beverages

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Review

Carob-Based Functional Beverages: Nutritional Value and Health Properties

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Abstract: Functional carob beverages have recently attracted consumer attention as a natural and sustainable alternative due to their excellent nutritional profile and associated health benefits. Derived from the pods of the carob tree (*Ceratonia siliqua L.*), which thrives in Mediterranean regions, these beverages are naturally sweet, caffeine-free, and rich in bioactive compounds, including polyphenols, dietary fiber, and essential minerals. This review highlights the nutritional composition of carob beverages, noting their high fiber content, antioxidant capacity, and lack of stimulating alkaloids, making them an ideal option for health-conscious consumers. The manufacturing processes, phytochemical properties, and sensory qualities of carob beverages are discussed, along with their potential roles in promoting digestive, cardiovascular, and metabolic health. The growing interest in carob reflects broader trends in sustainable food systems and plant-based nutrition, positioning carob beverages as a promising choice in the functional beverage industry.

Keywords: antioxidants; fibers; polyphenols; carob juices; gut health

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1. Introduction

Carob (*Ceratonia siliqua L.*), an evergreen tree belonging to the Fabaceae (or Leguminosae) family, is native to the Mediterranean region and known for its remarkable resilience in harsh environments [1]. Due to its ability to adapt to drought and thrive even in poor soils, this plant requires low input management and has interesting agro-ecological characteristics, which favor its cultivation in territories with limited agronomic resources. Traditionally, the carob tree has been cultivated for its edible fruits, commonly called locust beans, which have always been used as a food resource for both humans and livestock, especially in times of low food availability. The world's largest producers of carob include countries such as Portugal, Italy, Morocco, and Turkey [2]. In the food industry, the seeds of carob pods are processed to make carob bean gum (locust bean gum (LBG), E410) additive, widely used for its stabilizing and densifying abilities, for beverages and desserts [3]. In recent years, however, interest in carob has also extended to the pod pulp, which makes up the bulk of the fruit and contains numerous bioactive compounds, making it a promising ingredient in many innovative food products [4]. This trend reflects the increasing focus on sustainable and environmentally friendly foods that enhance local resources. Carob is a valuable resource for the food industry in the production of functional foods due to its chemical profile. The bioactive compounds found in carob pulp, such as flavonoids, polyphenols, anthocyanins, phenolic acids, essential oils, carotenoids, vitamins, and minerals, give it remarkable nutritional properties and health benefits [5]. The pulp, characterized by a naturally sweet flavor and a nutritional profile comparable to that of cocoa, has attracted the interest of the food industry in the production of snacks, baked goods, yogurt, and functional beverages. These beverages are emerging as a promising segment in the food industry because of the potential health benefits they offer [4]. Free of caffeine and theobromine, carob is a viable alternative to cocoa, ideal for those seeking an option without alkaloid stimulants [6]. Carob's functional properties also include antioxidant, anti-inflammatory, antidiabetic, and cardioprotective activities, making it particularly attractive to health-conscious consumers. This review aims to provide a detailed overview of carob-based beverages, analyzing their nutritional and functional characteristics and discussing the potential health benefits associated with consumption of this fruit.

2. *Ceratonia siliqua* L.: Botanical Characteristics

The carob tree (*Ceratonia siliqua L.*) is a dioecious tree belonging to the Fabaceae family, subfamily Caesalpinoideae, order Fabales, and class Magnolipsida [7]. It is considered a resilient and versatile tree species native to the Mediterranean basin, which has attracted scientific interest for its ability to thrive in arid conditions and for its extensive uses in food, agriculture, and pharmacology [1]. In recent decades, the carob tree has spread to some areas with a Mediterranean-like climate, such as California, South America, South Africa, Argentina, Australia, and India, in the plateaus and medium-high mountains up to 1700 m above sea level [8,9]. This plant can be grown even in nutrient-poor and dry soils, thanks to its deep root system, which allows it to survive even in very arid, clayey, rocky, and calcareous areas, with a pH from 6.2 to 8.6 [8,10,11]. Owing to its resilience characteristics, it has always been considered not only an economic source for human and animal food, but also an ideal candidate for reforestation and soil conservation in the Mediterranean regions [12]. The carob tree is an evergreen tree, and its leathery leaves are 11.62 cm to 18.60 cm long, with a very thick single-layered upper epidermis that reduces water loss. The inflorescences are small reddish clusters without petals; flowering occurs from August to November. Fruit growth is slow and generally takes between 9 and 10 months to reach maturity and produce a dark or black fruit between July and September [8,13]. The fruit, which is the main raw material used in the industry, is a brown, indehiscent pod with irregular edges, elongated, straight or curved (10.10 cm to 20.34 cm long and 1.46 cm to 2.38 cm wide), and is mainly composed of three parts: the epicarp, the mesocarp, and the seeds (8 to 16 seeds in each pod). The pulp is the seedless part of the carob pod, of which the outer leathery layer is called the pericarp, and the inner region is called the mesocarp. The seeds are very hard and brown with a flattened, ovoid, biconvex shape; they are located transversely to the pod and separated from each other by succulent partitions [8,9,14]. Carob has a global production of about 191,355.64 tons per year [8]. Morocco supplies about 50% of global exports, followed by Spain with 18%, while Turkey and Italy contribute about 5% each [8].

