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Review on the Biological and Bioactive components of Cocoa (*Theobroma Cacao*). Insight on Food, Health and Nutrition

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ABSTRACT: Cocoa (*Theobroma cacao*) is a well-known tropical plant extensively cultivated for its beans, which are the primary raw material for chocolate production. This article aims to comprehensively review and analyze the bioactive compounds present in cocoa and their corresponding biological activities, highlighting their potential implications for human health. A systematic literature review was conducted to gather relevant research articles and reviews related to the bioactive compounds of cocoa and their biological activities. The databases used for the search included PubMed, Scopus, and Google Scholar, with keywords such as "cocoa bioactive compounds," "flavonoids," "theobromine," "antioxidant activity," and "cardiovascular health" used for data retrieval. The analysis revealed that cocoa is rich in bioactive compounds, such as flavonoids (e.g., catechins, epicatechins), methylxanthines (e.g., theobromine, caffeine), and polyphenols. These bioactive compounds have been associated with various biological activities, including potent antioxidant effects, anti-inflammatory properties, and vasodilation, which may positively influence cardiovascular health. The consumption of cocoa and its bioactive compounds may offer several health benefits due to their antioxidant, anti-inflammatory, and cardiovascular-protective properties. However, further research is necessary to fully understand the mechanisms of action and to determine appropriate dosage recommendations for harnessing the potential health benefits of cocoa.

1. INTRODUCTION

Cocoa, scientifically known as *Theobroma cacao*, is a fascinating and highly valued plant species that holds a prominent place in both natural and cultural realms. Renowned for its delectable flavor and aroma, cocoa has captivated human societies for centuries and continues to be a cherished ingredient in various culinary delights. Beyond its culinary significance, cocoa possesses a rich biological component that contributes to its unique characteristics and remarkable versatility (Guzmán-Alvarez et al., 2021). *Theobroma cacao* is a member of the Sterculiaceae family and is native to the tropical regions of Central and South America. The plant is characterized by its evergreen nature, reaching an average height of 4-8 meters, and is particularly suited to thrive in the warm, humid climates of its natural habitat. The cocoa tree features large, glossy leaves, and its canopy provides shade for the delicate cocoa pods that grow directly from the trunk and branches (Tan et

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al., 2021). The biological importance of cocoa lies primarily in its pods, which house the beans that are later transformed into the beloved cocoa products. The cocoa pods are oval or elongated in shape, with a variety of colors ranging from yellow to red to purple, depending on the cultivar. The pods contain an average of 30-50 seeds, or cocoa beans, enveloped in a sweet and tangy pulp. These beans are the essence of cocoa and serve as the raw material for various products such as chocolate, cocoa powder, and cocoa butter (Lima et al., 2011). Within the cocoa beans, numerous biological components contribute to their distinctive characteristics and significant economic value (Soares & Oliveira, 2022). Firstly, cocoa beans are rich in various alkaloids, most notably theobromine and caffeine. Theobromine, in particular, provides cocoa with its mildly stimulating effects and contributes to its bitter taste. Caffeine, on the other hand, adds a stimulating kick, albeit in lesser quantities compared to coffee. These alkaloids not only impact the sensory experience of consuming cocoa but also have potential physiological effects when ingested. Additionally, cocoa beans are an abundant source of various bioactive compounds, including polyphenols, flavonoids, and antioxidants (Sorrenti et al., 2020). These compounds have been linked to numerous health benefits, such as reducing inflammation, improving cardiovascular health, and potentially even exhibiting anticancer properties. The presence of these bioactive compounds has led to the popular notion that cocoa, when consumed in moderation, can be part of a healthy diet. The biological component of cocoa extends beyond the seeds themselves (Scapagnini et al., 2014). The cocoa tree plays a crucial role in tropical agroforestry systems, contributing to biodiversity conservation and ecosystem health. The dense foliage of cocoa trees provides habitat and shelter for a wide array of organisms, from birds and insects to reptiles and mammals. Moreover, cocoa plantations, when properly managed, can support sustainable farming practices and contribute to the overall well-being of the environment (N et al., 2023).

2. METHODOLOGY

Scientific articles used for this review were retrieved from ScienceDirect® (https://www.sciencedirect.com/search), Google Scholar (https://scholar.google.com/), , National Agricultural Library (AGRICOLA), (agricola.nal.usda.gov/help/quicksearch.html), PubMed® (https://pubmed.ncbi.nlm.nih. gov/), and SciELO (https://search.scielo.org/) databases.

The keywords used in the searches were: "Cocoa and biological activities", "*Theobroma Cacao* and its health perspectives", "*Theobroma Cacao* and nutritional benefits", "*Theobroma Cacao* and food applications", "*Theobroma Cacao* and industrial uses", "*Theobroma Cacao* and medicinal use", "*Theobroma Cacao* and pharmacological activities", "Theobroma Cacao and botanical activities", "*Theobroma Cacao* and phytochemistry", and "*Theobroma Cacao* and toxicity".

3. BOTANICAL DETAILS

3.1. Origin

Theobroma cacao, the main component in chocolate that we all know today, was first domesticated about 7500 years ago in the northern Peruvian Amazon before being dispersed throughout Central America. It was first utilized by the Chinchipe tribes in Peru before subsequently assimilating into the Chavin civilization. The Mokaya, Olmecs, Mayans, and Aztecs all used cacao as a sacred and spiritual beverage in Mesoamerica (Motamayor et al., 2002). Cacao was first brought to Europe by the Spanish through commerce with the Aztec tribes, where it was blended with milk, sugar, or honey to make the oldest form of what would later become chocolate. Despite the fact that practically everyone on earth has tried cacao as chocolate, its history and traditional usage reveal a lot about the spiritual value and original functions of this sacred plant. When we consider the history of cacao, the earliest known evidence points to the Chinchipe tribes in the Jaén region of northern Peru and their usage of cacao as a sacred beverage in ceremonies and rituals (Goya et al., 2022). The earliest cacao temple in the world, known as Montegrande, reveals a lot about how the early tribes perceived it, as well as its customary uses (Andújar et al., 2012). The temple was uncovered in 2010 by archaeologist Quirino Olivera, who also revealed cacao carvings on stone artifacts and ceramics. He thinks that the temple acted as a shaman's grave, and that the local tribes utilized cacao in their spiritual ceremonies to invoke the divine. These theories are also supported by genetic evidence, which demonstrates that wild cacao trees originated in the Peruvian Andes' foothills and first underwent domestication there before migrating north to Central America (N et al., 2023). The hieroglyphs and images of cacao that were discovered in their tombs and on the containers used to store their liquid cacao suggest that the Mayans were perhaps the first to record information about it. One of these vessels, found a Mayan tomb in Ro Azul, northeastern Guatemala, dates to 460–480 AD and bears characters that correspond to the Olmec and Mayan term "ka ka wa," or cocoa. In reference to how cacao rituals represented the fusion of man and woman to generate life and spirit, this word is a mix of the words "man," "woman," and "spirit"alluding to how the union of man and woman during cacao rites produced life and soul. The molinillo, a specialized whisk that could incorporate air into the cacao paste, was used in ceremonies to further illustrate this. The cacao jar represented the feminine (womb), the molinillo, the masculine energy (phallus), and the process of whisking the cacao to create air the creation of life (N et al., 2023). When the Aztecs arrived in Mexico, they learned how the Mayans used cacao and started creating their own cacao prepared. The Aztecs received cacao beans as tribute in the cacao-growing regions they conquered since they were unable to grow cocoa themselves (Panche et al., 2016). Liquid cacao was exclusively used on exceptional occasions and by the aristocracy in Mesoamerican civilizations. Large quantities of the beans were rumored to have been kept in storage facilities for the Aztec nobility, and images and records from the Mayan and Aztec eras show that they were used in marriage rituals, as kingly tributes, as trade currency, and even in ceremonies to gods like Ek Chuaj, the Mayan merchant deity and patron of cacao. Many places in Mesoamerica, including Guerrero, Colima, Tabasco, and the Gulf of Honduras, grew domesticated cacao trees in plantation-like settings, but the Criollo cacao beans from the province of Shoconochco, also known as Soconusco in Colonial times, were the most prized by the Aztec people. Traditionally, cacao was mashed into a paste and served as a beverage for ceremonial consumption. However, by the time the Spanish arrived, the mixture was shaped into little cakes and allowed to cool before setting up under a tree on glossy leaves to harden. The drink known as xocoatl (from Nahuatl words meaning "bitter water") was made by breaking up the cakes, mixing them with hot water, and beating the mixture until foamy. However, they added their own originality to the appropriated beverage by sweetening the bitter cocoa with sugar and spices. Following that, chocolate gained enormous popularity among the Spanish, who for almost a century after their discovery kept the production process a secret from the rest of Europe. The rest of western Europe swiftly discovered chocolate after the Spanish could no longer keep it a secret. In royal courts and specialized "chocolate houses" catering to the affluent, chocolate first arrived in France and then England. At the time, it was still only available as a drink. The upper classes praised hot chocolate as tasty and nutritious, and cocoa eventually earned a reputation as an aphrodisiac. The beginning of the Industrial Revolution, when steam-powered equipment enabled the production of cocoa powder significantly quicker and more economical, led to a reduction in the exclusivity of chocolate. By 1850, solid chocolate had become widely popular because of Joseph Fry's discovery that mixing cacao butter with cocoa powder resulted in a solid mass. The method of making chocolate desserts with flavorful filling—known as pralines by their Belgian inventor, Jean Neuhaus II—became widely known sixty years later. From that point on, the chocolate and cocoa industries saw an explosion in popularity and swift global expansion. Throughout its centuries-long evolution, one factor has remained consistent and cocoa has attracted devotees worldwide. Today, over 4.5 million tons of cocoa beans are consumed annually around the globe, in everything from drinks to candy bars. It's safe to say that the ancient Mesoamericans who pioneered the crop could never have imagined the popularity cocoa would someday experience. It is crucial that ethical production methods and sustainable farming techniques be applied across the cocoa supply chain in order to safeguard the future of chocolate and guarantee that it will be accessible to future generations. WCF has partnered with more than 100 businesses worldwide to improve the sustainability of the cocoa supply chain.

3.2. Habitat

Cocoa (*Theobroma cacao*), a revered tropical plant known for its esteemed beans that form the basis of chocolate production, thrives within a carefully tailored habitat designed by nature. Understanding the intricacies of this habitat sheds light on the conditions essential for cocoa's growth and the cultivation of its invaluable beans (Barrios-Rodríguez, Salas-Calderón, Orozco-Blanco, Gentile, & Girón-Hernández, 2022). The natural habitat of cocoa predominantly lies in the warm, tropical regions of Central and South America, where a confluence of environmental factors nurtures its development (Rio et al., 2013). Within this region, temperatures ranging from 20°C to 30°C (68°F to 86°F) provide the requisite warmth for optimal cocoa growth, with frost-prone areas unsuitable for its successful cultivation. Moreover, high humidity levels, typically exceeding 70%, play a crucial role in sustaining the vigor of cocoa trees, ensuring the health and vitality of their leaves and fruit (Delgado-Ospina et al., 2021). One of the vital factors contributing to cocoa's prosperity is a balanced and consistent distribution of rainfall. An annual precipitation of 1,000 to 2,500 mm (40 to 100 inches) allows cocoa trees to thrive, benefitting from the replenishing showers. However, excessive rainfall poses a risk, as cocoa trees are susceptible to waterlogging, which can lead to root decay and jeopardize their well-being. In the delicate equilibrium of altitude, cocoa finds its preferred elevation range, favoring areas between sea level and 1,000 meters (3,280 feet) (Yoroba et al., 2019). The altitude plays a decisive role in determining cocoa's growth rate and productivity, with the tree exhibiting its most remarkable development within this specific range. Regarding soil, cocoa exhibits a versatile palate, capable of adapting to various types such as sandy loam, clay loam, and volcanic soils. Despite this adaptability, cocoa demands one non-negotiable requirement from the soil beneath its roots – effective drainage. Thriving on well-draining soils, cocoa staunchly avoids the perils of water stagnation, which can inflict severe harm upon its existence. its natural habitat, cocoa displays an intricate dance with sunlight and shade. Flourishing under the partial shade of taller trees, young cocoa plants find solace, while mature trees yearn for ample sunlight to attain their full potential. This interplay of light and shade underscores the tree's wisdom in embracing the best of both worlds (Niether et al., 2018). Nestled within its habitat is a rich tapestry of biodiversity. Cocoa thrives amidst a diverse array of plant and animal species, fostering a harmonious ecosystem. This biodiversity serves not only as a captivating aspect of cocoa's habitat but plays a pivotal role in cocoa cultivation, supporting a thriving environment where the tree can flourish. Nonetheless, the paradise of cocoa's habitat is not immune to adversity (Daniel et al., 2018). Pests and diseases loom as persistent threats, necessitating vigilant management strategies. The protection of cocoa trees from these challenges assumes paramount significance, ensuring the continuity of the tree's existence and safeguarding the future of the cherished chocolate industry. Beyond its native territory, cocoa cultivation has extended to equatorial regions such as Ivory Coast, Ghana, Indonesia, Nigeria, and Brazil. In these territories, human endeavors align with the nuances of nature to foster thriving cocoa plantations.

