Reception: **October 19, 2020** | Acceptance: **December 15, 2020**

SCIENTOMETRIC ANALYSIS ON RESEARCH AND TECHNOLOGICAL INNOVATION TRENDS IN THE EXPLOITATION OF COCOA (*THEOBROMA CACAO L.*) BY-PRODUCTS

—

Diego Fernel Peñaloza Albarracín[1] • diegofernel.penaloza@ustabuca.edu.co

Laura Jimena Laiton Daza[1] • laurajimena.laiton@ustabuca.edu.co

Daniel Felipe Caballero Yáñez[1] • daniel.caballero@ustabuca.edu.co

Teresa del Socorro BlancoTirado[1] • teresa.blanco01@ustabuca.edu.co

César Acevedo Argüello[2] • cesar.acevedo@ustabuca.edu.co

Martha Cervantes Díaz[3] • martha.cervantes@ustabuca.edu.co

1 USTAGRI RESEARCH GROUP, FACULTY OF AGRICULTURAL AND LIVESTOCK BUSINESS ADMINISTRATION, UNIVERSIDAD SANTO TOMÁ (USTA), COLOMBIA.

2 ESPIRAL RESEARCH GROUP UNIDAD DE BIBLIOMETRÍA CRAI, UNIVERSIDAD SANTO TOMÁS (USTA), COLOMBIA.

3 GIADS RESEARCH GROUP, FACULTY OF ENVIRONMENTAL CHEMISTRY, UNIVERSIDAD SANTO TOMÁS (USTA), COLOMBIA.

To quote this article:
Peñaloza Albarracín, D. F., Laiton Daza, L. J., Caballero Yáñez, D. F., Blanco Tirado T. S., Acevedo Argüello, C., & Cervantes Díaz, M. (2021). Estudio cienciométrico de tendencias en el aprovechamiento de los subproductos del cacao (Theobroma cacao L.). *Espacio I+D, Innovación más Desarrollo, 10*(27). https://doi.org/10.31644/IMASD.27.2021.a05

— Abstract—

Cocoa is one of the strategic crops for Colombia's rural development policy. Its production chain has an important role not only in economic sectors but also in social and environmental sectors, as it has been considered for the substitution of illicit crops and the restitution of lands. Colombian cocoa bean is recognized worldwide for its quality and aroma and is used as a raw material in the confectionery and chocolate, cosmetics, and pharmaceutical production industries. In Colombia, more than 35.000 families of small producers derive their livelihood from cocoa cultivation.

Approximately, 20% of the fruit is used for the cocoa derivatives industry and the remaining 80% is dried as residues in the form of a pod husk, mucilage, and bean shell. To determine the potential of cocoa residues as an additional source of income for cocoa farmers, scientometric techniques were used to extract indicators of scientific output and inventiveness. In this work, scientific indicators and relational matrices were obtained based on a review of articles and patents that enabled the potential use of cocoa residues to be determined within the principles of the circular economy, which may derive in additional income options for cocoa farmers. Chemical compounds such as polyphenols, alkaloids, and polysaccharides of interest to the food, cosmetic and pharmaceutical industries, were identified, mainly within products obtained from valorization processes. Environmental applications that involve the development of products from cocoa pod husk for soil bioremediation are also highlighted, as well as agricultural applications such as the use of bean shells for the production of biofertilizers, bio fungicides, and growth regulators.

Keywords

Circular economy; cocoa, by-products; exploitation, scientometrics.

Cocoa is a crop of strategic importance worldwide due to its growing demand, mainly as a raw material in the global food and cosmetic industry (Campos *et al*., 2018; Vásquez *et al*., 2019). In Colombia, cocoa cultivation ranks fifth in harvested area with 6.5% of the total area of agro-industrial crops and is surpassed only by coffee crops (29.8%), oil palm (14.1%), sugarcane (11.8%), and sugarcane (8.7%) (DANE, 2014).

