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Cocoa honey: Agro-industrial waste or underutilized cocoa by-product?

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ABSTRACT

The global cocoa and chocolate market is projected to reach EUR 169 billion by 2026 due to factors such as the growth of confectionery products in Asian countries and increased demand for premium cocoa-based products. In addition, there is an increasing demand for products with high cocoa content and organic chocolates. International commodity price fluctuations and the COVID-19 pandemic have had negative impact on global market prices also influencing the efficiency of circular economy. Therefore, cocoa production chain faces the challenge of finding sustainable ways to increase production while meeting the demands of modern society. Innovative developments in this area include adding value to residues, which account for approximately 80% of the fruit. Cocoa honey is a translucent juice produced during the cocoa fermentation process, with chemical and sensory characteristics similar to cocoa pulp. This juice has high contents of pectin, minerals, and fructose and technological potential to develop new products is foreseen. Its sweet taste, for instance, can be exploited in food preparations as a natural substitute for refined sugar. This review aimed to elucidate the nutritional, technological, and economic importance of the use of this edible underutilized by-product through innovative applications in the food and beverage industry.

1. Introduction

Cocoa was exploited by the Mesoamerican people in the humid forest region along the Orinoco River basin, a warm region of Central America, probably since 1000 BCE. This perennial tree fruit was used as an ingredient in the preparation of a strong, bitter and spicy beverage consumed during political and religious rituals by Moda et al. (2019). In 1737, the species was named *Theobroma cacao* by the Swedish botanist Carl von Linné, and the term cocoa ("food of the gods") refers to the divine origin that ancient people attributed to this fruit. With maritime expansions, cocoa was taken by Spanish explorers to Europe in the 16th century, where the cocoa-based bitter drink was modified, and new recipes containing sugar and milk were developed and incorporated into the European diet (Henderson et al., 2007). Currently, cocoa and its derivatives are present in diets worldwide.

2. Market and challenges

Economic exploitation of cocoa is mainly based on the use of its seeds (often called "beans") by chocolate processing industries. Misevic et al. (2020) projected the global size of the chocolate confectionery market from EUR 116.79 billion in 2017 to exceed EUR 169 billion in 2026. It is estimated that the overall European market alone could grow up to USD57 billion by 2024 (Mordor Intelligence, 2019). In addition, the Asia-Pacific region is a strong market for cocoa ingredients, with 4.5% increase in consumption expected between 2015 and 2020, compared with 1.7% worldwide (Euromonitor International, 2016). Factors such as the growth of confectionery in countries as China and India and the increased demand for healthy confectionery products and premium foods are some of the incentives for new business in the contemporary cocoa world. Another stimulating factor for market growth is the increasing demand for products with high cocoa content and organic chocolates (Jambor et al., 2017).

Cocoa is, therefore, a strategic commodity, but as an export product, its market is hampered by international price fluctuations. The COVID-19 pandemic affected the cocoa market, reducing the global demand and stability of various logistic chains. An increase of 1.7% in the world production of cocoa was estimated for 2019 before the COVID-19 interference (Ginatta et al., 2020). A good example of logistic issues is the difficulty related to international shipping of containers of cocoa derivatives. The craft and small chocolate businesses were the most affected by cancellation of industry events and closure of shops specialized in high-quality chocolate in the recessive global trend. In some cocoa farms located in isolated areas, production was maintained despite the re-

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strictions in labor activities and supply delivery. Nevertheless, increased chocolate sales were observed in many countries during the COVID-19 social distancing. This increase may be related to the sale of chocolate and derivatives in food retail and via e-commerce. In addition, chocolate can be “a source of indulgence and comfort that consumers look for in times of uncertainty” (CBI, 2020). Extension of the effects of the COVID-19 pandemic on this commodity will depend on many factors: (i) profile of demand for chocolate in the near future; (ii) extension of the effects of the pandemic on Ivory Coast and Ghana, which are responsible for approximately 60% of the global cocoa production; (iii) extension of economic disruptions in the productive and distribution chain; (iv) changes in the purchasing power of current consumers of chocolate and derivatives (CBI, 2020).

Several alternatives have been proposed to maintain the economic balance of the cocoa market preserving local biodiversity, such as diversification of production and, in the case of family farming, the use of agroforestry systems (Djuideu et al., 2021). Adapting the cocoa chain to current international challenges requires an innovative ability and, regardless of the current scenario, the tendency points to a growing demand for chocolate with high cocoa content and products with differentiated consumption experiences.

3. Cocoa production

Approximately 4.834 million tons of cocoa were produced worldwide in 2018/19 to meet the demand for this product. This amount corresponds to an increase of 3.9% in relation to 2017/18. According to the International Cocoa Organization (ICCO, 2019), currently, 85% of the global production of cocoa beans is concentrated in seven countries: Ivory Coast, Ghana, Ecuador, Cameroon, Nigeria, Indonesia, and Brazil. Conversely, processing and industrialization of cocoa predominate in regions that do not produce the fruit, such as Europe (37%) and the USA (8%). Some of the largest chocolate industries are located in Europe, the USA and Japan, but cocoa production outside these countries reduces costs and is a strategy to increase appreciation for fine-flavored and artisan cocoa products in domestic markets (Escobar-Osorio et al., 2019). Unlike the other major cocoa producing countries, Brazil has a well-established production chain: it produces the fruit, holds an industrial cocoa bean processing park, and manufactures chocolate (Conceição et al., 2020).

In addition to the 2020s world economy problems, climate change can cause a severe reduction in cocoa production in Western Africa, a region that concentrates approximately 70% of the global cocoa production. According to Ginatta et al., 2020, efforts are also needed to overcome challenges such as low productivity, climate change, and food security in Latin American cocoa, aiming at increased quality standard and diversity of flavors, with environmental respect.

Cocoa production in Brazil is mainly concentrated in the states of Bahia and Pará. Although a decline was verified in the early 1990s due to cocoa diseases and socioeconomic factors, the state of Bahia, where approximately 70 chocolate brands derived from cocoa of origin are available, has been successful in increasing productivity per hectare and verticalizing the production chain in its southern region. More recently, a commodity-driven cocoa expansion reached southeastern Pará state (Schroth et al., 2016) and nowadays Bahia state produces around 54.13% and Pará Sate accounts for 40% (Conceição et al., 2020).

New developments in the cocoa fermentation process have resulted in shorter production time and improvement in aroma quality in Ecuador. In addition, the innovations implemented do not require the use of a large amount of mucilage to start fermentation, increasing the disposal volume of this by-product. The artisanal use of cocoa honey (cocoa mucilage juice) has been employed by a small segment as a way to increase the income of middle-sized producers. Ecuador is working to introduce the ISO 34101 criteria for sustainable production of cocoa (premium, organic and sustainable cocoa) as a differentiation strategy (Ginatta et al., 2020).

In Peru, the adoption of a hybrid variety (CCN-51) resulted in sixfold increase in cocoa production 1998 to 2018, when the yield reached 800 kg/ha (Blare et al., 2021). According to Pisco-Caldas (2019), 0.59 kg of cocoa honey (*exudado*) is obtained for each kilogram of dry beans in Peru. Aiming to reduce the consequent environmental impact of discarding this product, a beverage was prepared using cocoa honey and whey, another under-utilized by-product. The minimum profit margin calculated for trading this experimental juice was 40.7%.

In Colombia, there are many interesting practices and scenarios aimed at increasing technology and quality of cocoa production, including changes in the fermentation system to allow adequate drainage of cocoa honey during this process. Although Colombia is still struggling to improve the classification of domestically produced cocoa and to increase market participation, the country features environmental conditions that favor the production of premium cocoa products, and approximately 95% of its production comprises fine-flavor cocoa (Escobar-Osorio et al., 2019). Production of fine-flavored cocoa depends on many factors, including fermentative conditions, which are important to maintain chocolate sensory characteristics to differentiate fine from bulk flavor (Santander et al., 2021).

Ivory Coast is responsible for approximately 40% of the global cocoa production, providing income for 20% of its population. However, global warming has affected the Ivorian production, with severe economic consequences in the last decade (Koissy and N’zué, 2020). In Ghana, cocoa is the most important export product and the major activity for 30% of its population. Local production comprises mainly cocoa liquor, cocoa butter, cocoa powder and cocoa cake, along with a small production of confectionary products (Aboud and Sahinli, 2019). Despite the low productivity issue, Ghanaian cocoa has prominent international reputation because of its high quality, and most of its production is for export (Victor et al., 2010).

4. Cocoa honey production during cocoa processing

Cocoa fruits (pods) have a thick shell filled with seeds (beans) embedded in a mucilaginous white pulp. After harvesting, the fruits (pods) are opened or broken, still in the field, and the beans are removed along with the pulp (Rojo-Poveda et al., 2020). This process results in a mass of cocoa beans and, still in the field, a spontaneous fermentation process immediately begins. Fermentation continues in troughs and consists of an important step to remove the mucilaginous pulp and develop chocolate flavor precursors. There are several species of microorganisms that play an important role in the hydrolysis and solubilization of cocoa pulp mucilage. Pectinolytic enzymes that act in the beginning of the fermentation step degrade pectin and, therefore decrease the viscosity of the cocoa mass, facilitating the incorporation of oxygen and stimulating the growth of acetic bacteria that continue the fermentation process (Chagas Junior et al., 2020). Metagenomics analysis of classical spontaneous cocoa fermentation has been recently published (Almeida et al., 2020). After fermentation, the cocoa beans are dried, roasted, heated, crushed and peels are removed. Next, the resulting cocoa nibs, butter and beans are used in the production of chocolate and confectionaries.

