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Review Article

Carob (*Ceratonia siliqua* L.) Seed Constituents: A Comprehensive Review of Composition, Chemical Profile, and Diverse Applications

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Carob (*Ceratonia siliqua* L.) is a tree species native to the Mediterranean region and belongs to the Fabaceae family. The tree is well-known for its sweet and nutritious fruits, which have been used for long time as a nutritious food. In addition to the edible fruits, the carob tree also produces seeds that are highly prized for their ability to produce carob gum (locust bean gum). The carob seed consists of three main components: the shell, the endosperm, and the embryo. The shell is the outermost layer of the seed, followed by the endosperm, which is the largest part of the seed and contains high levels of carbohydrates and proteins. The embryo is the smallest part of the seed and is rich on bioactive compounds. Carob seed constituents have attracted considerable attention due to their exceptional nutritional and therapeutic properties in various industries, including food, medicine, pharmaceuticals, cosmetics, and textiles. The high content of bioactive compounds in carob seeds, such as polyphenols, tannins, and flavonoids, is believed to be responsible for their antioxidant and anti-inflammatory properties. The use of carob seed constituents in the food industry is mainly due to their ability to act as thickeners and stabilizers in various foods. They are used as a substitute for other thickening agents such as guar gum and carrageenan, due to their superior properties. In the pharmaceutical industry, carob seeds have been found to have antidiabetic, antihyperlipidemic, and anticancer properties, among others. The cosmetics industry is also interested in the ingredients of carob seed, as they can improve hydration and elasticity of the skin. They are also used as a natural alternative to synthetic thickeners in cosmetic formulations. The textile industry has also recognized the potential of carob seed constituents, as they can be used as a natural dye and as a sizing agent to improve the strength and durability of textiles. In summary, carob seed constituents offer a wide range of applications in various industries, owing to their high content of bioactive compounds, excellent nutritional and therapeutic profile, and ability to act as thickeners, stabilizers, and antioxidants. This review has highlighted the latest findings on the chemical composition, applications, and health benefits of carob seed constituents.

1. Introduction

Ceratonia siliqua L., commonly known as carob, is a perennial tree that thrives in the Mediterranean region and the Middle East. Its distribution has extended to other tropical zones, such as Florida and California in the United States, Australia, Argentina, and Africa, as reported by Palaiogianni et al. [1] and illustrated in Figure 1. Furthermore, this botanical species can be found in several localities within Bulgaria, comprising the Black Sea shoreline, the Balkan Mountains, and the southern-central and northeastern parts of the country [2].

This plant belongs to the Fabaceae family, which is also commonly referred to as Leguminosae in the scientific community [4–6]. It grows in semiarid and arid bioclimatic zones in a variety of soil conditions, including salty soils [7]. The nomenclature of this organism has its origins in the etymology of two distinct linguistic roots. Specifically, the Greek term "kera," denoting "horn" in the context of keratomorph morphology and the Latin word "siliqua" referring to the rigidity and contour of the carob fruit have been combined to form its scientific designation [8]. The carob tree can attain a height of 8–17 meters, with a large semispherical corona and a hefty trunk covered with rough brown crust and robust branches (Figure 2(a)) [9]. The fruit of the carob is called "pod" due to the absence of right or curved, long and flattened, thickened cracks at sutures, 1.5–3.5 cm wide, 1 cm thick, and 10–30 cm long (Figure 2(b)) [4, 10]. The pulp and the seeds (90% and 10%, respectively, of the weight of the fruit) [11] present the constituents of the carob pod. The pulp consists of a pericarp (outer layer) and a mesocarp (inner region) containing the seeds (Figure 2(c)). The shell, endosperm, and embryo are the three main parts of the carob seed (Figure3). Seeds are brown, hard, and 10 mm long, weighing about 0.2 g each (Figure 4) [12, 13].

Carob pulp is the main element of the fruit and is high in sugar (48–56%). It can be used to make syrup and molasses in the agri-food industry and used as flour to substitute cocoa in cakes and ice cream and other baked goods [14, 15]. It contains dietary fiber, which can be used in the pharmaceutical field due to its many health benefits [16]. Carob pulp also contains a variety of bioactive substances, such as polyphenols, amino acids, fibres, cyclitols, and minerals [4]. The latter is an important source of macroelements such as calcium, potassium, magnesium, and phosphorus. In addition to that, it contains trace elements such as zinc, manganese, and iron [17]. According to the study conducted by Papageorgiou et al. [18], the pulp also has a high content of vitamins such as vitamins D, E, and B6 and folic acid. Meanwhile, the carob seed contains three major components: gum, polyphenols, and proteins [4]. The initial stage in the production of carob gum is to remove the shell from the seed using thermomechanical or chemical methods [19]. After the separation process, the endosperm is subjected to grinding and sieving to initiate the production of locust bean gum (LBG). This naturally occurring substance is commonly used as a food additive (E410) and has a wide range of applications in the pharmaceutical industry [20, 21]. This substance exhibits versatile functional properties such as stabilizing, thickening, and gelling, rendering it an essential ingredient in food technology. Additionally, its applicability extends beyond the food industry, finding utility in the production of pharmaceuticals, cosmetics, textiles, paints, and numerous other products [17].

The global average output of carob pod has decreased in recent years: from 165,990 tonnes in 2013 to 136,612.75 tonnes in 2018 [20]. These results are explained by a decrease in carob-growing total land area in major producers including Spain. Carob tree farming in the European Union (EU) has become unprofitable due to the introduction of less expensive LBG alternatives for instance guar gum (GG), xanthan gum (XG), and tara gum (TG), which is also used as thickener, polymer for food packaging, and binding agent [22]. However, medicinal and food business interests justify the cultivation of carob trees in many countries. As presented in Figure 5, Morocco (26.09%), Portugal (19.56%), and Turkey (19%) were the top three global producers of carob pods from 2015 to 2021 [23].

