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REVIEW ARTICLE

Chocolate: An overview of functional potential and recent trends in fortification

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Abstract

Chocolate is a delectable sweet enjoyed all over the world. Made from dried cocoa beans, through the process of roasting, grinding, and conching, chocolate is known for its taste and flavor. Although the sugar content of chocolate is limiting its reach to the health-conscious population, chocolate is endowed with immense medicinal benefits. The major ingredient of chocolate, cocoa, *Theobroma cacao* L., is a plant known as the "Food of the Gods" due to the abundance of polyphenols present in it. Processing conditions and parameters affect the polyphenol stability. Roasting process conditions affect the polyphenols of cocoa beans, especially the epicatechin and procyanidin. The variety of cocoa beans, quality and presence of fat, sugar, emulsifiers, drying time, and temperature are the important influencing factors affecting the polyphenol content of chocolate. Chocolate possesses antioxidant, antidiabetic, anticancer, anti–inflammatory, and good mood food properties but it is also shown to be prebiotic and helps in alleviating the symptoms of Alzheimer's and heart disease. The functional properties of chocolate can be enhanced by the addition of certain foods/ functional ingredients. This paper reviews the role of chocolate as a functional food, the effect of processing on polyphenols, and the recent developments in improving the functional properties of chocolates through fortification.

Keywords: Cocoa beans components; Polyphenols; Flavonoids; Chocolate processing; Functional properties; Fortification.

Highlights

- Functional potential of chocolate: Prebiotic, antioxidant, antidiabetic, good mood food, for Alzheimer's disease (AD), anticancer, antihypertensive, and anti-inflammatory
- Effect of processing on chocolate: Fermentation for brown cocoa colour and flavour precursors. Roasting affects polyphenol stability
- Improvements in the functionality of chocolate: Fortification of chocolates with the addition of fruits e.g. mulberry, lemon powder, passion fruit seeds, and probiotic strains

1 Introduction

Chocolate is considered the most popular sweet in every section of the age groups of people all over the world. The popularity of chocolate is not just an overnight sensation, it has taken several thousand years from Mayo people in 400 AD, who first planted the cacao tree to the Aztec people, who used cocoa beans as currency. Cocoa beans are the major ingredient of chocolate and related products. In 1875, Daniel Peter developed milk chocolate by using condensed milk powder from Henri Nestlé. A major popular commercialization of chocolate occurred after the production of the first dark chocolate by Rudolph Lindt in Switzerland (1879) by involving the “conching” method; conching enhanced the smoothness of chocolate (Verna, 2013). The world’s annual cocoa production in 2021-22 was around 4.9 million tons. Around 60% of the total cocoa beans are produced in the countries Cote d’Ivoire and Ghana, followed by Ecuador with a 7% share (Swiss Platform for Sustainable Cocoa, 2022). Around 43% of the cocoa production are utilized by the chocolate industry. In 2021, revenue generated by the global chocolate confectionery market was US $ 0.99 trillion (Statista, 2022). The Indian chocolate market was US$ 2.4 billion and is expected to reach US$ 4.1 billion in 2028 at a CAGR of 8.8% during 2023-2028 (India Chocolate Market, 2022) . The growth of the cocoa sector is driven by its popularity, extensive appeal in all age groups, and perceived health benefits.

Functional foods are now becoming popular all over the world as consumers have started taking seriously diet and health correlation and rising disposable income levels of consumers in developing countries and their health consciousness encouraging them to pay some more bucks on fortified / functional food. Considering taste, aroma, and nutritive value almost all food can be termed functional food up to some extent but nowadays, foods are thoroughly examined based on physiological benefits, which may reduce the risk of chronic diseases or help in the optimization of health and such research turned the food technologist’s and industrialist’s interest towards a new approved food category called functional food (Hasler, 2002). Once the father of medicine Hippocrates in 400 BC believed to be quoted that 'Let thy food be thy medicine and medicine be thy food', is now regaining momentum. Swedish naturalist Carl von Linné (1753) named the cocoa plant *Theobroma cacao* L.: Food of the Gods (Verna, 2013). Cocoa butter and cocoa liquor are the major ingredients in chocolate making. The use of *T. cacao* as a medicine has been known for ages but little information was available for the use of cacao as a “potential promoter of health” (Singh et al., 2017).

Earlier, the major concern regarding the consumption of chocolate was its high fat and sugar content leading to the development of caries, high blood pressure, coronary artery disease, and diabetes. However, now awareness about the functional and medicinal benefits of chocolate is gaining ground. Chocolate is a rich source of bioactive compounds that have beneficial effects on heart health, insulin secretion, and brain function among others (Allen et al., 2008; Taubert et al., 2007). Research studies are reporting the effect of the use of chocolate on multiple ailments and conditions including aging, high blood pressure, gut microbiota, cancer, depression, diabetes, and Alzheimer’s disease among others.

This paper reviews the bioactive compounds in chocolate, the role of chocolate as a functional food, and recent developments in improving the functional properties of the chocolates. It highlights the efficiency of chocolate in the systemic health, metabolism, and immune system beyond its consideration as good mood food.

2 Processing of chocolate

Cocoa fruit at the harvesting stage contains about 30-40 seeds. The seeds are covered by a mucilaginous pulp which is removed by yeast and bacteria during fermentation. The fermentation step is essential for the development of chocolate flavor and lasts from three to seven days. This step also produces aroma precursors. Fermentation is followed by drying where the moisture content is reduced to 5% to7% at 45°C to 60 °C and shelf life is increased. Dried cocoa beans or nibs are then broken to reduce the size of the kernel and then roasted at around 120°C to 150 °C to develop the chocolate flavor. The nibs are then ground to cocoa liquor.

