Review

Carob bean (*Ceratonia siliqua L.*): a new perspective for functional food

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ABSTRACT

Background

Carob (*Ceratonia siliqua* L.) is an evergreen tree that belongs to the Leguminosae family and is typical of the Mediterranean basin. It is well known for its valuable locust bean gum obtained from carob seeds. However, the food industry can obtain different carob products from carob fruit after processing. Carob products are good sources of dietary fibre, sugars, and a range of bioactive compounds such as polyphenols and D-pinitol.

Scope and Approach

Bioactive compounds present in carob fruit and its derived products help control many health problems such as diabetes, heart diseases, and gastrointestinal disorders due to their anti-hyperglycaemic, antioxidant, and anti-inflammatory activities. So, carob products have a great potential to be used as a functional food ingredient.

Key Findings and Conclusions

This article focuses on carob characteristics and processing, chemical composition, health benefits, and applications in food formulations to explore the potential of carob in developing a wide variety of health-beneficial food products.

1. Introduction

Less known fruit species, including carob, are gained more popularity recently. They include a high content of non-nutritive, nutritional, and bioactive compounds such as flavonoids, phenolics, anthocyanins, phenolic acids, and as well as nutritional compounds such as sugars, essential oils, carotenoids, vitamins, and minerals. Less known fruits have distinct flavour and taste, excellent medicinal value, and health care functions as well (Engin & Mert, 2020; Eyduran et al., 2015; Gundogdu et al., 2014; Kaskoniene et al., 2020).

Carob (*Ceratonia siliqua* L.) is an evergreen tree that belongs to the Leguminosae or *Fabaceae* family (subfamily *Caesalpinioideae*) native to the Mediterranean region. It has been widely exploited since antiquity due to its edible fruits (commonly referred to as pods or merely carob). It is still currently used in agro-food industries and soil restoration purposes (Tous & Antoni, 2013). In the last years, the average production of carob pod in the world was reduced from 165,990 tonnes in 2013 (Yatmaz & Turhan, 2018) to 136,612.75 tonnes in 2018 (FAOSTAT, 2020). The fall of carob cultivated hectares in important producers such as Spain explains these figures. Carob trees have been traditionally used to obtain locust bean gum (LBG; thickener E410) from the pod seeds that accounts for only 10% of the pod's weight. The emergence of cheaper substitutes for LBG, such as guar or xanthan gum, made carob tree cultivation no longer profitable in the EU (López-Sánchez, et al. 2018). However, many countries still cultivate carob trees, which is justified by pharmacological and food industry interests. The main worldwide producers of carob pod from 2015 to 2018 were Portugal (28.83%), Italy (23.11%), Morocco (16.11%), and Turkey (10.39%) (FAOSTAT, 2020)(Table 1).

The four main genetic groups of *C. siliqua* identified are SM, South Morocco; SS, South Spain; CM, central Mediterranean including genotypes from Portugal, Algeria, France, Sardinia, Sicily and Balearics; EM, eastern Mediterranean (*i.e.* Greece, Cyprus and Lebanon) (Viruel et al., 2019). The use of carob dates to the ancient Egyptians who fed livestock with carob pods and are also reputed to have used the gum as an adhesive in mummy binding. The Arabs used the carob seed as a unit of weight. They called the seed *qirat* or *karat*, and the standard weight of the carob seed became the unit of weight for gold and precious stones. At present, carob pods are commonly used in cakes, cookies, drinks, and various snacks in Egypt. Jams and liquors are made from carob in Turkey, Malta, Portugal, Spain, and Sicily. In Libya, a syrup named *rub* is extracted from carob and used to make *asida*, a traditional dessert.

The carob tree is a xerophytic (drought-resistant) species, well adapted to the Mediterranean region's ecological conditions with deep root systems, which are intolerant to waterlogging (Gucel & Sakcali, 2012). Given the rising climatic crisis, this plant requires little maintenance and can be a good solution in the future, both ecologically and economically. Santos et al. (2019) reported high accuracy the thermal growing conditions of carob tree cultivated in the Algarve region, a limited area with a well-defined climate in Portugal. This study confirms that carob tree is better located in warm areas with low chill requirements, where temperatures ranged between 16 to 36 °C for more than 50% of the hours of a year. This feature is one reason why the possible role of carob tree in the fire protection of agro-forest ecosystems of Mediterranean countries is considered. Besides, it is an essential component of Mediterranean vegetation, that in the absence of pruning practice, it is converted into bush-like growing formations. Another reason is their easy planting propagation (Srečec et al., 2017). This knowledge is of great importance for different socio-economic sectors, such as agriculture and forestry, e.g., by assisting bioclimatic zoning and suitability assessments.

Carob has a great potential to be used in the food industry, not only for its health benefits (Goulas et al., 2016) and its characteristic strong aroma, which remains even after processing. This unique property may be explained by the presence of acids, esters and aldehydes/ketones emitted from carob fruit and powder, which are biogenic volatile organic compounds that contribute to plant growth, breeding and defence (Krokou et al., 2019). On the other side, the food industry's diversification and innovative development, brand new technological modernisation, and product-line expansion strategies are needed. Lobanov et al. (2018) studied the economic impact of incorporating vegetal ingredients in the innovative production of flour-based functional foods**.** In particular, the production of a lecithin bun with 4% of carob resulted in an increased content of proteins, fat and fibres and a decreased carbohydrate content, with better production efficiency than the production of lecithin bun without carob. The price of the carob bun is only 6% higher than the one without carob addition. This analysis allows recognising carob bean as an excellent raw material to produce gluten-free bread and flours enriched with vitamins, minerals, and proteins.

This work aims to review and highlight the beneficial aspects of carob and its potential for use as a functional ingredient in the food industry, opening new perspectives for this sustainable crop.

2. Carob characteristics and processing

Functional food is defined as a food or beverage product containing nutraceutical or food-grade bioactive agents with health benefits over and above normal nutritional function (McClements & Xiao, 2014). Nowadays, there is a growing interest 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 (Goulas et al., 2016), flavouring properties (Foundation & Aue, 1997), and nutrition benefits (Papaefstathiou & Agapiou, 2018). The carob tree grows up to 8–17 m high, with a broad semispherical crown and a thick trunk with brown, rough bark and sturdy branches (Figure 1a; Tous & Antoni, 2013). The tree produces fruit in an edible bean/pod, which is also known as locust bean. The beans (pods) hang in the form of clusters and remain green until fully matured (Figure 1b). The mature fruit is a long scimitar-shaped pod (10 to 25 cm) and contains several hard seeds embedded in a pulp (Figure 1c). The pods vary significantly in morphological characteristics such as dimension, size, weight, shape, density, colour, and seed-to-pulp ratio due to differences in cultivar varieties and climatic conditions (Benchikh et al., 2014; Nasar-abbas et al., 2016; Tous & Antoni, 2013). The seed:pulp ratio can vary between 10-20%:80-90%, increasing from cultivated type to wild type, because the pulp part of the wild type is smaller than the cultivated one (Yatmaz & Turhan, 2018). Carob seeds are characterised by a brown colour, significant hardness, a length around 10 mm, and a weight of about 0.2 g per seed. Seeds are composed by peel (30–33% w/w), endosperm (42–46% w/w), and germ (23–25% w/w) (Figure 1c; Tous & Antoni, 2013).