Several recent reviews have discussed the chemical composition and some extraction techniques to recover bioactive compounds from carob constituents (pulp, leaves, whole pods, and some seed constituents (carob gum)) [4, 16, 20]. Without special attention to the entire seed, the literature also lacks a critical review of the phytochemical composition of the carob seed constituents (focusing only on the endosperm given its economic importance) and the agri-food, medicinal, pharmaceutical, and other uses of these components. The uses of relevant extraction technologies for the extraction of bioactive substances from carob seed constituents other than the endosperm are envisaged. This review aims to gather all information and data concerning carob seed constituents and chemical composition on the one hand and the other hand to gather and discuss all uses and applications of carob seed constituents in the agri-food, pharmaceutical, medicinal, and other fields.

2. Carob Seed Chemical Composition

Carob seeds have a brown colour, are rather hard, measure around 10 mm in length, and weigh about 0.2 g each [12]. The carob seed was divided into three parts, as mentioned in Table 1 and illustrated in Figure 4: peel (30–35%), endosperm (40–50%), and germ (20–25%) [24].

2.1. Carob Seed Peel (CSP)

2.1.1. Chemical Composition. Insufficient data are available concerning the characteristics of carob seed husks, since only three research studies have been documented encompassing their usage. Table 2 presents the proximal composition and total soluble solids that were obtained.

The large difference in moisture values is explained by the use of different analytical methods by the authors. According to Dakia et al. [25], the CSP has a large concentration of arabinose

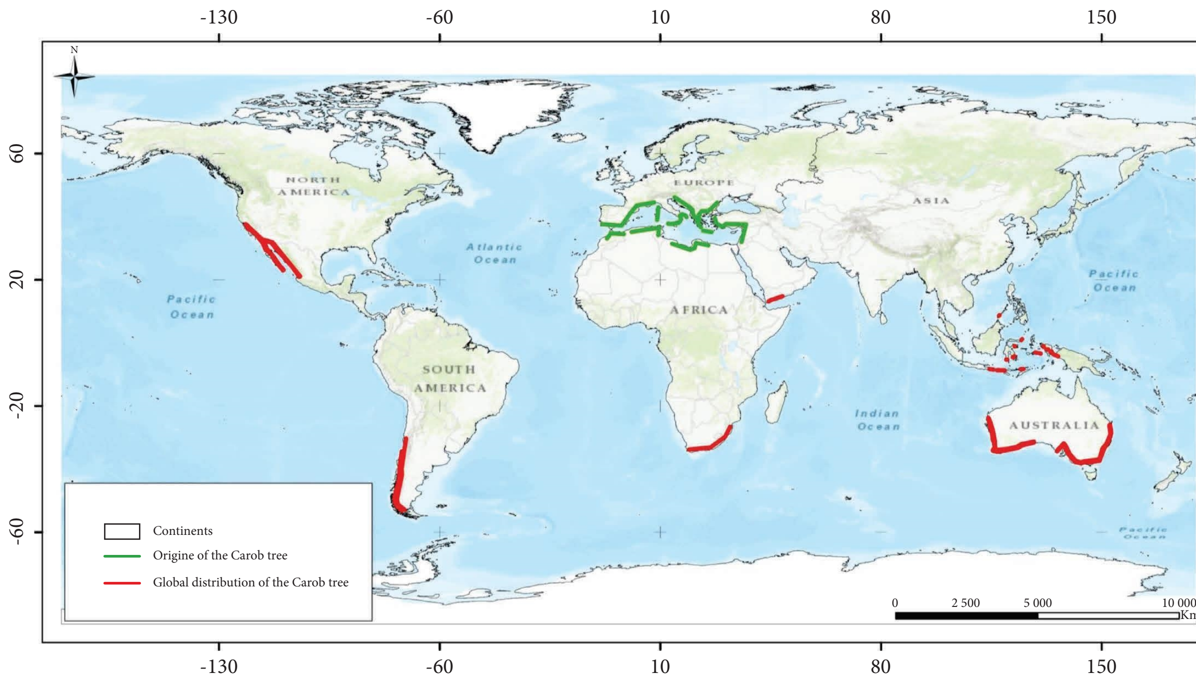

Figure 1: Geographical distribution and origin of carob. Source: Battle and Tous [3].

Figure 2: Morphology of the carob tree and its fruits. (a) The carob tree. (b) Mature carob pod. (c) Constituents of carob pod.

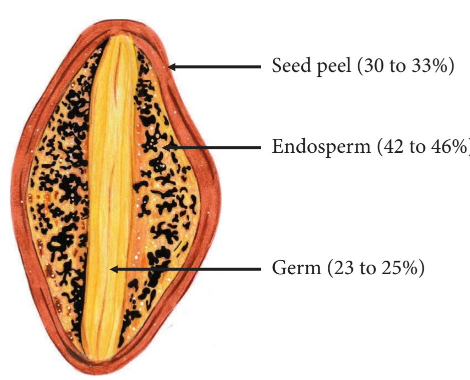

Figure 3: Carob seed constituents.

(20.29%) and xylose (6%), with lower concentrations of rhamnose (1.11%), mannose (0.67%), glucose (1.23%), and galactose (1.58%). Furthermore, it was discovered that CSP is an essential source of insoluble dietary fiber (61.64 ± 0.32%), which even exceeds the content of antioxidant-rich sub-products like apple peels [28].

