Comprehensive REVIEWS in Food Science and Food Safety

Carob Kibble: A Bioactive-Rich Food Ingredient

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Abstract: Carob (*Ceratonia siliqua* L.) is well known for its valuable locust bean gum obtained from the carob seeds. Separation of seeds from the pod leaves behind the carob kibble which is a good source of dietary fiber, sugars, and a range of bioactive compounds such as polyphenols and pinitol. Bioactive compounds present in carob kibble have been found to be beneficial in the control of many health problems such as diabetes, heart diseases, and colon cancer due to their antidiabetic, antioxidant, and anti-inflammatory activities. Carob kibble has substantial potential to be used as a food ingredient. This article focuses on the composition, health benefits, and food applications of carob kibble.

Keywords: anti-inflammatory, antioxidant activity, kibble, pinitol, polyphenols

Introduction

Carob (*Ceratonia siliqua* L.) is an evergreen tree that belongs to the family Leguminosae (subfamily Caesalpiniodeae). The scientific name derives from the Greek *keras* meaning horn, and the Latin *siliqua*, alluding to the hardness and shape of the pod (Batlle and Tous 1997). The tree is native to the Mediterranean region and it has been cultivated since ancient times throughout the Mediterranean basin, usually in mild and dry places (Ramon-Laca and Mabberley 2004). It can be grown on marginally productive lands with low to medium rainfall (250 to 500 mm/year). Some species were also introduced to the United States of America (California), Mexico, South Africa, and Australia (Esbenshade and Wilson 1986; Esbenshade 1994).

Carob is predominantly grown in the Mediterranean climate zones of the world. FAO (Food and Agriculture Organization of the United Nations) has estimated an area of 81832 ha with a total production of 163000 metric tons of carob pods. The top 5 carob-producing countries are Spain (40000 tons annually), Italy (31000 tons), Portugal (23000 tons), Greece (22000 tons), and Morocco (20500 tons). These countries hold 25%, 19%, 14%, 13%, and 12% of the world production, respectively. Other carob-producing countries include Turkey, Cyprus, and Algeria, with annual production of 14000, 5000 and 3000 tons, respectively (FAOSTAT 2012). The yield of carob pods depends on variety, region, environmental condition, and cultural practices (Barracosa and others 2007). In the major carob-producing countries, Spain and Italy, the average yields are around 1000 and 2300 kg/ha, respectively. However, Lebanon, with 9000 kg/ha, has the highest carob yield per hectare (FAOSTAT 2012).

The tree produces fruit in the form of 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. The pods are ready to be harvested when they change into dark brown color and become shriveled due to reduction in moisture content. The mature fruit is a long scimitar-shaped pod (10 to 25 cm) and contains several hard seeds embedded in a pulp (MacLeod and Forcen 1992). The pods vary significantly in morphological characteristics such as dimension, size, weight, shape, density, color, and seed-to-pulp ratio due to variety and climatic conditions.

The use of carob dates back to the ancient Egyptians who fed the pods to livestock and are 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 (Rol 1973).

Since the beginning, the fruit of carob tree has been used as a food, such as candy, mainly due to its high sugar content (Calixto and Cañellas 1982). In recent times, the food application of carob pods is limited to its seeds, which represent only about 10% of the weight of the pod (Bouzouita and others 2007). A white to creamy powder, known as locust bean gum or carob bean gum, is extracted from seed endosperm and is widely used as a natural food additive (E-410) in the food industry to function as a thickener, stabilizer, and flavorant (Bouzouita and others 2007). The gum is also used in the cosmetic, pharmaceutical, textile, paint, oil drilling, and construction industries (Barak and Mudgil 2014). The separation of seeds results in a significant quantity of de-seeded broken carob pods as a by-product, commonly known as kibble. Kibble is mainly used for animal feed (Karabulut and others 2006; Kotrotsios and others 2011; Obeidat and others 2012). Other uses include extracting sugars for making syrup or bioethanol (Sánchez-Segado and others 2010; Mazaheri and others 2012; Sánchez-Segado and others 2012; Ercan and others 2013). Carob kibble is a rich source of valuable compounds such as dietary fiber (Khlifa and others 2013) and a range of bioactive polyphenols (Makris and Kefalas

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doi: 10.1111/1541-4337.12177

Table 1–Chemical composition of carob kibble.

Constituent	Proportion (%)
Total sugars	45 to 52
Sucrose	35 to 45
Fructose	6 to 7
Glucose	2 to 4
Crude fiber	Up to 40
Protein	2 to 7
Ash	2 to 3
Fat	0.5 to 1
Total polyphenols	1.4 to 2.0

Source: Albanell and others (1991); Avallone and others (1997); Turhan and others (2006); Makris and others (2007); USDA (2009); Khlifa and others (2013).

