Cocoa Bean Shell By-Products as Potential Ingredients for Functional Food and Beverage - A Review

Abstract. Cocoa processing generates by-products such as pod husks, pulp, and bean shells. Among these, cocoa bean shells (CBS) stand out as a significant by-product, comprising approximately 10% to 17% of the total weight of cocoa beans. These shells are typically separated from the cocoa beans before or after roasting. A large amount of waste can be produced during the mass processing of cocoa beans; in one year, the world has 700,000 tons. CBS contains various nutrients and beneficial compounds, including approximately 50% dietary fiber, proteins, minerals, vitamins, volatile compounds, and various polyphenols. The objectives of this review encompass assessing the potential of CBS as a valuable ingredient for developing functional foods and beverages. Our methodology involved a comprehensive literature search across multiple scholarly databases, focusing on journal articles exploring CBS utilization in functional foods and beverages. The results reveal CBS as a promising by-product with significant opportunities for value addition, presenting itself as a potential functional ingredient for food and beverage applications. However, the limited literature on developing CBS-based fermented beverage products akin to kombucha and kefir underscores the need for further research to explore their untapped potential fully.

1 Introduction

Theobroma cacao L., often known as cocoa, refers to the fruit of the cocoa tree. There are twenty acknowledged varieties of cacao (Theobroma cacao L.), although it is worth noting that the following three kinds are widely recognized and favored. The Criollo, Forastero, and Trinitario cultivars have been documented as being available [1]. This plant's seeds, commonly known as cocoa beans, consist of an outer shell or test enclosing two cotyledons and a tiny germ [2]. After harvesting cocoa beans, they endure a series of essential processes,
including fermentation and drying. Shelling is then performed to obtain both nibs and shells, with shells being the first by-product [3]. The cocoa bean shell (CBS) and germ removal are conducted in specific procedures before or after the roasting step [4,5]. The incorporation of cocoa bean shells in cocoa bean-derived products is deemed unfavorable due to its adverse effects on the production process and the overall excellence of the final product. The shell composition of cocoa products is of considerable significance as an indicator of quality. The European Union directive about cocoa and chocolate has established a prescribed % upper threshold of 5% for including shell, encompassing the germ, in cocoa nibs. This restriction is contingent upon the fat-free dry cocoa content [2].

CBS constitutes between 10% - 17% of cocoa beans’ overall weight, as Hashimoto et al. (2018) reported [6]. Furthermore, Ho et al. (2014) research has indicated that these proportions may differ depending on the cocoa beans’ fermentation. Considering the weight % of CBS and the previously cited data on cocoa output, it can be inferred that the global production of CBS trash exceeds 700 thousand tonnes, with Europe alone contributing over 250 thousand tonnes [7]. According to a study conducted by Afrane and Ntiamoah (2011), it has been demonstrated that the production of one kilogram of chocolate yields around 98 grams of CBS [8]. The escalating demand for cocoa beans has accumulated this by-product, posing a significant concern about its appropriate disposal. This difficulty may be further aggravated by legal limits [9]. The disposal of CBS has substantial economic and environmental problems [10]. CBS contains polyphenols that possess potential phytotoxic properties [11]. Additionally, it is worth noting that CBS exhibits significant amounts of theobromine, a scientifically proven hazardous substance to specific non-human species [12]. Moreover, prior research has documented the presence of toxicity in aquatic organisms [13].

The nutritional profile of CBS is comparable to that of cocoa beans, with the exception of lipids, which are more prevalent in cocoa beans [14]. In addition, investigating the number and composition of phenolic compounds found in the shell is of significant interest, as this particular group of chemicals has been suggested to have significant antioxidant abilities [2]. The chemical composition profile of the CBS reveals the presence of compounds that indicate potential applications of this by-product in the food industry.

In recent times, there has been an increasing focus on the conversion of food processing remaining residue into valuable products by bioconversion. Consequently, industrialized nations are formulating strategic policies to foster the development of a circular economy based on bio-based concepts [15,16]. Due to all these factors, strategies for the valorization of CBS have emerged in various disciplines, and numerous studies have been conducted to identify potential uses for this by-product.

Considering the nutritional value of CBS, new applications and increased economic value are possible. This underutilized by-product can reduce cocoa waste while expanding functional food and beverage ingredient options. This review aims to consolidate the current literature on using CBS applications within the food and beverage.

