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Ethnobotany of the Carob Tree (*Ceratonia siliqua*): Nutritional, Medicinal, and Ecological Significance

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ABSTRACT: The carob tree (Ceratonia siliqua), a leguminous species native to the Mediterranean basin, holds a prominent place in regional ethnobotany because of its multifaceted uses in traditional diets, natural medicine, and agroecological systems. Belonging to the Fabaceae family, this fruit-bearing tree is appreciated for its nutritional richness: its pulp is high in natural sugars, the seeds contain valuable fats, and the pods are a source of essential minerals such as potassium, calcium, and phosphorus. Moreover, its leaves and pods are rich in polyphenols and antioxidants. From an ecological standpoint, the carob tree demonstrates exceptional resilience to water scarcity, making it a strategic species for reforestation and land restoration in arid and degraded environments. Economically, it has significant value, as its derivatives are employed in the food, pharmaceutical, and cosmetic industries. This review provides an overview of the chemical composition and bioactive properties of C. siliqua, while emphasizing its ethnobotanical relevance and its contributions to human health and sustainable development.

1. INTRODUCTION

The term “carob tree” is derived from the Moroccan Arabic terms *El kharoube*, the *Berber ahkhabou*, and the Hebrew *charuv*. Its Latin name, Ceratonia, comes from the Greek word *keratia*, meaning “little horn,” referring to the carob’s horn-shaped mature pods. The species name, siliqua, refers to a pod or silique. The carob tree (Ceratonia siliqua L.) belongs to the legume family of the Fabales order. It is a sclerophyllous, xerophilic, thermophilic, heliophilous, and calcicole species native to the arid and semi-arid regions of the Mediterranean and Arabian Peninsula. The tree is primarily found in the Mediterranean, including Spain, Italy, Greece, Portugal, and Morocco [1] [2] (Figure 1).

In Morocco, the carob tree grows in the plains and mid-mountains of the Rif, Middle Atlas, High Atlas, and Anti-Atlas regions, thriving in bioclimates ranging from humid to subhumid, semi-arid, and coastal arid, with both hot and temperate variants. Its largest natural population is in the Tafechna and Ait Ishaq regions (Khénifra province), situated at altitudes of 600–1000 meters, where it is found alongside other forest species and sheltered from wind and cold [3].

Interest in the carob tree is increasing not only because of its resilience, adaptability to various soil types, quality wood, and ornamental value but also for its seeds, which are commercially significant, with their value surpassing that of wood production [3]. The carob tree plays an important socio-economic and ecological role, especially in dry regions and areas facing desertification, which is a growing concern in the Mediterranean basin. Mediterranean ecosystems often experience irregular rainfall and long dry summers, which, along with human activity, lead to the degradation of vegetation and rapid soil erosion. To combat this, the use of multifunctional tree species like the carob tree, which is well-suited to climatic challenges and can thrive on marginal lands, is a promising strategy for reforestation and soil restoration [3].

Moreover, the carob tree has significant economic value, with its pods containing more sugar than sugar cane or sugar

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beets. These pods are used in both the food and pharmaceutical industries. Carob fruits, also known as pods or croquettes, have been an essential source of nutrition for humanity for thousands of years. Archaeological evidence suggests that humans were using carob as far back as 43,000 years ago, and it was present on the Greek islands 9,000 years ago [4]. Today, the demand for carob products has surged, driven by the growth of the food and therapeutic industries [5].

This review will first explore the carob plant's main botanical components, followed by a discussion of its biological activity, industrial applications, and therapeutic effects.

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This tree is primarily found across Mediterranean countries such as Spain, Italy, Greece, Portugal, and Morocco [1][2] (Figure 1). In Morocco, it thrives in the plains and mid-mountain regions of the Rif, Middle Atlas, High Atlas, and Anti-Atlas, spanning diverse bioclimatic zones from humid to subhumid, semi-arid, and coastal arid climates. Its most extensive natural stands are located in Tafechna and Aït Ishaq (Khénifra province), at altitudes between 600 and 1000 meters, often in mixed forests and protected microclimates [3].

