

Nutritional Benefits and Antihyperglycemic Potential of Carob Fruit (*Ceratonia siliqua* L.): An Overview

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ABSTRACT

Carob (*Ceratonia siliqua* L.), a plant native to the Mediterranean, is a member of the legume family and its fruit is called a pod. The flesh of the pod (pulp) is very rich in sugar, while the seeds are high in protein. The pod is also a good source of minerals such as potassium, calcium and phosphorus. It is rich in polyphenols and antioxidants. Due to its nutritional composition, it is suitable for improving human well-being. This article reviews the chemical composition of locust bean fruit and its biological effects on human health. Understanding the traditional uses of locust bean fruit in relation to its potential as an anti-diabetic agent is important in view of the numerous recent scientific studies on its pharmacological properties. The study focuses on in vivo and in vitro antihyperglycemic research, as well as the nutritional profile and potential food applications of this natural product for food formulation and fortification. Based on its chemical and pharmacological properties, this species is believed to have beneficial preventive and therapeutic effects, particularly in hyperglycemia. Researchers can further extract and isolate bioactive compounds from different carob fractions to develop pharmaceutical products and functional foods for the food and pharmaceutical industries.

Keywords: *Ceratonia siliqua* L., nutritional profile, Antihyperglycemic potential, pharmacological applications, natural bioactive compounds.

INTRODUCTION

Scientists are currently focusing on species with high potential in terms of bioactive and nutritional properties. The carob tree has valuable properties that hold promise for several scientific disciplines, particularly in the field of medicine and food technology (Brassescio et al., 2021). The scientific name for carob is *Ceratonia siliqua* L,

this name is derived from the Greek term ‘*Kera*’ which refers to the keratomorphic shape of the fruit, and the Latin word ‘*siliqua*’ which refers to the firmness and form of the pods (Laaraj et al., 2023). Carob is a member of the Leguminosae family and is an evergreen tree that grows in arid and semi-arid regions of the Mediterranean. It is resistant to salinity and drought. It provides ecological and economic benefits and contributes

to the local vegetation (Goulas et al., 2016). The highest production of carob pods from 2015 to 2021, as presented in Figure 1, being located in Morocco (26.09%), Portugal (19.56%) and Turkey (19%) (FAOSTAT, 2023).

The carob fruit has historically been used primarily for animal feed, with limited human consumption. However, in recent years, the fruit and its by-products have found use in the food and beverage industry (Gioxari et al., 2022). Comprising 90% of the fruit, the pulp contains a range of biologically active substances, such as polyphenols, carbohydrates, amino acids, fibers, and minerals, while the remaining 10% is made up of seeds. Carob seeds contain gum, flavonoids, and proteins (Fidan et al., 2020; Zhu et al., 2019). The extract of carob pod exhibits high antioxidant activity and therapeutic effects. It has been shown to reduce cholesterol levels, inhibit cell proliferation, protect against cardiovascular diseases, and safeguard the kidneys (Corsi et al., 2002; Rtibi et al., 2017). Additionally, it has a hypoglycemic effect by decreasing the activity of intestinal enzymes, including maltase, sucrase, lactase, and amylase (Darwish et al., 2021). Carob has pharmacological properties in the digestive system, including antidiarrheal, antibacterial, anti-ulcer, and anti-inflammatory effects. It also has a laxative effect on gastrointestinal motility (Dahmani et al., 2023). Furthermore, carob can be used as a natural antioxidant in the form of a supplement to reduce oxidative stress damage (Rtibi et al., 2015).

Due to its therapeutic value and nutritional significance, the carob fruit has garnered attention owing to its high content of dietary fibers and bioactive compounds that confer various biological activities. This overview seeks to elucidate the medicinal and nutritional properties of the carob

fruit, emphasizing its medical and pharmaceutical applications, particularly focusing on the anti-diabetic effect of this fruit.

A variety of scientific databases were utilized in our literature search, such as Scopus, ScienceDirect, Web of Science, Springer, PubMed, and the Google Scholar search engine. The primary keyword employed in this investigation was the common name of *Ceratonia siliqua* L. (Carob), which is pertinent to the field of study.