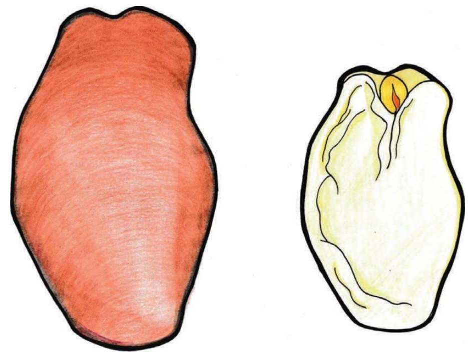

Figure 4: Morphology of the carob seed.

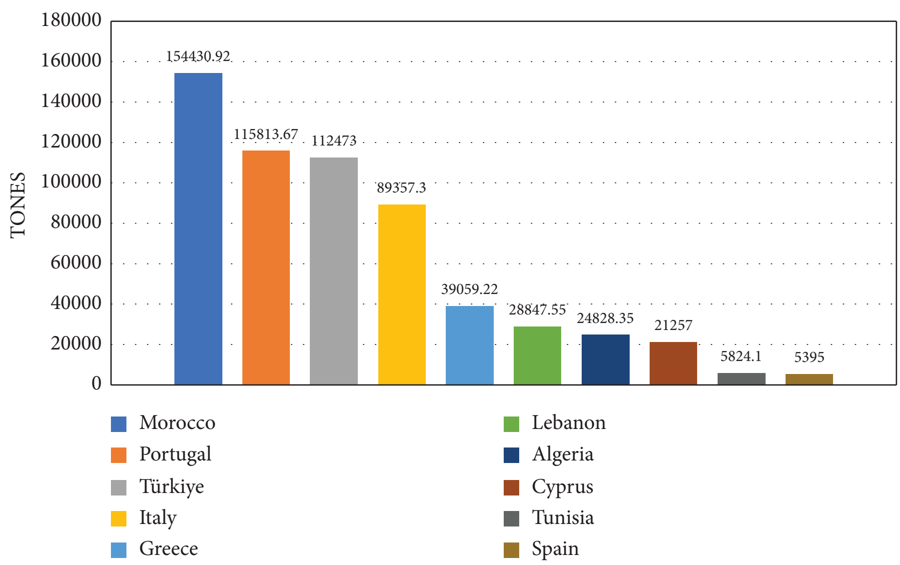

Figure 5: Production of locust beans (carobs): top 10 producers (sum 2015–2021). Source: [23] (March 16, 2023).

Table 1: The carob seed components and its proportions.

Seed fragment	Proportion (%)
Peel	30–35
Endosperm	40–50
Germ	20–25

Source: [24].

Table 2: Proximal composition and total soluble solids of carob seed peel.

Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrates (%)	Total soluble solids (°Brix)
0.12–15.30	3.71 to 4.86	0.31 to 0.54	2.34 to 3.70	75.83 to 93.29	6.80

Source: [25–27].

2.1.2. Total Phenolic Levels (TPL) and Radical-Scavenging Capability (DPPH). According to the research carried out by Lakkab et al. [29], it was discovered that CSP demonstrated a markedly greater accumulation of total phenolic content, amounting to 9573 ± 1 mg GAE/100 g extract in contrast to other by-products, such as potato peel which only registered 68.7 ± 5.7 mg GAE/100 g dry weight [30] and carob pulp (4.53 ± 0.8 mg/100 g of dry matter) [10], which are typically recommended for similar beneficiation procedures. CSP also demonstrated the greatest ability to inhibit the discoloration of β-carotene compared to BHT (58.3% versus 46%) [29]. This was explained by high content of phenolic compounds. Similar findings were obtained in a recent investigation concerning the leaf extract of the carob tree [31].

2.2. Carob Seed Endosperm (CSE). The white, translucent endosperm, commonly known as carob gum, LBG, or E410, is found inside the carob seeds, which are covered by the peel of carob seeds [22]. Referring to the steps illustrated in Figure 6, the preparation of LBG (E410) involves grinding endosperm once it has been separated [20]. Mekhoukhe et al. [32] reported that separating the components of seeds results in a yellowish endosperm with a higher yield of 46.04%, while the purified gum obtained is in the form of a white powder, with a yield of 23.31%. However, Lagha-Benamrouche et al. [33] discovered that the values are 39.44% for the crude gums and 4.026% for the purified gums.

2.2.1. Chemical Composition. Comprised of galactose (G) and mannose (M) in a ratio of approximately 1 : 3.1–1 : 3.9 [4], the main component of CSE is galactomannan, which accounts for about 80% of the endosperm mass, with proteins and impurities contributing to the remaining 20% [20]. The protein content of LBG consists of albumin and globulin (32%), with the remaining percentage attributed to glutelin [19]. The impurities comprise ashes and acid-insoluble substances [34].

The composition of high-quality refined LBG (rLBG) is represented in Table 3, and the low-quality crude LBG (cLBG) exhibits similar composition to rLBG, except for the protein content, which is higher and ranges from 13.4% to 21.4%, exceeding the range of 5-6%. According to studies conducted by Verma et al. [35], this notable variation in protein content can be attributed to the existence of structural proteins and enzymes, alongside the possible inclusion of seed germs as contaminants.

2.3. Carob Seed Germ (CSG). The term "germ" refers to the residual portion obtained after the extraction of the outer and inner gum layers of the seeds during the processing procedure. It constitutes approximately one-third to half of the seed [37]. Proteins, lipids, and phenolics are among the functional and nutritionally important components found in germs [21, 37].

2.3.1. Chemical Composition. Based on the existing literature concerning the chemical composition of CSG, this particular constituent was found to have a significantly high nutritional profile [21]. The germ contains a considerable amount of protein, accounting for more than half of its weight. Moreover, more than 50% of these proteins were found to be water-soluble [38]. Table 4 shows the proximate composition of CSG meal.