2 Methods and Literature Research

This literature review aims to assess relevant sources concerning the use of cocoa bean shells in functional foods and beverages. Initially, we conducted a journal search using the term ‘cocoa bean shell’ with tools like ‘publish or perish.’ We conducted a comprehensive literature search by utilizing multiple scholarly databases, namely Scopus, Google Scholar, PubMed, Web of Science, SciFinder, ResearchGate, and SciELO. The search encompassed the period from 2000 to 2022. Our selection process focused on journal articles on CBS utilization in functional foods and beverages, excluding other contexts. Additionally, we manually examined bibliographies to identify further scientific papers and sources. The primary source of our literature acquisition was Google Scholar.
3 Results and Discussion

3.1 Composition of CBS

3.1.1 Proximate Composition

Multiple researchers have investigated the proximate composition of CBS, and an in-depth summary of these results may be seen in Table 1. The proximate composition of CBS includes proteins, lipids, carbohydrates, moisture, and ashes, as reported by [17]. It has been noted that CBS has similarities to cocoa beans. However, it has been observed that CBS significantly reduced fat content compared to cocoa beans. This reduction in fat content is compensated by a substantial increase in dietary fiber [14]. The proximate composition of CBS can exhibit considerable variation due to multiple factors inherent to its vegetable nature. These factors include the climatic conditions of the region of cultivation, the use of diverse industrial facilities for cacao processing, and the conditions employed during fermentation, drying, and roasting [18,19].

Table 1. Proximate composition of CBS (g/kg dry matter)

<table>
<thead>
<tr>
<th>Reference</th>
<th>[14]</th>
<th>[20]</th>
<th>[21]</th>
<th>[17]</th>
<th>[10]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Fat</td>
<td>185</td>
<td>68.1</td>
<td>66.2</td>
<td>20.2</td>
<td>23</td>
</tr>
<tr>
<td>Protein</td>
<td>116</td>
<td>181.2</td>
<td>167.1</td>
<td>158.5</td>
<td>209</td>
</tr>
<tr>
<td>Ash</td>
<td>75</td>
<td>81</td>
<td>114.2</td>
<td>73.5</td>
<td>79</td>
</tr>
<tr>
<td>Moisture</td>
<td>47</td>
<td>101.2</td>
<td>-</td>
<td>77.1</td>
<td>59</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>785</td>
</tr>
<tr>
<td>Fiber</td>
<td>504</td>
<td>606</td>
<td>605.4</td>
<td>567</td>
<td>551</td>
</tr>
</tbody>
</table>

The moisture content of CBS ranges from 47 to 101.2 g/kg dry matter, with significant variation influenced by the roasting process [22]. Bonvehi & Coll (1999) reported moisture values between 3.6% and 7.8%, concluding that this range is suitable for maintaining CBS storage [23]. However, it has been noted that CBS exhibits significant hygroscopic properties, which may lead to the growth of molds when stored in environments with elevated moisture levels [10].

The ash content of CBS is an essential parameter to consider in its potential utilization within the food industry. Previous studies have reported a range of ash content in CBS, typically falling between 73.5 to 114.2 g/kg of dry matter. It is noteworthy that the roasting process can significantly influence this value, leading to an approximate 15% increase [22]. Furthermore, research by Osundahuns et al. (2007) identified the predominant components within CBS ash as sodium and potassium, with concentrations of 7.2 g and 3.1 g per 100 g of CBS ash, respectively [24]. It is essential to acknowledge that the presence of ash content in CBS may pose challenges in their application in the food industry. This challenge is attributed to the higher metal ions associated with ash, which can accelerate oxidation reactions in the final products [17]. Understanding these factors is vital when considering the incorporation of CBS into various food products. The protein content of CBS is a notable aspect, ranging from 116 to 209 g/kg of dried matter, as reported in the reviewed literature. This substantial protein quantity has led researchers to explore CBS as a promising potential protein source [2]. However, it's important to note that the roasting process often has an adverse effect on this parameter. Agus et al. (2018) observed a decrease in crude protein content from 27.43% to 25.07% following roasting [22]. Moreover, Bonvehi and Coll (1999) found that CBS contains essential amino acids, constituting 44.7% of the total amino acid composition [23].
The fat content of CBS is a notable parameter, ranging from 23 to 185 g/kg dry weight, considerably lower than the approximate 50% fat content found in cocoa beans [23]. It is important to note that the roasting process can significantly impact CBS fat content. Agus et al. (2018) reported a reduction of approximately 36% in fat content following roasting, underscoring the effects of this process on both fat and protein content [22]. Furthermore, CBS fat exhibits distinct characteristics, including high acidity and a higher content of unsaponifiable matter than cocoa bean fat, as elucidated by El-Saied et al. (1981). It's worth emphasizing that CBS fat is not typically considered equivalent to cocoa butter [25]. In a study conducted by Lessa et al. (2018), non-fermented CBS was found to consist of 34.7% unsaturated fatty acids and 64% saturated fatty acids, with these percentages shifting to 51.2% and 48%, respectively, after undergoing fermentation [26].