3. Health Benefits

The carob tree is known for its many functional properties and health benefits derived from its different components: pod, pulp, and seeds (Figure 1). These components are used in various fields, from nutrition to the food and pharmaceutical industries. Carob contains about 80% carbohydrates, of which sucrose, glucose, maltose, and fructose are the main ones. The protein content is estimated at about 7%, while the fat content is 2% [15]. It is particularly valued as a source of fiber, polyphenols, and galactomannans, making it suitable for both food uses and as a supplement for cardiovascular health, weight management, and digestion support, and highly versatile and beneficial for human health.

Figure 1. Carob pod constituents (whole pods, carob pulp, and carob seeds).

3.1. Pod Pulp

Pulp represents the main part of the carob fruit (about 90%). The chemical composition of carob pulp varies according to different genetic, environmental, and climatic factors [5]. A recent study by Simsek et al. analyzed the amino acid and sugar content [16]. Protein content ranged from 6.09% to 9.08%, depending on the harvest periods, and total amino acid content ranged from 3.87 to 8.21%; 57% of the total amino acids in the pulp are aspartic acid, glutamic acid, alanine, leucine, and valine. The same authors found a high sugar content, with 50–65% sugars, especially fructose, sucrose, and glucose (40.26%, 31.42%, and 17.69%, respectively), which makes it a valid alternative to sugar and cocoa [17]. Nasar-Abbas et al. have shown it has a high crude fiber content (up to 40%), mainly cellulose and hemicellulose, but is poor in fats (0.5–0.7%) and ash (1.5–2.4%) [18,19]. Several clinical studies have shown that carob fiber improves lipid parameters in humans. According to Ruiz-Roso et al., consumption of carob fiber (4 g/day) as a dietary supplement for 4 weeks by volunteers with hypercholesterolemia improved plasma lipid parameters, including total cholesterol, LDL cholesterol, LDL-C/HDL-C ratio, and triglycerides (by 17.8%, 22.5%, 26.2%, and 16.3%, respectively) compared to the placebo group [20]. Similar results were shown by Zunft et al. in a double-blind (placebo-controlled) clinical study, in which consumption of 15 g/day of carob fiber for 6 weeks lowered LDL cholesterol by 10.5% [21]. Another important compound found in carob pulp is D-pinitol (3-o-methyl-d-chiro-inositol), a cyclic polyol with antitumor, antidiabetic, antioxidant, and anti-aging properties [22]. A recent study on D-pinitol and cellular insulin sensitivity indicated that this inositol has the ability to inhibit insulin secretion from rat pancreatic beta cells (INS 1) incubated with a high glucose medium (11 mM). The mechanism of inhibition is probably due to the blockading of ERK1/2 phosphorylation, thus reducing insulin gene expression [23]. In addition, recent studies have shown that polyphenols present in carob pulp, such as gallic acid, flavonoids, condensed tannins, and proanthocyanidins, contribute to reducing the risk of cardiovascular diseases and tumors due to their ability to neutralize free radicals [24,25]. A study by Rahal El Kahkahi et al. found that the dietary fiber in carob helps reduce LDL cholesterol levels, and lipid levels, decreasing the risk of atherosclerosis and other cardiovascular diseases [8]. The pulp is also a source of tannins, compounds that promote better digestion and have astringent effects that can help with gastrointestinal disorders, including diarrhea [1] (Tables 1 and 2).

3.2. Carob Seeds (Locust Bean Gum)

Carob seeds constitute 10% of the pod weight and are particularly known for producing carob gum, a natural thickening and stabilizing agent with numerous applications in the food, pharmaceutical, cosmetic, and biotechnology sectors, approved as a food additive worldwide (E410) [26–28]. This polysaccharide is rich in galactomannans, known for their ability to absorb water and form gels. Galactomannan is a natural polymer consisting of galactose and mannose in a ratio of 1:4, comprising approximately 80% of the endosperm weight [29].

Carob gum has high nutritional values: 10–12% moisture, 5% protein, 1.0% ash, 1.0% crude fiber, 0.5% fat, and 80–85% galactomannan, and is therefore widely used in the food industry as a natural thickener in ice creams, creams, and yoghurts, reducing the need for artificial additives and improving the texture of products [2,27]. Galactomannans in the seeds also slow glucose absorption, which is important for blood sugar control and type 2 diabetes management, and the high fiber and complex polysaccharide content in carob seeds also acts as a prebiotic fiber, promoting gut health and helping prevent constipation [30]. Furthermore, carob seeds are a valuable source of phenolic compounds and antioxidants, and contain high concentrations of macro and micro minerals such as Ca, Fe, Mg, and Zn [24,31] (Tables 1 and 2).

