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Review

# Functional chocolate: exploring advances in production and health benefits

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**Summary** Chocolate has been a part of human consumption for millennia, serving as a confection, medicine and aphrodisiac. Chocolate consumption is increasing worldwide, and independent of the age or social background. The substantial content of chocolate may provide consumers with antioxidant, anti-inflammatory, antimicrobial, antiallergenic, and anticarcinogenic benefits. Beyond such properties, diverse bioactive ingredients are utilised in the creation of functional chocolate products aiming at promoting health and meeting the modern consumers' demands and market orientations. These products are primarily focused on enhancing nutraceutical effects, such as antioxidant activity, protein content and prebiotic effects. Additionally, the use of A2 milk powder in chocolate production holds promising expectations towards enhancing the digestibility of the products. Due to the superior affinity of proteolytic enzymes, A2 milk can be digested more easily than A1 milk. In this way, with the addition of A2 milk to chocolate, it may become more easily digestible. The objectives of this review are a comprehensive understanding of the evolution of chocolate consumption, its health benefits, and the contemporary innovations in chocolate production. Additionally, the potential for developing easily digestible, functional chocolates made from A2 milk, which could rejuvenate functional chocolate production, is discussed in this article.

**Keywords** A2 beta-casein, A2 milk, bioactive components, cocoa, digestibility, functional chocolate, health.

## Introduction

Chocolate consumption has increased extremely in the world in the 21st century. The allure of this food is mostly due to its ability to induce pleasant sensations and uplifting feelings. From a nutritional and pharmacological perspective, chocolate and cocoa have been connected to the prevention and treatment of various diseases, especially obesity, owing to their antioxidant, anti-inflammatory, cardiovascular and metabolic effects (Loffredo *et al.*, 2016; Godočiková *et al.*, 2017). With the growing recognition of the connection between nutritious eating and wellness, the food industry has started producing functional foods, a relatively new category that offers health advantages beyond basic nutrition (Büker *et al.*, 2021). The main purpose of the food industry is to increase the protein content, the antioxidant activity and the prebiotic and probiotic effects of the products (Hossain *et al.*, 2021a; Jovanović *et al.*, 2022). In this regard, chocolate attracts an enormous interest in the functional food sector due to its high level of nutritional content, health benefits and popularity (Tolve *et al.*, 2018).

The deep-rooted history of chocolate began with the cultivation of the *Theobroma*, known as the cocoa tree, by the Maya people in South America (Muhammad *et al.*, 2019; Monteiro *et al.*, 2023). For the Maya, the beverage consisting of cocoa mixed with hot water and sweetened by adding spices is described as chocolate (Lippi, 2015). Among the Aztecs, cocoa and chocolate were described as the 'Food of the Gods'

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and were consumed as a beverage for ceremonial purposes. Additionally, they used chocolate as a therapeutic drug because they believed it had medicinal properties (Monteiro *et al.*, 2023). Cocoa, brought to Europe with an understanding of its commercial value in the 16th century, has been described as 'brown gold, and, consequently, the consumption of chocolate prepared from cocoa rapidly became widespread for different purposes such as treatment of some diseases (Lippi, 2015)'.

The composition of cocoa beans may differ as a result of genetic and environmental variables (Żyżelewicz *et al.*, 2021). According to different cocoa samples, they are known to contain 0.9%–8.1% of moisture, 0.9%–7.3% of ash and 3.1%–19.4% of fibre (Aremu *et al.*, 1995; Lippi, 2015; Djikeng *et al.*, 2018; de Melo *et al.*, 2020; Grassia *et al.*, 2021). Cocoa beans contain 8%–54% carbohydrates, comprising monosaccharides, disaccharides, oligosaccharides, sugar alcohols, starch and dietary fibres (Liendo *et al.*, 1997; de Melo *et al.*, 2020). Due to its high carbohydrate content, it is well recognised to have bioactive characteristics (Barišić *et al.*, 2019). The composition of carbohydrates is significant for the development of taste in the manufacture of chocolate (Jean-Marie *et al.*, 2022). Proteins constitute 7.9%–22.5% of the dry weight of cocoa beans (Agus *et al.*, 2018; de Melo *et al.*, 2020). They contain mainly albumin and globulin proteins (Rawel *et al.*, 2019; Jean-Marie *et al.*, 2022) containing high levels of lysine, glutamic acid, aspartic acid, arginine and leucine amino acids (Barišić *et al.*, 2019; Jean-Marie *et al.*, 2022). The determination of protein-based flavourings may be crucial for flavour development in chocolate manufacturing (Rawel *et al.*, 2019). In addition, cocoa beans contain 33%–62% cocoa butter, almost all of which are composed of triacylglycerols (TAG's) (de Melo *et al.*, 2020). TAG's contain varying amounts of palmitic, stearic and oleic acids, ranging from 24% to 38%, and low amounts of linoleic acid (Barišić *et al.*, 2019; Febrianto *et al.*, 2022). The composition of cocoa butter, extractability, melting point and crystallisation properties are significant criteria for chocolate production (Barišić *et al.*, 2019). These factors significantly influence the texture, flavour and overall quality of chocolate products, highlighting the importance of understanding TAG composition and cocoa butter characteristics in the chocolate-producing process.

There are approximately 30–50 olive-sized seeds in the shell of the cocoa fruit, and these beans are referred to as cocoa, which is pivotal as the primary ingredients in chocolate (Jean-Marie *et al.*, 2022). The transformation of cocoa into chocolate occurs as a result of a series of processes that begin with the cocoa bean (Muhammad *et al.*, 2020; Bölek *et al.*, 2022). These processes can be listed as the fermentation of the cocoa bean, drying, roasting and then, grinding the bean to obtain cocoa liquor, followed by the production of various chocolates by adding other ingredients (Żyżelewicz *et al.*, 2021; Angor *et al.*, 2023). The components in cocoa vary greatly depending on the bean variety and origin as well as the agricultural and processing processes; this process may lead to alterations in the composition of chocolate (Barišić *et al.*, 2019; Rawel *et al.*, 2019). The main commercial categories of chocolate are milk, dark and white chocolate, which are manufactured using different proportions of ingredient in chocolate production (Rawel *et al.*, 2019; Jovanović *et al.*, 2022). Moreover, other seeds may be found to produce chocolate-like products using similar processes as cocoa, for example, the *cupuacu* seeds (Souza *et al.*, 2020).

Chocolate has been enhanced with a variety of useful ingredients since it is not only seen as a sweet delight but also as a product that promotes a healthy way of living. People are now gravitating towards nutrient-dense, naturally occurring resources due to the quickly growing trend of healthy eating and conscientious consumerism (Sik *et al.*, 2021; Shahbazi *et al.*, 2022). During the COVID-19 epidemic, consumer interest in functional foods has increased significantly. In light of this, the food industry has started to develop novel foods that can be enhanced with a variety of bioactive substances in order to promote healthy living and well-being, as well as prevent and treat degenerative and chronic illnesses (Sik *et al.*, 2021; Darwish *et al.*, 2023). In summary, the chocolate industry is always changing to meet the needs of consumers and the latest trends in healthy living, which results in a constant stream of new, useful products being introduced. This transformational process repositions chocolate as a smart option for people who are health-conscious, going beyond the conventional view of it as a delicious indulgence. The advantages of chocolate as well as the investigations and analyses of the present functional chocolates are outlined in this review. Furthermore, it highlights how A2 milk can be used in this situation as a creative way to improve the functional qualities of chocolate.

## Chocolate production and its variations

Chocolate production consists of basic steps such as the harvesting and processing of cocoa beans, followed by the transformation of the resulting product into various types of chocolate. Cocoa beans, the raw material for chocolate production, are known as the most significant source of phenolic compounds. Considering the importance of the nutritional and health values of the products obtained after production, the conditions and parameters of the methods and technological processes used in chocolate production are of great importance (Kowalski *et al.*, 2023).

 