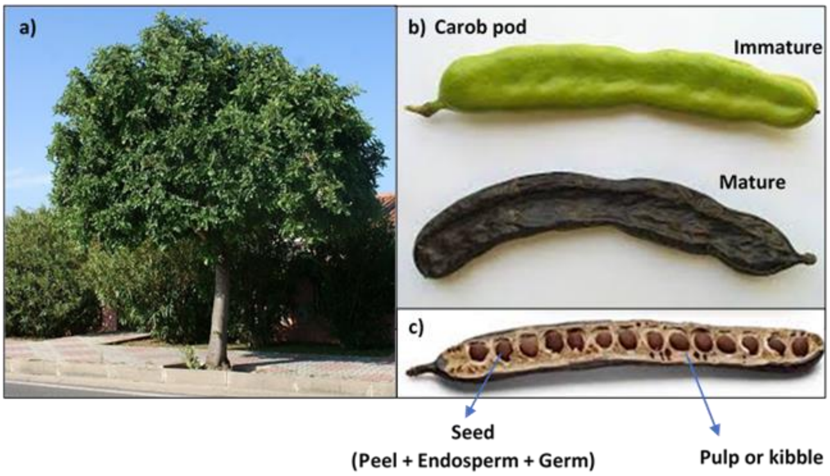

Figure 1. a) Carob tree (*Ceratonia siliqua* L.), b) Immature and mature carob pod, c) Carob pod constituents (Tous & Antoni, 2013).

Carob pods are rich in sugars (45-52%) and crude fibre (up to 40%) but poor in protein (2-7%) (Nasar-abbas et al., 2016). Most of the protein is found in the seed germ (55-65%) (Dakia et al., 2007), and the seed endosperm contains a high percentage of galactomannan (80-85%) (Barak & Mudgil, 2014). Due to the differences in the composition and functional properties, carob pulp and seeds are used separately to produce many products. The main industrial uses of the carob fruit are shown in Figure 2.

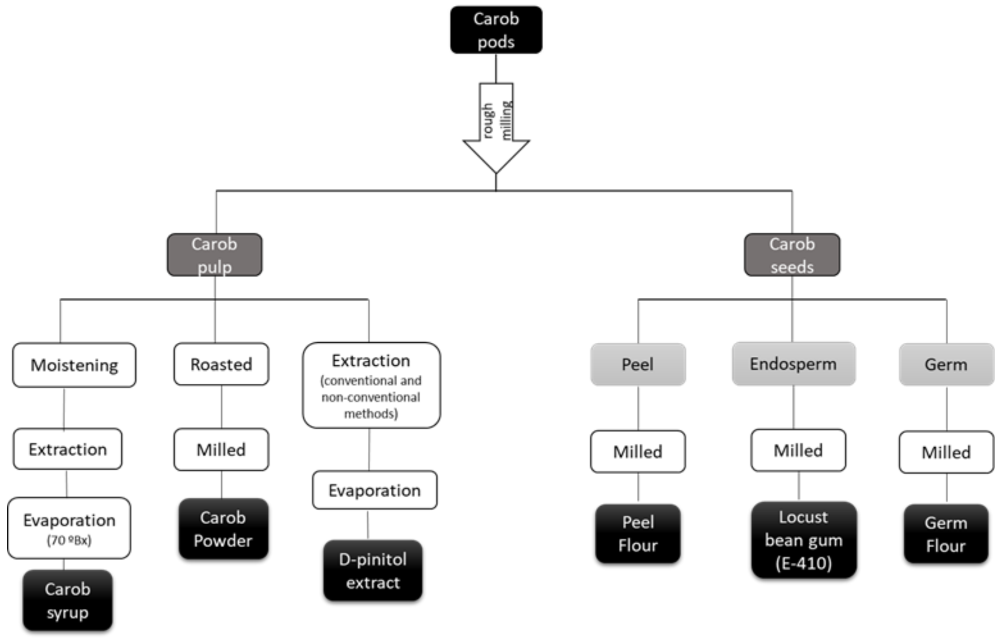

Figure 2. Main industrial uses of carob fruit (Durazzo et al., 2014; Ersan et al., 2020; Tounsi et al., 2017; Yousif & Alghzawi, 2000).

The manufacture of primary carob products such as flour, powder, and syrup requires pre-separation of seeds from the pod (Loullis & Pinakoulaki, 2018). The carob pods are dried after harvesting to reduce moisture to around 8%, and subsequently, they are kibbled to separate the seeds from the pulp portion. The pulp is processed differently, depending on whether it will be used for animal feed or food products. For animal feed, the pulp is grounded into different sizes based on the kind of livestock to be fed. In the food industry, the pulp is processed to obtain carob syrup and carob powder (Tous & Antoni, 2013). Carob syrup is obtained by leaving the grounded carob pulp in water. The mixture is then drained and boiled until desirable consistency (Özcan et al., 2009). Aziz & Hicham (2014) optimised the carob syrup production from different populations of Moroccan carobs. The authors used an experimental design to investigate the effect of three parameters (extraction temperature, extraction time and ratio of water to pulp) on syrups yields. As results, the optimum conditions were extracting temperature of 43.45 °C, extracting time of 2.40 h and extraction ratio solvent (water) to the pulp of 2.27 (v/w). The syrup yield from the different regions varies between 28.76 and 37.22 g/100 g (% w/w). The production and purification of sugar syrup can also be performed by a 10 column system connected in series, reaching a syrup yield of at least 90% (Petit & Pinula, 1995).

The pulp is first dehulled for carob powder production, grounded to different sizes, roasted and finally milled into a fine powder, called carob flour or powder (Yousif & Alghzawi, 2000). Based on the time and temperature used for roasting, lightly, medium, and highly roasted carob powder can be obtained. Generally, in conventional roasting of carob pulp, a temperature range of 120–180 °C (mostly around 150 °C) is used for 10–60 min.

Additionally, D-pinitol (3-o-methyl-d-chiro-inositol) extract can be obtained from carob pulp. This natural compound, related to the important family of inositols, is present in carob in high levels and increases this *Leguminosae*'s value due to its pharmacological importance related to anti-cancer, anti-diabetic, antioxidant, and anti-ageing properties (López-Sánchez et al., 2018). Besides the classic extraction associated with the syrup carob production, D-pinitol extraction from carob pulp was studied using microwave (Ersan et al., 2020), supercritical CO_2 (Cháfer & Berna, 2014) and ultrasound (Tetik & Yüksel, 2014) techniques.

Finally, the carob seed consists of three parts: the peel (husk), the endosperm and the germ. At first, the seeds are dehusked by treatment with dilute sulphuric acid or with a thermo-mechanical treatment known as acid peeling and thermal peeling, respectively (Prajapati et al., 2013). The isolated endosperm is then milled and sieved to obtain fine particle size powder of native locust bean gum (LBG), a polymer used as a natural food additive, and several applications in the pharmaceutical industry (Barak & Mudgil, 2014). The LBG produced from the acid peeling treatment is whitish and has a high viscosity. Simultaneously, the one from thermo-mechanical peeling is somewhat darker due to heating or roasting operations. The produced LBG can be further clarified by dissolving in water under heating conditions. The solution is filtered to remove insoluble substances and then dried and milled to obtain clarified or purified LBG (Tous & Antoni, 2013).