The dark chocolate is made by mixing cocoa liquor, sugar, cocoa butter and emulsifiers. To produce milk chocolate, milk, and other ingredients are added and refined to reduce the particle size of solids.

After refining, the mixture undergoes a conching operation wherein the chocolate mass is agitated at a high temperature of around 50 °C. Conching is followed by tempering, which consists of heating, cooling, and mixing (Figure 1) (DiMattia et al., 2017; Shafi et al., 2018).

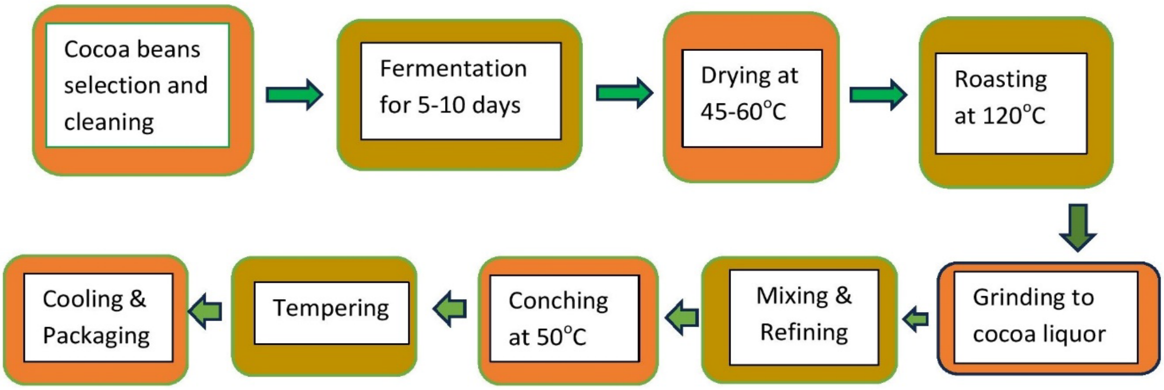

Figure 1. Cocoa processing for chocolate manufacture.

3 Biology of cocoa

Cocoa is a dried and fully fermented cocoa bean product derived from *T. cacao*, an evergreen tree in the family Malvacae. The name signifies "Food of God" in Greek. There are two main groups of Cocoa beans, purple seeded Forestero, the most widely used cocoa bean, and Criollo, the lesser used mild flavoured high-quality cocoa (Sein et al., 2009). The cocoa plant is a branching tree with simple, pointed (lanceolate) leaves measuring up to 61 cm (24 in) long and 10 cm (4 in) wide (Figure 2). The tree produces clusters of pale-yellow flowers each with five petals and sepals. The cocoa pods can be green-white, yellow, purplish or red in color each of which contains 20-50 seeds, the cocoa beans are arranged in five distinct rows (Figure 3, Figure 4). The cocoa tree can reach 4–20 m (13-66 ft) in height. Cocoa is also known as cacao, koko or Kacao. The plant has its origin in the upper Amazon region of South America (PlantVillage, 2022). In India, the first Criollo type cocoa plantations were installed in the Nilgiris' Kallar and Burliar Fruit Stations in 1930-35, and their performance was examined (Malhotra & Apshara, 2017).

Taxonomy of Cocoa:

Kingdom- Plantae

Order- Malvales

Family- Malvacae

Genus- *Theobroma* L.

Species- *Theobroma cacao* L.

Figure 2. Cocoa tree.

Figure 3. Cocoa Pod.

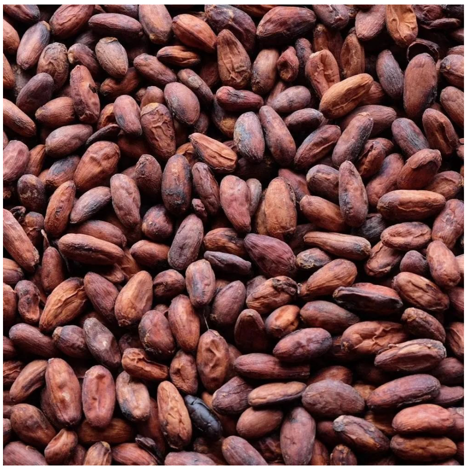

Figure 4. Cocoa beans.

4 Components of cocoa

Cocoa quality is affected by the fermentation time and temperature, drying to the optimum moisture content and roasting conditions. Characterization of cocoa beans is essential for their quality evaluation (Penido et al., 2021).

Cocoa beans have a composition that includes lipids, carbohydrates, proteins, minerals and bioactive components with rich functional properties. The physicochemical properties of cocoa beans have been presented in Table 1. The main component of cocoa beans is lipid fraction, the cocoa butter, approximately 50%, mainly constituted by neutral lipids, with a predominant fraction of triglyceride molecules. Oleic acid, stearic acid and palmitic acid are the main constituents of cocoa butter. Protein fraction constitutes 10% to 15% of the dry weight of cocoa seeds, and it is composed of 52% and 43% of albumin and globulin fractions, respectively. Other proteins, such as glutelins and prolamins, are present in lower concentrations. Cocoa beans are also rich in carbohydrates (31%), fiber (16%), and minerals (Shahanas et al., 2019). Cocoa beans contain stimulant substances, such as theobromine, caffeine, and theophylline, named purinic alkaloids, which affect the central nervous system (Bertazzo et al., 2013).