Carob fruit's nutritional profile

Carob fruit is a complex mixture of secondary metabolites, rich in nutrients such as fiber, sugar, and polyphenols. It contains numerous minerals and amino acids, making it an excellent source of protein according to the World Health Organization's (WHO) requirements (Miś & Dziki, 2013). Carob fruit contains sulfur-containing amino acids, acidic and hydroxylic amino acids, aliphatic amino acids, basic amino acids, and amidic amino groups. Around 57% of the amino acid composition in pods is made up of basic and amidic amino groups (Ikram et al., 2023).

Calcium and potassium are found in large quantities in carob fruits, with concentrations reaching 970 mg·100 g⁻¹ dry weight and 1120 mg·100 g⁻¹ dry weight (Rizzo et al., 2004). Carob fruit also contains microminerals like manganese, nickel, cobalt, zinc, barium, iron, and cobalt, with iron being the most concentrated (Goulas et al., 2016). Compared to seeds, pods contain a lower concentration of bio components such as magnesium and phosphorus (Barak & Mudgil, 2014). Carob pulp fibers are divided into two categories: soluble and insoluble fibers. The process of obtaining natural fibers of carob has been licensed

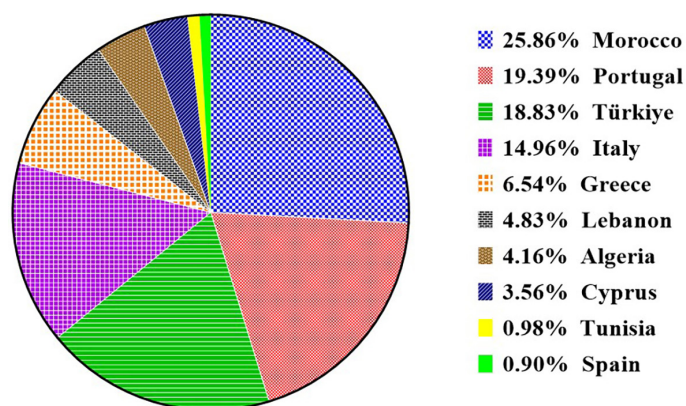


Figure 1. Production of locust beans (carobs): top producers (sum 2015–2021)

(Ikram et al., 2023), with lignin, cellulose, and hemicellulose making up the insoluble portion of dietary fibers. The higher content of polyphenols in carob fiber distinguishes it from other types of dietary fiber. Nasar-Abbas et al. reported that carob fiber is not fermented and is insoluble in water (Nasar-abbas et al., 2016). Carob fiber, which consists of a specific class of carbohydrates, can dissolve in water at a maximum concentration of 100 g/L. The rheology of doughs in baked goods is influenced by carob fiber (Nawrocka et al., 2016).

Chemical composition of carob fruit

Extensive research has been conducted to determine and quantify the nutritional and functional components of carob. These researches have shown that carbohydrates, such as glucose, fructose and sucrose, account for about 40 to 60% of the composition of the carob pulp. this later have a protein content of approximately 3 to 4%, a fat content of 0.4–0.8%, and significant levels of dietary fiber (11%), and minerals (1 to 6%) (Arribas et al., 2019; Elfazazi et al., 2017; Oziyci et al., 2014). Boublenza and co-workers identified linoleic acid, oleic acid and palmitic acid as the main fatty acids found in carob oil (Boublenza et al., 2017). stating that the process of drying and extraction of the carob affects its mineral and phenolic profiles, as well as its antioxidant activity (Stavrou et al., 2018). The nutritional composition of carob fruit varies depending genetic, cultivar, seasonal, and environmental factors. Although the carob pod has a high sugar content, it is also rich in insoluble fiber and microconstituents such as vitamins, minerals, inositol, and phenolic compounds

(Gioxari et al., 2022). High-Performance Liquid Chromatography methods were used to analyze the sugar and organic acid levels in mature fruit pods of three different carob genotypes from various regions of Turkey. The genotypes were found to contain high levels of glucose, fructose, xylose, sucrose, citric acid, oxalic acid, fumaric acid, malic acid, succinic acid, and ascorbic acid (Polat et al., 2023). Table 1 summarizes the chemical composition of carob pulp powder, which contains a variety of macro and micro nutrients.