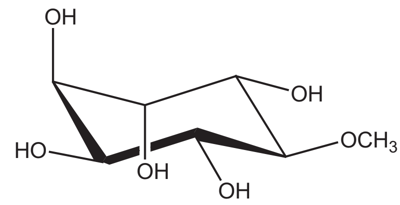

Figure 1–Chemical structure of D-pinitol.

2004). The effective utilization of this industrial by-product as a source of natural bioactive compounds is becoming the focus of researchers. Carob fiber and polyphenol-rich preparations have shown good potential for a diverse variety of health benefits, including reduction in (LDL) low-density lipoprotein cholesterol in hypercholesterolemic patients, regulatory effect on blood glucose level, beneficial effect on body weight, and improved digestion and lipid utilization (Koebnick and Zunft 2004; Gruendel and others 2007; Ruiz-Roso and others 2010; Valero-Muntildoz and others 2014). This review highlights the aforementioned aspects of carob kibble and its potential for use as a raw material in the food industry.

Carob Kibble Composition

The chemical composition of carob kibble is given in Table 1, however it varies with genetic, environmental and climatic factors, and harvesting time (Albanell and others 1991; Avallone and others 1997; Sánchez and others 2010; Khlifa and others 2013). The plant type (male, female, or hermaphrodite) and cultivar significantly influence the chemical composition (especially the phenolic profile) and biological activities of carob kibble (Custodio and others 2011b). Carob kibble is high in sugar content which ranges from 30% to 60% with the main sugars being sucrose (65% to 75% of the total sugars), fructose and glucose (15% to 25% of the total sugars) (Ayaz and others 2007; Biner and others 2007; El Batal and others 2011). The high sugar content makes them suitable for citric acid production by *Aspergillus niger* (Roukas 1998), lactic acid fermentation by *Lactobacillus casei* (Turhan and others 2010), and bioethanol production, preferably by solid-state fermentation with *Saccharomyces cerevisiae* (Roukas 1994a, 1994a, 1996; Ercan and others 2013) or *Zymomonas mobilis* (Mazaheri and others 2012; Saharkhiz and others 2013). Carob kibble also contains appreciable amounts of fiber (up to 40%), protein (2% to 7%) and minerals such as potassium (993 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) and low levels of fat (0.9% to 1.3%) (Albanell and others 1991; Shawakfeh and Erefej 2005; Turhan and others 2006; Turhan 2011; Khlifa and others 2013). Carob kibble has a nutty, chocolate-like flavor (Fadel and others 2006; Medeiros and Lannes 2009, 2010). Unlike chocolate or cocoa, it is almost free from caffeine and theobromine (stimulants) and oxalic acid (a potential source of kidney stone formation) (Craig and Nguyen 1984). Carob kibble also contains very low fat (about 1%) and sodium contents making it a healthy food ingredient (Makris and Kefalas 2004).

Inositols

In addition to the main sugars (sucrose, glucose, and fructose), carob kibble contains low concentration of other sugars such as maltose, raffinose, stachyose, verbascose, xylose, inositols, and others (Ruiz-Aceituno and others 2013). Inositols are polytols of cyclohexane with the empirical formula $C_6H_{12}O_6$. There are 9 stereoisomers of inositol, but only 5 are naturally occurring. They are myo-inositol, chiro-inositol (D-pinitol), scyllo-inositol, muco-inositol, and neo-inositol. Of these, myo-inositol is the precursor of the other 4 isomers (Campbell and others 2011). Inositols have been found in various types of plants. Free inositols (myo- and chiro-) and methyl-inositols (pinitol derived from chiro-inositol; ononitol and sequoyitol from myo-inositol) have been detected in edible legumes (Schweizer and others 1978; Clements and Darnell 1980). Soybeans and peanuts are considered to be good sources of inositols. However, carobs contain much higher amounts of inositols than any other legume.

D-Pinitol, 3-*O*-methyl-D-chiro-inositol (Figure 1), is a plant bioactive component (Phillips and others 1982). This compound was named after the pine tree from which it was isolated for the 1st time. Pinitol has now been isolated from a variety of other plant species. It has been found as a dominant component of the low-molecular-weight carbohydrate fraction in the family *Leguminosae* (Streeter 2001; Garland and others 2009) and, among them, the most pinitol-rich sources include soybean and carob (Poongothai and Sripathi 2013). D-(+)-Pinitol (3-*O*-methyl-D-*chiro*-inositol), *myo*-inositol, and D-(+)-*chiro*-inositol were isolated from carob powder. The concentration of D-pinitol ranged from 5% to 7.5% (dry weight of the powder) whereas *myo*-inositol and *chiro*-inositol were minor components with concentrations of 0.5% to 1% and 0.1%, respectively (Baumgartner and others 1986). Higher D-pinitol (methyl-inositols) contents (113 mg/g) in carob has been reported in a recent study from Spain which was much higher than those in other legumes such as soybean (3.5 mg/g), chickpea (2.0 mg/g), and lentil (2.0 mg/g) (Ruiz-Aceituno and others 2013). When compared with other D-pinitol-rich plants, carob pods are the least expensive source with the highest content (Turhan 2011, 2014).

