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REVIEW ARTICLE

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Traditional culinary uses, food applications, and potential health benefits of Peruvian Mesquite (*Prosopis juliflora, Prosopis pallida*), research advances and challenges: a review

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Abstract

Prosopis trees are leguminous plants that are frequently grown in arid, semiarid, tropical, and subtropical locations due to their remarkable capacity to withstand harsh soil conditions. Compared to other leguminous plants, Prosopis species are still neglected despite their promise. *Prosopis juliflora* (*P. juliflora)* and *Prosopis pallida (P. pallida)* are both referred to as "Mesquite" or "Algarrobo" in Peru. The purpose of this systematic literature review is to clarify the dietary benefits and food applications of Prosopis species (*P. juliflora* and *P. pallida*). A systematic search for relevant articles was conducted on SCOPUS, PubMed/Medline, and WOS. The literature review revealed that Mesquite products have been used in a variety of industries, such as construction, food, and medicine. However, their medicinal use has not been evaluated in clinical trials. Most available evidence pertaining to its health benefits was concentrated on in vitro and in vivo experimental studies. Due to its substantial fiber, protein, and polyphenol content, its nutritional value as a partial replacement for wheat flour and for boosting the nutritional profile of baked goods, drinks, and other food items is being investigated. Further research is required to fully explore food applications and nutritional potential benefits of these neglected leguminous plants.

Keywords Mesquite, Prosopis juliflora, Prosopis pallida, Food application, Nutritional value

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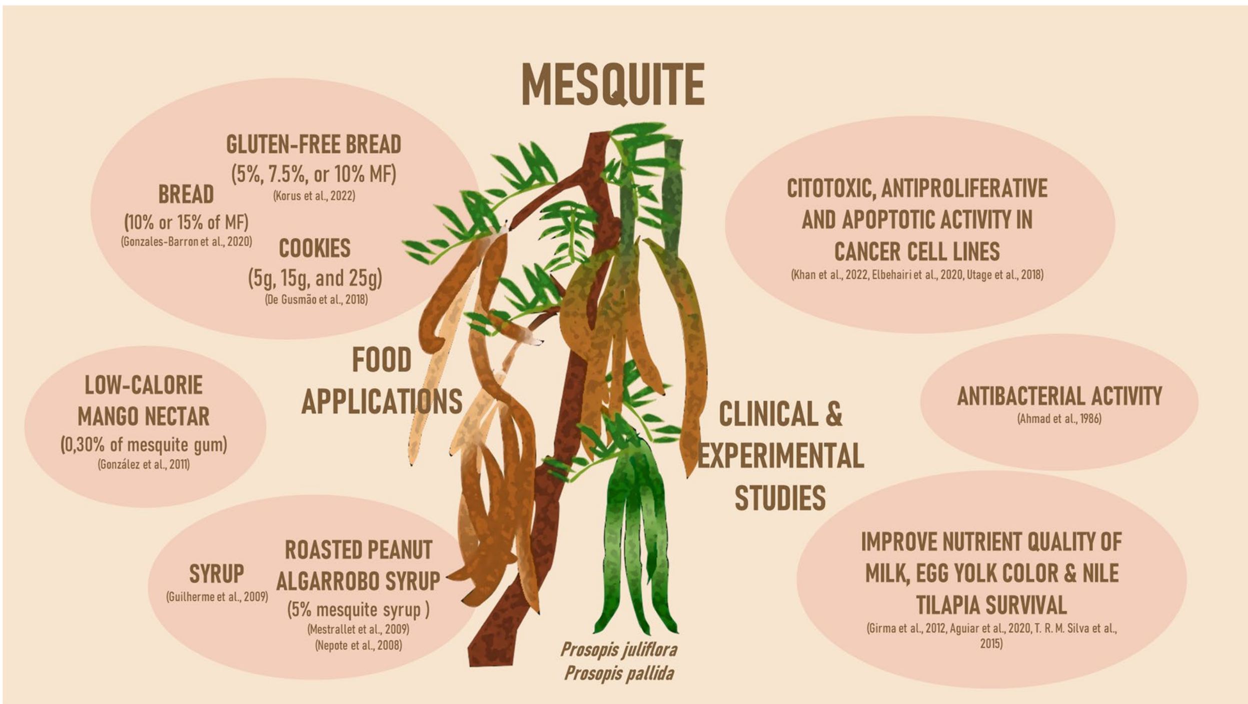
Graphical abstract



Introduction

Legumes are an important component of the human diet and play a major role in food security and environmental sustainability [1]. Among them, Prosopis species are still an underutilized variety of legumes. The Prosopis genus comprises nitrogen-fixing trees encompassing 44 species, including *Prosopis pallida, Prosopis juliflora, Prosopis farcta*, *P. velutina*, *P. glandulosa*, *P. laevigata*, and *P. cineraria* [2]. Among these, *Prosopis pallida (P. pallida) and Prosopis juliflora* (*P. juliflora)* are extensively cultivated in Peru and referred to as "Algarrobo" [3]. Prosopis is known as Mesquite in Mexico and as "Tamarugo" in northern Chile [4]. Most of the Prosopis species are native to North and South America; however, three have originated from Asia and one from Africa. They thrive in arid, semiarid, tropical, and subtropical regions and can survive in saline and alkaline soils where no other plant species grow [5]. Despite its great qualities, Prosopis is less widely used compared with other legumes. Prosopis is not only a good source of wood for use as construction or fencing material, but can also be used in the food and pharmaceutical industry [6]. Moreover, a recent study showed that biodiesel obtained from *P. juliflora* can be used directly to power a gasoline engine with a constant-speed single cylinder. Its unique chemical activity results in a considerable reduction of carbon monoxide, hydrocarbon, and smoke emissions [7].

Prosopis can be consumed in drinks, candies, syrup, jellies, bread, and cookies using the flour obtained from grinding dry pods. Its brownish-tanned flour has a characteristic sweet aroma comparable to that of cocoa, coconut, or caramel [8]. In addition, the gum obtained from Mesquite has properties similar to those of Arabic gum, an emulsifier widely used in the food industry [9]. Its main functional properties include its water solubility, intrinsic viscosity, and ability to emulsify. The unique properties of Mesquite's gum have enabled its use as a functional hydrocolloid [10].

To summarize, Prosopis has been cultivated for its fruit and flour, for feeding livestock, for use as firewood, and as a raw material for making fence posts, furniture, weapons, and tools [11]. Moreover, its by-products also have medicinal value [12]. In traditional medicine, Prosopis has been widely used for therapeutic purposes. The decoction of its flowers and branches exhibits antidiabetic properties, and its leaves have antibacterial, antihyperglycemic, antioxidant, and antihyperlipidemic effects [13]. In a recent in vivo study, the ethanolic extract of Prosopis pods was shown to inhibit α-glucosidase activity, which is the likely underlying mechanism of its antihyperglycemic effect. Therefore, it is a potential alternative treatment for diabetes mellitus [14]. In Peru, there is a high demand for Prosopis mainly for the production of charcoal, which is necessary for the preparation of a very popular national traditional dish called "Pollo a la Brasa" (Peruvian roasted chicken) on is concentrated along the coast, government institutions find it challenging to implement programs aimed at protecting the oldest Mesquite forests. Consequently, the cutting and charring of Mesquite trees is currently illegal [15]. This systematic literature review aimed to provide a synthesis of available information regarding the history, traditional uses, food applications, and health benefits of *P. juliflora* and *P. pallida*, both of which are extensively and historically cultivated in Peru.