Carbohydrate content in CBS is a crucial parameter, with reported values ranging from 504 to 606 g/kg dry weight. However, these values exhibit significant variation due to factors such as the inclusion of fiber content and the utilization of subtraction-based calculations [17]. This variability underscores the importance of understanding the methodology used in determining carbohydrate content. The non-digestible component of CBS carbohydrates is primarily composed of pectic polysaccharides (45%), cellulose (35%), and hemicelluloses (20%), collectively constituting dietary fiber [27]. Glucose emerges as the predominant monosaccharide in CBS, accounting for over 50% of the carbohydrate composition, followed by galactose, mannose, rhamnose, arabinose, and xylose in descending order of abundance [27–29]. This distinctive carbohydrate profile in CBS offers insights into its potential applications and utilization in various industries.

### 3.1.2 Dietary Fiber

Structural carbohydrates, known as non-starch polysaccharides, comprise CBS's dietary fiber (DF). It is made up of plant cell wall remnants that are difficult for humans to digest and absorb in the small intestine, and it has no energy value due to full or partial fermentation in the large intestine [30]. Outside variables like weather and soil conditions primarily influence the amount of DF. These chemicals build up in CBS with enough moisture and high day and night-time temperatures. In non-fertile and non-volcanic soils, they have reported low levels of water-soluble pectin in CBS.

Additionally, the variability of the seed coming from nearby plantations has been linked to the variation in the quantity of water-soluble pectin and polyphenols, indicating that cocoa origin is an essential quality indicator [31]. Whether or not they are roasted affects how much fiber is in CBS. Additionally, it is determined that the Maillard chemical synthesis in roasted seeds and shells improves the fiber content [27].

The values for dietary fiber (DF) in CBS are comprised of three components: total dietary fiber (TDF), soluble dietary fiber (SDF), and insoluble dietary fiber (IDF), as documented in existing literature. CBS fiber has been determined in various research, which has resulted in notable variances for these values. Based on the findings of Redgwell et al. (2003), the gravimetric estimation of fiber content in CBS, including the Klason fraction, constitutes approximately 63.6% of the dried weight of CBS. Specifically, the soluble dietary fiber (SDF) accounts for 11.7% of the CBS weight, while the insoluble dietary fiber (IDF) makes up 51.9% of the CBS weight [27]. On the other hand, the proportion of fiber ascertained through the measurement of total polysaccharides amounted to a mere 38.2%. In their study, Lecumberri et al. (year) reported that the dry matter basis (d.m.) yielded values of 60.54%. However, the proportion of soluble dietary fiber accounted for only 10.09% of the total composition. According to Lecumberri et al. (2007), the composition of CBS fiber would be approximately 45% pectic compounds, 35% celluloses, and 20% hemicelluloses, excluding the Klason fraction [21].
The range of IDF and SDF fractions calculated for the TDF content of CBS falls between 52.23 and 56.98 g/100 g dry matter, with IDF/SDF ratios ranging from 2.19 to 2.90. It is important to note that the functional properties of dietary fiber depend on the balance between IDF and SDF. Generally, SDF has a high capacity for hydration and forms viscous solutions, which can contribute to various biofunctional characteristics. Therefore, an increased SDF content is particularly intriguing due to its potential impact on these biofunctional properties [17].

3.1.3 Phenolic Compound

Polyphenolic compounds and dietary fiber constitute the most intriguing and extensively studied components within CBS and are the primary contributors to the biofunctional properties of CBS [32]. Phenolic compounds, considered secondary metabolites, are predominantly found in the pigment cells of cotyledons and play distinct roles in the physiology of plants [33]. These multifaceted compounds play pivotal roles in plants' growth, reproduction, and defense mechanisms against various pests. Notably, the phenolic compound profiles within plant species exhibit variations, particularly among different varieties [34].