3.3. Whole Pod

The entire pod is often processed to create carob flour, a naturally sweet flour, excellent for those following a diet free of refined sugars or cocoa. It also provides a quick source of energy but is free of caffeine and theobromine, making it an option for those on a stimulant- and allergen-free diet [28,32]. Examples of food uses include using carob flour as a substitute for cocoa in baking or in beverages and mixing it with other cereal products [6]. This flour is also used to produce carob syrup, a natural source of sugar [4,33]. The carob pods contain 1–6% minerals [34], mostly calcium, potassium, magnesium, sodium, phosphorus, copper, zinc, and iron [35], considerable amounts of soluble dietary fiber, water-soluble tannins, flavonol glycosides (mainly quercetin-3-O-rutinoside, quercetin-3-O-glucoside, quercetin-3-O-galactoside, kaempferol-3-O-glucoside, myricetin-3-O-galactoside, and myricetin-3-O-glucoside), and gallic acid [36,37]; as demonstrated by Youssef et al. [15], carob flour is rich in vitamins E, D, C, niacin, B6, and folate, but also contains high levels of the cyclic polyol D-pinitol, and monosaccharides [38,39]. A study by Fidan et al., found that carob flour had high amounts of protein (22.56%) and dietary fiber (28.17%) [40], which can help prolong the feeling of satiety, supporting weight management and improving metabolism. The flavonoids contained in the pod have anti-inflammatory properties, potentially beneficial for chronic inflammatory conditions [5]. The study by Benchikh et al. [41] demonstrated that the antioxidant activity of carob pods decreases proportionally with ripening. Similar results were also shown by Saci et al. [42], suggesting that unripe carob is an important source of antioxidants such as total phenolics, total flavonoids, and ascorbic acid. In addition to antioxidant activity, a study by Rtibi et al. [43] demonstrated the ability of aqueous extract of carob pods to scavenge reactive oxygen and free radicals by inhibiting myeloperoxidase (MPO) activity in a concentration-dependent manner, but also antioxidant, antidiarrheal, antibacterial, antidiabetic, hypoglycemic, glucose anti-absorbent, anti-inflammatory, and antiulcer effects. Qasem et al., demonstrated the ability of methanol extract of unripe pods of *C. siliqua* to inhibit enzymatic carbohydrate metabolism, mainly α-amylase (IC50 = 92.99 $\pm$ 0.22 µg/mL) and α-glucosidase (IC50 = 97.13 $\pm$ 4.11 µg/mL) activities [44]. The work of Custodio et al. [45] reported the in vitro inhibitory activity of aqueous decoctions of carob on α-amylase and α-glucosidase, 74% and 97%, respectively, at 1 mg/mL, and attributed such pharmacological actions to its antioxidant activity, which scavenges free radicals and/or inhibits lipid peroxidation. All leaf decoctions had a significantly high total phenolic content, mainly gallic acid in leaves and gentisic acid in stem bark. Chait et al. detected ten phenolic acids (gallic acid, p-hydroxybenzoic acid, hydroxycinnamic acid, caffeic acid, p-coumaric acid, ferulic acid, sinapic acid, protocatechuic acid, vanillic acid, and syringic acid), and six flavonoids (quercetin, kaempferol, myricetin, catechin, epicatechin, and rutin) in soluble and insoluble fractions, and demonstrated the inhibitory effect of carob powder on α-amylase and α-glucosidase activities, concluding that these carob phenolic compounds could affect glucose metabolism by inhibiting carbohydrate digestion. [25]. Rtibi et al. also evaluated the reduction of intestinal glucose absorption of an aqueous extract of unripe carob pod, confirming that the phytochemical composition, mainly polyphenols and flavonoids, may be responsible for hypoglycemic effects, also due to the high content of fiber and complex carbohydrates in carob pods [46,47]. Macho-González et al. evaluated the antidiabetic and hypoglycemic capacity in vivo of carob. A reduction in intestinal carbohydrate absorption in mice was highlighted, probably due to the inhibition of sodium–glucose transporter-1 (SGLT1) by condensed tannins [47]. By the same authors, the protection and regeneration of pancreatic β cells and the increase in insulin secretion were also evaluated as antidiabetic mechanisms of carob pod extract in a rat model of type 2 diabetes mellitus with an increase in hepatic glycogen synthesis, mediated through PI3K/AKT/GSK3 signaling pathways [48]. Carob pods are also a rich source of D-pinitol, which has an important role in modulating the insulin signaling pathway [49,50]. In several studies, carob fruit extract has been reported to have potential health benefits, including reducing LDL levels in hypercholesterolemic patients and postprandial hyperglycemia, with a beneficial effect on body weight and improving lipid digestion and utilization [48,51,52]. Macho-González et al. also found that carob extract significantly reduced pancreatic lipase activity in vitro and postprandial triglycerides and cholesterol in the blood of treated rats, measured after 7 days, which is related to the ability of carob fiber to reduce fat digestibility and absorption in the intestine due to the reduced availability of bile micelles [53].