Lam et al. (2022) studied the physico-chemical properties of 14 varieties of cocoa beans from Vietnam. Among the 14 varieties of dried fermented cocoa beans, TD8 had the largest size (1.5g mass, 25.02mm Length x 14.28mm width x 7.96mm thickness). The moisture content of the cocoa beans was in the range of 5.64-6.99% (wb) and the fat content of seven varieties was more than 50%. When compared to the Ghanaian beans, the TD8 variety was of better quality as Ghanaian cocoa beans were of smaller mass (1.31g), smaller size, and higher moisture content. Higher moisture content indicates a shorter shelf life.

Cocoa liquor is the paste produced using ground, broiled, shelled, and fermented cocoa beans, called nibs. It contains both nonfat cocoa solids and cocoa butter. Cocoa butter contains a noteworthy number of fatty acids, while the nonfat cocoa solids contain fiber, minerals, vitamins, and polyphenols. Beans of cocoa are exceptionally rich sources of many essential minerals, which include magnesium, copper, potassium iron, etc. A study shows that minerals found in cocoa may affect vascular health and function, improving cocoa's nutritional effects. The abundantly found mineral in cocoa is magnesium responsible for catalysing a multitude of biological reactions, including protein synthesis and energy production, while copper found in dark chocolate is required for processes, such as iron transport, glucose metabolism, infant growth, and brain development (Jalil & Ismail, 2008; Steinberg et al., 2003). Cocoa and cocoa-based foods contain remarkable quantities of vitamin D2 and are recognized as sources of vitamin D2 (Kühn et al., 2018). The aroma profile of the cocoa beans depends on whether the beans are dry, roasted, or processed into cocoa liquor or chocolate, the genotype, and variety. The Criollo variety has higher fine concentrations of fruity, nutty, wood, floral, herbaceous, and caramel flavour while the Forastero cocoa possesses predominant aromas of malt, honey, chocolate, caramel, and low acidic and alcoholic flavour (Quelal et al., 2023)

4.1 Cocoa polyphenols

Cocoa includes a variety of phytochemicals, with polyphenols accounting for the biggest group of molecules inside the unfermented seed accounting for around 6% to 8%w/w along with methylxanthine compounds, mainly theobromine, and caffeine. Polyphenols are secondary plant metabolites that protect plants against herbivores, ultraviolet (UV), and pathogen damage (Salvador et al., 2018). Polyphenols have been linked to a variety of biological activities, including antioxidant, antiproliferative, antiapoptotic, anti-inflammatory, and anticancer properties (Cinar et al., 2021; Thakur et al., 2020). Polyphenolic compounds with a high number of flavonoids are found in cocoa, specifically flavanols, also known as flavan-3-ols, anthocyanins, and flavonols. The flavanols account for around 60% of non-fermented cocoa beans. The main flavan-3-ols are the monomeric forms, (−)-epicatechin and (+)-catechin, and their oligomeric and polymeric forms, procyanidins. The types of flavanols found in cocoa beans are (−)-epicatechin, the most abundant, and (+)-catechin, procyanidin B1, and

B2. The other flavanols present in trace amounts are epigallocatechin, epigallocatechin-3-gallate, procyanidin B2-O-gallate, procyanidin B2-3,3-di-O-gallate, procyanidin B3, procyanidin B4, procyanidin B4-O-gallate, procyanidin C1, and procyanidin D (Sorrenti et al.,2020). The catechin, epicatechin, and procyanidins prevail in antioxidant activity (Katz et al., 2011). Cocoa flavonoids are a promising component that increases the effectiveness of vitamin D in skeletal muscle cells (Abballe et al., 2021). Theobromine is studied for its antitumor, anti-inflammatory, and cardioprotective role (Martínez-Pinilla et al., 2015). The health benefits of flavanols and the methylxanthines in cocoa have been reviewed by many researchers (Table 2).

4.2 Bioavailability of Cocoa polyphenols

Bioavailability is the amount of the compound or metabolite that reaches the systemic circulation after the administration of an acute or chronic dose of an isolated compound or a compound containing food (Oracz et al., 2020). Polyphenols are xenobiotics (foreign to animal life) for the human body and therefore their bioavailability is low when compared to macro and micronutrients. Only a fraction of low molecular weight polyphenols is absorbed in the small intestine and the remaining oligomeric and polymeric polyphenols reach the colon and are subjected to the enzymatic activity of the gut microbiota. The colon microbiota breaks down the polyphenols into low molecular weight phenolics that are absorbable metabolites (Cardona et al., 2013).

Dark (black) chocolate has been more of an object of investigation compared to milk chocolate as the polyphenols amount in milk chocolate are lesser than in dark chocolate due to the lower amount of cocoa used in milk chocolate (10 ± 15%) compared to black chocolate (30 ± 50%). Also, milk proteins, especially caseins being relatively proline-rich, may impair the absorption of procyanidins due to complexation. Thus, dark chocolate is said to possess a higher potential to be beneficial to human health (Wollgast & Anklam, 2000).

Table 1. Physico-chemical properties of Cocoa beans.