Carob bioactive composition

The bioactive compounds found in carob fruit have pharmacological potential and can be useful in the control of several health problems, including diabetes, cardiovascular disease and gastrointestinal disorders (Brassescio et al., 2021). The three main groups of polyphenols present in carob fruit are flavonoids, gallotannins, and phenolic acids. The content of polyphenols in carob fruits ranges from 45 to 53.76 mg gallic acid equivalents per 100 g, depending on factors such as genetics, environment, and extraction methods (Cavdarova & Makris, 2014). While flavones (apigenin, chrysoeriol, luteolin), flavanones (naringenin), and iso-flavones (genistein) are present with modest concentrations in carob fruits, flavonols (kaempferol, myricetin, and quercetin) and their glycosidic derivatives (quercetin, myricetin, and rhamnosides) are notably abundant (Goulas et al., 2016). In addition to polyphenols, other substances abundant in carob powder, such as xanthonenes, carotenoids and saponins, have shown health benefits. These substances can also be used as sources of nutraceutical and medicinal ingredients (Karim & Azlan, 2012).

Pharmacological investigations have shown that therapeutic plants, such as the carob tree, contain tannins, including condensed tannins and hydrolysable tannins, which can reduce elevated blood glucose levels (Ajebli & Eddouks, 2018). The polysaccharides found in carob fruit, such as carob fibre and carob bean gum (also known as locust bean gum), are widely used also in the pharmaceutical industry. According to Zhu et al. carob gum and fiber can help protect against several illnesses, such as diabetes, colon cancer, heart disease, and irregular bowel movements (Zhu et al., 2019). carob pods are a valuable organic food due to their high concentration of D-pinitol compared to other plants or legumes. The substance was quantified in samples of carob syrup from Cyprus

Table 1. Chemical composition of carob pulp powder

Chemical/Nutritional components	Amount range in Carob powder (%)
Moisture contents	6.3–7.6
Ash	2.3–3.2
Protein	1.7–5.90
Dietary fiber	11.7–47.0
Starch	0.1–0.2
Carbohydrates	42.0–86.0
Glucose	3.0–7.3
Sucrose	15.0–34.0
Fructose	2.0–7.4
D-Pinitol	5.1–5.8

Note: Source – Boublenza et al., 2017; Brassescio et al., 2021; Moumou et al., 2023.

(Christou et al., 2019). In recent years, there has been a significant increase in pharmacological interest in this molecule due to its multifunctional capabilities through various signaling pathways including anti-cancer effects, regulation of insulin-like activity and metabolism in type 2 diabetes mellitus, antioxidant properties, hepatoprotective effects, immunomodulation, regulation of Th1/Th2 cytokines, prevention of Alzheimer's disease, antidepressant effects, enhancement of creatine retention, and prevention and improvement of selective α -secretase pathology (López-Sánchez et al., 2018). D-pinitol, derived from carob extracts, is a stable compound that exhibits superior insulin-regulating activity compared to other natural compounds, such as polyphenols, under biological stomach conditions. This characteristic enhances its bioavailability in the human body (Martins & Azab, 2022). Future research is expected to focus on identifying and isolating bioactive compounds from various carob fractions. Controlled clinical trials will be conducted to correlate these bioactive with different pharmacological activities.

Carob's potential as an anti-diabetic pharmaceutical food

Diabetes is a chronic disease that affects the pancreas, resulting in insufficient insulin production or utilization. This leads to hyperglycemia and long-term damage to the kidneys, liver, blood vessels, and nerves (Basharat et al., 2023). It is estimated that by 2025, 300 million people