3.3. BY-PRODUCTS OF COCOA

One of the most significant agricultural products in the world is cocoa. According to the most recent data available, the International Cocoa Organization (ICCO) estimates that the world produced 4638 thousand tons of cocoa beans in 2017–2018. Only 30% of the cocoa fruit is made up of beans, leaving a sizable amount of underused and frequently wasted byproducts. Because it is possible to extract valuable molecules from industrial by-products, their utilization has grown more appealing (Figueroa et al., 2020). Cocoa pod husk, mucilage/pulp, and cocoa shell are the three remaining fractions following the extraction of the cocoa seeds, and they may be easily separated from one another architecturally and chemically. These fractions or by-products are currently employed to create both low-value and high-value products, the latter of which utilizes the use of relevant innovative technologies to obtain bioactive substances such as methylxanthines, pectin, minerals, antioxidants, and dietary fiber. As functional additives in numerous industries, these bioactive substances present a significant economic and environmental opportunity, the part and uses of cocoa tree (*Theobroma cacao*) is in Table 1. The fluid paste, or liquor, that is produced when the cocoa bean is processed is used to make cocoa powder and chocolate (Guzmán-Alvarez et al., 2021). Direct sales of chocolate include solid bars for consumption, cocoa in packages, and baking chocolate. Additionally, it is employed by confectioners as a coating for candy bars, boxed chocolates, and bulk chocolate, by bakers and producers of baked goods as a coating for a variety of cookies and cakes, and by ice cream makers as a coating for frozen novelty items. To flavor a variety of foods and to give "chocolate" items like syrups, toppings, chocolate milk, prepared cake mixes, and medications their flavors, cocoa powders, chocolate liquor, and mixtures of the two are used extensively.

Table 1
The byproducts of cocoa tree (*Theobroma cacao*).

By Products of Cocoa	Uses
SWEATINGS	These are the liquid byproducts that are produced when pulp is fermented. It has been suggested that these sweats could be used to make vinegar or alcohol. These can be used to make jams and jellies because they contain 0.9 to 1.19% pectin.
COCOA POD HUSK	It can be employed in the production of black soap. In Nigeria, potassium hydroxide, sodium hydroxide, and potassium carbonate are used to make soap.
COCOA POD ASH	Potassium hydroxide and potassium carbonate are present in trace amounts in cocoa pod ash (16.07% and 56.73%, respectively). By replacing these compounds with cocoa pod husk ash, (R) investigated the production of black soap. They were able to make black soap from cocoa waste by harvesting this feature of the cocoa bean together with other agricultural wastes.

3.4. Nutritional Benefits of Cocoa

Naturally abundant in minerals and nutrients, cocoa has a wealth of health advantages. Among the many health advantages of cocoa powder are its support for brain health, stabilization of blood pressure, maintenance of cholesterol levels, good source of antioxidants, treatment of diabetes, reduction of obesity, healing properties, mood enhancer, strengthening of cardiovascular health, prevention of cancer, treatment of constipation, and support for skin, The nutritional content of cocoa is shown in Table 2 below.

Table 2
The nutritional content of cocoa in percentage per 100g.

Macronutrients.	Percentage
Protein	15-21%
Carbohydrates	~15%
Lipids	10-25%
Fiber	25-40%
Micronutrients	**Per 100g**
Vitamin A(Retinol)	<0.2mg
Vitamin E(Tocopherol)	2.5mg
Vitamin B1(Thiamine)	0.3mg
Vitamin B1(Riboflavin)	0.4mg
Vitamin B3(Niacin)	0.7mg
MINERALS	Per 100g
Sodium (Na)	0.03g
Potassium (k)	4.3g
Calcium (ca)	151mg
Phosphorus (P)	700mg
Iron (Fe)	26mg
Magnesium (mg)	555mg
Copper (cu)	5mg.

3.4.1 Carbohydrates

Freshly grown cocoa beans have a potential carbohydrate content of between 12 and 14 percent, as well as sizable amounts of fiber. Fresh pulp has enough simple sugar to have a sweet flavor (Samanta et al., 2022). Pentosans (2–3%), citric acid (1–2%), and salts (8–10%), primarily potassium complexes, are also present in the pulp. However, the digestible carbohydrate content and composition of the cocoa pod (pulp and beans) are significantly changed after six or more days of bacterial fermentation, as per the conventional method of processing cacao beans (Obinze et al., 2022). The pulp is broken down during this process, resulting in the production of a variety of complicated compounds, including different short-chain sugars and ketoacids, eventually acetic acid and alcohol. Fermentation as a process due to the creation of fermentation products, also lowers the bean's carbohydrate content to 5 to 6% (Gutiérrez-Ríos et al., 2022). In this regard, it is significant to note that cacao beans can be processed either by straightforward drying or by fermentation, which is frequently referred to as "sweating" due to the heat and moisture generated (Maicas, 2020). Compared to products made through "sweating" or intensive fermentation, products made through drying are typically more bitter.

3.4.2 Proteins

The protein level in cocoa beans is normal for many seeds, but the quality of the protein depends on how evenly certain key amino acids are distributed. The chemical score for cocoa protein is less than 25, due to the low amount of methionine, as compared to a common reference protein, such as egg white, whose biological value and chemical score of 100 serves as a comparable baseline. necessary amino acids required to create "complete" proteins. The chemical score is a system for grading proteins according to their chemical make-up, specifically the amounts of important amino acids in comparison to a selected reference (Rawel et al., 2019). A protein is chosen to serve as a benchmark, and other proteins are graded in relation to it. Egg protein is typically employed with the presumption that its amino acid profile is excellent for humans, meaning that when administered at the necessary protein-requirement-meeting dose, all essential amino acid needs will be satisfied (Puglisi & Fernandez, 2022). In order to make more comparisons, the biological values and chemical rankings for two relatively "good" protein sources, soybean protein isolate and casein, are provided for further comparisons. When one of them is ingested as the only source of protein, the scores of 65 and 50 indicate that there is one essential amino acid whose concentration in relation to the requirement is only 50–65 percent. But over the course of a day, a variety of proteins are consumed (Jäger et al., 2017). In Central America and Mexico, it was highly customary to combine the consumption of cocoa and corn. Depending on the relative distribution of various proteins in these two when consumed together, the chemical score of the mixture can significantly enhance along with the biological quality. The proteins are deemed complementary once an enhancement has been made. The amino acid content of the combination is increased when cocoa and maize are combined. For instance, corn has higher levels of methionine, while cocoa's amino acid composition helps corn's low lysine and tryptophan contents (Marsh et al., 2013). When a person's diet has enough calories, they need roughly 0.8 g of protein per kg of body weight, or 12 to 16 percent of their daily caloric intake, to maintain a positive nitrogen balance. Consequently, with the proper complementation

3.4.3 Minerals

The mineral aids in nerve cell defense and lowers the danger of neurological illnesses. Magnesium is a mineral that helps support healthy muscular and neurological system function, and cocoa powder contains this mineral. Zinc, a mineral that aids in wound healing, is abundant in chocolate prepared with 30% cocoa or more (Kirkland et al., 2018). Consuming cocoa powder can be beneficial if you have cancer and are receiving radiation treatment. It has been demonstrated that the selenium in cocoa powder limits the harmful side effects of radiotherapy in cancer patients (N et al., 2023). Magnesium is necessary to control muscle contraction and support nerve activity. Additionally, the mineral aids in nerve cell defense and lowers the danger of neurological illnesses. Magnesium is a mineral that helps support healthy muscular and neurological system function, and cocoa powder contains this mineral.

3.4.4 Lipids

Theobroma oil, often known as cocoa butter, is a pale-yellow vegetable fat derived from Vitamin E. It has numerous health benefits for the body, and cocoa butter is a good source of this vitamin. The health of your blood, brain, skin, and reproductive system are all supported by vitamin E. Due to its high fatty acid content, cocoa butter is an excellent choice as the main component of skin creams. Skin hydration is aided by fatty acids. The fat in cocoa butter forms a barrier that keeps moisture in and stops skin from drying out (N et al., 2023). To obtain cocoa butter, producers ferment, dry, roast, strip, and press cocoa beans. Many topical therapies for illnesses like eczema and dermatitis include cocoa butter as a key ingredient. The skin can heal after an outbreak thanks to cocoa butter's protective oil basis and high moisture content. UV radiation exposure can alter the appearance of skin, harm skin cells, and possibly raise the chance of developing skin cancer. The polyphenols in cocoa butter may lessen your risk of developing skin diseases and shield your skin from damaging UV radiation (D'orazio et al., 2013). Heart disease and other illnesses are at risk due to high cholesterol. Your risk of having a heart attack can be decreased by managing this risk factor with cocoa butter. Stearic acid, which is present in cocoa butter, can be transformed by your liver into the monounsaturated fatty acid oleic acid. Oleic acid increases levels of good (HDL) cholesterol while decreasing levels of harmful (LDL) cholesterol. Vitamin K is present in modest quantities in cocoa butter. Your body needs vitamin K to maintain and grow bones.

3.4.5 Vitamins

Chocolate is a nutrient-rich food because it is a powerhouse of phyto-nutrition, even rivaling fruits and vegetables, the cacao bean was a significant component of the Mesoamerican diet because it sustains life and increases energy (Lippi, 2013). Science has improved its techniques for examining the general nutritional value of foods during the past few decades. These testing techniques and other studies have produced encouraging bioactive results, which point to cocoa's outstanding nutritional profile. The cocoa bean includes the following nutrients, to name a few: Thiamine (Vitamin Bl) is required for the metabolism of protein, fat, and carbs. In order to create the body's energy source, adenosine triphosphate (ATP), vitamin B1 is necessary for every cell. Vitamin B1 is necessary for the regular operation of nerve cells. According to research, it can treat anemia and may also aid in the prevention of diabetes, Alzheimer's disease, and canker sores. Vitamin B2 (riboflavin) is a water-soluble vitamin that is necessary for the metabolism of lipids and amino acids, for the activation of vitamin B6 and folic acid, and for the conversion of carbohydrates into adenosine triphosphate (ATP)(R).Vitamin B2 (riboflavin) is a water-soluble vitamin that is necessary for the metabolism of lipids and amino acids, for the activation of vitamin B6 and folic acid, and for the conversion of carbohydrates into adenosine triphosphate (ATP). Vitamin B2 can function as an antioxidant in some circumstances. It has been proven to be effective in treating cataracts, anemia, canker sores, and migraines (Averianova et al., 2020).Niacin (vitamin B3): Essential for the process of converting carbs into energy. Alcohol processing and the formation of fat from carbohydrates both require it. Niacin, a type of vitamin B3, controls cholesterol as well. Niacin may be useful in the treatment of dysmenorrhea, osteoarthritis, acne, and excessive cholesterol/triglycerides, according to scientific research (Shah et al., 2013).Vitamin B5 pantothenic acid is required to produce the neurotransmitter acetylcholine and is involved in the Kreb's cycle, which produces energy. Additionally, it is necessary for the creation, transfer, and release of energy from lipids. Pantothenic acid is required for the synthesis of cholesterol, which is required for the production of steroid hormones and vitamin D. The adrenal glands are also stimulated by pantothenic acid. Many medical professionals think pantothenic acid can lower cholesterol and may be useful in the treatment of rheumatoid arthritis (Hrubša et al., 2022). Vitamin C, or ascorbic acid, is essential for a variety of biological processes. As an antioxidant, vitamin C is known to shield the body from a number of diseases linked to free radicals, such as heart disease and lung disease (caused by smoking). In addition to assisting in the formation of collagen and reducing the incidence of cataracts, stroke, and issues associated with heavy metal toxicity, vitamin C also appears to have immune-stimulating properties.

