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# Multidimensional strategies for sustainable management of cocoa by-products

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**Introduction:** The limited understanding of the potential applications of cocoa by-products, due to the scarcity of studies that integrate scientific research and patent analysis, hinders the proper use of these by-products and compromises their role in promoting sustainability in the food industry.

**Methodology:** In this study, a multidimensional review encompassing scientific and patentometric analyses of cocoa by-products was conducted. Databases (Web of Science, Scopus, and Medline/PubMed) were utilized with search terms (Cocoa* OR Theobroma cacao AND by-product*) to identify scientific articles (144). Additionally, we explored earch databases [Espacenet and National Institute of Industrial Property (INPI)], employing a combination of earch terms and international classification codes (Cocoa* OR Theobroma cacao AND by-product* AND A23G), to identify the generated technologies (73).

**Results and discussion:** The results revealed a significant concentration of scientific research in the agricultural and biological sciences (68%), focusing on the bioactive and biofunctional composition of the cocoa by-products. Additionally, interest in technological innovation related to these by-products was identified, as evidenced by the increased number of patent registrations after 2020. These findings suggest a significant potential for growth in this sector and provide valuable insights for future research and product development within the food industry.

KEYWORDS

**scientific prospection, sustainability, *Theobroma cacao*, by-product, technological prospection**

## 1 Introduction

Cocoa (*Theobroma cacao* L.) is a berry fruit native to South America that grows on the trunk and branches of cocoa trees from the Malvaceae family. The fruit can attain lengths of up to 25 cm, whereas trees can reach heights of 10 m (Vásquez et al., 2019). In 2019, global cocoa production averaged 5.6 million tons, with the Ivory Coast ranking as the largest producer. During cocoa processing, beans produce chocolate and various cocoa derivatives, including liquor, powder, butter, and cocoa paste. These products are in high demand globally, with annual growth rates of approximately 3.6% in North America and 1.7% in the European Union. However, cocoa processing generates by-products, notably

the cocoa pod shell and tegument, categorized as residual biomass, constituting up to 80% of the fruit's dry weight (Vásquez et al., 2019).

These by-products contain bioactive compounds, such as pigments, polyphenols, fibers, proteins, lipids, and carbohydrates, which exhibit notable biological properties, including antioxidant, anti-inflammatory, and anticarcinogenic activities. Moreover, they have applications in various sectors such as water treatment and energy. The increased scientific exploration of the health benefits of these residues offers the potential to reduce food waste and garner societal interest. Monitoring and raising awareness regarding the importance of reducing waste, ensuring food security, and mitigating environmental impacts is crucial for reducing food waste during processing (Arun et al., 2020).

Global food waste exceeds 1.3 billion tons and is projected to reach an average of 2.6 billion tons by 2025, with a corresponding economic loss of 400 billion US dollars. This emphasizes the urgent need to establish sustainable and environmentally compatible methodologies for industrial by-product applications to maximize their potential utilization (Kumar et al., 2022).

Cocoa by-products, including the shell and husk, are primarily generated in the field during the initial processing and can constitute up to 80% of the fruit weight. The large-scale production of cocoa waste biomass poses a significant environmental concern for cocoa-producing and processing countries. Political and social instability in some of these countries, along with fluctuations in the US dollar value, directly influence cocoa prices, leading to price volatility, reduced investments, and increased tax burdens. Implementing the effective management of residual biomass could enhance the financial situation of producers and industries through innovative technologies. In 2017, the value of the cocoa industry shells and other by-products increased by approximately USD 244 million, indicating the growing utilization of these by-products by industries worldwide (Vásquez et al., 2019).

Understanding cocoa by-products within the scope of scientific research and patents is important to guide efforts to develop new technologies. This knowledge is fundamental for expanding the ability to anticipate and stimulate the organization of innovative systems. Accordingly, the primary objective of this study is to investigate cocoa by-products using multidimensional scientific and patentometric analyses.

# 2 Methodological aspects

This review defines cocoa by-products as products derived from cocoa fruits without well-established commercialization, such as pods, tegument, oil, leaves, and honey, compared to derivatives such as liquor and cocoa butter, which are highly commercialized in the food and cosmetic industries.

The study was divided into scientific and technological analyses because of the structure of scientific articles and patents being differentiated as tools for disseminating different types of knowledge (Otero et al., 2022). In February 2024, data was collected from scientific articles and patent documents using the Web of Science, Scopus, Medline/PubMed, Espacenet, and National Institute of Industrial Property (INPI) technological databases. The search included the following term combinations: "Cocoa* OR *Theobroma cacao* AND by-product*" and "Cocoa* OR *Theobroma cacao* AND by-product* AND A23G."

To ensure data accuracy in evaluating cocoa by-product usage, the documents were analyzed and either selected or excluded based on the eligibility criteria. This study included articles and patent documents on cocoa by-products (cocoa pods, cocoa bean shells, cocoa honey, mucilage, and cocoa pulp). Conversely, articles and patent documents that did not address the topic of cocoa by-products were excluded.

The results and discussion are divided into: (1) general data found, (2) annual evolution of articles and patent documents, (3) application areas and most reported by-products of articles and patent documents, (4) international classification codes, and holders, of patent documents, (5) origin country's of articles and patent documents, (6) co-occurrence analysis. The study results were presented using tables and figures created using various software tools (Excel and PowerPoint [Microsoft 365]; VISME [https://www.visme.co]; VOSviewer [version 1.6.18]; CANVA [https://www.canva.com]). The term "patent document" refers to submitted and granted patents.

# 3 Results and discussion

## 3.1 General data found

After applying the eligibility criteria, 220 articles and 84 patent documents were included in this study (Figure 1).

## 3.2 Annual evaluation of articles and patent documents

The first scientific study using cocoa by-products, was identified through analysis, dated 1981 (composition of cocoa husk fat related to cocoa butter), conducted by El-Saied, Morsi, and Amer. This study determined the composition of cocoa shell fat in relation to cocoa butter (El-Saied et al., 1981). Subsequently, an increase in publications was observed from 2005 (seven publications), with technological advancements cocoa products in different fields, particularly in the food and pharmaceutical industries (Vásquez et al., 2019). A variable growth profile was observed until 2008 (eight publications), peaking in 2018 (21 publications) (Supplementary Figure 1).