According to the *Fondo de Estabilización de Precios del Cacao*, FEPCACAO, between 2013 and 2017, world cocoa bean production grew by 19% (from 3.34 to 4.63 million tons). Of this increase, 76% corresponded to cocoa from Africa, 16% from the Americas, and 8% from Oceania. In contrast, between 2011 and 2017, the increase in Colombian production was 62.7%, which earned it the 10th position in bean production worldwide (FEPCACAO, 2018).

According to FEPCACAO (2020), Colombia has been increasing interest in this crop, since in just 10 years, between 2009 and 2019 it went from producing 36,118 to 59,740 tons of dry beans.

The production of dry cocoa beans generates a significant volume of crop residues, including mucilage and pod husk. At the industrial level, an additional by-product known as bean shell is generated. The mucilage corresponds to the white covering of the seed, the bean shell to the covering of the kernel, and the pod husk to the covering of the entire fruit. The pod husk and mucilage are the residues that are generated in the greatest quantity during the grain fermentation and drying processes (Sodré *et al*., 2012; Lu *et al*., 2018; Campos *et al*., 2018; Vásquez *et al*., 2019).

From the perspective of sustainability, Colombia has included the bioeconomy to achieve green economic growth and within it, the circular economy as one of its fundamental axes. Additionally, residues from agricultural production, also known as residual biomass, are an integral part of the bioeconomy and circular economy perspectives in the country. (National Planning Department, 2018a).

In this sense, and consideration of the high content of biomolecules of industrial interest present in these residues, their revaluation is key to generate new products or inputs that supply crucial demands of bioactive ingredients for the cosmetic, pharmaceutical, food, and agricultural sectors (National Planning Department, 2018b).

Based on the Colombian production of dry beans in 2019 (59,740 tons) and that approximately 80% of the cocoa fruit corresponds to pod husk and mucilage (Campos *et al*., 2018; Vásquez *et al*., 2019), it could be stated that in that year's production approximately 238,960 tons of biomass were discarded during harvesting and fermentation, material that is generally underutilized at the cocoa farm level (Lu *et al*., 2018; Vásquez *et al*., 2019).

Currently, in the environment of Santander producers, it is also common for cocoa harvest residues, such as pod husk, to be discarded and piled in the

lots to be later incorporated as organic matter into the crop. However, unless the pod husks are subjected to a composting process, stacking in the lot is recognized as an inadequate practice, as it constitutes a potential source of proliferation of pests and diseases for the crop (Sodré *et al*., 2012; Lu *et al*., 2018). For its part, mucilage is generally lost as leachate (drained) during the seed fermentation process or is used for jams production.

Although there is current information on the use of cocoa residues, the enormous volume of records available in specialized databases makes it difficult to categorize the information and to know both the trends and the dynamics of research on the use of pod husk and mucilage. This situation makes it difficult to make decisions regarding the orientation of basic or applied research processes to develop the potential of these residues, which would result not only in the diversification of income for cocoa farming families but also in the reduction of these residues as sources for the spread of pests and diseases.

Thus, through the development of a scientometric exercise of scientific articles and patents, potential uses of cocoa harvest residues were identified by obtaining products and compounds of interest in different consumer industries, using keyword relational databases.

2. MATERIALS AND METHODS

To establish the scientific dynamics related to the use of cocoa residues, the scientific articles indexed in the *Scopus* reference database (Elsevier, B.V. 2020) during the period 1980-20l9 were considered. For the inventive step, the Derwent Innovation Index patent database (Clarivate, 2020) was used for the time interval 2000-2020. In both cases, the search terms used were: "*Theobroma cacao*"; cocoa; cocoa waste*; residue*; epicarp*; mucilag* "pod husk"; endocarp*; mesocarp*; "bean shell"; "bean husk"; pulp*; biomass; "residual biomass"; valorization; valorisation; by-products; exploitation.