The ethnobotanical significance of the carob tree is profound. It has been traditionally used for food, medicine, and fodder in Mediterranean societies for millennia. Its seeds, historically more valuable than the wood, are now commercially important in the food and pharmaceutical industries. Interest in C. siliqua continues to grow because of its exceptional resilience, adaptability to marginal soils, high-quality wood, and ornamental appeal.

Beyond its cultural and traditional importance, the carob tree plays a crucial ecological and socioeconomic role, especially in arid regions facing increased desertification. Mediterranean ecosystems, often subjected to irregular rainfall and prolonged summer droughts, are increasingly degraded by human activities. Soil erosion and vegetation loss are pressing challenges. In this context, multifunctional, drought-resistant species such as the carob tree present promising ethnobotanical solutions for land rehabilitation, reforestation, and sustainable agroforestry [3].

Economically, the carob fruit (commonly known as a pod or croquette) is highly valued, containing more sugar than sugarcane or sugar beet. These pods have long served as a vital nutritional source for human populations. Archaeological evidence indicates carob use as early as 43,000 years ago, with documented presence in the Greek islands dating back 9,000 years [4]. Today, the surge in demand for carob-based products is closely tied to the expansion of natural food markets and therapeutic industries [5].

This review will first examine the main botanical features of the carob plant, then analyze its biological activity, industrial relevance, and therapeutic applications, with a special focus on its ethnobotanical importance across Mediterranean regions.

Figure 1. Carob tree and fruit.

2. CHEMICAL COMPOSITION OF CAROB

The chemical composition of carob has been extensively researched [6] (see Table 1). It can vary based on factors such as species, growing conditions, harvest timing, soil properties, climate, geographical location, and original properties of Carob [7]. In addition, variables like cultivar, temperature [8], drought [9], and salinity [10] also influence its composition. The primary chemical components of the carob pod include moisture, ash, sugars, proteins, amino acids, lipids, minerals, vitamins, polyphenols, and dietary fiber (both soluble and insoluble). Table I presents the key chemical constituents and mineral content found in carob pulp and seeds.

The composition of these components is influenced by the cultivar, growing location, and harvest time. A study in Turkey comparing the sugar profiles of carob pulp from cultivated and wild varieties revealed that sucrose is the most predominant sugar in both varieties, with wild varieties containing lower amounts of glucose and fructose compared to cultivated ones. In spite of these differences, the relative levels of individual sugars were similar in both groups [1]. The carob pulp consists of roughly 50% sugars (primarily sucrose, glucose, fructose, and maltose), 18% cellulose and hemicellulose, 16–20% tannins, and 1–2% protein. In contrast to cocoa, carob is free from theobromine and caffeine. It is also a good source of essential minerals such as calcium, phosphorus, potassium, magnesium, and pectin [11].

3. ECOLOGICAL CHARACTERISTICS OF THE CAROB TREE

The carob tree, a member of the Caesalpiniaceae family, is a slow-growing, evergreen, dioecious shrub [1] [16]. Originating from Arab countries, it thrives in a mediterranean climate and is a thermophilic species [17]. The carob tree is drought-resistant but sensitive to cold [1]. It typically grows to a height of 8 to 15 meters and can live for up to 500 years. This species is often planted to help combat deforestation and desertification by reducing soil erosion [18]. The tree's small red flowers bloom between September and November [2] and, after fertilization, produce pods containing carob seeds. These seeds are used to produce carob gum, a

Table 1
Chemical and mineral composition of carob pulp and carob seed.