Technical analysis, revealed that patent documents on cocoa by-products have been granted since 1913. The application of this invention refers to an elaborate process for preparing cocoa and its by-products and obtaining improved fat percentage (Edwards, 1913). However, a notable increase was observed only in 2001, when two patent documents were filed. This pattern was not linear, with no documents filed in 2005 or d 2006, and a peak, of 14 files in 2020.

A comparison of scientific and technological publications from 2003 to 2014, revealed, numerous publications on patent documents (53 publications and 12 patents). In 2015 and 2017, the findings were comparable (six and five publications and three and two patent documents, respectively). From 2018 to 2023, scientific submissions have more than doubled in relation to patent

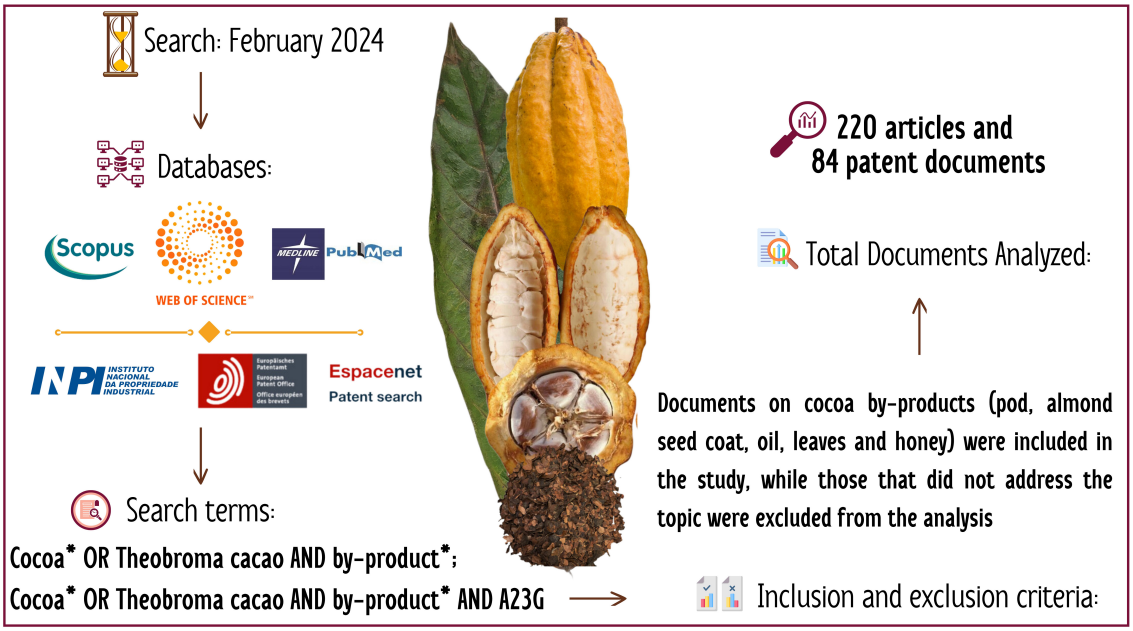


FIGURE 1
Methodological flowchart.

documents (138 publications and 42 patent documents). Over the years, the number of publications (72.6%) regarding the use of cocoa by-products has exceeded that of patent documents (27.3%). Although patentable academic discoveries continue (Rasmussen et al., 2006). Several issues related to patent deposits must be addressed, including the commercialization of these academic centers and the authors and holders to which this request will be linked (Fini et al., 2010; Lawson, 2013).

A decrease in patent applications by 2024 may reflect the 18-month confidentiality period required in the patenting phase (counted from the filing date), and the time interval for documents to be indexed in the database (Oliveira et al., 2021).

The results of this analysis highlight the potential applications of cocoa by-products in poorly investigated areas, such as medicine, cosmetics, and microbiology. Applying these alternative matrices in the development of new studies and technologies will make the current cocoa production scenario more sustainable and valuable.

## 3.3 Application areas and most reported by-products of articles and patent documents

The current relevance of cocoa by-products is manifested by the diversity of their applications (Figure 2). The field of agricultural and biological sciences led with 85% of the publications, followed by Health Science (11.6%) and Exact and Earth Sciences (3.2%).

Evaluation of cocoa products, particularly their nutritional composition, has garnered significant attention over the years. For instance, Azizah et al. (1999) investigated the antioxidant properties of cocoa shells. In this study, it was defended conscious consumption of foods of natural origin with high nutritional value. However, the authors also highlight the need to study the nutritional composition and antioxidant activities of this product. The findings from this study revealed that both cocoa shell and nibs exhibit strong antioxidant activity when methanol is used as a solvent an activity >0.8/10 μL extract for both.

Hidalgo et al. (2019) further investigated the health benefits of cocoa by-products, particularly by examining their effects on cardiovascular health following the consumption of cocoa pods and teguments obesity-inducing diet. The authors emphasized the high fiber content, carbohydrates, proteins, and flavonoids in the by-products, which can modulate obesity and lipid disorders. After 5 weeks of treatment, notable reductions were observed: up to 39% in body weight, 27% in systolic blood pressure, 55% in triglycerides, and 24% in total cholesterol.

Recorded cocoa production in 2020/2021 exceeded 5 million tons of cocoa beans. With cocoa pod husks representing 80% of the associated waste and up to 76% of the cocoa bean dry weight. Cocoa shell was the most frequently studied by-product (51%), followed by teguments (41%). Interest in this by-product has increased both commercially and industrially through scientific investigations and patent filings. Its composition includes ash, cellulose, hemicellulose, lignin, pectin, protein, and minerals such as calcium and potassium (Vandenberghe et al., 2022) (Supplementary Figure 2).