From post-harvesting to dry bean production, the cocoa industry generates a significant amount of agro-industrial waste such as pod shell, pulp and seed peel (Ruesgas-Ramón et al., 2019). In addition to these residues, sour-sweet juice is drained as result of pulp liquefaction due enzymatic action over pectin (Santos et al., 2014; De Vuyst and Leroy, 2020; Díaz-Muñoz et al., 2021). Production of this by-product begins during the breaking of fruits in the field, continues during transport to the fermentation site, and is mainly drained during the step of cocoa paste fermentation. The process is traditionally carried out using wood presses, but stain less steel equipment has already been introduced in some farms, with the advantage of reducing contamination by microorganisms and increasing the volume of juice obtained, without influencing the product characteristics (Abballe et al., 2021). Fig. 1 shows some stages of cocoa fruit processing.

Fig. 1. Images of cocoa fruit processing to obtain cocoa beans. A: Intact cocoa fruit; B: Open cocoa pod showing the thick shell surrounding the seeds embedded in the mucilaginous white pulp; C: Broken cocoa fruit exposing the internal shell; D: Cocoa honey dripping from the mucilage; E: Fermentation of cocoa beans; F: Dry cocoa beans; G: Cocoa honey. Pictures by C.P.G. (author) and free images from Pixabay.

Fig. 2. Aspect of cocoa honey.

This translucid juice has chemical and sensory characteristics similar to those of the original pulp and is regionally called cocoa honey (*miel de cacao* in Spanish; *mel de cacau* in Portuguese) (Santos et al., 2014), also cited in the literature as cocoa sweating and exudado (Vásquez et al., 2019; Balladares et al., 2016). The name cocoa honey refers to the macroscopic characteristics and flavor of this juice, which resembles sensory characteristics of bee's honey such as the sweet taste, although it is not a bee product.

With the continued increase in global demand for cocoa and chocolate, the industry faces the challenge of increasing production and sustainability in the cocoa chain. Development of innovative uses of cocoa residues (shells, mucilage and honey), which account for approximately 80% of cocoa fruit, is of great importance for the producing countries.

One initial and extremely important issue to speed the development of cocoa honey-based products lies in the small number of scientific reports and, therefore, of scientific data, that this by-product features in the international literature. In addition, most of the theses, papers, and reports addressing cocoa honey published to date have been developed in cocoa-producing countries and have thus mostly been published in local languages such as Portuguese and Spanish, limiting the spread of information. The appearance of cocoa honey is shown in Fig. 2.

5. Cocoa honey identity

Some physicochemical characteristics and constitution of cocoa honey described in the literature are presented in Table 1. Cocoa honey is rich in carbohydrates, and total sugars, is acid, and has low percent ash content (~0.2%) (Neto et al., 2016; Santos et al., 2014), low fat profile (< 3.54% lipids) and possesses minerals such as calcium, magnesium and phosphorous (Anvoh et al., 2009). Total dietary fibers content in cocoa honey is lower than 1% (Table 1), although Vásquez et al. (2019) reported 16.89%. Total soluble solids content of 14.03 Brix (Neto et al., 2016) has been described for a cocoa honey sample of Brazilian origin. Balladares et al. (2016) reported higher total soluble solids content (19.6 Brix) for an Ecuadorean cocoa honey.

Calcium, iron, sodium, potassium and zinc are some of the minerals detected in cocoa honey (Table 2). Calcium content is noteworthy since its amount in cocoa honey (171.5 mg L^{-1}) is higher than in cocoa pulp (54 mg/kg) (Anvoh et al., 2009; EFSA, 2019).

Regarding pH, the literature has average reported values between 2.76 (Brazilian sample) (Neto et al., 2016) and 3.58 (Ecuadorean sample) (Balladares et al., 2016), corroborating the acidic flavor of this product. Natural acidity is an important factor to limit the development of some contaminant microorganisms, making the medium restricted to lactic and acetic bacteria, molds, and yeasts. As a naturally flavored sour-sweet juice, it presents reducing sugars, varying between ~8 and 10% in Brazilian and 6.39% in the Ecuadorean sample studied by Balladares et al. (2016). These differences may be related either to the different origins or to the condition of the samples analyzed, since cocoa fruits utilized in Balladares et al. experiments were contaminated by pathogens such as *Moniliophthora perniciosa* (witches' broom), *M. roreri*, or *Phytophthora palmivora* (Balladares et al., 2016).

Glucose (2.13–21.4%), fructose (1.06–4.42%) and sucrose (2.13–4.06%) are the main carbohydrates found in cocoa honey (Fig. 3) (Leite et al., 2019; Balladares et al., 2016; Neto et al., 2016; Anvoh et al., 2009; Gyedu and Oppong, 2003). Overall, the contents of fructose, glucose and sucrose in cocoa honey are important for proposing processing parameters, such as the ideal temperature for thermal treatments and the control of degradation events associated with fermentation. These parameters can also be utilized to ensure product quality, including the detection of possible adulterations.

Vitamin *C* levels in cocoa honey are between 7.64 and 10.9%. Although this amount does not make the vitamin *C* content in cocoa honey comparable with those of fruits such as orange and tangerine, a glass of cocoa honey juice (200 mL) corresponds to over 20% of the recommended dietary allowance (Silva et al., 2014). This allowance is in the range of 75–110 mg although it varies according to country, gender and healthy conditions (Carr and Lykkesfeldt, 2020). Ingestion of fresh cocoa honey without processing is a common habit during cocoa production by nearby community, taking advantage of all nutritional properties (González and Jaimes, 2005). Literature suggests that processed juices can also retain sensory and nutritional quality, including vitamin *C* content (Atuonwu et al., 2020).

6. Cocoa honey processing

The high microbial load present in the cocoa fruit, associated with the artisanal conditions of its post-harvesting process and the improper materials utilized in the construction of fermentation troughs and utensils, shorten the shelf life of cocoa honey, making it an underutilized product. Even after removal of cocoa honey from the fermentation trough, microorganisms are still active, producing rheological and sensory changes. Thus, a major obstacle to the use of cocoa honey to prepare

Table 1
Composition and nutritional evaluation of cocoa honey.

Source	Acidity (%)	Ash (%)	Carbohy-drate (%)	Density (g/mL)	Fat (%)	Moisture (%)	Pectin (%)	pH	Reducing Sugars (%)	Total Sugars (%)	TSS (Brix)	Total Fibers (%)	Total Protein (%)
Nunes et al, 2020 [a]	8.33 ± 0.60	0.36 ± 0.05	19.50 ± 1.20	nr	1.45 ± 0.20	86.38 ± 0.09	0.51 ± 0.01	3.50 ± 0.01	10.41 ± 0.05	18.00 ± 0.05	17.00 ± 0.01	nr	0.62 ± 0.17
EFSA 2019[b]	nr	0.50 ± 0.20	19.5 ± 1.20	nr	<0.2	78.70 ± 1.10	nr	nr	nr	17.00–20.00	16.00±2.00	0.80 ± 0.50	0.60 ± 0.20
Leite et al., 2019[c]	10.34± 0.00	0.59± 0.15	11.80 ± 0.09	nr	0.19 ± 0.08	85.86 ± 0.09	0.36 ± 0.02	3.51 ± 0.04	nr	14.70 ± 8.60	13.30 ± 0.01	nr	1.20 ± 0.49
Pacheco and Trujillo (2019)[c]	nr	0.23	16.47	nr	0.01	82.46	nr	3.43–3.72	nr	nr	16.0–17.0	0.14	0.69
Pisco-Caldas, 2019[b]	0.36	0.30	nr	nr	nr	82.43	nr	4.89	nr	17.57	nr	nr	1.08
Sosa and Manayay, 2018[c]	1.08	0.40	14.57	1.058	0.10	84.61	nr	3.20	2.93	15.49	16.60	0.10	0.22
Balladares, et al., 2016[c]	nr	nr	nr	1.10 ± 0.01	nr	nr	nr	3.58 ± 0.07	6.39	12.33	19.60 ± 0.57	nr	nr
Neto et al., 2016[c]	0.73 ± 0.00	0.23 ± 0.00	nr	nr	nr	87.22 ± 0.01	nr	2.76 ±0.02	10.20 ± 0.00	nr	14.03 ± 0.06	nr	nr
Torres-Vallejo et al., 2016[c]	0.91	nr	nr	1.076	nr	80.50	nr	3.87	nr	nr	16.00	nr	0.38
Santos et al., 2014[c]	0.07 ± 0.00	0.26 ± 0.01	nr	nr	0.25 ± 0.02	83.21 ± 0.94	0.078 ± 0.00	3.30 ± 0.10	8.63 ± 0.04	11.30 ± 0.24		0.23 ± 0.06	1.11 ± 0.04
García and Moreta, 2013[c]	1.00	0.30	nr	nr	0.10	86.50	nr	3.59	nr	nr	15.00	0.10	0.40
Luzuriaga, 2012[c]	1.00	0.30	nr	nr	0.10	86.50	nr	3.78	nr	16.5	19.00	0.10	0.40
Anvoh et al., 2009[b]	nr	3.76 ± 0.84	nr	nr	3.54 ± 0.20	85.30 ± 8.60	nr	3.75 ± 0.81	nr	nr	16.17 ± 0.74	nr	7.20 ± 0.21

[a]cocoa pulp; [b]cocoa juice and [c]cocoa honey.