2.1. Carob pulp chemical composition

The chemical composition of carob pulp varies with genetic, environmental, climatic factors, and harvesting season. The plant type (male, female, or hermaphrodite) and cultivar significantly influence carob pulp's chemical composition and biological activities. Simsek et al. (2017) collected the carob fruits (wild and cultivated) from Mersin in Turkey at different harvest periods (May to August) and analysed the amino acid and sugar contents. Protein content ranged from 6.09% (cultivated) to 9.08% (wild), depending on the harvest periods. Total amino acid contents ranged between 3.87 and 8.21%. Cultivated carob harvested in May showed the highest amount of aspartic acid (1.28%). The authors found the highest fructose and glucose contents (40.26 and 17.69%) in wild carob fruit harvested in the June period. They also found the sucrose content of wild and cultivated carob fruit at the latter harvested to be highest (30.58 to 30.08% and 31.42 to 30.77%, respectively). In another study, carob fruit contained 6.90–7.44% fructose, 2.0–2.26% glucose, and 32.6–45.4% sucrose (Khlifa et al., 2013). Avallone et al. (1997) reported moisture (6–10%), ash (1-6%), protein (1–5%), fat (0.4–0.8%), sucrose (27–40%), D-glucose (3–5%), D-fructose (3–8%) and starch (0.1-1.3%) contents (in dry weight) of carob pod samples from eastern parts of Sicily in Italy. In the same work, the total polyphenol (15.8-24.4 mg/g), condensed tannins (proanthocyanidins: 2.09-3.89 mg/g), and hydrolysable ones (ellagitannins: 0.34-0.68 mg/g and gallotannins: 0.2-0.6 mg/g) contents were also reported. There is great variability of phenolic and tannic fractions in carob pod samples (Avallone et al., 1997). Özcan et al. (2009), Oziyci et al. (2014) and Ayaz et al. (2007) reported minerals contents of the carob fruit, being consensual that major proportions are of potassium (970 to 1089 mg/100 g), calcium (266 to 319 mg/100 g), phosphorous (76 to 79 mg/100 g), and magnesium (55 to 56 mg/100 g). Carob pulp also contains appreciable amounts of dietary fibre, principally insoluble fibre (68.4%) (Owen et al., 2003). It is almost free from stimulants such as caffeine and theobromine (Loullis & Pinakoulaki, 2018).

All these phytochemicals represent an essential source of nutrients and compounds that are beneficial to human health. Consequently, traditional products produced from carob pulp, such as syrup and powder, can be considered functional food products.

2.1.1. Syrup

Özcan et al. (2009) studied the composition and mineral contents of carob syrup. According to these authors, the product does not contain oil and had higher moisture values (34.65%), total sugar (63.88%), and higher water and alcohol solubility when compared to the carob fruit. The syrup has the highest values regarding mineral composition (potassium, phosphorus, and calcium). Besides, carob syrup has higher levels of silver and titanium than carob fruit, and it does not contain zinc. These physicochemical characteristics allow considering carob syrup as a functional ingredient. Fidan et al. (2019) evaluated the physicochemical characteristics of sponge cakes enriched with carob syrup. They proved that the replacement of sugar with carob syrup increased the protein content level (from 8.44 to 12.57g/100 g in dry weight) but did not observe significant changes in the carbohydrates and dietary fibres contents. They previously evaluated the content of reducing sugars and total carbohydrates in carob pulp before and after extraction of syrups (Fidan et al., 2016). During carob processing, increases in reducing sugars were observed and could be from carbohydrate hydrolysis during storage or heat treatment during syrup production. The carbohydrate content in the syrup prepared from Turkish carob pods was highest, with the sucrose content especially reaching up to 45 g/100 g dry weight compared with the sucrose content in carob pulp (34.2 g/100 g dry weight).

Concerning the natural phenolics contents of carob, Dhaouadi et al. (2014) suggested that carob syrups exhibit antioxidant, antibacterial and antifungal activities affected by sugar supplementation syrup processing. Avoiding sugar addition during syrup preparation preserves carob syrup bioactivities and prevents negative nutritional attributes since sucrose is associated with physiological disorders (mainly diabetes and obesity).

Additionally, it is known that carob is the only raw material from which D-pinitol can be isolated in quantities enough for possible commercial exploitation (López-Sánchez et al., 2018). Tetik et al. (2011) determined the D-pinitol content of 10 different carob syrup samples purchased in Turkey. D-pinitol means the content was found to be 84.63 ± 10.73 g/kg dry weight. Christou et al. (2019) developed a gas chromatography-mass spectrometry (GC–MS) method to quantify D-pinitol in carob syrup samples with origin in Cyprus. D-pinitol was determined in 13 carob syrup samples, and the mean concentration was 68.58 ± 4.80 g/kg dry weight. Compared to other plants or legumes, carob appears to be the richest source of D-pinitol, highlighting carob's role as a functional organic food (López-Sánchez et al., 2018).

2.1.2. Powder

The chemical composition of carob powder is given in Table 2, however it varies with genetic, environmental and climatic factors (Faik A. Ayaz et al., 2009; Carbas et al., 2019; Özcan et al., 2009; Petkova et al., 2017). To obtain powder or flour from carob fruit, a roasted, milled, and sieved processing must be carried out. Conventional roasting (with hot air) has been used since ancient times. However, and recently, some works approached the use of the microwave for roasting, concluding that this is a less time and energy-consuming method, allowing to obtain a final product with a higher nutritional profile when compared to the one obtained with conventional heating (Gunel et al., 2018, 2019). The roasting step is crucial to attaining the product's stability throughout storage, affecting its chemical composition (Boublenza et al., 2017; Červenka, et al., 2019; Vitali Čepo et al., 2014). In this last aspect, sugar caramelisation and Maillard reaction favour the production of furans, esters and pyrroles that recall cocoa's aroma (Foundation & Aue, 1997). Moreover, the release of phenolics occurs through the ruptured of high-molecular complexes from the carob matrix or the partial degradation of phenolics, which results in the production of different types of antioxidant molecules (Boublenza et al., 2017). These phenolic compounds and Maillard reaction products contribute to carob products' beneficial health properties such as antioxidant capacity.

The chemical characteristics of carob powders are significantly influenced by the plant's variety or geographical origin and the carob pod's ripening stage (Farag et al., 2019; Srour et al., 2016). Rodríguez-Solana et al. (2019) demonstrated that the carob roasting degree and variety have an apparent positive effect on total phenolics content and antioxidant activity. Özcan et al. (2009) roasted, milled and sieved carob fruit obtained from local carob-processing plants in Antalya, Turkey, and compared the chemical composition and mineral content of carob flour the ones of the carob fruit. Protein, oil, crude fibre, ash and energy values of carob fruit and carob flour were not statistically different. Still, the water solubility of carob flour was lower than the solubility of the fruit. Carob flour contains potassium, phosphorus, calcium, and sodium in higher amounts regarding the mineral composition.

Furthermore, the contents in silver, aluminium, barium, iron, and zinc determined in the carob flour were the highest ones. Youssef et al. (2013) studied the chemical composition of carob powder obtained from Aswan, Egypt. They concluded that the powder is also rich in vitamins E, D, C, Niacin, B6 and folic acid. In Faro, Portugal, Carbas et al. (2019) reported that commercially available carob flours had high dietary fibre levels, total phenols, D-pinitol, monosaccharides, and antioxidant activity. Another study from Turkey (Fidan et al., 2018) demonstrated that carob flour had high amounts of protein (22.56%) and dietary fibre (28.17%), being a good source of antioxidants, particularly polyphenolic compounds and minerals (Mg, Fe, and Zn). These phytochemicals have important healthy and nutritional properties that corroborate the use of carob flours as food ingredients. Applying carob flour as a cocoa substitute in the confectionery (Loullis & Pinakoulaki, 2018) or beverages and mixtures with other cereals-based products are examples.