The phenolic compound content has been shown to exhibit significant variation based on factors such as plant genotype, cocoa variety, geographic origin, and even the harvest season (Hernández-Hernández et al., 2019). Bruna et al. (2009) have associated higher polyphenol content with stress conditions affecting cocoa trees [31]. Factors like fermentation type and duration have also been demonstrated to influence polyphenolic quantities [35]. Polyphenols can be degraded due to the exposure of cocoa beans to high temperatures and light during manufacturing processes, such as roasting or sun-drying [31].

Several research studies have been conducted to determine the quantities of phenolic compounds in CBS. These studies mainly assess the total phenolic content (TPC), total flavonoid content (TFC), and total tannin content (TTC). The measurements of these compounds are often represented as milligrams of gallic acid equivalents (GAE) or catechin equivalents (CE) per gram of dried CBS. For example, in a study conducted by Bruna et al. (2009), the authors examined the composition of bioactive compounds, specifically polyphenols and hydrocolloids, in CBS sourced from various regions, including Madagascar, Ghana, Trinidad, Venezuela, and Ecuador. The study demonstrated a significant association between polyphenols content and the CBS's antioxidant activity. The polyphenolic component concentration in cocoa hulls exhibited a mean range of 2.56 to 4.06 mg GAE per gram of dried material [31].

Moreover, Nsor-Atindana et al. (2012) highlighted the nutritional value of CBS, particularly its richness in dietary fiber, protein, and polyphenols. Their evaluation of TPC, TFC, and TTC (PC) in CBS phenolic extracts, utilizing various solvents including 80% acetone, ethanol, methanol, and water, resulted in values ranging from 17.21 to 41.82 mg GAE/g dried, 1.65 to 5.49 mg CE/g dried, and 2.36 to 12.90 mg CE/g dried, respectively [36].

Furthermore, Papillo et al. (2019) researched polyphenol extraction from CBS using different protocols, including water and a water-ethanol mixture, with stirring and sonication processes. Their findings indicated a TPC range of 40.8 to 93.3 mg CE/g of dried extract. Although polyphenols have potential as functional ingredients in foods, they are limited by their instability. To solve this, CBS was microencapsulated via spray-drying to enhance its potential as a bakery ingredient [37].

Adding to the discussion, González et al. (2019) found seven quercetin derivatives in CBS extract, which are natural antioxidants with various beneficial effects like anti-inflammatory and neuroprotective properties, owing to their ability to counter oxidative stress [38].
3.1.4 Methylxanthines

CBS, a cocoa-based product, contains significant levels of methylxanthines, including theobromine and caffeine. Both compounds positively affect the central nervous system, contributing to cocoa's popularity. Theobromine in chocolate exhibits a weaker effect on the central nervous system than caffeine [39]. These compounds are characteristic of cocoa and migrate from cocoa cotyledons into the beans during fermentation and roasting. Further degradation of bioactive components can occur during the manipulation of CBS [33,40].

Multiple studies have investigated methylxanthine levels in CBS. Barbosa-Pereira et al. (2018) observed theobromine concentrations ranging from 4.64 to 10.92 mg/g dw and caffeine concentrations from 1.59 to 4.21 mg/g dw, highlighting variations linked to cocoa origin and cultivar [41]. Barišić et al. (2020) reported theobromine at an average of 3.906 mg/g dw and caffeine at 0.646 mg/g dw in untreated cocoa shells [42]. Adamafio (2013) also noted potential theobromine concentrations of up to 21 g/kg, subject to cocoa bean origin, fermentation, and roasting conditions [12]. On the other hand, Rojo-Poveda and colleagues found in 2019, theobromine levels in CBS can be 5 to 7 times higher than caffeine levels. To put it in simpler terms, for every 100 grams of dried CBS, you might have around 0.39 to 1.83 milligrams of theobromine and only 0.04 to 0.42 milligrams of caffeine [10]. Hernández-Hernández et al. (2018) discovered that theobromine levels in raw CBS were at 3.90 milligrams per gram. However, these levels increased to 12.00 milligrams per gram in fermented CBS [33].

Considering the moderate caffeine concentration and other methylxanthines, CBS may offer interesting bioactive properties for human health, potentially adding value to CBS as a biofunctional beverage ingredient.