3.5. Bioactive Compounds of Cocoa

Cocoa (*Theobroma cacao*), the esteemed tropical plant renowned for its delectable beans used in chocolate production, also contains a wealth of bioactive compounds that contribute to its allure and potential health benefits. The study of these compounds within cocoa falls under the domain of phytochemistry, shedding light on the intricate chemical composition and biological activities of this beloved plant.

3.5.1 Phenolics

Phenolics constitute a prominent group of bioactive compounds found in cocoa, including flavonoids, catechins, and procyanidins. These phenolic compounds imbue cocoa with its distinctive taste and aroma while also playing a pivotal role in its antioxidant properties (Melo et al., 2021). The antioxidant capacity of cocoa phenolics helps neutralize harmful free radicals in the body, thereby mitigating oxidative stress and potentially reducing the risk of various chronic diseases, such as cardiovascular ailments and certain types of cancer. Furthermore, these phenolic compounds have been associated with anti-inflammatory Díaz, 2023).

3.5.1.1 Phenolic Composition Analysis of Cocoa Varieties Phenolic compounds, such as polyphenols and flavonoids, are bioactive molecules found naturally in cocoa beans. They play a significant role in defining the sensory characteristics and nutritional value of cocoa and chocolate (Balentić et al., 2018). These compounds not only influence the flavor profile but also contribute to the antioxidant properties that have garnered cocoa and dark chocolate attention for their potential health benefits (Urbańska & Kowalska, 2019). In this section, we explore the phenolic composition of various cocoa varieties, each known for its unique flavor profile and distinct attributes. Through rigorous analysis and quantification of these phenolic compounds in both cocoa mucilage and cocoa bean shell, we aim to uncover valuable insights into the differences and similarities among these varieties.

3.5.1.1.1 Sample A - Criollo Sample A represents Criollo cocoa beans, which are known for their unique flavor profile. This sample exhibits a significantly higher concentration of mucilage compared to the other samples. The thicker mucilage layer in Criollo beans can pose specific challenges and opportunities in chocolate production. Firstly, Criollos thick mucilage may necessitate modifications in the fermentation process to ensure complete breakdown and optimal flavor development (Liang et al., 2021). Secondly, the increased sugar content in the mucilage can result in sweeter-tasting cocoa beans, potentially influencing the Criollos renowned complex and fruity flavor profile (Saman et al., 2020). Careful processing is required to preserve these delicate flavor notes.

3.5.1.1.2 Sample B - Forastero: Sample B represents Forastero cocoa beans, one of the most widely cultivated varieties worldwide. In this sample, there is a notable difference in the cocoa bean shell thickness, which is thinner compared to other samples. This characteristic can affect the chocolate production process (N et al., 2023). The thinner shell may lead to quicker roasting times, potentially impacting the development of flavor during roasting. It also presents the challenge of maintaining even roasting to ensure consistent flavor in the final chocolate product. Additionally, the thinner shell might result in more breakage during roasting or grinding, affecting production efficiency.

3.5.1.1.3 Sample C - Trinitario: Sample C represents Trinitario cocoa beans, a hybrid variety that combines the flavor attributes of Criollo and the robustness of Forastero. This sample displays statistically significant differences with higher levels of phenolic compounds compared to other samples. Trinitario's increased phenolic content makes it an attractive choice for health-conscious consumers seeking chocolates with enhanced antioxidant properties. However, it's important to note that the higher phenolic content may lead to a more intense and potentially bitter flavor profile (Ahmed et al., 2020). Chocolate producers working with Trinitario beans might need to consider blending this variety with others to achieve a well-balanced flavor.

3.5.1.1.4 Sample D - Nacional: Sample D represents Nacional cocoa beans, also known as Arriba cocoa, predominantly grown in Ecuador. This sample has a remarkably low caffeine content compared to the other samples. The low caffeine content in Nacional beans can be appealing to consumers looking for chocolate with reduced caffeine, making it a suitable option for evening consumption (Zeng et al., 2022). However, it's essential to acknowledge that this low caffeine content might alter the perceived energy-boosting effects typically associated with chocolate. Table 3 identified the phenol component (Total Polyphenols and Total Flavonoids), the cocoa bean variety (Criollo, Forastero, Trinitario, and Nacional), and the measurements for cocoa mucilage (expressed in mg GAE/100 mL) and cocoa bean shell (expressed in mg GAE/100 g DW) for each sample. These measurements provide an overview of the composition of the mucilage and bean shell for these hypothetical cocoa samples.

Table 3
Phenolic Composition Analysis of Cocoa Varieties

Phenol Component	Variety	Cocoa Mucilage (mg GAE/100 mL)	Cocoa Bean Shell (mg GAE/100 g DW)
Total Polyphenols	Criollo	72.22 ± 1.53	42.17 ± 16.10
Total Polyphenols	Forastero	80.15 ± 2.35	35.98 ± 11.74
Total Flavonoids	Trinitario	55.87 ± 1.94	28.36 ± 7.92
Total Flavonoids	Nacional	62.43 ± 2.10	38.22 ± 9.87

Table 5
Nutritive value of dried cocoa husk, chocolate bean cake,chocolate bean shell, bermuda grass.

Feed Material	Protein(%)	Fiber(%)	Fat (%)	Non-Fiber Carbohydrates	Gross Energy (MJ/Kg)
Dried cocoa husk	6.8-10	24.00-35.40	1.60-2.40	46.60	10.70
Chocolate bean cake	15.1-28.6	5.80-10.30	5.50-16.50	42.10	7.60
Chocolate bean shell	14.5-21.6	17.40-20.90	3.10-5.20	40.60	5.10
Bermuda grass	6-9	31.50	2.10	-	8.70

3.5.2 Alkaloids

Cocoa is a natural repository of alkaloids, with theobromine and caffeine being the most well-known examples. Theobromine, the primary alkaloid in cocoa, exhibits stimulating effects on the central nervous system, though milder than caffeine (Zeng et al., 2022). Alkaloids contribute to cocoa's characteristic taste and have been linked to potential mood-enhancing properties, further contributing to the pleasurable experience of consuming cocoa-based products. Additionally, alkaloids may have cardiovascular benefits, as some studies suggest they could promote vasodilation and enhance blood flow (Nehlig, 2013).

3.5.3 Carotenoids

Carotenoids, while present in cocoa in smaller amounts compared to other compounds, contribute to the rich color spectrum observed in cocoa beans. The most notable carotenoid found in cocoa is beta-carotene (Andarwulan et al., 2021). Carotenoids are renowned for their antioxidant properties, shielding cells from oxidative damage caused by free radicals. Although present in smaller quantities, the presence of carotenoids in cocoa adds to its overall antioxidant capacity, supporting the plant's potential health benefits.

3.5.4 Terpenoids

Terpenoids in cocoa, although less studied compared to other bioactive compounds, are present in varying concentrations and offer a diverse range of potential health benefits. These compounds contribute to the characteristic aroma of cocoa and may possess antimicrobial and anti-inflammatory properties (N et al., 2023). Terpenoids' potential role in supporting the body's defense mechanisms underscores their significance in the overall composition of cocoa's bioactive compounds.

3.5.5 Organic acids

Organic acids are a group of compounds characterized by the presence of one or more carboxyl groups (-COOH). In cocoa, these organic acids play a significant role in shaping the flavor profile and acidity of the beans. Notably, citric acid and malic acid are among the most abundant organic acids found in cocoa beans. Citric acid imparts a tangy and slightly sour taste, contributing to the overall sensory experience of cocoa-based products (N et al., 2023). Moreover, citric acid also serves as a natural preservative, aiding in extending the shelf life of cocoa goods. On the other hand, malic acid contributes to cocoa's characteristic tartness, influencing the overall taste perception of cocoa-based delicacies (N et al., 2023). Besides flavor modulation, these organic acids also participate in essential metabolic processes within the human body. Citric acid, for instance, is a pivotal component of the citric acid cycle, a fundamental metabolic pathway vital for energy production in cells (Granchi et al., 2019). While cocoa also contains smaller amounts of oxalic acid, its impact on cocoa-based products is generally considered to be minor. Overall, the presence of organic acids in cocoa contributes not only to its sensory appeal but also underscores the biological significance of these compounds.

3.5.6 Glycosides

Glycosides represent a class of compounds where a sugar molecule is bound to a non-sugar moiety, known as the aglycone. In the context of cocoa, one of the primary glycosides present is theobromine. As a glycoside, theobromine is less readily absorbed by the body. However, upon metabolism, it releases the active theobromine, contributing to cocoa's mild stimulating effect (Martãnez-Pinilla et al., 2015). Theobromine is known for its vasodilatory properties, which widen blood vessels, potentially enhancing blood flow. Additionally, it

Table 4
The production of biofuels from industrial waste of *Theobroma cacao*.

Product	Biomass	Process	Result	
Biochar	CPH	low-temperature pyrolysis with dwell durations of 30 to 120 minutes, spaced out by 30 minutes.	Contains a lot of potassium and has a calorific value of 17.8 MJ/kg. The end product resembles lignite in terms of its properties as a biofuel.	(Shah et al., 2013)
Biochar	CPH	Pyrolysis at temperatures of 250, 300, and 350°C. Activation process with HCl to reduce the values of free fatty acids to use cooking oil used in the production of biodiesel.	In comparison to the esterification process using H2SO4, the activated carbon produced from CPH demonstrated improved retention of free fatty acids.	(Melo et al., 2021)
Bioethanol	CPH	Over a time frame of 0–8 days, fermentation employs Zymomonas mobilis. Microorganisms were added in percentages ranging from 8 to 16% v/v.	Under 8-day conditions and a 14% v/v concentration, an alcohol graduation of 10.62% was achieved.	(Zeng et al., 2022)
Bioethanol	CM	Pichia kudriavzevii fermentation for five days at a temperature of 30 °C.	The outcome reveals that the highest amount of ethanol was 13.8 g/L.	(Andarwulan et al., 2021)
Bioethanol	CM	For 12 days, Saccharomyces cerevisiae was employed for fermentation.	Considering the amount of mucilage, the bioethanol production rate of 4.85% is considered to be low.	(N et al., 2023)
Bioethanol	CBS	fermentation lasting six days with varying yeast concentrations; hydrolysis pretreatment with H2SO4 at temperatures between 30 and 80 degrees Celsius at intervals of 50 and 150 minutes.	With a pH of 8, 0.05 mg/g of yeast was used for fermentation, and the process took 6 days to produce 8.46% bioethanol. It was found that pH had the greatest impact.	(Goya et al., 2022)
Biogas	CPH	The aerobic digesting procedure was employed in conjunction with a hydrothermal pretreatment at various temperatures (150-220°C) for periods of 5–15 minutes.	The biogas yields by pretreatment were as follows: acid 162.8, alkaline 564.8, ground without treatment 220.8, and unground without treatment 243.3; the greatest production was achieved on day 18 of the procedure.	(Ahmed et al., 2020)
Biochar	CBS	The estimated yield of untreated CPH biogas was 357 l (N)/kg VS, whereas the estimated yield of pretreated biomass biogas at 150 °C for 15 minutes was 526.38 l (N)/kg VS.	The liquid smoke obtained had a concentration of 18–23%. The amount of coal, ash, and water produced by the faster heating was greater, and the finished product had a calorific value of 22.97 MJ/kg	(Subramaniam et al., 2019)
Liquid smoke	CBS	temperature increases of 5 to 15 degrees Celsius each minute during pyrolysis at 450, 500, and 550 degrees Celsius.	The liquid smoke obtained had an 18–23% concentration. With a calorific power of 22.97 MJ/kg, the product generated at a faster rate of heating produced more coal, ash, and water.	(Saman et al., 2020).

exhibits mild diuretic effects, aiding in the elimination of excess fluids from the body. While theobromine is one of the key glycosides in cocoa, it is not the only one. Glycosides, in general, are of considerable interest due to their potential health implications. In cocoa, glycosides collectively contribute to the plant's unique biochemical composition, making it an intriguing subject of scientific investigation (Soares & Oliveira, 2022). Understanding the role of glycosides in cocoa adds to our appreciation of its complexity and potential physiological effects.