2.2. Carob seeds chemical composition

As previously mentioned, the main use of carob seeds is LBG production, a popular natural polymer consisting of galactose (G) and mannose (M) in the ratio 1:4 and hence known as galactomannan (Kapoor & Divisions, 2005). LBG is obtained by grinding the endosperm layer after dehulled without damaging the endosperm and the germ (Prajapati et al., 2013). The major portion of LBG endosperm is galactomannan, which comprises approximately 80% of the endosperm weight, corresponding the remaining part to proteins and impurities. The commercial LBG powder contains approximately 10–12% moisture, 5% protein, 1.0% ash, 1.0% crude fibre, 0.5% fat, and 80–85% galactomannan of which 50-65% is mannose, 14-18% is galactose and the rest are traces of glucose, rhamnose, arabinose and xylose (Barak & Mudgil, 2014). LBGs can differ in their G:M ratio, chemical composition, and physicochemical properties such as solubility, molecular size and dynamic viscosity. Those depend on the origin, variety and age of the carob tree, growth conditions (*e.g.*, climate and soil) and polysaccharide extraction method used for crude gum purification (Bouzouita et al., 2007; Haddarah et al., 2014; Smith et al., 2008). LBG is widely used as a thickener and stabiliser with numerous applications in the food, pharmaceutical, cosmetic, and biotechnology industries (EFSA Panel on Food Additives Nutrient Sources added to Food et al., 2017). It is a globally approved food additive (E410) with proven enhanced properties used in different food matrixes. This gum is used as an edible film/coating to increase the shelf life of fresh fruits, vegetables, and meat products. Additionally, it is a relevant constituent of many products such as beverages, yoghurt, noodles, puddings, cheeses, water-based jellies, candies, fish products, ketchup, mayonnaise, bakery products, and frozen foods to improve texture properties (Barak & Mudgil, 2014).

With the large quantities of LBG being produced annually, an appreciable amount of carob germ flour is coproduced as a by-product of the process (Smith et al., 2008). Dakia et al. (2007) studied the dehulling procedure's influence on the germ meal composition, observing small reductions in protein and lipid contents from acid extraction. The carob germ (consisting of fine fragments of hull and endosperm), which could be obtained industrially, is 8.3% moisture, 6.5% ash, 6.6% lipids (neutral and polar) containing approximately 21% polar lipids, 54.7% crude proteins, and has an energy value of 17.5 kJ/g (Dakia et al., 2007). The composition and molecular weight distribution of carob germ protein were analysed by Smith et al. (2008). They used the modified Osborne extraction procedure (Osborne, 1907) to divide proteins into the following solubility classes: water and salt soluble proteins (albumins and globulins), aqueous alcohol-soluble (nonreduced) proteins (prolamins), insoluble aqueous alcohol-soluble (reduced) proteins (cross-linked prolamins), and alkali-soluble proteins (glutelins). They determined that the carob germ flour proteins contained albumin and globulin (ca. 32%) and glutelin (ca. 68%) with no prolamins detected, which determines the gluten-free concept (Cebolla et al., 2018). Prolamins have been widely studied due to their role in the rheological characteristics of bakery and pasta products made from wheat flour (Mamone et al., 2011; Martínez-Esteso et al., 2016). Rice & Ramstad (1950) compared the amino acid composition of gluten to carob proteins. They found significant differences between the two proteins, with carob germ proteins having less cysteine, glutamic acid, phenylalanine, and more of the charged amino acids, arginine, aspartic acid lysine. Feillet & Roulland (1998) isolated proteins from carob germ flour as described by Rice & Ramstad (1950) and designated these proteins as “caroubins”. Feillet & Roulland (1998) concluded that the ability of caroubin to form a viscoelastic material might result from protein interactions. Components such as lipids and carbohydrates may also contribute to the viscoelastic properties of the material. Bengoechea et al. (2008) also studied the amino acid composition and the nature of the subunits that compose carob germ proteins. These authors obtained 96.5% of protein content by alkaline extraction, followed by isoelectric precipitation of proteins. A high number of amino acids like glutamic acid, aspartic acid and arginine was detected. Carob proteins were composed of aggregates formed by 131 and 70 kDa subunits linked by non-covalent bonds and other peptides strongly bounded by disulfide interactions. Both aggregates and subunits were formed mainly by 100 and 48 kDa monomers linked by disulfide bonds. A considerable content of high molecular mass peptides strongly bounded were also found. Proteins became partially denatured and thermally stabilised at acidic conditions (pH=2). Furthermore, the relatively high content of phospholipids (11.8%, v/v) might increase the antioxidant potential and improve the baking performances of flour fortified with carob seed germ (Siano et al., 2018).

The carob seed peels extracts obtained by sequential extraction with solvents with different polarities were studied by Lakkab et al. (2019). These authors concluded that carob seed peel has high phenolics contents and strong antioxidant activity. They assessed its effects on mood disorders and anxiety, opening new mechanistically approaches to antidepressant and anxiolytic drug development.

More recently, Fidan et al. (2020) evaluated the chemical composition, antioxidant potential and functional properties of carob seeds. They concluded that carob seeds are a valuable source of phenolic compounds and antioxidants. Carob seeds also presented high proportions of proteins, lipids, and galactomannan with functional properties (good swelling properties and oil-holding capacity) that could improve the nutritional value of foods in which they are incorporated. Furthermore, the seeds have high concentrations of macro and micro minerals such as Ca, Fe, Mg, and Zn (Oziyci et al., 2014).

3. Health benefits

Numerous studies have revealed physiological responses to carob fruit and its products that may be considered health beneficial by healing and preventing chronic diseases. The carob chemical components and their biological properties associated with health benefits are presented in Table 3.

3.1 Antioxidant properties

Reactive oxygen species (ROS) and reactive nitrogen species (RNS) are a wide variety of free radicals and ions. They are produced either from normal cell metabolisms *in situ* (cellular redox process) or from external sources (pollution, cigarette smoke, radiation, medication, alcohol, cooking). These species play a dual role as both toxic and beneficial compounds. The delicate balance between their two antagonistic effects is an essential aspect of life. At low or moderate levels, ROS and RNS exert beneficial effects on cellular responses and immune function. At high concentrations, they generate oxidative stress, a deleterious process that can damage all cell structures. Oxidative stress plays a significant part in developing chronic and degenerative ailments such as cancer, arthritis, ageing, autoimmune disorders, cardiovascular and neurodegenerative diseases. The human body has several mechanisms to counteract oxidative stress: (i) by producing antioxidants, which are either naturally produced *in situ* that can be 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.); (ii) or externally supplied through foods and/or supplements such as vitamins C (ascorbic acid) and E (tocopherol), carotenoids, polyphenols such as anthocyanins, omega-3 and omega-6 fatty acids, and uric acid. Endogenous and exogenous antioxidants act as "free radical scavengers" by preventing and repairing damages caused by ROS and RNS (Graves, 2012; Lushchak, 2014; Pham-Huy et al., 2008).

Using different *in vitro* assays such as 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,20-azino-bis [3-ethylbenzthiazoline-6-sulphonic acid] (ABTS) and the ferric ion reducing antioxidant power (FRAP), several studies have shown the antioxidant activity of carob extracts (Benchikh & Louailèche, 2014; Carbas et al., 2019; Goulas & Georgiou, 2020; Mekhoukhe et al., 2018; Quiles-Carrillo et al., 2019). Most of these works have studied different phenolics extraction conditions, and they have directly related the content of phenolic compounds with the antioxidant activity. Goulas & Hadjisolomou (2019) studied the effect of triple-step digestion on the stability of phenolics and antioxidant potency in carob products. They concluded that the carob phenolics are degraded, released from the food matrix, or attached to other food or digestive juice constituents.