3.2 The Potential of CBS as a Functional Food and Beverage

3.2.1 CBS as a Functional Food

CBS, often considered a by-product of chocolate production, has shown remarkable potential as a valuable ingredient in various food products. Several studies have explored their applications, shown in Table 2, leading to promising outcomes across various items. Rojo-Poveda et al. (2020) demonstrated that substituting wheat flour with CBS powder in biscuit production yielded high-fiber biscuits, with sensory preferences varying among formulations [43]. Notably, CBS enhanced the appeal of tagatose biscuits, offering the potential for creating diabetic-friendly biscuit options. In a separate study, Martínez-Cervera et al. (2011) found that soluble cocoa fiber from CBS was a promising alternative to oil in chocolate muffin recipes. This increased moisture and a tender texture while mitigating hardening during storage. Although challenges such as reduced height and perceived bitterness were noted, potential solutions, including recipe adjustments and flavor enhancement, were identified. Further consumer acceptance studies are warranted due to the modified products' significantly reduced fat content and increased fiber content [44].

Table 2. Utilization of CBS as a functional food

<table>
<thead>
<tr>
<th>Type of Products</th>
<th>Ingredients</th>
<th>Functional compound</th>
<th>Result</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscuit</td>
<td>Wheat flour, sucrose, tagatose, butter (&gt;82% fat), CBS powder, baking powder,</td>
<td>Dietary powder</td>
<td>CBS powder was used to substitute wheat flour in biscuit production, resulting in high-fiber biscuits meeting specific criteria. Sucrose biscuits were preferred</td>
<td>[43]</td>
</tr>
<tr>
<td>Type of Products</td>
<td>Ingredients</td>
<td>Functional compound</td>
<td>Result</td>
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<tr>
<td>Muffin</td>
<td>Flour, egg yolk, egg white, milk, sugar, cocoa, oil, cocoa fiber, bicarbonate of soda, citric acid, salt</td>
<td>Dietary fibre as fat replacer</td>
<td>A promising substitute for oil in chocolate muffin recipes is provided by soluble cocoa fiber, which leads to increased moisture, a tender texture, and reduced hardening during storage.</td>
<td>[44]</td>
</tr>
<tr>
<td>Biscuit</td>
<td>Wheat flour, sugar, shortening, and an amount of powder of microencapsulated polyphenols</td>
<td>Phenolic compound</td>
<td>Microencapsulation can enhance the stability of CBS antioxidant polyphenols. This promising technique can enrich bakery products with polyphenols when combined with spray-drying and maltodextrins.</td>
<td>[37]</td>
</tr>
<tr>
<td>Chocolate</td>
<td>Cocoa mass, cocoa butter, milk powder, whey powder, powdered soy lecithin, polyglycerol polyricinoleate, palm oil, coconut oil, treated and unthreatened cocoa shell</td>
<td>Dietary fibre and phenolic compound</td>
<td>CBS causes a slight reduction in polyphenol content as a fiber source to chocolate, but it is not a significant difference from commercial chocolates. Other ingredients in the chocolate recipe also impact polyphenol levels, indicating a need for further research to understand the precise mechanisms and implications of these interactions.</td>
<td>[45]</td>
</tr>
<tr>
<td>Pork sausage</td>
<td>Pork meat, back fat, ice, NPS, Sugar, mixed spice, CBS powder</td>
<td>Dietary fibre</td>
<td>CBS powder at concentrations of 0.75% and 1% in emulsion-type sausages led to positive effects, including enhanced moisture content, improved emulsion stability, increased viscosity, favorable color characteristics, and sensory attributes.</td>
<td>[46]</td>
</tr>
<tr>
<td>Gluten-free Bread</td>
<td>Corn, rice cream soup, tapioca starch, sugar, vegetable fibres, salt, thickening agents, flavourings.</td>
<td>Dietary fibre</td>
<td>Adding various dimensional fractions of CBS affected the properties of gluten-free bread, such as proximate composition, water absorption, crumb grain, specific volume, moisture content, and color. The supplementation improved bread color and texture, indicating the potential of CBS fractions as a functional ingredient for enhancing gluten-free bread.</td>
<td>[47]</td>
</tr>
</tbody>
</table>

Furthermore, the research conducted by Barišić et al. (2020) highlighted the feasibility of incorporating cocoa shells as a source of dietary fiber into chocolate production with minimal impact on polyphenol and methylxanthine content. While this addition led to a slight reduction in polyphenol content, it was not significant compared to commercial chocolates, emphasizing the potential for enhancing the nutritional profile of chocolate products.
However, the interactions between cocoa butter equivalents, proteins, and polyphenols require further investigation to understand their implications for bioavailability. Furthermore, other ingredients in chocolate formulations influenced polyphenol levels, underscoring the importance of additional research to elucidate the precise mechanisms involved [45].