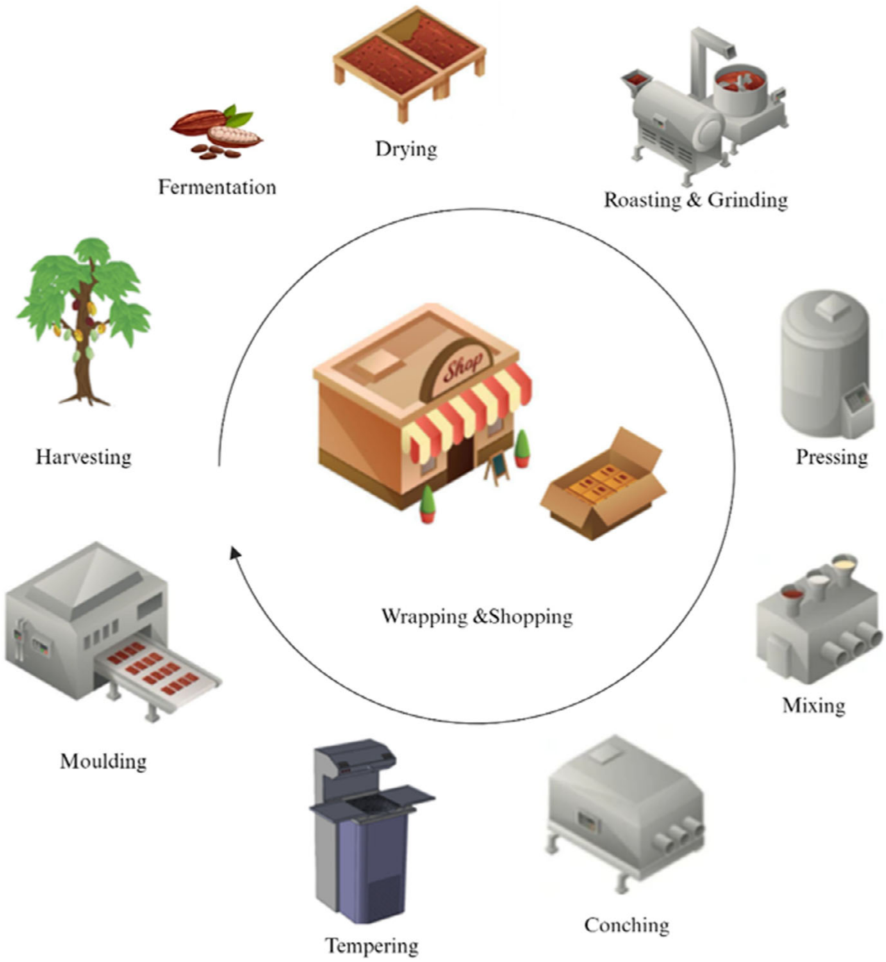


**Figure 1** Schematic representation of the basic chocolate production process.

The fermentation process, which is the next step after harvesting cocoa beans for chocolate production, is known as one of the main factors that affect flavour formation and bitterness removal, as well as the chemical and bioactive composition of cocoa beans. In a study, it has been shown that the total phenolic content and antioxidant level of cocoa beans increase in the later days of the fermentation process (Tee *et al*., 2022). Following the fermentation process, various methods such as sun drying, air drying, mechanical drying, microwave drying and freeze-drying are used in the drying process to prevent mould formation, stabilise aroma compounds and reduce moisture content in the beans (Fig. 1). As the moisture content decreases, the water activity of the food also decreases. Temperature and drying time are key parameters directly affecting the quality of cocoa beans. Additionally, it is important to prefer any drying method that minimises the exposure of the food to ultraviolet light, oxidation and heat to preserve the bioactive components necessary for high product quality (Dzelagha *et al*., 2020). After the drying process, the beans move on to the roasting process to fully develop their flavours through caramelization and enhance their taste. This process affects the sensory parameters of the final product, chocolate. As a result of applying high temperatures during roasting, cocoa beans are sterilised, but a decrease in total phenolic content and total flavonoid content is observed after this process, which takes place for 5–120 min in the range of 120–150 °C (Kowalski *et al*., 2023). Following the roasting process, cocoa beans are ground into a fine paste called cocoa mass or cocoa liquor using various types of equipment such as ball mills, conche machines or roller refiners (Bolenz & Langer, 2020).

After the production of cocoa mass, it can be further processed by pressing to produce cocoa powder and cocoa butter. Cocoa solids are used to make cocoa powder, while cocoa butter is used to add fat content to chocolate products and create a smooth texture. A study has shown that the pressing time affects the brightness of cocoa powder and the fat content, but not the temperature (Anoraga *et al*., 2019). Once cocoa powder and cocoa butter are produced through grinding and pressing, the chocolate-making process can begin. Chocolate liquor is refined in a machine called a conche, which mixes and aerates the chocolate to develop its texture and flavour (Toker *et al*., 2019). After refining the chocolate mixture, it undergoes a tempering stage based on heating and cooling to specific temperatures to ensure it has the correct crystal type and texture. This process, which gives chocolate a shiny appearance, also helps prevent the formation of air bubbles. Tempered chocolate is then moulded into bars, bonbons, or various shapes and packaged as chocolate products (Quiñones-Muñoz *et al*., 2011).

Differences in ready-to-consume chocolate varieties are diversified based on their flavour profiles and utilisation in culinary applications, leading to each chocolate type acquiring distinct characteristics of its own. One type of chocolate, bitter chocolate, is made from cocoa solids, cocoa butter and sugar, with minimal or no milk solids added. It boasts a rich, intense flavour profile and higher cocoa content (Nouri *et al*., 2019). Compared to bitter chocolate, milk chocolate presents a creamier texture and a sweeter taste, comprising cocoa solids, cocoa butter, sugar and milk powder or condensed milk for incorporation (Liang & Hartel, 2004). White chocolate, on the other hand, is made from cocoa butter, sugar, and milk solids but does not contain cocoa solids. Compared to dark or milk chocolate, it exhibits a milder and creamier taste profile (Vercet, 2003). Ruby chocolate, characterised by its natural pink hue, is a newer variety made from cocoa beans. It features a fruity, slightly tangy flavour profile (Tuenter *et al*., 2021). Filled chocolates are chocolates containing various fillings such as caramel, nuts, fruits or cream, thereby offering a variety of textures and flavours. The occurrence of bloom in filled chocolates is contingent upon the interplay between liquid oil and solid fat (De Clercq *et al*., 2014). Each type of chocolate has its unique characteristics, flavour profile and uses in culinary applications.

The recommended daily consumption of chocolate and its derivatives varies depending on factors such as age, overall health status and specific dietary requirements. Generally, consuming moderate amounts of dark chocolate with high cocoa content (at least 70% cocoa solids) has been associated with potential health benefits due to its rich antioxidant content, particularly flavonoids. These benefits may include improved cardiovascular health, cognitive function and mood regulation (Montagna *et al*., 2019; Lamport *et al*., 2020). For adults, consuming approximately 20–30 g (about 1–2 small squares) of dark chocolate per day may be considered as part of a balanced diet. However, it is imperative to be mindful of portion sizes and overall calorie intake, as chocolate is calorically dense, and excessive consumption may contribute to weight gain and other health issues (Buitrago-Lopez *et al*., 2011; Nehlig, 2013; West *et al*., 2014). In contrast, milk chocolate and white chocolate contain higher amounts of sugar and saturated fat and lower levels of cocoa solids compared to dark chocolate. Therefore, their consumption should be limited (Wollgast & Anklam, 2000). In summary, incorporating moderate amounts of dark chocolate into a balanced diet rich in fruits, vegetables, whole grains and lean proteins can contribute to overall health and well-being. However, maintaining moderation and balance is crucial, and individuals with specific health concerns or dietary restrictions should seek personalised recommendations from healthcare professionals or registered dietitians.

## Health benefits of chocolate

Polyphenols, a source of nutritional and therapeutic value, make up to 10% of the dry weight of cocoa beans (Komes *et al*., 2013; Carvalho *et al*., 2018). The polyphenols are characterised as free radical scavengers, demonstrating antioxidant and anti-inflammatory effects that contribute to the improvement of immune function (Nambiar *et al*., 2018; Zohreh, 2020). Researches indicate that the increase in plasma polyphenols after chocolate consumption leads to improved plasma antioxidant capacity and a reduction in plasma lipid oxidation (Wang *et al*., 2000; Di Mattia *et al*., 2017; Leyva-Soto *et al*., 2018). Furthermore, it has been established that the consumption of polyphenol-rich cocoa and chocolate under conditions requiring high physical exertion enhances the antioxidant status and the oxidative stress response (Table 1) (Faria *et al*., 2011; Gadhiya *et al*., 2018). It is believed to affect the oxidative and inflammatory states, which may be connected to chocolate's bioactive composition's capacity to modify the microbiome (Fraga *et al*., 2005; Gadhiya *et al*., 2018).

The non-flavonoids and flavonoids found in cocoa include procyanidins, epicatechins, catechins and phenolic acid (Laličić-Petronijević *et al*., 2017; Hossain *et al*., 2022a). It is known that cocoa flavonoids cause a bitter taste, notably in chocolate types containing high cocoa (Febrianto *et al*., 2022). In healthy adults, the consumption of flavonoid-rich dark chocolate improves endothelial and platelet functions, which may be associated with higher plasma epicatechin concentrations (Table 1) (Ostertag *et al*., 2013; West *et al*., 2014; Loffredo *et al*., 2018). In addition, chocolate polyphenols have some protective effects on the cardiovascular system (Nambiar *et al*., 2018; Pereira *et al*., 2019). The consumption of foods high in

 

**Table 1** Health impact related to consumption of chocolate

| Health impact | Chocolate type | Outcome | References |
|---|---|---|---|
| Cardiovascular diseases and chronic diseases related | Dark chocolate | • Exhibit a reduction in risk of essential hypertension | Yang *et al.* (2024) |
| | | • Exhibit a reduction in plasma levels of tumour necrosis factor-α | Ribeiro *et al.* (2023) |
| | Sugar-free dark chocolate | • Exhibit an improvement in blood glucose level | Oliveira *et al.* (2022) |
| | Milk and dark chocolate | • Exhibit an improvement in endothelial functions | Dural *et al.* (2022) |
| | Dark chocolate | • Exhibit a reduction in blood pressure | Matsumoto *et al.* (2020) |
| | Polyphenol-rich dark chocolate | • Exhibit a reduction in postprandial plasma glucose elevations | Kawakami *et al.* (2021) |
| | Cocoa-rich chocolate | • Exhibit improvement in vascular function | Pereira *et al.* (2019) |
| | Flavanol-enriched dark chocolate | • Exhibit a reduction in genotoxic stress effect | Leyva-Soto *et al.* (2018) |
| | Dark chocolate | • Exhibit an improvement in endothelial functions | Loffredo *et al.* (2018) |
| | † | • Exhibit a reduction in the risk of type 2 diabetes mellitus | Mathew *et al.* (2017) |
| | Dark chocolate | • Exhibit an improvement in lipid profile | Lee *et al.* (2017) |
| | | • -Exhibit an improvement in lipid profile<br>• Exhibit an improvement in high-density lipoprotein cholesterol | Souza *et al.* (2017) |
| | | • Exhibit an improvement in high-density lipoprotein cholesterol<br>• Exhibit an improvement in arterial elasticity | da Teixeira *et al.* (2017) |
| | Epicatechin-rich dark chocolate | • Exhibit an improvement in exercise capacity<br>• Exhibit an improvement in high-density lipoprotein cholesterol | Taub *et al.* (2016) |
| | Dark chocolate | • Exhibit an antioxidant activity due to $NOX_2$ down-regulation | Loffredo *et al.* (2016) |
| | | • Exhibit an improvement in vascular function | Esser *et al.* (2014) |
| | | • Exhibit an improvement in endothelial function and arterial stiffness | West *et al.* (2014) |
| | | • Exhibit reduction risk of heart failure | Petrone *et al.* (2014) |
| | Flavanol-enriched dark chocolate | • Exhibit an improvement in platelet function | Ostertag *et al.* (2013) |
| | Dark chocolate | • Exhibit an improvement in high-density lipoprotein cholesterol<br>• Exhibit reduction in abdomen circumference | Di Renzo *et al.* (2013) |
| | | • No significant difference in the short-term consumption of dark chocolate on the blood pressure | Chan *et al.* (2012) |
| | Cocoa product | • Exhibit a reduction in the blood cholesterol | Jia *et al.* (2010) |
| | Dark chocolate | • Exhibit an increase in the plasma antioxidant capacity<br>• Exhibit an improvement in the oxidative stress markers | Spadafranca *et al.* (2010) |