Additionally, the critical role of the food matrix was underlined as the food components had a protective effect against pH changes and enzymatic activities along with digestion. Other works demonstrated that the antioxidant capacity also depends on the carob fruit maturity. Benchikh et al. (2014) showed that carob pods have the highest total phenolic, total flavonoid and ascorbic acid content in the unripe stage. Therefore, the antioxidant activity decreases significantly throughout the ripening process. Similar results were obtained by Saci et al. (2019), suggesting that the extract of unripe carob may provide a substantial source of secondary metabolites, which act as natural antioxidants; moreover, they have a neuroprotective effect *in vitro*.

Several studies revealed a positive correlation between the strong antioxidant activity and the positive effect on rabbit growth performance (Abu Hafsa et al., 2017), spermatogenesis (Sadat et al., 2019) and mood disorders (Lakkab et al., 2019).

In addition to the antioxidant activity of carob extract due to its strong scavenging effect on reactive oxygen and free radicals, Rtibi et al. (2015a, 2015b) proved the capacity of carob pods aqueous extract to inhibit the myeloperoxidase (MPO) activity in a concentration-dependent manner. The MPO-activity blockage by the carob extracts has, therefore, the ability to reduce the production of hypochlorous acid (HOCl) from H_2O_2.

Carob honey is another well studied carob-based product. Its composition depends highly on the type of flowers utilised by the bees (Wang & Li, 2011). El-Haskoury et al. (2017) characterised the physicochemical composition and antioxidant activity of carob honey collected in Moroccos. The antioxidant capacity of the honey samples was correlated with their biochemical constituents, such as total phenol and flavonoids content. Previously, El-Haskoury et al. (2015) reported that carob honey has diuretic, natriuretic, and kaliuretic activity without side effects of hypokalemia observed using furosemide.

3.2. Anti-hyperglycaemic and anti-absorptive of glucose properties

An important therapeutic strategy used for diabetes (type 2) regulation and control is the inhibition of α-amylase and α-glucosidase, two key-enzymes in type 2 diabetes mellitus. α-glucosidase, after its catalysis activity, releases glucose into the blood, which provokes an increase in its level. Inhibitors of these enzymes delay carbohydrate digestion and prolong overall carbohydrate digestion time, causing a diminution in the level of glucose absorption and therefore decreasing the postprandial plasma glucose rise. In this respect, the work of Custódio et al. (2015) reports the *in vitro* inhibitory activity of water decoctions of leaves, germ flour, pulp, locust bean gum and stem bark of carob tree on α-amylase and α -glucosidase. Leaves and stem bark decoctions had significant antioxidant activity and the highest total phenolics content. The major compounds were identified as gallic acid in the leaves and gentisic acid in the stem bark. Chait et al. (2020) were pioneers in studying carob anti-diabetic activities during gastrointestinal digestion. These authors proved the inhibitory effect of carob powder and its digested fractions on α-amylase and α-glucosidase activities. Additionally, they detected ten phenolic acids and six flavonoids in soluble (free and conjugated) and insoluble fractions of undigested carob, and, after *in vitro* gastrointestinal digestions, they identified that the most bioaccessible phenolic acids and flavonoids were gallic acid, chlorogenic acid, (+)-catechin and rutin. Myricetin and gallic acid were the most abundant metabolites of the residual fraction of carob phenolics after faecal fermentations. With all this, they concluded that these carob phenolic compounds might influence glucose metabolism by inhibiting carbohydrate digestion.

Rtibi et al. (2017) developed a study that supports the use of immature (unripe) carob pod aqueous extract on the reduction of intestinal glucose absorption. They confirmed that the degree of maturity of carob characterised by a different phytochemical composition, principally polyphenols and flavonoids, may be responsible for hypoglycemic and hypolipidemic effects. The results proved that intestinal glucose transport inhibition represents an important component through which immature carob can reduce blood glucose, probably by the known ability of polyphenols to modify carbohydrate digestion and absorption. Another possible mechanism may be attributed to fibre in carob pods because of complex carbohydrate, high molecular weight and viscous, soluble dietary fibres to retard glucose absorption (Macho-González et al., 2017).

As previously referred, carob pods is also a known source of D-pinitol (Tetik et al., 2011). Inositols and their derivatives, such as inositol-(phospho)glycans have important roles in physiological processes, principally in modulating the insulin signalling pathway (López-Gambero et al., 2020). Bañuls et al. (2016) assessed the effects of a 12-week administration of an oral nutritional inositol-enriched beverage (IEB) on blood glycaemia (fasting and postprandial states). These authors concluded that IEB daily oral ingestion for 12 weeks positively influenced insulin resistance and the percentage of glucose change after main meals and overnight fasting in non-obese prediabetic subjects. Therefore, inositol from carob extract administration has a potential therapeutic effect in insulin resistance-related diseases.

3.3. Anti-hyperlipidemia properties

Increased postprandial lipemia is reflected with elevated levels of lipids, such as total cholesterol (TC), low-density lipoprotein cholesterol (LDL), very low-density lipoprotein cholesterol (VLDL) and triglycerides (TG), which are widely recognised as risk factors for cardiovascular disease (CVD). High levels of oxidised LDL (OxLDL) is another relevant risk for oxidative stress and endothelial dysfunction associated with CVD progression (Chan et al., 2013). In several studies, it has been reported that carob fruit extract has potential health benefits, including reduction of LDL levels in hypercholesterolaemic patients, beneficial effect on body weight, and improvement of digestion and lipid utilisation (Abu Hafsa et al., 2017).

Macho-González et al. (2018) demonstrated, for the first time, the hypolipidemic properties of carob fruit extract (CFE) in healthy Wistar rats, modifying postprandial lipemia by reducing the extents of fat digestion and absorption. These results showed that the fibre could lower triglycerides, total cholesterol, and low-density lipoprotein cholesterol. The effect of CFE-enriched meat-consumption on lipemia and lipoprotein profile in Wistar rats was posteriorly assessed. The authors confirmed the hypoglycemia, hypoinsulinemia, hypotriglyceridemia and decreased triglyceride-enriched-VLDL in rats fed with the high-saturated-fat diet containing CFE-enriched meat when compared to a control group (Macho-González et al., 2019). Additionally, they proposed a mechanism related to CFE effects on lipoprotein metabolism and insulin signalling (Macho-González et al., 2020), proving a remarkable and direct relation between antioxidant properties and postprandial hyperglycemia and hyperlipidemia reduction in healthy animals. Experiments with rabbits showed that insoluble dietary fibre from carob pod could reduce atherosclerosis development. The results suggested that increased expression of aortic sirtuin-1 and peroxisome proliferator-activated receptor-γ coactivator-1α may play a key role in the beneficial effects of carob fibre in dyslipidemia (Valero-Muñoz et al., 2019).

All these effects do not seem to be due to only one carob fruit component but rather to the synergistic action of different constituents. These include polyphenols and flavonoids of quercetin glycosides, high amounts of insoluble fibre (cellulose and hemicellulose) and only negligible soluble fibre amounts. Flavonoids may act by making liver cells more efficient to remove LDL from the blood. For this, flavonoids increase LDL receptor densities in the liver by binding to apolipoprotein B (El-Beshbishy et al., 2006).