Cocoa bean variety	Mass (g)	Moisture	Ash	Fat	Protein	References
Dried fermented cocoa bean (Vietnam variety)	1.5	5. 64%- 6.99%	2.57%-3.7%	50%-55%	12.82%-13.94%	Lam et al. (2022)
Dried cocoa beans (Ghanaian variety)	1.31	5%-24%	2.3%-3.5%	50.4%-55.21%	18.8%	Bart-Plange & Baryeh (2003)

Table 2. Cocoa Flavanol and Methylxanthine compounds and Health Benefits.

Cocoa bioactive compounds	Health benefits	References
Flavanols: Monomeric – (-) Epicatechin and (+) Catechin Oligomeric- Procyanidin	Cardioprotective, Anti-Inflammatory, Anticancer, Anti-hypertensive, Antioxidant Protection from neurodegeneration and neuroinflammation Improving insulin sensitivity	Scapagnini et al. (2014), Sies et al. (2005), Shahanas et al. (2019), Baba et al. (2001), Katz et al. (2011)
Methylxanthines: Theobromine and Caffeine	Neurocognitive effect Stimulation of heart muscles Relaxation of bronchial muscles	Martínez-Pinilla et al. (2015), Smit et al. (2004), Smit & Blackburn (2005)

5 Functional properties of chocolate

Chocolate possesses immense functional potential and has been proven and acknowledged by many researchers (Figure 5). Several studies have focused on the antioxidant, good mood, and anti-inflammatory properties among others. The different functional properties of chocolate are as follows:

5.1 Chocolate as prebiotic

Prebiotics were first introduced in 1995 by Gibson and Roberfiod as nondigestible food component that selectively triggers growth or activity in gastrointestinal microbiota and better the health status of host. Study findings were supported by Hayek (2013) in which there was an increase in the *Bifidobacteria* and *Lactobacilli* due to consumption of cocoa rich drinks. Tzounis et al. (2011) compared the effect of the consumption of high cocoa *versus* low-cocoa flavanol drinks on gut microflora. The results of this study validated the claim of an increase in the *Bifidobacteria* and *Lactobacilli* and a decrease in Clostridia. Chocolate has proven a role in exceptional human sicknesses and problems and its position may be through modulations of the intestinal microbial species as established in the latest posted studies. Konar et al. (2016) observed the ability of chocolate to carry probiotic strains and prebiotics. Research is necessary to observe the effect of processing conditions on the functionality of these bioactive ingredients and their bioavailability and bio accessibility. Ordinarily utilized prebiotics are fructo-oligosaccharides/oligofructose (FOS), galacto-oligosaccharides (GOS), inulin, isomalto-oligosaccharide (IMO), beta-glucan and psyllium husk (Singla & Chakkaravarthi, 2017). Tzounis et al. (2011) observed that utilization of cocoa flavanols can essentially influence the development of select gut microflora in people, which recommends the potential prebiotic benefits related to the dietary consideration of flavanol-rich food. Silveira et al. (2015) conducted a study that recommended that goat cheese whey and prebiotics (a blend of inulin with oligofructose) might be utilized as utilitarian additives in defining a probiotic chocolate goat dairy beverage to keep up adequate probiotic practicality and improve its thickness and sensory features. Yonejima et al. (2015) observed that the processing of chocolate is an adequate method of shaping probiotics to be transferred to the intestine in a viable condition and to be effective for host health. Nambiar et al. (2018) successfully incorporated Microencapsulated *Lactobacillus plantarum* HM47 into milk chocolate, that found to be a potential carrier for the probiotic by retaining the bacterial cells viable for 180 days at 25 °C, thus validating the claim that milk chocolate could be a successful carrier for probiotics and the *L. plantarum* HM47 might be a potential probiotic for human.

Wiese et al. (2019) explored the prebiotic effect of lycopene and dark chocolate on gut microflora, blood, liver metabolism, skeletal muscle tissue oxygenation, and skin. An increase in *Bifidobacterium adolescentis* and *B. longum* was observed in all groups having lycopene and also in *Lactobacillus* for groups having dark chocolate. It has been reported that polyphenols support the growth of beneficial gut microbiota, such as *Lactobacillus* and *Bifidobacterium*, while reducing the number of pathogenic species, such as *Clostridium perfringens* (Sorrenti et al., 2020).

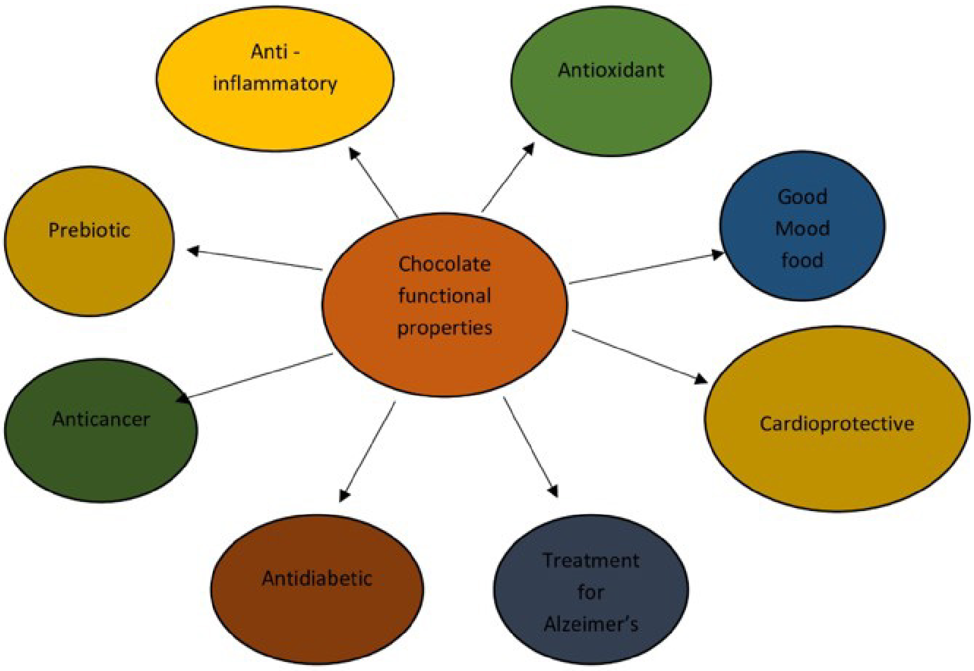

Figure 5. Functional properties of Chocolate.