Materials and methods

Search strategy

A systematic literature search was conducted in SCOPUS, Web of Science, and PubMed/Medline databases until July 17, 2023. The keywords used were "Peruvian mesquite," "mesquite," "Prosopis pallida," "mesquite tree," "mesquite flour," "P. pallida," "P. juliflora," "Prosopis pallida," "Prosopis juliflora," "Algarrobo flour," "algarrobina" and the following key terms: "uses," "nutritional," "health," "product," "bioactive," "ingredient," "therapeutic," "benefits," "properties," "culinary," "product," "food application," "history," "traditional," "sensory," "clinical trial," "human." This systematic literature review was conducted in accordance with the guidelines in the PROSPERO protocol concerning systematic literature search, article selection, and data summarization [16].

Study selection

The Mendeley software was used for article selection. The inclusion criteria were articles that included key terms related to "Prosopis Juliflora" and "Prosopis pallida," "Peruvian Mesquite" and terms related to nutritional profile, health benefits, history, food applications, and development of products with Mesquite.

There was no language restriction. Articles that did not contain "Prosopis juliflora" and "Prosopis pallida," "Peruvian Mesquite," as well as articles not related to the nutritional profile, health benefits, history, food applications, ancestral uses, and traditional culinary uses were excluded. All articles were independently screened by two authors (AB and SB), and discrepancies, if any, were resolved by consensus with a third author (MC). Data extraction was independently conducted by two authors (AB and SB), and discrepancies were resolved by consensus with a third author (MC).

Results

Selection of studies

A total of 1713 articles were retrieved on database search. After eliminating duplicates, 1092 articles were screened for eligibility by reviewing the titles and abstracts (Fig. 1). Among the records screened, 874 were excluded, and 218 full-text articles were further assessed for eligibility. After a full-text review, 108 articles were excluded, primarily due to being literature reviews (n = 45) and not related to species *P. juliflora* or *P. pallida* (n = 45). Five additional studies were retrieved after a manual search of reference lists of the included articles. A schematic illustration of the literature search and study selection criteria is presented in Fig. 1. Finally, a total of 85 articles (n = 75) were selected for inclusion in the review. These included articles related to food applications (n = 8), cultural and historical background (n = 36), traditional culinary uses (n = 10), nutritional profile (n = 10), and experimental studies (n = 21) of *Prosopis juliflora* or *Prosopis pallida* (Fig. 2).

Ancestral uses

P. juliflora is native to central and northwestern South America, as well as semiarid areas of Mexico. From here, this species has been introduced in other arid and semiarid regions of the world, where it is considered an invasive plant, [17, 18] It belongs to the Fabaceae family, which comprises 44 species, mostly from the Americas [2]. Prosopis fruits are composed of approximately 70% pericarp and 30% seeds [19]. There nonetheless is a wide morphological variability depending on the production site. For example, in the northern, central, and southern regions of Mexico, Prosopis fruits are used to prepare bread, flour, and syrup [20].

To obtain the flour, the moisture content of the fruits must be greatly reduced before being finely milled (i.e., the milling process). The drying stage is essential to obtaining flour, as Prosopis fruits have high hygroscopic activity. This is attributed to their sugar content, due to which they can absorb moisture from the environment very easily. The reported drying temperature required to achieve approximately 4%–6% humidity varies between 50 and 70 °C [21].

Prosopis genus has been widely used [22], consumed [23], and cultivated by different pre-Hispanic civilizations [24] including ancient Peru [15, 25]. A systematic study of the Mesquite tree population in northern Peru by botanist Ramón Ferreyra indicated the existence of three species of Prosopis (pallida, juliflora, and affinis) with a predominance of the pallida variety [4, 26]. Even the species *P. limensis* and *P. chilensis* were deemed to be native to the riverine oases of the Peruvian coasts