Martínez-Rodríguez et al. (2013) assayed a non-extractable-tannates rich carob-fibre (PF-1®) in a developed milk matrix. After a 4-week interventional study with human volunteers (400 mL daily consumption of this functional food, containing 20 g of PF-1®/L), they verified a decrease in triglyceride and total cholesterol levels in all participants. This preliminary study highlights the probable positive influence of this functional food on regulating the lipid profile and bowel function in humans.

3.4. Gastrointestinal benefits

Gastrointestinal disorders (GID) are responsible for increasing deaths across Europe annually, with an associated heavy economic burden to the healthcare system (Anderson et al., 2014). The most common GID include gastritis, peptic ulcers, *Helicobacter pylori* infection, gastric cancer, and colorectal cancer. In the last years, the gastroprotective effect of carob pods aqueous extract (CPAE) has been thoroughly studied. Rtibi et al. (2015b) evaluated the gastroprotective role of the CPAE (15 days) against oxidative stress induced by acute ethanol exposure in rats. They concluded that CPAE exerts protective effects against acute ethanol-induced ulceration in the gastric mucosa. This is due to the antioxidant properties; the CPAE counteracted EtOH-induced gastric lipoperoxidation, reversed the decrease of sulfhydryl groups (−SH) and hydrogen peroxide levels, and prevented the depletion of antioxidant enzyme activity of superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx).

Other multifactorial gastrointestinal disorders such as constipation and diarrhoea have been studied in the last years. Rtibi et al. (2016) investigated the putative effects of CPAE on gastrointestinal transit (GIT), diarrhoea and intestinal epithelium permeability in healthy rats and mice depending on its degree of maturity. They showed that mature carob pods' water extract significantly increased the GIT (depending on the doses). In contrast, the aqueous extract of the immature carob pods induced a significant decrease in the GIT.

They suggested that there is a difference in the chemical composition of both extracts. The extract of mature carob pods has high fibre and sugar contents; these compounds are absent or present in low quantity in immature carob pods. It was established that fibres and sugars in high concentrations cause the acceleration of the GIT process (Mudgil & Barak, 2013). The high total tannins content present in the immature carob pods may be responsible for inhibiting GIT and diarrhoea. Concerning the intestinal epithelium permeability, the aqueous extract of immature carob pods causes an inhibition of the secretion, implying a transit slowdown. In contrast, the authors showed that the aqueous extract of mature carob pods causes an increase in the intestinal secretion, facilitating the GIT.

The protective effect of carob in ulcerative colitis, another gastrointestinal diseases related to inflammation and oxidative stress, has also been studied (Aboura et al., 2017; Rtibi et al., 2016). The analysis of myeloperoxidase activity, cytokines and oxidative damage after the dextran sulfate sodium-induced sub-acute experimental ulcerative colitis in the rat model, with and without the administration of carob extract, determined that the high polyphenols content of carob fruit prevented colonic shortening and reduced the colonic severity lesions and biochemical alterations.

4. Food applications

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 (McClements & Xiao, 2014). 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 4. The enhanced properties of the final products are highlighted.

The processing conditions of carob pods to obtain syrup and powder defines the functional properties required by the food industry. Carob syrup (60, 70 or 80 °Brix) were characterised by important reducing sugars content, dark colour and functional properties with high antioxidant activity and emulsifying capacity. These improved properties can be attained from non-enzymatic browning reactions occurring during juice boiling. Microwave drying at different power levels (100, 300 and 600 W) is useful for dehydrating the by-product obtained after juice extraction and producing carob powders with high dietary fibres, brown colour, and water/oil retention capacity (Tounsi et al., 2017). Different degrees of carob flour roasting can also affect the physicochemical characteristics and acceptability of different bakery products. In cakes and cookies, the incorporation of carob flour increased the viscosity of cake batters. It increased the solid elastic-like behaviour of the cookie doughs, indicating a more robust interaction of the ingredients. The addition of highly roasted carob flour only reduced the acceptability of cakes. Simultaneously, in the cookies, there was a decline in the acceptability of all carob flour cookies (Román et al., 2017). Srour et al. (2016) also proved that beverages formulated with roasted carob powder had higher ratings for residue levels, colour, odour (caramel, mocha, and roasted coffee), flavour (mocha and roasted coffee), viscosity, mouthfeel, and bitter aftertaste.

Furthermore, it is important to understand the physical and chemical properties of carob products and their interdependence to use them efficiently as a functional food ingredient. For example, when Benković et al. (2017) studied physicochemical properties of carob flours produced with and without seeds, they concluded that carob flours containing seeds had a higher cohesion index and higher cake strength values than flours without seeds. Additionally, the extraction efficiency of polyphenols and flavonoids and the antioxidant capacity depended on the cohesion and cake formation ability of flours. Regarding the carbohydrates, samples without carob seeds established higher total sugar and soluble polysaccharides content.

When Fidan et al. (2019) replaced wheat flour with 50% carob flour as a functional ingredient in sponge cakes resulted in an increase in dietary fibre (from 2.45 to 18.28 g/100 g dry weight), protein (from 8.44 to 23.93 g/100 g dry weight) and carbohydrate content (from 65.40±5.20 to 86.10±2.70 g/100 g dry weight). The cakes with carob flour showed differences in cell size and uniformity and sweetness and crumb tenderness, confirming that the replacement of ingredients positively influenced sensory characteristics. These properties add nutritional and biological values to traditional culinary products, also depending on the remaining ingredients. Papaefstathiou & Agapiou (2018) studied the nutritional composition of twenty traditional carob food products, comparing results with the pulp of Cypriot carob cultivars. They concluded that despite carob fruit and carob powders could be recommended to be included in humans' daily diet as they contain valuable nutrients and low fat while having a sweet taste, carob products only partially satisfied healthy and nutritional claims: 60% in terms of fat, 25% in terms of dietary fibres, and 80% in terms of minerals.

Another important benefit of carob product is that they can be used in the bakery industry as gluten-free flour. Several authors investigated the effects of incorporating carob flour in several gluten-free cakes, bread, and snacks. Martin-Diana et al. (2017) developed a gluten-free cracker snack through the inclusion of carob by-products (germ and seed peel). They concluded that germ and seed peel from carob processing by-products provided protein and antioxidant activity to the formulated food products. Indeed, by the composition of both raw materials, the germ and peel concentration had a significant linear effect on the protein and carbohydrate (fibres) contents, respectively. Regarding the phenolic content, the inclusion of germ increased it, reaching the highest values at 5.44% germ and no peel. The phenolics corresponded to proanthocyanidin, gallotannins, tannins, catechins and flavonols (Albertos et al., 2015), and these polyphenols would be responsible for the antioxidant activity of the product. In addition to the nutritional profile, the physicochemical parameters and sensorial analysis were determined. In the first case, they observed that at maximum concentrations of germ (17.6%) and concentrations close to 6.5% for peel, the product absorbed and retained the maximum water proportion water. This behaviour could be attributed to the presence of remaining gums (galactomannan) from the endosperm. The water activity (aw) also was analyzed since it is an indicator of quality for snacks. Aw decreased with increasing germ and peel concentrations. Also, firmness and hardness increased linearly with the increment of germ on the formulation. Regarding the sensory analysis, the cracker with germ and peel ranked the lowest in acceptability. They affected the general acceptability of the final product, especially the germ, probably because of the high content of tannins and catechins, which provide important bitter and astringent flavour. Colour differences among crackers may have also affected the general acceptability.

