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A Recent Trend on Functional and Therapeutic Role of Carob Beans In Food Products

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ABSTRACT

Background: Carob (Ceratonia siliqua L.) is a nutritious and medicinal evergreen crop of the Leguminosae family, cultivated in Mediterranean regions of West Asia and North Africa. Although its sustaining worth has been recognized for prosperity, its therapeutic characteristics have only recently been investigated, regardless of that some of those facts have been employed in ancestral remedies for generations

Purpose: To study the different functional and therapeutic role of carob beans and its utilization in the food products

Conclusions: Carob products are high in fibre, carbohydrates, and beneficial components such as polyphenols and D-Pinitol. Because of their anti-hyperglycaemic, antioxidant, and an-ti-inflammatory properties, bioactive chemicals found in carob fruit and its derivatives help treat a variety of health issues, in-cluding diabetes, heart disease, and gastrointestinal disorders. The current review focuses on functional properties of carob beans and its potential in generating a wide range of health-beneficial food and formulations.

1. Introduction

Carob (Ceratonia siliqua) is a pine tree of the Fabaceae (Legumes) family. Its natural habitat is western Asia, but following domestication, it extended throughout the whole Mediterranean basin, as well as the western coastlines. Italy (23.11%), Turkey (10.39%) Portugal (28.83%), and Morocco (16.11%) were the biggest producers of carob globally from 2015 to 2018. The yield of carob pods is affected by many variables, including variety, location, cultural customs, and environmental conditions (Nasar Abbas et al., 2016). Carob pod has numerous uses in paints, polishes, adhesives, ceramics, cosmetics, film emulsions, oil drilling, and pharmaceuticals (Mudgil et al., 2014). Numerous studies support the utilization of carob produce and its derivatives as a useful food and food additives (Fidan et al., 2020). A presentation on carob pod commercial manufacturing and processing is detailed in Fig. 1. In the food sector, carob has a lot of promising benefits because of its many health advantages, (Goulas et al., 2016) which persists even after processing. Further, in numerous baked goods, milk formulas, it is used as a substitute for cocoa. Additionally, by fermenting carob pods with bacteria, fungi, and algae, various organic acids, alcohols, and enzymes can be produced (Tsatsaragkou et al., 2014; Srour et al., 2016; Custódio et al., 2015; Yatmaz et al., 2016). This unusual quality may be explained by the existence of biogenic volatile chemical substances, such as ketones/aldehydes, esters, and acids. Due to its positive impacts on health, carob pulp is receiving more and more attention as an ingredient in a variety of culinary products.

The majority of studies, however, focused on characterizing whole carob or seeds for their specific phytochemical elements. This study intends to examine and underline the carob's positive qualities as well as its potential to be used as an effective working component in the food sector, providing new insights into crop sustainability. The detailed functional characteristics of the carob bean and the food products derived from it are highlighted in this review article.