The cocoa shell is the outer part of the fruit and is characterized by its rough texture, oval shape, and noticeable thickness. Owing to its diversity, color variations can be observed, ranging from light yellow purple shades. Furthermore, their intrinsic properties provide protection against environmental agents, pests, and potential damage during harvesting. It represents a significant proportion, up to 80% of the total fruit weight, making its disposal a challenging and relevant issue. Additionally, cocoa shells are rich

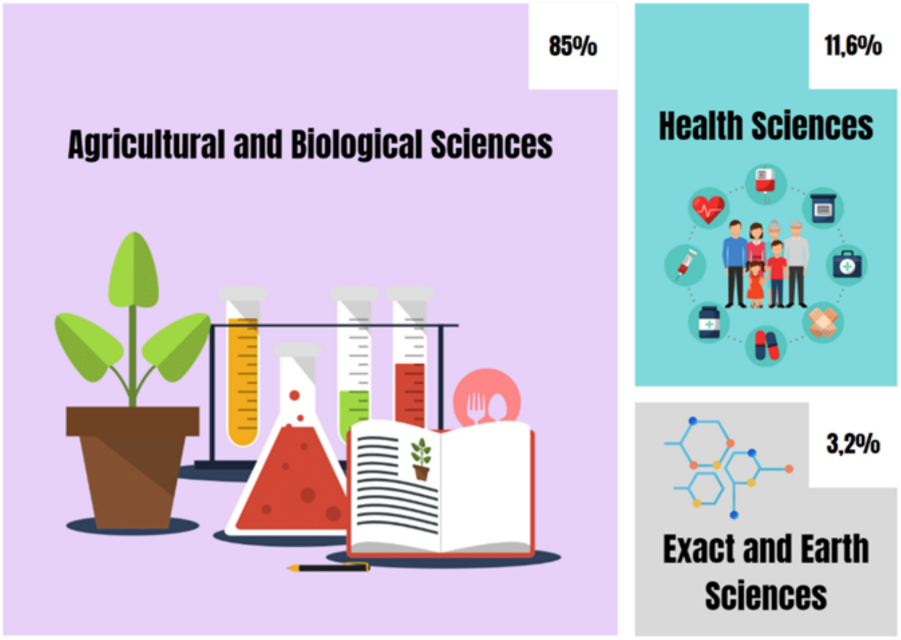


FIGURE 2
Application areas of cocoa by-products from Web of Science, Scopus, and Medline/PubMed databases.

in lignin, non-starch polysaccharides, terpenoids, flavonoids, and free amino acids, such as glutamine and lysine. Commonly used in soil fertilization owing to its substantial mineral content, there is also a growing interest in exploring their potential applications in other fields, including the food industry, pharmaceutical sector, and cosmetics industry (Vásquez et al., 2019).

Tegument is a by-product rich in bioactive compounds, gaining recognition and application in the food processing industry. Its composition includes carbohydrates, proteins, and low lipid content, as well as theobromine, methylxanthines, dietary fibers, and phenolic compounds (Souza et al., 2022). To provide a comprehensive overview, Table 1 summarizes selected key articles related to cocoa husk and tegument the Web of Science, Scopus, and Medline/Pubmed, organized according to scientific and technological relevance.

The studies fall within the biological and agricultural sciences (Table 1), aligning with Figure 1; 51.8% of the studies focused on assessing the nutritional potential of cocoa by-products, particularly their antioxidant activities.

Souza et al. (2022) assessed the potential for using flour derived from cocoa shells and almonds as a substitute for wheat flour in preparing chocolate cakes. It was deemed possible to replace up to 75% of wheat flour with cocoa shell flour without compromising the acceptability of the product.

Rojo-Poveda et al. (2019) evaluated the antidiabetic activity of a functional beverage made from ground cocoa bean shells and teguments, and demonstrated promising potential in inhibiting a key enzyme in glucose metabolism (α-glucosidase). However, the acceptability of the beverage was affected by its taste, possibly owing to the presence of methylxanthines and polyphenols.

Mariatti et al. (2021) investigated technologies for extracting nutritional compounds from cocoa by-products and identified a composition rich in proteins, lipids, dietary fibers, and polyphenols. These compounds have promising applications, particularly in the functional food and beverage industry, a growing market valued at over 1.28 billion dollars.

Balentić et al. (2018) reviewed the possible applications of cocoa bean husks/teguments, with an emphasis on the food industry, where the development of extracts containing total phenols (14 mg/g), theobromine (10 mg/g), caffeine (4.21 mg/g), and catechin (1.02 mg/g) can be used in various food matrices.

Several studies have demonstrated that incorporating dietary fiber into various food matrices, their properties functional. In addition to its numerous health benefits, fiber eases satiety, making it a promising product for reducing portions, sizes particularly in animal foods. Several by-products, such as cocoa pod shells, are rich in dietary fiber and can be used as food ingredients. They are also rich in minerals such as potassium, magnesium, phosphorus, and calcium, have a high soluble pectin content, and are sources of hydrolase enzymes. Moreover, studies on the techno-functional properties of dietary fiber have recently demonstrated its ability to retain water and its potential as a substitute for emulsifiers (Delgado-Ospina et al., 2021).

In the field of technology, the food industry reported the most patent deposits (44%), followed by the chemical and biochemical industries (23%) (Figure 3A). Within the food industry, these by products are primarily used for the development of food ingredients (49%) (Figure 3B), followed by functional foods and beverages (19%).