In another work, Berk et al. (2017) investigated the effects of partial replacement of rice flour by carob bean flour at different concentrations (10%, 20%, and 30%) in gluten-free cakes. First, the specific gravity was determined, observing that the increased carob bean flour amount in the formulation led to the thicker batter, which might be due to increased fibre and sugar content. Increasing fibre content might obstruct mixing efficiency and aeration of gas bubbles. Then, the specific volume of cakes was studied. Although it did not create a significant difference, 20% carob bean flour added samples had relatively higher volume than 10% and 30% carob bean flour containing cakes, respectively. Textural analysis of cakes was evaluated in terms of hardness. Increasing carob bean flour concentration from 10% to 20% and 30% created a significant difference in hardness. Since air incorporation in cake batter during mixing is one of the factors that affect the hardness of cakes, increasing carob bean flour concentration in formulation might make incorporation of air in batter difficult with increasing viscosity. This might be due to not only increase in fibre content but also soluble components in the formulation. Due to the high-water holding capacity of fibre, the viscosity of cake batter tended to increase with concentration.

Claudia Arribas et al. (2020) determined the content of phenols in dry (uncooked) and cooked experimental samples based on different proportions of rice/bean and supplemented with whole carob flour (WCF), as well as in a commercial rice-based pasta whose phytochemical content has not been previously studied. The pasta quality was assessed by determining the texture and colour properties. The supplementation of the different rice/bean samples with 10% WCF increases the content of phenolic compounds, both in the uncooked and the cooked samples. The antioxidant activity was linked to the presence of phenols supplied by the bean and WCF flours and other antioxidant compounds such as the Maillard reaction products formed during the pasta-making drying step. As mentioned above for the phenolic compounds, the presence of WCF increased the antioxidant activity in comparison to the same formulations without this legume. The colour parameters of both the cooked and uncooked fettuccine showed significant differences between the samples with or without WCF. These differences can be linked to the brown colour of the raw WCF and the processing conditions, both in the making and the cooking processes. The supplementation of fettuccine with 10% WCF decreased the hardness compared to the same pasta without WCF, probably due to the increase in dietary fibre content, which may have led to crashes or breaks inside the fettuccine strand, thus weakening the pasta structure. The improvement of the texture parameters observed could meet the expectation of consumers of GF products.

Gluten-free bread from rice flour substituted with carob flour and resistant starch (RS) was investigated (K. Tsatsaragkou et al., 2014). Carob flour addition increases the water absorption of the dough. Increased amounts of carob flour caused a reduction in moisture values, for the same water content, due to the increased water holding capacity of carob flour, ascribed to both protein (caroubin) and dietary fibres (locust bean gum) content. Carob and water content did not significantly affect porosity, surface porosity and elasticity values. Porosity values were greater than those found for bread without carob flour, whereas elasticity values were lower.

In several works (Arribas et al., 2017; Arribas et al., 2019a, 2019b) studied the effect of extrusion on nutritional components, the bioactive compounds content and textural analysis of various gluten-free formulations based on carob fruit, pea and rice flour blends. The extruded formulations containing whole carob fruit can be considered a good source of protein, dietary fibre, and phenolic compounds (anthocyanins, flavonols, tartaric esters, and total phenols). The antioxidant activity and the different groups of phenols showed a positive correlation in the extrudates. On the other hand, a higher amount of carob flour caused a lower preferred colour by the panellists. This could be related to the brown colour of the products formulated with carob flour, leading to a slight rejection of these products. The analysis of the different aroma and taste parameters tested scores did not show any correlation with the amount of legumes in the extrudates and no unpleasant odours or flavours were detected. In conclusion, the addition of 5% carob fruit flour did not significantly affect the overall quality of these extrudates, and therefore these novel extrudates would be well accepted by consumers.

(Tsatsaragkou et al., 2017) determined the influence of the particle size of carob seed flour on the quality of fresh and stored gluten-free rice-based bread. Bread made with carob flour showed a lower specific volume than commercial mixtures. Among the carob breads, the incorporation of coarser (FA) and finer (FD) fraction led to the production of breads with increased specific volume. Their lower amount of protein than the other fractions and the higher amount of dietary fibres (polysaccharides from the endosperm of the carob seed) might improve the specific volume. On the other hand, the addition of carob flour to produce gluten-free rice breads significantly modified the crumb colour and presented lower firming rate; thus, the presence of carob flour had an anti-staling effect that was independent on the particle size distribution.

Given the use of seed germ flour for food applications, carob seed was characterised by high protein content (25.7%), while mannose and galactose were the dominating monosaccharides. Moreover, the isolated galactomannan from carob seeds demonstrated good swelling properties, *i.e.*, 30.1 ml per g sample and oil-holding capacity (27.9 g/g sample) (Fidan et al., 2020). Attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) analyses detected a high proportion of β-sheet conformation for *C. siliqua* germ proteins, suggesting that carob germ flour could be technologically best suited for use in baked and cooked food formulations (Mamone et al., 2019). Turfani et al. (2017) proved that blending wheat flour with carob seed flour at 5-6% or 10-12% modified the dough's technological properties and bread characteristics. Carob seed flours increased dough tenacity while reducing extensibility. This is probably related to the tenacity of the hydrated carob fibres and the viscoelastic properties of the germ caroubins. Germ caroubins, like gluten, can form fibrils and sheets and contain large polymeric proteins that are cross-linked by disulfide bonds. On the other hand, carob seed flours increased water absorption up to about 40%. This behaviour is related to the fact that the great number of hydroxyl groups and the carob soluble fibre structure allow more hydrogen bonding with water than gluten and starch (Barak & Mudgil, 2014). Moreover, in the case of carob seed germ flour, it is reported that caroubins are more hydrophilic than gluten (Smith et al., 2008). Regarding the specific volume, its increase or decrease depended on the amount and type of carob flour. When baking blends at 5% level carob flour substitution, it did not present differences with respect to the wheat flour control. However, a proportion of 10% or more of substitution with carob seed germ flour reduced the loaf volume. In contrast, refined carob seed flour produced a statistically significant increase of loaf volume and raw carob seed flour a slight increase that was not significant. This is attributed to reduced extensibility and weakening of the gluten network due to dilution, reduced hydration, and interaction with fibres and non-gluten proteins, reducing the gas-retention ability. Carob flours enriched bread with soluble dietary fibres, insoluble dietary fibres, phenolic compounds and lignans, thus enhancing its antioxidant properties. The addition of raw carob seed and carob germ flours increased polyphenols in bread, especially the free ones. Two lignans, secoisolariciresinol and isolariciresinol, were found in wheat bread.

In some cases, reactive 1,2-dicarbonyl compounds (DCs) are generated from carbohydrates during food processing and storage (Hellwig et al., 2018). They are formed mainly by dehydration and redox reactions. They substantially impact on food palatability because they have an essential role in aroma and colour formation. They can also be formed under physiological conditions, covalently modifying proteins *in vivo* and impair their function. However, they are precursors of advanced glycation end products (AGEs), and cytotoxic effects of several DCs have been reported. The most abundant DCs in food are 3-deoxyglucosone, 3-deoxygalactosone, and glucosone, predominating over methylglyoxal, glyoxal, and 3,4-dideoxyglucosone-3-ene. 3-Deoxyosones are precursors of furan derivatives such as furfural and hydroxymethylfurfural (HMF). HMF is a prominent indicator of thermal treatment of carob flour (Vitali Čepo et al., 2014) and syrup (Sengül et al., 2007). Even so, it is essential to quantify these compounds and to understand their physiological effects.