Table 2
Some minerals reported in cocoa honey.

Element	Leite et al., 2019 (mg.100 mL^{-1})	Gyedu and Oppong, 2003 (mg.100 mL^{-1})	Anvoh et al., 2009 (mg/L)
Aluminum (Al)	0.15 ± 0.07	nr	nr
Barium (Ba)	0.38 ± 0.01	nr	nr
Calcium (Ca)	nr	0.089	171.5 ± 34.01
Copper (Cu)	0.07 ± 0.00	nr	nr
Iron (Fe)	1.35 ± 0.02	nr	nr
Magnesium (Mg)	nr	0.086	82.5± 0.81
Manganese (Mn)	0.30 ± 0.01	nr	nr
Phosphorus (P)	nr	0.023	62.47 ± 3.43
Potassium (K)	nr	0.090	950 ± 16.32
Selenium (Se)	0.19 ± 0.00	nr	nr
Sodium (Na)	0.48 ± 0.04	0.085	30.5 ± 3.77
Zinc (Zn)	0.40 ± 0.01	nr	nr

nr = not reported

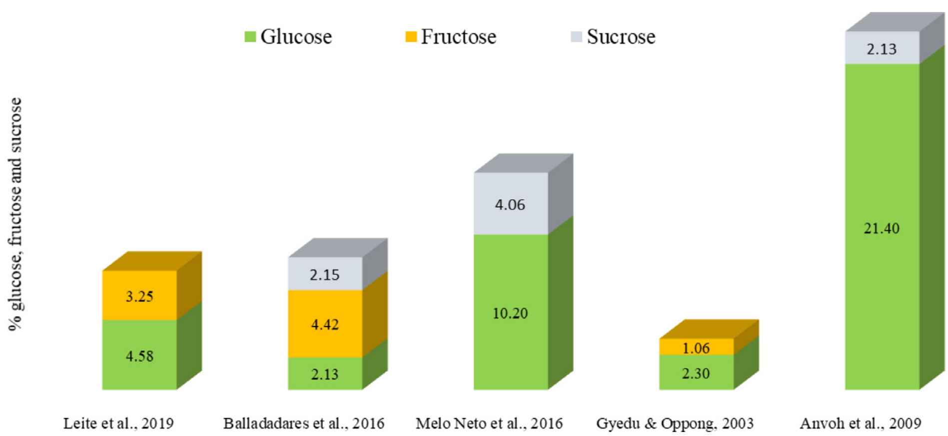

Fig. 3. Contents of glucose, fructose and sucrose in cocoa honey.

cocoa honey-based juices or as an ingredient for the food industry is adequate conservation, which should be capable of avoiding degradation due to the continuous fermentation process.

In natura cocoa honey is often frozen after its collection to avoid spoilage during transportation before processing (Santos et al., 2014). Temperatures described for conservation of this product are within -18 to -20 °C. Pasteurization (70 °C for 20 min) prior to frozen was reported (Leite et al., 2019). Although the cost and effects of cocoa honey processing are not reported, thermal pasteurization is an unexpensive process, estimated to cost of 1.5 ¢/L (orange juice) (Sampedro et al., 2013). The cost of pasteurization (processing) and refrigeration (storage) of probiotic mango juice was reported on a study on the technological and commercial viability of mango juice where the processing and storage costs were estimated to be equivalent to 20% and 5%, respectively of the total value of the raw material (Dhillon et al., 2021).

Other processes already utilized to stabilize beverages that can be evaluated to improve the quality of cocoa honey include quick pasteurization at higher temperature (Ishara and Gunasena, 2021), pasteurization combined with UV-C radiation and mild heat (Gouma et al., 2020), pulsed electric fields (Yildiz et al., 2019), and thermal-electrical ohmic heating (Abedelmaksoud et al., 2018).

Production of juice from cocoa honey was accomplished after partial removal of cocoa mucilage, homogenization, addition of ingredients, and moderate pasteurization at 77 °C for 1 min. In sequence, conservative additives sorbate and benzoate were added, followed by polyethylene packaging and rapid cooling at 10 °C for 8 min (Ortiz and James, 2005). Quimbita et al. (2013) proposed thermal stabilization of cocoa honey for nectar production using pasteurization processes with similar operating conditions (77 or 85 °C for 1 min and 88 °C for 15 s). In this process, chemical stabilization with sodium metabisulfite and ascorbic acid was used to avoid enzymatic darkening.

Among the chemical conservation processes, addition of metabisulfite has been widely used to inhibit enzymatic and non-enzymatic darkening reactions and effectively suppress microbial growth in the wine industry (Ahmadi et al., 2018). Although some concerns on sulfides toxicity (Han et al., 2020), successful experimental results have been reported using potassium metabisulfite to prepare cocoa honey jelly. Alternative processes, such as microwave and gamma radiation, are options to minimize the negative effects that some conventional conservation processes have on antioxidant contents such as ascorbic acid and vitamin C in cocoa honey (Firouzi et al., 2021).

Drying by atomization was reported as a good option to avoid cocoa honey degradation while retaining phenolic compounds contents. In the process, cocoa honey was mixed with 11% maltodextrin and the powder obtained retained 51% of vitamin *C* and 66.2% of antioxidant capacity (Huerta, 2019).

In Ghana, cocoa pulp has been used since the 1990s to produce alcoholic beverages, and evolved strains adapted to high temperatures for industrial fermentation of cocoa pulp have been developed (García-Ríos et al., 2021). Pasteurized, frozen cocoa pulp has recently been endorsed by the European Food Safety Authority (EFSA) regarding food safety, aiming at its commercialization in the European Community (EC) (EFSA, 2019). This can be a way to disseminate and increase the commercialization of cocoa honey juice, since it has physicochemical properties and macro- and micro-nutrient contents similar to those of cocoa pulp.

7. Technological potential of cocoa honey in the food industry

In the cocoa market, cocoa beverages present the greatest tendency to consumption increase, especially led by groups of consumers with increasing affinity to frequent snacking habit and consumption of beverages (Allied Market Research, 2019). Among these consumers, there are groups with specific food preferences, demanding new flavors that should have good acceptance of the unique flavor of cocoa honey. In the same way, there is an increasing trend in the consumption of fruits and fruit-derived products with functional properties. The so-called superfruits, which included cocoa, are a good example and comprise several other fruits such as açaí (*Euterpe oleracea*) from South America, goji berry (*Lycium barbarum*) from China, durian (*Durio zibethinus*) from Southeast Asia, and moringa (*Moringa oleifera*) from northwest India (Tacer-Caba, 2019).The superfruits market is sustained by the search for health and nutrition, which many times is related to the antioxidant properties and bioactive phytochemicals found in these fruits (Chang et al., 2019). An overview of the global tropical fruit puree segment estimated a market of USD 5 billion by the end of 2027 (Report Linker, 2021). The Food and Agriculture Organization of the United Nations (FAO) estimates an expansion of 9.6% in major tropical juices market in 2020 (Food and Agriculture Organization, 2019).

As afore mentioned, cocoa honey is rich in glucose (4.58 ± 0.12% w/v) and fructose (3.25 ± 0.03% w/v) (Leite et al., 2019). The latter is a carbohydrate with insulin-independent metabolism and slow absorption (glycemic index 20) that has less effect on glycemia than glucose (glycemic index 100) (Rytz et al., 2019). Sugar plays an important technological role in food and beverages production acting as flavor enhancement and balancing, color formation, volume and texture, promoting fermentation and ensuring the preservation against decay, being also an energy source for the human body (Goldfein and Slavin, 2015). However, consumption of sucrose-rich foods such as corn syrup is increasing, mainly in western countries. Sucrose uptake has been associated to increasing of non-communicated metabolic diseases such as obesity, type 2 diabetes, non-alcoholic fatty liver disease (Herman and Samuel, 2016) and immune system issues (Jones et al., 2021). In this way, high consumption of cocoa honey is not advised although the sweetness of cocoa honey can be exploited in food preparations as a substitute for sugarcane, corn syrup and refined sugar.

Sweeteners are among the primal ingredients in the confectionery industry, although the current tendency in the acceptance of sugar-free or low-sugar products (Misevic et al., 2020). On a related perspective, the Swiss multinational Food and Beverages Company Nestlé has developed a product named "sugar cocoa" using discarded cocoa pulp. This pulp contains compounds such as monosaccharides (fructose, fucose, galactose, glucose, rhamnose), disaccharides (lactose, maltose, sucrose) and oligosaccharides. "Sugar cocoa" does not contain refined sugar and is intended to be utilized in foods and beverages preferably in chocolate confectionery with a natural approach, providing natural sweetness without compromising flavor, texture and quality (Vieira et al., 2020).