Polyphenols

Phenolic compounds are considered to impart most of the organoleptic properties particularly taste and color, to different plant parts and also contribute to many health benefits (Scalbert and others 2002). Flavonoids are considered as soluble polyphenols which get absorbed in the digestive tract and are found in blood as such or in conjugation with sulfates or glucuronic acid, whereas insoluble polyphenols, like condensed tannins and lignins, are mostly recovered in the feces (Cherniack 2011). Carob kibble is a unique product rich in dietary fiber content with a high concentration (1.7%) of polyphenols (Table 1) (Turhan and others 2006; Makris and others 2007; Khlifa and others 2013). The polyphenol content of carob kibble is similar to that of polyphenol-rich grain legumes such as lupin (Khan and others 2015). The qualitative and quantitative data on polyphenols in carob have been elucidated along with

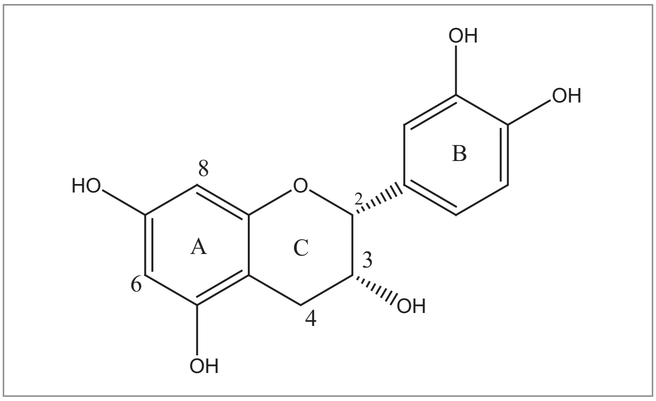

Figure 2–The basic repeating unit ((–)-epicatechin) in condensed tannins.

their antioxidant activity (Kumazawa and others 2002). The major polyphenols present in carob include gallic acid and polymers of flavan-3-ol and flavan-3,4-diol subunits (Owen and others 2003). Carob kibble also contains tannins which are complex polyphenolic compounds and can be classified into 2 groups: hydrolyzable and condensed tannins or proanthocyanidins.

Hydrolyzable tannins. Numerous scientific epidemiological studies have correlated fruit and vegetable consumption with a lower risk of cancer, degenerative, and cardiovascular diseases (CVDs). Food components playing an important role in this context include plant polyphenols such as hydrolyzable tannins. Isolated hydrolyzable tannins from edible and/or nonedible plants have shown strong biological activity in the form of antitumor, antimutagenic, antidiabetic, antiproliferative, antibacterial and antimycotic properties (Okuda and Ito 2011). Hydrolyzable tannins are widespread secondary metabolites in the plant kingdom characterized by their solubility in water and molecular masses between 500 and 5000 Dalton. They engage in the usual phenolic reactions and form precipitates with proteins and alkaloids. They form polymers of gallic acid or ellagic acid (gallo- and ellagitannins) by esterification with a central molecule, commonly glucose or a polyphenol such as catechin (Koleckar and others 2008). The hydrolyzable tannins are getting increased attention in various scientific and commercial areas, especially in the food sector due to their well-known astringency which affects food quality. They may also increase the shelf-life of foods due to their antioxidant properties and/or antimicrobial activity (Buzzini and others 2008). Owen and others (2003) revealed that carob not only has a high content of phenolic antioxidants, comparable to other Mediterranean foods such as olives, but also contains a rich variety of individual components from several classes. Altogether, 24 major phenolic compounds have been identified and quantified. Joslyn and others (1968) isolated 9 hydrolyzable tannins from carob pods and, among them, 2 galloyl glucoses were identified. They have reported that many kinds of hydrolyzable tannins, such as galloyl glucose compounds, were present in carob pods in large amounts.

Condensed tannins. Condensed tannins are flavonoid polymers (Figure 2). Carob kibble is rich in condensed tannins; they are formed by groups of flavon-3-ol and their gallic esters, gallic acid, catechins, epicatechin gallate, epigalocatechin gallate, and quercitin glycosides (Saura-Calixto and others 2010). Condensed tannins release anthocyanin aglycones (potent antioxidants) when heated under acidic conditions and they differ in the nature of their constitutive units, sequences, chain lengths, and presence of substituents. Condensed tannins are practically nonfermentable and are mainly insoluble (Schofield and others 2001). The main constituents of carob polyphenols are condensed tannins, containing the flavan nucleus and insoluble in the usual organic solvents. It was found that the catechins and leucoanthocyanidins present in green carob pods may be regarded as precursors of these tannins (Tamir and Alumot 1969). Joslyn and others (1968) stated that the major leucoanthocyanins in carob pods were highly polymerized leucodelphinidins.