As per the FAO/WHO guidelines, the CSG displays significant amounts of essential amino acids (lysine) [21] and nonessential amino acids such as arginine and alanine [4]; as indicated in Table 5, the essential amino acid content of CSG flour is characterized by a high concentration of leucine, lysine, threonine, and phenylalanine and relatively lower amounts of isoleucine, valine, histidine and tryptophan. Moreover, this flour is distinguished by particularly low levels of sulfurized amino acid (Met + Cys) and average levels of aromatic amino acids (Phe + Tyr).

The CSG exhibits a fatty acid composition characterized by significant proportions of oleic acid (45%), linoleic acid (32.4%), palmitic acid (16.6%), and stearic acid (4.7%), with a saturated/unsaturated fatty acid ratio of 22 : 78 [13]. Similar results were obtained by Salinas et al. [40]. They have shown that the germ oil contains a significant amount of highly unsaturated fatty acids ranging from 5 to 8%.

3. Carob Seed Applications

3.1. Processing. In order to extract the seeds from the pulp of carob pods, the pods are first subjected to kibbling, as outlined by Barak and Mudgil [19]. The resulting seed peels are then separated from the endosperm and germ by aqueous thermal pretreatment, which involves immersing the entire seeds in boiling water for a duration of 60 minutes. Following this treatment, the husk, endosperm, and germ components of the swollen seeds can be effortlessly isolated through manual means, without causing any disruption to the tegument [35]. The separated peels and germs are subsequently dried and milled, and the resulting powder is stored in accordance with the methodology described by Lakkab et al. [26]. The endosperm of the carob seed can be extracted and crushed to give rise to a white powder marketed under the name of "carob gum." It contains the great majority of the galactomannans which are sought by industries, especially the food industry for their texturizing properties [41]. The extraction process used must not degrade the galactomannans so that their techno-functional properties remain intact, while guaranteeing a certain purity of the gum obtained. The residual enzymes must also be denatured in order not to hydrolyse the galactomannans when they are put into an aqueous solution. Conventional extraction processes for natural gums cannot be applied to carob because of the extreme hardness of its seeds [42, 43]. A general industrial extraction and purification process adapted to carob gum from pods and more specifically from carob seeds is proposed in Figure 6, and it includes several major steps.

The hardness of the carob seed coat makes it extremely difficult to process. This process begins with dehusking (acid or thermomechanical), splitting, milling, sieving, clarifying, and drying. Dehusking is completed by treating with dilute sulfuric acid at high temperatures to carbonize the seed coat. A thorough washing and brushing process is then carried out to separate the remaining fragments of the seed coat from the endosperm. Then, the germ components are separated from the intact endosperm parts. This process extracts a highly viscous, whitish gum from the carob seeds.

Carob seed can be roasted in a rotary kiln, where the seed coat is detached by bursting. The endosperm halves are then obtained from the charred shell and fragmented germs. The germ obtained by this method has a darker hue. Since no

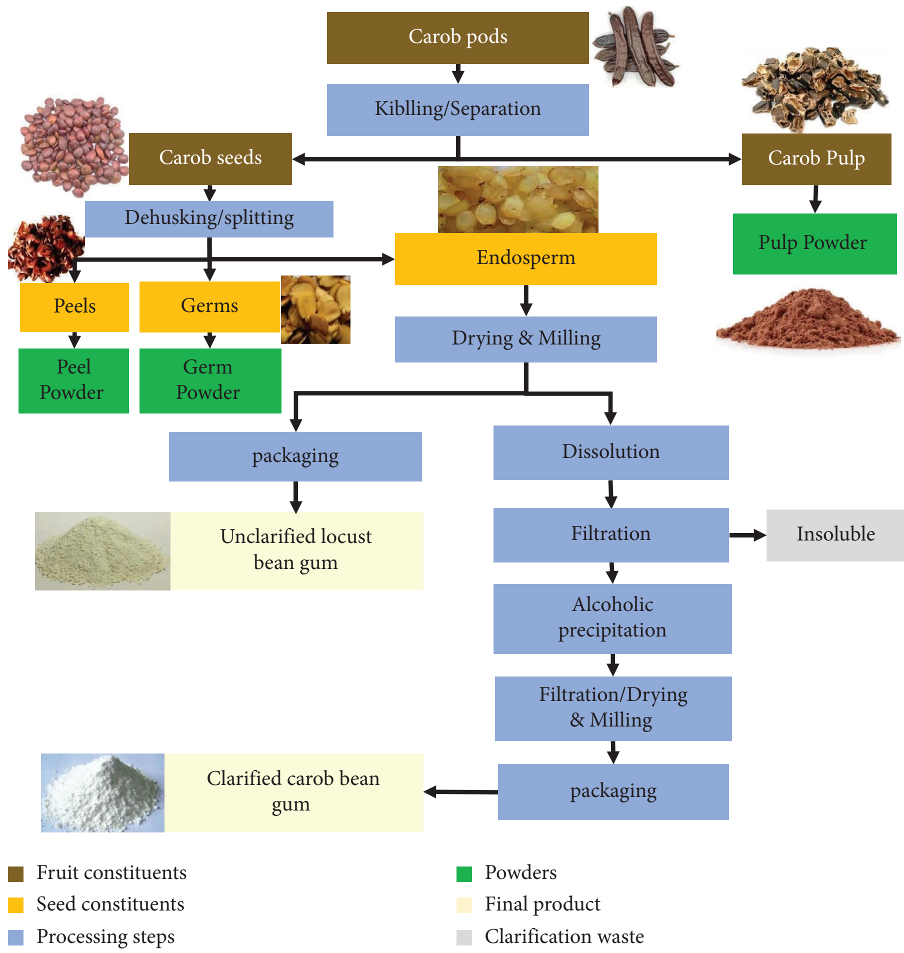

Figure 6: Locust bean gum processing flow chart.