The high viscosity of cocoa honey is associated with presence of pectin, which can reach 1.5 g/100 g^{-1} (Vásquez et al., 2019). Pectin is a cell wall polysaccharide that has versatile gelling properties and the ability to bind to several important natural industrial components, such as cellulose, starch, chitosan, and proteins (Gawkowska et al., 2018). This property makes pectin suitable as a gelling agent for fruit-based products such as jams, fruit drinks, confectionery, and bakery fillings, as reported for some tropical fruits such as umbú and cajá (Santos et al., 2021).

The pectin used in many sectors of industry is mostly recovered from agro-industrial waste. High-value, pectin-based products have been developed, namely, polymers and wrapping edible films from citrus peel (Mellinas et al., 2020; Jridi et al., 2020) and encapsulated bioactive compounds (Ishwarya et al., 2021). Due to its importance in the industry, several new extraction processes have been described aiming at new applications for pectin (Yu et al., 2021). The extraction and characteristics of pectin from cocoa shells aiming its industrial use have also been studied (Mollea and Chiampo, 2019).

The characteristic taste of cocoa honey justifies its use and application in the food industry. Fresh cocoa honey (extracted up to 24 h after fruit harvesting) contains pectin, sugar, and acids in levels adequate for producing jams (Santos et al., 2014). Products such as alcoholic beverages, syrups, jellies, and liqueurs made with cocoa honey have been produced by extractive communities, cooperatives, and artisanal food producers. Some of them include kefir-based drinks (Puerari et al., 2012), mixed açai and cocoa honey jelly (Neto et al., 2013), and sugar-free jam (Santos et al., 2014).

As the fruit, cocoa honey has phytochemicals with antioxidant capacity, such as flavonoids (7.19 $\mu g.mL^{-1}$) (Silva et al., 2014). The content of phenolic compounds is described to reach 101.50 ± 0.03 mg gallic acid equivalent.100 g^{-1} in cocoa honey (Silva et al., 2014), which is comparable to the value described for cocoa pulp (103.76±4.79 mg gallic acid equivalent.100 g^{-1}) (Endraiyani et al., 2016). Cocoa honey is also able to reduce 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals (6.34 g/g extract). Cocoa honey from Nacional x Trinitario variety was active in three antioxidant assays, 2,2′-azino-bis(3-ethylbenzothiazoline)-6-sulfonic acid (ABTS) radical inhibition, ferric reducing antioxidant power (FRAP) and oxygen radical absorbance capacity (ORAC) (8.54, 7.89, 1.33 µM Trolox Equivalent mL^{-1}, respectively) (Rodríguez and Joel, 2020). Organic acids were reported in cocoa honey constitution, mainly ascorbic, citric and malic acids (18.3±7.5, 9.1±0.6 and 3.6±0.5 mg mL^{-1}, respectively) (Vásquez et al., 2019).

Some informal reports have shown the use of cocoa honey in the production of ice-cream, mixed jellies, wines and vinegars, and the use of pectin in less-sugar jellies. The use of cocoa honey in foods was the target of some patents (Santos and Kalid, 2020; Scampini, 2020), listed in Table 3. Some related patents using cocoa pulp are also presented, including the evaluation of powered cocoa pulp juice in confectionary in Japan (Mizumura and Kitajima, 2020), as well as sweetening substances from the cocoa pulp for production of chocolate in Germany (Krähenmann and Windhab, 2019).

In addition to the exquisite flavor, coco honey marketing may add an extra gain of 0.6 dollars per kilogram of beans. Apart from the possibilities of using cocoa honey outside the chocolate industry, its employment in the development of novel cocoa/chocolate products is strategic.

8. The future of cocoa honey

Cocoa honey has been increasingly used in the past decades, although with limitations due to the scarcity of studies on conservation and technological improvement of its physicochemical, biochemical and microbiological characteristics, thus hindering its exploitation and commercialization (Silva et. al., 2014). As the modern cocoa industry urgently needs to minimize agro-industrial wastes and add value to by-products aiming the sustainability of food processing, it will certainly benefit from the incorporation of cocoa honey into innovative products such as cocoa-based beverages and premium chocolates. Frozen bottled cocoa honey is already being produced, and its addition in innovative foods and beverages is expected (Santos and Kalid, 2020). On a preliminary analysis, cocoa honey utilization seems to be economically feasible. It can be estimated that a farm with an average productivity of 300 kg of dried almond per ha generates 0.59 kg of cocoa honey per kg of dried almond (Kongor et al., 2018; Pisco-Caldas, 2019). Therefore, on a cultivated area of 100 ha, the average extraction of cocoa honey will reach 17,700 kg per crop. Using the methodology of Tesfaye et al. (2021) to calculate the economic feasibility, and estimating the unit cost of US$ 1.96 per kg, with 150% profit, an equilibrium point can be reached with 590 kg. Therefore, monthly profitability for the sale of pasteurized and frozen cocoa honey can reach US$ 1,947.00, with recovery of the initial investment in up to five years. The valorization of wastes and by-products with organoleptic, nutritional and functional characteristics important for human health, such as cocoa honey, requires modernization of production systems, which is of crucial importance for the bioeconomy of the countries where cocoa is among the most important commodities produced. The cocoa market growth will certainly adapt to the consumers' preference for products with sustainability seals. Initiatives to increase the sustainability of cocoa production also include ways to use cocoa pod husk. These husks are the main by product of cocoa processing (up to 75% weight of whole fruit) and have been studied for bio-fuels production, application in food industry (Lu et al., 2018) and to substitute pine wood in materials destined to furniture

Table 3
Patents on cocoa honey and cocoa pulp.

Patent number	Depositing institutions	Patent scope	References
BR 102013 005053-9 B1	University of São Paulo (USP, Sao Paulo, Brazil) and State University of Southwest Bahia (UESB, Bahia, Brazil)	Food compositions of chocolate and edible ice-cream containing cocoa honey	Lannes et al., 2013
BR 102015 013975-6 A2	Federal University of Bahia Recôncavo (UFRB, Bahia, Brazil)	Functional carbonated drink	Santos et al., 2015
BR 102016 025928-2 A2	Federal University of São João Del Rey (UFSJ, Minas Gerais, Brazil)	*In natura* cocoa pulp-based drink with probiotic addition	Magalhães et al., 2016
BR 102018016061-3 A2	Private deposit (Brazil)	Process of production of spirits (*aguardente*) through the preparation, fermentation and distillation of cocoa honey	Scampini, 2020
BR 102019008474-0 A2	National Industrial Learning Service (SENAI, Bahia, Brazil) & Federal University of Bahia (UFBA, Bahia, Brazil)	Drink obtained from cocoa honey and manufacturing process of the referred beverage	Oliveira et al., 2019a
BR 102019008531-2 A2	National Industrial Learning Service (SENAI, Bahia, Brazil) & Federal University of Bahia (UFBA, Bahia, Brazil)	Powdered cocoa honey obtained from concentrated cocoa honey and manufacturing processes of concentrated cocoa honey and powdered cocoa honey	Oliveira et al., 2019b
BR 102019008742-0 A2	Private deposit (Brazil)	Craft beer production using cocoa honey as an adjunct	Rodrigues, 2019
BR 102019009487-7 A2	Private deposit (Brazil)	Essences, perfumes and natural colonies obtained from the endocarp of the fruit, pulp or cocoa honey	Eskes, 2019
DE3112994 A1	Carle and Montanari SpA (Italy)	Process and apparatus for pasteurization-sterilization, deacidification and alkalization of cocoa juice	Bonora and Chiappa, 1980
EP 3 520 621 A1	Société des Produits Nestlé S.A. (Switzerland)	Chocolate products, ingredients, processes and uses	Festring et al., 2019
EP 3 777 550 A1	Private deposit (Germany)	Method for obtaining a sugar-containing substance from cocoa fruit and use of the sugar-containing substance in the production of chocolate	Hoppe et al., 2019
FR 2 849 374 B1	Private deposit (France)	Cosmetic and/or dermatological composition based on cocoa pulp	Derhy, 2002
JP 2021 506225 A	Société des Produits Nestlé S.A. (Japan)	Food products, ingredients, processes, and uses	Viera et al., 2018
OA 10776 A	*Association Ivoirienne des Sciences Agronomique* (AISA) *Centre Ivoirien de Recherches Tecnologiques* (CIRT) (Ivory Cost)	Manufacture of stabilized juice clarified vinegar wine from syrup jam and jelly from cocoa juice making cocoa liquor classifications	Koffi et al., 1993
PE 62018 Z	Private deposit (Peru)	Blender propeller to remove the slime or mucilage from cocoa and other fruits	Gavilan et al., 2016
US4331692A	Private deposit (USA)	Cocoa fruits and products	Drevici and Drevici, 1979
WO 2017/044610 A1	Private deposit (USA)	Method for production and use of syrup derived from the fruit pulp of the cacao pod	Toth et al., 2016
WO 2017/062603 A1	Wm. Wrigley Jr. Company (USA)	Shelf stable, high moisture fruit confection products from cocoa pulp	Willcocks et al., 2016
WO 2019/149292 A1	Reishi Colombia S.A.S. (Colombia)	Functional food and producing process	De Echeverri et al., 2018
WO 2020/115248 A1	Cabosse Naturals Nv (Belgium)	Cocoa pulp derived powder, method for obtaining thereof and its applications	Bernaert and Greiner, 2019
WO 2020/158927 A1	Meiji Co., Ltd (Japan)	Cocoa pulp juice dried powder, food product after blending, and producing methods	Mizumura and Kitajima, 2020
WO 2021/026089 A2	Mars, Incorporated (USA)	Spray dried cocoa pulp	Castro et al., 2020

industry (Veloso et al., 2020). Bioactive compounds with nutritional potential present in inedible cocoa residues have also been described (Balentić et al., 2018; Hamadi et al., 2020; Cádiz-Gurrea et al., 2020; Rojo-Poveda et al., 2020; Eletta et al., 2020, Vasquez et al., 2019).