worldwide will have diabetes. According to the World Health Organization, diabetes is predicted to be the seventh leading cause of death by 2030 (Skalli et al., 2019). The pathophysiology of diabetes is regulated by insulin or hypoglycemic oral medications. The primary objective of novel medicines for managing hyperglycemia is to reduce or prevent glucose absorption. Several medicinal plants and extracts, rich in flavonoids and polyphenols, have been found to be effective anti-diabetic agents (Chao & Henry, 2010). The carob tree and its fruit have been used in traditional folk medicine and human consumption for an extended period. The fruit of this plant has also been used as an herbal treatment for managing diabetes (Boublenza et al., 2019). The anti-diabetic activity of carob fruit and its extract is attributed to the fruit's phytochemical content. These substances can be used as dietary supplements to treat diabetes and hyperglycemia by preventing the absorption of intestinal glucose (Figure 2) (Prakash et al., 2015). Several studies have shown that carob fruits and their by-products have antihyperglycemic properties. The following sections provide a summary and analysis of the *in vitro* and *in vivo* experiments that have been done so far, showing how bioactive compounds in different parts of the carob fruit can help lower blood glucose levels.

In vitro antihyperglycemic

As previously mentioned, the bioactive components of the carob fruit have been associated

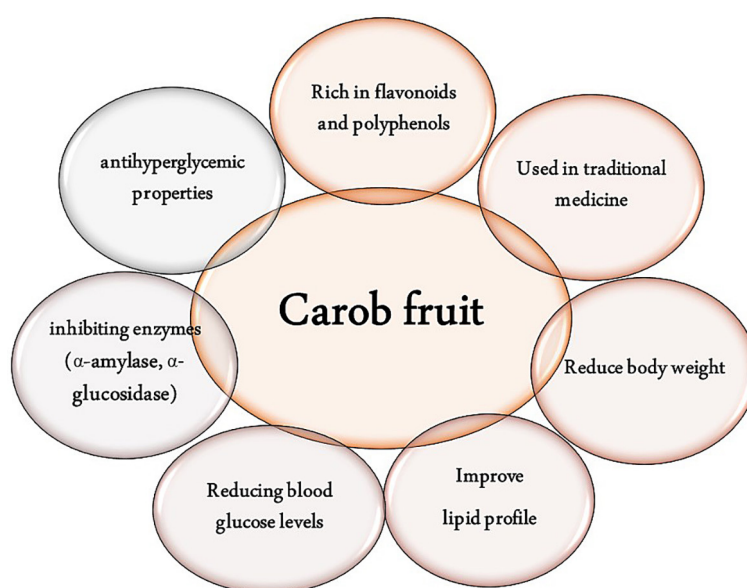


Figure 2. Potential of carob as a pharmaceutical anti-diabetic food

with several pharmacological actions, such as antioxidant protection, blood sugar and cholesterol reduction, cardiovascular protection, and cytotoxicity. *In vivo* toxicological examinations have shown that carob pods have beneficial effects on hyperglycemia and cholesterolemia. The presence of carob fiber is responsible for these effects (Moumou et al., 2023). Qasem et al. (2018) evaluated the *in vitro* inhibitory effect of the methanolic extract of carob pods against α -amylase and α -glucosidase. The study also found that carob does not cause any damage to hepatocytes or pancreatic β cells. In addition, acute oral intoxication did not result in an alteration of liver and kidney function or histological sections in rats. (Qasem et al., 2018).

Siano et al. (2023) discovered that carob seed germ flour has a lot of flavonoids that are important for health. It has a lot of apigenin 6,8-C-di- and poly-glycosylated derivatives, with schaftoside being the most notable. Furthermore, they demonstrated that apigenin 6,8-C-di-glycosides inhibit the activity of α -glucosidases and α -amylase in the small intestine. The study conducted by Kavvoura et al. (2023) investigated the use of extracts from seeded pods and seeds of carob in cosmetics using human skin fibroblast cultures. they found that these extracts inhibited the development of advanced glycation end products (AGE). Glycation is a chemical process where sugars or their byproducts attach to the amino groups of proteins without the involvement of enzymes. Non-enzymatic glycation causes proteins to age at a molecular level by altering their structure and function. It also plays a role in the development of diabetes mellitus at different stages (Jaisson & Gillery, 2018).