In the research of El Rabey et al., methanolic extract of carob pod powder (20% *w*/*w*) caused a reduction in serum total cholesterol, triglycerides, and LDL cholesterol, and an increase in HDL cholesterol in rats fed a high-fat, high-cholesterol diet for two months [54]. Similar values were found by Hassanein et al., where feeding rats with carob powder (10 and 20% *w*/*w*) in a diet containing 10% fat and 1% cholesterol improved the lipid profile after 6 weeks [55].

Furthermore, a study showed that insoluble dietary fiber from carob pods could reduce atherosclerosis and dyslipidemia in New Zealand male rabbits fed a high-fat diet supplemented with 3% insoluble, polyphenol-rich carob fiber. The effects were associated with increases in LDL receptor expression and hepatic lipase activity, by 42% and 91%, respectively. In addition, the expression of the enzyme involved in triglyceride synthesis, glycerol phosphate acyltransferase (GPAT), was also significantly reduced by 20.38% compared to the control group fed a high-fat diet [56].

The gastroprotective effect of aqueous extract of carob pods has also been evaluated in several studies. Rtibi et al. evaluated the ability of the extract against oxidative stress induced by acute ethanol exposure in rats, concluding that it has a protective action against acute ethanol-induced ulceration in gastric mucosa, also reducing EtOH-induced gastric lipoperoxidation and hydrogen peroxide levels, and preventing the depletion of antioxidant enzyme activity of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) [46]. In addition to the antioxidant action, the role in gastrointestinal disorders such as constipation and diarrhea was also evaluated. Rtibi, Selmi, et al. [57] studied the effects of aqueous extract on gastrointestinal transit, diarrhea, and intestinal epithelial permeability in healthy rats and mice according to maturity. They demonstrated that the aqueous extract of immature carob pods, with low fiber and sugar content, induced a significant decrease in gastrointestinal tract disorders and inhibition of secretions, implying a slowing of gastrointestinal transit. Rtibi et al. also demonstrated that the aqueous extract of unripe pods also had a dose-dependent hypoglycemic effect in alloxan-induced diabetes in rats, probably due to the inhibition of glucose absorption in the intestine by phenolic molecules, tannins, and fibers contained in the extract [58]. These results are very similar to those obtained by Qasem et al., where the glycemia was reported in diabetic rats induced by intraperitoneal injection of streptozotocin–nicotinamide and gavaged with methanolic extract of immature carob pods [44]. Also, in the study by Hussein et al., carob powder reduced the blood glucose level (115.94 ± 1.69 mg/dL) compared to the diabetic control group (649.23 ± 1.81 mg/dL) [59]. Aboura et al., also studied the protective effect of carob in ulcerative colitis, demonstrating that the high polyphenol content of carob fruit prevented colon shortening and reduced the severity of colonic lesions and biochemical alterations [60] (Tables 1 and 2).

Table 1. Health benefits of carob components.

	Health Benefits	References
Pod Pulp	Antitumor	[20–22]
	Antidiabetic	[20]
	Antioxidant	[20]
	Anti-aging	[20–22]
	Cardiovascular health	[8,21,22]
	Gastrointestinal health	[1]
Carob seeds	Food additive	[2,23,24]
	Antioxidant	[21]
	Gut health	[26,27]
Whole pod	Food additive	[4,6,15,24,28]
	Antioxidant	[22,31,32,35–37,39,41,48]
	Gut health	[34,35,41,48]
	Anti-inflammatory	[5,37]
	Antiradical	[38,39]
	Antibacterial	[38]
	Hypoglycemic	[22,38,39,41,43,44]
	Antiulcer	[38,48,49]
	Antidiarrhea	[38,48]
	Cardiovascular health	[41,44–47]

Table 2. Main bioactive compounds present in carob.