In a separate study, Choi et al. (2019) investigated the utilization of CBS powder at concentrations of 0.75% and 1% in emulsion-type sausages. Including CBS powder led to positive effects, including enhanced moisture content, improved emulsion stability, increased viscosity, favorable color characteristics, and sensory attributes. Furthermore, the addition of CBS powder also exhibited inhibitory effects on lipid oxidation. This discovery underscores the potential of CBS powder as a naturally derived component to augment the quality of meat products [46]. Lastly, Rinaldi et al. (2020) investigated the addition of different dimensional fractions of CBS to gluten-free bread, which impacted various product characteristics. Although adverse effects were observed regarding crumb grain and specific volume, the supplementation improved bread color and textural attributes [47].

In summary, these studies collectively underscore the versatility of CBS as a valuable ingredient in food products, offering opportunities for improved nutritional profiles, enhanced product quality, and the creation of innovative, health-conscious food options.

3.2.2 CBS as Functional Beverages

CBS has emerged as a versatile ingredient for beverage products, as highlighted by several studies in Table 3. Dos Anjos Lopes et al. (2021) demonstrated that CBS is rich in fibers and phenolic compounds, positioning them as valuable ingredients for various food products. In their study, iced tea made from CBS proved to be a simple, cost-effective, and reasonably well-accepted beverage option, with a notable phenolic compound content, making it an eco-friendly choice for health-conscious consumers [48]. Delgado-Ospina et al. (2023) carried out a study that concluded that CBS infusion is safe for consumption, nutritious, and beneficial to health. This beverage contains important macro- and micronutrients and water-soluble pigments such as polyphenols, anthocyanins, and melanoids, potentially providing various health benefits. It's worth noting that particle size reduction may intensify bitter and astringent flavors in such infusions [49]. Adi et al. (2023) explored the health benefits of CBS Criollo tea, finding that it had antioxidant properties and could control blood cholesterol, suggesting its potential as a functional beverage [50].

<table>
<thead>
<tr>
<th>Type of Products</th>
<th>Ingredients</th>
<th>Functional Compound</th>
<th>Result</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iced Tea</td>
<td>CBS, sugar, water, and ice</td>
<td>Phenolic content</td>
<td>The iced tea made from CBS demonstrated simplicity, affordability, reasonable acceptability, and a notable phenolic compound content, making it a potential eco-friendly and functional beverage option for cost-conscious consumers.</td>
<td>[48]</td>
</tr>
<tr>
<td>CBS Infusion</td>
<td>CBS at different particle sizes, water</td>
<td>Phenolic content, antioxidant capacity, volatile organic compounds</td>
<td>Essential macro- and micronutrients, along with water-soluble pigments such as polyphenols, anthocyanins, and melanoids, are provided by CBS infusion, which can contribute to health benefits. However, a reduction in particle size may intensify bitter and astringent flavors.</td>
<td>[49]</td>
</tr>
<tr>
<td>Type of Products</td>
<td>Ingredients</td>
<td>Functional compound</td>
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<tr>
<td>CBS Criollo Tea</td>
<td>CBS, lemongrass, ginger, turmeric, aromatic ginger, mineral water</td>
<td>Flavonoid, condensed tannins, steroid/triterpenoid</td>
<td>CBS extract has strong antioxidant properties, effectively reducing DPPH free radicals, and may help maintain healthy blood cholesterol levels. Lighter-colored samples with less CBS were preferred for color and aroma, while samples with less CBS were favored for taste.</td>
<td>[50]</td>
</tr>
<tr>
<td>CBS Beverage</td>
<td>CBS with different particle size, water</td>
<td>Polyphenol content, theobromine, and caffeine</td>
<td>The most functional beverages were produced with the most petite particle sizes, mainly when percolation techniques were used. Production using the French press technique was not dependent on CBS particle size, which could simplify the process.</td>
<td>[10]</td>
</tr>
<tr>
<td>Tea</td>
<td>Cocoa beans of 3 different origins (Vietnam, Malaysia, and Venezuela), water</td>
<td>TPC, TFC, antioxidant capabilities, and methylxanthine compound</td>
<td>Regional differences in TPC, TFC, and antioxidant capabilities were observed in single-origin cocoa bean shells (CBS) and nibs. The highest antioxidant properties were exhibited by raw CBS from Venezuela, which could tolerate roasting up to 100°C, influencing the cocoa tea's antioxidant properties and flavor profiles.</td>
<td>[49]</td>
</tr>
<tr>
<td>CBS beverage on capsules and tea bags</td>
<td>CBS, cocoa beans, mineral water, and aromatic ingredients</td>
<td>Total Phenolic Content, Radical Scavenging Activity, α-Glucosidase Inhibition Capacity</td>
<td>The coconut-flavored formulation is well-received by consumers in capsule and tea bag forms, as CBS is a functional ingredient in hot beverages.</td>
<td>[51]</td>
</tr>
</tbody>
</table>