	Component	Value (g/100g of dry matter)	References		Component	Value (g/100 g of dry matter)	References
Pulp	Humidity	10.2 ± 0.13	[12]	**Seed**	**Lipids**		[13]
	Ash (Cendres)	3 ± 0.05			- Oleic Acid	45 ± 0.4	
	Proteins	2.74 ± 0.03	[14]		- Linoleic Acid	32.4 ± 0.3	
	Lipids	1.15 ± 0.07			- Palmitic Acid	16.6 ± 0.15	
	Total Sugar	83.7 ± 2			- Stearic Acid	4.7 ± 0.15	
	- Sucrose	44 ± 0.74			Proteins	25.7 ± 0.18	
	- Glucose	2.16 ± 0.09			**Sugars**		
	- Fructose	7.04 ± 0.17			- Sucrose	8.1 ± 0.04	
	Total Polyphenols	17 ± 0.5			- Glucose	2.2 ± 0.01	
	- Tannins	6.7 ± 0.12			- Mannose	54 ± 0.5	
	Fibers	6.9 ± 0.06			- Galactose	15.5 ± 0.14	
	Minerals (mg/100 g)				Total Polyphenols (mg GAE/g MS)	1.76 ± 0.29	
	Phosphorus (P)	76.22			Flavonoids (mg QE/g MS)	0.3 ± 0.02	
	Potassium (K)	1003.5			**Minerals (mg/Kg MS)**		
	Calcium (Ca)	268.57			Calcium (Ca)	8300 ± 30	
	Magnesium (Mg)	96.43			Magnesium (Mg)	894 ± 3	
	Iron (Fe)	2.1			Manganese (Mn)	188 ± 1	
	Zinc (Zn)	0.45			Zinc (Zn)	124 ± 0.5	
	Caloric Value	284.6 ± 17.4 KJ/100g			Boron (B)	90 ± 0.4	
					Iron (Fe)	71 ± 0.2	
					Copper (Cu)	49 ± 0.1	
					Energy Value	17.5 KJ/g	[15]

widely sought additive in the food industry for its texturizing properties [19], as well as in pharmaceuticals [20].

Recently, the carob tree has gained commercial value, leading to renewed interest in its cultivation [21] [22]. The growing demand for carob products, spurred by the development of the food industry, has increased interest in planting carob trees, particularly in the Mediterranean region [23].

The carob tree flourishes in a variety of climatic environments, including coastal arid, semi-arid, sub-humid, and humid regions, both temperate and hot. It thrives particularly well in temperate and warm subhumid climates. The tree prefers superficial, red soils, and crusted surfaces.

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From an ethnobotanical perspective, the carob tree has played a longstanding role in traditional food systems and local medicinal practices in Mediterranean and North African cultures. Its small red flowers bloom between September and November [2] and, after fertilization, produce pods containing carob seeds. These seeds are used to produce carob gum, a widely sought additive in the food industry for its texturizing properties [19], as well as in pharmaceuticals [20].

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In addition to its economic and ecological value, the carob tree holds significant ethnobotanical importance because of its adaptability and historical integration into rural livelihoods. It flourishes in a variety of climatic environments, including coastal arid, semi-arid, sub-humid, and humid regions, both temperate and hot. The tree thrives particularly well in temperate and warm subhumid climates and prefers superficial, red soils, and crusted surfaces.

3.1. Climate Conditions

The climate in the study area varies: the Tellian region experiences a Mediterranean climate, while the high steppe plains are characterized by a continental climate. Continental climates are known for extreme temperature fluctuations between winter and summer, as well as between day and night. Summers are hot, winters are cold with frequent frosts, and rainfall is scarce. These conditions result from the area's continental location and its isolation by mountain ranges that block maritime influence, such as the Tell Atlas, which shields the steppe region from Mediterranean effects [22].

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3.2. Soil Preferences and Tolerance

Carob trees can adapt to a wide range of soil types, from poor sandy soils and rocky hills to deeper soils. However, they cannot tolerate waterlogging, in spite of having deep root systems. In areas with shallow, rocky soils, tree size and productivity are limited. The ideal soil for carob trees is well-drained sandy loam, though calcareous soils with a high lime content are also suitable. Carob trees exhibit tolerance to salinity, with Winer (1980) reporting a tolerance to soil salt levels up to 3C [17].

Carob trees are xerophilous, able to survive in dry climates without irrigation, and thrive in environments with annual rainfall between 250 and 500 mm [23]. While drought-resistant, the trees require a minimum of 550 mm of rainfall for optimal production [24]. However, many researchers consider annual precipitation of 300 to 350 mm sufficient for acceptable yield [23], [25].