Bioactive Compounds	Effect on Health	References
Gallic acid, cinnamic acid, epigallocatechin, catechin, quercetin, myricetin, kaempferol, rutin	Antioxidant, anti-inflammatory, antibacterial, antitumoral, cardiovascular effects	[24,25,42,43]
Tannins	Antidiarrheal and cardiovascular effects	[1,24]
Galactomannan, cellulose, hemicellulose	Gastrointestinal effects, hypocholesterolemic, hypolipidemic, antidiabetic	[8,20,21,30]
D-pinitol	Antidiabetic, antitumoral, antioxidant, anti-aging, hypoglycemic	[22,23]
Flavonol glycosides	Hypocholesterolemic	[39]

4. Carob's Safety

Carob is traditionally used for the treatment of various disorders. Different portions of carob have shown many biological activities due to the presence of bioactive compounds (Table 1). However, only a few clinical studies have shown the effects of carob, and its mechanisms of action have not been sufficiently investigated. Consequently, little is also known about the safety of carob. In the literature, there are animal studies where the effects of different administrations of various portions of carob were investigated [44,61]. In all cases, the animals, both male and female, never showed symptoms of toxicity. The administration of various percentages of carob in animals never resulted in organ damage or behavioral changes. In the study of Sadegh et al., mice showed ataxia and hypoactivity when treated with higher doses of 2 g/kg carob extract [62]. In no case was animal mortality recorded. Most in vivo studies showed a good level of safety of carob and its use.

5. Potential Use in Food Processing

In recent years, carob has been shown to be a promising option for the food industry, especially to produce functional foods [5,63,64]. Due to its physicochemical composition, carob is suitable for improving the nutritional value of several food products [3]. Carob derivatives that can be used by the food industry include carob pulp flour, carob gum (or carob seed gum), a natural thickener, and carob syrup [65].

Carob pods are rich in natural sugars, such as sucrose, glucose, and fructose. They are also a significant source of insoluble fiber, which promotes digestive health. The polyphenol content, including phenolic acids and flavonoids, gives antioxidant and anti-inflammatory properties, helping to reduce the risk of cardiovascular disease and protecting against some tumors [66]. Carob also contains compounds that may have antidiabetic and cholesterol-lowering effects, helping in managing blood sugar and reducing LDL cholesterol [67]. Several recent studies have highlighted the usefulness of carob and the possibility of using it to produce functional foods. It is important, however, to fully understand the physical and chemical properties of carob derivatives to effectively exploit them as functional ingredients in the food industry [4,24]. Due to the high presence of sugars, moreover, carob can be used as a natural sweetener, which is the reason why it easily finds great application in the production of desserts, functional energy bars, and spreadable creams [68,69]. Studies on pastries made with carob flour showed that carob positively influenced the nutritional and sensory quality of the final product [70,71]. In the study by Pawłowska et al., it was evaluated how carob could replace cocoa in muffin production [72]. In addition, these muffins had higher antiradical activity, as well as higher levels of genistein and phytosterols. The sensory quality of the muffins with carob was also found to be positive, indicating that the use of carob in bakery products can be an economical alternative to cocoa. Muffins with carob were found to be sweeter than those with cocoa only. This aspect is significant because it implies that the use of carob could reduce the amount of sugar needed in the preparation of desserts, supporting the production of healthier products than the traditional ones on the market. In addition, the possibility of substituting carob for cocoa in various products could be an excellent strategy for innovative products with excellent nutritional and sensory properties [6]. Carob powder contains lower amounts of fat and significantly higher amounts of dietary fiber than cocoa. The lower fat content reduces calorie levels, while the high dietary fiber, combined with unique polyphenolic compounds, provides numerous health benefits. Replacing cocoa powder with carob powder also results in the minimization of alkaloids, such as theobromine and caffeine [4]. In addition, if it undergoes a roasting process, carob acquires a cocoa-like aroma, which makes it more acceptable to consumers' taste [33,73].

Carob is also increasingly appreciated as an alternative ingredient for gluten-free preparations in the baking industry [74]. Carob flour improves the texture, volume, and sensory quality of gluten-free products, making them closer to traditional versions. It also adds nutrients beneficial for a balanced diet and meets the needs of those with celiac disease [3]. Several researchers have studied the effect of incorporating carob flour into various gluten-free products, such as cakes, breads, and snacks [70,74,75]. Martin-Diana et al. developed a gluten-free cracker through the addition of carob by-products (seed germ and seed husk) [76]. The inclusion of high levels of these two by-products increased protein content and antioxidant activity, although it produced an increase in hardness and a change in the expected color of the product. Carob can be used also as a natural additive due to the polysaccharide in its seeds, particularly galactomannan [24,67]. This compound enhances texture, replaces artificial additives, and provides a more sustainable alternative [77]. Galactomannan also promotes satiety, helping to control calorie intake, while its viscosity slows carbohydrate absorption, supporting stable blood sugar levels. In many countries, galactomannan extracted from carob seeds is approved as a food additive under the designation E410 [78]. It is mainly used as a thickener, stabilizer, and emulsifier in many food products, including ice cream, yogurt, desserts, and sauces, due to its ability to improve texture and consistency. Galactomannan, being of natural origin, is considered a healthier and more sustainable alternative to synthetic additives, posing no risks when consumed in recommended amounts. Its use in food products provides not only nutritional benefits but also a safer, more eco-friendly option.