In vivo antihyperglycemic

In their investigation, Hamza and Alsiny (2015) explored the impact of gamma-ray irradiation at a level of 10 kGy on a combination of carob and roselle extracts in male rats afflicted with alloxane-induced diabetes mellitus. The primary objective was to assess the anti-diabetic and antioxidant properties of this treatment regimen. The administration of either unrefined or irradiated carob and roselle extracts to diabetic rats at a dose of 10 ml/kg body weight over a period of 6 weeks resulted in the mitigation of alloxan-induced hyperglycemia as well as hepatic and endocrine irregularities. These findings indicate that a blend

of raw and γ -irradiated carob and roselle extracts can partially rectify the metabolic alterations induced by alloxan exposure, leading to diabetes. Furthermore, gamma irradiation at a 10 kGy dose also enhances the overall phenolic composition of dried carob and roselle (Hamza & Alsiny, 2015). Another study conducted by Al-Saeed et al. evaluated the relieving effect of carob ethanol extract, this time on male guinea pigs with experiment-induced diabetes, and concluded that carob extracts have good spermatogenic and anti-diabetic properties. they conclude that Carob could prevent diabetes and improve the function of the male reproductive system (Al-Saeed et al., 2019).

Said et al. (2017) conclusively demonstrated that Nile tilapia fish (*Oreochromis niloticus*), when exposed to lead and fed a diet enriched with carob extract, experienced improved plasma glucose levels. These findings were corroborated by Mokhtari et al., who illustrated that carob ether extract reduced blood glucose levels in diabetic male rats (Mokhtari et al., 2011). These results have been explained by the presence of fibers, phytosterols, and tocopherol in the carob extract, which can cause a decrease in blood glucose levels and stimulate the beta cells of the pancreas to secrete more insulin into the bloodstream (Said et al., 2017).

Hussein et al. (2022) conducted an *in vivo* investigation which found that carob powder significantly reduced blood glucose and cholesterol levels in male albino rats. The study suggests that medicinal plant powders, such as carob, have the potential to be a unique treatment for people with diabetes, obesity, and atherosclerosis. Based on the study discussed in this paragraph, we strongly recommend conducting carefully controlled clinical studies to further investigate the bioactive components derived from carob in various animal models. Table 2 presents a collection of diverse investigations that have explored the various applications of carob, both *in vivo* and *in vitro*.

Carobs based food products

The food industry can utilize carob fruit to produce a variety of carob products, which are high in sugars, dietary fibre, and a range of bioactive ingredients, including polyphenols and D-pinitol (Brassescio et al., 2021). Carob syrup is a typical Mediterranean product that has a high concentration of dietary fiber, sugars, polyphenols, and important minerals. Compared to other

Table 2. Studies on biological activities of carob related to diabetes

Carob fractions/ bioactive	Mode of investigations	Pharmacological activities	References
Carob seeds extracts	<i>In vivo</i> trials on male diabetic rats	Blood glucose lowering activities	(Mokhtari et al., 2011)
Carob fruit extracts	<i>In vivo</i> trials	Antidiabetic effects	(Hamza & Alsiny, 2015)
Carob pods extracts	<i>In vivo</i> trials	Blood glucose, and toxins lowering effects	(Said et al., 2017)
Carob pods	<i>In vitro</i> and <i>in vivo</i> trials	Inhibiting impact on both α -amylase and α -glucosidase, enzymes involved in glucose metabolism	(Qasem et al., 2018)
Carob honey	<i>In vivo</i> trials on diabetic rats	Hypoglycemic and hepatoprotective effects	(El-Haskoury et al., 2019)
Carob ethanolic extracts	<i>In vivo</i> trials on alloxan induced pigs	Antidiabetic affects	(Al-Saeed et al., 2019)
Meat enriched with Carob fruit extract enriched	<i>In vivo</i> trials	Improvement of pancreatic beta cells dysfunction	(Macho-González et al., 2020)
Aqueous extracts of carob pods	<i>In vitro</i> trials	Hypoglycemic and antioxidant effects	(Darwish et al., 2021)
Carob powder	<i>In vivo</i> trials on diabetic albino rats	Blood glucose and lipids lowering effects	(Hussein et al., 2022)
Carob pulp flour	<i>In vivo</i> trials	Hepatoprotective and antihyperglycemic activities	(Martić et al., 2022)
Carob pods and seeds extracts	<i>In vitro</i> trials	Suppression of advanced glycation products	(Kavvoura et al., 2023)