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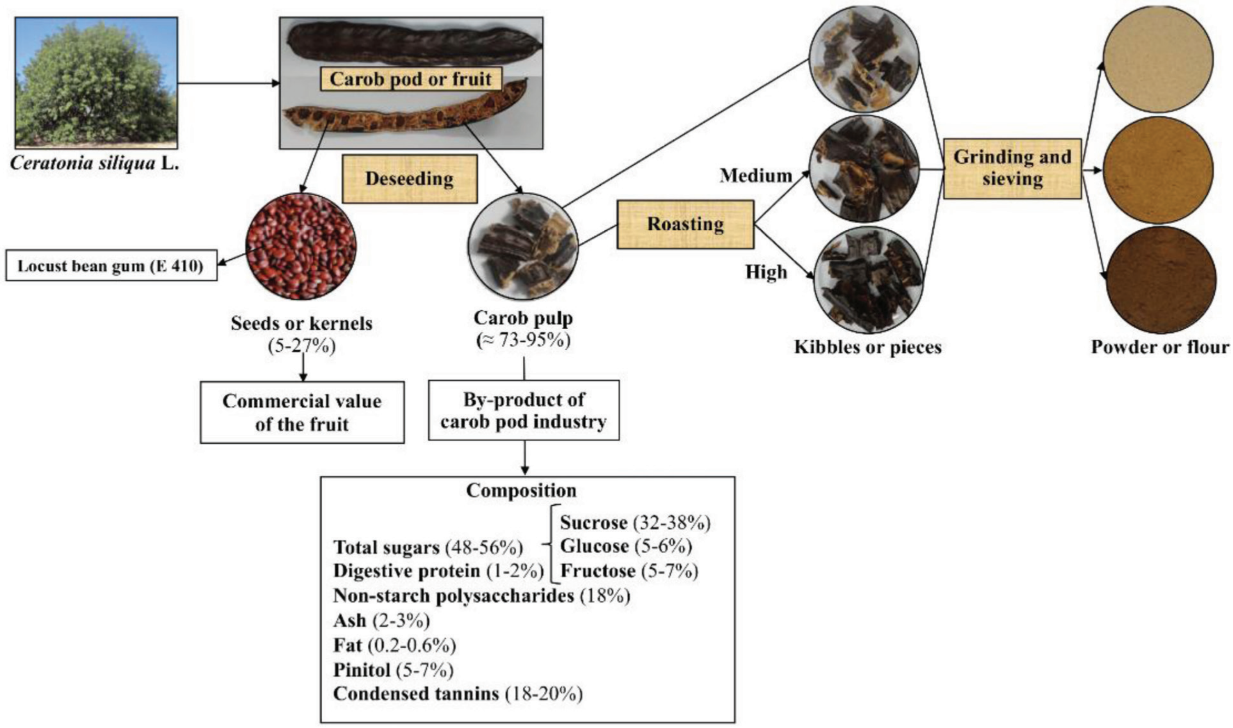

Figure 1: Commercial production of nutritional and functional by products of carob pod.

2. Carob beans as Functional Food

Functional food can be described as a food or beverage product which consist of nutraceutical or food-grade bioactive agents with therapeutic effects and above normal nutritional function.Recently, people are more interested in supplements derived from natural, traditional and non-traditional foods as possible sources of biologically active substances with proven health properties for inclusion in the human diet (Baumel et al., 2018). About that, carob (Ceratonia siliqua L.) holds potentially significant importance for the food industry due to its phytochemical constituents with functional properties as detailed in the following sections. We have discussed the chemical elements of carob and its biological features linked to their health benefits shown in (Table 1).

Table 1: Chemical elements of carob and biological features linked to health benefits.

S.No	Chemical Elements	Health Advantages/ Illness/ Biological Features	Target disease control	Carob fraction/ Part
1	Chlorogenic acid, Rutin Myricetin, Polyphenols	Inflammatory and Antitumoral activities, Neurogenerative disease	Abdominal obesity control	Powder of carob pulp
2	Epigallocatechin, Catechin, Syringic Acid	Antioxidant, Antibacterial, Antifungal	Help prevent heart and brain disease	Extract of carob pulp
3	Insoluble dietary fibre	Enhanced lipoprotein metabolism	Diabetes, heart disease and some type of cancer	Pulp of carob
4	D-pinitol	Anticancer/ Hepatoprotective	Improves liver	Pulp of carob
5	Flavonoids, condensed tannins	Antihypertensive activity, Antidepressant effect	Lower cholesterol	Peel of carob seed
6	Sugar, fibre, pyrogallol	Laxative and anti- diarrheal activities	Heart disease control	Carob pod
7	Galactomannan	Gastrointestinal effects		Seed endosperm