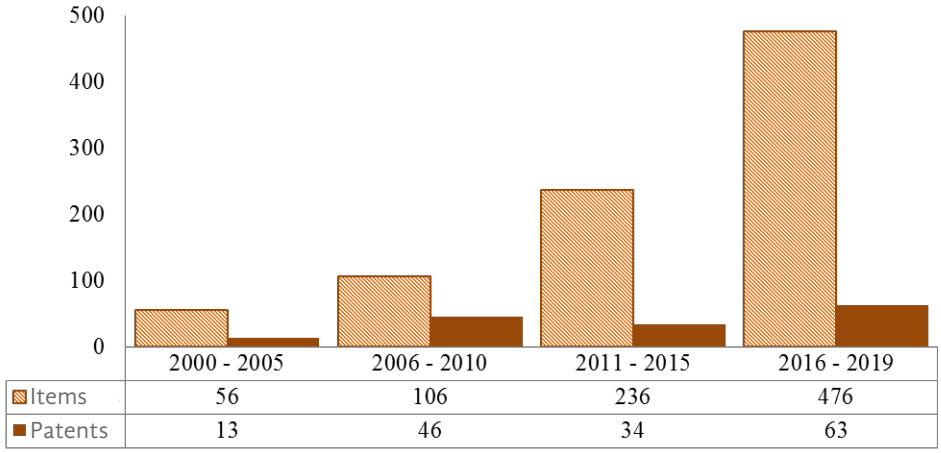
Once the information was obtained, trends in the valuation of harvest residues were identified using scientometric indicators (publications by year and country) and matrices that related the different types of cocoa waste and non-food uses. The data obtained were analyzed using the text mining program VantagePoint® (Search Technology, Academic Version 12.0) and vos viewer (version 1.6.15, 2020, Centre for Science and Technology Studies, Leiden University, The Netherlands).

3. RESULTS AND DISCUSSION

The most relevant results of this scientometric analysis are presented below.

Scientific and inventive dynamics related to the use of cocoa waste at a global leve

According to the structured search equation, 1042 scientific articles and 3717 patent families were retrieved: Image 1 shows an increasing trend in the number of documents in the study period. For articles, the annual growth rate was calculated from 1980 using Price's Law (Price, 1976), which presented a value of 9.37% with a high correlation of the data (R^2 = 0.96). In the case of patents, 2001 was taken as a reference and a growth rate of 26.01% was obtained with a correlation of R^2 = 0.93.



	2000 - 2005	2006 - 2010	2011 - 2015	2016 - 2019
Items	56	106	236	476
Patents	13	46	34	63

Image 1. Dynamics of scientific and inventive activity in the valorization of cocoa harvest residues. Source: Own elaboration

Most productive countries according to the number of scientific publications related to the use of cocoa residues

In terms of scientific production worldwide, Brazil recorded 146 publications, followed by Nigeria with 103, the United States with 93, and Malaysia with 83, as the most important countries researching this topic. In Latin America, in addition to Brazil, Colombia stands out with 40 registrations, Mexico with 32 and Ecuador with 20. In the case of patents, the patent offices, where innovations related to the use of cocoa residues in non-food applications, are registered and analyzed. Russia was identified with 57, China with 23, the United States with 21, and Brazil with 18.

Relational matrices

Within the residues generated in the cocoa harvest, three (3) groups of interest with potential for valorization in industries other than food were identified. According to the search equation structured for this study, 12

publications were found for the waste called mucilage, 147 for "cocoa bean shell" and 146 for "cocoa pud husk". In general, different applications can be derived from these residues as shown in Image 2.