3.5.7 Flavonoids

Flavonoids represent a diverse class of polyphenolic compounds abundant in cocoa beans. These compounds are characterized by their intricate molecular structures, and cocoa contains various subclasses of flavonoids, including catechins, epicatechins, and procyanidins. Flavonoids are potent antioxidants, crucial in counteracting oxidative stress and neutralizing harmful free radicals within the body. Catechins and epicatechins, for instance, contribute to cocoa's characteristic bitter taste while offering significant health benefits (Nwosu et al., 2022). They have been associated with improved cardiovascular health, partly through promoting the healthy function of blood vessels and reducing inflammation. Procyanidins, another subclass of flavonoids found in cocoa, have also garnered attention for their potential cardiovascular benefits. As antioxidants, flavonoids in cocoa enhance its overall antioxidant capacity, highlighting its potential contributions to human health (Onyibe et al., 2021). Moreover, flavonoids are an active area of research, and further understanding of their physiological effects in the context of cocoa consumption may

Table 6
Compounds found in Cocoa and their formulas, structures and functions.

S/N	COMPOUND	FORMULA	FUNCTIONS/USES	
1	flavanols	C15H14O2	They have anti-inflammatory, cardioprotective, anti-cancer, hypolipidemic, anti-diabetic, anti-microbial, and anticancer properties.	(Urbańska & Kowalska, 2019)
2	Anthocyanidins	C15H11O+	I. They mostly serve the purpose of coloring plant parts with red, blue, and purple shades, among other colors. ii. They help to avoid diabetes and obesity. III.Anthocyanins have been proved to have the ability to modify cognitive and motor performance, improve memory, and play a part in delaying the effects of aging on cerebral function.	(Jimmy & Jose, 2011).
3	Proanthocyanidins	C31H28O12	I. They boost blood vessel strength in those who have diabetes (increased blood sugar level) and high blood pressure (hypertension). ii. They helps in the prevention of cancer iii. They also assist in the treatment of nutritional deficiencies.	(Liang et al., 2021)
4	Caffeine	C8H10N4O2	It helps the brain and neurological system to be more active. it also causes a greater flow of hormones like cortisol and adrenaline throughout the body. Caffeine can also help you feel awake and alert in moderation.	(Pucciarelli, 2013)
5	Theobromine	C7H8N4O2	It functions as a diuretic, a vasodilator, and a cardiac stimulant. Additionally, it might help in the treatment of fatigue and orthostatic hypotension.	(De Feo et al., 2020)
6	Methylxanthines	C6H6N4O2	They relax the smooth muscles of the bronchi, esophagus, and gastroesophageal sphincter.	(Ludovici et al., 2017)
7	Catechin	C15H14O6	They assist control vascular tone by triggering endothelial nitric oxide. Due to the anti-inflammatory effects of the capillaries and the suppression of vascular cell growth factors involved in atherosclerosis, it also contributes significantly to the prevention of the progression of atherosclerosis.	(Mendoza-Meneses et al., 2021)
8	Procyanidins	C30H26O13	They protect the circulatory and heart systems. They might act as antioxidants and prevent nitrosamine formation. They might guard against their effects in healthy cells. Together, they and vitamin C reduce the risk of breast cancer.	(Balentić et al., 2018)

unlock even more significant health implications.

3.5.8 Essential oils

While cocoa does not contain substantial quantities of essential oils compared to some aromatic plants, it does possess trace amounts of these volatile compounds (Edo, Makinde, et al., 2022). Essential oils are primarily found in the cocoa butter, which is extracted from cocoa beans during chocolate production. These oils are responsible for cocoa's characteristic aroma and flavor, contributing to the sensory pleasure experienced while consuming cocoa-based products. Despite their relatively small presence, essential oils in cocoa significantly influence its overall sensory appeal (Edo, 2022a). The distinct scent and taste of cocoa play an integral role in the cultural and culinary appreciation of this cherished commodity. Although essential oils are not the primary focus of cocoa, their contribution to the overall flavor experience should not be underestimated.

3.5.9 Saponins

Terpenoids, the largest category of plant extracts, includes the saponins as a subclass. Saponins' amphipathic nature makes them active as surfactants with the potential to interact with elements of cell membranes, such as cholesterol and phospholipids, making them potentially valuable for the development of cosmetics and medications (Hassan et al., 2021). Saponins can act as antifeedants and protect plants from fungus and bacteria in plants. Animal digestion and nutritional absorption may both be improved by certain plant saponins (found, for example, in spinach and oats). The flavor of saponins is frequently bitter, which can make plants less palatable (for example, in cattle feeds) or potentially endanger animal life. Cold-blooded animals and insects are harmful to some saponins at specific concentrations (Edo, 2022b). Saponins lower cancer risks, blood glucose response, and blood lipid levels in the body. Legumes (soya, beans, peas, lentils, lupins, etc.), asparagus, spinach, onion, garlic, tea, oats, ginseng, licorice, etc, are some saponin containing food and plants (Akpoghelie et al., 2022).

3.5.10 Phytic Acid

Plant seeds contain phytic acid, a special natural compound. It serves as the main phosphorus storage form. Due to how it affects mineral absorption, it has drawn a lot of interest. Iron, zinc, and calcium cannot be absorbed due to phytic acid, which may result in mineral shortages, that is why it is frequently referred to as an anti-nutrient (Akpoghelie et al., 2022). Phytic acid is present in grains, nuts, legumes, and plant seeds. These foods include a wide range of amounts of these compounds which is 0.98 ± 0.13 g/100 g. Several techniques, like soaking, sprouting, and fermentation, can be used to lower the amount of phytic acid in food (Erhonyota et al., 2022). Phytic acid may have several positive health effects, such as protection against oxidative damage and insulin resistance. Vegans, vegetarians, and anyone who consumes a lot of foods high in phytates may be at risk (Edo, Onoharigho, et al., 2022).

3.5.11 Phytosterols

Dietary intake of phytosterols causes a reduction in intestinal cholesterol absorption, which in turn triggers a subsequent rise in the body's endogenous cholesterol synthesis as a means of maintaining liver cholesterol homeostasis (Nwosu et al., 2022). It gives protection against colon cancer, breast cancer, and prostate cancer (Edo, Onoharigho, et al., 2022). Constipation, vomiting, indigestion, heartburn, flatulence, and discolored stools are a few of the side effects. After your body adjusts to the supplement, many of these symptoms will go away on their own. There is a higher chance of adverse consequences with higher phytosterol dosages (N et al., 2023).

3.6. Biological Activities of Cocoa

3.6.1 Antioxidant Activities

The antioxidant activities of cocoa are one of its most well-documented and significant attributes. Cocoa is rich in a variety of bioactive compounds, particularly phenolics and flavonoids, which contribute to its potent antioxidant properties (Aydinlik et al., 2021). Antioxidants play a vital role in the body by neutralizing harmful free radicals. Free radicals are unstable molecules that can damage cells and contribute to oxidative stress, which is associated with various chronic diseases and aging processes. When left unchecked, oxidative stress can lead to cellular damage and inflammation (N et al., 2023). The bioactive compounds in cocoa, particularly flavonoids such as catechins and epicatechins, act as powerful antioxidants. They have the ability to scavenge free radicals, neutralizing their damaging effects and preventing oxidative damage to cells. These flavonoids work in synergy with other antioxidants found in cocoa, including phenolic acids, procyanidins, and carotenoids, further enhancing cocoa's overall antioxidant capacity (N et al., 2023). Numerous studies have confirmed the antioxidant activities of cocoa. For instance, research has shown that cocoa consumption leads to an increase in antioxidant levels in the blood, which contributes to improved overall antioxidant status. Regular intake of cocoa-based products has also been associated with reduced markers of oxidative stress in the body. Moreover, the antioxidants in cocoa have shown promise in protecting against various chronic diseases. Studies have suggested that cocoa consumption may be linked to a reduced risk of cardiovascular diseases, as these antioxidants may help maintain healthy blood vessel function and support cardiovascular health (N et al., 2023). Additionally, the potential neuroprotective effects of cocoa antioxidants have been explored, showing possible benefits for cognitive function and brain health.

3.6.2 Antimicrobial Activities

The antimicrobial activities of cocoa, although not as widely studied as its antioxidant properties, are still an area of scientific interest and investigation. Cocoa contains certain bioactive compounds that have shown potential antimicrobial effects against various microorganisms, including bacteria, viruses, and fungi (N et al., 2023). One of the key bioactive compounds in cocoa with antimicrobial properties is theobromine. Theobromine is an alkaloid present in cocoa beans, responsible for its mild stimulating effects. Studies have indicated that theobromine exhibits some level of antimicrobial activity, particularly against certain bacteria. It has been shown to inhibit the growth of certain oral bacteria associated with dental caries and periodontal disease (N et al., 2023). However, it is essential to note that the antimicrobial activity of theobromine is generally considered to be less potent compared to conventional antimicrobial agents used in medicine. In addition to theobromine, cocoa contains other compounds that may contribute to its antimicrobial effects (N et al., 2023). Some studies have suggested that certain flavonoids found in cocoa, such as catechins and procyanidins, possess antimicrobial properties (N et al., 2023). These flavonoids have demonstrated inhibitory effects against various bacteria and viruses, potentially contributing to cocoa's antimicrobial activities. While cocoa's antimicrobial activities are intriguing, it is important to recognize that they are not a substitute for proper hygiene and sanitation practices. Antimicrobial properties in cocoa should not be relied upon as the sole means of preventing or treating infections. Instead, they add to the overall appeal of cocoa as a potential health-promoting food (Akpoghelie et al., 2022).

3.6.3 Anti-cancer Activities

The potential anticancer activities of cocoa have been a subject of scientific interest and investigation, raising intriguing possibilities about the role of this beloved treat in cancer prevention and treatment (Martín et al., 2016). While research is still in its early stages, several bioactive compounds found in cocoa, particularly its flavonoids and other polyphenols, have shown promising effects in laboratory and animal studies. One of the key mechanisms through which cocoa's bioactive compounds may exert their anticancer effects is by acting as antioxidants (Goya et al., 2022). Cocoa is rich in flavonoids, such as catechins and epicatechins, which are known for their potent antioxidant properties. These antioxidants have the ability to neutralize harmful free radicals, which are unstable molecules that can cause cellular damage and contribute to the development of cancer. By reducing oxidative stress and protecting cells from damage, cocoa's antioxidants may help prevent or slow the initiation and progression of cancer. In addition to their antioxidant effects, cocoa's bioactive compounds have shown potential anti-inflammatory properties. Chronic inflammation is linked to an increased risk of cancer development and progression. Cocoa's anti-inflammatory effects, attributed to its flavonoids and other compounds, may help modulate the body's inflammatory response, potentially reducing the risk of cancer and slowing its growth (Ahmed et al., 2020). Furthermore, certain compounds in cocoa have been investigated for their ability to regulate the cell cycle, the process by which cells grow, divide, and die (Baranowska et al., 2020). Abnormal cell cycle regulation is a hallmark of cancer, as cancer cells often evade the normal checks and balances that control cell growth. Cocoa's bioactive compounds may help regulate the cell cycle, preventing uncontrolled cell growth and inhibiting tumor formation. Another intriguing aspect of cocoa's potential anticancer activities is its ability to induce apoptosis in cancer cells. Apoptosis is a natural process of programmed cell death that helps maintain tissue homeostasis (Subramaniam et al., 2019). Cancer cells often evade apoptosis, leading to uncontrolled cell growth and tumor formation. Cocoa's bioactive compounds may trigger apoptosis in cancer cells, causing them to self-destruct and preventing tumor growth. Moreover, cocoa's potential antiangiogenic effects have also been explored. Angiogenesis is the formation of new blood vessels that tumors need to grow and spread. Some studies have suggested that cocoa flavonoids may inhibit angiogenesis, potentially limiting the blood supply to tumors and impeding their growth (Saman et al., 2020). It is essential to approach cocoa as part of a balanced diet and lifestyle, rather than a standalone treatment for cancer.