5.2 Chocolate as an antioxidant

Each cell of our body is protected naturally with adequate antioxidant mechanisms for protection against any hazardous effects of Reactive oxygen species (ROS) developed within the body or those that penetrate our body from the environment. Endogenous antioxidant defense system (ADS) comprises enzymatic and nonenzymatic antioxidants. The utilization of natural antioxidants was obligated as a rational strategy to combat stress-related diseases. Plant polyphenols are considered to be important dietary antioxidants, and dietary intake of these compounds can be up to 1200 mg per day. Flavonoids, phenolic acids, and procyanidins are considered the main polyphenol classes and they all possess strong antioxidant potential confirmed in chemically based assays (Srdić-Rajić & Ristic, 2016). Single servings of cocoa and cocoa products are found to contain more phenolic antioxidants than most other foods. Batista et al. (2016) evaluated the total antioxidant capacity (TAC) and total phenolic compounds (TPC) of cocoa beans and chocolate made from spontaneous and inoculated fermentations of different cocoa varieties by Fourier transform infrared spectroscopy (FTIR), as well as conventional methods: 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′- azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS). All samples of cocoa at the beginning of fermentation found the highest level of theobromine and caffeine. Another study indicated that the antioxidant capacity of cocoa powder could be attributed to the presence of phenolic compounds, especially flavonoids (Maleyki & Ismail, 2010). Magrone et al. (2017) investigated the immunomodulatory effects of polyphenols contained in chocolate and the results concluded that cacao liquor polyphenols (CLP), the polyphenol fraction purified from cacao liquor, inhibited ROS (O_2 and H_2O_2) production by activated granulocytes and lymphocytes.

An interesting study by Baranowska et al. (2020) noted that the antioxidant power of cocoa was much higher than the bioactivity of a mixture of individual cocoa compounds and the interactions or synergy between bioactive compounds determine the bioactivity of the foods.

5.3 Role of chocolate as cardioprotective

Sakaki et al. (2019) highlighted the polyphenols' protection role against cardiovascular heart disease by acting as antioxidants and impairing the development of atherosclerosis. Flavonoids reduce cardiovascular disease (CVD) incidence and mortality along with different CVD biomarkers, but various subclasses of flavonoids may produce different effects. Changes in study designs make comparisons difficult; thus, future epidemiologic and intervention studies with similar methodologic designs will allow for improved reconciliation of their finding. Polyphenol-rich diets have been shown in several clinical trials to be useful in the prevention and treatment of CVDs due to their antioxidant, anti-inflammatory, antiplatelet, and other pleiotropic effects (Behl et al., 2020). A more recent meta-analysis found that supplementing with cocoa (300-1000 mg/day) in chocolate could help protect against noncommunicable diseases (NCDs) like cardiometabolic illnesses, metabolic syndrome, diabetes, hypertension, stroke, atherosclerosis, memory loss, and cancer. To prove these findings, more controlled trials are required. In older persons, a diet rich in cocoa and dark chocolate may help to promote neuro–cardiovascular connection (Singh et al., 2022). *In vitro* and animal model studies have shown that cocoa flavonoids upregulate enzymes that act as a vasodilator of the coronary arteries. The European Food Safety Authority (2012) has stated that to get the claimed effect, 200 mg of cocoa flavonoids should be consumed daily (Pucciarelli, 2013). Polyphenols are viewed as of extraordinary restorative value due to their pleiotropic properties and structural diversity. They are acceptable candidates for the prevention and treatment of ischemic heart disease, as they minimize myocardial oxygen utilization or potentially increase oxygen flow, improve myocardial metabolism after ischemia/reperfusion (I/R), secure the remaining myocardial cells or re-establish myocardial constriction (Du et al., 2016).

5.4 Chocolate for Alzheimer’s disease (AD)

Alzheimer’s disease (AD) is a neurodegenerative disorder in which gradual cognitive impairment leading to dementia is observed. Epidemiological studies have indicated that dietary habits and antioxidants from diet can influence the incidence of neurodegenerative disorders such as Alzheimer's and Parkinson's diseases. Waterhouse et al. (1996) noted for the first time that cocoa and chocolate contribute as a large share of dietary antioxidants. Cocoa and its products are good sources of flavonoids. Depending on the method used in its production, cocoa powder can contain as much as 10% flavonoids on a dry weight basis (Steinberg et al., 2003). Extracellular deposits of amyloid-β (Aβ) plaques and intracellular neurofibrillary tangles of hyperphosphorylated tau proteins are the neuropathological features of Alzheimer's disease (AD). The treatment of Alzheimer's patients with sources of flavonoids has been shown to improve their cognitive performance. Clinical and epidemiological findings suggest a protective effect of flavonoids and polyphenols against neurodegenerative disease are supported by data obtained in animal models (Calderaro et al., 2022).