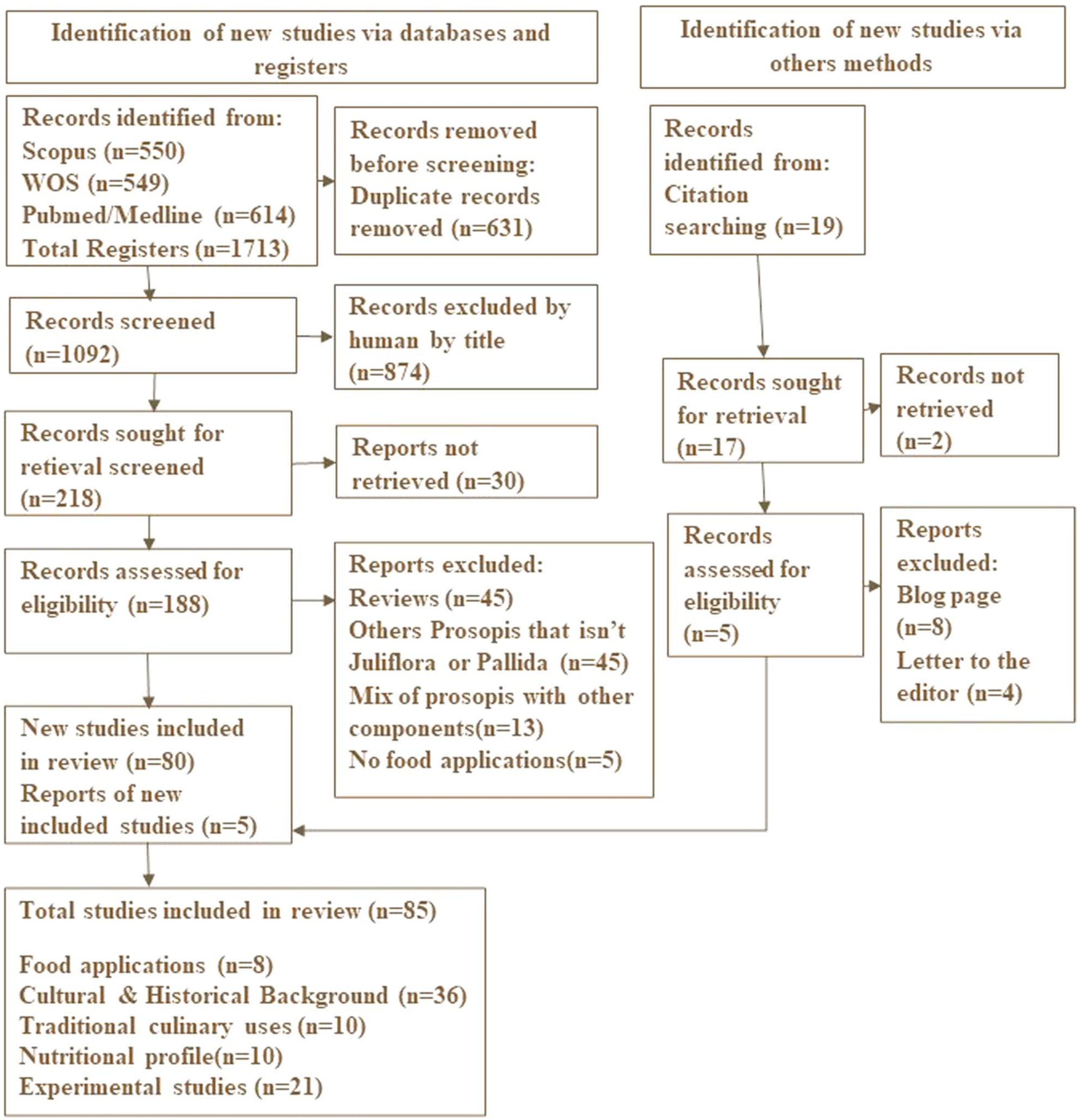


Fig. 1 PRISMA flow diagram of the study screening and selection process

[15]. The name "Algarrobo" was likely coined by the Spaniards, due to its resemblance to a Mediterranean tree of the genus Ceratonia called Algarrobo (Mesquite) [15]. Furthermore, in the Peruvian coast, it is also referred to as "huarango" whose origin is Quechua and means "a thousand" (probably related to its great longevity). Approximately five millennia ago, Prosopis was already being used for the construction of the first monuments, such as the Huaca Prieta and Caral, in northern and central Peru [15].

Given its heavy, dense, and durable composition, the wood of *P. pallida* is utilized for the construction of canoes, furniture, and different types of tools [27]. Prosopis wood is commonly used as fuel for cooking and heating purposes [28].

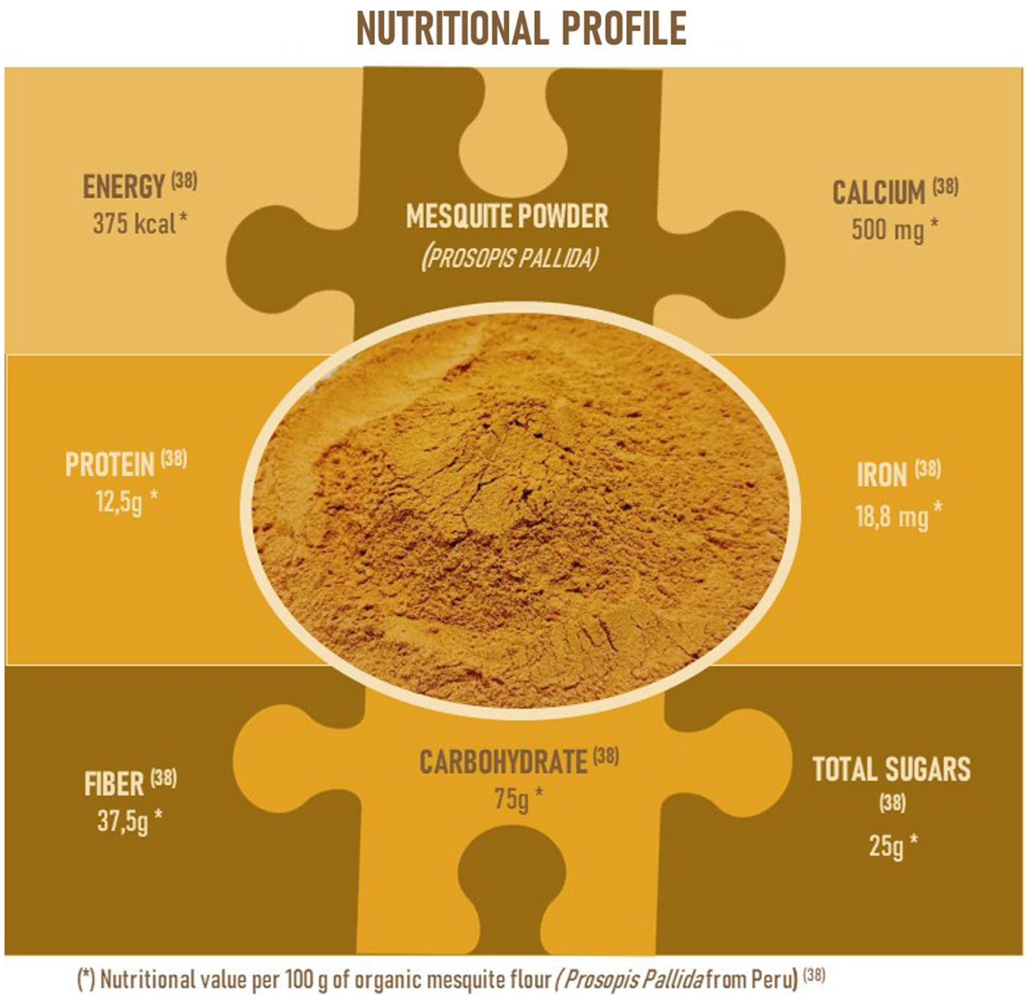


Fig. 2 Nutrition profile of mesquite powder (*Prosopis pallida*)

With regard to its nutritional components, the seeds of *P. pallida* are rich sources of bioactive phenolic and proteins which were also appreciated as a relevant food source for indigenous communities [4]. Specifically, Prosopis seeds were mainly ground into flour and consumed as porridge and beverages [29]. This flour was also consumed as a nutritional supplement due to its relatively high protein content [30]. Similarly, various parts of the *P. pallida* tree were also used in traditional medicine [29]. For instance, the bark, leaves, and pods were used to prepare infusions, decoctions, or poultices to treat ailments such as digestive issues, respiratory, or skin disorders [19]. Furthermore, it is considered an aphrodisiac in ancient folklore [31]. While the bark and pods have a particular use, the inner bark of *P. pallida* was processed to extract fibers which were then spun and woven into textiles [32].

Nutritional benefits

The mature fruit of the genus Prosopis consists of an exocarp (i.e., epicarp, mesocarp, and endocarp) which protects the seed (i.e., episperm, endosperm, and cotyledons) [33]; over 70% of the fruit corresponds to the pericarp, while the remaining 30% is composed of seeds [34]. Interestingly, some Prosopis trees can produce around 300 kilograms of fruits per year [35]. Moreover, *P. pallida* and *P. juliflora* produce bigger and sweeter fruits. Prosopis pods are enriched in fiber and soluble sugars (46%) [36] and can also contain a moderate to high quantity of proteins. Of note, pod meal contains between 250 and 280 g/kg of glucose and around 70g–120 g/kg of crude protein [37].