Table 3: The composition of high-quality refined LBG (rLBG).

Component	Proportion (%)	References
Moisture	9.20	[32]
Protein	0 : 1 to 6	[35, 36]
Ash	0.1–1	[35]
Fat	0.9	[32]
Fiber	0.29	[32]
Galactomannan	75 to 85	[4, 36]

Table 4: Carob seed germ meal composition (%/dry matter).

Component	Estimated analysis (% of dry matter)	References
Moisture	5.76 ± 0.32	[39]
Ash	6.34 ± 0.15	[39]
Protein	53.13 to 67.1	[12, 20, 33]
Lipids	2.26 ± 0.13	[39]

sulfuric acid is used, no by-products are produced. The endosperm is then ground into fin powder, resulting in the gum as the final product [35].

3.2. Food Applications

3.2.1. Seed Peel. Since the seeds are the major constituent of the carob fruit, the peel surrounding them can be considered a secondary outcome with potential for upcycling as a high-value food. However, it is commonly used as animal feed [35]. The presence of notable concentrations of bioactive compounds in CSP confirms the exceptional antioxidant properties of this natural substance. These results suggest that CSP can serve as a natural antioxidant for minced fish preservation in refrigerated settings [44]. In a study aimed to investigate the influence of carob by-products (i.e., peel and germ) on the development of snacks, noteworthy alterations in the sensory, nutritional, and antioxidative attributes of the

Table 5: Amino acid composition of carob seed germ flour.

Amino acids	g/100 g protein
Asp + Glu	40.015
Arg	13.521
Leu	7.375
Lys	7.002
Phe + Tyr	7.591
His	2.962
Phe	3.984
Thr	4.177
Gly	5.301
Ser	5.368
Val	3.743
Ile	3.422
Tyr	3.607
Ala	4.825
Pro	4.315
Trp	1.676
Met + Cys	1.462
Cys	1.290
Met	0.172

Source: [38].

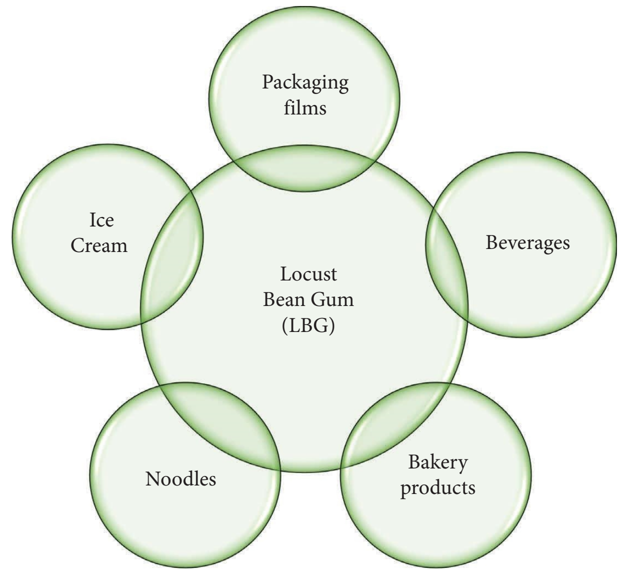

Figure 7: Main applications of LBG in food product formulation processes.

snack cracker were observed upon their incorporation into the formulation. As a result, a judicious selection of both constituents in the range of 4–14% for the germ and approximately 9% for the seed peel was deemed imperative to yield a product that exhibits harmonious physicochemical and bioactive features [45].

3.2.2. Locust Bean Gum. The endosperm obtained by the isolation process is eventually sold as LBG. The overall processing protocol for LBG is carefully formulated to ensure that all impurities are excluded from the germ or coat segment that could potentially affect its characteristic features (as shown in Figure 6) [21]. LBG is as a pioneer among galactomannans used as a dietary supplement in various industries such as paper, textile, pharmaceutical, cosmetic, and food, and this compound occupies a prominent position [46]. Due to its remarkable thickening, stabilizing, and biodegradable properties, LBG is widely used as a food additive with the designation E 410. The use of LBG as a stabilizer and thickener in foods has gained popularity due to its natural origin. The functional mechanism of LBG is associated with its ability to control the water phase in foods. Several reports have supported the potential of LBG for food applications [18, 47]. Figure 7 shows the food applications of LBG.

(1)Food Packaging Films and Edible Coating. There is a growing trend in the agri-food sector to use edible films or coatings made from natural polymers and food additives to extend the shelf life of perishable foods, including fresh fruits and vegetables and meat products [22]. Recently, an increasing number of new environmentally friendly films or coatings based on biodegradable polymer have been developed. LBG, a natural polymer that is both edible and biodegradable, has been selected to produce films or coatings that can be consumed [48]. This is to mitigate the adverse effects of minimal processing on freshly cut fruits [49]. To date, edible LBG-based coatings have been used extensively in the field of food preservation [50]. Licciardello et al. [51] and Rizzo et al. [52] conducted a study that showed that an LBG-based coating enriched with natural active compounds displayed higher antibacterial activity, thereby preserving the freshness of white shrimp and artichoke slices during refrigeration.

(2)Beverages. LBG has a remarkable capacity to maintain its stability over a wide range of pH values, making it an extremely suitable option as a stabilizing and thickening agent for a wide variety of beverages. In contrast, LBG is soluble in hot water, making it a viable option for beverage applications since most beverage manufacturing processes involve heat treatment. This property allows LBG to extend the shelf life of beverages by attenuating phase separation and contributing to thickening properties [19]. A recent study has shown that the use of stabilizers such as pectin, LBG, and GG helps to maintain the turbidity of fruit juices during storage while enhancing the natural appearance of the product, aligning with the concept of "clean labelling" [53].