The composition of cocoa bean shell has garnered significant interest in the food, pharmaceutical, and cosmetic industries, primarily because of its biological properties and because it is a natural, low cost ingredient. Valuing this by-product, in addition to guaranteeing economic benefits through the development of new

TABLE 1 Main articles found with cocoa shell and tegument in Web of Science, Scopus, and Medline/Pubmed databases.

| Title | By-product reported | Purpose | Nutritional and functional aspects | References |
|---|---|---|---|---|
| The potential of imidazole as a new solvent in the pretreatment of agro-industrial lignocellulosic biomass | Pod | Extraction of biomolecules | Lignocellulosic biomass | Valladares-Diestra et al., 2023 |
| Chemical characterization and *in vitro* digestibility of Amazonian seeds and agro-industrial by-products with potential for animal feed | Pod | Determine chemical characteristics and *in vitro* digestibility for animal feed | Chemical composition (fiber, calcium, phosphorus, etc.) | Yoplac et al., 2022 |
| Elephant grass silage with the addition of regional by-products | Pod | Study the effects of cocoa husk addition in elephant grass silage | Chemical and nutritional composition, digestibility | Figueiredo et al., 2022 |
| Effect of feeding cocoa bean by-products (*Theobroma cacao* L) on productive performance in improved creole chickens | Tegument | Determine the effect of including cocoa by-products in the diet of Creole chickens | Nutritional quality | Leiva et al., 2022 |
| Extraction of methylxanthines by pressurized hot water extraction from cocoa shell by-products as a natural source of functional ingredients | Tegument | Extract theobromine and caffeine | Theobromine and caffeine quantification, antioxidant activity | Pagliari et al., 2022 |
| Effect of extraction solvents on phenolic compounds of *Theobroma cacao* L. By-products using ultrasound-assisted extraction | Pod | Extract phenolic compounds | Polyphenol content, antioxidant activity | Jamaluddin et al., 2022 |
| UHPLC-MS characterization and antioxidant and nutritional analysis of cocoa waste flours from the Peruvian Amazon | Pod | Characterize the antioxidant properties and nutritional value of cocoa by-product flour | Chemical and nutritional composition and antioxidant potential | Vargas-Arana et al., 2022 |
| Cocoa by-products: characterization of bioactive compounds and beneficial health effects | Pod and tegument | Study the properties and possible applications of cocoa by-products | Chemical and nutritional composition, biofunctional potential | Soares and Oliveira, 2022 |
| Process intensification technologies for the recovery of valuable compounds from cocoa by-products | Pod and tegument | Evaluate successful polyphenol extraction processes from a literature review | Polyphenol extraction | Mariatti et al., 2021 |
| Inclusion of cocoa by-products in the diet of dairy sheep: effect on the fatty acid profile of ruminal content and the composition of milk and cheese | Tegument | Evaluate the effect of cocoa husks in the feeding of dairy sheep | Chemical and nutritional composition | Campione et al., 2021 |
| Antioxidant effect of cocoa by-products and cherry polyphenol extracts: a comparative study | Pod | Investigate the protective effects of cocoa husk extract against oxidative stress | Antioxidant activity | Felice et al., 2020 |
| Effects of cocoa by-products and a modest weight loss intervention on the concentration of serum triglycerides in overweight subjects: proof of concept | Pod | Evaluate the effect of by-products on the diet of overweight patients | Bioactive compounds | León-Flores et al., 2020 |
| An approach to value cocoa bean by-products based on subcritical water extraction and spray drying using different carriers | Tegument | Establish an efficient and sustainable technological procedure for the valorization of food by-products | Stability evaluation of phenolics and polyphenols using maltodextrin (MD) and whey protein as carriers in the spray drying process | Jokić et al., 2020 |
| LC-MS and spectrophotometric approaches for evaluation of bioactive compounds from Peru: cocoa by-products for commercial applications | Pod | Qualitatively determine phytochemical composition using HPLC-MS | Phenolic and flavan-3-ol content and antioxidant capacity | Cádiz-Gurrea et al., 2020 |
| Structural characterization of pectin obtained from cacao pod husks. Comparison of conventional and subcritical water extraction | Pod | Characterize pectin | Pectin | Muñoz-Almagro et al., 2019 |
| Effects of particle size and extraction methods on cocoa bean shell functional beverages | Tegument | Evaluate the effects of particle size, extraction methods of bioactive compounds, and consumer acceptance of a functional beverage | Methylxanthine and polyphenolic content, antioxidant, and antidiabetic properties | Rojo-Poveda et al., 2019 |

*(Continued)*

TABLE 1 (Continued)

| Title | By-product reported | Purpose | Nutritional and functional aspects | References |
|---|---|---|---|---|
| Obesity and cardiovascular risk improvement using cocoa by-products in a diet-induced obesity murine model | Pod and tegument | Characterize cocoa by-products and analyze their effects on cardiovascular risk | Chemical and nutritional composition, biofunctional potential | Hidalgo et al., 2019 |
| Cocoa Shell: a by-product with great potential for wide applications | Pod and tegument | Valorizate cocoa shell bioactive compounds and possible applications | Bioactive compounds (theobromine, caffeine, flavonoids...) | Balentić et al., 2018 |
| Quality control of Amazonian cocoa (*Theobroma cacao* L.) by-products and microencapsulated extract by thermal analysis | Tegument | Evaluate the thermal profile of by-product extracts (and of its microparticles) obtained by spray drying to preserve its biological activity | Polyphenol content and antioxidant activity | Alves et al., 2018 |
| Integrated, green-based processes using supercritical CO2 and pressurized ethanol applied to recover antioxidant compounds from cocoa (*Theobroma cacao*) bean hulls | Tegument | Selectively recover antioxidant compounds from the by-product | Total phenolic content and antioxidant activity | Mazzutti et al., 2018 |
| Cacao pod husks as a source of low-methoxyl, highly acetylated pectins able to gel in acidic media | Pod | Evaluate optimal conditions for pectins extraction | Pectin | Vriesmann and Petkwicz, 2017 |
| Cocoa pod husks, a new source of hydrolase enzymes for preparation of cross-linked enzyme aggregate | Pod | Cross-linked enzymatic aggregate repair | protein source | Yusof et al., 2016 |
| Linear programming formulation of a dairy drink made of cocoa, coffee, and orange by-products | Tegument | Develop enriched dairy beverages using industrial by-products | Polyphenol content, antioxidant activity | Quijano-Aviles et al., 2016 |
| Optimized preparation and characterization of CLEA-lipase from cocoa pods | Pod | Hydrolytic activity | Across-linked enzymatic Greek | Khanahmadi et al., 2015 |
| Improving the nutritional quality of cocoa pods (*Theobroma cacao*) through chemical and biological treatments for ruminant feeding: *in vitro* and in vivo evaluation | Pod | Improve the nutritional quality of cocoa husk for ruminant feed | Nutritional composition and nutrient digestibility | Laconi and Jayanegara, 2015 |
| Chemical, technological, and *in vitro* antioxidant properties of cocoa (*Theobroma cacao* L.) by-products | Pod and tegument | Determine the chemical, technological, and antioxidant properties | Food and antioxidant activity | Martínez et al., 2012 |
| Intake, total digestibility, microbial protein production, and the nitrogen balance in ruminant diets based on agricultural and agro-industrial by-products | Tegument | Evaluate the effects of including by-products in animal diet | Digestibility of nutrients | Azevêdo et al., 2011 |
| Bioactive compounds and antioxidant activity of cocoa hulls (*Theobroma cacao* L.) from different origins | Tegument | Characterize the bioactive compound contents of by-products from different geographical origins | Polyphenols and hydrocolloids | Bruna et al., 2009 |
| Antioxidant capacity of methanolic and water extracts prepared from food processing by-products | Tegument | Evaluate the antioxidant capacity, with the purpose of use as a food preservative agent | Antioxidant activity and free radical scavenging activity | Amin and Mukhrizah, 2006 |
| Antioxidant and biological activity of phenolic pigments from *Theobroma cacao* hulls extracted with supercritical CO2 | Tegument | Extract phenolic fractions from the by-product using supercritical $CO_2$ | Antioxidant activity | Arlorio et al., 2005 |
| Chemical evaluation of cocoa by-products | Pod and tegument | Chemical evaluation to investigate the use of by-products in animal feed | Chemical composition (mineral content, theobromine,...) | Abiola and Tewe, 1991 |
| Tannin levels and their degree of polymerization and specific activity in some agro-industrial by-products | Pod | Tannin determination for incorporation into animal feed | Tannins (total phenols, condensed tannins, and protein precipitating capacity) | Makkar et al., 1990 |