The average minimum temperature in the coldest month ranges from 0 to 9°C in coastal regions and from –2 to 4°C in semiarid and arid areas. The average maximum temperatures in the hottest month vary by continent, ranging from 28 to 31°C on the coast and from 33 to 38°C in the high steppe plains [26]. In the study area, the minimum temperature of the coldest month is 10°C, recorded in the Aïn Sefra–Naâma region of Algeria.

Understanding these soil preferences is essential not only for modern cultivation but also in the context of ethnobotanical knowledge, as traditional communities have long selected planting sites based on soil type and local experience. Such ethnobotanical practices reflect centuries of observation and adaptation, guiding carob cultivation in diverse Mediterranean landscapes.

4. THE USES AND IMPORTANCE OF THE CAROB TREE

The carob tree holds significant agro-sylvo-pastoral value, offering substantial socioeconomic and ecological benefits. Because of its ability to adapt to water limitations, it is well-suited to arid and semiarid regions [3]. Moreover, the tree has considerable economic importance, with its pods being richer in sugar than both sugar cane and sugar beets, making them valuable for use in the food and pharmaceutical industries.

In addition to its environmental resilience, the carob tree has long been recognized in ethnobotany for its versatile uses in traditional food systems, animal fodder, and rural livelihoods. Its pods, which are richer in sugar than both sugar cane and sugar beets, are highly valued in ethnobotanical contexts as a natural sweetener and nutritional resource. Today, they continue to hold considerable economic importance, particularly in the food and pharmaceutical industries.

4.1. Carob's role in the food sector

Carob is widely used as a substitute for cocoa. Cocoa substitutes are ingredients that can replace cocoa in products such as biscuits, cakes, desserts and chocolates, either partially or fully, while reducing fat content or enhancing other properties of the final product [27].

Carob powder stands out as it does not contain the antinutrients caffeine and theobromine [28], and it has a higher crude fiber content compared to cocoa powder. In addition, carob powder offers significant potential as an alternative to cocoa because it contains similar phytochemicals [29]. Carob powder provides nutritional advantages over cocoa powder, including lower fat content and higher fiber levels [30]. In contrast to cocoa, carob powder is free from caffeine, theobromine, and oxalates. Caffeine and theobromine are known stimulants, while oxalates, when interacting with calcium in human tissues, can form calcium oxalate and lead to kidney stones [31]. Because of its high sugar content, mainly sucrose, carob is also used as a natural sweetener [30].

From an ethnobotanical perspective, carob powder has long been valued in traditional diets as a safe and nutritious alternative to cocoa. It stands out because of the absence of antinutrients such as caffeine and theobromine [28], which are present in cocoa and act as stimulants. Moreover, carob powder contains a higher crude fiber content compared to cocoa powder.

The ethnobotany of carob also highlights its phytochemical profile, which shares similarities with cocoa, offering potential health benefits [29]. Nutritionally, carob powder provides advantages over cocoa powder, including lower fat content and higher fiber levels [30]. Unlike cocoa, carob powder is free from caffeine, theobromine, and oxalates—the latter being compounds that can combine with calcium in human tissues to form calcium oxalate, a contributor to kidney stones [31]. Because of its naturally high sugar content, predominantly sucrose, carob has also been used traditionally as a natural sweetener [30].

4.1.1. Locust bean gum as a food additive

The most commonly used carob-based product in the food industry is locust bean gum (LBG or CBG) [32]. This food additive (E410) is valued for its textural properties, functioning as a thickener and stabilizer. It is widely used in products such as ice cream, mayonnaise, pastries, soups, baby food, and dairy items [33]. Beyond the food industry, it is also utilized in pharmaceuticals, cosmetics, paints, shoe polish, textiles, and paper [23]. Locust bean gum forms highly viscous solutions at relatively low concentrations and is known for producing stronger, more elastic gels, especially when combined with other gums such as carrageenan, agar, and xanthan gum [34].