**Table 1** (*Continued*)

| Health impact | Chocolate type | Outcome | References |
|---|---|---|---|
| | Flavonoid-rich dark chocolate | • Exhibit an improvement in endothelial function | Shiina *et al.* (2009) |
| | Dark chocolate | • Exhibit a reduction of serum C-reactive protein levels<br>• Exhibit a reduction of inflammation | di Giuseppe *et al.* (2008) |
| | High-polyphenol dark chocolate | • Exhibit a reduction in blood pressure<br>• Exhibit an improvement in the insulin sensitivity | Grassi *et al.* (2008) |
| | Polyphenol-rich dark chocolate | • Exhibit a reduction in blood pressure<br>• Exhibit an improvement in the insulin sensitivity | Grassi *et al.* (2005) |
| | Flavanol-rich milk chocolate | • Exhibit an improvement in the oxidative stress markers | Fraga *et al.* (2005) |
| | Procyanidin-rich chocolate | • Exhibit an increase in the plasma antioxidant capacity<br>• Exhibit a decrease in plasma lipid oxidation | Wang *et al.* (2000) |
| Performance related | White, milk and dark chocolate | • Exhibit a reduction in induced pain intensity | Hajati *et al.* (2023) |
| | Dark chocolate | • Modulate obesity-induced inflammation | Eskandari *et al.* (2020) |
| | | • Exhibit a reduction in oxidative stress markers<br>• Exhibit a reduction in markers of muscle damage | Cavarretta *et al.* (2018) |
| | | • Modulate muscle carbohydrate partitioning<br>• No significant difference in cycling time-trial | Stellingwerff *et al.* (2014) |
| | | • Exhibit an increase in antioxidant capacity | Davison *et al.* (2012) |
| | | • Exhibit a reduction in oxidative stress markers<br>• Maintenance mobilisation of plasma-free fatty acids | Allgrove *et al.* (2011) |
| | | • Modulate metabolic changes | Djarova *et al.* (2009) |
| Psycho-pharmacological activities related | Polyphenol-rich dark chocolate | • Exhibit improvement in cognitive performance and concentration during continuous and demanding tasks | Sasaki *et al.* (2024) |
| | The combination of chocolate with fish oil and probiotics | • Exhibit improvement in spatial memory and learning | Faccinetto-Beltrán *et al.* (2022) |
| | Dark chocolate | • Exhibit a reduction in fatigue<br>• Exhibit improvement in cognitive function | Nemoto *et al.* (2022) |
| | | • Exhibit improvement in memory, memory consolidation and locomotor activity | Kalantarzadeh *et al.* (2020) |
| | | • Exhibit improvement in cognitive performance<br>• Exhibit an increase in nerve growth factor in plasma | Sumiyoshi *et al.* (2019) |
| | | • Exhibit a reduction in absolute power of the Delta and Theta bands, and improvement in absolute power of the Alpha and Beta bands in most brain regions, especially in the temporo-occipital leads | Santiago-Rodríguez *et al.* (2018) |

 

**Table 1** (*Continued*)

| Health impact | Chocolate type | Outcome | References |
|---|---|---|---|
| | Flavanol-rich chocolate | • Exhibit improvement in working memory following sleep deprivation | Grassi *et al.* (2016) |
| Gut health related | Dark chocolate | • Modulate exercise-induced intestinal permeability | Nocella *et al.* (2023) |
| | | • Exhibit improvement in gut microbial metabolic activity<br>• Exhibit improvement in high-density lipoprotein cholesterol | Martin *et al.* (2012) |
| | | • Modulate energy metabolism and intestinal microbial activities | Martin *et al.* (2009) |
| Dental health | Milk chocolate | • Exhibit an increase in the level of gingival inflammation | Fahmi *et al.* (2023) |
| | Probiotic chocolates | • Exhibit a reduction in acidogenic properties | Janani *et al.* (2019) |
| | White, milk, dark and caramel chocolate | • Exhibit alterations in dental plaque pH | Vasanthakumar *et al.* (2016) |

†Not identified.

flavonoids is inversely related to the risk of cardiovascular disease (Shiina *et al*., 2009; Esser *et al*., 2014; Magrone *et al*., 2017). In the study conducted by Yang *et al*. (2024), the effect of dark chocolate on various cardiovascular risk factors was investigated. According to the results of the study, it was revealed that dark chocolate may have potential benefits for the cardiovascular system, including improving endothelial function, coronary artery vasodilation, preventing platelet adhesion and reducing blood lipid levels (Yang *et al*., 2024). Another study conducted by Ribeiro *et al*. (2023) aimed to evaluate the effects of dark chocolate consumption containing 70% cocoa on inflammation and oxidative stress markers in patients with chronic kidney disease on haemodialysis. According to this study, while chocolate consumption caused a decrease in plasma tumour necrosis factor-α levels of participants, no clear effect was determined on oxidative stress markers.

In a study conducted by Allgrove *et al*. (2011), the effects of regular consumption of dark chocolate before extensive long-term exercise on plasma metabolites, hormones and oxidative stress markers were investigated. The research results suggest that consuming dark chocolate may help reduce oxidative stress in the body during physical activity (Allgrove *et al*., 2011). Furthermore, it has been demonstrated that dark chocolate consumption can contribute to increased mobilisation of plasma-free fatty acids, which are significant for energy production during exercise (Allgrove *et al*., 2011). Despite these findings, the consumption of dark chocolate did not significantly affect the plasma concentrations of the measured hormones or cytokines (Allgrove *et al*., 2011). Elite football athletes face high oxidative stress and muscle injuries due to intense physical exercise (Djarova *et al*., 2009; Cavarretta *et al*., 2018). Consistent with other studies on athletes (Davison *et al*., 2012; Hajati *et al*., 2023), according to a study conducted by Cavarretta *et al*. (2018), regular supplementation with dark chocolate appeared to enhance antioxidant capacity and decrease markers of muscle damage. In another study involving healthy volunteers, the effects of consuming dark chocolate and white chocolate on plasma epicatechin levels, DNA resistance to oxidative stress, and total antioxidant activity were compared (Spadafranca *et al*., 2010). The results indicate that while consumption of dark chocolate improves DNA resistance against oxidative stress and enhances antioxidant activity, no significant effects were observed with white chocolate consumption (Spadafranca *et al*., 2010). Additionally, the consumption of flavonoid-rich chocolate has a significant impact on diseases including diabetes, stroke and heart diseases (Petrone *et al*., 2014; Lee *et al*., 2017; Maskarinec *et al*., 2019).

Several studies have examined the relationship between type 2 diabetes (T2D) and chocolate consumption (Mathew *et al*., 2017; Oliveira *et al*., 2022). According to a study, findings indicate that sugar-free dark chocolate sweetened with stevia, erythritol and inulin leads to a decrease in postprandial blood sugar levels in individuals with diabetes and that sugar-free chocolates can be used as a potential benefit for glucose control in these individuals (Oliveira *et al*., 2022). Another study published in 2022 revealed that chocolate consumption acutely reduces N-terminal pro-brain natriuretic peptide values in heart failure (Dural *et al.*, 2022). It has also been determined that the consumption of dark chocolate improves endothelial functions by increasing dilation values (Dural *et al.*, 2022).

Chocolate is considered to have a beneficial impact on lipid metabolism, potentially increasing levels of high-density lipoprotein (HDL) cholesterol and decreasing levels of low-density lipoprotein (LDL) cholesterol (Table 1) (Jia *et al.*, 2010; Di Renzo *et al.*, 2013; Vargas-rechia *et al.*, 2015; Taub *et al.*, 2016; da Teixeira *et al.*, 2017; Souza *et al.*, 2017). In a study conducted by Taub *et al.* (2016), the consumption of dark chocolate was found to be associated with an increase in HDL levels and a decrease in triglyceride levels among sedentary subjects (Taub *et al.*, 2016). Additionally, the research demonstrated a decrease in oxidative stress indicators in skeletal muscle, indicating an improvement in exercise efficiency and general well-being (Taub *et al.*, 2016). A recent study suggests that dark chocolate supplementation, combined with jump rope exercise, may positively affect inflammatory markers, adipokines and body composition in obese adolescent boys (Eskandari *et al.*, 2020).

Some chocolate varieties have been linked to lower blood pressure and increased insulin sensitivity in healthy people (Grassi *et al.*, 2005, 2008; Matsumoto *et al.*, 2020; Kawakami *et al.*, 2021). According to a randomised crossover study involving 20 middle-aged Japanese volunteers, the consumption of dark chocolate was associated with blood pressure-lowering effects (Matsumoto *et al.*, 2020). Another study aimed to evaluate short-term changes in children's blood pressure by providing dark chocolate to schools. The results of the study indicated that there were no significant differences in the short-term blood pressure levels of the children (Chan *et al.*, 2012).

The study by di Giuseppe *et al.* (2008) aimed to investigate the relationship between consuming dark chocolate and serum C-reactive protein (CRP) levels (di Giuseppe *et al.*, 2008). C-reactive protein serves as a marker of inflammation in the body, and elevated levels are associated with an increased risk of chronic diseases such as cardiovascular disease (di Giuseppe *et al.*, 2008). According to the study's findings, an inverse relationship was observed between dark chocolate consumption and CRP concentrations (di Giuseppe *et al.*, 2008), suggesting that regular consumption of dark chocolate may reduce inflammation (di Giuseppe *et al.*, 2008). The bioactive compounds in chocolate may help prevent and treat certain types of cancer (Lippi, 2015; Saadatdoust *et al.*, 2015). With a potent antiproliferative function, these bioactive compounds may inhibit cancer cell growth and tumour development (Saadatdoust *et al.*, 2015).