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of fifteen promising chocolate markets published by Misevic et al. (2020) showed particularities in the demands of some countries that may inspire the cocoa industry to incorporate cocoa honey into several innovative products.

Agro tourism is among the initiatives that may assist with disseminating agricultural products with new flavors and unique ethnic and niche products (Péréz Gálves et al., 2020), experienced by cocoa-producer's countries such as Ghana (Bantacut and Raharja, 2018; Eshun and Tichaawa, 2020). In some Brazilian farms, tourists can participate in cocoa harvesting and taste fresh cocoa juice as it drips from the fruit. Production of chocolate with regional appeal was proposed as strategy for the integration between the cocoa chain and tourism in the Amazon region. Meanwhile, cocoa honey has also gained the media and consumers in the producing countries, and there are various gourmet recipes available online.

9. Conclusions

Changes in eating habits driven by several factors such as the search for health and the concern for sustainability have provided opportunities for the cocoa industry to grow outside conventional applications such as cocoa nibs, chocolate bars, and confectionery products. Moreover, the increasing purchasing power of consumers and the consequent higher level of expectation for new products comprise a strategic scenario for cocoa honey that features regional appeal, nutritional benefits, and unique sensory attributes. The dissemination of cocoa honey in regional fairs, tasting experience in visits to cocoa farms, and its incorporation into both homemade and gourmet recipes are emerging ways to introduce cocoa honey as a natural exotic juice into the national and international markets.

Additionally, the path towards rural sustainability that meets the United Nations Sustainable Development Goals (SDG) requires a new look at waste and by-products. New technologies and suitable conservation techniques aimed at extending shelf life, reducing contamination, and preventing degradation of nutritional compounds are essential for the incorporation of coca honey into the production chain.

The examples discussed in this review report the technological potential of cocoa honey for the food industry and the prospects for developing modern technologies for the use, conservation, addition of value and development of new functional and nutraceutical products from this important by-product of the cocoa industry. Further research in the area should also broaden the horizon, presenting possibilities for employing cocoa honey in the pharmaceutical and cosmetic industry, making cocoa production more sustainable as cocoa honey goes from residue/by-product to raw material.

Declaration of Competing Interest

none.

CRediT authorship contribution statement

Christiano Pedro Guirlanda: Visualization, Writing – original draft, Writing – review & editing. **Geisa Gabriela da Silva:** Writing – original draft, Writing – review & editing. **Jacqueline Aparecida Takahashi:** Writing – review & editing.

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REFERENCES

Abedelmaksoud, T., Mohsen, S.M., Duedahl-Olesen, L., Elnikeety, M.M., Feyissa, A.H., 2018. Optimization of ohmic heating parameters for polyphenoloxidase inactivation in not-from-concentrate elstar apple juice using RSM. J. Food Sci. Technol. 55 (7), 2420–2428.

Abballe, C., Gomes, F.M.L., Lopes, B.D., Oliveira, A.P.F., Berto, M.I., Efraim, P., Tfouni, S.V., 2021. Cocoa beans and derived products: effect of processing on polycyclic aromatic hydrocarbons levels. LWT Food Sci. Technol. 135. doi:10.1016/j.lwt.2020.110019, Article 110019.

Aboud, A., Sahinli, M.A., 2019. Swot and tows analysis: an application to cocoa in Ghana. Sci. Pap. Manag. Econ. Eng. Agric. Rural Dev. 19, 13–24.

Ahmadi, F., Lee, Y.H., Lee, W.H., Oh, Y.K., Park, K.K., Kwak, W.S., 2018. Preservation of fruit and vegetable discards with sodium metabisulfite. J. Environ. Manag. 224, 113–121. doi:10.1016/j.jenvman.

Almeida, O.G.G., Pinto, U.M., Matos, C.B., Frazilio, D.A., Braga, V.F., Von Zeska-Kress, M.R., De Martinis, E.C.P., 2020. Does quorum sensing play a role in microbial shifts along spontaneous fermentation of cocoa beans? An *in silico* perspective. Food Res. Int. 131, 109034. doi:10.1016/j.foodres.2020.109034.

Anvoh, K.Y.B., Zoro Bi, A., Gnakri, D., 2009. Production and characterization of juice from mucilage of cocoa beans and its transformation into marmalade. Pak. J. Nutr. 8-2, 129–133. doi:10.3923/pjn.2009.129.133.

Atuonwu, J.C., Leadley, C., Bosman, A., Tassou, S.A., 2020. High-pressure processing, microwave, ohmic, and conventional thermal pasteurization: quality aspects and energy economics. J. Food Process Eng. 43 (2), e13328.

Balladares, C., Chóez Guaranda, I., García, J., Sosa, D., Pérez, S., González, J.E., Viteri, R., Barragán, A., Quijano Avilés, M., Manzano, P., 2016. Physicochemical characterization of *Theobroma cacao* L. mucilage, in Ecuadorian coast. Emir. J. Food Agric. 741–745. doi:10.9755/ejfa.2016-02-187.

Balentić, J., Ačkar, D., Jokić, S., Jozinović, A., Babić, J., Miličević, B., Šubarić, D., Pavlović, N., 2018. Cocoa shell: a by-product with great potential for wide application. Molecules 23 (6). doi:10.3390/molecules23061404, Article 1404.

Bantacut, T., Raharja, S., 2018. Determination of the prospective processed cacao product and calculation of the added value in agro-tourism based on cacao agroindustry in pidie jaya regency. Acta Univ. Cibiniensis 22 (1). doi:10.2478/aucft-2018-0004.

Bernaert, H., Greiner, M., 2019. Cacao Pulp Derived Powder, Method for Obtaining Thereof and its Applications. Cabosse Naturals Nv, Belgium https://patents.google.com/patent/WO2020115248A1/en?oq=WO + 2020%2f115248 + A.

Blare, T., Corrales, I., Zambrino, L., 2021. Can niche markets for local cacao varieties benefit smallholders in peru and mexico? Choices 35 (316), 141. https://www.choicesmagazine.org/UserFiles/file/cmsarticle_764.pdf.

Bonora, B., Chiappa, O., 1980. Process and Apparatus for Pasteurisation-Sterilisation, Deacidification and Alkalisation of Cocoa Juice. Carle and Montanari SpA, Italy https://patents.google.com/patent/DE3112994A1/en?oq=DE3112994A1.

Cádiz-Gurrea, M.l.L., Fernández-Ochoa, A., Leyva-Jiménez, F.J., Guerrero-Muñoz, N., Villegas-Aguilar, M.C., Pimentel-Moral, S., Ramos-Escudero, F., Segura-Carretero, A., 2020. LC-MS and spectrophotometric approaches for evaluation of bioactive compounds from Peru cocoa by-products for commercial applications. Molecules 25. doi:10.3390/molecules25143177, Article 3177.

Carr, A.C., Lykkesfeldt, J., 2020. Discrepancies in global vitamin C recommendations: a review of RDA criteria and underlying health perspectives. Crit. Rev. Food Sci. Nutr. 1 (14). doi:10.1080/10408398.2020.1744513.

Castro, A.J., Glazier, B.D., Ben-Yoseph, E.M., Hsu, C.H., Kelleye, S., Unlu, E., Willcocks, N.A., Collins, T.M., 2020. Spray Dried Cacao Pulp. Mars Incorporated, USA https://patents.google.com/patent/WO2021026089A2/en?oq=WO+2021%2f026089+A2.

Chagas Junior, G.C.A., Ferreira, N.R., Lopes, A.S, 2020. The microbiota diversity identified during the cocoa fermentation and the benefits of the starter cultures use: an overview. Int. J. Food Sci. Technol. doi:10.1111/ijfs.14740.

Chang, S.K., Alasalvar, C., Shahidi, F., 2019. Superfruits: phytochemicals, antioxidant efficacies, and health effects–a comprehensive review. Crit. Rev. Food Sci. Nutr. 59, 1580–1604. doi:10.1080/10408398.2017.1422111.

Conceição, R.L.C., Macedo, R.D.D., Pires, M.M., 2020. Specialization and competitiveness: analysis of Brazilian exports of cocoa beans and products. Rev. Mex. Cienc. Agríc. 11 (6), 1207–1219. doi:10.29312/remexca.v11i6.2348.