2.2. Anticancer and Related Activity

Carob is rich in phytochemicals and recent studies have shown that it has anti-cancer, anti-proliferative, and pro-apoptotic effects. The polyphenol quercetin promotes apoptosis (programmed cell death) in leukaemia cells by directly targeting the anti-apoptotic protein Bcl-x. It also works well in the tumour micro environment, shrinks tumours and prevents angiogenesis (formation of new blood vessels), as demonstrated in pancreatic and breast cancer xenograft models (Zhao et al., 2016). Carob fruit also contains gallic acid (phenolic acid), which inhibits the growth of osteosarcoma (bone cancer), Forester et al. investigated gallic acid and its derivatives involved in the antiproliferative activity of human colonic cell lines. Carob fibre extract and tannins are also anticancer agents and inhibit the growth of human colonic adenoma and adenocarcinoma cells by protecting these cells from oxidative stress. It has been demonstrated in the literature that the ethyl acetate fraction of carob leaves has a significant shielding result against induced hepatotoxicity and nephrotoxicity in rats (Hsouna et al., 2011).

2.3. Anti-hyperlipidaemic Activity

Coronary heart disease and stroke account for 38% of all deaths in the United States. Hyperlipidaemia, defined as increased levels of cholesterol, triglycerides, or both that are in the blood, which promotes atherosclerosis and can be a major cause of cardiovascular disease (Nelson et al., 2013). Eating a high-fibre diet lowered the risk of heart disease and mortality by lowering total serum and LDL concentrations in the blood. Carob fibre extract (CFE) reduced pancreatic lipase activity in rats, decreased fat digestion and absorption, and increased faecal fat excretion, thereby increasing postprandial fat excretion. Carob is rich in fibre and phenolic chemicals, both of which have antihyperlipidemic properties. Studies have shown that increasing the antioxidant content of carob showed hepatoprotective effects, reducing lipoproteins and oxidative stress in hypercholesterolemic rats (El-Rabey et al., 2017). The insoluble fibre contained in the pods attenuated the detrimental effects of hepatic dyslipidaemia by altering the SIRT1 and PGC-1 signalling pathways, which are crucial for cholesterol and triglyceride metabolism in the liver.

2.4. Anti-diabetic Effects

Diabetes is a chronic disease in which the pancreas either does not generate enough insulin or produces too much or does not use the insulin produced by the body. Uncontrolled diabetes causes hyperglycaemia and elevated blood sugar levels, which causes serious harm to kidneys, liver, blood vessels, and nerves. The number of people with diabetes is rapidly increasing. By 2025, the number of persons affected by diabetes is expected to grow by 300 million. Diabetes will be the sixth largest cause of mortality by 2030, according to the World Health Organization. Diabetic etiologies are treated with insulin or oral hypoglycaemic therapy. Controlling hyperglycaemia requires new drugs that reduce or limit glucose absorption (Chao et al., 2010). Due to their high flavonoid and polyphenol content, several herbs and extracts have been used as effective antidiabetic agents. Carob berries and extracts have also been implicated in anti-diabetic effects due to their complex phytochemical composition. These chemicals, which inhibit glucose transport and absorption in the intestine, can be used as dietary supplements to treat hyperglycaemia and diabetes. Carob leaves and bark is potent against α-amylase and β-glucosidase, two carbohydrate hydrolases that digest carbohydrates and cause postprandial hyperglycaemia in diabetic patients. Another study found that carob can be used to treat diabetes by improving glucose tolerance, inhibiting glucose absorption, and protecting rats from alloxan-induced diabetes (Hamza et al., 2015). Additionally, studies have shown that replacing sucrose with natural pinitol-rich sweeteners reduces glucose metabolic dysfunction in patients with impaired glucose tolerance (IGT) and normalizes dysfunctional glucose metabolism. Pancreatic cells can counteract insulin resistance in the early stages by increasing insulin production. Functional food enriched with locust bean fruit (CFE) extract ameliorate pancreatic cell dysfunction, resulting in increased insulin levels and decreased hyperglycaemia, making it a beneficial strategy for the treatment of type 2 diabetes in its late stages (Macho-González et al., 2020). Consumption of CFE-fortified meat increases lipoprotein metabolism and insulin signalling efficiency by lowering VLDL and plasma triglyceride levels through increased faecal fat excretion (Macho-González et al., 2020).