The intense physical activity performed by football athletes can cause increased intestinal permeability, allowing harmful substances such as lipopolysaccharides (LPS) to enter the bloodstream and cause damage (Nocella *et al.*, 2023). In a study conducted by Nocella *et al.*, the effect of consuming dark chocolate containing 85% cocoa on the intestinal permeability biomarkers of elite football athletes was examined (Nocella *et al.*, 2023). According to the results of the study, it was revealed that the consumption of dark chocolate may help modulate exercise-induced intestinal permeability among elite football athletes (Nocella *et al.*, 2023). In a study conducted by Martin *et al.*, the effect of dark chocolate consumption on energy metabolism, intestinal microbiota, and stress-related metabolism was investigated (Martin *et al.*, 2009). According to the results of the study, it was revealed that consumption of dark chocolate had beneficial effects on stress-related alterations in energy metabolism and intestinal microbial activities (Martin *et al.*, 2009).

Cocoa products contain theobromine and caffeine, two significant methylxanthines/alkaloids with remarkable health benefits (Table 1) (Karača *et al.*, 2020; Sik *et al.*, 2021; Kongor *et al.*, 2024). Their psycho-pharmacological properties indicate that they can influence the mood that occurs with the consumption of cocoa and chocolate (Yeo & Thed, 2022). On the other hand, chocolate has several other psycho-pharmacological activities that increase cognitive performance, including preventing hearing loss, increasing contrast sensitivity, improving visual acuity and decreasing mental tiredness (Santiago-Rodríguez *et al.*, 2018; Sumiyoshi *et al.*, 2019). The study conducted by Sasaki *et al.*, aimed to determine whether consuming chocolate with high polyphenol content helps maintain cognitive performance during challenging tasks (Sasaki *et al.*, 2024). According to the results of the study, it was revealed that the consumption of chocolate containing high polyphenols protected cognitive performance and improved concentration (Sasaki *et al.*, 2024). A recent study conducted by Nemoto *et al.* aimed to determine whether the consumption of dark chocolate could reduce fatigue and subsequently improve cognitive function and brain structure (Nemoto *et al.*, 2022). The results showed that the consumption of dark chocolate led to a reduction in both mental and physical fatigue in participants (Nemoto *et al.*, 2022). It has been demonstrated that some chocolate' polyphenols reach the brain by crossing the blood–brain barrier and may accumulate in the brain, thus having the possibility of affecting the central nervous system (Faria *et al.*, 2011). The study conducted by Kalantarzadeh et al. aimed to investigate the effects of different dark chocolate diets on memory functions and brain corticosterone levels in rats under chronic stress (Kalantarzadeh *et al*., 2020). Various dark chocolate diets showed different effects on brain functions under chronic stress (Kalantarzadeh *et al*., 2020). According to the results of the study, while restricted and compulsory dark chocolate diets appeared to positively affect memory under stress, memory consolidation, locomotor activity, serum and hippocampal corticosterone levels improved only in the compulsory dark chocolate diet (Kalantarzadeh *et al*., 2020). The raw material of chocolate, cocoa, has the potential to be used as a preventive agent for some neurodegenerative diseases, including Alzheimer's disease (Faria *et al*., 2011; Cerit *et al*., 2016).

Additionally, cocoa is rich in magnesium, selenium, zinc, iron elements and vitamins providing individuals with essential daily vitamins and minerals through chocolate consumption (Febrianto *et al*., 2022). Other beneficial effects of chocolate consumption can include a suppression of appetite and the maintenance of circadian fitness under conditions of shift work or jet-lag (Lippi, 2015; Succi *et al*., 2017).

In addition to the beneficial health effects associated with incorporating chocolate into the diet, there are several health concerns linked to excessive chocolate consumption (Ren *et al*., 2019; Sanlier *et al*., 2022). These include weight gain, dental issues and diabetes (Greenberg & Buijsse, 2013; Vasanthakumar *et al*., 2016; Sanlier *et al*., 2022; Fahmi *et al*., 2023). Such problems typically arise from the overconsumption of chocolates high in sugar and fat content (Ren *et al*., 2019). A recent study conducted by Fahmi et al., involving a total of 120 children aged 6–12, aimed to investigate the relationship between milk chocolate consumption habits, chronotype, and gingivitis in children during the mixed dentition period (Fahmi *et al*., 2023). The findings revealed that both milk chocolate consumption habits and chronotype could potentially influence the development or severity of gingivitis in children during the mixed dentition period (Fahmi *et al*., 2023). In another study examining the effect of chocolate on oral health in children, it was determined that probiotic chocolates were less acidogenic than other chocolates (Janani *et al*., 2019). These findings suggest that chocolate can be used as a probiotic carrier and promote oral health (Janani *et al*., 2019). This study offers a new approach to the development of chocolate formulations that can contribute to oral health for children (Janani *et al*., 2019).

In the context of diabetes, body weight is positively correlated with T2D (Oliveira *et al*., 2022). At this point, it is crucial to consider consuming chocolates with high sugar and fat content (Oliveira *et al*., 2022).

Furthermore, consuming large quantities of chocolate can lead to insomnia and an increased heart rate due to its caffeine and theobromine content (Latif & Majeed, 2020; Hernández-González *et al*., 2021). A recent study showed that the timing of chocolate intake in the morning or evening/night affected sleep patterns and temperature rhythms (Hernández-González *et al*., 2021). However, another study aimed to investigate the effects of consuming chocolate rich in flavanols on cognitive abilities and cardiovascular parameters following sleep deprivation (Grassi *et al*., 2016). According to the results of the study, the consumption of flavanol-rich chocolate may enhance cognitive performance, particularly working memory, after sleep deprivation (Grassi *et al*., 2016). It is also hypothesized that sleep deprivation may mitigate the negative effects on cardiovascular parameters (Grassi *et al*., 2016).

On the other hand, in a study conducted by Latif & Majeed (2020), the relationship between chocolate consumption frequency and heart rate variability in young women was investigated. The study divided participants into three groups: 'No regular chocolate consumption', '2–4 servings/week' and '5 or more servings/week' (Latif & Majeed, 2020). However, no significant difference in heart rate variability parameters was observed among these groups (Latif & Majeed, 2020).

Additionally, some individuals may experience migraines or allergic reactions as a result of excessive chocolate intake (Khuda & Williams, 2015; Aladdin *et al*., 2022). Consequently, the consumption of dark chocolate with a higher cocoa content is considered a favourable approach to health, owing to its antioxidant properties and reduced sugar content.

## Current functional chocolate products

Today, the rapidly increasing trend of healthy eating and conscious consumption has driven people towards nutritious, natural and healthy resources (Sik *et al*., 2021; Shahbazi *et al*., 2022). Consumer's interest in functional foods has particularly accelerated during the COVID-19 pandemic. Under this framework, the food industry has begun to develop new foods that can be fortified with various bioactive ingredients to prevent and treat chronic and degenerative diseases as well as to support healthy living and well-being (Sik *et al*., 2021; Darwish *et al*., 2023). These foods are known as functional foods and they may be manufactured by the addition of bioactive compounds to food compositions (Fig. 2) (Gültekin-Özgüven *et al*., 2016). Additionally, the varieties of chocolate – including white, dark and milk chocolate – exhibit varying effects on the production process of functional chocolate (Kavitha *et al*., 2016; Sik *et al*., 2021). The selection of chocolate variety represents an important aspect that impacts how functional advantages are delivered in the product.

It is crucial to pinpoint bioactive elements that ensure health advantages, whether by improving