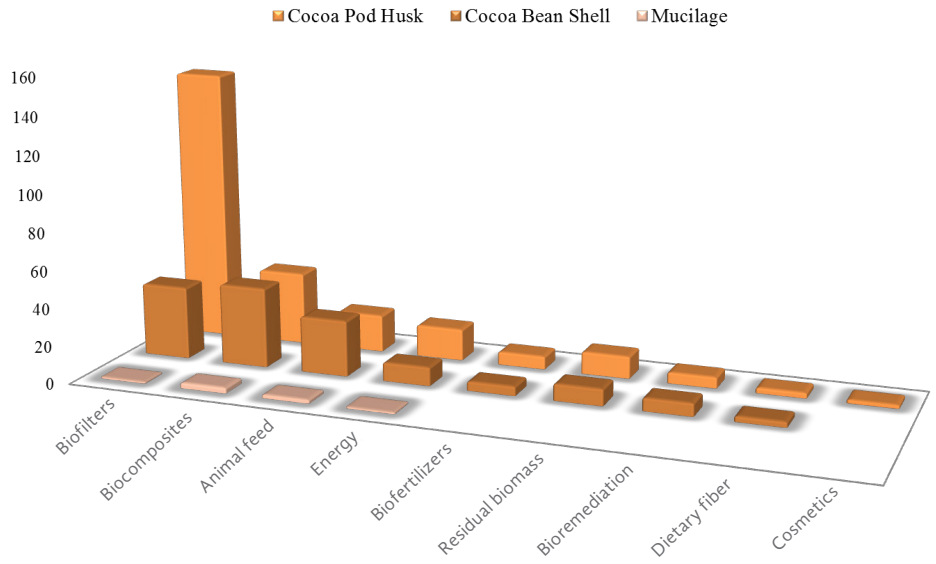


Image 2. Potential uses for the valorization of cocoa (*Theobroma cacao*) organic residues. Source: Scopus database (Elsevier, 2020). Vantage Point (Academic Version 12.0)

A matrix was obtained that relates the potential uses of these cocoa residues with the countries worldwide and in Latin America that research the subject the most (Image 3). Bio-compounds, activated carbon, animal feed, and residual biomass are the applications on which research efforts are concentrated in Brazil, Nigeria, The United States, among others, as can be seen in Image 3. In the case of Colombia, interest is focused on obtaining bio-compounds, activated carbon, and the use of residual biomass. For Mexico, the main focus is on activated carbon.