3.6.4 Anti-inflammatory activities of cocoa

The anti-inflammatory activities of cocoa have been a subject of scientific investigation, revealing the potential health benefits of this delightful treat beyond its taste and aroma. Cocoa contains a rich array of bioactive compounds, particularly flavonoids and other polyphenols, which contribute to its anti-inflammatory properties (N et al., 2023). Inflammation is a natural immune response that helps protect the body from harmful stimuli, such as pathogens and tissue damage. However, chronic inflammation is associated with various chronic diseases, including cardiovascular diseases, neurodegenerative disorders, and certain types of cancer. The anti-inflammatory effects of cocoa's bioactive compounds are believed to help modulate the body's inflammatory response and reduce excessive inflammation (Rudrapal et al., 2022). Flavonoids, such as catechins and epicatechins, are abundant in cocoa and have been extensively studied for their anti-inflammatory effects. These compounds have been shown to inhibit the production and activity of inflammatory molecules, such as cytokines and prostaglandins, which are involved in the inflammatory process. By reducing the levels of these proinflammatory molecules, cocoa's flavonoids help mitigate inflammatory responses within the body (Al-Khayri et al., 2022). Furthermore, cocoa's bioactive compounds may act as antioxidants, neutralizing free radicals and reducing oxidative stress. Oxidative stress can trigger inflammation, and by reducing it, cocoa's antioxidants may indirectly contribute to its anti-inflammatory effects. The anti-inflammatory activities of cocoa are particularly relevant to cardiovascular health. Chronic inflammation is a significant factor in the development of atherosclerosis, a condition characterized by the buildup of plaques in blood vessels. By reducing inflammation, cocoa's bioactive compounds may help support healthy blood vessel function and contribute to cardiovascular well-being. Additionally, cocoa's potential anti-inflammatory effects extend to brain health. Inflammation is involved in neurodegenerative diseases like Alzheimer's and Parkinson's disease. By modulating inflammatory responses, cocoa's bioactive compounds may have neuroprotective effects, potentially supporting cognitive function and brain health. While the evidence for cocoa's anti-inflammatory activities is promising, it is important to approach this research with caution. Most studies have been conducted in laboratory settings or animal models, and more clinical trials involving human subjects are needed to fully understand the extent and clinical implications of cocoa's anti-inflammatory effects in humans. Moreover, cocoa-based products, particularly those with added sugars and fats, should be consumed in moderation, as excessive consumption may have adverse effects on health, including potential weight gain and dental issues.

3.6.5 Antifertility activities of cocoa

The potential antifertility activities of cocoa have been a topic of interest in the scientific community, exploring the effects of cocoa consumption on reproductive health and fertility. However, it is essential to note that the research in this area is limited, and the evidence is not well-established. As a result, the antifertility activities of cocoa should be interpreted with caution, and more research is needed to fully understand its implications. Some studies have suggested that certain compounds found in cocoa, such as theobromine, may have effects on reproductive hormones and sperm quality (Gabrielsen & Tanrikut, 2016). Theobromine is an alkaloid present in cocoa beans, responsible for its mild stimulating effects. While theobromine is structurally related to caffeine, its impact on the reproductive system is less studied and less pronounced than caffeine. In some animal studies, high doses of theobromine have been associated with reduced fertility and adverse effects on reproductive organs (Cappelletti et al., 2015). However, these studies often used significantly higher doses than what would be typically consumed through dietary sources. On the other hand, some studies have shown that moderate cocoa consumption may not have significant adverse effects on fertility. In fact, cocoa has been traditionally consumed in various cultures for centuries without any apparent negative impact on reproductive health. It is crucial to recognize that the effects of cocoa on fertility may vary among individuals, and factors such as dose, duration of consumption, and individual differences can influence its potential impact on reproductive health. It is also important to differentiate between cocoa consumption and cocoa-based products. While cocoa in its pure form contains various bioactive compounds, cocoa-based products, such as chocolate, may contain additional ingredients, such as sugar and fats, that can influence overall health and potential effects on fertility.

3.6.6 Anti-hypertensive activities

Cocoa contains flavonoids such as epicatechin, catechin, and procyanidins, which have been linked to potential health benefits, particularly in reducing blood pressure (hypertension). These flavonoids are found in high concentrations in cocoa, but they are also present in smaller amounts in other plant-derived foods. Historically, native Latin American Indians consumed cold, unsweetened drinks made from raw, dried cacao powder, often combined with starch and spices (Urbańska & Kowalska, 2019). However, when cocoa was brought to Europe by the Spanish, they modified the beverage by heating it, adding sugar, and introducing various other ingredients. Modern cocoa processing methods, including roasting, conching, dutching, and the addition of sugar, milk, vanilla, and emulsifiers, have led to diverse flavors and smoothness in chocolate products. However, this processing also affects the flavanol content in cocoa, leading to a significant decrease in the concentration of monomeric flavanols like epicatechin and catechin (Urbańska et al., 2021). Clinical trials examining the impact of cocoa on blood pressure have highlighted the importance of comparing flavanol dosages rather than just the amounts of chocolate or cocoa products consumed (Martin & Ramos, 2021). Flavanol content in fresh and fermented cocoa beans is about 10% (100 mg/g), whereas commercially available dark chocolate typically contains only about 0.5% flavanols. Studies have shown that the blood pressure-lowering effects of cocoa are associated with the production of endothelial nitric oxide (NO), which promotes vasodilation, thereby reducing blood pressure. Additionally, cocoa flavanols inhibit the activity of angiotensin-converting enzyme (ACE), resulting in improved cardiovascular health and insulin sensitivity, contributing to the antihypertensive properties of cocoa (Figure 1).

3.6.7 Anti sickling potential

The formation of defective hemoglobin causes the hereditary disorder known as sickle cell anemia, which leads to the malformed and amorphous red blood cells known as "sickle cells." The body's oxidative stress process is greatly facilitated by sickle cells, which commonly impede blood flow, resulting in painful attacks, strokes, and other health problems. Numerous medicines have been developed to improve the management of this condition. Additionally, the high expense of these therapies and a variety of other disadvantages prevent the patients from benefiting from them (Jimmy & Jose, 2011). *Theobroma cacao* (T. cacao) extract from the South West and Littoral regions of Cameroon was studied to determine its anti-sickling potential. T. cacao was procured from Penja and Manfe and then extracted with water and hydroethanolic solvent at pH 3 (along with PH, PA, MH, and MA). Researchers evaluated the extract's antioxidant potential by examining its capacity to decrease iron (FRAP), scavenge free radicals (DPPH and ABTS), and had a general number of polyphenols and flavonoids (Baliyan et al., 2022). Research on the antioxidant capacity of *Theobroma cacao* is aided by measurements of the activities of catalase, SOD, glutathione peroxidase, reduced glutathione, and malondialdehyde. The antisickling effects, osmotic fragility tests, and principal component analysis (PCA) of the extracts were the subjects of additional investigation. The concentration of polyphenol and flavonoids was high in PH, PA, MH, and MA.With a focus on the cocoa extract from Manfe, these extracts also demonstrate extremely powerful anti-radical action against the DPPH and ABTS radicals, with IC50 values ranging from 3.24 to 6.35 g/ml and from 4.87 to 19.29 g/ml, respectively. The PCA results revealed that the extract of Manfe had a stronger capacity to reduce sickling, guard against hemolysis, and control enzyme activity under stress induction (Imaga, 2013). These results suggest that these locations' cocoa bean extracts, particularly Manfe, could be used to treat sickling. The information needed to fully support the use of cocoa in the treatment of sickle cell anaemia. Anti-sickling potential of cocoa and other biological activities are shown in (Figure 2) below.

3.6.8 Anti atherosclerotic activities

Add to the list of cocoa-related cardiovascular protective mechanisms by describing further preventive advantages of cocoa on atherosclerosis and cardiovascular disease in Cardiovascular Research. In a carefully controlled series of in vitro testing, these effects were discovered. In recent years, the idea that atherosclerosis is an inflammatory disease of the arterial vascular wall has become widely accepted. Extracellular matrix (ECM) formation and cell migration are two complicated

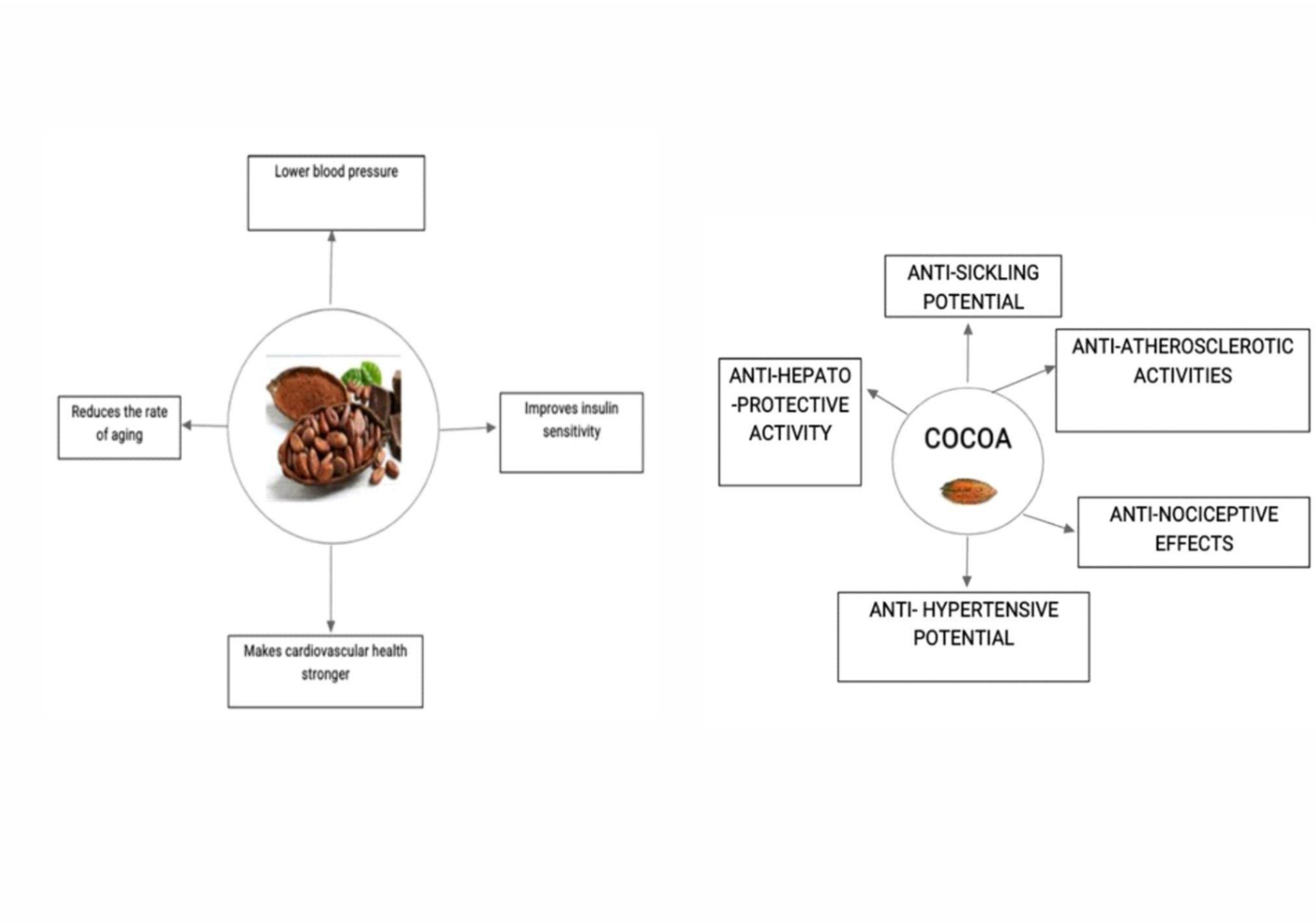

Figure 1. Components of cocoa seed and powder and its functions in blood pressure control and an illustration of the biological properties of cocoa.