products, generates environmental benefits. Thus, it reduces waste streams and cause soil damage (Pagliari et al., 2022).

A highlight in the development of cocoa by-product food ingredients is the 2010 patent document (Kannar et al., 2008), which describes a manufacturing process for sugar-containing desired levels of phytochemicals by incorporating by-products such as cocoa husk/tegument. The 1931 patent document (Monsanto Chemical Works Ltd, 1929) aimed to develop an economical

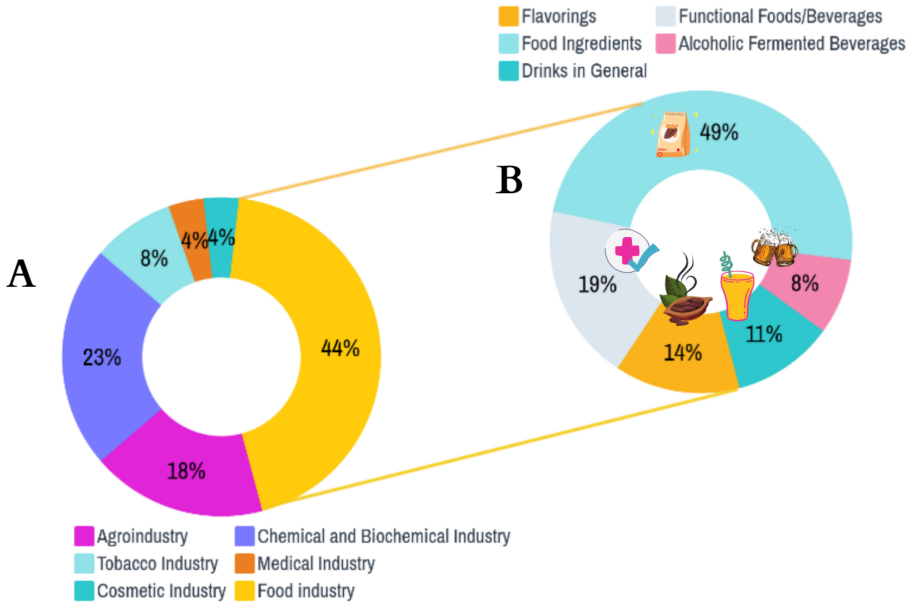


FIGURE 3
Distribution of patent document application areas **(A)**, with a focus on the food industry **(B)**, regarding the use of cocoa by-products found in the Espacenet and INPI databases.

process for extracting fats and alkaloids from cocoa by-products to improve their commercial viability. Regarding developing products with functional applications, a 2009 patent document (Anton and Mateos-Aparicio, 2008) described a prebiotic product with high concentrations of soluble fibers by applying rapid sustainable techniques, using water as a pressurizing fluid to increase fiber levels effectively.

Recently, the industrial and scientific technology sectors have invested in developing new technologies that exploit the nutritional potential of cocoa by-products. This approach aims, to meet consumer demands and mitigate the environmental impacts associated with the inappropriate disposal of these products (Mariatti et al., 2021). For effective planning and technological development, understanding the outlook of by-product use is necessary. The shell, that is, the cocoa pod, is the most highlighted by-product inEspacenet. An INPI search revealed that cocoa pods (32%) and honey (25%) were well-represented (Supplementary Figure 3).

The classification of cocoa by-products is important given that many of these by-products, resulting from fruit processing, are frequently discarded in landfills without proper commercial valorization. Therefore, over time, pulp, which is, essential for cocoa honey production, and the honey, itself have demonstrated significant market value, supported by scientific research and specialized publications, as well as culinary applications. A search on the Google search engine in Brazil (https://www.google.com/) showed that the price of a liter of cocoa honey in February 2024 reached R$83.00. Therefore, the transformation of cocoa honey from a by-product to an item with added commercial value, such as nibs and cocoa butter (designated as cocoa derivatives), the fundamental role of these products play in the commercial appreciation of cocoa.

Agricultural by-products, such as teguments, have garnered attention, primarily because of decreased natural resources and serious environmental issues. Its production is estimated to be significant considering the global production of cocoa, where the weight of its by-product represents 12–20% of the cocoa seed (Okiyama et al., 2017). Therefore, it is important to understand the technologies involved in the use of these compounds. Listed in order of relevance, Table 2 summarizes some of the main patent documents mentioning cocoa husk and seed coats in the Espacenet and INPI databases.