Carob also has considerable application in the dairy industry, especially in the production of fermented products, such as kefir and yogurt [79,80]. In the study by Arab et al., the incorporation of carob flour effectively improved the antioxidant potential of yogurt, which is not usually a source of phenolic compounds [81]. The addition of carob flour also promoted the growth of the probiotics by 15.96% during cold storage. In kefir production, the presence of carob increased bacterial counts during the first week of storage, showing inulin-like prebiotic activity [82,83].

These findings demonstrate that carob can serve as a versatile and healthy ingredient in the production of functional foods aimed at promoting physical well-being and reducing the risk of diet-related diseases. Carob's unique composition enhances the nutritional, sensory, and functional qualities of food products. Its versatility offers significant nutritional and technological benefits, making it an ideal ingredient to meet the growing demand for natural, healthy, and functional foods [84]. However, ongoing studies are evaluating the presence of 5-hydroxymethylfurfural (HMF) in carob-based confectionery products, which could limit their daily consumption [36]. HMF is a known indicator of quality degradation and can form during processing. It is associated with harmful effects, including mutagenic, carcinogenic, and cytotoxic properties [85]. Since carob typically undergoes thermal processing, such as roasting, before being incorporated into food products, this issue warrants careful consideration. There are studies in the literature evaluating the HMF content in carob products [36,86]. This value was always well below the legal limit (40 ppm) [85], but we believe it is nevertheless important to bring this aspect to light, which should be considered if a carob-based food product is to be produced [87,88].

6. Carob-Based Beverages

Due to the growing demand for natural and sustainable alternatives in functional beverages [4,84], carob, known for its natural sweetness, rich dietary fiber, and bioactive compounds, gives beverages an interesting nutritional profile and a naturally sweet and aromatic taste [89]. Carob beverages, free from caffeine and theobromine, offer a viable alternative to traditional drinks, catering to the specific needs of various consumer groups, including the elderly, children, and individuals with hypertension or food intolerances [64]. In Mediterranean and Middle Eastern regions, carob has historically been used to produce beverages such as kharrub in Morocco, jallab in Syria, and carob juice in Egypt [90–92]. In these regions, carob-based beverages have historically been used in folk medicine for their nutritional and therapeutic properties [93]. Indeed, although carob is not formally recognized as a medicine in modern Western practices, it has been widely used in traditional

Eastern cultures to treat various ailments, thanks to its nutrient-rich composition, fiber, antioxidants, and minerals [94]. There are also alcoholic drinks and liquors from the carob, such as aloja, typical of Argentina [95].

In addition to the preparation of juices and sweet drinks, carob has also historically been used to produce fermented beverages, due to its high concentration of simple sugars, which makes it ideal as a substrate for fermentation by microorganisms [96,97]. Fermentation further amplifies carob's nutritional and functional benefits, as recent studies [98] have shown, highlighting improved antioxidant and nutritional properties in fermented carob-based beverages. In fact, numerous studies in the scientific literature focus on the industrial fermentation of carob [99,100]. An exciting development in functional beverages is the emergence of carob-based probiotic drinks, which support gut health [101].

Thanks to its prebiotic properties, carob promotes the growth of beneficial gut bacteria, improving microbiota balance and enhancing the bioavailability of minerals and antioxidants [102]. Carob-based beverages meet the needs of a market increasingly oriented toward healthy food options.

The adoption of carob in beverage production can also contribute to sustainable development goals using local ingredients and the enhancement of environmentally friendly crops.

6.1. Production of Carob Beverages

Most carob preparations are artisanal blends following traditional recipes [95,103]. Carob-based beverages can be obtained by various methods, such as infusions or concentrated extracts, and can be further modified in terms of density and sweetness to obtain a variety intended for a range of consumer tastes [104]. The selection of the method for each production step is important to obtain a high-quality, good-tasting beverage. Generally, the production process (Figure 2) starts with the selection and cleaning of the carob pods, followed by a possible roasting process, grinding, and filtration. Roasting the carob pod before extraction is a common practice, as the Maillard reaction that occurs during heating intensifies the aroma and enriches the flavor profile of the beverage [36]. In addition, roasting allows the astringency caused by the tannins in carob to be reduced, improving the drink's pleasantness without compromising its health characteristics [104]. Table 3 summarizes possible methods to prepare carob-based beverages found in the literature.