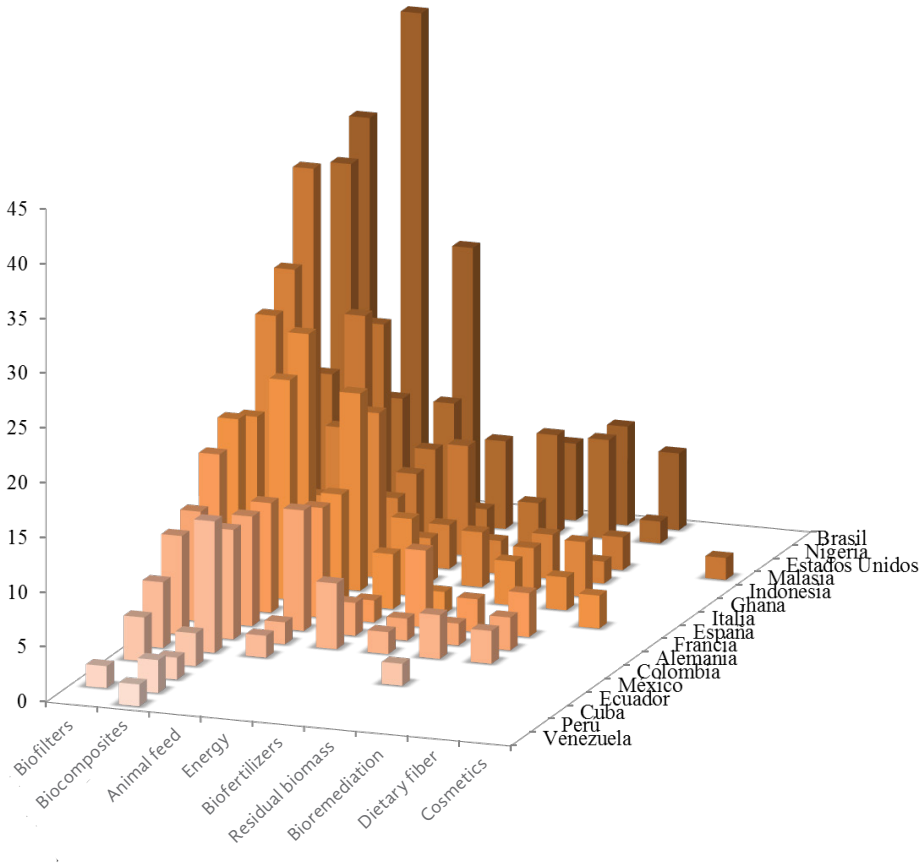


Image 3. Distribution by country of the main products for the valorization of cocoa (*Theobroma cacao*) organic residues. Source: Scopus database (Elsevier, 2020). Vantage Point (Academic Version 12.0)

Inventive trends related to the uses of cocoa residues

Regarding inventive dynamics, the same query criteria were used as in the scientific activity. As a result, 7586 basic patents were obtained, which were purified considering only those related to the three cocoa residues of interest (pod husk, bean shell, and mucilage). Based on this criterion, 122 families were identified that show the use of cocoa residues for food and non-food purposes. In order to characterize the non-food uses, which are the subject of this study, the natural language phrase decomposition algorithm was applied with Vantage Point® software. The attributes of interest were Type of waste; derived raw material; use; area of application; patent number and country.

According to the above, in addition to the potential use for the food industry, bio compounds such as polyphenols, alkaloids, and polysaccharides can be recovered from cocoa residues, which are of interest for pharmaceutical and cosmetic applications or used as residual biomass for the production of biofuels and products for different environmental applications.

From the search equation used, 17 patents with non-food uses of these residues were identified, some of which are included in Table 1.

Table 1
Relevant opportunities to valorize cocoa harvesting residues

Residue	Derived raw material	Use	Area of application	Patent	Countries
Pod husk	Sheets for roofing	Protect from electromagnetic waves	Environmental	JP2010197347A	Japan
	A mixture of shells and resin	Solid fuel	Energy	KR201464728A	Korea
	Monoliths* of activated carbon	NI**	NI**	ES2013737A	Spain
Bean shell	Shell extract	Dermatological Protection against UV rays and pollutants	Cosmetics	FR20038727A	France
	Bean shell	Biofertilizer, bio fungicide, growth regulator	Agricultural	MY2012PI700653A	Malaysia

*Although the patent is for the production of monoliths, it is worth noting that several authors have reported their use in bioremediation processes as adsorbents of heavy metals and dyes.
**Not indicated in the patent.

Source: Derwent Innovation Index database (Clarivate, 2020). Vantage Point (Academic Version 12.0)

CONCLUSIONS

Of the three cocoa harvest by-products, food and non-food uses were identified. The food ones mainly use mucilage. While pod husks have wide applications in animal feed and environmental uses. Environmental applications include the production of biofilters, new roofing materials, and products for soil and water bioremediation. The use of bean shells, a by-product generated mainly by the cocoa liquor industry, was found to be associated mainly with the development of cosmetic formulations such as sunscreens and also with the production of biofertilizers and growth regulators with potential use in the agricultural sector.

Although these harvest residue valorization options are key to generate innovative processes that provide additional income to small and medium Colombian cocoa producers, it is necessary to advance in the identification and formulation of strategies that promote the development of companies that are capable of adding value to these by-products, as well as articulating with small producers to promote new perceptions and management practices of this biomass.

Acknowledgments

The authors thank Universidad Santo Tomás, Seccional Bucaramanga for funding the project *Estudio cienciométrico del aprovechamiento de los residuos de cosecha de cacao en la VIII Convocatoria Interna de Semilleros de Investigación 2019*; and the Unidad de Bibliometría del CRAI Biblioteca de la Universidad Santo Tomás, seccional Bucaramanga.