In terms of nutrient content, the leaves of *P. pallida* from northern Peru show high variability in terms of the concentrations of nutrients. These changes may be

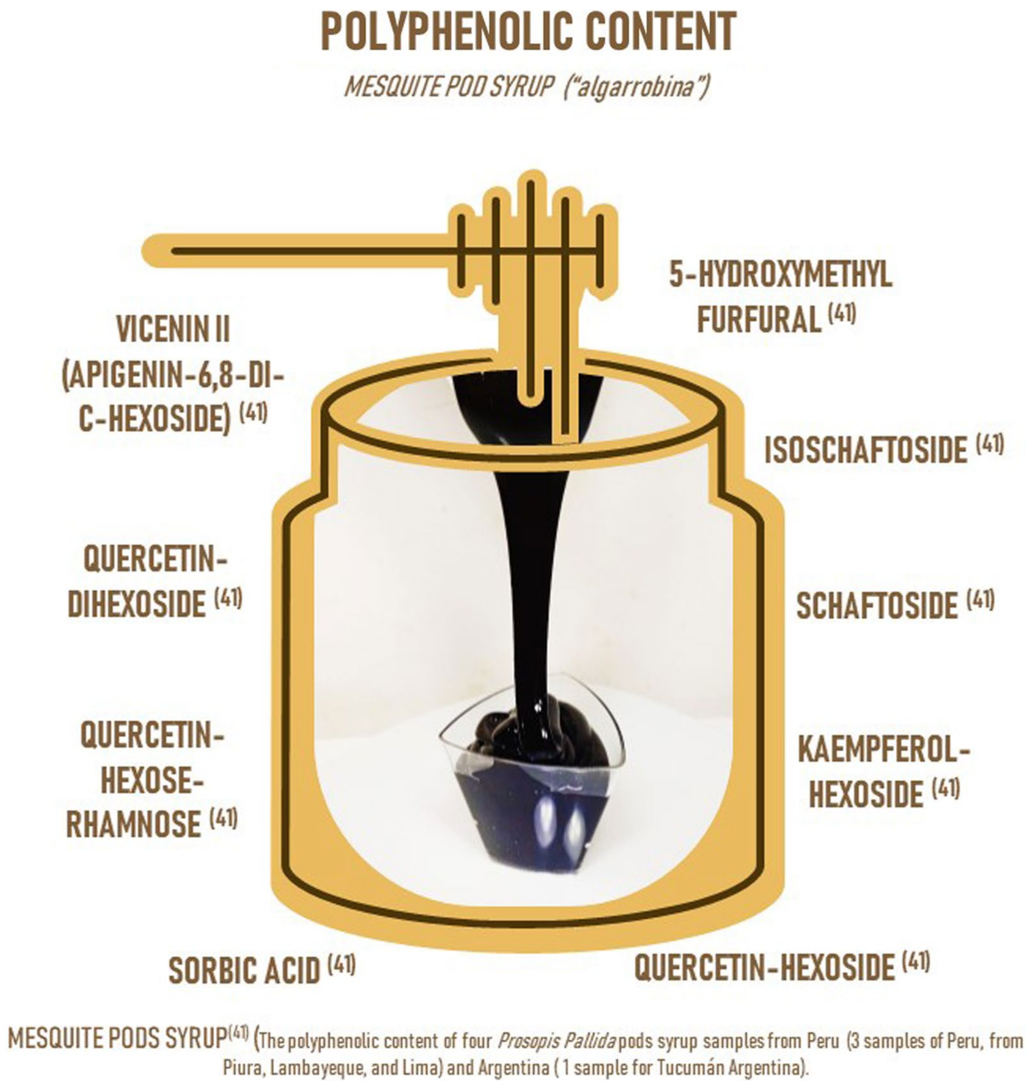


Fig. 3 Polyphenolic content of mesquite pod syrup (*Prosopis pallida*)

related to chemical characteristics and nutrients in the soil. Therefore, leaf characteristics and nutrients can be an indicator of soil condition [3].

Mature pods are ground to produce flour, which is known as "Mesquite flour" in the USA and "Algarroba flour" in South America. Mesquite flour is brown-colored and has a coffee-like aroma that resembles the aroma of cocoa and hazelnut [21]. Likewise, Peruvian *P. pallida* flour is a source of fatty acids, such as palmitic, oleic, and linoleic. Specifically, it contains tocopherols and is rich in dietary fiber [32] and protein while having low sugar content [21] compared to *P. alba* flour [36]. Details of Peruvian *P. pallida* flour nutritional profile by the USDA database are in Fig. 2 [38]. Since wheat flour is lysine-deficient, the addition of Mesquite flour to wheat flour can complete its amino-acid profile [39]. Moreover, its flour contains tocopherols, oleic acid, polyunsaturated and monounsaturated fatty acids [40].

Therefore, Mesquite flour has strong potential for use in healthy cereal-based formulations [20]. Another subproduct, syrup (obtained from ripe fruits), is used to promote weight gain in malnourished children and also administered to infants exhibiting delayed motor development, and to promote lactation in women [41]. Mesquite syrup contains polyphenolic compounds. According to liquid chromatography studies, the main phenolics identified were derived from apigenin, such us C-glycosyl flavonoids, 6,8-C-pentoside-C-hexoside, and 5-hydroxymethyl furfural, and further details are in Fig. 3. [42] Moreover, syrups made from *Prosopis* have shown cytotoxic activity over human lung fibroblast and gastric adenocarcinoma cell lines. Due its C-glycosyl flavonoid content, mesquite syrup may exhibit anti-inflammatory and antioxidant properties, hence acting as a nutraceutical [42].

Potential health benefits

Plants contain chemicals that protect them from various microorganisms. For example, extracts obtained from different parts of the plants have been traditionally used to treat various types of infections. This also applies to *P. juliflora*. Biological activity of Mesquite leaves, fruits, and pods is shown in Table 1. These plants have been traditionally used for treating colds, gastrointestinal disorders, influenza, inflammation, liver, and eye problems [43]. Decoction of its leaves and seeds has been used to treat certain wounds [44], while its leaves have been used as eye compresses to combat infection [45]. *P. juliflora* tea is also believed to alleviate digestive disorders [46]. It is also used to treat measles, hoarseness, and sore throat, and to heal wounds [44, 47]. In vitro and in vivo studies have demonstrated the potential benefits of Prosopis extracts as an antioxidant, antibacterial, antitumor, and anticancer agent [48].

Prosopis genus contains the following compounds: flavonoids, alkaloids, phenolics, steroids, terpenes [49], tannins, catechins, quercetin O-glycosides, and mesquitol [50]. The bioavailability of Prosopis depends on its phenolic contents, particularly catechin.