Dietary fiber

Dietary fiber is one of the most important food ingredients used in nutritional and functional foods. Several epidemiological studies have shown a relationship between an increase in the consumption of dietary fiber and a decrease in certain illnesses such as gastrointestinal disease (Mendeloff 1987; Munakata and others 1995), hypercholesterolemia (Tinker and others 1991; Bagger and others 1996), colorectal cancer (Cassidy and others 1994; Reddy 1995; Peters and others 2003), and other diseases (Hallfrisch and others 1995; Bagger and others 1996; Gondal and others 1996). Dietary fiber has also a positive effect on calcium bioavailability and immune function (Tungland and Meyer 2002). In addition, the incorporation of fiber in foods results in a reduction in their caloric value, which can help in weight control (Lattimer and Haub 2010). To improve the dietary fiber contents of food products, researchers have used different ingredients high in dietary fiber contents, such as lupin flour (Jayasena and others 2010a; Jayasena and others 2010b; Jayasena and Nasar-Abbas 2012; Nasar-Abbas and Jayasena 2012), potato peel (Arora and Camire 1994), apple pomace (Wang and Thomas 1989), oat bran, rice bran, or barley fiber fractions (Hudson and others 1992), and apple skin powder (Rupasinghe and others 2008). Carob dietary fiber is unique in its composition due to the presence of high amounts of polyphenols, mainly tannins. About 50% of the weight of the carob dietary fiber corresponds to polyphenols (Saura-Calixto 1988), and this makes it a different fiber than the other dietary fiber sources. These polyphenols are condensed tannins (proanthocyanidins), formed by groups of flavan-3-ol and their gallic esters, gallic acid (Avallone and others 1997), catechins, epicatechin gallate, epigalocatechin gallate, and quercetin glycosides (Owen and others 2003). This is a predominantly insoluble and practically nonfermentable dietary fiber.

Carob fiber is the main by-product in carob syrup processing. Carob kibble is soaked in water overnight, which dissolves majority of the carbohydrates. Then the water-soluble extract is collected and the remaining material consists of mostly dietary fiber. The fiber extract typically contains (on dry weight basis) dietary fiber 75%, carbohydrates 6%, protein 5%, fat 2%, and a range of minerals and polyphenols (Haber 2002). Carob fiber is mainly insoluble, however, substantial amounts of soluble polyphenols are present such as gallic acid, hydrolysable tannins (gallotannins), and flavonol glycosides (Owen and others 2003). This high dietary fiber and polyphenol containing product has a great potential to be used as a functional food ingredient in a range of food products.

Health Benefits

Over the last few decades, extensive research has been conducted on dietary compounds that provide health benefits, including protection against diseases, in particular CVD, diabetes, and cancer. These bioactive compounds include phytoestrogens, carotenoids, citrus limonoids, organosulfur compounds, and polyphenols. The basic mechanisms implicated in the potential health effects of polyphenols are mainly inhibition of lipid and DNA oxidation (antioxidant activity) and the regulation of gene expression

(Kris-Etherton and others 2002; Patil and others 2009). Recent studies have demonstrated that carob powder is effective in the prevention of colon cancer, lowering cholesterol, and reducing the risk of type 2 diabetes (Klenow and others 2008; Mohamed and others 2008; Ruiz-Roso and others 2010). Hence, carob has substantial potential to be utilized in developing novel functional foods with health benefits.

Antioxidant properties

Reactive oxygen species/reactive nitrogen species are regularly produced in the human body (in biological systems) for physiological signaling pathways and to destroy viruses and bacteria in leucocytes during infection (Forman and others 2008). These radicals are typically unstable and cause damage to lipids, proteins, and DNA, and, they participate in pathogenesis and aging (Kehrer and Smith 1994). The chronic exposure to oxidative stress is considered as an initiating event in the development of degenerative diseases (Brown and Borutaite 2006). Polyphenols reduce oxidative stress by scavenging these free radicals through electron-donating properties, generating relatively stable phenoxyl radicals or chelating redox-active transition metals (Santos-Buelga and Scalbert 2000; Scalbert and others 2002). Many dietary phenolics are known to provide health benefits due to their various biological activities, such as antioxidant and anti-inflammatory properties (Scalbert and others 2002). Furthermore, phenols reduce the risk of some chronic diseases such as cancer and heart diseases (Bu-Abbas and others 1996; Custodio and others 2009).