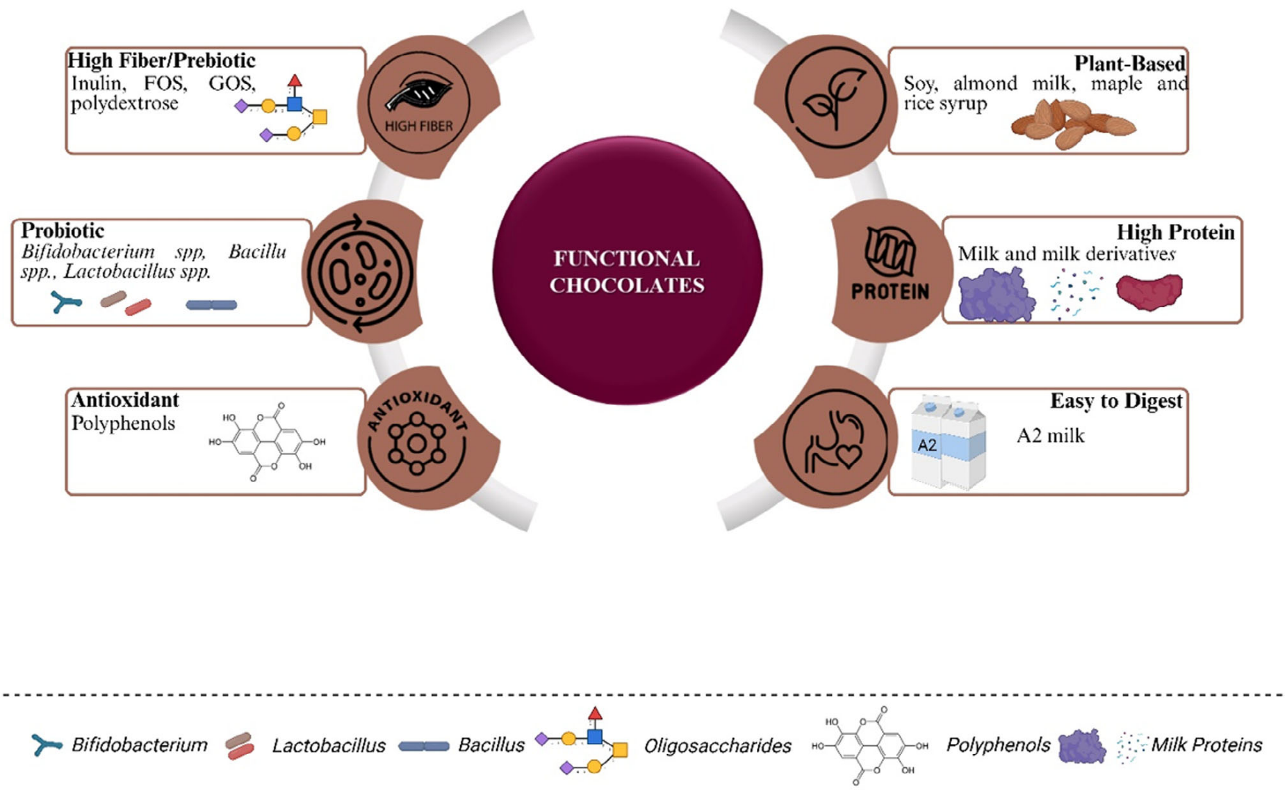


**Figure 2** Different types of functional chocolates.

essential nutrition or triggering known healthy effects when crafting functional foods (Table 2) (Sik *et al.*, 2021). Various bioactive substances can be employed for this purpose (Erdem *et al.*, 2014). The principal components that can be utilised as food replacements or enrichment agents include soluble and insoluble fibres, prebiotics, probiotics, postbiotics, paraprobiotics, psychobiotics, parapsychobiotics, synbiotics, minerals, vitamins, herbal extracts and other phytochemicals (Duman *et al.*, 2021; Zarić *et al.*, 2023). These bioactive substances may include essential fatty acids. Fatty acids, carotenoids, tocopherols, polyphenols, phytosterols and oil-soluble vitamins are only a few examples of the hydrophobic nature of most bioactive substances (Muhammad *et al.*, 2021). An essential component of bioactive substances, omega-3 fatty acids, are a subclass of polyunsaturated fatty acids (Gómez-Fernández *et al.*, 2021; Faccinetto-Beltrán *et al.*, 2022). Several medical diseases, such as coronary heart disease, blood platelet aggregation, high cholesterol levels and many carcinomas, have been shown to be helped by eicosapentaenoic acid and docosahexaenoic acid in both prevention and treatment (Faccinetto-Beltrán *et al.*, 2022).

### High-fibre/Prebiotic-based chocolates

Dietary fibres have gained popularity as useful food additives due to their strong capacity to absorb water, low digestible energy content and claim that they aid the digestive system, leading to their inclusion in food compositions (Bolenz *et al.*, 2006; Lončarević *et al.*, 2021). These health advantages underscore the importance of dietary fibre in terms of nutrition and have encouraged consumers to choose foods with high content in fibre (Lončarević *et al.*, 2021). Various studies have established the value of dietary fibre, with cereal bran, especially wheat bran, being the most popular source of fibrous fibres added to functional food products (Małecki *et al.*, 2020; Lončarević *et al.*, 2021). Numerous research on the addition of dietary fibre to functional food items, including baked goods, drinks, confectionery, dairy, frozen dairy, meat, pasta and soups, have been published (Bolenz *et al.*, 2006; Rezende *et al.*, 2015; Bouaziz *et al.*, 2017). Thus, prebiotics and probiotics can be seen as a promising approach to enhancing the nutritional profile of chocolate and expanding the functional food market (Konar *et al.*, 2014; Silva *et al.*, 2017).

 

**Table 2** Current functional chocolate studies

| Functional property | Content | Transmission strategy or delivery system | Chocolate variety | References |
|---|---|---|---|---|
| Probiotic | *Streptococcus thermophilus* | Spray-dried | Dark and milk chocolate | Nebesny *et al.* (2005) |
| | *Lacticaseibacillus casei*<br>*Lacticaseibacillus paracasei/casei* | Freeze-dried | Dark chocolate | Nebesny *et al.* (2007) |
| | *Lacticaseibacillus casei* | | Milk chocolate | Żyżelewicz *et al.* (2010) |
| | *Lactobacillus helveticus*<br>*Bifidobacterium longum* | Microencapsulated | | Possemiers *et al.* (2010) |
| | *Lactiplantibacillus plantarum* | – | Dark chocolate | Foong *et al.* (2013) |
| | *Lactobacillus acidophilus*<br>*Bifidobacterium lactis* | Freeze-dried | Milk and dark chocolates | Laličić-Petronijević *et al.* (2015) |
| | *Lactobacillus acidophilus*<br>*Lacticaseibacillus casei* | | Milk chocolate | Rouhi *et al.* (2015) |
| | *Lactobacillus brevis* subsp. *coagulans*<br>*Lactobacillus brevis* | | Chocolate | Yonejima *et al.* (2015) |
| | *Lactobacillus acidophilus*<br>*Lacticaseibacillus rhamnosus*<br>*Bifidobacterium lactis* | | Milk chocolate | Zarić *et al.* (2016) |
| | *Lacticaseibacillus casei*<br>*Lactobacillus acidophilus* | | White, milk and dark chocolates | Kemsawasd *et al.* (2016) |
| | *Lactobacillus acidophilus*<br>*Bifidobacterium animalis* subsp. *lactis* | | Milk and dark chocolates | Klindt-Toldam *et al.* (2016) |
| | *Lactobacillus acidophilus* | | Milk chocolate | Kavitha *et al.* (2016); Oliveira & Deliza (2021) |
| | *Lactobacillus acidophilus*<br>*Bifidobacterium animalis* subsp. *Lactis* | | Chocolate | Silva *et al.* (2017) |
| | *Lacticaseibacillus paracasei*<br>*Lactobacillus acidophilus* | | Milk chocolate | Toker *et al.* (2017) |
| | *Lacticaseibacillus rhamnosus*<br>*Lacticaseibacillus paracasei*<br>*Lacticaseibacillus casei*<br>*Limosilactobacillus reuteri* | | Dark chocolate | Succi *et al.* (2017) |
| | *Lactobacillus acidophilus*<br>*Streptococcus thermophilus*<br>*Bifidobacterium breve* | Microencapsulated | Milk, semisweet and dark chocolate | Laličić-Petronijević *et al.* (2017) |
| | *Lactobacillus acidophilus*<br>*Lacticaseibacillus paracasei* | Freeze-dried | White chocolate | Konar *et al.* (2018) |
| | *Lactiplantibacillus plantarum* | Spray-dried | Dark chocolate | Mirković *et al.* (2018) |
| | | | Milk chocolate | Nambiar *et al.* (2018) |
| | *Lactobacillus helveticus* | Freeze-dried | | Gadhiya *et al.* (2018) |
| | *Bacillus coagulans* | | Dark chocolate | Kobus-Cisowska *et al.* (2019) |
| | *Lacticaseibacillus rhamnosus* | | Chocolate | Hossain *et al.* (2021b) |
| | *Lactobacillus acidophilus*<br>*Lacticaseibacillus rhamnosus*<br>*Lactobacillus sanfranciscensis*<br>*Lactiplantibacillus plantarum*<br>*Lacticaseibacillus casei*<br>*Bifidobacterium animalis* subsp. *lactis*<br>*Streptococcus thermophilus* | | | Hossain *et al.* (2021a) |
| | *Lactiplantibacillus plantarum*<br>*Lacticaseibacillus rhamnosus* | Spray-dried | Milk chocolate | Gómez-Fernández *et al.* (2021); Faccinetto-Beltrán *et al.* (2022) |
| | *Lactobacillus delbrueckii* subsp. *bulgaricus* | Freeze-dried | Chocolate | Hossain *et al.* (2022b) |
| | *Lactobacillus acidophilus* | – | Milk chocolate | Islam *et al.* (2022) |
| | *Lacticaseibacillus rhamnosus*<br>*Lacticaseibacillus casei* | Freeze-dried | Chocolate | Hossain *et al.* (2022a) |