(3)Bakery Products. The use of LBG in bakery has been shown to have beneficial effects on bakery goods, including increasing their volume and prevention of natural deterioration over time [54]. When LBG was incorporated into a wheat flour suspension, it resulted in a decrease in the bonding temperature, accompanied by an increase in various viscosity parameters. In addition, it was observed that the addition of LBG improved the water-absorption capacity and the development time of the wheat flour dough [55]. These favorable rheological properties, combined with its ability to soften the crumb texture, make purified LBG a promising agent for enhancing bakery performance and justify its inclusion as a reformative ingredient [56].

(4)Noodles. It has been found that the addition of LBG to dough improves the rheological properties of the dough and the consistency of the cooked noodles made from it. This enhancement in texture is attributed to the strengthening

influence of the gum on the gluten network, which promotes the amelioration of the textural properties of the noodles. In addition, noodles prepared using LBG exhibit lower cooking loss and swelling index [57].

(5)Ice Cream. In a study conducted by Cavender and Kerr, it was demonstrated that the implementation of microfluidization in ice cream mixes containing LBG resulted in a significant improvement in acceptability, particularly with respect to the perceived attribute of creaminess [58]. The same authors, in a comprehensive study of the profound effects of microfluidization on the structural properties and sensory attributes of ice cream mixes, showed an increase in viscosity and an improvement in sensory properties. Incorporation of microfluidized LBG also facilitated the formation of larger particles and promoted the development of a well-crosslinked structure in thawed serum [59]. Investigation of the effects of the structure of flexible polysaccharides (LBG and GG) and rigid polysaccharides (XG) on the rheological, tribological, textural, and sensory properties of ice cream suggests that flexible polysaccharides may be considered a more suitable fat substitute compared with rigid polysaccharides for improving the sensory properties of reduced-fat ice cream [60].

(6)Exploring Additional Functional Properties of LBG in Food Applications. The addition of LBG or GG has been shown to be effective to improve the foaming rate and the capacity of reconstituted egg white solutions based on egg white powders, thus improving the specific volume, texture, and appearance of the cake [61]. This is consistent with the results of the study conducted by Ming Li, which investigated the effect of various polysaccharides, including LBG, GG, XG, and arabic gum (AG), on the rheological properties, β-carotene stability, gel properties, and printing performance of whey protein isolate (WPI) emulsion gels for 3D printing. In this study, LBG and GG exhibited superior attributes such as improved freeze resistance, enhanced printability, and higher product quality [62]. In addition, Taghian Dinani et al. [63] investigated the effects of different hydrocolloids and their concentrations on the textural and sensory properties of meat analogues prepared with plant protein isolate (PPI) and wheat gluten (WG), and they found that certain hydrocolloids, including LBG, GG, and XG, have the potential to improve the structural integrity, browning tensile strength, and juiciness of meat.

3.2.3. Germ. The CSG is commonly used as animal feed or human consumption [16]. Due to its high nutritional value, characterized by a protein content of more than 50% (w/w), fractionation of proteins in carob germ flour revealed that about 68% of this protein consists of water-insoluble glutelins. This particular fraction of water-insoluble proteins, known as *caroubin* [64], was analyzed and compared with wheat glutenin in terms of its molecular weight distributions, mixing chrematistics, and viscoelastic properties in both linear and nonlinear regions. The results of the farinograph mixing test showed that *caroubin* exhibited a faster hydration rate compared to wheat glutenin. This was attributed to the absence of proteins with a molecular weight greater than 100 kDa in *caroubin*, as well as its hydrophilic nature, which is different from the properties of wheat glutenin. In the linear range, *caroubin* showed higher values for G' and G'' after 4 min and 35 min mixing intervals, indicating a stiffer system compared to wheat glutenin. However, the phase angle values revealed comparable linear viscoelastic network properties for both proteins after both mixing times [65]. Moreover, its use has been suggested as an ingredient in baked products tailored to the needs of individuals suffering from celiac disease [66]. Smith et al. [67] demonstrated that the addition of CSG flour and hydroxypropyl methylcellulose (HPMC) to gluten-free bread formulations can result in a high-quality product with comparable crumb hardness and specific gravity to wheat-based bread. They concluded that the addition of CSG flour in gluten-free bread represents a real opportunity to diversify gluten-free products.

3.3. Pharmaceutical and Medicinal Applications

3.3.1. Medicinal Effect of Carob Seed Peel Compounds. The potential health benefits of carob seed peels were studies by Lakkab et al. [26, 29] and Rico et al. [27], who confirmed their remarkable antioxidant properties. The studies conducted by these researchers brought to light the richness of bioactive compounds. These compounds play an important role in exerting various effects on different conditions, such as mood disorders, antioxidant and antihypertensive activity, regulation of abdominal obesity, anxiolytic, and antidepressant effects, as well as the prevention of neuropsychiatric disorders such as schizophrenia. These results suggest that CSP may be a valuable source of natural compounds with significant health benefits.

3.3.2. Endosperm. CSE possesses several favorable properties, including biocompatibility, bioabsorbability, biodegradability, and nonmutagenicity, as well as mucoadhesive properties and the ability to produce easily excreted degradation products, as demonstrated by Braza et al. [68]. As a result, this natural substance has received considerable attention in the pharmaceutical and biomedical industries due to its potential applications in various forms such as tablets, gels, and nanoparticles [69, 70]. The results of these studies suggest that CSE could serve as a valuable natural resource with significant potential for the production of novel and efficient biomedical products.

(1)Health Benefits. Several studies have shown physiological responses to LBG that can be considered beneficial to health by curing and preventing chronic diseases. Table 6 lists the health benefits of LBG.