Carob kibble is a rich source of polyphenolic antioxidants (Loeb and others 1989). Their extraction from carob kibble has attracted considerable scientific interest to use them as natural antioxidants mainly in foods to prevent the rancidity and oxidation of lipids (Kumazawa and others 2002; Botega and others 2009). In recent years, much research has focused on plants and their by-products to extract natural and low-cost antioxidants that can replace synthetic additives such as butylated hydroxyanisole and butylated hydroxytoluene, which might be liver-damaging, carcinogenic (Ak and Gulcin 2008), and more generally toxic (Moure and others 2001).

Two carob extracts, 1 containing 35% tannins and the other containing 85% condensed tannins, were used in a cooked pork meat system and compared for their antioxidant activity with α-tocopherol, a well-known antioxidant commonly used in foods, during a 6 mo frozen storage trial. Both carob extracts demonstrated a significantly higher antioxidant activity than the α-tocopherol (Bastida and others 2009). Addition of 50 mg tannin-rich carob fiber to sunflower oil doubled the frying life of the oil by inhibiting the formation of undesirable compounds such as triacylglycerol-derived polar material and polymers (Botega and others 2009). There is an increased demand to develop novel natural compounds for food preservation aimed at replacement of synthetic antioxidants and antimicrobials. The assessment of the antioxidant potency of carob pod extracts by using 2 *in vitro* models showed that carob contains polyphenols with appreciable antiradical and reducing properties, and the values obtained were comparable to those for red wines and pure polyphenolic antioxidants (Makris and Kefalas 2004). Along with polyphenols, inositols also contribute to the antioxidant potential of carob kibble in maintaining good health (Campbell and others 2011).

Cholesterol-lowering effect

CVDs are among the major causes of death in developed countries. There is compelling evidence that CVD is principally related to an elevation of LDL cholesterol. Cholesterol, cholesterol esters, and triglycerides are transported within LDL particles (protein component ApoB) from their sites of absorption or synthesis to sites of bioactivity. In the artery wall, LDL oxidation and accumulation in macrophages (differentiated from circulating monocytes after adhesion to the vessel wall) are early events of plaque formation (atherosclerosis). Atherosclerosis involves the hardening and narrowing of arteries, thus putting blood flow at risk. It is the usual cause of heart disease, stroke, and peripheral vascular disease (Zern and Fernandez 2005).

The consumption of polyphenol-rich carob fiber has shown beneficial effects on the human blood lipid profile (Zunft and others 2001). The lipid-lowering effect of carob fiber (rich in insoluble dietary fiber and polyphenols) was investigated in a pilot study over 8 wk involving 47 volunteers with moderate hypercholesterolemia (total cholesterol 232 to 302 mg/dL). Consumption of 15 g of carob per day as a supplement to their regular diet resulted in a reduction of 7.1% in mean total cholesterol and 10.6% in LDL cholesterol after 4 wk. HDL (high-density lipoprotein) cholesterol and triglyceride levels remained unchanged. The pilot study was followed by a randomized, placebo-controlled, double-blind, and parallel arm clinical trial involving 58 volunteers (33 women and 25 men) suffering from hypercholesterolemia (5.2 to 7.8 mmol/L corresponding to 200 to 299 mg/dL). Half of the volunteers (nonplacebo group) consumed 15 g carob fiber per day as an ingredient of 4 slices of bread and 1 fruit-bar. After the 6 wk intervention period, the total and LDL cholesterol concentrations were 9.5% and 10.5% lower, respectively, in the carob fiber group than the placebo group. No significant effect was found on HDL cholesterol concentration (Zunft and others 2003; Zunft and others 2004).

In another study by Ruiz-Roso and others (2010), consumption of high-polyphenol carob fiber (4 g twice a day) for 4 wk resulted in reduction in total cholesterol by 18% and triglycerides by 16%. In a comparative study on rats with experimental hypercholesterolemia, the cholesterol-lowering effect of carob fiber was found to be 4 times stronger than that of psyllium husk (Perez-Olleros and others 1999b). Similarly, when carob fiber was added in the diet, rats which were fed 50 g/kg fiber and 25 g/kg cholesterol showed a significant reduction of cholesterolaemia (187 mg/dL) compared to those which consumed cellulose added diet (238 mg/d) (Perez-Olleros and others 1999a). The greater reduction of cholesterol levels in rats obtained with carob fiber than that of psyllium husk may be due to the nonfermentable polyphenols in carob fiber which could prevent reabsorption of the sterols trapped in the small intestine (Remesy and others 1993; Gelissen and Eastwood 1995). It can also be explained by high bile acid binding capacity of carob fiber leading to a significantly increased excretion of bile acids and sterols (Wursch 1979). The cholesterol lowering effect of carob fiber was found to be closely associated with an increased activity of cholesterol 7 α-hydroxylase and an increased bile acid excretion which is presumed to be mainly responsible for hypocholesterolemic activity of carob fiber (Zunft and others 2004).