4.1.2. Carob's potential in fruit ripening and oxidation

Research has suggested the use of carob's total polyphenol extract (PPT) as a natural alternative to chemical agents that accelerate fruit ripening. This research involved extracting PPT from carob and assessing its effects on fruit oxidation. The study, which evaluated the effect of PPT on strips of apple, banana, and lemon, indicated that carob PPT plays a significant role in accelerating browning and oxidation in fruits under experimental conditions (free air, room temperature) (Figure 2). These findings highlight the role of carob PPT in the ripening of fruits, suggesting that it could be an effective natural solution for controlling the ripening process [16], [17].

After treatment of the apple wall with total polyphenol extracted from the carob tree for 4 days, the change of color and an increase in color lightening (shine) can be observed. This is a fruit quality criterion which can be explained by the stimulation of ethylene which causes ripening (Figure 3) [16].

Carob syrup, another product deeply rooted in ethnobotany, can be used as a natural sugar substitute in various food recipes. It is often utilized to soften and preserve seasonal fruits, as well as in homemade cakes, cookies, and treats. In addition, it serves as a topping for desserts, can be drizzled over skewers or pancakes, is used as a marinade for meats, and acts as a sweetener in both hot and cold beverages [31].

The Codex Alimentarius allows the inclusion of a variety of optional ingredients in food products, including

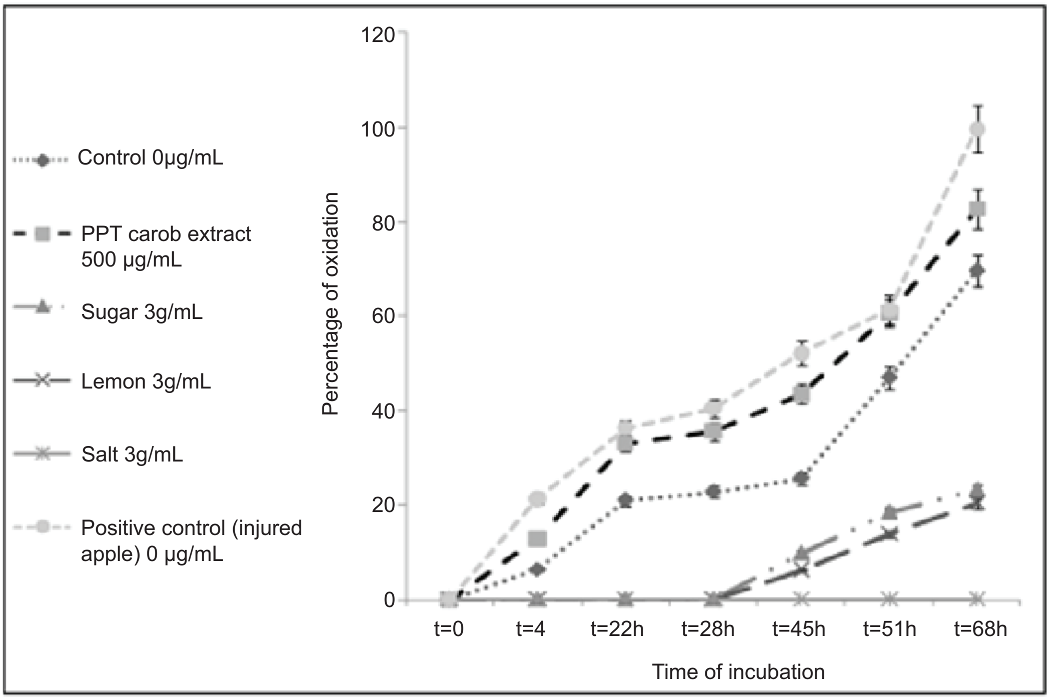

Figure 2. Evolution of the percentage of apple coverslip oxidation under different conditions (control, lemon, salt, sugar and PPT extract) [16].

Figure 3. Observation of maturation evolution of apple, banana and lemon (polyphenol and control case) after t = 70h [16].

acidity regulators, carbonating agents, colors, emulsifiers, flavor enhancers, preservatives, stabilizers, thickeners, and sweeteners. In the production of fermented milk products like yogurt, additives such as locust bean gum, gelatin, starch, carrageenan, xanthan gum, guar gum, alginate, carboxymethylcellulose, and agar are commonly used to enhance texture, consistency, and visual appeal [36].