Between the phenolic compounds identified in mesquite, 5-hydroxymethyl furfural (HMF) is known to be produce from the dehydration of hexose sugars, such as inulin, cellulose, and sucrose under acidic conditions [51]. It has shown that antioxidant activity on high fat diet induced liver damage, reducing ROS and malonaldehyde levels in mice [52]. Moreover, HMF exerts significant dose-dependent protective activity over free radical damage on erythrocytes [53]. The ROS scavenging properties of HMF may be due its chemical structure since it has functional reactive groups such as aldehyde oxygen, double bonds, and oxygen in its furan ring [54], since it may easily attract free radicals and electrons [55]. Experimental studies have shown that HMF can increase SOD activity in forebrain ischemia [57] and hippocampal neural injury mice [56], thus reducing free radicals damage and inhibiting oxidative stress induced by glucose apoptosis in endothelial cells [58].

The anti-nutritional compounds can nonetheless hinder its nutritional qualities. However, this can be prevented by applying heat. Similarly, protein-phenolic compound interactions can increase the absorption of quercetin from Prosopis [6].

P. juliflora is also considered a reliable source of piperidine alkaloids [59], including juliflorine, julifloricine, julifloridine, juliprosine, juliprosinene, juliflorinine, 3' oxojuliprosopine, sceojuliprosopinol, and 3-oxojuliprosine 3'-oxo-juliprosine [46]. These have been extracted by isolating different parts of the plant showing pharmacological activity [41]. For example, leaf extracts of *P. juliflora* showed various degrees of inhibitory activity against different species of bacteria [72].

In this regard, *P. juliflora* extracts have shown a protective role against hepatotoxicity induced by *Staphylococcus aureus*, probably through neutralizing lipid peroxidation products by upregulating intrinsic antioxidant mechanism [62]. Flavonols and mesquitol have been reported as the main secondary metabolites responsible for the antioxidant activity of Prosopis [63].

In vitro and in vivo studies have provided evidence of the antimicrobial, antioxidant, antimalarial, larvicidal,

Table 1 Summary of bioactive components of Mesquite *P. juliflora* and *P. pallida*

Prosopis		Bioactive components	Biological activity
P. juliflora	Leaves	Juliflorine	Inhibition of acetyl cholinesterase Blocking calcium channels [60] Antidermatophytic [61] Hemolytic [62]
	Leaves, pods	Juliprosopine Prosoflorine Juliprosine	Decreasing gas production during ruminal digestion [41] Inhibitor of acetylcholinesterase and butyrylcholinesterase enzymes [63] Antimicrobial activity [64] Growth inhibitory activity [65]
	Fruits	Patulitrin	Activity against lung carcinoma [66]
	Heart wood	Mesquitol	Antioxidant activity [67]
	Leaves	Piperidine alkaloids	Inhibition of drug-resistant fungi Glial cell activation [68]
	Seeds, leaves	Alkaloids, flavonoids, tannins, anthraquinones, and quinones	Inhibition of H+, K+, ATPase of H. pylori [69]
P. pallida	Fruit	Phenolic compound	Antihyperglycemia [70]

Table adapted from [44, 71]

Table 2 Summary of in vivo and in vitro studies of *Prosopis juliflora* and *Prosopis pallida*

Country	Animals and study characteristics	Dosage	Time period	Main results and conclusions	References
India	BALB/c mice aged 6–8 weeks, G1-control ($n = 6$) G2-esperimental ($n = 6$)	All mice were injected with B16f10 cells (1×10^5/0.1 mL of PBS, pH 7.2) mixed with Matrigel (1:1) Group-2 mice received intraperitoneal injection of *Prosopis Juliflora* leaves methanol extract (PJLME) (25 mg/kg/day)	17 days	PJLME induces apoptosis via intrinsic pathway, reduces the expression levels of epithelial–mesenchymal transition markers in B16f10 melanoma cells. Significantly decreases antiapoptotic protein Bcl2 and upregulates proapoptotic markers. It also reduced the tumor volume of B16f10 cells as compared to tumors in untreated mice. PJLME has potential to interact with different therapeutic targets of cancer cells	[94]
India	Prostate cancer LNCaP	*Prosopis juliflora* methanolic leaves extract (PJME) Doses of PJME: 15, 30, 60, 120, and 240 µg/mL	24 h	PJME showed potent antiproliferative and apoptotic effects in prostate cancer LNCaP cells through modulation of Bcl-2 family proteins expression as well as caspase activation (*$p < 0.01$, **$p < 0.001$)	[95]
Brazil	$n = 40$ male, non-castrated, crossbred Santa Inês lambs aged 120 days	4 groups: CON: Without Mesquite pod meal (MPM) MPM25: 250 g/kg MPM50: 500 g/kg MPM75: 750 g/kg	84 days	Mesquite pod meal can be safely used as an energy feed source up to 750 g/kg of dry matter in the diet, without changing the carcass characteristics. Moreover, the ratio of PUFAS and saturated fatty acids was 0.077, which is related to meat quality	[96]
Brazil	$n = 5$ Dorper lambs, male, 4 months old	Enriched Mesquite piperine alkaloid extract (MPA) MON 100 g/kg dry matter DM: positive control (MON) D0: negative control (No additive) Doses: 6.6, 17.3, 27.8 mg/kg Dry matter	115 days	MPA intake at doses ranging from 17.3 to 27.6 mg/kg of dry matter increases fiber digestion, proportion of digestible energy, and metabolism. Doses from 6.6 to 27.8 mg/kg reduce gross energy as methane and improves energy and protein utilization in lambs	[97]
Brazil	$n = 40$ male, uncastrated Santa Inês lambs, randomized	4 groups: CON: Without Mesquite pod meal (MPM) MPM25: 250 g/kg MPM50: 500 g/kg MPM75: 750 g/kg	90 Days	Including up to 750 g/kg Prosopis juliflora pod meal in grazing lambs' diet is a viable option to replace corn. It improves NFC intake and NDF digestibility and total weight and improves the gain/feed ratio	[98]
Brazil	$n = 160$ Nile tilapia juveniles	6 groups of corn replacement for Mesquite Bean Flour (MBL): D0, D20 = 20% MBF, D40 = 40% MBF, D60 = 60% MBF D80 = 80% MBF D100 = 100%MBF	24 h	MBF can replace 100% of the corn in diets for Nile tilapia, without affecting zootechnical and hematological variables and providing protein-sparing effect	[18]
Kenya	$n = 24$ BALB/c mice of mixed sexes 8–10 weeks old	*Prosopis* juliflora leaf extract (PJLE) Groups: GI: 100 mg/kg PJLE GII: 1 mg/kg SSG GIII: saline solution control	3 weeks	*P. juliflora* exhibited higher inhibitory effects against Leishmania donovani promastigotes as well as amastigotes and induced significantly higher IgG antibody levels as compared to SSG ($p < 0.05$)	[99]

Table 2 (continued)