sources, this syrup contains a significant amount of D-pinitol, indicating its potential for medical purposes, such as reducing blood glucose levels (Tetik et al., 2011). The carob is used in cold beverages, baked goods, and confections, and is widely recognized for its commercial value (El-fazazi et al., 2020; Rasheed et al., 2019). Carob powder is often used as a substitute for cocoa due to its high sugar content and lack of caffeine and theobromine, which are stimulants (Rasheed et al., 2019). According to Boublenza et al., the total polyphenol content and antioxidant activity of carob powder are increased by roasting temperature. Therefore, roasted carob powder can be used as a dietary supplement and as an ingredient in various dishes (Boublenza et al., 2017).

Carob pulp, which is high in carbohydrates, proteins, and minerals, has various industrial applications and is gluten-free, making it a good alternative to cereal-derived products for patients with celiac disease (Boublenza et al., 2019). Additionally, Arribas et al. have demonstrated that extruded gluten-free snacks made from carob pulp have anti-proliferative, anti-inflammatory, and anti-microbial properties, making them a healthy option (Arribas et al., 2019). A new type of gluten-free fettuccine has been developed using rice or white beans and enriched with 10% carob fruit. The inclusion of carob fruit has increased the overall dietary fibre content, enhancing the practical value of the fettuccine (Arribas et al., 2020). Macho-González et al. (2020)

Table 3. Food products developed from carob different fractions

Products	Carob fraction used	Health benefits
Carob tea	Beans and seeds	Provides calcium and phosphorus, so may benefit bones
Carob syrups	Pods and seeds	Gluten free, so beneficial in celiac disease
Carob powder	Seeds and beans	Cocoa substitute, and improves digestion
Carob cream and spread	Pulp	Antioxidant
Carob snack bars	Fruit	Helpful in diarrhea
Bakery products	Seeds, pods, pulp	Nutritional
Meat products added with carob powders and extracts	Pods, seeds and pulp	Antihyperglycemic and antiobesity effects
Carob supplements	Seeds and pods	Rich in micronutrients

Note: Source – Arribas et al., 2020; Nasrallah et al., 2023; Rodríguez-Solana et al., 2021; Stavrou et al., 2018.

investigated the potential of beef supplemented with carob fruit extracts as a remedy for type 2 diabetes mellitus in its later stages.

Locust bean gum is a well-known polysaccharide derived from the carob seed. It is composed of galactomannan and is commonly used as a thickening and texturizing agent (E410) in food, medicine, and cosmetics (Laaraj et al., 2023; Nasrallah et al., 2023). Siano et al. found that carob bean germ powder not only inhibits the activity of α -glucosidase and α -amylase, but also slows down the degradation of reducing sugars when incorporated into pasta. Therefore, carob bean germ powder is a valuable ingredient in low-glycemic index cereal-based recipes (Siano et al., 2023). A range of food products that have been developed, or can be developed by carob, involving their potential health promoting capacities, are given in Table 3.

CONCLUSIONS

The link between today's dietary habits and lifestyle choices and the incidence of serious diseases such as obesity, diabetes, and cardiovascular disease is becoming increasingly clear. Carob, known for its functional properties, is becoming increasingly popular on the market for its ability to alleviate certain health problems. The food industry is in the process of researching and further developing this area. Researchers have investigated the medicinal potential of carob fruit, and its fractions, such as pulp, and seeds, due to their biologically active ingredients. Various scientific experiments have investigated the blood glucose-lowering effects *in vivo* and *in vitro*, as well as the nutritional potential of carob fruit constituents, and this overview provides a brief summary of these findings. From these results, it was concluded that the carob fruit contains considerable amounts of fiber, sugar, proteins, and D-pinitol. Depending on the different fractions of the carob fruit, it has a high content of polyphenols, polysaccharides, tannins, and other bioactive elements. Enriching certain foods with carob makes them more functional and allows them to reap potential health benefits. In short, the carob fruit is a versatile but underutilized product that contains numerous bioactive substances that can exert various activities, especially antihyperglycemic activity.

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