Cimini et al. (2013) investigated the effect of cocoa polyphenolic extract on a human AD *in vitro* model. The results obtained demonstrated that cocoa polyphenols triggered neuroprotection by activating the BDNF survival pathway, both on Aβ plaque treated cells and on Aβ oligomers treated cells, resulting in the counteraction of neurite dystrophy. The results obtained supported the use of cocoa powder as a preventive agent for neurodegeneration.

Cocoa directly or indirectly affects signal transduction pathways which are involved in neuronal death and neuroprotection, supporting the possibility of its capable use as a preventive agent for neurodegenerative diseases characterized by oxidative stress. Cocoa extracts were found effective in preventing the oligomerization of Aβ.

5.5 Chocolate as good mood food

Positive mood can be created in various ways but if food can make mood positive then it is just like icing on the cake. Chocolate is considered a good mood food due to the presence of numerous compounds, that act on the brain and produce a sense of delight that no other food matches (Shin et al., 2022). In a study, it was found that participants who were instructed to eat chocolate mindfully had a greater increase in positive mood compared to those who were instructed to eat chocolate non-mindfully or with crackers either mindfully or non-mindfully. Further analysis also revealed that self-reported liking of the food partially mediated this effect (Meier et al., 2017). Xu et al. (2019) explored temporal changes in the perceived flavor of chocolate ice cream when consumed in a laboratory, café, university study area, and a city bus stop and further investigated how emotion and electrophysiological measures were influenced by these environments. When caffeine and theobromine found in chocolate were investigated for synergistic mood effects it was found that caffeine increases alertness and blood pressure. Theobromine decreases calmness and blood pressure but when a combination of caffeine and theobromine is taken then it has similar effects as caffeine alone but no effect on blood pressure (Mitchell et al., 2011). Chocolate’s serotonin elevating activity also raises a positive mood in a person. Mood-elevating properties of chocolate can be boosted with the intention of the person who ingests it (Radin et al., 2007). On a daily basis of consumption of 40 g dark and milk chocolate during a period of two weeks emerges to be an adequate way to minimize perceived stress in females (Al Sunni & Latif, 2014).

5.6 Chocolate as antidiabetic

Antioxidant effects of cocoa polyphenols directly influence insulin resistance and, in turn, minimize the risk for diabetes. Cocoa rich chocolate persuades pancreatic β-cell regeneration and prompt insulin secretion, which has a hypoglycemic effect, and also enhances glucose tolerance. Insulin sensitivity can also be improved by the vasodilatory effect of cocoa (Shah et al., 2017). Blood pressure and insulin response could be related to the regulation of nitric oxide production by dark chocolate flavanols. Precise intake of dark chocolate enhances insulin sensitivity in healthy as well as glucose-intolerant hypertensive people (Ackar et al., 2013; Grassi et al., 2005).

5.7 Chocolate's role as anti-inflammatory

Flavanol-rich dark chocolate exerts anti-inflammatory effects both by increasing mRNA expression of the anti-inflammatory cytokine IL-10 and by attenuating the intracellular pro-inflammatory stress response and this mechanism may also improve cardiovascular health (Kuebler et al., 2016). Air pollution generates up-regulation of inflammatory myocardial genes and endotoxin plays a decisive role in the inflammatory response. Daily intake of dark chocolate may reduce myocardial inflammation and have cardioprotective properties in the setting of air pollution exposures (Villarreal-Calderon et al., 2012). In many studies, cellular targets have been investigated and molecular mechanisms of disease prevention proposed, especially for the prevention of cancer and cardiovascular diseases as well as for alleviating the response to inflammation reactions (Wollgast & Anklam, 2000).

5.8 Chocolate as a cancer inhibitor

Saadatdoust et al. (2015) examined the antitumor effects and mechanisms of cocoa diet on colitis-associated colon cancer (CAC) by applying the azoxymethane/dextran sulfate sodium model. The findings demonstrated that the cocoa diet suppresses CAC tumorigenesis, it could be seen that cocoa could significantly decrease the tumor incidence and size in CAC-induced mice which concludes that cocoa may be a potential agent in the prevention and treatment of CAC. Vettori et al. (2022) observed improvement in nutritional status and functionality in older people with cancer in palliative care on consumption of 55% cocoa chocolate. Although a very small number of observational epidemiologic studies indicate weak support for reduced mortality related to cancer, but intervention studies have indicated favorable changes in biomarkers assessing antioxidant status (Maskarinec, 2009).

6 Effect of processing on functional properties of chocolate

The flavour, colour and texture of chocolate are dependent on chocolate processing. The characteristic flavour is due to the flavanol, theobromine, and caffeine content of the chocolate. The processing steps affect the flavanol and methylxanthine content and composition. The fermentation process develops characteristic brown cocoa colour and generates flavour precursors, leading to a reduction in bitterness and astringency in the dried cocoa beans. During fermentation and drying, the quantity of anthocyanins, total polyphenols, and sucrose decrease, whereas glucose and fructose increase (Barrientos et al., 2019). The cocoa polyphenols undergo enzymatic oxidation by polyphenol oxidase or non-enzymatic, which are then polymerized and bind with proteins forming high- molecular weight tannins responsible for the colour and flavour. There is a rapid decrease in the epicatechin, procyanidin, and anthocyanidins (Di Mattia et al., 2017). During drying, the polyphenol content is reduced by enzymatic browning. Due to insufficient usage of hot air dryers, drying cocoa beans in the presence of smoke results in greater polycyclic aromatic hydrocarbon (PAH) contamination (Abballe et al., 2021). Tran et al. (2021) concluded that with increasing HPJ (high-pressure jet) processing pressure, improved stability was seen, with a maximum observed when chocolate milk was processed at 500 MPa.