Country	Animals and study characteristics	Dosage	Time period	Main results and conclusions	References
Iran	*n* = 506 One-day-old Ross 308	Control Diet (Mash) 3%, 6%, 9% of Mesquite fruit	28 days	Broilers fed pelleted diets containing 9% Mesquite fruit, especially at the grower and finisher periods, had the highest daily FI and BWG, higher energy, and protein efficiency ratio compared to birds receiving mash feed	[100]
Saudi Arabia	Adenocarcinoma (MCF-7), hepatocellular carcinoma (HepG2), and colorectal cancer (LS-174 T) cell line	Ethyl acetate extract of *P. juliflora* leaves 10 mg of the crude extract diluted with 100 µL of DMSO	48 h	*P. juliflora* leaves extract showed higher cytotoxic effect on adenocarcinoma than hepatocellular carcinoma and colorectal cancer cell line, showing antiproliferative effects in different pathways throughout the cell stages	[101]
Brazil	*n* = 5 crossbred dairy cows	Mesquite pod meal (MPM): D0 = 0% MPM D1 = 1.5% MPM D2 = 3.0% MPM D3 = 4.5% MPM D4 = 6% MPM	20 days	Dietary inclusion of up to 3.0% Mesquite pod meal as a palatability enhancer increases the percentage of milk solids, lactose, fat, and protein. Therefore, Mesquite pod meal can be included in diets for dairy cows to improve the nutritive value of milk	[102]
India	Human breast cancer cell lines (MDA-MB-231, MCF-7) and human keratinocytes HaCaT *n* = 10 Balb/c female mice	Prosopis juliflora leaves methanolic extract (PJLME) 20 mg/kg day PJLME	17 days	PJLME is more selective toward inhibition of TNBCs like MDA-MB-231 as compared to hormone dependent MCF-7 breast cancer cells, and interestingly, it has very small adverse effect against normal human keratinocytes Cells	[103]
Kenya	*n* = 64 KALRO hens, 43 weeks	Ground Prosopis Juliflora pods (GPJP) G1 = 0% GPJP G2 = 10% GPJP G3 = 20% GPJP G4 = 30% GPJP	8 weeks	30% GPJP in layers diet has no effect on egg quality. Layers offered diets with up to 10% GPJP had a similar performance to those on the Control diets. A 10% GPJP inclusion in layer diets may lower the cost of production	[104]
Mexico	*n* = 72, adult female rats intact and ovariectomized	MPE 4 g/kg	3 months	MPE can stimulate epithelial growth in the uterus and vagina of gonadally intact females and is capable of inducing a mild effect in the behavior of OVX females. Its effects were similar to phytoestrogens, daidzein, and genistein	[105]
Brazil	*n* = 25 Holstein-Zebu crossbred dairy steers, 18-month-old	Mesquite pod meal (MPM) in replacement of corn G1 = 0 g kg G2 = 250 g kg G3 = 500 g kg G4 = 750 g kg G5 = 1000 g kg	84 days	The replacement of corn by MPM did not affect nutrient intake, animal performance, and feeding behavior. Therefore, MPM can be used in Holstein-Zebu crossbred dairy steers' diet with total corn replacement	[12]
Brazil	*n* = 240 tilapia juveniles	Mesquite meal bran in replacement of corn G1 = 0% G2 = 33% G3 = 66% G4 = 100%	70 days	The inclusion of up to 20% of algaroba bran replacement in diets for Nile tilapia, reared at low temperatures, does not impair zootechnical performance and improves fish survival	[106]

Table 2 (continued)

Country	Animals and study characteristics	Dosage	Time period	Main results and conclusions	References
India	*n* = 24 3–5-year-old Malpura rams	Prosopis juliflora pods (PJP) in replacement of the concentrate mixture (barley, groundnut, mineral mixture, common salt, and vitamin supplements) G1 = 0% G2 = 30% G3 = 40%	30 days	Prosopis juliflora pods can replace concentrate mixture up to 40% in sheep feeding without having any adverse effect on nutrient intake and utilization as well as on ruminal attributes. Therefore, could substitute cereal grains and oil cakes to economize ruminants feeding	[107]
Brazil	*n* = 336, male Nile tilapia fish	Mesquite pod bran (MPB) G1 = 5% MPB G2 = 10% MPB G3 = 20% MPB G4 = 5% Cassava leaf bran G5 = 10% Cassava leaf bran G6 = 20% Cassava leaf bran	60 days	Mesquite bean bran and cassava leaf bran may be used in Nile tilapia's feed up to 20% inclusion level without compromising the zootechnical performance and altering the chemical composition of carcass. However, reduction in size of intestinal villi suggests lower nutrient absorption	[108]
Etiopía	*n* = 180 Bovans Brown Hens 26-week-old	Ground Prosopis juliflora pods (GPJP) T1 = 0% T2 = 10% T3 = 20% TE = 30%	12 weeks	30% GPJP inclusion level in the ration of layers improved egg yolk color. Up to 20% GPJP inclusion in layers ration is recommendable based on the performance of the birds, although 10% GPJP inclusion may be more economical	[109]
Egypt	One patch Nile tilapia fry from laboratory	Corn replacement diets win Prosopis juliflora pods powder (PJPP) G2: 20 g kg G3: 40 g kg G4: 60 g kg G5: 80 g kg G6: 100 g kg	20 days	PJPP can be used as a complementary ingredient, not as a sole ingredient diet, to tilapia feeds at 60 g/kg level during fry and fingerlings stages to stimulate roughage consumption and to maintain dietary protein for growth	[110]
Pakistan	Gram positive and Gram-negative bacteria	30, 40, 50 y 100 µg juliflorine dihydrochloride in 10 mg/mL distilled water solution	24 h	Among Gram positive bacteria, juliflorine was found to be effective against *Streptococcus pyogenes*, *Staphylococcus aureus*, *Corynebacterium diphtheriae var. mitis*, *C. hofmanni* and *Bacillus subtilis*. *Streptococcus faecalis* was resistant to all antibiotics except for ampicillin and juliflorine	[111]

Bcl2 B cell lymphoma 2, *ERK* mitogen-activated protein kinases, *PJML* Prosopis juliflora methanolic extract, *PUFAs* polyunsaturated fatty acids, *LNCaP* androgen-sensitive human prostate adenocarcinoma cells

NFC non-fibrous carbohydrates, *NDF* neutral detergent fiber, *SGG* sodium stibogluconate, *FI* feed intake, *BWG* body weight gain

TNBC triple negative breast cancer, *DMSO* dimethyl sulfoxide, *KALRO* Kenya agricultural and livestock research organization