(2)Pharmaceutical Applications. In the field of drug delivery (DD), LBG has many applications and enables the production of various DD agents [80], such as nanoparticles, microspheres, microcapsules, microparticles, films, hydrogels, and tablets. LBG finds its main biopharmaceutical application in the formulation of oral delivery systems. However, there are also documented cases where LBG has been used for buccal, ocular, topical, and colonic delivery [77]. Figure 8 shows the primary pharmaceuticals applications of LBG.

Table 6: Health advantages of locust bean gum.

Health benefits	References
(i) Gastrointestinal effects	[71]
(ii) Hypolipidemic effect	[72]
(iii) Reduces/controls diabetes (antidiabetic actions)	[4, 72]
(iv) Control of hypercholesterolemia	[73]
(v) Reduction of inflammation, Crohn's disease, ulcerative colitis, and inflammatory-related bowel disease	[50, 74, 75]
(vi) Deliver water-absorption properties and cohesive attributes for diarrheal excreta	[76]
(vii) Reduced absorption of nutrients	[77]
(viii) Decrease intestinal glucose absorption by inhibiting the sodium-dependent electrogenic glucose transporter, also known as SGLUT-1	[78]
(ix) Antiregurgitation	[79]
(x) Antihyperlipidemia	[73]

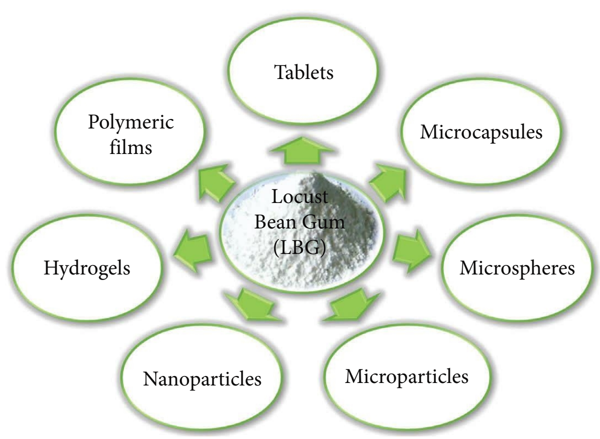

Figure 8: Main applications of LBG in the development process of various drug delivery systems.

(1) Modified tablet production

The ability of LBG to swell enables controlled drug release from matrix tablets, as demonstrated by its use in the preparation of fast-dissolving tablets. These tablets exhibited a shorter dispersion time compared to synthetic superdispersants. In a study with sixteen healthy volunteers, tablets with a 2 : 3 LBG : xanthan ratio showed the highest bioavailability [81, 82]. In addition, the formulation containing 5% LBG was found to be the most suitable for preparation of rapid tablets and to have significant potential for the effective treatment of inflammation, especially in sudden exacerbations of pain [81].

(2) Microcapsules

Microcapsules are tiny particles with a hollow structure consisting of a solid shell enclosing a central region in which various materials such as drugs and similar substances can be temporarily or permanently enclosed [83]. These capsules have been used to encapsulate *Lactobacillus rhamnosus* biofilm probiotics by employing LBG and alginate. The microcapsules have desirable properties, such as high density and controlled release in the gastrointestinal tract. The biofilm cells are protected from the acidic conditions of the stomach by the microcapsules, and their release occurs gradually in the intestinal tract, with the aim of achieving a complete and sustained discharge [84]. Burgain et al. [85] pointed out the advantages of alginate in bacterial cells encapsulation due to its biocompatibility and cost-effectiveness. The addition of LBG or XT to alginate can produce capsule matrices that have a high affinity for water and can swell. The resulting viscous gel layer may facilitate dissolution of the capsule and delay its release into the gastrointestinal tract. This concept was proposed by Torres et al. [86] and supported by Verma et al. [35].

(3) Microspheres

Microspheres are commonly used components of multiparticulate drug delivery systems offering both medical and technological advantages [87]. Alginate microspheres have been used for long-term oral drug delivery but have had stability problems and released drugs too quickly at higher pH values. To solve this problem, an interpenetrating network (IPN) based on alginate and LBG was developed to maintain the release of aceclofenac during oral administration. Using the Korsmeyer–Peppas model, in vitro dissolution tests showed sustained release of aceclofenac for 8 hours. The prepared sustained release microspheres of aceclofenac were considered a promising method to reduce dosing intervals, according to Jana et al. [88].

(4) Microparticles

Microparticulate systems are a new approach in the pharmaceutical industry for transporting drugs and biomaterials for diverse purposes. These systems can produce solid particles from oils, modulate solubility, control taste and flavour, prevent drug evaporation, protect drugs from oxidation, and prevent incompatibilities. [89]. In other words, microparticulate systems provide a versatile means of delivering pharmaceutical agents with unique properties that can improve drug efficacy and stability. Celecoxib microparticles can be prepared using LBG and XG. In vitro experiments have shown that the addition of significant amounts of LBG and XG results in an improved drug release profile. The drug content and physicochemical properties of the microparticles are stable for up to six months at different temperatures. Moreover, the drug release rate is faster in the early phases of intestinal pH and slower in the later phases, while gastric pH does not seem to affect drug release. These findings were published by Sharma et al. [75]. The results obtained by Grenha et al. [90] demonstrate that pulmonary administration of sparsely-dried LBG microparticles loaded with first line antitubercular drugs (rifabutin (RFB) and isoniazid (INH)) has superior efficacy in reducing pulmonary mycobacterial infection compared to the concurrent oral administration of RFB/INH.

LBG-based microparticles selectively target macrophages and represent a promising approach for tuberculosis treatment [90].