During the drying of cocoa beans, the brown polymers are synthesized as a result of oxidation of polyphenols, thus helping to form new flavor compounds and reduce bitterness (Goya et al., 2022).

The roasting process is one of the important methods in the processing of cocoa beans. High temperature processing may lead to the loss of some important features of beans like texture, color, and also some bioactive compounds such as polyphenols. So, it is important to cautiously select the relevant roasting process. A study by Żyżelewicz et al. (2016) concluded that roasting process conditions affected the polyphenols stability of cocoa beans. Polyphenol compounds were more stable when bean samples were roasted in the air with increased relative humidity, with constant conditions of temperature and airflow rate. The study showed that the use of air flow rate v=0.5 m/s and RH=0.3% resulted in lower degradation of polyphenolic compounds compared to the use of the flow rate v=1 m/s during roasting. Regardless of the roasting conditions it was found that the greatest degradations were observed for epicatechin and procyanidin, while at the same time, the catechin content increased. So, the process of chocolate preparation affects the concentration of various phenolic compounds in the finished products. DSC melting curves of chocolates depend on many factors such as the quality and presence of fat, sugar addition and/or emulsifiers, and particle size distribution in chocolate while the content of fiber in dark chocolates influences the textural (particularly acoustic) properties (Ostrowska-Ligęza et al., 2018). Drying time, temperature, polyphenol volatility, and moisture of grain are factors that influence the degradation profile of polyphenols for fixed gas velocity (Alean et al., 2016). The consequences of processing conditions on the acceptability of chocolate depend on the origin of cocoa beans. For most consumers, the acceptability of chocolate was significantly decreased when Ghana cocoa beans were roasted for a longer period. While, for some consumers, the most acceptable dark chocolate samples were those produced for each of the cocoa geographical origins considered, with specific combinations of roasting time and conching time. This study found that it was important to select the relevant roasting and conching conditions to produce specific chocolates from single origins with a guarantee of highest acceptability (Torres-Moreno et al., 2011).

An improvement was seen in the yield value, viscosity, texture, and color of the chocolate when the percentage of cocoa liquor prepared from unroasted cocoa beans was increased compared to roasted cocoa beans. It was also examined that with the increase in cocoa liquor content obtained from unroasted beans, polyphenol content also increased along with enhancing oxygen radical antioxidant capacity of chocolate (Żyżelewicz et al., 2018).

7 Recent developments in fortification of chocolate

The functional properties of chocolate can be enhanced by fortification with certain foods/ functional ingredients. Dark and milk chocolate contains ingredients like sugar, cocoa butter, full cream milk powder, cocoa liquor, lecithin, vanilla, and cocoa. Dark chocolate contains the least amount of added ingredients with a high cocoa percentage which makes it more functional, milk chocolate has the least amount of cocoa liquor, and so has fewer bioactive components. Chocolate shows a decrease in polyphenol and flavonoid contents during the processing of cocoa beans. The bioactive compounds content can be made up with fortification. Some of the recent studies on the fortification of chocolate have been presented in Table 3.

Godočiková et al. (2017) studied the effect of the addition of mulberry and sea buckthorn on the antioxidant levels of dark chocolate. They reported that chocolate improved with mulberry displayed higher polyphenolic content and antioxidant capacity while enhancement with ocean sea buckthorn did not show such huge improvement in antioxidant characteristics but increased the levels of bioactive compounds despite the lower amount of cocoa solids.

Albak & Tekin (2014) developed a Functional Chocolate by using Spices and Lemon Peel Powder. Moisture and color variation was observed in aniseed and cinnamon chocolates. Ginger was the most effective additive on the melting point and the total polyphenol content of dark chocolate and ginger chocolate was close to dark chocolate in terms of moisture and color while cinnamon had higher polyphenol content in comparison with dark chocolate. Giacometti et al. (2016) conducted a study on mice that shows that cocoa polyphenols exhibit antioxidant, anti-inflammatory, anticarcinogenic, and anti-necrotic activity in carbon tetrachloride intoxicated mice. A study finds that fermented and partially fermented cocoa beans had high polyphenol content which is related to an extremely astringent and bitter flavor that could be decreased to a certain concentration by appropriate incubation with polyphenol oxidase while retaining the polyphenols beneficial for daily health owing to antioxidant activity (Misnawi et al., 2002).

Erdem et al. (2014) investigated the effect of the addition of the probiotic strain *Bacillus indicus* HU36 and dietary fiber (maltodextrin and lemon fiber) on the color and organoleptic properties of dark chocolate. The addition of bacteria and dietary fiber did not have any negative effects on product color and sensory properties but the sweetness, firmness, and adherence were improved with the addition of dietary fiber. A functional dark chocolate with improved functional, organoleptic, and textural properties was developed with the incorporation of flaxseed oil and honey (Singh et al., 2020). Significant improvement in sensory properties and antioxidant activity were observed in the chocolate.