**Table 2** (*Continued*)

| Functional property | Content | Transmission strategy or delivery system | Chocolate variety | References |
|---|---|---|---|---|
| | *Lactiplantibacillus plantarum* | | | |
| | *Lactobacillus acidophilus* | | | |
| | *Lactobacillus sanfranciscensis* | | | |
| | *Bifidobacterium animalis* subsp. *lactis* | | | |
| Prebiotic | Inulin | – | Milk chocolate | Farzanmehr & Abbasi (2009); Konar (2013) |
| | Fructooligosaccharides | Dried powder | | Konar *et al.* (2014) |
| Prebiotic and antioxidant | | – | White chocolate | Morais Ferreira *et al.* (2017) |
| | Goji berry (*Lycium barbarum*) | Dried | | |
| Synbiotic | *Lacticaseibacillus casei* | Freeze-dried | Milk chocolate | Mandal *et al.* (2013) |
| | Inulin | | | |
| | *Bacillus indicus* | | Dark chocolate | Erdem *et al.* (2014) |
| | *Lacticaseibacillus paracasei* | | | Konar *et al.* (2017) |
| | *Lactobacillus acidophilus* | | | |
| | Inulin | Dried powder | | |
| | *Lactobacillus acidophilus* | Freeze-dried | Milk chocolate | Toker *et al.* (2018) |
| | Inulin | – | | |
| Antioxidant activity | Baobab Pulp | Powder | Dark chocolate | Monteiro *et al.* (2023) |
| | Chilli pepper | Dried | | Jaćimović *et al.* (2022) |
| | Orange | | | |
| | Raspberry | | | |
| | White tea (*Camellia sinensis*) | Free and microencapsulated | | Shahbazi *et al.* (2022) |
| | Jujube fruit | | | |
| | Pomegranate extracts (*Punica granatum*) | | White chocolate | Didar (2020) |
| | Chlorogenic acids | | Dark chocolate | Zohreh (2020) |
| | Mulberry molasses (*Morus alba L.*) | Microencapsulated | White chocolate | Didar (2023) |
| | Cinnamon barks (*Cinnamomum burmannii Blume*) | Nano-encapsulated | | Muhammad *et al.* (2021) |
| | Cinnamon barks (*Cinnamomum burmannii Blume*) | Essential oil | | Muhammad *et al.* (2020) |
| | Raspberry leaves (*Rubus idaeus* L.) | Freeze-dried | Milk, semisweet, and dark chocolates | Belščak-Cvitanović *et al.* (2012) |
| | Cinnamon powder (*Cinnamomum burmanii Blume*) | Nanoparticle | – | Muhammad *et al.* (2019) |
| | Muscadine grapes (*Vitis rotundifolia*) | Freeze-dried | Dark chocolate | Darwish *et al.* (2023) |
| | *Santolina chamaecyparissus* L. | Essential oil | | Bölek *et al.* (2022) |
| | Black mulberry (*Morus nigra* L.) | Extracts | | Godočiková *et al.* (2017) |
| | Sea buckthorn (*Hippophae rhamnoides* L.) | | | |
| | *Salvia Lavandiulaefolia* | Powder | | Zarić *et al.* (2023) |
| | *Salvia officinalis* | | | |
| | Acerola (*Malpighia glabra*) | Spray-dried | | |
| | Matcha green tea (*Camellia sinensis L.*) | Powder | White chocolate | Poliński *et al.* (2022) |
| | Moringa (*Moringa oleifera*) leaf | | | |
| | Blueberries | Freeze-dried | Milk and dark chocolates | Żyżelewicz *et al.* (2021) |
| | Raspberries | | | |
| | Blackberries | | | |
| | Pomegranates | | | |
| | Beetroots | | | |
| | Elderberry (*Sambucus nigra* L.) | Vacuum-dried extracts | Dark chocolate | Poliński *et al.* (2021) |
| | Black chokeberry (*Aronia melanocarpa*) | | | |
| | Passion fruit | Freeze-dried | | Yeo & Thed (2022) |
| | Oranges | | | |
| | Cornelian cherry (*Cornus mas* L.) | | White chocolate | Cerit *et al.* (2016) |
| | Spinach (*Spinacia oleracea*) | | | |
| | Bee pollen | Dried powder | | |

 

**Table 2** (*Continued*)

| Functional property | Content | Transmission strategy or delivery system | Chocolate variety | References |
|---|---|---|---|---|
| | Blackberry juice | Spray-dried | | Lončarević *et al.* (2018) |
| | Green tea (*Camellia sinensis L., Theaceae*) extract | | | Lončarević *et al.* (2019) |
| | Peanut extract | | Milk chocolate | Dean *et al.* (2016) |
| | Kale (*Brassica olereacea var. acephala*) | Freeze-dried | | Carvalho *et al.* (2018) |
| | Grape (*Vitis vinífera*) | | | |
| | Prunes | Dried | Milk and dark chocolate | Komes *et al.* (2013) |
| | Papaya | | | |
| | Apricots | | | |
| | Raisin | | | |
| | Cranberries | | | |
| | Nettle (*Urtica dioica* L.) | Freeze-dried | Milk, semisweet and dark chocolate | Belščak-Cvitanović *et al.* (2015) |
| | Beetroot (*Beta vulgaris* L.) | Dried powder | Dark chocolate | Kongor *et al.* (2024) |
| | Darjeeling Green tea | Powder | White chocolate | Godočiková (2019) |
| | Matcha Green tea | | | |
| | Earl Grey Black tea | | | |
| | Goji berry (*Lycium barbarum*) | Dried | | Morais Ferreira *et al.* (2016) |
| | Phytosterols | Spray-dried | Dark chocolate | Tolve *et al.* (2018) |
| | Black mulberries (*Morus nigra*) extract | | | Gültekin-Özgüven *et al.* (2016) |
| | Lemon balm (*Melissa officinalis* L.) extract | Freeze-dried | | Sik *et al.* (2021) |
| | Blueberry juice | Spray-dried | White chocolate | Jovanović *et al.* (2022) |
| | Opuntia cactus stems | Dried powder | Dark chocolate | Angor *et al.* (2023) |
| Dietary fibre | Resistant starch | Powder | White chocolate | Lončarević *et al.* (2021) |
| | Apple pomace | Dried | Milk chocolate | Büker *et al.* (2021) |
| | Inulin | Powder | Milk chocolate | Rezende *et al.* (2015) |
| | β-glucan | | | |

Prebiotics have been defined more precisely as 'selectively fermented ingredients that allow certain changes, both in the composition and/or activity in the gastrointestinal microbiota, that impart advantages', according to Roberfroid (Roberfroid, 2008). In the food industry, numerous foods can be fortified with prebiotics, and the use of nutrients like probiotics and prebiotics – that support well-being, health and a decreased risk of diseases – has increased globally. Since 2005, the market has seen the introduction of more than 500 new prebiotic-enriched products (da Silveira *et al.*, 2015). Prebiotics' nutritional and practical advantages have drawn the attention of researchers as well as the food industry (Scheid *et al.*, 2013). Prebiotic compounds are beneficial because of their nutritional benefits and the potential to improve some sensory features of food formulations (Sousa *et al.*, 2011; Morris & Morris, 2012).

Inulin, fructooligosaccharides (FOS), galactooligosaccharides (GOS), and polydextrose (PDX) are extensively researched and employed prebiotics (Morris & Morris, 2012). The use of these advantageous elements for enriching the appropriate material applies to chocolate (Konar *et al.*, 2018). Inulin satisfies a range of consumer expectations because it is prebiotic, rich in fibre, and low in calories (Konar, 2013). It can modulate physiological functions, such as lipid metabolism and the composition of gut bacteria. These functions enable improvements in the intestinal function and may help to reduce risk of colon cancer (Kalyani Nair *et al.*, 2010; Ilievska *et al.*, 2019). Prebiotic effects of inulin are associated with promoting the proliferation of beneficial bacteria in the colon, inhibiting the growth of harmful microorganisms, and potentially treating colonic dysfunctions (Kalyani Nair *et al.*, 2010). Due to its non-digestibility by the intestinal microbiota, inulin can be used as an ingredient in diabetic foods in the food industry (Fan *et al.*, 2016).

FOS are bifidogenic oligosaccharides that are nondigestible carbohydrates and dietary fibres (Kumar *et al.*, 2018). According to research, FOS' pharmacological effects, which are mostly similar to other prebiotics, may be listed as dietary fibre impact, mineral absorption, dental caries prevention, antidiabetic activity, anticancer activity, and reduce the risk of cardiovascular diseases (Kumar *et al.*, 2018; Kherade *et al.*, 2021). It is an ingredient of essential functional food due to its functional, organoleptic and nutritional qualities (Kherade *et al.*, 2021). Products made of FOS, which primarily contain short-chain fatty acids (SCFA), improve flavour and sweetness and are used to partially replace sugar in foods (Morais Ferreira *et al.*, 2017; Hossain *et al.*, 2021b).

The other major nondigestible carbohydrate that serves a prebiotic role is GOS. They have the ability to promote health, such as facilitating normal digestive activities, stimulating mineral absorption and decreasing blood lipid levels (Sangwan *et al.*, 2011; Lamsal, 2012). Researchers have evidence that GOS have an effect on immune modulation and reduces the risk of cancer (Sangwan *et al.*, 2011). While the prebiotic effect of GOS promotes the growth of beneficial bacteria, they confer resistance to pathogen colonisation, which is remarkable for its potential use in the treatment of inflammatory bowel disease (Laparra & Sanz, 2010; Sangwan *et al.*, 2011; Lamsal, 2012). The remarkable health benefits of GOS allow for a primary focus on prebiotic functional food development with GOS (Lamsal, 2012).

The prebiotic effect of PDX serves as a carbon source for microorganisms throughout the colon (Röytiö & Ouwehand, 2014; do Carmo *et al.*, 2016). After consumption of PDX, it is not digested in the small intestine and reaches the large intestine, where it is fermented into SCFA and gas by colonic microorganisms in the colon (Hernot *et al.*, 2009; Röytiö & Ouwehand, 2014; Hossain *et al.*, 2022b). In general, PDX has been shown in several studies to have an effect on postprandial benefits, such as energy intake, gastrointestinal function, nutrient absorption and immunological modulation (do Carmo *et al.*, 2016). PDX, the soluble fibre synthesised from glucose, is used to enhance the fibre content of foods (Costabile *et al.*, 2012). In the production of functional chocolate with prebiotics, the potential exists to reduce calories and sugar while simultaneously increasing fibre content. Several studies have been conducted to explore the production of high-fibre/prebiotic chocolates, emphasising the ongoing efforts in this area (Farzanmehr & Abbasi, 2009; Morais Ferreira *et al.*, 2017).

## Probiotic-based chocolates

Similar to prebiotics, probiotics alter the composition of the gut microbiota, and as a result, it has been demonstrated that they have an impact on both intestinal and overall body functions (Nebesny *et al.*, 2005, 2007). Its significance in terms of carrying probiotics has come to light when considering the popularity of chocolate eating (Yonejima *et al.*, 2015; Hossain *et al.*, 2022a). Consumers' quest for savoury foods that will meet their nutritional demands is driving a continued rise in the popularity of functional foods. Probiotics are one of these nutrients that may provide a positive effect on the composition of the gut microbiota and general health (Hossain *et al.*, 2022a). Some probiotics have been linked to functional features, including lowering the symptoms of digestive system diseases (Klindt-Toldam *et al.*, 2016; Islam *et al.*, 2022). However, bacterial cultures must still be alive and active at the time of intake in order to be effective (Żyżelewicz *et al.*, 2010; Foong *et al.*, 2013).