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From an ethnobotanical perspective, the traditional uses of carob extracts for food preservation and natural sweetening reflect a long-standing knowledge of its bioactive properties.

4.2. Use of the carob tree in medicine

Carob has been utilized by humans for centuries, primarily as a food source. However, traditional medicine in many cultures has also employed it to treat a variety of health conditions. The fruits (pods or kibbles) were the main component used for both nutrition and medicinal purposes, while decoctions and extracts were also prepared from other parts of the tree, particularly the leaves. Modern scientific studies have analyzed the chemical compositions of the carob tree's various parts, and antioxidants have been identified as key phytochemicals contributing to its nutritional and medicinal properties.

In addition to its potent antioxidant activity, carob and its extracts have been shown to possess a range of beneficial properties, including anticancer, neuroprotective, hepatoprotective, anti-aging, skin care, and antidiabetic effects [37]. Phenolics and carbohydrates are considered the most powerful antioxidants, though certain volatile compounds also exhibit similar activities to a lesser degree. A summary of these activities is provided in Table 2.

Carob is widely recognized for its anti-diarrheal properties. In addition, its high fiber content contributes to its hypocholesterolemic and hypoglycemic effects [38], while the phenolic compounds it contains are responsible for its antioxidant activity [39]. It has been commonly used in both culinary and medicinal traditions to combat cholesterol, treat acute childhood diarrhea, and address digestive disorders.

The carob tree's pulp is rich in sugars, its seeds contain fats, and the pods provide essential minerals like potassium, calcium, and phosphorus. The leaves and pods are particularly abundant in polyphenols and antioxidants. Because of its impressive nutritional profile, carob can be beneficial for human health. Locust bean gum, derived from carob, is also utilized in the pharmaceutical industry in products such as ointments, anti-celiac ingredients, pills, and toothpaste.

Clinically, carob has demonstrated potential in various therapeutic areas, including as an anticancer, anti-reflux, antidiabetic, antidiarrheal, antihyperlipidemic, antibacterial, antimicrobial, and antifungal agent. This highlights the significance of understanding the chemical properties and biological effects of carob fruits on human health.

The carob tree has been utilized by human societies for centuries, primarily as a source of nutrition. Its significance within the field of ethnobotany is well-established, as traditional medicinal systems across various cultures have employed different parts of the tree to address a range of health conditions. The fruit pods (also referred to as kibbles) constitute the principal component used for both dietary and therapeutic purposes, while decoctions and extracts derived from leaves and other tissues have also been widely applied. Contemporary phytochemical analyses have identified antioxidants as the principal bioactive compounds underpinning the tree's nutritional and medicinal efficacy.

Beyond its considerable antioxidant capacity, carob extracts have demonstrated diverse biological activities, including anticancer, neuroprotective, hepatoprotective, antiaging, dermatological, and antidiabetic effects [37]. Phenolic compounds and carbohydrates are recognized as the primary antioxidants, with certain volatile constituents contributing to a lesser extent. These pharmacological properties are summarized in Table 2.

From an ethnobotanical standpoint, carob is traditionally renowned for its antidiarrheal properties. Its high dietary fiber content further contributes to hypocholesterolemic and hypoglycemic effects [38], while the phenolic profile mediates its antioxidant activity [39]. Such attributes have underpinned its long-standing use in both culinary and medicinal practices aimed at managing cholesterol levels, treating acute childhood diarrhea, and alleviating various digestive disorders.

The pulp of the carob fruit is rich in sugars; the seeds contain lipids; and the pods provide essential minerals, including potassium, calcium, and phosphorus. Leaves and pods are particularly abundant in polyphenols and other antioxidants. This comprehensive nutritional profile underscores the potential of carob to contribute positively to human health. Furthermore, locust bean gum, a derivative of carob, has found pharmaceutical applications in ointments, anti-celiac agents, tablets, and dental care products.