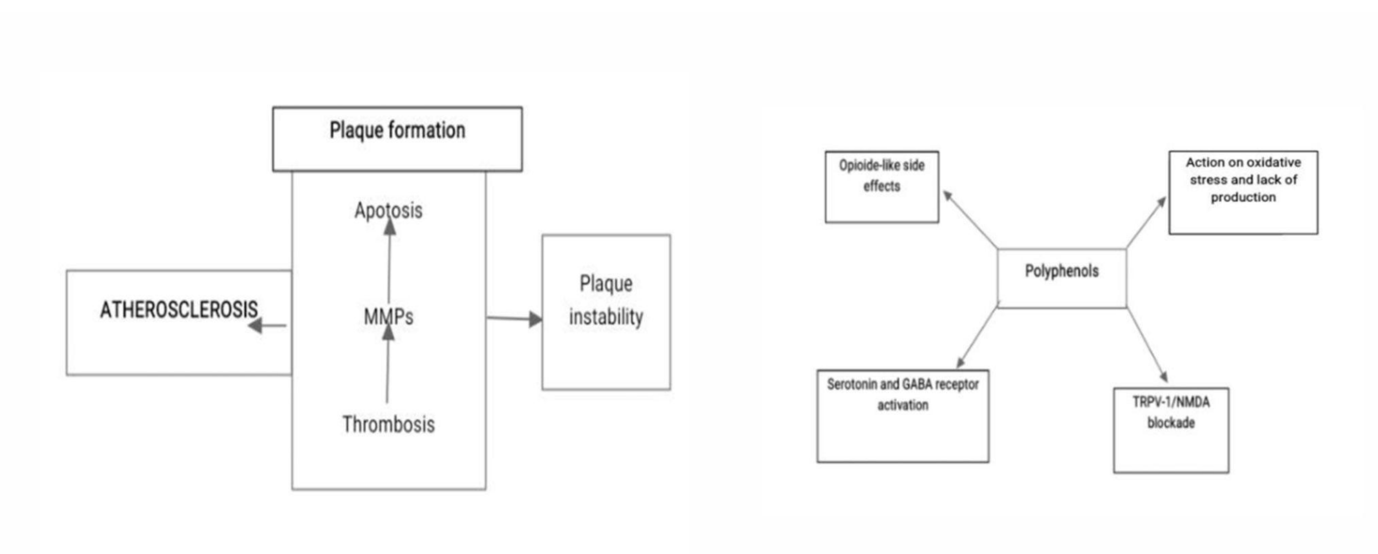

Figure 2. Development and instability of atherosclerotic plaque and the methylxanthines-containing compound's potential role in the antinociceptive properties of cocoa.

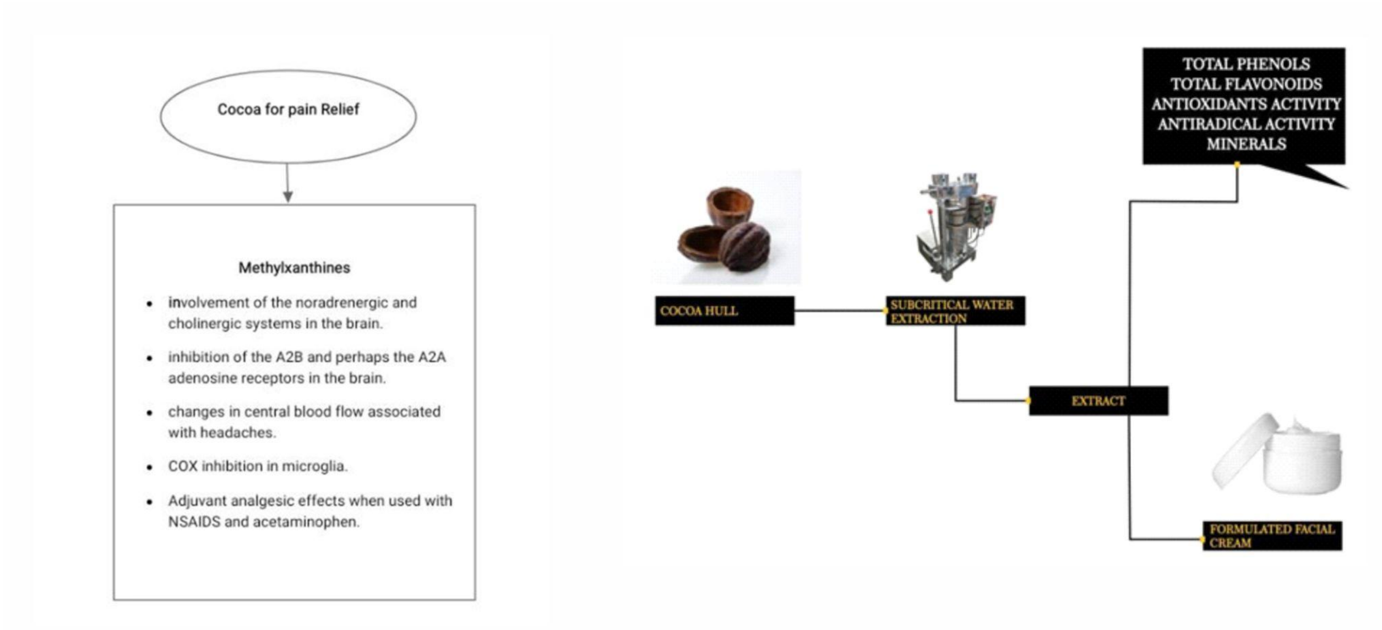

Figure 3. The Possible method for how cocoa's constituent polyphenols have anti-nociceptive properties and the processing techniques of different byproducts of *Theobroma cacao*.

processes that must occur in order for inflammation to produce the atherosclerotic fibrous plaque. Clinical atherothrombotic syndromes are brought on by plaque disruption in later stages of ECM degradation. The coordination between proteinases and their natural inhibitors regulates the degradation of the extracellular matrix (ECM) within the normal vessel wall. However, at regions of the fibrous cap that are prone to rupture, the balance may shift in favor of matrix degradation due to the secretion of various proteinases, including matrix metalloproteinases (MMPs), by accumulating macrophages and phenotypically altered vascular smooth muscle cells (VSMC). Some researchers propose that these enzymes play a role in plaque rupture. Therefore, blocking MMPs within the atherosclerotic plaque could potentially prevent disruptions and their clinical consequences. In a study cited, it was found that procyanidin-rich cocoa fraction (CPF) and procyanidin B2 effectively inhibited thrombin-induced expression and activation of the latent form of MMP-2 (pro-MMP-2) as well as thrombin-induced migration and invasion of VSMC (Lee et al., 2008). These inhibitory effects were attributed to the direct inhibition of a specific membrane-bound MMP, MT1-MMP, through the kinase MEK1. Interestingly, red wine polyphenols, which are known for their cardiovascular health benefits, did not exhibit the same inhibitory effects as CPF and procyanidin B2. Thrombin, a multifunctional serine protease, plays a significant role in vascular injury by converting fibrinogen to fibrin, activating platelets and MMPs, and exerting proinflammatory effects on endothelial cells and VSMC. It is a potent inducer of MMP-2 in both cell types. MT1-MMP, the first MMP known to be anchored to the cell membrane, is involved in cell movement and various inflammatory processes. It can degrade several components of the ECM, including fibrillar collagen 1, and is particularly important for processes like human monocyte endothelial transmigration and chemokine and nitric oxide-induced angiogenesis. In contrast, according to (Liang et al., 2021), both CPF and procyanidin B2 reduce the expression of pro-MMP-2 by directly inhibiting MEK1, which may provide protection against atherosclerosis (Figure 3). Interestingly, constitutive activation of MEK1 has been associated with increased angiogenesis and atherosclerosis. Previous studies using various MMP inhibitors to investigate their role in atherosclerotic plaque development and instability have yielded mixed results. For example, treatment with doxycycline reduces the activity and/or expression of MMP-9 and MMP-1, but this did not show significant effects on morphological characteristics or clinical outcomes in individuals with atherothrombotic disorders. MMPs can have diverse functions in different cell types, indicating that studying MMP functionality in specific cell types could help develop cell-type-specific MMP inhibition as a potential treatment for atherosclerosis. Notably, research has shown that cocoa powder has a suppressive effect on the growth of atherosclerotic plaques.

3.6.9 Anti-nociceptive activities

Global public health issues include pain. Effective medications are necessary for effective pain management in order to achieve the best analgesia with the fewest side effects. It appears vital to hunt for novel compounds due to the negative effects, physical dependence, and propensity for abuse reported with the present medications. The use of cocoa for therapeutic purposes, including the treatment of angina and heart pain, dates back to the 17th century (Pucciarelli, 2013). Cocoa beans contain a wide range of active substances. Methylxanthines and flavan-3-ols (like proanthocyanidins) are widely distributed among them

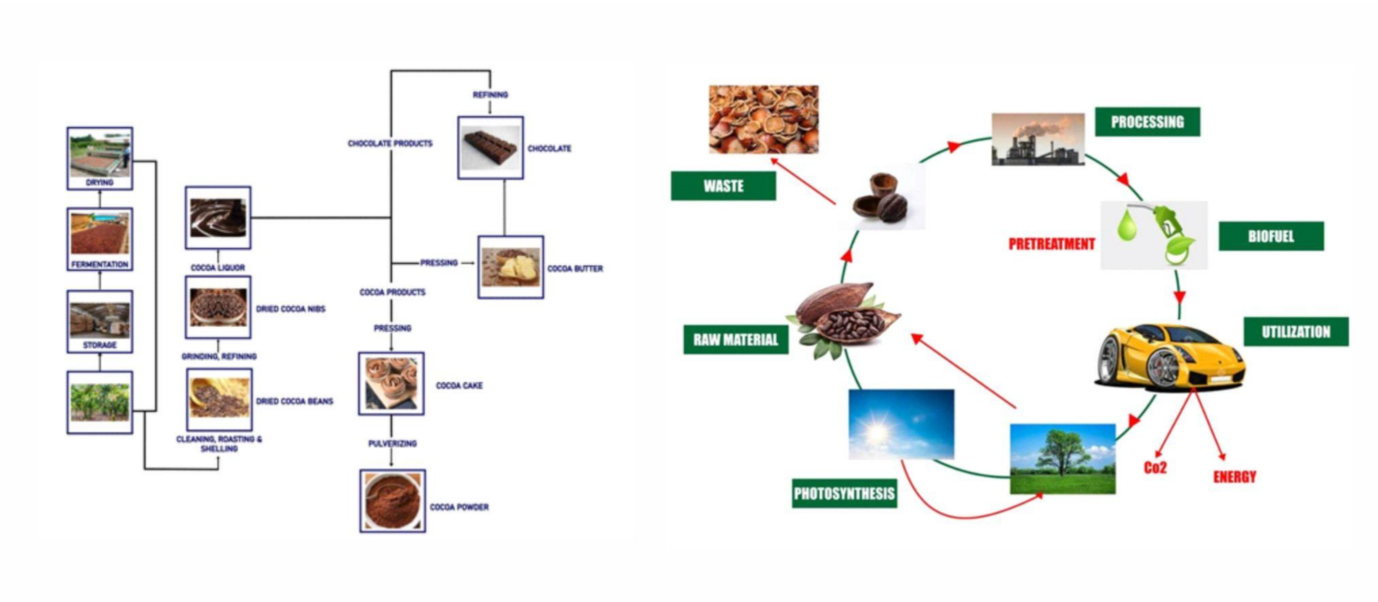

Figure 4. A flow chart demonstrating the different processing techniques of *Theobroma cacao* in the food industry and a diagram demonstrating the general circle for obtaining biofuels from *Theobroma cacao* industrial waste.

(Figure 4).