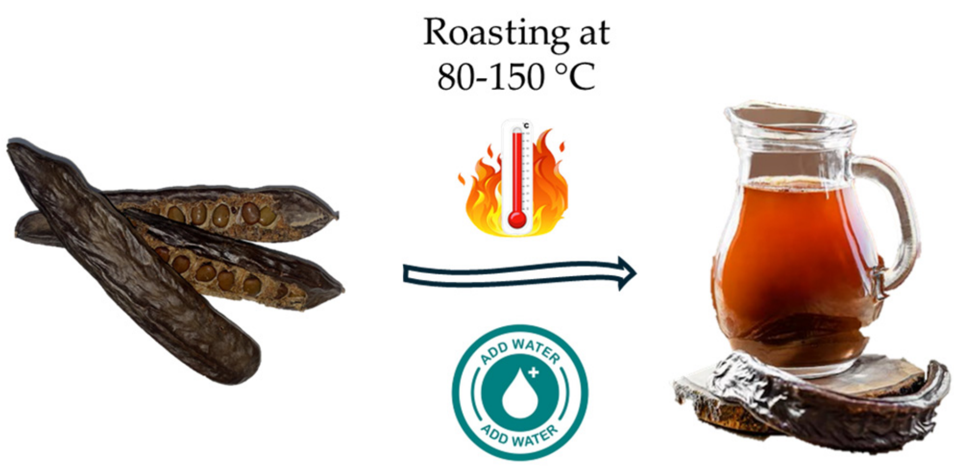

Figure 2. Main production steps of carob-based beverages.

Table 3. Possible methods to produce carob-based beverages.

Name	Origin	Production Method	References
Carob pulp beverage	Laboratory	Crush, clean, and dry carob pulp at 80 °C for 18 h, then mill. Combine 750 g pulp powder with 4 L water, heat to 80 °C for 60 min. Filter, sweeten, and pasteurize at 110 °C for 10 min. Store at 4 °C.	[19]
Kharrub	Morocco	Mix carob pulp with water. Heat to 80 °C while stirring for 45 min. Filter and cool.	[77]
Jallab	Syria	Boil the ingredients. Filter and serve with ice.	[78]
Aloja	Argentina	Crush pods with a pestle and soak in the dark for over 48 h.	[82]
Carob water kefir	Laboratory	Boil, filter, and pasteurize carob; add sucrose for sweetened version. Ferment water kefir (48 h). Add kefir to carob, ferment anaerobically (48 h). Store at 4 °C (up to 28 days).	[84]
Fermented carob milk	Laboratory	Reconstitute and sterilize skim milk. Inoculate with *Lactococcus lactis* C15 and *Lactobacillus brevis*. Add 4% carob. Incubate at 30 °C (16 h), store at 4 °C (28 days).	[85]
Carob-based fermented drink	Poland	Roast carob at 130 °C and mill. Mix with other ingredients, boil (5 min), cool, and filter. Inoculate and ferment at 27 °C (4 h), then 34 °C (4 h). Cool.	[89]
Carob-based dairy drink	Laboratory	Toast whole pods (150 °C, 60 min) and crush. Mix ingredients, heat to 75 °C (2 min). Filter and store at 4 °C.	[91]
Carob juice	Laboratory	Wash, drain, and air-dry carob fruits (2 h); separate seeds. Mix pulp with water (1:2), stir at 43 °C (160 min). Centrifuge to separate juice. Pasteurize juice (63 °C, 30 min). Store at 4 °C.	[92]

6.2. Bioactive Compounds in Carob-Based Beverages

The composition of carob beverages can vary depending on whether the whole pod, the pulp alone, or the seed is used in their production. Comparing the data in the literature, it is possible to see differences in the chemical composition according to the manufacturing processes [15,105,106]. In carob-based beverages, phenolic content is typically elevated, likely due to the dispersion of these compounds in the liquid form. Generally, all carob beverages have a high presence of total polyphenols, significantly higher than other fruit-based beverages on the market (compare carob at 100 mg GAE/100 mL vs. orange at 45 mg GAE/100 mL vs. pineapple at 35 mg GAE/100 mL, and vs. grape at 51 mg GAE/100 mL) [19,107]. In addition, it was seen that beverages produced by roasting carob had significantly higher amounts of total phenolic content (TPC). Roasting induces the breakdown of cell structures, which could have allowed the release of phenol and products of the Maillard reaction. Differences between drinks in phenolic compound content may be related to the variety used. In the study by Solana et al., the Galhosa, Mulata, and Aida varieties showed the highest TPC and the highest antiradical activity [108]. However, the determination of TPC using the Folin–Ciocâlteu test, as reported, may give an overestimated result. This test could also detect products with phenolic-type structure derived from the Maillard reaction that occurs during roasting. Therefore, it would be better to evaluate the presence of phenolics by other methods to see the real antioxidant and nutritional potential of carob beverages. In an HPLC analysis of the phenolic composition of milk fortified with carob, good values of gallic acid, chlorogenic acid, and rutin were found [98]. Similar results were obtained by Gülhan et al., who measured high values, mainly of gallic acid, in a water kefir prepared with carob [97]. The same had good amounts of minerals, especially for P, K, Mg, Ca, S, Fe, and Na. Studies in the literature only evaluate the phenolic profile and antioxidant activity of carob beverages produced so far. It would be interesting in the future to obtain results on other chemical–physical parameters of these products as well, given the interesting nutritional profile of carob.