2.5. Prevent Obesity

Obesity is defined as the accumulation of triglycerides in adipose tissue as a result of increased adipocyte proliferation and adipocyte hypertrophy. Obesity due to abnormal adipocytokine secretion is a crucial contributor to the development of several chronic illnesses, including diabetes, cardiovascular disease, and cancer. In this condition, reactive oxygen species and oxidative processes are out of balance, leading to various metabolic abnormalities such as hyperinsulinemia, altered lipid metabolism, and increased triglyceride stores. The adverse health effects of weight loss drugs and surgery have shifted focus to the use of natural products, especially functional diets that aid weight loss while providing the nutrients the body needs (James et al., 2017). Carob is a superfood with strong antioxidant capacity that helps treat chronic lifestyle-related diseases. By feeding mice a high-fat diet and administering carob polyphenols (CPP), it was found that CPP functions as an anti-obesity chemical that inhibits adipocyte hypertrophy and increases in adipose tissue mass. The high antioxidant capacity of carob tree by-products makes them promising therapeutic agents for the treatment of metabolic syndrome (MetS). MetS is a multifactorial condition characterised by abdominal obesity, hyperglycemia, hypertension, and atherogenic dyslipidaemia (Rico et al., 2019) which raised the risk for heart disease and type 2 diabetes. MetS is more likely to occur due to poor diet, such as frequent snacking and consumption of high-energy foods. Healthy snacking behaviour, on the other hand, can control appetite, induce satiety, and reduce postprandial glycaemic responses while enhancing food quality. Rico et al., created a functional snack containing carob and wakame seaweed to address his NAFLD (non-alcoholic fatty liver disease), a liver symptom of MetS. According to Rico et al., functional snacks made from carob can cure fatty liver by increasing fat oxidation and decreasing oxidative stress. Carob contain significant amounts of dietary fibre, ttherefore, foods high in fibre have a low-calorie value, which helps with weight management (Lattimer et al., 2010).

2.6. Antioxidant Properties

ROS (reactive oxygen species) and RNS (reactive nitrogen species) are two forms of free radicals and ions. They are produced either locally by regular cellular metabolism (redox activities in cells) or outside (pollution, cigarette smoke, radiation, drugs, alcohol, cooking). These species function as both poisonous and helpful compounds. A precise balance between two conflicting effects is a fundamental component of life. At low to moderate quantities, ROS and RNS are advantageous to cellular responses and immunological function. At large concentrations, they create oxidative stress, a dangerous process that can kill all cell components. Cancer, arthritis, ageing, autoimmune disorders, cardiovascular and neurological diseases are all the influence of oxidative stress. The human body has several mechanisms to combat oxidative stress, including the production of antioxidants, which are classified as enzymatic antioxidants (superoxide dismutase, catalase, glutathione peroxidase, and glutathione reductase) or non-enzymatic antioxidants (lipoid acid, glutathione, L-ariginine, coenzyme Q10, lactoferrin, etc.). Endogenous and exogenous antioxidants act as "free radical scavengers," preventing and repairing ROS and RNS damage (Graves, 2012; Lushchak, 2014; Pham-Huy et al., 2008). Saci et al. (2019) observed similar results, suggesting that unripe carob extract can act as a natural antioxidant and provide large amounts of secondary metabolites with neuroprotective effects in vitro. Several studies have demonstrated high antioxidant activity and improved developmental performance in rabbits (Abu Hafsa et al., 2017; Sadat et al., 2019; Lakkab et al., 2019; Rtibi et al., 2015a; Rtibi et al., 2015b)

3. Commercial Functional Food Products From Carob Beans

Great challenges for the food industry are the clear demonstration of the health benefits of natural ingredients sources before they can be successfully incorporated into functional food products with regulatory compliance and consumer acceptance. Several studies in recent years have demonstrated the versatility and functionality of different carob products used in the production of functional foods. The processing of whole carob fruit to obtain different carob products significantly affects physicochemical and functional properties. The carob products can be used as natural ingredients in the food industry due to flavouring or colouring effects and improved final products' characteristics. Some examples of foodstuffs with the addition of carob products are presented in Table 2. The enhanced properties of the final products are highlighted.