REFERENCES

AGRONET. (2020). Reporte: Área, producción y rendimiento nacional por cultivo. https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=1

Betancur G., C. M., Moñux Chercoles, D., Canavire B, G., Villanueva, D. F., García G, J., Renza, L. M., Méndez N, K., Zúñiga, A. C., & Pérez. S, E. O. (2018). *Estudio sobre la bioeconomía como fuente de nuevas industrias basadas en el capital natural de Colombia n.o 1240667, Fase I*. Departamento Nacional de Planeación. https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Bioeconomia/informe%201/1-INFORME%20BIOECONOMIA%20FASE%201%20FINAL%2024012018.pdf

Campos - Vega, R., Nieto-Figueroa, K. H., & Oomah, B. D. (2018). Cocoa (Theobroma cacao L.) pod husk: Renewable source of bioactive compounds. *Trends in Food Science & Technology, 81*, 172-184. https://doi.org/10.1016/j.tifs.2018.09.022

Departamento Administrativo Nacional de Estadística DANE. (2014). Décima entrega de resultados. Tercer Censo Nacional Agropecuario. DANE https://www.dane.gov.co/files/CensoAgropecuario/entrega-definitiva/Boletin-10-produccion/10-Boletin.pdf.

Departamento Nacional de Planeación. (2018a). *Bioeconomía y sectores potenciales en Colombia Resumen*. Recuperado el 25 de agosto de 2019, de Departamento Nacional de Planeación: https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Bioeconomia/informe%201/2-PPT%20BIOECONOM%C3%8DA%20Y%20SECTORES%20POTENCIALES_COLOMBIA%20.pdf

FEPCACAO. (2018). *Informe de gestión año 2017 del fondo de estabilización de precios del cacao – FEP CACAO*. FEPCACAO. http://www.fepcacao.com.co/wp-content/uploads/2018/05/INFORME-DE-GESTION-VIGENCIA-2017-FEPCACAO.pdf

FEDECACAO. (2020). Boletín de prensa: Así quedó el ranking de producción de cacao en Colombia. FEDECACAO. http://www.fedecacao.com.co/portal/index.php/es/2015-04-23-20-00-33/1193-boletin-de-prensa-asi-quedo-el-ranking-de-produccion-de-cacao-en-colombia.

Lu, F., Rodriguez-Garcia, J., Van Damme, I., Westwood, N. J., Shaw, L., Robinson, J. S., Warren, G., Chatzifragkou, A., McQueen Mason, S., Gomez, L., Faas, L., Balcombe, K., Srinivasan, C., Picchioni, F., Hadley, P., & Charalampopoulos, D. (2018). Valorisation strategies for cocoa pod husk and its fractions. *Current Opinion in Green and Sustainable Chemistry, 14*, 80-88. https://doi.org/10.1016/j.cogsc.2018.07.007

Ministerio de Agricultura. (2016). *Estrategia Colombia Siembra*. Ministerio de Agricultura. https://www.minagricultura.gov.co/Documents/Estrategia_Colombia_Siembra.pdf

Ministerio de Agricultura & fedecacao. (2013). *Guía ambiental para el cultivo de cacao*.

Price, D. D. S. (1976). A general theory of bibliometric and other cumulative advantage processes. *Journal of the American Society for Information Science, 27*(5), 292-306. https://doi.org/10.1002/asi.4630270505

Sodré, G. A., Venturini, M. T., Ribeiro, D. O., & Marrocos, P. C. L. (2012). Extrato da casca do fruto do cacaueiro como fertilizante potássico no crescimento de mudas de cacaueiro. *Revista Brasileira de Fruticultura, 34*(3), 881-887. https://doi.org/10.1590/S0100-29452012000300030

Vásquez, Z. S., de Carvalho Neto, D. P., Pereira, G. V. M., Vandenberghe, L. P. S., de Oliveira, P. Z., Tiburcio, P. B., Rogez, H. L. G., Góes Neto, A., & Soccol, C. R. (2019). Biotechnological approaches for cocoa waste management: A review. *Waste Management, 90*, 72-83. https://doi.org/10.1016/j.wasman.2019.04.030