Alkaloids, amides/amines, and other kinds of polyphenols (such as flavonols, anthocyanins, stilbenes, and phenolic acid derivatives) are also present. According to this, the primary cocoa components with anti-inflammatory and antinociceptive actions are now thought to be catechin polyphenols, anthocyanidins, and proanthocyanidins (De Feo et al., 2020). In order to recapitulate the data for cocoa flavonoids' anti-inflammatory and anti-nociceptive properties, this review is being written. There are no experiments by any of the writers using human subjects or animals; instead, this article is based on already completed research. Additionally, it was recently discovered that cocoa suppressed the activation of trigeminal neurons and the expression of nociceptive protein in the ganglion and spinal cord (De Feo et al., 2020). According to a study (Bowden et al., 2017), mice fed a diet high in cocoa demonstrated a reduction in neurogenic inflammatory orofacial discomfort. Additionally, a study demonstrated how dietary cocoa administration was able to raise the levels of several peptides in the blood that have anti-inflammatory and anti-nociceptive properties, while at the same time inhibiting the expression of pro-phlogogenic proteins and neuronal sensitization to reduce inflammation (De Feo et al., 2020). Male Sprague-Dawley rats were fed either a control diet or a diet high in cocoa before receiving an injection of complete Freund's adjuvant (CFA) into the capsule of the temporomandibular joint. When injected, CFA, which contains heat-killed mycobacteria, causes a painful, protracted inflammatory state that encourages prolonged activation of trigeminal ganglion neurons and glia. Cocoa induced an increase in the glial production of the glutamate transport protein GLAST, which clears the excitatory neurotransmitter glutamate from the surroundings of second-order neurons. Cocoa also had the ability to lower the levels of calcitonin gene-related peptide (CGRP) in the spinal trigeminal nucleus. In this regard, various studies point out how the release of CGRP might promote cellular activation at the level of glial cells, leading to an increased synthesis of proinflammatory chemicals. Similar to this, it has been demonstrated that CGRP can boost the production of purinoreceptor (P2X) 3 and protein kinase A (PKA), which enhances the sensitization of nociceptive neurons at the level of the spinal glia. P2X and PKA levels increased in a CFA-dependent manner, whereas cocoa suppressed this. Dietary chocolate boosted the expression of the anti-inflammatory protein MAP kinase phosphatases 1 (MKP-1), which was another significant finding from this research. MKP play a role in the regulation of inflammatory and nociceptive processes as well as the cellular responses mediated by the mitogen-activated protein kinase (MAPK).Additionally, cocoa was able to suppress the expression of glial-fibrillary-associated protein (GFAP), a marker of activated astrocytes and microglia, as well as the inflammation brought on by cytokines dependent on CFA (Wancket et al., 2012). These findings are consistent with those from a different study (Wancket et al., 2012), in which rats fed a diet rich in cocoa displayed raised basal levels of the MAPK phosphatases MKP-1 and MKP-3, preventing the cerebral peripheral flogosis caused by MAPK. Accordingly, eating cocoa was found to suppress the baseline neuronal production of CGRP as well as the expression of inducible nitric oxide synthase (iNOS).It is well known that activated iNOS might encourage enhanced NO generation, a fundamental free radical gas that has impacts on initiating and amplifying inflammation and discomfort (Sierra et al., 2014). Since both CGRP and iNOS gene expression have been demonstrated to be controlled through numerous mechanisms, including the MAPK pathways, it is likely that cocoa repression

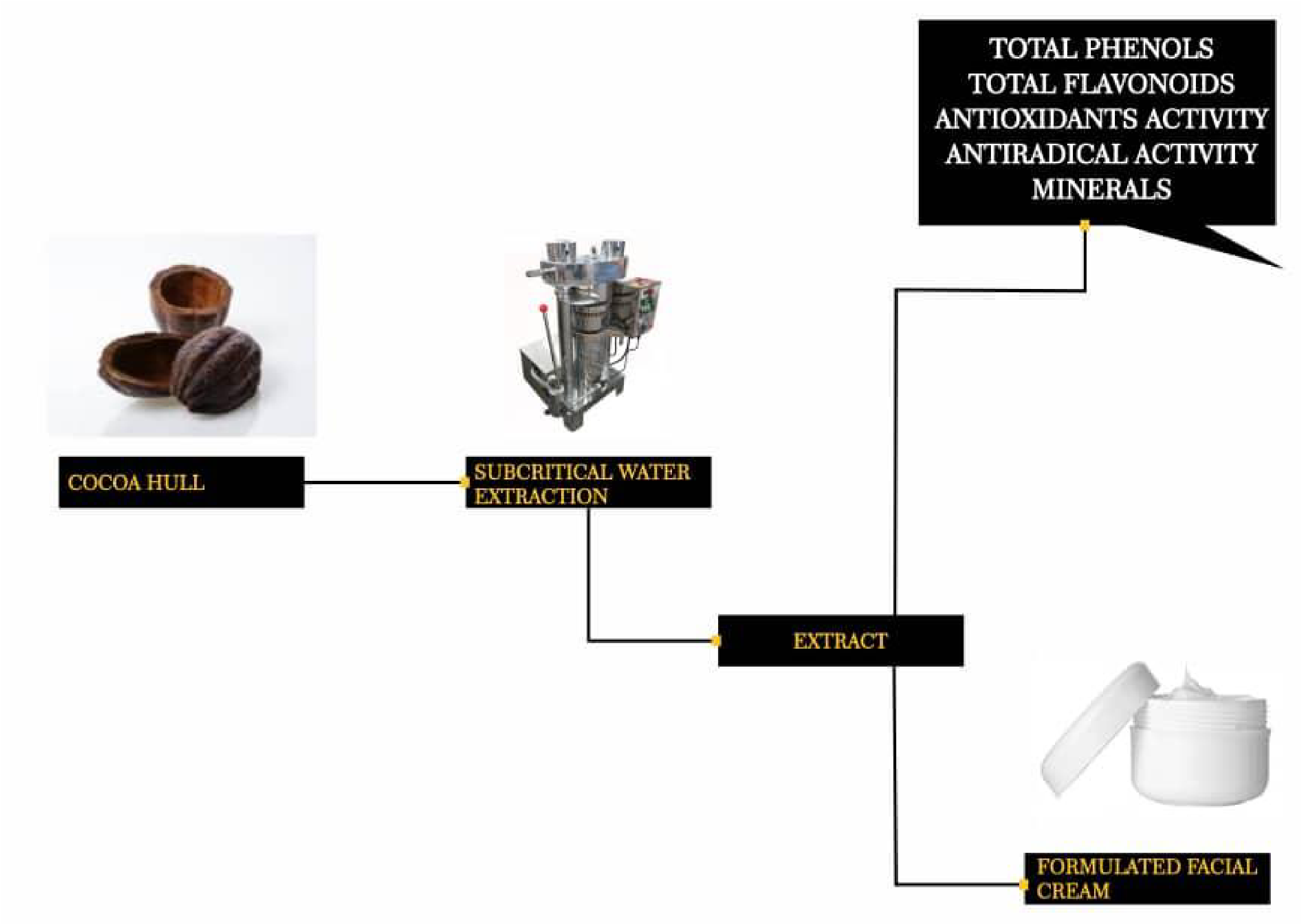

Figure 5. The process of getting facial cream from a cocoa hull.

of CGRP and iNOS expression involves overexpression of MKP and inhibition of MAPK pathways. Furthermore, a variety of cocoa-derived chemicals may influence neurons and glial cells to provide antinociceptive actions. According to findings from epidemiological, preclinical, and human intervention research, cocoa may have beneficial effects on a number of chronic pathologies, including cardiovascular disease and other illnesses linked to inflammation and oxidative stress (Figure 5). One of the most important societal challenges in terms of both cost and suffering is pain, which is a global public health issue. Many plants that contain polyphenols have long been used in traditional medicine to treat pain. Flavonoids may be useful for the creation of novel natural analgesics because research has shown that they have antinociceptive characteristics.

3.7. Application of Cocoa in Various Industries

3.7.1 Use of cocoa in the pharmaceutical industry

According to reports, cocoa contains natural antioxidants that act as free radical scavengers and preserve cell membranes, safeguard DNA, stop the oxidation of low-density lipoprotein (LDL) cholesterol that causes atherosclerosis, and stop plaque from forming on arterial walls (Kiokias et al., 2018). The procyanidins and their monomeric precursors, epicatechin and catechin, which prevent LDL oxidation, are thought to be responsible for cocoa's antioxidant properties. High-density lipoprotein (HDL) cholesterol levels are elevated and LDL oxidation is inhibited by dark chocolate and cocoa (Ludovici et al., 2017). Cocoa was once thought of as a gastronomic pleasure, but now some people utilize it as medication. Asthma, bronchitis, diarrhea caused by infectious intestinal illnesses, and lung congestion are all treated with cocoa seed. It is also used as an expectorant. The seed coat is used as a tonic, a general medication, and a treatment for diabetes, problems with the liver, bladder, and kidneys. The development of analytical technology has allowed for a proper mapping of the cocoa's metabolic pathways, which provides important details about its functions. Cocoa promotes mitochondrial biogenesis, which aids in weight loss. By introducing glucose transporter 4 into the membrane of skeletal muscles, it improves muscle glucose absorption. Cocoa offers neuron protection and improves memory and elevates one's mood thanks to its antioxidant qualities. Immunoglobulin E secretion during allergic reactions is decreased. It may have an impact on gut bacterial growth and immune response. It does so by preventing nuclear factor-B from causing inflammation. When used medicinally, cocoa butter functions as an anti-inflammatory moisturizer that provides comfort to skin suffering from the swelling, itchiness, and redness typical of illnesses including psoriasis, eczema, and rashes. According to legend, cocoa butter works to promote relaxation while also boosting the body's natural defenses. In turn, this makes it easier to deal with stress by reducing tiredness, which frequently compromises immunity. Without triggering new sensitivities, cocoa butter is soft enough to be used to soothe burns and infections.

3.7.2 Use of cocoa in food technology/ industries

Preprocessing and processing are the two steps that make up the cocoa bean processing process. The first includes the activities performed on the cocoa producer's field, such as harvesting, fruit opening, removal of the seeds and pulp, fermentation, bean drying, and storage. The second phase of the procedure often utilized in industry is where the ingredients for making chocolate and its derivatives are obtained ®. The distinction between one grade or quality and another is not particularly noticeable in chocolate and cocoa products. The blend of beans used—there are roughly 20 commercial grades available—the type and quantity of milk or other ingredients used, and the type and intensity of roasting, refining, conching, or other processing methods used—all affect the quality of the chocolate. There are hundreds of varieties available on the market, either by themselves or in conjunction with other foods or confections, and chocolate and cocoa goods are only loosely categorized. According to research, chocolate with 70% cocoa content is a good source of bioactive amines, including polyamines, cadaverine, putrescine, phenylethylamine, tyramine, and tryptamine (Dala-Paula et al., 2021). In addition, dark chocolate protein is a rich supply of tryptophan, phenylalanine + tyrosine, and histidine isoleucine but a poor supplier of leucine, lysine, and threonine (do Carmo Brito, Campos Chisté, da Silva Pena, Abreu Gloria, & Santos Lopes, 2017). According to studies many industries currently produce chocolate and other goods using cocoa, cocoa beans or cocoa almonds to be the major raw material source. The country with the greatest consumption rate is reportedly Switzerland. One of the most popular meals and confections is chocolate, which is a widely known example of a cocoa product that is frequently processed. But from cocoa, products like cocoa liquor, natural cocoa butter, cocoa cake, cocoa syrup, cocoa powder, etc. Figure 4 demonstrates the flow chart of the processing techniques of *Theobroma cacao* in the food industry. The many processing steps affect the ultimate quality of the cocoa products, particularly in terms of scent and flavor. Precursors of aroma and flavor are always developed by post-harvest processing (fermentation, drying, and roasting).

3.7.3 Use of cocoa as a source of biofuel

The industrial wastes from the production of cocoa in particular are a source of usable biomass that may be used to create new goods including food, animal feed, cosmetics, chemicals, and even biofuels. The waste products from the cocoa industry include cocoa bean shells, mucilage, and cocoa pod husks, all of which include substances with potential use in various sectors. However, due to the lignocellulose concentration of these by-products, pretreatment is necessary to fully utilize them. As a result, a variety of biofuels can be created depending on the conversion technology chosen to produce the best biomass yield. According to recent studies, industrial wastes from the cocoa industry are used to make solid, liquid, and gaseous biofuels (Mendoza-Meneses et al., 2021). After cocoa beans are processed to make chocolate, the cocoa hull is left behind as biowaste. Approximately 6.7 million metric tons of cocoa byproducts are produced in Central and West African nations, which account for 71.4% of the world's total production of cocoa biowaste (Balentić et al., 2018). Large amounts of bio-waste produced by the agriculture, food processing, and chocolate sectors place new management challenges on top of an already heavy ecological and economical burden. Due to the fact that biowaste is frequently replete with valuable compounds that can be tapped by the right technologies, new developments in the circular economy and biowaste management are focused on bio waste valorization through the manufacture of added-value chemicals or biofuel (Kee et al., 2021). In order to make biofuels, cocoa hull was either used to make ethanol by Saccharomyces cerevisiae fermentation or mesophilic biomethane. Other uses for cocoa hull were additionally looked into, such as the creation of special adsorbent beds from cocoa shells for the removal of pollutants from waste waters, including heavy metals, gasses, and industrial dyes, as well as the production of activated carbon for the same purpose. The general circle for obtaining biofuels from *Theobroma cacao* industrial waste is demonstrated.