Chocolate and chocolate-based products are appropriate probiotic delivery systems, protecting the survival of various bacteria strains (Table 2) (Possemiers *et al.*, 2010; Islam *et al.*, 2022). From this information, researchers and food companies have developed functional chocolate and chocolate-based products using different probiotic strains, such as *Bacillus coagulans*, *Bacillus indicus*, *Bifidobacterium animalis* subsp. *lactis*, *Bifidobacterium breve*, *Bifidobacterium lactis*, *Bifidobacterium longum*, *Enterococcus faecium*, *Fructolactobacillus sanfranciscensis*, *Lactobacillus acidophilus*, *Lacticaseibacillu casei*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Lactobacillus helveticus*, *Lacticaseibacillus paracasei*, *Lactiplantibacillus plantarum*, *Lacticaseibacillus rhamnosus*, *Levilactobacillu brevis*, *Limosilactobacillus reuteri* and *Streptococcus thermophilus* (Table 2) (Laličić-Petronijević *et al.*, 2015; Zarić *et al.*, 2016; Toker *et al.*, 2018).

Synbiotic is a combination of probiotics and prebiotics designed to work in harmony, fostering a balanced and healthy gut microbiome (Mandal *et al.*, 2013). Taking this concept a step further, synbiotic chocolate emerges as a unique and innovative product that seamlessly integrates the goodness of probiotics and prebiotics with the delightful experience of indulging in chocolate (Rouhi *et al.*, 2015). This novel approach involves incorporating specific probiotic strains and prebiotic components into the chocolate formulations (Mandal *et al.*, 2013; Toker *et al.*, 2017). Manufacturers, by doing so, can craft functional foods that not only deliver the satisfying taste of chocolate but also provide additional health benefits (Konar *et al.*, 2017). Synbiotic chocolate, therefore, becomes a pleasurable treat that goes beyond mere indulgence, actively contributing to the promotion of gut health and overall well-being (Rouhi *et al.*, 2015). The combined action of probiotics and prebiotics in this chocolate variant creates a harmonious environment in the digestive system, supporting the growth of beneficial bacteria and optimising the overall microbial balance (Konar *et al.*, 2018).

## Antioxidant-based chocolates

Cacao is a shelf-stable food matrix that has a medium or long shelf-life food product (Godočiková, 2019). The antioxidant potential of chocolate depends on the raw material, its origin, genetics, cultivation and post-harvest processes, and the production processes of the chocolate (Mirković *et al.*, 2018). In functional food production, polyphenol-enriched chocolate has an enhanced antioxidant capacity (Table 2) (Belščak-Cvitanović *et al.*, 2012; Angor *et al.*, 2023). There are various strategies to boost chocolate's polyphenol content. One of these is the production of chocolate from polyphenol-enriched cacao (Jaćimović *et al.*, 2022). Another way is the flavonoid content – which is a class of polyphenols present in chocolate – can be increased after the addition of the form of plant extracts and marine-derived food, which are potential sources of antioxidants (Dean *et al.*, 2016; Didar, 2020; Jovanović *et al.*, 2022). Different phenolic extracts with the correct source and percentage of phenolic may be considered ideal sources for improving antioxidant activity when added to chocolate formulations (Poliński *et al.*, 2022; Didar, 2023). The addition of these antioxidant-rich functional ingredients may significantly modify the sensory characteristics and nutraceutical properties of the base product into which they are incorporated (Belščak-Cvitanović *et al.*, 2015; Angor *et al.*, 2023). In general, the functional products that enrich the polyphenol content demonstrate a greater antioxidant capacity due to their higher absorption in the gastrointestinal system (Kemsawasd *et al.*, 2016).

### Plant-based chocolates

On the other hand, global consumption of plant-based functional foods is growing quickly in the food marketing industry as a result of their rising popularity. The term 'plant-based' refers to a contemporary consumer trend that involves eschewing animal-based items in favour of plant-based alternatives, consuming fewer animal-based meals overall, or else adhering into dietary regimens that place a greater or even sole emphasis on plant-based products (Aschemann-Witzel *et al.*, 2021). Considering the crucial roles that plant-based elements, particularly proteins, play in the production of functional foods for human consumption that promote health and well-being (Lončarević *et al.*, 2019). Numerous researchers have investigated the potential impact of substances derived from various plant sources on a variety of disorders, including those with cardiovascular risk factors, obesity, metabolic syndromes, *etc.* (Lippi, 2015). The results of these studies suggest that plant-based foods should be included in the human diet to reduce the risk factors for certain metabolic illnesses. In this direction, there are several applications of plant-based functional chocolates in the food sector (Morais Ferreira *et al.*, 2016; Poliński *et al.*, 2021). By substituting components of plant origin for those of animal origin in the chocolate production process, food companies can make vegan functional chocolates. Soy, almond milk, maple and rice syrup are examples of plant sources that can be chosen for the production of plant-based functional chocolates (Wang *et al.*, 2008).

### High protein-based chocolates

The significant interest in high-protein products on the market has become part of the current trends in healthy and functional nutrition. A broad group of consumers, especially physically active people, would rather be used to products enriched in protein or in which protein is the main ingredient (Małecki *et al.*, 2020). The type of proteins used can alter the nutritional values, textural parameters or physicochemical parameters of the product (Małecki *et al.*, 2020). High-protein content functional chocolate, including bars, can be produced by adding microalgae, protein-enriched fractions from plants and milk components (Barišić *et al.*, 2019; Kobus-Cisowska *et al.*, 2019; Małecki *et al.*, 2020). Milk and milk derivatives, with their bioactive constituents, are highly preferred components for the production of protein-rich chocolate (Attaie *et al.*, 2003; Karav, 2019; Arslan *et al.*, 2021; Kaplan *et al.*, 2022b).

### Easy to digest chocolates

The primary nutrients for human nutrition are milk and dairy products, which are among the most produced and consumed foods worldwide. Milk plays a crucial role in several physiological functions, particularly those related to immune system development (Duman & Karav, 2023). This is achieved by various proteins and peptides, including growth factors, immunoglobulins, enzymes, inhibitors, hormones and antibacterial substances (Karav *et al.*, 2017; Bolat *et al.*, 2022).

Despite the beneficial effects of milk on health, a lot of people cannot consume milk and its derivatives because of health problems. Studies have demonstrated that these problems are closely related to A1 milk consumption (Jianqin *et al.*, 2015; Ramakrishnan *et al.*, 2020). In this situation, the A2 milk approach has drawn attention to the production of functional chocolate. It is noteworthy that A1 milk is characterised by a higher concentration of A1 β-casein protein, whereas A2 milk is distinguished by a greater prevalence of A2 β-casein protein (Fig. 3) (Kaplan *et al.*, 2022a).

These variants display dissimilarities in their biological properties, protein structure, charges, digestion points and products generated after digestion. One significant difference between the A1 and A2 variants of β-casein is the type of digestive products they produce. When the A1 variant is digested through gastrointestinal proteolysis, it creates a bioactive peptide called β-casomorphin-7 (BCM-7), which activates μ-opioid receptors of the body (Singh *et al.*, 2023). These