3.1. As a Food Additive (Stabilizer/thickener)

LBG is used as a thickener and stabilizer as a food additive (E-410) in many dairy, meat and bakery products. Due to its excellent bioactive profile, it is also used in diet products and dietary supplements. However, dietary usage varies by application, with typical addition levels ranging from 0.2% to 0.5% (Mudgil et al., 2014). Few of its application in food industries include: binding water, controlling texture, affecting crystallization, preventing creaming or sedimentation, improving freeze-thaw behavior, synergizing starch products, preventing deterioration, maintaining turbidity in juices and soft drinks. Wielinga reported the technological role of LBG in extendong shelf-life of foods by foam stabilization (Wielinga et al., 2010). Additionaly, the texture of frozen foods, dairy products, and baked goods is determined by synergistic interactions between LBG and other biopolymers. Caseinate LBG biopolymers were found to exhibit significant emulsifying properties in oil-in-water emulsions at various pH value. Moreover, their emulsifying and stabilizing abilities are attributed to protein-polysaccharide interactions resulting from electrostatic interactions, hydrogen bonding, and van der Waals forces. LBG improves the rheological properties of goat milk yogurt while maintaining the microbiological longevity of yogurt cultures and probiotic bifidobacterial species.

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Moreover, for frozen desserts, key concerns include product crystal size, viscosity, texture, and melting temperature. LBG contains galactomannan, a thickening agent which can be used to prevent ice crystal formation and improve the melting properties of ice cream. Chavez et al, (2018) found that LBG improved the mouthfeel, perceived viscosity, and melting properties of frozen goat milk desserts. Further research found that LBG reduced ice cream mix overflow, increased melting time, and improved the sensory properties of both animal and vegan ice cream. LBG can be used as a fat substitute to reduced-fat or low-fat dairy products and has a significant impact on the texture and organoleptic properties of the products. Furthermore, it can be used as a natural substitute for thickeners in the jam industry without affecting the organoleptic or physio-chemical properties of the jam (Mekhoukhe et al., 2021).

3.2. Cocoa Substitute

Coca is an important agricultural commodity as it is the main ingredient in chocolate-based products. It is also of great economic and social importance around the world. Several factors contribute to slowing coca supply growth, creating an imbalance between supply and demand, pushing up coca prices. To meet customer demand, sustainable alternative products are needed to overcome these problems. Carob is a natural, inexpensive coca substitute with many similarities that make it an ideal coca substitute. Carob powder is made by peeling, grinding and roasting the carob pulp. Carob is roasted at 120-180°C for 10-60 minutes, depending on the desired end result. Carob powder has a characteristic coca-like aroma, flavour and colour when roasted due to the caramelization of sugar and the Maillard process (Srour et al., 2016). Therefore, carob can be used as a cocoa substitute and offers a variety of benefits, including no caffeine and theobromine stimulants, high fibre supplementation, low fat content, and high antioxidant potential (Papageorgiou & Boublenza, 2017). Akdeniz et al. (2021) showed that carob is an excellent substitute for coca in dark and milk chocolate formulations, with no significant difference in organoleptic properties or consumer acceptability. Carob chocolate is also rich in nutritional value because carob has a low fat and high fibre content. Another study demonstrated the effective manufacture of chocolate using carob instead of cocoa, and the product is useful for conditions such as diabetes, celiac disease, caffeine intolerance, or calorie-conscious groups (Lanfranchi & Salem, 2012). Carob-based icings with excellent rheological and sensory properties have also been developed to replace chocolate icings and coatings in confectionery and bakery products. According to Pawowska et al. (2018) carob-based baked goods are more nutritious, have higher anti-radical properties, and have better sweet and sensory properties than cocoa-based baked goods, aldehydes, lactones, furans, pyrrole derivatives and other aromatic components, as well as retaining the appropriate texture and organoleptic properties.