(5) Nanoparticles

Polymeric nanoparticles have shown great potential for oral delivery of biopharmaceuticals, as numerous studies have highlighted their significant contribution to improving oral drug bioavailability by facilitating cellular internalization [91]. In a study by Braza et al. [68], the chemical modification of LBG was used to synthesize nanoparticles by polyelectrolyte complexation. The produced derivatives were used for the preparation of LBG-based nanoparticles, which are reported for the first time in this study. The physicochemical characteristics of the nanoparticles were heavily dependent on the composition and charge ratios employed during the complexation process. In general, the observed features are considered suitable for drug delivery [68]. LBG and chitosan nanoparticles are being developed as an immunoadjuvant therapy for oral vaccination [92].

(6) Hydrogel

Hydrogels are used extensively in drug delivery systems due to their high water content, which facilitates enhanced drug permeation [93]. In addition, hydrogels can control drug release by undergoing structural changes in response to internal or external stimuli [94]. In 2011, Marianecci et al. [95] formulated a hydrogel by mixing LBG and XG in a 1 : 1 ratio. This hydrogel was employed to encapsulate niosomes. It showed protective effect on the integrity of the vesicles and resulted in a 50 h delay in drug release from the generated formulation, as documented by the same authors and in another study by Verma et al. [96]. However, despite their beneficial properties, there are still certain limitations in the use of hydrogels as drug delivery systems [97]. To overcome these limitations, a novel biocompatible dual drug delivery carrier was developed by incorporating specific microparticles into a κ-carrageenan/LBG hydrogel. The composite hydrogel exhibited improved release kinetics for two types of drugs, with a slower release rate compared with that of the microparticles and hydrogel alone at 37°C. Sustained release of the drug was achieved over a period of 7 days at 37°C [98].

(7) Polymeric films

Polymeric films are solid dosage form systems used for decoration, protection, and functionalization [99]. A polymer film was prepared from LBG crosslinked with butanediol diglycidyl ether. The film obtained has exceptional swelling properties, in the range of 300%–500%, and is efficiently degraded under the action of colon bacteria [35].

3.3.3. Germ. The potential bioactive activities aimed at attenuating the risk factors associated with metabolic syndrome were specifically investigated for CSG. The results revealed that germ has higher antioxidant capacity and also exhibits significant antihypertensive activity [27]. Furthermore, carob germ has been recognised as a dietary food for human consumption and a possible ingredient for gluten-free cereal-based products. The protein fraction of carob germ exhibits remarkable heterogeneity which makes this seed component very interesting for various dietary applications, particularly in the context of celiac disease diet [17].

Table 7: The LBG's applications.

Field of use	Application
Cosmetics	Emulsions and foams, like those found in shaving cream and toothpaste
Textiles	Coloring thickener
Paper	Material recovery flotation product; surface treatment thickening
Petroleum	To improve stability, used as a flocculant
Mining	Used in separation processes (flotation)
Well sinking	Moisture absorbent wall reinforcing
Explosives	Explosives water binder
Breeding	Animal food

Source: [3].

4. Other Applications

LBG is the most commonly used carob seed ingredient in a variety of technical fields. It is used in a variety of applications, including printing, photography, plastics, adhesives, and cosmetics [100]. It is also used to reinforce paper and textiles (as a strengthening agent), to control rheology (flow behaviour), to thicken latex paints, to break up and drill oil wells, and to make explosives [101]. LBG is also used in paper manufacturing and pet foods [19]. Table 7 shows some applications for the LBG carob.

5. Reactions and Adverse Effects (Allergies and Toxicity)

To date, no adverse effects of LBG with carob seeds have been observed. According to one study, the addition of dietary fiber to infant formula, such as LBG, may reduce the availability of minerals such as calcium and iron [102]. However, the safety of LBG has been thoroughly evaluated by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), which classified it as nontoxic. Comprehensive exposure assessments have shown that the main use of LBG does not raise any safety concerns. Regarding human digestion, LBG is known to be poorly digested and not fully absorbed. In 90-day toxicity studies in rodents, no adverse effects were observed even at the highest levels studied. Furthermore, studies on its potential carcinogenicity have shown no evidence of carcinogenic effects [72, 103].

Legume seeds generally contain antinutritional substances such as trypsin inhibitors [104]. Martínez-Herrera et al. [105] discovered that it is possible to deactivate the effect of these substances by heating (e.g., at 121°C for 25 min) to make the germ meal, the carob seed, useful for human and animal nutrition. CSG also contains tannins, which can cause palatability problem due to their astringent taste and slow digestion of the feed. According to Filioglou and Alexis [106], tannins limit the digestibility of proteins by either direct binding direct regions of the protein molecule or inhibiting the digestive enzyme noncompetitively.

6. Conclusion

The exploitation of natural resources, particularly by-products, has increased recently, forcing industries to look for legal ways to incorporate these ingredients into their final products. Carob seeds, once considered food waste, have recently emerged as a natural resource with interesting nutritional values and useful properties that make them a highly recommended additive in a number of industries, including food, drugs, medicines, cosmetics, and others. Carob seeds are composed of a shell, an endosperm, and an embryo, which ensures a balanced content of proteins, carbohydrates, polyphenols, and galactomannans that guarantee a perfect swelling and a good oil retention capacity as well as a remarkable content of macro- and microelements. Due to their specific composition, these parts, especially the endosperm, find crucial use in many of the abovementioned fields. After numerous applications of the famed LBG-containing endosperm, new research focused on the shells and germ of the carob seed, which were previously considered as by-products of the carob seed. The shell was found to be high in dietary fiber (61.64%) and phenolic compounds (9573 ± 1 mg GAE/100 g of extract). The germ, on the other hand, has been shown to be an excellent source of protein, containing a high concentration of important amino acids. In order to successfully use the seeds of the carob tree as functional ingredients in a variety of applications, it is crucial to understand the physicochemical and biochemical properties of their components, their identification, and their interaction.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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