De Echeverri, C.J., Restrepo Gutierre, S., Echeverri Jaramillo, A., Restrepo Gutierrez, S., 2018. Functional Food and Process for Producing Same. Reishi Colombia S.A.S, Colombia https://patents.google.com/patent/WO2019149292A1.

De Vuyst, L., Leroy, F., 2020. Functional role of yeasts, lactic acid bacteria and acetic acid bacteria in cocoa fermentation processes. FEMS Microbiol. Rev. 44 (4), 432–453. doi:10.1093/femsre/fuaa014.

Díaz-Muñoz, C., Van de Voorde, D., Comasio, A., Verce, M., Hernandez, C.E., Weckx, S., De Vuyst, L., 2021. Curing of cocoa beans: fine-scale monitoring of the starter cultures applied and metabolomics of the fermentation and drying steps. Front. Microbiol. 11, 3446. doi:10.3389/fmicb.2020.616875.

Dhillon, H.S., Gill, M.S., Kocher, G.S., Panwar, H., Arora, M., 2021. Preparation of *Lactobacillus acidophilus* enriched probiotic mango juice. J. Environ. Biol. 42, 371–378.

Djuideu, C.T., Bisseleua, H.D., Kekeunou, S., Ambele, F.C., 2021. Rehabilitation practices in cocoa agroforestry systems mitigate outbreaks of termites and support cocoa tree development and yield. Agric. Ecosyst. Environ. 311. doi:10.1016/j.agee.2021.107324, Article 107324.

EFSA - European Food Safety Authority, 2019. Technical report on the notification of pulp from *Theobroma cacao* L. as a traditional food from a third country pursuant to Article 14 of regulation (EU) 2015/2283. EFSA Support. Publ. 16, 1724E. doi:10.2903/sp.efsa.2019.EN-1724.

Eletta, O.A.A., Adeniyi, A.G., Ighalo, J.O., Onifade, D.V., Ayandele, F.O., 2020. Valorisation of cocoa (*Theobroma cacao*) pod husk as precursors for the production of adsorbents for water treatment. Environ. Technol. Rev. 9 (1), 20–36. doi:10.1080/21622515.2020.1730983.

Endraiyani, V., Ludescher, R.D., Di, R., Karwe, M.V., 2016. Total phenolics and antioxidant capacity of cocoa pulp: processing and storage study. J. Food Process. Preserv. 41 (4), e13029. doi:10.1111/jfpp.13029.

Escobar-Osorio, D.R., Juárez-Panzo, M., Martínez-López, B.Y., Romero-Cortes, T., Cuervo-Parra, J.A., Tirado-Gallegos, J.M., Utrilla-Vazquez, M., Morales-Ovando, M.A., 2019. Producción de etanol a partir de jugo de mucílago de cacao (*Theobroma cacao*) como subproducto de la fermentación. In: Proceedings of the VI Encuentro Internacional Sobre Biotecnologia En La. Tlaxcala, México UAT.

Eshun, G., Tichaawa, T.M., 2020. EuroEconomica developing agro-tourism tours on the cocoa sector in Africa: emerging issues from Ghana. EuroEconomica 39 (1). https://dj.univ-danubius.ro/index.php/EE/article/view/243.

Eskes, A. https://patents.google.com/patent/BR102019009487A2/pt?oq=BR + 102019009487.

Derhy, Y. https://patents.google.com/patent/FR2849374B1/en?oq=FR + 2849374B1.

Festring, D., Kuschel, B., Vieira, J.B., 2019. Chocolate Products, Ingredients, Processes and Uses. Société Des Produits Nestlé S.A., Switzerland https://patents.google.com/patent/EP3520621A1/en?oq=EP+3520621A1.

Firouzi, S., Khorshidi, A., Soltani Nabipour, J., Barzi, S.M.Z., Amani, M., Ay, M.R., 2021. Evaluation of gamma and electron radiations impact on vitamins for onion preservation. Appl. Radiat. Isot. 167. doi:10.1016/j.apradiso.2020.109442, Article 109442.

Gawkowska, D., Cybulska, J., Zdunek, A., 2018. Structure-related gelling of pectins and linking with other natural compounds: a review. *Polymers* 10 (7). doi:10.3390/polym10070762, Article 762.

Food, Agriculture OrganizationFAO, 2019. Ultra-processed foods, diet quality, and health using the nova classification system. Rome, Italy 48. http://www.fao.org/publications/card/en/c/CA5644EN/.

García, S.V., Moreta, F.A., 2013. Optimización y aprovechamiento del residuo (exudado del mucílago) de la almendra fresca del cacao (*Theobroma cacao* L.) CCN51 en la elaboración de vinagre. Tsafiqui Rev. Cient. Cienc. Soc. 4, 7–19.

García-Ríos, E., Lairón Peris, M., Muñiz Calvo, S., Heras, J.M., Ortiz-Julien, A., Poirot, P., Rozès, N., Querol, A., Guillamón, J.M., 2021. Thermo-adaptive evolution to generate improved *Saccharomyces cerevisiae* strains for cocoa pulp fermentations. Int. J. Food Microbiol. 342. doi:10.1016/j.ijfoodmicro.2021.109077, Article 109077.

Goldfein, K.R., Slavin, J.L., 2015. Why sugar is added to food: food science 101. Compr. Rev. Food Sci. Food Saf. 14 (5), 644–656. https://onlinelibrary.wiley.com/doi/full/10.1111/1541-4337.12151.

González, C., Jaimes, M., 2005. Desarrollo Experimental Del Proceso Para La Obtención De Jugo Derivado Del Mucílago De Cacao. Tesis de Grado, Universidad Industrial De Santander, Bucaramanga-Colombia.

Gouma, M., Álvarez, I., Condón, S., Gayán, E., 2020. Pasteurization of carrot juice by combining UV-C and mild heat: Impact on shelf-life and quality compared to conventional thermal treatment. Innov. Food Sci. Emerg. Technol. 64. doi:10.1016/j.ifset.2020.102362, Article 102362.

Gyedu, E., Oppong, H., 2003. Cocoa Pulp Juice (Sweatings) and its Potential for Soft Drink, Jam and Marmalade Production. International Workshop on Cocoa By-Products Ghana, Accra.

Hamadi, A., Yeddou-Mezenner, N., Lounis, A., Ali, R.M., Hamad, H., 2020. Upgrading of agro-industrial green biomass residues from chocolate industry for adsorption process: diffusion and mechanistic insights. J. Food Sci. Technol. 58 (3), 1081–1092. doi:10.1007/s13197-020-04622-z.

Han, X., Zhu, F., Chen, L., Wu, H., Wang, T., Chen, K., 2020. Mechanism analysis of toxicity of sodium sulfite to human hepatocytes L02. Mol. Cell. Biochem. 473, 25–37. doi:10.1007/s11010-020-03805-8.

Henderson, J.S., Joyce, R.A., Hall, G.R., Hurst, W.J., Mcgovern, P.E., 2007. Chemical and archaeological evidence for the earliest cacao beverages. Proc. Natl. Acad. Sci. 104 (48), 18937–18940. doi:10.1073/pnas.0708815104.

Herman, M.A., Samuel, V.T., 2016. The sweet path to metabolic demise: fructose and lipid synthesis. Trends Endocrinol. Metab. 27, 719–730. doi:10.1016/j.tem.2016.06.005.

Hoppe, J., Bachmeir, J., Aretz, J., 2019. Method for Obtaining A Sugar-Containing Substance from Cocoa Fruit and Use of the Sugar-Containing Substance in the Production of Chocolate. Alfred Ritter & Co KG Gmb, Germany https://patents.google.com/patent/EP3777550A1/en?oq=EP3777550A1.

Huerta, I.C.P., 2019. *Influencia Del Secado Por Atomización De Mucílago De Cacao (Theobroma Cacao l.) En El Contenido De Polifenoles y Capacidad Antioxidante.* Tesis Para Optar El Título De Ingeniero En Industrias Alimentarias. Universidad Nacional Agraria La Molina Facultad de Industrias Alimentarias, Lima, Perú.

ICCO, 2019. Production of cocoa beans. ICCO Quarterly Bulletin of Cocoa Statistics, Vol. XLV, No. 4, Cocoa year 2018/19. https://www.icco.org/wp-content/uploads/Production_QBCS-XLV-No.-4.pdf (accessed 8 May 2020)

Ishara, S., Gunasena, D., 2021. Heat resistant moulds in pasteurized fruit syrups. Eur. J. Agric. Food Sci. 3 (1), 104–111. doi:10.24018/ejfood.2021.3.1.199.

Ishwarya, S.P., Sandhya, R., Nisha, P., 2021. Advances and prospects in the food applications of pectin hydrogels. Crit. Rev. Food Sci. Nutr. 1 (25). doi:10.1080/10408398.2021.1875394.

Jambor, A., Toth, A.T., Koroshegyi, D., 2017. The competitiveness export of global cocoa traders. Agris line Pap. Econ. Inform. 9 (3), 27–37. doi:10.7160/aol.2017.090303.