OVX ovariectomized, *MPE* Mesquite pod extract

Table 3 Food applications of *P. pallida* and *P. juliflora*

Product	Prosopis spp.	Quantity	Results	References
Bread	*Prosopis pallida*	10% or 15% of MF	MF increased F and UFA. Up to 10% MF level, significantly increases loaf volume and reduced Cr resilience and WA	[20]
Cookies	*Prosopis juliflora*	5 g, 15 g, and 25 g/100 g of WF, store for 4 months	Use of MF showed high concentration of Ca, Fe, and P on cookie dough, increased WA, Bt, and Bg	[112]
Syrup of Prosopis compared to cashew apple syrup	*Prosopis juliflora*	–	Mesquite honey contains minerals K, Ca, Cu, Fe, Mn, Zn. Mesquite honey has a high mineral content (Cu, Fe, Zn, and Mn) compared to cashew apple syrup, except for Na and Mg	[113]
Low-calorie mango nectar	*Prosopis juliflora*	0,30% of Mesquite gum	The viscosity using the highest gum concentration provides an excellent sensory characteristic to the elaborated nectars	[114]
Gluten-free bread	*Mesquite flour Prosopis spp.*	5%, 7.5%, or 10% MF of corn starch /potato starch (ratio 4:1–600 g)	The inclusion of MF increases storage and acceptability of color (7.5% MF, highest), odor, and flavor. MF (7.5% and 10%) lowered hardness (storage)	[115]
Bread	*Prosopis spp.*	30% of WF	MF produced elastic structure, protective effect on starch granule disruption during cooling, decreased volume with increased MF level. MF at 20% produced quality bakery products with improved nutritional components	[116]
Roasted Peanut with Mesquite pod syrup	*Prosopis spp.*	85% Roasted Peanut, 5% Mesquite	Mesquite pod syrup had the highest protective effect in the roasted peanut product stored at room temperature	[117]
Roasted Peanut with Mesquite pod syrup	*Prosopis spp.*	85% Roasted Peanut, 5% Mesquite, 10% dried-solid mixture	Roasted peanut with Mesquite showed higher intensity ratings in brown color, roughness, glossy, powdery, sweetness, and salty sensory attributes and lower intensity ratings in raw/beany flavor than in RP	[118]

MF mesquite flour, *WF* wheat flour, *Cr* crumb

insecticidal, antitumor, anthelmintic, antiemetic, and anti-cholinesterase activity of *P. juliflora* [73]. In addition, the methanol extract of *P. juliflora* flowers showed a greater inhibitory effect against *E. coli, S. flexneri, P. aeruginosa, K. pneumonia, B. cereus, E. faecalis,* and *L. monocytogenes* compared to 10 µg/mL gentamicin [72]. The relevant details and results of in vitro and in vivo studies are summarized in Table 2.

Traditional culinary uses and food applications

In Argentina, there is a beverage named "Chicha" or "Aloja," which is made from the fermentation of pods in water and has a relatively high alcohol content. Another drink made from Prosopis pods is "Añapa," which is obtained by mixing ground pods and cold water. Coffee is another beverage obtained from Mesquite, which is produced by roasting and grinding the pods [74].

On the other hand, *P. laevigata* and *P. glandulosa* are the most common Mesquite species in Mexico that can also be found in Peru. Nowadays, it is consumed directly, in syrup, as flour, in the form of dried candies called "Queso" or "Piloncillo," or even, as a drink made by boiling water or milk with pods and corn meal [75]. It is sometimes also used as an alcoholic beverage [45].

Although beverages made from Mesquite have not been as widely documented in the central Andes as those made from maize, the fruit is commonly used in food and beverages in the northern regions of Argentina, Chile,

Table 4 Food applications of other *Prosopis spp.*

Product	Prosopis spp	Quantity	Results	References
Bread	MF (*Prosopis glandulosa*), PF, GBF	Legume flour (20%) and wheat flour (80%)	Bread with only MF contained more fiber; With MF, bread volume decreased 7%. MF has a significant fiber content (19.9%) and a higher polyphenol content (474.77 mg GAE/g) and antioxidant capacities compared to the other legumes	[119]
"panettone-like" bread	*Prosopis alba*	MF150 g/kg MF250 g/kg MF350 g/kg	MF diminished the resilience and increased the adhesiveness of doughs. MF, lower heights, and firmer Cr, smaller irregular alveoli with thicker walls. Sensory acceptability with highest punctuation (250 g/kg). After 8 weeks of frozen storage, no changes were observed in the texture compared with non-frozen bread	[120]
Bread	*Prosopis alba*	15%, 25% and 35% of MF	MF less stable dough, higher fermentation times, lower volumes, compact, and darker Cr. Improved fiber content (6–9 g/100 g)	[121]
Cookies and Fried chips	*Prosopis chilensis-algarrobo cotyledon flour (ACF)*	10% and 20% ACF	MF in both products showed a significant increase of protein, lipids, ash, crude fiber, available lysine, and total dietary fiber. All of the cookies trials ("I like it very much"); chips with 10% of AFC highest acceptance ("I like it")	[122]
Muffins	*Prosopis laevigata*	175 g MF toasted at 60 °C or 175 g MF toasted 70 °C with 175 g WF	MF protein concentration 97%. Tannin [58% [70 °C]/48%[60 °C]]. Sensorial analysis for MF products were high	[123]

MF mesquite flour, *WF* wheat flour, *Cr* crumb

and the Peruvian coast. A traditional drink in northern Peru (Piura) is "Yupisin," a beverage obtained by boiling Mesquite pods, without concentrating. It can be consumed directly and is also incorporated into desserts [36]. Accordingly, beverages called "Añapa" and "Ulpo" are sourced from the unfermented Mesquite in the southern Andes areas. On the southern coast, "Chicha de Huarango" is prepared by fermenting Mesquite fruits in December [15, 36]. Additionally, Ulpo is traditionally consumed by shepherds and children who are sick or malnourished because of its high energy content and easy preparation. In the northern coast of Peru, Mesquite is widely used for the manufacture of a syrup known as algarrobina, which is thicker than honey [36], flour, and animal feed [15, 36, 76, 77]. The uses of algarrobina include traditional Peruvian cocktails, especially "Algarrobina," which is a cocktail elaborated by blending evaporated milk, egg yolk, gum syrup, pisco, algarrobina, ice, and powdered cinnamon for sprinkling. Algarrobina is also added to fruit juices, fruit salads, and milkshakes due to its natural sweetening and flavoring properties [36].

Mesquite flour can be used as dietary fiber, protein, animal feed, endosperm gum, and germ protein concentrates [78]. The addition of Mesquite flour to bread dough helps increase its elasticity, resulting in softer yet smaller pieces of leavened bread. In sweet bread, a 5% addition of Mesquite flour enhances the texture and flavor. For cookies, Prosopis flour can be a substitute for wheat flour by up to 25%. Moreover, because of its high sugar content, Prosopis can be used in sugar-reduced recipes. Although the addition of Mesquite floor in cookies leaves a discernible bitter aftertaste, empirical evidence from sensorial analysis indicates that it continues to garner favorable reception among consumers. In flour form, Prosopis pulp can be used in a variety of products, such as cakes and ice cream. Further details of food applications of *P. juliflora* and *P. pallida*, as other Prosopis spp., are provided in Tables 3, 4, and Fig. 4.