In addition to polyphenols, inositols have proven to exhibit a wide range of health benefits. The most attractive health benefits of myo-inositol are the effects on metabolism. It could increase the sensitivity of insulin, increase the level of blood HDL cholesterol (good cholesterol), and decrease the level of serum LDL cholesterol and triglycerides (Maeba and others 2008; Croze and Soulage 2013).

Anticarcinogenic properties

There have been advances in cancer research during the past decade. However, the rate of cancer incidence is increasing at an alarming rate. Many studies have suggested a protective role of tannins and other polyphenols against cancers (Bu-Abbas and others 1996; Cao and others 1996). Carob fiber extract has been found to have protective effects against oxidative stress in adenoma cells that might defend against or slow down the carcinogenic process in colorectal cancer. Colorectal cancer is one of the most prevalent cancers in Western societies. Carob fiber, consisting of polyphenols, strongly inhibits proliferation (due to inhibition of DNA synthesis) of both adenoma and adenocarcinoma cells of the human colon (Klenow and Glei 2009). Aqueous extracts of carob pods showed a marked alteration in cell proliferation of a mouse hepatocellular carcinoma cell line and also induced apoptosis in the cells (Corsi and others 2002). This demonstrated that carob pods contain antiproliferative agents that could be of practical importance in the development of functional foods and/or chemopreventive drugs. Studies have revealed that an extract of carob germ has considerable antioxidant activity, and it reduced the viability of cervical cancer (HeLa) cells (Custodio and others 2009; Custodio and others 2011a).

Antidiabetic properties

Type 2 diabetes is highly prevalent in most developed world, with diet exerting a significant role in the etiology of the condition. Postmeal studies have shown a direct correlation between glycemic index and insulinemic index of foods, and the resultant lowered insulinemic index is thought to be of benefit in the prevention of or managing type 2 diabetes. Slowly digestible foods that result in lower blood glucose response are beneficial to health and help in managing diabetes and hyperlipidemia (Wolever 1990). Administration of crude polyphenol extract of carob pods to male rats showed a significant reduction in blood glucose after 30, 60, and 120 min when compared with the control group (Mohamed and others 2008). Compounds in carob may be reducing the blood glucose response by inhibiting the enzyme activity (amylases) resulting in the slow rate of starch digestion (McDougall and others 2005). Carob flour, particularly carob fiber, being rich in polyphenols and tannins, has a high potential to be incorporated into diabetic-friendly foods.

Inositols provide great health potential and have been proposed for treating disorders such as diabetes mellitus, obesity, atherosclerosis, and hypertension (Ostlund and Sherman 1996; Kim and others 2005; Croze and Soulage 2013). Both animal experiments and human clinical trials showed significant antidiabetic effects of myo-inositol (Croze and Soulage 2013). Among the inositols, D-pinitol plays an important role in controlling diabetes. In a clinical trial, the effect of D-pinitol on the postprandial blood glucose response in patients with type 2 diabetes mellitus was examined. Fifteen Korean subjects with type 2 diabetes mellitus (7 men, 8 women; 60.3 ± 3.1 y old) ingested cooked white rice containing 50 g of available carbohydrate with or without prior ingestion of pinitol. Pinitol was given as a 1.2-g dose at 0, 60, 120, or 180 min prior to rice ingestion. Capillary blood glucose levels were monitored for 4 h after rice consumption. The ingestion of 1.2 g of pinitol 60 min prior to rice consumption controlled postprandial capillary blood glucose most effectively. It significantly diminished the postprandial increase in plasma glucose levels measured at 90 and 120 min after rice consumption ($P < 0.05$). The incremental area under the plasma glucose response curve for subjects who consumed both pinitol and rice was significantly lower than that for subjects who consumed only rice ($P < 0.05$). Therefore, pinitol was found useful in controlling postprandial increases in blood glucose in patients with type 2 diabetes (Kang and others 2006). Experiments showed that pinitol had antihyperglycemic effects on diabetic mice. Oral administration of soy pinitol and carob pinitol (10 mg/kg) significantly decreased blood glucose at 2 to 6 h in streptozotocin-induced diabetic rats (Kim and others 2005). Plasma glucose and HbA1c in treatment groups were significantly decreased in comparison with control groups. Pinitol could also effectively control plasma glucose in type 2 diabetic patients by increasing insulin sensitivity (Bates and others 2000). Therefore, the pinitol containing carob kibble may be exploited to reduce type 2 diabetes problem.

