed for its activity against prostate cancer [67]. Additionally, another study explored the inhibitory activity of the methanolic extract of *Prosopis juliflora* against melanoma cells B16f10, indicating potential application in future cancer therapies [68]. *Prosopis laevigata* has also been studied for its activity in cervical cancer, yielding promising results [69]. Collectively, these studies support the potential for future research on the anticancer properties of *Prosopis pallida* extracts.

Table 3. Anticancer activity assays performed with tara extracts—*C. spinosa* (Molina) Kuntze (P2Et).

Assays	Results	Country	Reference
Human adipose-derived mesenchymal stem cells (hAMSC)	hAMSC did not alter the cytotoxic activity of P2Et extract	Colombia	[70]
Chronic toxicity testing in Wistar rats and New Zealand rabbits at a dose of 1000 mg/kg	P2Et shows no cytotoxic activity on Wistar rats and New Zealand rabbits	Colombia	[61]
Murine mammary carcinoma 4T1 and the melanoma model B16-F10	Standardized P2Et extract reduces tumor cells in B16-F10 melanoma model	Colombia	[71]
Patients diagnosed with breast cancer	P2Et triggers an antitumor immune response and enhances immune infiltration.	Colombia	[72]
K562 Pgp (−) and K562 Pgp (+) leukemic cell lines, endothelial cells (EC, Eahy.926 cell line) and mesenchymal stem cells (MSC) cultured in 2D and 3D.	Extracts derived from P2Et have potential as an adjuvant in anti-leukemic therapy without increasing the effects associated with conventional chemotherapy.	Colombia	[73]

Table 3. *Cont.*

Assays	Results	Country	Reference
Murine mammary carcinoma cell line 4T1	Nanoencapsulation of P2Et led to higher dose administration slightly improving bioavailability and biological activity in breast cancer treatment in rats	Spain	[66]
3T3 cancer-associated fibroblasts (CAF)	Interference with the generation and functionality of CAFs.	Colombia	[65]
K562 and Reh leukemic cell lines	Reduction in the number of leukemic cells after 12 h of treatment	Colombia	[74]
Study conducted in healthy subjects to evaluate maximum tolerated dose and toxicity at dose limits	Oral administration of P2Et is safe in healthy humans with a maximum tolerated dose of 600 mg/d	Colombia	[60]
In animals: *Mus musculus* and mouse strains	P2Et has mutagenic activity and is not genotoxic under laboratory conditions.	Colombia	[61]

3.5. Antimicrobial Properties of Tara, Algarrobo, and Pacae

The study of extracts and/or essential oils from plants originated from the necessity to address antimicrobial resistance caused by the inappropriate use of antibiotics. These extracts have the potential to combat microbial pathogens and certain viruses because plants synthesize secondary metabolites and various phytochemicals. Some of the plant-derived compounds are classified such as alkaloids, phenolics, polyphenols, flavonoids, quinones, tannins, coumarins, terpenes, lectins and polypeptides, and saponins, among others [75].

Fabaceae such as tara, algarrobo, and pacae share some of the secondary metabolites mentioned above, which makes them potential natural antimicrobials. Plants of this genus exhibit high biological activity, including antimicrobial and/or antifungal properties [76].

The mechanisms of action of these metabolites have been studied for decades. Some proposed mechanisms for tannins include the inhibition of extracellular microbial enzymes, the deprivation of substrates necessary for microbial growth, and the direct action on microbial metabolism by inhibiting oxidative phosphorylation. Additionally, a mechanism involving iron deprivation has been proposed [77]. Research is ongoing to establish the precise antimicrobial mechanisms of tannins. It has been suggested that free phenolic hydroxyl groups could bind to enzymes through covalent and noncovalent bonds, altering their function. Other mechanisms described for tannic acid include interruption of peptidoglycan synthesis, iron chelation, membrane disruption, efflux pump inhibition, and fatty acid synthesis [78,79].

Regarding flavonoids, Yuan et al. [79] mentioned that the mechanisms of these metabolites on Gram-positive bacteria may involve damaging the lipid bilayer of the cell membrane, thereby inhibiting the respiratory chain or ATP synthesis. Recently, Yan et al. [80] reported that some mechanisms of flavonoids on Gram-negative bacteria may include the inhibition of DNA gyrase, as well as acting on the cell membrane and inhibiting quinones in the respiratory chain.

Another important aspect in the study of antimicrobial activity is the method used to evaluate plant extracts. Several conventional in vitro methods are widely used, including disk diffusion, agar diffusion, and broth dilution. In the disk diffusion method, a filter paper disk soaked with the plant extract is placed on the surface of agar previously seeded with the microorganism. The extract diffuses, forming in a halo of inhibition. In the agar diffusion method, a hole is made in the agar where the plant extract is placed. During incubation, the extract diffuses through the agar containing the test microorganism, forming an inhibition zone around the well. This method can also be used to determine the minimum inhibitory concentration (MIC). Regarding investigations into the antimicrobial activity of pacae (*Inga feuillei*), no reports have been found in the Scopus and Google Scholar databases. However, antimicrobial activity has been reported in other species of the *Inga genus*. Pistelli et al. [81] demonstrated that the methanolic extract of the aerial parts of *I. fendleriana* (from the Andean forests of Venezuela and Bolivia) inhibited Gram-positive bacteria, such as some *Staphylococcus aureus* and *S. epidermidis strains*, while Gram-negative bacteria were not inhibited. In the study by Maziero et al. [82], a hydroalcoholic extract of *I. semialata* (Vell.)