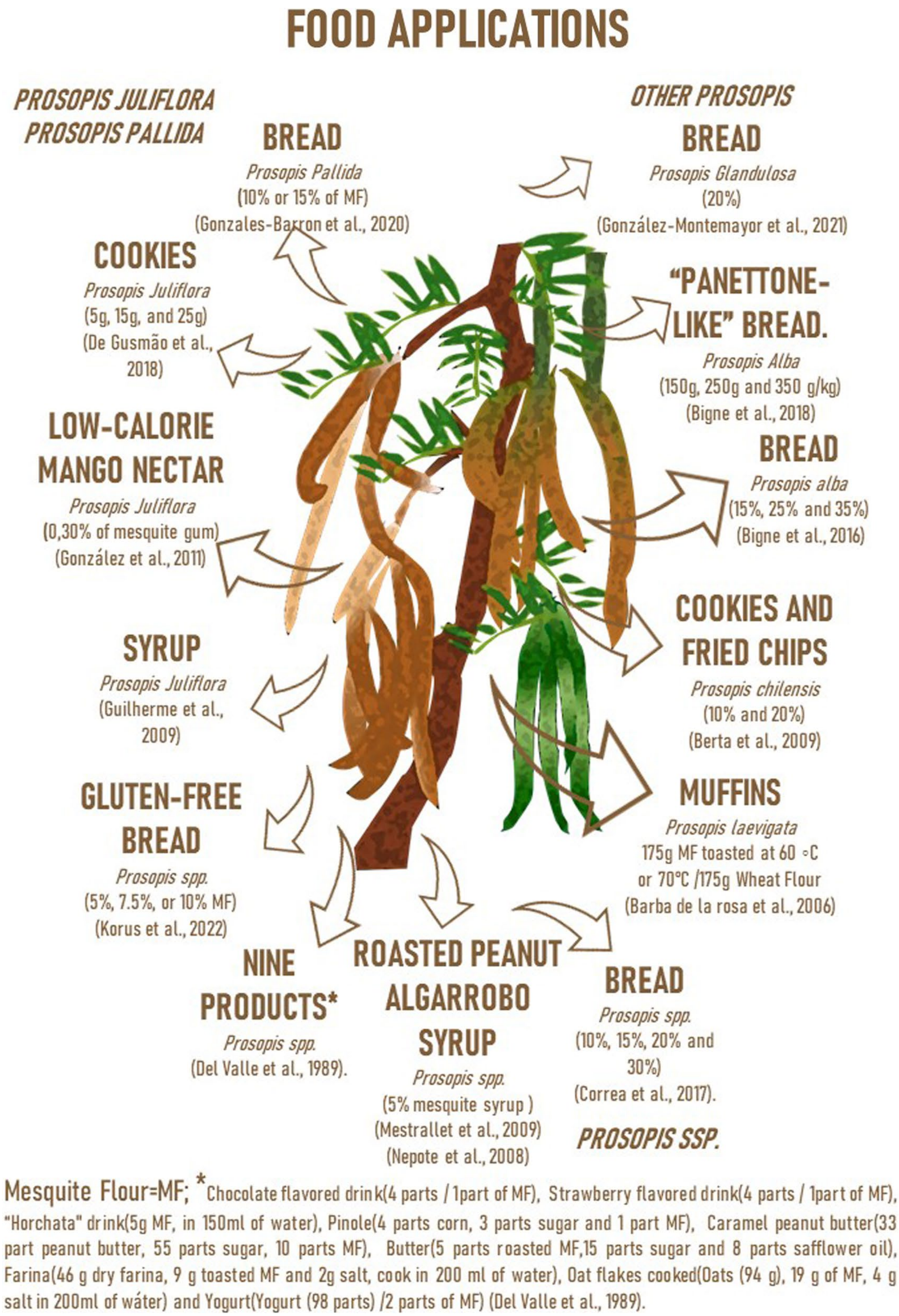


Fig. 4 Food applications of *Prosopis spp.*

Challenges and future perspectives

The ability of Prosopis to flourish in complex conditions indicates its great potential for reducing desertification in the context of the phenomenon of climate change [79]. Plants of this genus can produce many active seeds that can disperse over long distances [80–82]. This process is referred to as "biological invasion," which explains why *P. juliflora* has been considered a threat to native biodiversity [83]. Several mechanisms have been proposed by which exotic trees achieve the invasion process, including the production of allelochemicals and their ability to compete for water and nutrients with other plants [84–86]. From this perspective, several authors have pointed out the potential challenge posed by Prosopis overgrowth for the native species and biodiversity [87–89], which would ultimately affect endemic flora and fauna [90]. Therefore, it is declared as a major invasive weed in regions where its growth can cause a sizable economic impact. For instance, in Ethiopia, the area invaded by *P. juliflora* was estimated to increase annually by 8.3%, and the invasion of just over one million hectares translates to an estimated loss of 600 million dollars [91]. Conversely, in the early 1980s, Prosopis cultivation was promoted in the city of Baringo, Kenya, where it was used as timber, firewood, and charcoal, to improve the living conditions of underprivileged people [92]. Likewise, they are particularly important in times of drought, since the large size of their lateral roots allows them to access subway water reserves, and their leaves are capable of absorbing moisture during rainy seasons. Early identification of potential diversification habitats is a cost-effective way to control its growth [93].

The consumption of carob in South America is ancestral, both in powder and syrup form (algarrobina); however, clinical trials on the benefits of consuming mesquite powder are scarce, but very necessary, due to the multiple benefits, observes in both, vitro and in vivo studies. Moreover, current animal studies show that mesquite may be considered as a sustainable animal feed alternative, compared to wheat bran and corn, without compromising animal nutrition or growth. In addition, unlike mesquite that grows in areas where there are droughts and the soil is infertile, wheat and corn require more water for their production. Partial feeding with mesquite increases protein intake in animals and therefore muscle growth and supports animal nutrition which results in higher performance and health.

In Peru, mesquite is considered an emblematic tree of the northern coast of the country, being of great importance for the welfare of communities, due to its multiple uses and products obtained from its transformation. It is also a key species for the functionality of dry forest ecosystems and the maintenance of ecosystem services. Despite the ecological and social importance of mesquite forest, the threats to their populations and ecosystems continue, few efforts have been made to determine the progress of scientific knowledge about mesquite species, and whether they respond to the needs of forest users.

Conclusions

Mesquite is traditionally used in Peruvian gastronomy (*Prosopis juliflora and Prosopis pallida*) and several countries of Latin America. Continuing the incorporation of this millenary plant into modern diet is vital. It has been consumed for centuries and offers numerous essential nutrients, including fiber, polyphenols, proteins, iron, phosphorus, magnesium, and calcium. Moreover, it provides a unique and delicious flavor to various baked goods, breads, cookies, muffins, and beverages. In Peru, algarrobina is extensively consumed with dairy products and is used in a variety of products, even in fruit salad, as a replacement for honey. Further studies in food applications of *P juliflora* and *P. pallida* are encouraged to develop functional products that can help improve dietary fiber intake and general well-being.

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Author contributions
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