Jones, N., Blagih, J., Zani, F., Rees, A., Hill, D.G., Jenkins, B.J., Bull, C.J., Moreira, D., Bantan, A.M., Cronin, J.G., Avancini, D., Jones, G.W., Finlay, D.K., Vousden, K.H., Vincent, E.E., Thornton, C.A., 2021. Fructose reprogrammes glutamine-dependent oxidative metabolism to support LPS-induced inflammation. Nat. Commun. 12 (1), 1–13. https://www.nature.com/articles/s41467-021-21461-4.

Jridi, M., Abdelhedi, O., Salem, A., Kechaou, H., Nasri, M., Menchari, Y., 2020. Physicochemical, antioxidant and antibacterial properties of fish gelatin-based edible films enriched with orange peel pectin: Wrapping application. Food Hydrocoll. 103, 105688. doi:10.1016/j.foodhyd.2020.105688.

Koffi, l.B., Kouakou, K., Bi, Z.I., Kouassi, A., Angbo, S.F., 1993. Manufacture of Stabilized Juice Clarified Vinegar Wine from Syrup Jam and Jelly from Cocoa Juice Making Cocoa Liquor Classifications. Association Ivoirienne des Sciences Agronomique (AISA) and Centre Ivoirien de Recherches Tecnologiques (CIRT), Ivory Cost https://patents.google.com/patent/OA10776A/en?oq=OA+10776+A.

Koissy, Y.V.A., N'zué, F.F., 2020. Climate change and cocoa production in Côte d'Ivoire: should we worry? J. Econ. Bus. 3 (2), 965–979.

Kongor, J.E., De Steur, H., Van de Walle, D., Gellynck, X., Afoakwa, E.O., Boeckx, P., Dewettinck, K., 2018. Constraints for future cocoa production in Ghana. Agrofor. Syst. 92 (5), 1373–1385.

Krähenmann, U., Windhab, E. https://patents.google.com/patent/DE102019004355A1/en.

Lannes, S.C.D.S., Da Silva, M.V., Da Silva, E.N., Ramos, D.D.C., Su, F., 2013. Food Compositions of Chocolate and Edible Ice Cream Containing "Cocoa Honey. University of São Paulo (USP, Sao Paulo, Brazil) and State University of Southwest Bahia (UESB, Bahia, Brazil) https://patents.google.com/patent/BR102013005053B1.

Leite, P.B., Machado, W.M., Guimarães, A.G., Carvalho, G.B.M.D., Teixeira Magalhães-Guedes, K., Izabel Druzian, J., 2019. Cocoa's residual honey: physicochemical characterization and potential as a fermentative substrate by *Saccharomyces cerevisiae* AWRI726. Sci. World J. doi:10.1155/2019/5698089.

Lu, F., Rodriguez-Garcia, J., Van Damme, I., Westwood, N.J., Shaw, L., Robinson, J.S., Warren, G., Chatzifragkou, A., Mason, S.M., Gomez, L., 2018. Valorisation strategies for cocoa pod husk and its fractions. Curr. Opin. Green Sustain. Chem. 14, 80–88. doi:10.1016/j.cogsc.2018.07.007.

Luzuriaga, D., 2012. Extracción y Aprovechamiento Del Mucílago De Cacao (Theobroma Cacao) Como Materia Prima En La Elaboración De Vino. Universidad Tecnológica Equinoccial. Quito-Ecuador. Thesis de grado. http://repositorio.ute.edu.ec/bitstream/123456789/4930/1/47745_1.pdf.

Magalhães, J.T., Valadares, H.M.S., Gonçalves, D.B., Granjeiro, P.A., Guimarães, G.M., Moreira, M.T., Soares, L.A., 2016. In Natura Cocoa Pulp-Based Drink with Probiotic Addition. Federal University of São João Del Rey (UFSJ, Minas Gerais, Brazil) https://patents.google.com/patent/BR102016025928A2/pt?oq=BR102016025928.

Gavilan, M.R., Gavilan, C.R.R., Gavilan, C.K.R..

Mellinas, C., Ramos, M., Jiménez, A., Garrigós, M.C., 2020. Recent trends in the use of pectin from agro-waste residues as a natural-based biopolymer for food packaging applications. Materials 13 (3). doi:10.3390/ma13030673, Article 673.

Neto, M., A., B., Bonomo, R.C.F., Fontan, R.C.I., Ferreira, A.C.R., Gonçalves, G.R.F., Mello, D.L.N., 2016. Physical chemical characterization and thermophysical properties of cocoa honey. Rev. Gest. Inov. Tecnol. 6 (1), 2944–2953. doi:10.7198/s2237-0722201600010016.

Melo Neto, B.A., Carvalho, E.A., Pontes, K.V., Barretto, W.S., Sacramento, C.K, 2013. Chemical, physico-chemical and sensory characterization of mixed açai (*Euterpe oleracea*) and cocoa´s honey (*Theobroma cacao*) jellies. Rev. Bras. Frutic. 35 (2), 587–593. doi:10.1590/s0100-29452013000200030.

Misevic, P., Volarevic, H., Peric, M., 2020. The trend analysis of less sugar chocolate confectionery markets. In: Proceedings of the *Economic and Social Development (Book of Proceedings), 52nd International Scientific Conference on Economic and Social Development*, p. 654.

Mizumura, S., Kitajima, M. https://patents.google.com/patent/JP2020124123A/en.

Moda, L.R., Boteon, M., Ribeiro, R.G., 2019. Cocoa and chocolate market economic scenario: opportunities for the Brazilian cocoa culture. Braz. J. Dev. 5 (10), 21203–21225. doi:10.34117/bjdv5n10-281.

Mollea, C., Chiampo, F., 2019. Valorization of cocoa husks: pectin recovery. Int. J. Food Sci. doi:10.1155/2019/1212081, Article 1212081.

Oliveira, R.S., Machado, B.A.S., Leal, I.L., Santos, V.S., Da Silva, E.N., Umsza-Guez, M., 2019. Powdered Cocoa Honey Obtained from Concentrated Cocoa Honey and Manufacturing Processes of Concentrated Cocoa Honey and Powdered Cocoa Honey. National Industrial Learning Service (SENAI, Bahia, Brazil) & Federal University of Bahia (UFBA, Bahia, Brazil) https://patents.google.com/patent/BR102019008531A2/pt?oq=BR+102019008531.

Oliveira, R.S., Machado, B.A.S., Santos, V.S., Da Silva, E.N., Umsza-Guez, M., 2019. Drink Obtained from Cocoa Honey and Manufacturing Process of the Referred Beverage. National Industrial Learning Service (SENAI, Bahia, Brazil) & Federal University of Bahia (UFBA, Bahia, Brazil) https://patents.google.com/patent/BR102019008474A2/pt?oq=BR+102019008474.

Ortiz, C.G., James, M.R.J., 2005. Desarrollo Experimental Del Proceso Para La Obtencion De Jugo Derivado Del Mucilago De Cacao. Universidad Industrial de Santander Facultad de Ingenierias Fisicoquimicas Escuela de Ingenieria Quimica Bucaramanga, Colômbia.

Pacheco, N., Trujillo, J., 2019. *Obtención De Etanol Por Fermentación Alcohólica A Partir Del Exudado De La Pulpa De Cacao (Theobroma cacao* L.). Universidad Nacional Mayor de San Marcos, Facultad de Farmacia y Bioquímica, Lima, Perú.

Pérez Gálvez, J.C., Torres-Matovelle, P., Molina-Molina, G., González Santa Cruz, F., 2020. Gastronomic clusters in an Ecuadorian tourist destination: the case of the province of Manabí. Br. Food J. 122 (12), 3917–3934. doi:10.1108/BFJ-11-2019-0870.

Pisco-Caldas, J.W., 2019. *Caracterización Reológica De Una Bebida Elaborada Com Exudado De Cacao (Theobroma Cacao l.) CCN51 y Suero Láctico*. Tesis Para Optar El Título De: Ingeniero En Indústrias Alimentarias. Universidad Nacional Agraria De La Selva, Perú.

Puerari, C., Magalhães, K.T., Schwan, R.F., 2012. New cocoa pulp-based kefir beverages: microbiological, chemical composition and sensory analysis. Food Res. Int. 48 (2), 634–640. doi:10.1016/j.foodres.2012.06.005.

Quimbita, F., Rodriguez, P., Vera, E., 2013. Uso del exudado y placenta del cacao para la obtención de subproductos. Rev. Tecnol. ESPOL 26 (1).

CBI (2020) - Centre for the promotion of imports from developing countries, 2020. The bittersweet impact of COVID-19 on the cocoa and chocolate market.Retrieved from https://www.cbi.eu/news/bittersweet-impact-covid-19-cocoa-chocolate-market (accessed 20 October 2020)

Mordor Intelligence, 2019. Premium chocolate market - growth, trends and forecast (2020 –2025). https://mordorintelligence.com/industry-reports/premium-chocolate-market (accessed 8 May 2020)

Rodrigues, L.B.O. https://patents.google.com/patent/BR102019008742A2/pt?oq=BR+102019008742.