Ekantari et al. (2019) fortified the dark and milk chocolates with nanocapsules carotenoid of *Spirulina platensis* and studied its stability. The nanocapsule (0.372%) was added to the chocolate paste and cocoa butter in the composition 27.5:25 (milk chocolate) and 58:24.5 (dark chocolate). The fortified chocolates did not show significant differences in aroma, texture, and taste.

Kumari et al. (2021) studied the addition of butter fruit milkshake powder, a blend of avocado pulp and dairy ingredients (pasteurized toned milk, sugar, maltodextrin) at 30% level to the chocolate on the phenolic content and antioxidant activity of the fortified product.

Wheat germ is a byproduct of the wheat milling industry and is characterized by high levels of protein, dietary fiber, essential amino acids, unsaturated fatty acids, and high polyphenol and flavonoid content. Al-Marazeeq (2018) fortified the dark chocolate with wheat germ (10%) and found that protein and mineral content increased significantly whereas the fat content decreased. The sensory properties of the fortified chocolate were moderate compared to the control.

Ozer et al. (2022) developed functional chocolate using gamma-amino butyric acid (GABA) producer microencapsulated *Lacticaseibacillus rhamnosus* NRRL B-442 strain for patients having an anxiety disorder.

Chocolate can be a good carrier for delivering bioactive ingredients as it can mask unpleasant flavors. Bioactive compounds such as ω-3 fatty acids, phenolic extracts, vitamins, probiotics, and minerals have been added to chocolate formulations. Studies on sugar-free chocolates with added nutraceuticals have been carried out and these chocolates have high potential as next-generation functional foods (Faccineto-Beltran et al., 2021).

A high amount of waste is generated during the industrial processing of fruits, and it is rich in bioactive components (Khedkar & Zahid, 2022; Khedkar & Singh 2018). This waste can be utilized in the production of value-added products. Yeo & Thed (2022) made use of passion fruit with seeds and orange peel for the preparation of dark chocolate. This addition caused an increase in dietary fiber as well as the antioxidant activity of chocolate.

Table 3. Fortification of chocolate.

Chocolate variety	Fortification with	Functionality improvement	References
Dark chocolate	Mulberry and Sea buckthorn	Higher antioxidant activity with mulberry and higher bioactive compounds with sea buckthorn	Godočiková et al. (2017)
	Microencapsulated phytosterols (MP)	Dark chocolate fortified with 15% MP showed higher antioxidant activity	Tolve et al. (2018)
	Bacillus indicus HU36 and dietary fiber (maltodextrin and lemon fiber)	Improvement in sensory and textural properties in fortified chocolates with probiotic strain and dietary fiber	Erdem et al. (2014)
	Wheat germ	Increase in protein and mineral content with addition of 10% wheat germ	Al-Marazeeq (2018)
	Dates and palm	Date and palm syrup used as alternative to sucrose	Ibrahim et al. (2020)
	D-tagatose and inulin	Inulin and D-tagatose were used to replace sucrose in the ratio 25%-75% and 100%	Shourideh et al. (2012)
White & Milk chocolate	Lyophilized Grape and kale	Higher mineral and polyphenol content	Carvalho et al. (2018)
	Cinnamon nanoparticles	Antisolvent precipitation produced cinnamon nanoparticles (2%w/w) increased the antioxidant activity and polyphenol content of white and milk chocolates	Muhammad et al. (2018)
White chocolate	Encapsulated green tea extract	Improvement in total polyphenol content from 0.41 (mg GAE/kg) in white chocolate to 2.73 in fortified chocolate with 100mg/kg Encapsulated green tea extract	Lončarević et al. (2019)
	Encapsulated Blackberry juice	Improvement in melting time and hardness with 100g/kg fortification of white chocolate	Lončarević et al. (2018)
Milk and dark chocolate	Nanocapsules carotenoid of *Spirulina platensis*	Milk and dark chocolates were fortified with nanocapsules containing carotenoid of *Spirulina platensis* and the aroma, taste and texture of the products were compared to the control	Ekantari et al. (2019)

8 Future scope

The global chocolate market is increasing steadily at a Compound Annual Growth Rate (CAGR) of 3.7% during the period 2022-2030 (International Institute for Sustainable Development, 2019). The new trends in the chocolate industry are low sugar content chocolates, sustainable and ethical chocolate production with fair trade practices, ethical sourcing, and ecofriendly packaging, chocolates with innovative flavors and textures, personalization and customization along with the use of new technology e.g. 3D printing, Artificial Intelligence (AI) in development of flavours and precision tempering (Cascade Chocolate Company, 2023). There is increasing consciousness among consumers regarding the benefits of chocolates as a functional food. The functional food market is growing at a faster rate. Chocolate is generally savored for its feel-good factor, but its specific health benefits are now increasingly popular, and the functionality of the chocolates can be enhanced using specific functional ingredients. Although chocolate is rich in bioactive compounds, the presence of high sugar poses a hurdle in reaching the masses, especially the diabetic population. There is a scope for the development of sugar-free chocolates with added bioactive compounds for a target population.

9 Conclusion

In today's scenario where the increasing population and inadequate eating habits are posing a challenge to world food researchers to develop a food with increased functionality without affecting its quality characteristics, chocolate can act as a vehicle for targeted functional benefits. Chocolate contains a high amount of bioactive compounds due to the presence of cocoa butter and cocoa liquor and has medicinal benefits such as anti-hypertensive, mood enhancer, anticancer, antioxidant, antidiabetic, cardioprotective properties, etc. The benefits may be enhanced by the addition of fruits bioactive components for specific medicinal purposes.

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