6.3. Sensory Evaluation

The organoleptic properties of carob beverages are closely related to the chemical composition of the pod, which is rich in natural sugars, fiber, phenolic compounds, and tannins [19]. These components contribute to the beverages' distinct sweet flavor, balanced by moderate astringency. Tannins, present in significant amounts in carob pods, are primarily responsible for the astringent and slightly bitter taste of these beverages [19,90,109]. However, the strong astringent taste impact, although resulting from the natural chemical profile of carob, may be undesirable to some consumers [110]. Studies by Soares et al. suggest that despite the beneficial characteristics associated with carob's bioactive compounds, the excessive presence of tannins imparts a bitter note, thus reducing the product's acceptance in certain applications [111]. In Rababah et al.'s hedonic evaluation tests, for example, carob juice received an average score of more than 7 on a scale of 1 to 9, establishing it as a beverage valued for its overall quality and palatability, despite its contrasting sweetness and astringency [109]. The flavor notes of carob beverages can include tones that develop especially if the pod is subjected to a roasting process. This process changes its bittersweet intensity through Maillard reactions, and the flavor profile varies significantly depending on the variety of the fruit, processing techniques, and growing conditions [36]. Flavors are derived in part from volatile compounds, such as aldehydes and ketones, which contribute to this range of aromatic nuances [112]. Srour et al. showed that both carob variety and roasting treatment have a significant effect on the sensory properties and acceptability of these products [104]. In their study, beverages formulated with roasted carob powder had higher acceptability scores. From these results, they recommended using only roasted carob powder for beverage production due to the great effect roasting has on sensory attributes to obtain a satisfactory beverage for consumers. Furthermore, the varieties Baladi Ikleemel Kharoob (BIK) and Akkari (AK) gave higher sensorial values. The simple sugars present in carob, such as glucose, fructose, and sucrose, provide sweetness, which balances the astringency from tannins [66]. Polyphenols, including catechins and procyanidins, further intensify astringency and introduce bitter notes [113]. From the panel test carried out in another study, the incorporation of different concentrations of carob pulp powder to the cocoa drink did not please panel members compared to the control [64]. However, in another study in which cacao was also replaced with percentages of carob, it was highlighted that sensory acceptability was good depending on the sucrose concentration (in particular, a concentration between 13 and 21.41% gave a higher acceptance) [114]. Regarding texture, the fiber content, particularly of galactomannans, is responsible for the viscosity and perceived "body" of the beverage [115]. The food industry's interest in these beverages is motivated by their potential for health. However, it is important to modulate the sensory profile of the beverage according to consumer preference.

7. Conclusions

The high content of bioactive compounds in the carob fruit and its components make carob products innovative ingredients that can potentially be used in the development of a wide range of health-beneficial food products.

Applications of carob in industrial nutrition and health require further study to assess the real potential effect this plant provides. Moreover, even though carob pulp and seeds are the most widely used products, other parts could be evaluated for commercial use. For example, carob leaves are rich in tannins that could be targeted for various uses, including pharmaceutical applications. Carob processing waste could also be valorized. Furthermore, the cultivation of carob in arid and semi-arid areas could be encouraged because it would offer economic benefits to farmers, improve the soil. and contribute to environmental sustainability through carbon sequestration and the protection of biodiversity. In this way, a carob crop will promote economic development, stimulating the production of innovative and alternative products, as well as contributing to the protection and enhancement of plant biodiversity.

Although the availability of carob-based beverages is limited compared to other plant-based alternatives, they represent a growing segment with high potential for future development and a good response from consumers aware of the functional benefits and nutritional properties offered by this versatile plant. The growing interest in carob beverages reflects the trend towards sustainable and plant-based food systems, positioning carob as a promising choice in the functional beverage sector to integrate into mainstream markets. Advances in processing and flavor enhancement, particularly through optimized roasting techniques, could improve the sensory appeal of carob beverages, attracting a broader consumer base. Functional carob beverages have an excellent nutritional profile and are naturally sweet, caffeine-free, and rich in bioactive compounds, including polyphenols, dietary fiber, and essential minerals, and have a great impact on health, particularly cardiovascular, metabolic, and digestive health.

The lack of stimulant alkaloids makes them an ideal option for consumers. Additionally, the potential to develop new formulations, such as carob-based blends with other plant-based ingredients, fortified versions, or functional enhancements targeting specific health benefits, could position carob beverages as a versatile choice in the functional beverage sector.

Further future studies examining these benefits are needed to promote carob beverages as a staple in health-conscious and environmentally friendly diets worldwide. Although the availability of carob-based beverages is limited compared to other plant-based alternatives, they represent a growing segment with high potential for future development and a good response from consumers aware of the functional benefits and nutritional properties offered by this versatile plant.

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