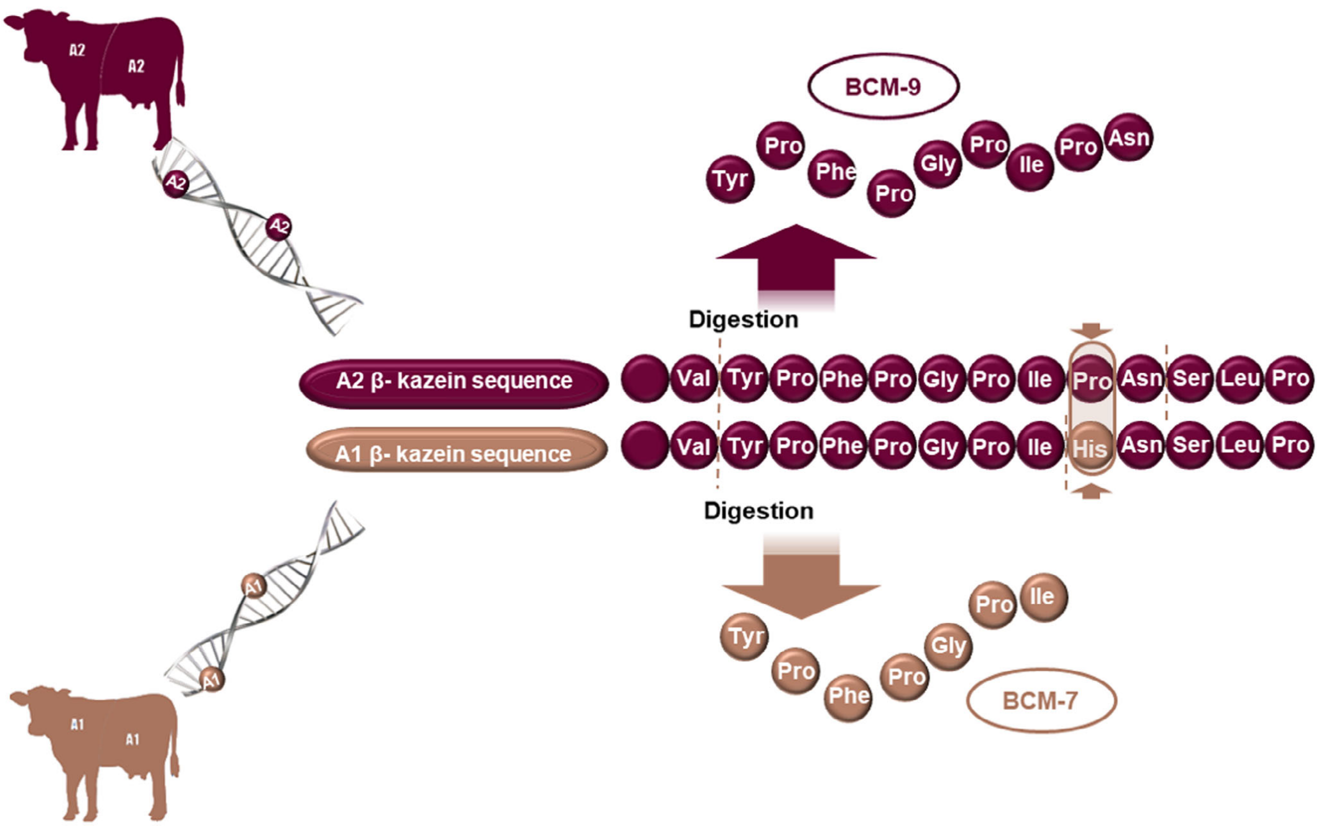


**Figure 3** The distinction between beta-casein types A1 and A2 as well as the release of BCM-7 and BCM-9 molecules.

receptors regulate the body's response to pain. On the other hand, the digestion of the A2 variant leads to the formation of β-casomorphin-9 (BCM-9) (Kamiński *et al.*, 2007). After consuming regular milk with the mutated form of β-casein, the BCM7 metabolite is formed. This form of milk is difficult for human-associated digestive enzymes to breakdown and has been proven to be the main cause of digestive and health disorders related to the intake of milk and its derivatives. On the other hand, A2 milk containing β-casein is not associated with a trigger to cow's milk protein allergy, activation of μ-opioid receptors of the body or any health issues (Sun *et al.*, 1999). A potential solution for individuals experiencing gastrointestinal discomfort after consuming milk has been suggested to lie in the consumption of A2 milk. A2 milk is believed to be devoid of the protein that is responsible for such digestive issues, rendering it a suitable option for those who experience such problems (Gustavsson *et al.*, 2014; Milan *et al.*, 2020). Recent studies examining the effects of A1 and A2 milk on digestive discomfort have yielded noteworthy findings (Milan *et al.*, 2020). Specifically, these studies have demonstrated that individuals unable to tolerate A1 milk did not experience any gastrointestinal issues after consuming A2 milk (Ho *et al.*, 2014; Jianqin *et al.*, 2015). Furthermore, recent research suggests that A2 milk is effective in reducing gastrointestinal symptoms associated with lactose intolerance, while A1 milk decreases lactase activity and increases gastrointestinal-related symptoms (Kaplan *et al.*, 2022a).

Overall, switching to A2 milk may hold promise as a solution for individuals with milk sensitivities. A2 milk is easily digested and might not cause serious diseases. In this way, A2 milk is becoming widespread in the global market in numerous food products, especially milk and dairy products, infant formulas, chocolate varieties, snacks and food supplements. Therefore, A2 milk is seen as a functional dairy product due to its natural health benefits (Bentivoglio *et al.*, 2020; Kaplan *et al.*, 2022c).

## Conclusion

This article focuses on various aspects highlighting how chocolate, consumed from the past to the present, has been equipped with functional features to adapt to the changing demands of consumers. At this point, the emphasis is on different elements added to chocolate, such as various plant extracts, probiotics, prebiotics, protein and health-beneficial ingredients, to meet consumer demands and to create diverse consumer portfolios. Chocolate is not just perceived as a sweet treat, but as a product that supports a healthy lifestyle, leading to its enrichment with various functional components. For instance, plant extracts added to chocolate are known for their antioxidant properties, providing consumers with a healthy option. The inclusion of probiotic and prebiotic ingredients creates a product friendly to the digestive system, while added protein can enhance the nutritional value of chocolate and provide energy. Milk chocolate is the most preferred type of chocolate worldwide. In this context, the use of A2 milk as the milk powder in the production of milk chocolate contributes significantly to the production of easily digestible functional chocolate. A2 milk is particularly suitable for consumers with digestive problems due to its ability to be digested by proteolytic enzymes. This highlights a specific market segment targeting individuals with a focus on healthy eating and digestive sensitivities when consuming chocolate.

In conclusion, the chocolate industry undergoes continuous evolution to align with consumer demands and trends in healthy living, consistently introducing numerous new products with functional features. This transformative process extends beyond the traditional perception of chocolate as a delectable indulgence, repositioning it as a sensible choice for health-conscious consumers. As we look to the future, the sector is well-positioned to explore more deeply into customised diets, taking advantage of developments in personalised nutrition to customise chocolate recipes to meet particular dietary demands and digestive sensitivity. With a more meaningful connection being made between enjoyment and well-being, this individualised approach has the potential to completely change how consumers view and use chocolate in their daily lives. Because of this, functional chocolate has a bright future ahead of it, thanks to its capacity to improve and maintain general health and vitality in addition to its exquisite flavour.

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## Conflict of interest

The authors declare no conflicts of interest.

## Ethical approval

This paper does not require ethical approval.

## Informed consent statement

Not applicable.

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## Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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The article aims to evaluate the effect of baobab flour concentration on the development of functional dark chocolate, focusing on physical, chemical, nutritional, and sensory evaluations. In our article, which generally discusses the products that can be added to functionalize chocolate, the inclusion of this article, which discusses the parameters of adding baobab flour in the production of functional chocolate, has introduced a different perspective.

Morais Ferreira, J.M., Azevedo, B.M., Silva, F.G.D., Luccas, V. & Bolini, H.M.A. (2016). Isosweetness concentrations of sucrose and high-intensity sweeteners and antioxidant activity in white chocolate with functional properties. *International Journal of Food Science & Technology*, **51**, 2114–2122.

This study explores the potential of adding prebiotic component fructooligosaccharides (FOS) to white chocolate to create a functional chocolate with health benefits. FOS, a significant compound, supports gut health and reduces risks associated with excessive sugar consumption. Within the scope of the article submitted for review, FOS, one of the preferred prebiotics in functional chocolate production, is comprehensively described, and sample studies are presented in Table 1.

Morais Ferreira, J.M., Azevedo, B.M., Luccas, V. & Bolini, H.M.A. (2017). Sensory profile and consumer acceptability of prebiotic white chocolate with sucrose substitutes and the addition of goji berry (*Lycium barbarum*). *Journal of Food Science*, **82**, 818–824.

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Nemoto, K., Kokubun, K., Ogata, Y., Koike, Y., Arai, T. & Yamakawa, Y. (2022). Dark chocolate intake may reduce fatigue and mediate cognitive function and gray matter volume in healthy middle-aged adults. *Behavioural Neurology*, **2022**, 1–8.

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Oliveira, D. & Deliza, R. (2021). Comparison of consumer-based methodologies for optimizing the development of new products: a case study with probiotic chocolate flavored milk. *Food Science and Technology International*, **27**, 539–553.

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Rawel, H., Huschek, G., Sagu, S.T. & Homann, T. (2019). Cocoa bean proteins—characterization, changes and modifications due to ripening and post-harvest processing. *Nutrients*, **11**, 428.

Ren, Y., Liu, Y., Sun, X.Z. *et al.* (2019). Chocolate consumption and risk of cardiovascular diseases: a meta-analysis of prospective studies. *Heart*, **105**, 49–55.

Rezende, N.V., Benassi, M.T., Vissotto, F.Z., Augusto, P.P.C. & Grossmann, M.V.E. (2015). Effects of fat replacement and fibre addition on the texture, sensory acceptance and structure of sucrose-free chocolate. *International Journal of Food Science & Technology*, **50**, 1413–1420.

The article aims to investigate the effect of various factors including composition, processing conditions, and formulation on the sensory properties and quality of chocolate. Additionally, the article aims to discuss the potential use of inulin, a dietary fiber, as a substitute for fats and sugars in food products, leading to the development of products with a more balanced nutritional composition without compromising texture. Within the scope of the study submitted for your evaluation, the properties of dietary fibers and their utilization in studies on the production of functional chocolate have been examined. In addition, changes in texture and sensory properties have also been discussed.

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da Silveira, E.O., Neto, J.H.L., da Silva, L.A., Raposo, A.E.S., Magnani, M. & Cardarelli, H.R. (2015). The effects of inulin combined with oligofructose and goat cheese whey on the physicochemical properties and sensory acceptance of a probiotic chocolate goat dairy beverage. *LWT – Food Science and Technology*, **62**, 445–451.

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Souza, J.M.L., Rocha, J.M., Cartaxo, C.B.C. *et al.* (2020). Monitoring and optimization of Cupuaçu seed fermentation, drying and storage processes. *Microorganisms*, **8**, 1–34.

Spadafranca, A., Martinez Conesa, C., Sirini, S. & Testolin, G. (2010). Effect of dark chocolate on plasma epicatechin levels, DNA resistance to oxidative stress and total antioxidant activity in healthy subjects. *British Journal of Nutrition*, **103**, 1008–1014.

Stellingwerff, T., Godin, J.P., Chou, C.J. *et al.* (2014). The effect of acute dark chocolate consumption on carbohydrate metabolism and performance during rest and exercise. *Applied Physiology, Nutrition, and Metabolism*, **39**, 173–182.

Succi, M., Tremonte, P., Pannella, G. *et al.* (2017). Survival of commercial probiotic strains in dark chocolate with high cocoa and phenols content during the storage and in a static in vitro digestion model. *Journal of Functional Foods*, **35**, 60–67.

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Toker, Ö.S., Pirouzian, H.R., Konar, N. & Polat, D.G. (2018). βv seeding as an alternative pre-crystallization technique in synbiotic milk chocolate production. *GIDA*, **43**, 422–431.

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Tolve, R., Condelli, N., Caruso, M.C., Barletta, D., Favati, F. & Galgano, F. (2018). Fortification of dark chocolate with microencapsulated phytosterols: chemical and sensory evaluation. *Food & Function*, **9**, 1265–1273.

Tuenter, E., Sakavitsi, M.E., Rivera-Mondragón, A. *et al.* (2021). Ruby chocolate: a study of its phytochemical composition and quantitative comparison with dark, milk and white chocolate. *Food Chemistry*, **343**, 128446.

Vargas-rechia, C.G., Vargas-rechia, C.G., Reicher, F. *et al.* (2015). A profile of the south African table grape market value chain. *Bioresource Technology*, **6**, 1–14.

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