Rodríguez, Z., Joel, B., 2020. Evaluación De La Actividad Antioxidante En El Mucílago De Cacao (Theobroma Cacao l.) Variedades: ccn-51 y Nacional. UTEQ, p. 90 Quevedo.

Rytz, A., Adeline, D., Lê, K.A., Tan, D., Lamothe, L., Roger, O., Macé, K., 2019. Predicting glycemic index and glycemic load from macronutrients to accelerate development of foods and beverages with lower glucose responses. Nutrients 11 (5), 1172. https://www.mdpi.com/2072-6643/11/5/1172/htm.

Rojo-Poveda, O., Barbosa-Pereira, L., Zeppa, G., Stévigny, C., 2020. Cocoa bean shell—a by-product with nutritional properties and biofunctional potential. Nutrients 12 (4). doi:10.3390/nu12041123, Article 1123.

Ruesgas-Ramón, M., Suárez-Quiroz, M.L., González-Ríos, O., Baréa, B., Cazals, G., Figueroa-Espinoza, M.C., Durand, E., 2019. Biomolecules extraction from coffee and cocoa by-and co-products using deep eutectic solvents. J. Sci. Food Agric. 100 (1), 81–91. doi:10.1002/jsfa.9996.

Sampedro, F., McAloon, A., Yee, W., Fan, X., Zhang, H.Q., Geveke, D.J., 2013. Cost analysis of commercial pasteurization of orange juice by pulsed electric fields. Innov. Food Sci. Emerg. Technol. 17, 72–78. doi:10.1016/B978-0-12-820563-1.00023-8.

Santander, M., Vaillant, F., Sinuco, D., Rodríguez, J., Escobar, S., 2021. Enhancement of fine flavour cocoa attributes under a controlled postharvest process. Food Res. Int., 110236 doi:10.1016/j.foodres.2021.110236.

Santos, C.O.D., Bispo, E.D.S., Santana, L.R.R., Carvalho, R.D.S.D., 2014. Use of "cocoa honey" (*Theobroma cacao* L) for diet jelly preparation: an alternative technology. Rev. Bras. Frutic. 36 (3), 640–648. doi:10.1590/0100-2945-042/13.

Santos, F.L., Taddei, P.P.A., Silva, S.J.S., Dos Santos, S.S., Passo, M.S., 2015. Functional Carbonated Drink. Federal University of Bahia Recôncavo (UFRB, Bahia, Brazil) https://patents.google.com/patent/BR102015013975A2/en?oq=BR102015013975.

Santos, R.A.R., Neta, M.T.S.L., Silva, M.A.A.P., Carnelossi, M.A.G., Narain, N., 2021. Process optimization for elaboration of cajá-umbu (*Spondias spp.*) fruit jelly: the effect of pulp and pectin contents on sensory attributes and volatile constituents. Int. J. Gastron. Food Sci. 24. doi:10.1016/j.ijgfs.2021.100315, Article 100315.

Santos, F.C.G., Kalid, R.A., 2020. Prospecção tecnológica: um estudo de tecnologias aplicadas ao processamento e derivados de cacau. Pesq. Soc. Desenv. 9 (3). doi:10.33448/rsd-v9i3.2354.

Toth, J., Lopata, J., Schweizer, C., Pachard, S. https://patents.google.com/patent/WO2017044610A1/en?oq=WO+2017%2f044610+A.

Scampini, A.L.C., 2020. Processo de produção de aguardente pela preparação, fermentação e destilação do mel de cacau. Patent N° BR. https://patents.google.com/patent/BR102018016061A2/pt?q=aguardente&inventor=scampini&oq=scampini+aguardente. 102018016061-3A2.

Schroth, G., Garcia, E., Griscom, B.W., Teixeira, W.G., Barros, L.P., 2016. Commodity production as restoration driver in the Brazilian Amazon? Pasture re-agroforestation with cocoa (*Theobroma cacao*) in southern Pará. Sustain. Sci. 11, 277–293. doi:10.1007/s11625-015-0330-8.

Silva, E.N., Ramos, D.C., Menezes, L.M., Souza, S.O., Lannes, S.C.S., Silva, M.V., 2014. Nutritional value and antioxidant capacity of "cocoa honey" (*Theobroma cacao* L.). Food Sci. Technol. 34 (4), 755–759. doi:10.1590/1678-457X.6447.

Drevici, U., Drevici, N. https://patents.google.com/patent/US4331692A/en?oq=US4331692A.

Euromonitor International, 2016. Global trends and developments in Cocoa ingredients (world). Strategy Briefing, https://www.euromonitor.com/global-trends-and-developments-in-cocoa-ingredients-world/report (accessed 20 October 2019)

Sosa, J.M.R., Manayay, E.D.R., 2018. Aprovechamiento del mucílago de cacao (*Theobroma cacao*) en la formulación de una bebida no alcohólica. Tesi Ingeniería de Industrias Alimentarias, Facultad de Ingeniería Química e Industrias Alimentarias, Universidad Pedro Ruiz Gallo, Lambayeque, Perú. https://hdl.handle.net/20.500.12893/2684 (accessed 20 September 2020)

Tacer-Caba, Z., 2019. The concept of superfoods in diet. The Role of Alternative and Innovative Food Ingredients and Products in Consumer Wellness, 1st ed. Academic Press.

Tesfaye, T., Ayele, M., Ferede, E., Gibril, M., Kong, F., Sithole, B., 2021. A techno-economic feasibility of a process for extraction of starch from waste avocado seeds. Clean Technol. Environ. Policy 23 (2), 581–595.

Torres-Vallejo, C., Díaz Ocampo, R., Morales, W., Velasco, R., Vera, J., Baren, C., 2016. Utilización del mucílago de cacao, tipo nacional y trinitario, en la obtención de jalea. Espamciencia 7 (1), 51–58. http://www.uteq.edu.ec/doc/page/35/Grupos.

Report Linker, 2021. Global tropical fruit puree industry. . Global Industry Analysts, April, 296 p. https://www.reportlinker.com/p05900679/ (accessed 22 September 2020)

Ginatta, G., Vignati, F., Rodrı́guez, M.D., 2020. Iniciativa Latino-americana del Cacao: Boletín No. 9. CAF: Banco de Desarrollo de América Latina, Caracas. https://scioteca.caf.com/handle/123456789/1593 (accessed 20 January 2021)

Vásquez, Z.S., De Carvalho Neto, D.P., Pereira, G.V., Vandenberghe, L.P., De Oliveira, P.Z., Tiburcio, P.B., Rogez, H.L.G., Neto, B.G., Soccol, C.R., 2019. Biotechnological approaches for cocoa waste management: a review. Waste Manage. 90 (1), 72–83. doi:10.1016/j.wasman.2019.04.030, (Oxford).

Veloso, M.C.R.A., Pires, M.R., Villela, L.S., Scatolino, M.V., De Paula Protásio, T., Mendes, L.M., Júnior, J.B.G., 2020. Potential destination of Brazilian cocoa agro- industrial wastes for production of materials with high added value. Waste Manage. 118, 36–44. doi:10.1016/j.wasman.2020.08.019, (Oxford).

Victor, A.S., Gockowski, J., Agyeman, N.F., Dziwornu, A.K., 2010. Economic cost-benefit analysis of certified sustainable cocoa production in Ghana. In: Proceedings of the 48th Conference of African Association of Agricultural Economists, Africa and the Global Food and Financial Crisis Cape Town, South Africa.

Viera, J.B., Cucelle, B., Festring, D., 2018. Food Products, Ingredients, Processes, and Uses. Société des Produits Nestlé S.A, Japan https://patents.google.com/patent/JP2021506225A/en?oq=JP+2021506225A.

Vieira, J.B., Kuschel, B., Festring, D., 2020. Food Products, Ingredients, Processes, and Uses. Société des Produits Nestlé S.A., p. 524 U.S. Patent Application No. 16/499.

Yildiz, S., Pokhrel, P.R., Unluturk, S., Barbosa Cánovas, G.V., 2019. Identification of equivalent processing conditions for pasteurization of strawberry juice by high pressure, ultrasound, and pulsed electric fields processing. Innov. Food Sci. Emerg. Technol. 57. doi:10.1016/j.ifset.2019.102195, Article 102195.

Yu, M., Xia, Y., Zhou, M., Guo, Y., Zheng, J., Zhang, Y., 2021. Effects of different extraction methods on structural and physicochemical properties of pectins from finger citron pomace. Carbohydr. Polym. 258. doi:10.1016/j.carbpol.2021.117662, Article 117662.

Willcocks, N., Unlu, E., Gao, Y., 2016. Shelf Stable, High Moisture Fruit Confection Products from Cacao Pulp. Wm.Wrigley Jr. Company, USA https://patents.google.com/patent/WO2017062603A1/en?oq=WO+2017%2f062603+A.

Allied Market Research, 2019. Cocoa products market by product type (cocoa beans, cocoa butter, cocoa powder & cake, cocoa paste & liquor, and chocolate) and application (confectionery, food & beverages, cosmetics & pharmaceutical): global opportunity analysis and industry forecast, 2019–2026. Allied Market Research. https://www.alliedmarketresearch.com/cocoa-products-market (accessed 20 october 2019).