Finally, lipid oxidations can affect the quality characteristics and safety of lipids foods and emulsions, losing their nutritional value. Goulas & Georgiou (2020) proved the potential of carob extracts to prevent lipid oxidation in food systems such as emulsions, sunflower oil, and cooked comminuted pork. Thus, the food industry must foster natural, safe, and low-cost antioxidant compounds to substitute synthetic additives such as butylated hydroxyanisole and butylated hydroxytoluene.

5. Data Collection

Our research, based on a framework for scoping review, included a thorough search of published literature in the last 15 years to collect a significant amount of information related to carob and its properties. The main keywords used were carob, chemical composition, pulp, seed, health, biological activity, phenolics, locust bean gum, pinitol, amino acids, sugars, fibres, minerals, functional food. The databases searched were Scopus and Web of Science. The quality assessments of the papers were not performed.

6. Conclusion

The current trends of a healthy lifestyle for health promotion and disease prevention have led the food industry to seek innovative health-beneficial food products based on natural sources. The high dietary fibre content and bioactive compounds of carob fruit and its products (powder, flour, and syrup), and their beneficial effects on gastrointestinal diseases, diabetes, hyperlipidemia, inflammation, and oxidative stress make carob products novel food ingredients, which have potential to be used in the development of a wide variety of health-beneficial food products. The incorporation of carob fruit and its derived products in food formulations enhance nutritional and functional value and improve technological functionality by imparting beneficial rheological properties and extending the shelf life of the final products. At present, carob flour or powder production is only done after the pulp separation. However, it has been demonstrated that the seed presence improves the cohesion index, food product strength values, the extraction efficiency of polyphenols and flavonoids, and the antioxidant capacity of the products. Consequently, it is crucial to understand the physical and chemical properties of carob products and their interdependence to use them efficiently as functional food ingredients.

Ethics Statement

None.

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Declaration of Competing Interest

The authors have declared no conflict of interest.

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Figure Legends

Figure 1. a) Carob tree (*Ceratonia siliqua* L.), b) Immature and mature carob pod, c) Carob pod constituents (Tous & Antoni, 2013).

Figure 2. Main industrial uses of carob fruit (Durazzo et al., 2014; Ersan et al., 2020; Tounsi et al., 2017; Yousif & Alghzawi, 2000).

Table 1. World average carob statistics from 2015 to 2018 (FAOSTAT, 2020).

	Portugal	Italy	Morocco	Turkey	Greece	Cyprus	Algeria	Spain	World
Area harvested (ha)	13,427	5,600	10,224	3,099	2,410	1,004	808	2,292	41,593
Yield (hg/ha)	29,393	56,385	21,532	45,776	59,377	71,571	45,762	8,382	32,839
Production (tonnes)	39,387	31,577	22,013	14,195	12,819	7,179	3,701	1,916	136,613
Production (%)	28.83	23.11	16.11	10.39	9.38	5.25	2.71	1.40	100

Table 2. Chemical composition of carob powder

Component	**Proportion (%)**
Moisture	6.3 to 7.6
Protein	1.7 to 5.90
Ash	2.3 to 3.2
Fat	0.2 to 4.4
Total dietary fibre	11.7 to 47
Starch	0.1
Total Carbohydrates	42 to 86
Fructose	2 to 7.4
Glucose	3 to 7.3
Sucrose	15 to 34
D-Pinitol	5.5

Source: (Faik A. Ayaz et al., 2009; Carbas et al., 2019; Özcan et al., 2009; Petkova et al., 2017).

Table 3. Carob chemical constituents and their biological properties associated with health benefits.

Chemical Constituents	Biological Properties/Health benefits/Disease	Carob Part/ Fraction	Reference
Polyphenols/Gallic acid and Gallotannins/Pyrogallol/Chlorogenic acid, (+)-Catechin, Rutin, Myricetin.	Glycemic control/Neurogenerative diseases/Antioxidant, anti-inflammatory and antitumoral activities /Abdominal obesity control/Antibacterial activity	Carob pulp powder	Chait et al., 2020; Fidan et al., 2018; Martínez-Villaluenga et al., 2018; Papakonstantinou et al., 2018; Rico et al., 2019; Rodríguez-Solana, Coelho, et al., 2019; Rtibi et al., 2015a
Polyphenols/Epigallocatechin gallate, Epigallocatechin, Catechin, Syringic acid, Quercetin glycoside, Gallic acid, Catechin gallate, Cinnamic acid	Antioxidant, Antibacterial, Antifungal activities/Cytotoxicity effects/Hepatoprotective effects	Carob pulp extract	Abulyazid et al., 2017; Dhaouadi et al., 2014
Insoluble dietary fibre	Enhanced lipoprotein metabolism, lowers total and LDL cholesterol/Hypoglycemic effect	Carob pulp	Macho-González et al., 2017, 2019, 2020; Valero-Muñoz et al., 2019
D-pinitol	Anti-diabetic activity/Anticancer/Hepatoprotective	Carob pulp	Bañuls et al., 2016; Christou et al., 2019; López-Sánchez et al., 2018
Polyphenols, Flavonoids, and condensed tannins/Quercetin and Apigenin derivatives/Tannic acid	Antioxidant and Antihypertensive activity/Abdominal obesity control/ Anxiolytic and Antidepressant effect	Carob seed peel	Lakkab et al., 2019; Rico et al., 2019
Flavonoids and tannins/Fibre and sugar/pyrogallol, catechin, gallic acid, tannic acid, chlorogenic acid, and epicatechin.	Antibacterial activity/ Anti-ulcer and Gastroprotective effect/ Laxative and Anti-diarrheal Activities	Carob pod	Abu Hafsa et al., 2017; Rtibi et al., 2015b, 2016
LBG/galactomannan	Gastrointestinal effects	Seed endos-perm	(Xie et al., 2020)

Table 4. Carob-based functional foods and main benefits ascribed.

Functional food	Positive effects	References
Wafer cream with carob pod and chicory root powder	• Low caffeine content • High amount of sugar • High antioxidant activity • Positive effect on physicochemical, rheological, and sensory properties	Habibzadeh & Seyedain Ardabili, 2019
Rice-based extruded snacks-like fortified with pea, bean and carob fruit	• High phenolic compounds content • High antioxidant activity • Improved textural attributes	Arribas et al., 2019b, 2019a
Muffin with carob powder	• High water activity • High total phenolics content • High antioxidant activity • High content of phytosterols and genistein • Increased browning index and FAST index	Červenka et al., 2019; Pawłowska et al., 2018
Bread with carob flour (pods and germ flours)	• Improved texture and sensory properties • Antimicrobial activity • High total phenolics content • High antioxidant activity • High gluten-aggregation • Improved bread quality	Hoehnel et al., 2019; Rico et al., 2018; Šoronja-Simović et al., 2016
Sponge cakes enriched with carob flour and carob syrup	• Higher level of dietary fibre, protein, and carbohydrate contents • Higher total moisture content • Positive influence in sensory characteristics	Fidan et al., 2019
Carob spread	• Good colour and textural characteristics • Excellent source of essential minerals • High total phenolic content • Low quantities of Hydroxymetylfurfural (HMF)	Aydın & Özdemir, 2017
Pasta enriched with carob flour	• Good colour, firmness and hardness • high antioxidant activity and sucrose. • High total phenols content • High Glycemic index	Arribas et al., 2020; Biernacka et al., 2017; Sęczyk et al., 2016
Sesame paste enriched with carob syrup	• Improved emulsion stability • High nutritional values	Tounsi et al., 2019
Low lactose yoghurt with carob flour	• High fibre content • High sweetness content	Moreira et al., 2017