A relationship between the patent documents presented here and the application areas regarding food ingredients and functional foods or beverages can be observed. Most patent documents describe the recovery or development of ingredients or food products rich in nutritional compounds or with beneficial health effects, such as developing foods with high protein content, polysaccharides, antioxidants, and low caffeine content (Carmenza et al., 2018). Regarding the development of nutritionally enriched compounds, a Brazilian patent document (Bradbury and Kopp, 2006) describes the composition of nutritional compounds from the cocoa husk/tegument. It is also possible to identify the use of these compounds in technological applications with health effects, such as the development of materials that suppress cholesterol levels (Ota et al., 1992). These data reflect considerable caution in the technology sector because, in addition to the use of these by-products in the food industry, there are concerns about the use of their constituents in terms of beneficial health effects.

Cocoa tegument is the main by-products of the cocoa and chocolate industry. Unlike other by-products, it is exported with cocoa beans and discarded at processing sites. Although not a part of chocolate formulations, it has sensory and nutritional properties similar to those of cocoa, including catechin

TABLE 2 Main patent documents mentioning cocoa shell and tegument in the Espacenet and INPI databases.

| Title | By-product reported | Purpose | Nutritional and functional composition | Year | References |
|---|---|---|---|---|---|
| Espacenet | | | | | |
| Functional food production process | Tegument | Produce a functional food | Proteins, polysaccharides, antioxidants, and low in caffeine | 2018 | Carmenza et al., 2018 |
| Sugar and their food product manufacturing processes | Tegument | Sugar manufacturing process | Phytochemicals | 2008 | Kannar et al., 2008 |
| Procedure for obtaining a prebiotic product with a high content of soluble fiber said product, and its applications | Tegument | Develop a prebiotic product | High soluble fiber content | 2008 | Anton and Mateos-Aparicio, 2008 |
| Material having increased cholesterol level suppressive activity and decreased HDL-cholesterol level suppressive activity and health foods/beverages containing the same | Tegument | HDL-cholesterol suppressing material | Hemicellulose | 1992 | Ota et al., 1992 |
| The recovery process of valuable products from cocoa by-products | Tegument | Recover fats and alkaloids | Fats and alkaloids | 1929 | Monsanto Chemical Works Ltd, 1929 |
| Treatment of by-products from the cocoa and chocolate industries | Tegument | Recover fats and alkaloids | Fats and alkaloids | 1927 | Livingston and Luthy, 1927 |
| INPI | | | | | |
| Nutraceutical composition comprising limonene and cocoa fiber dry extract for treating obesity | Tegument | Develop nutraceutical composition | Limonene and dry fiber extract | 2021 | Valerii, 2021 |
| Cocoa almond skin nano cellulose processes and production | Tegument | Nanocellulose extraction | Nanocellulose | 2020 | Lessa and Franco, 2020 |
| Ellagic acid production from cocoa hulls | Pod | Ellagic acid extraction | Ellagic acid | 2018 | Soccol et al., 2018a |
| Production of citric acid from cocoa hulls | Pod | Citric acid extraction | Citric acid | 2018 | Soccol et al., 2018b |
| Method of production of hemicellulosichydrolyzate from cocoa fruit peels | Pod | Produce hemicellulosichydrolyzate | Hemicellulose | 2017 | Santana and Dias, 2017 |
| Process for manufacturing a composition enriched with theobromine and a composition enriched with polyphenol from cocoa hulls, and a composition enriched with polyphenol | Pod | Enrich compost manufacturing | Theobromine and polyphenol | 2006 | Bradbury and Kopp, 2006 |
| The manufacturing process of glucosyltransferase inhibitors from cocoa seed husks | Tegument | Manufacture inhibitors | Glycosyltransferase | 1999 | Kim et al., 1999 |

Source: Own authorship (2023).

polyphenols, epicatechins, and procyanidins (Rojo-Poveda et al., 2020a). These similarities have prompted intensive investigations into their potential applications. In particular technological and scientific research has intensified to verify the potential of cocoa husk/tegument as a food additive or vitamin supplement due to its high nutritional content and low cost (Okiyama et al., 2017).

Over the years, remodeling of the food chain through sustainable and efficient approaches has become necessary. Thus, understanding and valuing the broad applications of food by-products has become increasingly necessary. With increasing global food demand, these products are increasingly being investigated, because of their nutritional diversity and ready to be exploited. In addition, these by-products have a low toxicity risk and are highly accepted by consumers (Rebollo-Hernanz et al., 2021).

## 3.4 International classification codes and holders of patent documents

Patent filings qualify in terms of their usefulness, novelty, and obviousness. Patent institutions categorize applications by using a standard hierarchy. The most widely used classification is IPC, which is a standardized taxonomy organized into herarchial. In this type of classification, the highest level is the section, followed by the class, subclass, subclasses, groups, and subgroups (Oryehun et al., 2021).

Collecting data from the technical analysis revealed the most frequently reported codes among the patent filings. Section A is the most frequently reported among the codes and addresses human needs, including agriculture, food products, tobacco, personal or domestic items, and health. Class A23, which addresses food or foodstuffs and their treatments, and the subclasses A23G, A23K and A23L, accounted for the highest proportions. The A23G subclass particularly addresses cocoa, its products, and its derivatives. The most reported subsequent sections were C, chemical, and metallurgical, followed by B, and processing operations. The results obtained from the analysis of the IPC codes on cocoa by-products corroborate the findings on the application areas (Supplementary Figure 4).

Regarding the holders, it was possible to identify that companies led patent filings in Espacenet (67%) and INPI (42%); however, educational and research institutions at INPI ranked second with 35% (Figure 4).