Clinically, carob has exhibited promising therapeutic effects across multiple domains, such as anticancer, antireflux, antidiabetic, antidiarrheal, antihyperlipidemic, antibacterial, antimicrobial, and antifungal activities. These findings highlight the critical importance of integrating ethnobotanical knowledge with contemporary biomedical research to fully elucidate the chemical and biological properties of carob and to optimize its use for human health benefits.

5. CONCLUSION

In conclusion, carob offers a wide range of health benefits, particularly because of its high fiber content, rich polyphenols, and antioxidant properties. Its proven effects in treating conditions like acute childhood diarrhea, cholesterol management, and digestive disorders have made it a staple in both traditional culinary and medicinal practices. The various bioactive compounds found in carob, such as those in the pods, leaves, and seeds, contribute significantly to its therapeutic potential. Moreover, carob's diverse applications in the pharmaceutical industry further demonstrate its versatility, from its use in ointments to anti-celiac ingredients and beyond.

While carob's potential as an anticancer, antidiabetic, antihyperlipidemic, antibacterial, and antifungal agent is encouraging, continued research into its bioactive compounds, particularly polyphenols and antioxidants, is essential. Such studies could pave the way for carob's further integration into the pharmaceutical and food industries, offering more innovative health solutions.

Table 2
Major Medicinal Properties of Carob.

Property	Activity	References
Analgesic	Seed aqueous extract was most efficient.	(Ben Ayache et al., 2020)
Anti-alopecia	Pods aqueous extract (with five other plants) downregulated IL-1α in HaCaT cells, suggesting nonscarring hair loss prevention activity.	(Pekmezci et al., 2018) (Elma, 2019)
Anti-Alzheimer	Pods methanolic extracts showed glucose-mediated glycation and AChE inhibition.	(Elma, 2019)
Antibacterial	Recognized for toxicity against microorganisms and hydrolytic enzymes.	[22] (Abdulkareem R. S.,2020) (Ben Othmen et al., 2020)[25](Darwish et al., 2021)
Anticancer	Luteolin, quercetin, apigenin, and taxifolin prevent the onset of certain cancers.	(Elbouzidi et al., 2023; Klenow et al., 2008; Custódio et al., 2009; Ghanemi et al., 2017; Gregoriou et al., 2021)
Anti-cobalt-toxicity	Seeds aqueous extract had protective effect against cobalt (Co+2) toxicity in onion (Allium cepa L.) bulbs.	(Macar et al., 2020)
Antidepressant	Seeds peel extracts showed activity in four depression tests.	(Agrawal et al., 2011; Lakkab et al., 2019)
Antidiabetic	Exhibits hypoglycemic activity.	Gruendel et al., 2007; Rtibi et al., 2017; Qasem et al., 2018; Lambert et al., 2018; García-Díez et al., 2022)
Antidiarrhea	Significant treatment activity in children with bacterial diarrhea.	(Loeb et al., 1989)
Anti-inflammatory	Inhibits enzymes responsible for inflammation.	Aboura et al., 2017; Rico et al., 2019; Martínez-Villaluenga et al., 2018)
Anti-obesity	Reduces high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglyceride levels in blood, aiding in the prevention and treatment of hyperlipidemia.	[46] [47] [48] [49] [50] [51] (Papakonstantinou et al., 2017; Gruendel et al., 2006; Jamous et al., 2018; Agrobiologia, 2025; Fujita et al., 2021)
Antioxidant	Leaves' ethanolic extract showed strong DPPH activity. Pods' flower aqueous extract had significant activity, determined by DPPH and FRAP methods.	(Kumazawa et al., 2002) [24] [25] [29] [34]
Antiviral	Quercetin, apigenin, catechin, and hesperidin showed good viral activity.	[26]
Antivenom	Pods' aqueous extract had weak activity against Egyptian horned viper (Cerastes cerastes) venom.	(Wahby et al., 2012)
Cardioprotective	Reduces HDL, LDL, and triglycerides, contributing to cardiovascular health.	(Ruiz-Roso et al., 2010; Valero-Muñoz et al., 2014)
Corrosion inhibition	Pods' methanolic extract exhibited corrosion inhibition activity on steel.	(Ghazi et al., 2022)
Enzyme inhibition	Inhibits amylase, maltase, sucrase, and lactase. Carob by-products extracted with 50% aqueous methanol showed AChE inhibition.	[26] [44] [57] [58] [59]
Fertility effects	Administration of pods' water extract to male mice improved sperm quantity and quality. Pods powder supplemented to aging roosters also improved sperm.	[60] (Nemati et al., 2022) [62]
Food	Mature pods' powder mixed with fermented milk exhibited probiotic activity. Seeds' powder was added to food products, improving taste, texture, and nutritional composition.	[63] [59] [62]
Gastroprotective	Aqueous extract protected against indomethacin-induced gastric ulcers in rats. Extract exhibited laxative and antidiarrheal effects depending on pod maturity.	Rtibi et al., 2016[66]
Hepatoprotective	Aqueous extract of immature pods protected against ethanol-induced liver toxicity. Treated mice showed reduced liver damage from Schistosoma mansoni infection.	(Souli et al., 2015; Al-Olayan et al., 2016; Rtibi et al., 2016)
Immune system (Antiallergic)	Carob syrup added to fish meals improved immune biomarkers. Inhibits enzymes such as AMP cyclase and Ca^{2+}-ATPase.	(Špoljarić et al., 2019; Abidar et al., 2020; Ammari et al., 2020)
Nanoparticles preparation	Fresh leaves aqueous extract reduced Ag(I) ions to prepare silver nanoparticles (AgNPs), with tested antibacterial and cytotoxic activities.	(Al Khafaji et al., 2024; Tamizhdurai et al., 2017)
Nephroprotective	Pods' aqueous extract administered to rats showed improvement in oxidative stress biomarkers, protecting against nephrotoxicity.	(Rtibi et al., 2016)
Nervous system, brain	Leaves aqueous extract inhibited AChE and improved cognitive parameters in zebrafish. Pods' aqueous extract helped alleviate brain injury in rats.	(Abidar et al., 2020; Ammari et al., 2020)
Pulmoprotective	Pods' aqueous extract alleviated lung injury caused by waterpipe smoke in rats.	(Saratsi et al., 2020)
Skin care	Aerial parts' (bark, leaves, and pods) extracts exhibited antioxidant activity and depigmentation effects, safe for use in cosmetic formulations.	(Lall et al., 2015; Mohd-Nasir et al., 2022)