Rojo-Poveda et al. (2019) also studied various extraction techniques applied to CBS, yielding beverages with distinct chemical profiles and consumer characteristics. While smaller particle sizes resulted in more functional beverages, highly functional options with abundant polyphenols and methylxanthines were less favored regarding taste and flavor. This indicates room for optimization to enhance consumer acceptance, possibly through encapsulation or adding pleasant ingredients [10]. Siow et al. (2022) investigated the antioxidant content and activity of single-origin CBS compared to nibs, revealing regional differences in their phenolic content and antioxidant capabilities. Venezuela's raw cocoa bean hulls exhibited the highest antioxidant properties, suggesting the potential for cocoa tea with distinct regional flavors and beneficial antioxidant effects [52]. Lastly, Cantele et al. (2020) investigate the use of CBS as a functional ingredient in hot drinks. The findings showed consumers liked both capsule and tea bag forms of CBS in their beverages. Moreover, the beverages contained significant amounts of polyphenols and exhibited functional properties such as antiradical and antidiabetic capacities, with over 50% in vitro bioaccessibility. However, more research is needed to confirm whether these health benefits are practical in vivo.

These studies collectively underscore the versatile applications of CBS in beverage products, offering both functional and flavorful options for consumers [51].
3.2.3 The potential development of CBS as a fermented functional beverage

CBS possesses high levels of polyphenolic compounds and exhibits strong antioxidant activity, making it a promising material for functional drink development. Fermentation is a well-established technique to enhance product quality, prolong shelf life, and increase functionality [53]. Fermented products are recognized for maintaining quality and safety, improving taste, and offering health benefits due to increased bioactive components from microbial and enzymatic transformations [54–56]. Moreover, fermented products can promote the growth of beneficial probiotics, supporting digestive health and microbial balance [57].

Kombucha tea, a fermented beverage produced by a community of bacteria and yeasts (SCOBY), has traditionally been made from sweet black tea. However, recent advancements have introduced new raw materials, including cascara, a coffee processing waste. Studies show that cascara-based kombucha exhibits enhanced antioxidant activity and increased phenolic compound content [58–61].

Water kefir, another probiotic drink, offers diverse ingredient options, such as tea, flowers, and fruit juice. Research has explored using various raw materials, including rosella flower tea, butterfly pea flower, soursop leaf tea, and kersen leaves. These studies have reported increased flavonoid content, anthocyanins, antioxidant activity, and the production of volatile organic compounds (VOCs), all contributing to enhanced functionality in water kefir [62–67].

Considering these findings, CBS presents substantial potential as a raw material for developing functional drinks through fermentation. Such an approach could unlock new opportunities for innovative beverage products with enhanced functionality and health benefits.

4 Conclusion

This review comprehensively explores CBS and its potential applications in food and beverages as a promising by-product for substantial value addition, especially as a functional ingredient. Studies in CBS as functional food showcase versatility, creating innovative, health-conscious options in biscuits, muffins, chocolate, pork sausages, and gluten-free bread. Similarly, in CBS as a functional beverage, the studies highlight its applications in tea, providing both practical and flavorful choices. Given the limited literature, further exploration of CBS-based fermented beverages, like kombucha and kefir, is crucial for unlocking untapped potential.

References


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