Upon reviewing the patent documents submitted by education and research institutes within the INPI, the State University of Santa Cruz, located in the city of Ilhéus in the southern region of Bahia, and the National Service of Industrial Learning/Bahia were notable, each with three patent deposits. Concurrently, the University Federal da Bahia had, two patent documents. The proposed patents include the development of products from compounds present in or extracted from cocoa by-products (Nery et al., 2020), particularly the production of beverages (Oliveira et al., 2019a), and powders developed from these by-products (Oliveira et al., 2019b).

Among the companies that filed patent documents in Brazil using cocoa by-products, some were foreign, such as the American Intercontinental Great Brands LLC, which focuses on manufacturing and supplying food products. Its patent documents focus on developing food products using cocoa by-products (Dimartino et al., 2021; Brandstetter et al., 2009). Kraft Foods R&D, INC, is among the world's largest companies in food products, with documents of American and German origin, technologies has developed technologies for grinding the seed husk of cocoa (Kopp et al., 2006), and development of enriched products with by-products (Bradbury and Kopp, 2006; Chronopoulos and Zuurbier, 2009). In the business sector, a primary consideration for starting a business is the existence of a potential market. In addition, factors that can contribute to increased organizational operations in each sector include the amount of scientific production, patent activity in the area, the presence of venture capital companies with an interest in the sector, and human capital, that is, the availability of people with the required skills and motivation (van Wilgenburg et al., 2019). In this study, the companies described in the Espacenet database confirmed this data.

Interest in cocoa beans has become an obstacle to popularizing technologies using these alternative matrices. Furthermore, the complexities and costs of the patent system may discourage researchers from seeking intellectual property protection and limited funding may be a sticking point, Bridging the gap between basic research and commercial applications is a constant challenge (Dunn and Kennedy, 2019).

Cocoa and chocolate trade transactions were recorded and estimated at USD 46.61 billion in 2021, forecasted to grow to USD 67.88 billion by 2029. However, the COVID-19 pandemic has adversely affect the expected demand in the sector. Nevertheless, the market has shown progressive growth following the consolidated global trajectory of chocolate confections. A significant increase in the share of global mills has led to an increased consumption of cocoa-derived ingredients (Fortune Business Insights, 2022).

## 3.5 Countries of origin articles and patent documents

In the scientific field, Brazil was the most frequently reported country, followed by Italy, Spain, Malaysia, Mexico and Belgium. Ruguengo et al. (2022) highlighted similar findings in the countries that most frequently addressed the valuable components of industrial by-products, including Brazil, Spain, and Italy (Supplementary Figure 5).

This may be because Brazil is one of the seven primary cocoa-producing countries, with, well-established production and factories exhibiting, good industrialization capacity for diverse cocoa derivatives, such as chocolate (Guirlanda et al., 2021).

Furthermore, the Executive Committee of the Cocoa Farming Plan (CEPLAC), affiliated with the Ministry of Agriculture, is an international authority in promoting cocoa cultivation in Brazil. For over 60 years, CEPLAC has encouraged urban and economic development in southern Bahia and other states, such as Pará, Amazonas, Rondônia, and Espírito Santo. Numerous projects have been developed by CEPLAC, which have driven advances in cocoa production and consumption cocoas well as research in this area (BRASIL Ministério da Agricultura e Pecuária, 2023).

As for the technological assessment, it was identified that the United States was the most prominent country (29%) followed by Japan (20%) in patent filing. Regarding the data obtained from the national database INPI, all documents analyzed that addressed the use of cocoa by-products were from Brazilian deposits, likely because the institution is responsible for Brazilian technological property concessions (Supplementary Figure 6).

The USA is among the main powers within the global agricultural system, and is responsible for innovation in the agrotechnological sector. Although the USA faces major limitations in environmental, demographic, and economic aspects, primarily due to a reduced labor force and aging population, it protects its technologies by filing patent documents (Veeck and Yu, 2020).

Brazil is the seventh largest producer of cocoa worldwide, with the largest plantations in the northern and northeastern regions. Northeast Brazil has the highest cocoa export rate with an average of 44,000 tons in 2020, amounting to approximately USD 184 million. Bahia accounts for almost 100% of cocoa exports, amounting to approximately 44,600 tons (Brainer, 2021). This state also holds the most patent documents related to cocoa by-product in Brazil. In particular, the southern of Bahia and the northern part of Espírito Santo predominate the cocoa cultivation system in a consortium with cabruca, that is, a native forest. In this cultivation method, cocoa plantations, unlike other plantations, favor the preservation of natural resources such as springs, a portion of the forest, and native trees. Southern Bahia has a cocoa plantation of approximately 250,000 ha in a cabruca (Rodrigues et al., 2021).

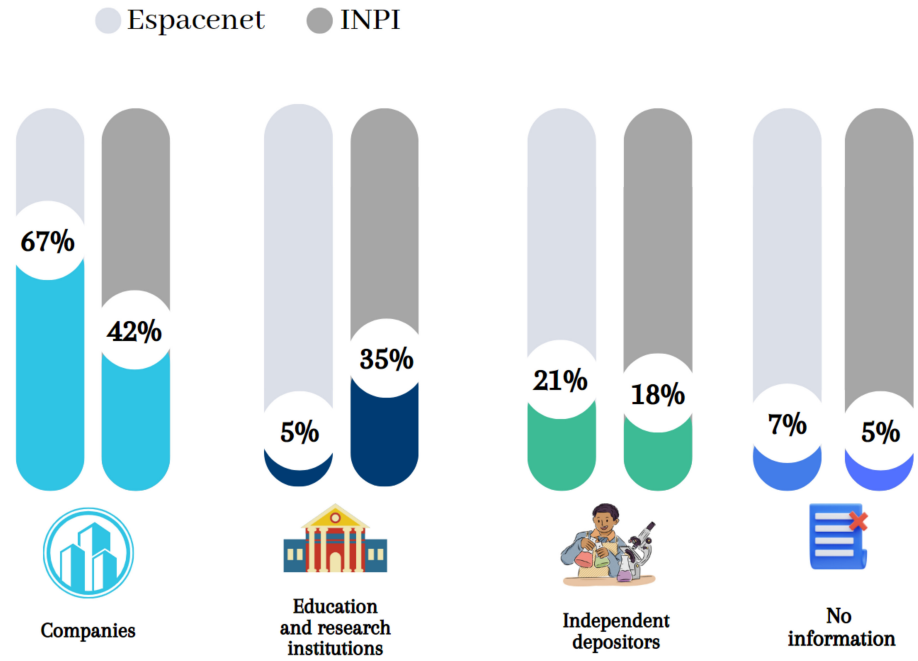


FIGURE 4
Holders of patent documents on using cocoa by-products found in the Espacenet and INPI databases.