Metabolic properties

Carob fiber-containing foods cause slower emptying of the stomach, being slowly digestible, thus resulting in more satiety, which is very useful for reducing obesity problems (Lee and others 2006). The use of carob flour has been of considerable value as a dietetic therapy for infantile diarrheal disturbance and bacterial dysentery in terms of shortening the duration of the disease (Achar 1951; Abella 1952). Carob bean juice when used in combination with ORS (oral rehydration solution of WHO) for the treatment of acute diarrhea in children resulted in reduction of the disease duration by 45% and stool output by 44% as compared to using ORS alone (Aksit and others 1998). The fruits are also traditionally used as an antitussive and against warts (Amico and Sorce 1997). Carob fiber is not easily fermentable in the human colon and causes a significant increase in the fecal volume (Perez-Olleros and others 1999b) which can help reduce constipation problem.

In summary, increasing consumption of dietary fiber and bioactive-rich foods is a critical step in stemming the epidemic of obesity, diabetes, and CVDs common in developed countries. Carob kibble has high amounts of dietary fiber as well as bioactive polyphenols and therefore has a double action in reducing the serum cholesterol level and has substantial potential in reducing CVD, diabetes, and obesity.

Food Applications

Carob powder (flour and fiber) as a health-beneficial food ingredient

Carob kibble (roasted or unroasted) can be milled into a fine powder which can be used as an ingredient in a wide range of processed foods, especially cereal-based baked products (Yousif and Alghzawi 2000). Its fine powder consistency makes it perfect for baking or cooking while mixing with other flours. It has a unique taste which adds sweetness to ordinary white flour. Flour made by beating the seeded pods has been utilized in breakfast foods (Smith and others 2012; Tsatsaragkou and others 2014a). Due to the unique composition of carob powder, its incorporation into food products can significantly increase the dietary fiber and polyphenol contents without any significant increase in the fat content (Makris and others 2007; USDA 2009; Durazzo and others 2014). Since allergenicity is one of the major concerns associated with any new food ingredient, the carob protein was not found to be allergenic in peanut-allergic children aged 4 to 14 y (Fiocchi and others 1999).

In addition to the nutritional profile, the rheological characteristics of dough can also be improved by the addition of carob kibble powder. Recent studies have found that the increased amounts of carob flour strengthen the bread dough made from rice (gluten free) by increasing its elasticity (Tsatsaragkou and others 2014a;

Tsatsaragkou and others 2014b). This particular elastic character of carob flour is due to the significant amounts of fiber which has the ability to absorb water, and thus the dough resists structural deformation.

Carob fiber, which is a by-product of carob syrup processing (the material remaining after water extraction of sugar from kibble), can also be milled into a fine powder which is suitable for use in a variety of food products, including baked goods, health bars, extruded products, dairy drinks, and dietary supplements (Çağlar and others 2013). Carob fiber, which is rich in dietary fiber and bioactive compounds (inositols and polyphenols), has a high potential to be used in a variety of foods similar to other high-fiber and bioactive-rich food ingredients such as lupin flour. Lupin flour has been successfully incorporated into a range of food products including muffins (Nasar-Abbas and Jayasena 2012; Rumiyati and others 2015), bread (Villarino and others 2015a,2015b, 2015c), biscuits (Jayasena and Nasar-Abbas 2011), and pasta and noodles (Jayasena and others 2010b; Jayasena and Nasar-Abbas 2012). Preliminary studies revealed that carob fiber has been successfully added to different baked goods, including bread, rolls, cakes, and cookies. It was found that 3% and 6% carob fiber added to wheat, rye, and multigrain breads and rolls, without changing the formulations, resulted in increased absorption of water and reduction in stickiness of dough (Haber 2002). The farinograph and extensograph tests have shown the dough made from the additions of carob fiber (1% to 5%) were rheologically more stable during mixing compared to dough with oat wholemeal (5% to 25%) (Mis and others 2012). Further studies are required on the incorporation of this valuable food ingredient into food products of commercial significance.