3.7.3.1 Cocoa Wastes used for the production of biofuel

Cocoa production generates significant by-products that have historically been considered waste with little economic value. One such by-product is cocoa pod husk (CPH), which makes up a whopping 73% of the overall weight during cocoa processing (Delgado-Ospina, Lucas-González, et al., 2021). For every tonne of cocoa beans harvested, around 10 tonnes of CPH are produced. This husk comprises the outer layer of the cocoa fruit and consists of three parts: the endocarp, mesocarp, and epicarp. However, there hasn't been much specialized research on the utilization of specific parts of the cocoa pod. Traditionally, CPH has been used as fertilizer in agroecosystems, but improper handling can lead to phytosanitary issues like pest and fungal diseases. Nevertheless, due to its chemical composition, CPH holds promise for various applications. Its high lignocellulose content makes it a potential candidate for biofuel production (N et al., 2023). Moreover, CPH contains minerals like calcium, potassium, phosphorus, magnesium, sodium, zinc, iron, and manganese, along with fiber and phenolic compounds. Another valuable by-product of cocoa is cocoa mucilage (CM), the white substance that coats the cocoa beans. CM, also known as sweating or pulp, is extracted during cocoa processing through controlled fermentation. Reports suggest that CM constitutes between 3 and 5% of the weight of cocoa and contains pectin, pentosans, citric acid, salts, cellulose, hemicellulose, and ligroin (N et al., 2023). The spongy cells in CM are rich in various chemical compounds, including 10-14% fermentable sugars such as sucrose, glucose, and fructose, as well as minerals like potassium, sodium, and calcium. Furthermore, the cocoa bean shell (CBS) is another essential waste product, constituting 10-17% of the overall weight of cocoa beans. CBS is formed during the roasting of the beans, and its weight may vary depending on the fermentation process. This waste is of great significance because important chemicals from the cocoa bean migrate to the shell during fermentation. As a result, various industries, including food, pharmaceutical, cosmetic, and agricultural, have found valuable uses for CBS due to its nutritious content. CBS contains fiber, theophylline, theobromine, catechins, epicatechins, procyanidins, phenolic compounds, methylxanthines, polysaccharides, and other chemicals. Its calorific value, which is slightly higher than average wood, makes it a potentially environmentally friendly alternative energy source.

3.7.3.2 Biofuels gotten from the waste of Cocoa Biofuels derived from cocoa industrial waste offer promising sustainable alternatives for energy production. Among these biofuels are biochar, bioethanol, bio-oil, and biohydrogen, each produced through different processes and having unique properties and applications. Biochar is created from cocoa pod husk (CPH) through thermochemical processes that yield bio-oil and a solid residue. To optimize biochar quality, temperatures between 400 and 800°C are used, though ongoing research explores alternative techniques. However, biochar produced at 500°C has shown high pH and lower performance. Bioethanol, another valuable biofuel, is produced by converting sugars using yeast, typically from starch-rich feedstock materials. Through pretreatment, lignocellulosic materials can be converted into glucose, enabling fermentation for bioethanol production (Tse et al., 2021). The versatility of cocoa residues, with their diverse by-products, makes them an excellent source for synthesizing bioethanol. Bio-oil, obtained through biomass pyrolysis, comprises a mix of organic chemicals such as sugar oligomers, monomers, carboxylic acids, aldehydes, ketones, esters, and alcohols. While bio-oil has numerous applications, its high corrosiveness due to carboxylic acids requires attention during utilization. It serves as low-quality boiler fuel and, after upgrading, high-quality car engine fuel. Additionally, it offers potential as a source of value-added chemicals, functional carbon materials, and binders. Researchers are investigating various pretreatments and downstream processing methods to further refine bio-oil and convert it into biofuels through hydrodeoxygenation. Biohydrogen, a sustainable and cost-effective fuel, can be produced through fermentation by bacteria. Thermochemical techniques and different biomass types can also yield biohydrogen. Cocoa industrial waste has become a subject of interest for producing biofuels, and several studies have explored this avenue (Mendoza-Meneses et al., 2021). However, large-scale and economically viable biohydrogen production poses challenges that require innovative pretreatments to enhance the bioavailability of simple sugars in biomass. The waste product from biohydrogen production is water vapor, which possesses a higher calorific value (142 MJ/kg) than methane, natural gas, and even petrol. This characteristic adds to the attractiveness of biohydrogen as a potential clean energy source. Overall, exploring biofuels derived from cocoa industrial waste offers a promising avenue for sustainable energy production and highlights the significance of efficient processing techniques to unlock the full potential of these biofuels. Continued research and development in this field can contribute to a greener and more environmentally friendly energy landscape. Studies on the production of biofuels from the industrial waste of cocoa are shown in Table 5.

3.7.4 Use of cocoa in the the cosmetic sector

Theobroma cacao seed butter, often known as cocoa butter, is a fat made from *Theobroma cacao* seeds. The fat is what is frequently utilized in chocolate. The fatty acids produced from cocoa butter are salted with sodium to form sodium cocoa butterate. Bath products, scents, deodorants, hair conditioners, depilatories, eye and face cosmetics, skin care products, and suntan lotions all include cocoa seed butter. Soaps employ sodium cocoa butterate. Theobroma cacao seed butter is a well-liked component included in a variety of skincare products, including lotions, creams, hand creams, and more. Additionally, cocoa butter has been connected in the past to a postponement of aging-related skin damage, keeping the skin as supple and smooth as possible for a longer period of time. This makes products containing cocoa butter more than just simple. The polyphenols in cocoa butter are believed to improve skin's hydration level, skin tone, suppleness, and collagen formation, which reduces the appearance of aging. These polyphenols in cocoa butter are thought to prevent skin sensitivity, damage, and aging. Cocoa Butter increases dermal circulation while promoting the repair of damaged skin and the formation of fresh, healthier skin that looks and feels younger, softer, and smoother. It does this by deeply entering skin to provide intensive hydration. It is thought that cocoa butter has photo-protective qualities that shield the skin from damaging UV rays. Additionally, it can be utilized to fend off heat inside or even frostbite. This is coupled with the study that indicates cocoa butter as an ingredient could prevent and aid treat various skin disorders and a great source of facial cream as seen in Figure 5. It is regarded as a rich emollient in the cosmetics industry, making it one of the main components, especially in body lotions and full body moisturizers, that can moisturize and give a soft and supple external barrier to even the driest skin (Purnamawati et al., 2017). Numerous studies have demonstrated that using cocoa butter has important protective advantages for the youthful elasticity, moisture, and look of skin that has aged, in part because of its antioxidant capabilities. Additionally, it has significant amounts of oleic acid and stearic acid, two essential fatty acids (EFAs) that our skin needs to stay healthy. Scars, stretch marks, and other regions of very dry, chapped skin can all benefit from its application to smooth out their look. Due to its high vitamin and antioxidant content, cocoa butter aids in defending the skin against environmental harm. It also contains phytochemicals, which are organic plant substances that may aid to condition the skin and may be useful in preventing damage from the sun's harmful UV rays. Cocoa Butter, when applied to hair, moisturizes to fortify strands and make them easier to maintain, hence preventing breaking and ensuing hair loss. In addition to restoring the naturally existing oils found in the hair and scalp, cocoa butter repairs damaged strands, stops additional damage, and also prevents further damage. Cocoa Butter calms the irritated, flaky, itchy problems associated with dandruff by providing the scalp with strong moisture. When styling hair, cocoa butter can be used as a nourishing pomade that adds thickness, adds volume and strength without weighing the hair down, improves resilience, eliminates frizz, and adds shine to most hair types.

3.7.5 Use of cocoa for agricultural production

At first glance, cocoa thus seems to be just another product for which rising worldwide demand places strain on already troubled tropical forests. The fact that cocoa can be produced in forest-like environments (agroforests), where it forms the understorey beneath a canopy of partner plants, makes it unique among other tropical commodities. These trees serve a variety of purposes, such as providing shade and microclimate protection for young cocoa trees, but they can also be productive (by providing wood, fuel, fruits, etc.), maintain soil fertility, store carbon, and serve as a home for pollinators and pest-predators of cocoa (Agnoletti et al., 2022). Additionally, compared to monoculture systems, they offer broader ecosystem services such higher carbon storage, water, energy, and nutrient cycles that are more similar to those of forest ecosystems, and greater biodiversity.

3.7.5.1 For Livestock Farming According to reports, one of these non-conventional feed sources that can take the place of pricey and inefficient traditional feed sources in animal diets is cocoa byproducts. Animal feed materials that have the potential to be used include cocoa bean meal, cocoa bean shells, and cocoa pod husks. Although theobromine, an antinutritional factor (ANF) that is harmful to livestock, significantly restricts their utilization, there are current nutritional technologies that can be used to enhance the application of these resources in livestock feeding systems (Oduro-Mensah et al., 2020). Cocoa-pods husk (CPH) is one of the by-products of cocoa processing. The enormous quantities of these materials are produced annually on the farm after crop harvesting and can serve as raw materials to the food processing industry which could be converted to animal. The process of processing cocoa yields a variety of byproducts, including the cocoa bean's husk, pulp, perspiration around the beans, and cocoa shells.

3.7.5.1.1 Chocolate Pud husk After harvest, the mucilage pulp covers the beans when they are taken out of the pod. When processing cocoa beans after harvest, local farmers typically remove the cocoa husk, which makes up between 2/3 and 3/4 of the weight of the fruit (the average fruit weighs about 400 g). (Costa et al., 2022) observed a favorable relationship in the chemical compositions of soybean hull, Bermuda grass, and cocoa pod husk. (Omotoso, 2019) stated that ruminants might get a significant amount of their energy needs met by cocoa pod husks. The nutritional components of cocoa pod husk are likewise strikingly similar to those of soybean hulls, which are frequently fed to animals in North America. Table 5 makes clear that both cocoa bean cake and cocoa bean shell are rich in crude protein (14–29% DM), an essential component of animal feed. For maintenance, ruminant animals require 10% DM crude protein, and for growth (R), they require 16% DM crude protein.

3.7.5.1.2 Chocolate Bean Shell An embryo and the seed coat make up the cocoa shell. The outer covering is a brown husk that is crisp, dry, and slightly fibrous, and it has a delicious aroma that is similar to chocolate. 2-3% of a cocoa nib that hasn't been separated from the shell may remain. Ruminant animals can obtain energy and the minerals P and Mg from cocoa shells (Laconi & Jayanegara, 2015). Table 4 lists typical values for the shells of cocoa beans. With regard to feeding value, the fiber level is similar to grass hay of medium quality. The cocoa shell has been shown to have a low phytase activity. The chocolate bean shell's chemical makeup suggests that it might be a valuable component for ruminant feeding. According to by (Makinde et al., 2019), cocoa bean shell contains 17.6% crude protein, 4.6% fat, 0.36% calcium, 0.61% phosphorus, 0.06% sodium, 61% magnesium, and 1.6% theobromine. (Makinde et al., 2019) came to the conclusion that cocoa shells proved to be an effective element in cattle feeding (for the production of meat or milk) throughout their feeding trials conducted up until the 1960s.

3.7.5.1.3 Chocolate Bean Meal You can make cocoa bean meals from leftover cocoa beans, crushed cocoa bean cakes, or factory waste. You can also get it from unsold cocoa beans. The amount of shell pieces included in the meal and the level of oil extraction both have a significant impact on the meal's composition. In Table 5 , reports on the cocoa meal's approximate composition are compiled. (Lattimer & Haub, 2010) provide further in-depth details on the fiber and carbs, as well as the quality of the protein and the amount of minerals they contain. The high fiber content and the presence of lignin and detergent fibers that are neutral and acidic in nature suggest that cocoa bean shells are better suited for ruminants than monogastrics.

3.8. Chemical Compounds Present in Cocoa

Cocoa contains a variety of bioactive compounds, including theobromine (C7H8N4O2) and caffeine (C8H10N4O2), which have distinct formulas and structures and serve as mild stimulants with potential effects on mood and physiological responses. The main chemical structures of cocoa are listed below in Table 6 .

3.9. Conclusion and future perspectives

Cocoa, with its rich array of bioactive compounds, including flavonoids and phenolics, exhibits diverse biological activities and potential health benefits. Its antioxidant and anti-inflammatory properties hold promise in promoting cardiovascular health and supporting brain function. Emerging evidence suggests potential anticancer effects, while its antimicrobial activities add to its intriguing potential. Further research is needed to fully understand its antifertility effects. Moderation and a balanced diet remain essential when enjoying cocoa-based products. Overall, cocoa's unique phytochemistry offers exciting prospects for enhancing human health, warranting continued scientific exploration to unlock its full potential.

4. COMPETING INTERESTS

The authors have no competing interests.

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AUTHOR CONTRIBUTIONS

GE, PS, GO, GE, FO, OO, SN, OR, MA, MO, RA, WN, PI were responsible for the conception and design of the study; GE, PS performed data collection. GE, PS performed data analysis and drafted the article. GE supervised the study, contributed to data analysis, interpretation, and critical revisions. All authors approved the final manuscript

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