C. siliqua stands as a quintessential model within ethnobotanical and phytopharmacological research, embodying a convergence of ancestral biocultural knowledge and cutting-edge biomedical science. Its extensive phytochemical repertoire—characterized by a rich assemblage of polyphenols, dietary fibers, and bioactive metabolites—underpins a broad pharmacodynamic spectrum encompassing antioxidative, antiproliferative, antidiabetic, anti-inflammatory, and antimicrobial effects. The corroboration of traditional medicinal claims through rigorous in vitro, in vivo, and clinical studies attests to its therapeutic versatility and substantiates its candidacy as a source of novel bioactive compounds.

The strategic integration of C. siliqua derivatives into pharmaceutical and nutraceutical industries not only valorizes its ethnobotanical legacy but also underscores the imperative for systematic standardization in extraction protocols, bioavailability enhancement, and formulation science. Advancing this domain necessitates a multidisciplinary approach that synergizes ethnobotanical insights, metabolomics, molecular pharmacology, and agronomic optimization to unravel mechanistic pathways and maximize clinical efficacy.

Prospective research endeavors should focus on high-resolution characterization of active constituents, elucidation of molecular targets, and comprehensive toxicological profiling, supported by well-designed randomized controlled trials. Furthermore, sustainable cultivation practices aligned with conservation biology principles will ensure the preservation of genetic diversity and ecological resilience. In integrating traditional wisdom with contemporary scientific rigor, C. siliqua epitomizes the paradigm of harnessing plant biodiversity to address pressing global health challenges and foster innovative natural therapeutics.

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AUTHOR CONTRIBUTIONS

Sabour Alaoui Sanaa was responsible for research concept and design, collection and/or assembly of data, data analysis and interpretation, writing the article, critical revision of the article, and the final approval of the article.

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The authors declare no conflict of interest.

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