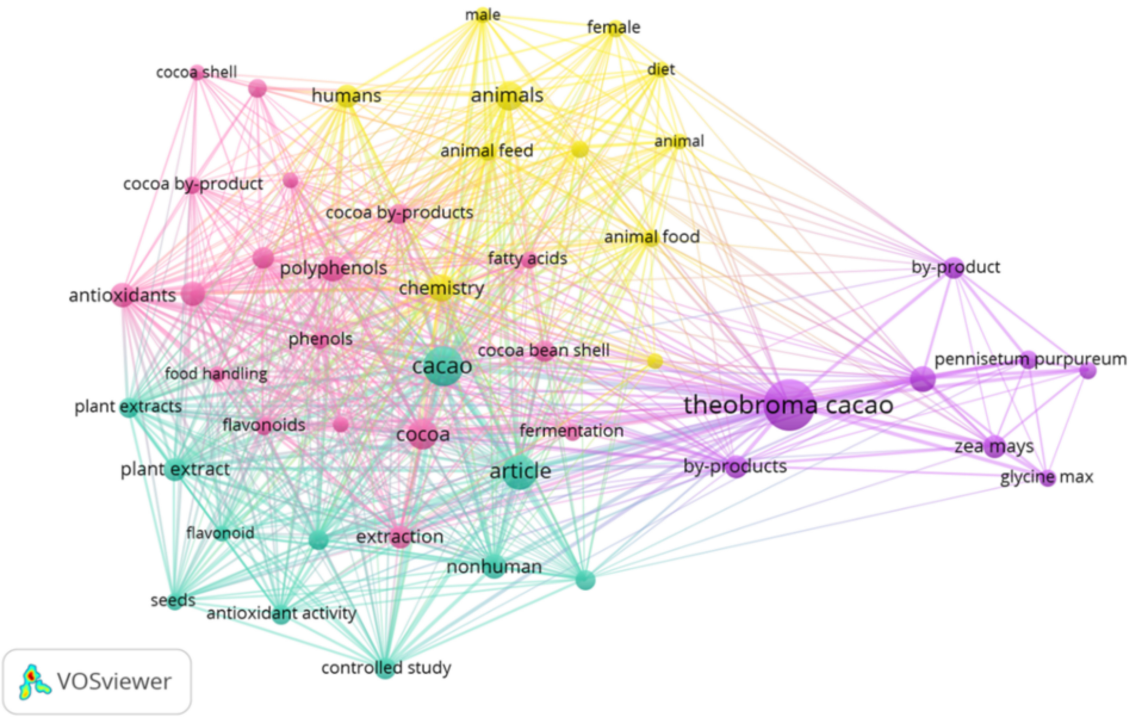


FIGURE 5
Analysis of co-occurrence of keywords in articles that address cocoa by-products.

The development of new products from industrial by-products for different applications has received considerable attention. Accordingly, industrialized countries seek strategic alternatives for their use and to add value to their products (Rojo-Poveda et al., 2020b). The data presented here are relevant for understanding the global perception of cocoa production and industrialization

processes, consequently, its by-products. The exports of these raw materials have reached $47 billion worldwide (Vandenberghe et al., 2022).

### 3.6 Co-occurrence analysis

This analysis focused on the exploring relationships between keywords in the investigated articles (Figure 5). The co-occurrence matrices form rows and columns, and their intersection represents the co-occurrences. This analysis aimed to verify the bibliographic potential of scientific articles or research literature (Zhou et al., 2022). Indeed, this strategy has become an effective statistical method for analyzing the associations among many variables, thereby aiding the understanding of scientific patterns and trends.

The similarities identified in this analysis were categorized into four clusters, first (pink), second (yellow), third (green), the fourth (lilac) (Figure 5). In the first cluster, the terms with the highest similarity were antioxidants, polyphenols, flavonoids, fatty acids, food handling, and fermentation. The second cluster comprised animals, animal feed, diet, and chemistry. The third cluster included cocoa, antioxidant activity, plant extracts, flavonoids and seeds and included a controlled study. In the fourth cluster, *Theobroma cacao* and its by-products showed the highest occurrence.

The associated data provide insights into the current trends in studies on the main aspects of cocoa by-products. Kay, analyzed in the articles included nutritional, biofunctional, chemical composition, food industry, food handling, agrarian sector, development of feeds and products for the agricultural sector.

## 4 Conclusions

The rise in scientific publications and patents highlights significant growth potential in this area. Agricultural and biological sciences are the primary fields of application, with a focus on the food industry. Cocoa almond shell and husks are the most studied by-products in both scientific literature and patents. The most relevant IPC code associated with these by-products is A23, related to food and processing. Brazil and Italy lead in scientific research, while the USA and Japan dominate patent production on Espacenet. Companies are the main patent holders on both Espacenet and INPI. Co-occurrence analysis revealed strong bibliographic connections, focusing on biofunctional aspects, chemical composition, and applications in agribusiness and related industries. It can therefore be concluded that the sustainable use of cocoa by-products is fundamental to the development of a more efficient, profitable production chain that is in line with global environmental and economic demands.

## Author contributions

LMS: Conceptualization, Investigation, Methodology, Writing – original draft. CDFR: Conceptualization, Data curation, Funding acquisition, Project administration, Supervision, Validation, Writing – reviews & editing. JCA: Writing – review & editing. ISAS: Writing – review & editing. VLS: Writing – review & editing. IPPS: Writing – review & editing. MNR: Methodology, Supervision, Visualization, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1460720/full#supplementary-material

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