C. Mart. inhibited the growth of *S. aureus*, *S. epidermidis*, *Micrococcus luteus*, and *Klebsiella pneumoniae* associated with recurrent infections. The analysis of the extracts showed the presence of gallic acid, epicatechin, and rutin. Another study with extracts of the bark and leaf of *I. jinicuil* (from some regions of Mexico) demonstrated antimicrobial activity against *Pseudomonas aeruginosa* (Gram-negative) and methicillin-resistant *S. aureus* (Gram-positive), with MIC values of <3.12 and 50 µg/mL, respectively [83]. Studies carried out on other species of the genus *Inga* support the potential antimicrobial activity of *I. feuillei*. Therefore, this review indicates a gap and the need for future studies on the biological activity of this plant native to the Peruvian region.

On the other hand, some research has demonstrated the antimicrobial effect of tara (*C. spinosa*) extracts against both Gram-positive and Gram-negative bacteria (Table 4). This may be attributed to the high concentrations of tannins and flavonoids [15]. Additionally, gallotannins and their hydrolysates extracted from tara pods have shown antimicrobial effects [14,84]. Two studies found in the Scopus database were conducted abroad, likely due to the advanced technology required to characterize the phytoconstituent fractions of tara. Only two studies have been reported in Peru in the last six years. This indicates that there are significant opportunities for further research on antimicrobial activity and its applications in various fields of study.

The antimicrobial activity of the Peruvian algarrobo tree (*Prosopis pallida*) has been little studied. In Peru, Armas et al. [17] demonstrated that an ethanolic extract from the leaves of *P. pallida* exhibited antimicrobial activity against the Gram-positive bacterium *S. aureus* ATCC 25923 at a concentration of 100 mg/mL, resulting in inhibition halos of 18.1 ± 1.2 mm using the agar diffusion method. Additionally, the extract's minimum inhibitory concentration (MIC) against *Staphylococcus aureus* was 1000 µg/mL. The author suggests that this inhibitory activity may be due to the presence of tannins, one of the most abundant components in the ethanolic extract. Other studies conducted outside Peru indicate that the flour extract of *P. pallida* can be used in the food industry due to its antibacterial and antifungal activity, along with its lack of hepatotoxicity. Minimum inhibitory concentrations of less than 0.30 mg/mL were observed against *Escherichia coli* ATCC 25922, *Salmonella typhimurium* ATCC 13311, *Aspergillus ochraceus* ATCC 12066, *Penicillium ochrocloron* ATCC 9112, and *Penicillium funiculosum* ATCC 36839 [45]. Moreover, other species of the *Prosopis* family have demonstrated antimicrobial activity [85,86]. This capability can be attributed to various metabolites produced by the plant, such as terpenes, phenolic compounds, tannins, and alkaloids. Additionally, a compound called juliflorine protects against some human pathogenic bacteria [45,72,85–87].

Table 4. Studies related to the antimicrobial activity of tara (*C. spinosa*).

Biological Product	Part Tested	Method	Effective Concentration	Bacteria	Gram Stain	Country	Reference
Hydroalcoholic extract	Pod	Disk diffusion	500, 750 and 1000 mg/dL	*Streptococcus* of the β-hemolytic group	Gram-positive	Peru	[15]
Hydroalcoholic extract and hydrolysate of gallotannins	Pod	Disk diffusion	35 mg GAE/mL	*Staphylococcus aureus*	Gram-positive	Peru	[14]
				Pseudomonas aeruginosa	Gram-negative		
Commercial extract of tannins (tara)		Disk diffusion	1.3 y 6 mg/mL	*Salmonella typhimurium*	Gram-negative	United Kingdom	[84]
Ethanolic extract	Leaves	Microdilution in broth	8 mg/mL	*Bacillus cereus*	Gram-positive	Czech Republic	[87]
			16 mg/mL	*Bacillus subtilis*	Gram-positive		
			0.5 mg/mL	*Enterococcus faecalis*	Gram-positive		
			16 mg/mL	*S. aureus*	Gram-positive		
			16 mg/mL	*S. epidermidis*	Gram-positive		
			-	*Streptococcus pyogenes*	Gram-positive		
			21 mg/mL	*Bacteroides fragilis*	Gram-negative		
			No activity	*Escherichia coli*	Gram-negative		
			No activity	*Pseudomonas aeruginosa*	Gram-negative		

4. Conclusions

These Fabaceae species have been extensively used since ancient times as food crops and in traditional medicine to combat infectious diseases. Their beneficial effects are attributed to their phytochemical content, mainly phenolic compounds such as flavonoids, tannins, and some organic acids such as coumaric, kaempferol, and quercetin, with *Caesalpinia spinosa* having the highest concentration, followed by *Inga feuilleei* and *Prosopis pallida*. The phenolic compound content correlates significantly with antioxidant activity, being highest in ethanolic extracts of *Caesalpinia spinosa*. There is considerable scope for further research on the anticancer and antimicrobial activities of these species, particularly for *Inga feuilleei* and *Prosopis pallida*, because existing studies on other species in the same family support their potential. The antimicrobial activity of *Caesalpinia spinosa* has shown promising results, especially against Gram-positive pathogenic bacteria, indicating the need for more studies on the antimicrobial properties of *Inga feuilleei* and *Prosopis pallida*, especially antifungal activity.

This article investigates the pharmacological potential of three Andean species of the Fabaceae family—*Prosopis pallida*, *Caesalpinia spinosa*, and *Inga feuilleei*—emphasizing their rich phytochemical composition, which encompasses notable antioxidant, antimicrobial, and anticancer properties. Despite their cultural and historical significance, these species remain underutilized and underresearched in scientific literature, presenting a significant opportunity for their revalorization, sustainable exploration, and novel applications in the food and pharmaceutical industries. The study underscores the necessity of further interdisciplinary research integrating ethnobotany, chemistry, and pharmacology, and proposes that the sustainable utilization of these species could yield substantial economic and ecological benefits in their regions of origin.

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