3.3. Gluten-free Products

Due to their sensory and nutritional properties, grain-based baked goods are an important part of the human diet. However, due to the gluten content, these products are not suitable for celiac disease. Celiac disease is an autoimmune disease caused by the consumption of gluten proteins that cause an inflammatory response in the small intestine. Celiac disease patients should eat vegetables, raw meat, pasta, bread, cookies and other processed products (starches and gluten-free flours). There is only a limited range of products on the market that can be used as replacements for the standard celiac diet. In recent years, food manufacturers have taken an interest in producing products that meet the unique nutritional needs of customer groups suffering from food issues and allergies. Gluten-free foods (GF) fall into this category, particularly for weight management and disease prevention. Because it is healthier, it is in high demand not only among celiacs but also among non-celiacs (Papageorgiou et al., 2015). The production of gluten-free products presents many technological obstacles to the food industry. These include texture development due to gluten deficiency, low nutritional value, and bland taste. GF products require specific additives and ingredients to replicate the structural functions of gluten. Starches from legumes (beans) and cereals (rice and sorghum) are used for this. Carob is another legume with great potential for producing GF goods. Locust bean gum has rheological properties similar to wheat gluten and a superior nutritional profile (Arribas & Tsatsaragkou, 2012). Cervenka et al. (2019) and Sciammaro et al. (2018) reported locust bean flour biscuits as more nutritious than control biscuits. However, high amounts of locust bean gum have some negative effects on product taste, crispness, colour and aroma. According to the finding by Skaltsi et al. (2021), the most ideal formulation for producing high quality gluten-free biscuits with acceptable physical, textural, and sensory properties is dried apple pomace (32.6%–47.58%), locust bean gum (16.2%–29.2%), and water (29%-43%). Carob flour is also used to make new gluten-free fettuccine and noodles that are better cooked, more nutritious and more functional (Arribas & Altiner, 2020).

3.4. Fermented Products

Fermentation is a metabolic process in which bacteria convert carbohydrates into organic molecules such as acids, gases and alcohols. Both major and minor nutrients are required for this transformation. However, using pure food sources makes the industrial process expensive. Carob pods are an important source for fermentation due to their high nutritional value. Carob is processed to make various carob products such as CBG, carob juice and carob flour. After extracting all these fractions, the remaining sugar source can be used in fermentation processes to make specific organic molecules (Yatmaz & Haddarah, 2013). Citric acid, a tricarboxylic acid, is frequently utilized in the pharmaceutical, food, and beverage sectors as an acidulant and taste enhancer. Researchers are focused on making it from cheap sources. According to the literature, *Aspergillus niger* fermentation of carob extract produced significant levels of citric acid (Haider et al., 2014). Carob can also be used as a carbon source in the production of the industrial chemical lactic acid. Lactic acid is in high demand as it is used as a monomer in the production of biodegradable polylactic acid (PLA), a sustainable bioplastic. *Lactobacillus casein* and carob extract can be used as fermentation media to obtain higher concentrations of lactic acid. However, the carob extract must be treated with an invertase enzyme before sucrose can be converted to monosaccharides that can be successfully metabolized by *L. casein*. The highest concentration achieved using yeast extract as nitrogen source was 68.79% compared to other nitrogen sources which produced 66.70% (Turhan et al., 2010).

Due to rising prices and environmental concerns, conventional fuel supplies are being replaced by renewable fuels. Research in this area focuses on meeting the world's energy needs by producing clean fuels using simple and inexpensive technologies. Ethanol can be produced sustainably from food and waste. Due to their high sugar and mineral content, carob and its waste can be used to produce bioethanol (Bindal et al., 2019). Further, Bindal et al. (2019) demonstrated that carob can be efficiently used for large-scale ethanol production by using strain of *Saccharomyces sp*. The food industry faces major hurdles before it can demonstrate the health advantages of natural ingredient sources in order for them to be effectively incorporated into functional meals with regulatory compliance and customer acceptability (McClements & Xiao, 2014). Several recent studies have proved the flexibility and use of various carob products in the development of functional diets. The processing of whole carob kernels into various carob products has a significant impact on their physio-chemical and functional properties.