Cocoa replacer

Carob kibble presents great potential to replace cocoa powder. In fact, carob powder has nutritional advantages over cocoa powder by having lower contents of fat (0.6%) and higher dietary fiber (40%) (USDA 2009) as compared to cocoa powder which contains 23% fat and 5% fiber (Yousif and Alghzawi 2000). Carob powder, in contrast with cocoa, contains no caffeine, theobromine, and oxalic acid. Caffeine and theobromine are well-known stimulants, and oxalic acid, when coming in contact with human tissues, reacts with calcium to form calcium oxalate, which forms part of a kidney stone (Massey and others 1993; Massey 2007; Schroder and others 2011). Based on the high oxalic acid content in cocoa, chocolate is considered as a high-oxalic acid food (Mendonca and others 2003), and The Oxalosis and Hyperoxaluria Foundation recommends that persons with kidney problems should avoid eating chocolate (OHF 2004). Because of its high sugar content (50%), of which 70% to 80% is sucrose, carob reduces the addition of processed sugar when used as a cocoa replacement (Yousif and Alghzawi 2000). Many previous studies have reported a cocoa-like aroma in roasted carob (Arrighi and others 1997). Moreover, roasting of the carob powder not only improves its color and flavor, but also results in an increase in the phenolic contents and antioxidant capacity (Şahin and others 2009). Roasting at 150 °C for 60 min was found to be the most appropriate heat treatment to improve the desirable characteristics of carob powder along with improvement in the flavor profile by reducing the concentration of isobutyric acid, which has an undesirable flavor (Berna and others 1997). Improvement in the aroma of the roasted carobs can also be attributed to a reduction in acids, alcohols, and aldehydes, amounting to 91.4% of the total 137 aroma components identified, and an increase in the amounts of furans, esters, and pyrroles (Cantalejo 1997). Fadel and others (2006) demonstrated that a cocoa substitute with similar characteristics to cocoa can be produced via Maillard technology by using a mixture of milled chicory roots and carob pods. In some countries, carob kibble is already in use as a cocoa replacer or extender.

Carob syrup as a sugar replacer

Since carob pods are high in sugar (50%), the production of carob syrup by extracting carob pods (or kibble) with water followed by concentrating it by heating is a traditional practice in many carob-growing areas of the world. Carob drink, obtained by extracting carob pods (or kibble) with water, is very popular is some of the Middle Eastern countries such as Egypt. Carob syrup made from carob kibble can be used in various food formulations as an alternative to sugar. It can be used as a topping for desserts, to pour over pikelets or pancakes, marinating meat, or as a sweetener in hot or cold drinks. It is found suitable to produce flavored yogurt, however, it prolongs the fermentation time by reducing the microbial activity (Atasoy 2009). Carob syrup-based culture media were found suitable for high-yield production of mannitol which is widely used in the pharmaceutical and chemical industries (Andrade and others 1999). Carob juice, when evaluated in comparison with grape juice, was found comparable in sensory properties, but had significantly higher total phenolics (19.8 mg gallic acid equivalents/g) content than grape juice (6.2 mg GAE/g) (Rababah and others 2013).

Shelf-life extension

Carob kibble is promising in offering a natural ingredient for food preservation, since a number of studies have revealed carob's antimicrobial activity against a wide range of microorganisms including *Listeria monocytogenes* (Tassou and others 1997; Ben Hsouna and others 2012). The water absorption and water-holding characteristics of fiber can be used to benefit the end product. Indeed, by holding moisture, carob fiber acts as a humectant to enhance the softness of baked products and thereby help extend shelf-life. Carob fiber binds around 3 times its weight in water which helps to improve product quality and reduce microbiological growth promoted by free water. The antioxidative activity of carob fiber in food systems can also help improve product shelf-life. In biscuits, for example, carob fiber showed an antioxidant effect and shelf-life extension similar to that of α-tocopherol (Haber 2002). Carob fiber when added to sunflower oil at a concentration of 50 mg/kg oil reduced tocopherol loss, triacylglycerol polymerization and oxidation during heating (Botega and others 2009). Oil frying life was doubled because the formation of triacylglycerol-derived polar material and polymers was inhibited by more than 50%. The research outcomes revealed that carob fiber can be successfully employed as an additive to cooking oils to increase shelf-life at frying temperatures, and thus decrease the potential toxicity of the heated oil (Sánchez-Muniz and others 2007).

Conclusions

The world is experiencing increasing health problems due to a range of factors, including the shift from rural to more sedentary urban life styles. As a consequence, there has been increasing demand for new innovative health-beneficial food products. The unique nutritional quality (high dietary fiber content and bioactive compounds) of carob kibble and its beneficial effects on excess body weight, diabetes, hyperlipidemia, inflammation, and oxidative stress make carob kibble a novel food ingredient which has substantial potential to be used for developing a wide variety of health-beneficial food products. The incorporation of carob kibble and its products in food formulations would not only enhances nutritional value but also improve functionality by imparting useful rheological properties and extend shelf life of the final product.

Acknowledgments

This paper was prepared as part of a project funded by the Rural Industries Research & Development Corporation (RIRDC), Australia. The authors acknowledge with gratitude the support provided by the RIRDC, Carobs Australia Inc., and Curtin University. Collaboration amongst these institutions was found invaluable for the preparation of the manuscript. The authors declare no conflict of interest. Authors are grateful to Dr Manfred Kroger, Professor Emeritus of Food Science, for his kind help in editing the manuscript and removing the language aberrations.

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