Carob products can be used as natural ingredients in the food industry due to their improved taste and colour characteristics. Table 3 shows some examples of different food category that have fortified carob products. Carob syrups (Brix 60, 70, or 80) were characterized by high antioxidant activity and emulsifying capacity, and high concentrations of reducing sugars. These improved qualities are attributed to the non-enzymatic browning process that occurs during juice cooking. The physio-chemical properties and acceptability of certain bread products may also be affected by the degree of roasting of the locust bean flour. This increased the hardness, elastic-like behaviour of cookie's dough indicating a more robust component interaction. In addition, in order to effectively use carob products as functional food ingredients, carob products must be understood in terms of their physical and chemical qualities, as well as their dependencies. Benkovic et al. (2017) investigated the physicochemical parameters of carob flour prepared with and without seeds and discovered that carob flour created with seeds had better cohesiveness indices and cake strength values than flour made without seeds. Furthermore, the cohesiveness and cake-forming ability of flour influenced the extraction efficiency of polyphenols and flavonoids, as well as the antioxidant capacity. In terms of carbohydrates, the carob seed-free sample contained more total sugars and soluble polysaccharides. These qualities give traditional dishes their nutritional and biological value, depending on the remaining ingredients. Papaefstathiou & Agapiou, (2018) compared the nutritional composition of 20 traditional carob foods with that of Cypriot carob meat. They concluded that carob fruits and powders can be recommended for inclusion in the daily human diet because they contain valuable nutrients and have a sweet taste yet are low in fat, whereas carob products can be recommended for their health and nutrition claims. Another important benefit of carob products is their use as gluten-free flours in the baked goods sector. Martin Diana et al. (2017) gluten-free crackers made from carob tree by-products (germ and seed coat) developed a snack. The polyphenols responsible for the product's antioxidant activity were anthocyanins, tannins, catechins, and flavanols (Albertos et al., 2015). Further, the germ and seed coats of carob processing-based by-products contributed to the protein and antioxidant activity of the engineered foods.

Table 3: Carob-based category of food and their primary advantages.

S.No	Food Category	Functional foods	Advantages
1.	Dairy Based	Carob spread	Colour and texture are both excellent. A great source of important mineral Total phenolic content is high
		Low lactose yoghurt with carob flour	Fibre content is high. Sweetness content is high

2.	Seed Based	Sesame pastes enriched with carob syrup	Enhanced emulsion stability and High nutritive value
3.	Cereal Based	Pasta enriched with carob flour	Colour, stiffness, and hardness are all excellent. High antioxidant activity and sucrose content and High total phenol content and glycaemic index
		Rice based extruded snacks like fortified with pea, bean and carob fruit	Phenolic chemicals in abundance, a high level of antioxidant activity, enhanced textural characteristics
		Muffin with carob powder	High level of water activity, High phytosterol and genistein concentration, Enhanced browning and FAST indexes
		Wafer cream with carob pod and chicory root powder	Caffeine content is low, High sugar content Improved physiochemical, rheological, and sensory qualities
		Bread with carob flour	Texture and sensory characteristics have been improved, Antibacterial action, Gluten aggregation is high
		Sponge cakes enriched with carob flour and carob syrup	High dietary fibre, protein, and carbohydrate content increased overall moisture content, A favourable impact on sensory properties

4. Conclusion and Future Trends

Health problems are increasing all over the world due to various causes such as modern lifestyles and large amounts of man-made materials. As a result, there is a great demand for articles that help reduce economic losses while providing many health benefits. The rich bioactivity profile and high fibre content of carob, as well as its effects on obesity, diabetes, oxidative stress, hyperlipidaemia and inflammation, make it an attractive food ingredient with potential for use in creating a wide range of health-promoting products. Additionally, locust bean (LBG) products improve rheology by imparting functional properties to foods, enhancing their nutritional profile, and prolonging the final product's shelf life when used as a food additive in recipes. Carob is undoubtedly beneficial not only for human health, but also for the economy and the environment. Further research is needed to analyse and investigate the neuroprotective effects of carob.

5. Competing Interests

None declared

6. References

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