detritus | Multidisciplinary Journal for Circular Economy and Sustainable Management of Residues

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THE USE OF AGRO-INDUSTRIAL WASTE TOWARDS A SUSTAINABLE CIRCULAR ECONOMY: A SYSTEMATIC REVIEW

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Article Info:
Received:
4 December 2024
Revised:
9 April 2025
Accepted:
28 April 2025
Available online:
4 June 2025

Keywords:
Utilization
Agro-industrial waste
Sustainability
Circular economy
Waste recovery

ABSTRACT
The agribusiness production model follows the linear economy model and generates waste, which, if not properly managed, causes economic, environmental, and social challenges. In this context, a substantial body of research indicates that there are sustainable alternative solutions that transform waste materials into raw materials, thereby reducing the amount of pollution. This article presents a systematic review of the use of agro-industrial waste as a sustainable solution, with a particular focus on its role in the transition to a circular economy. The significance of this work lies in identifying trends and opportunities for the use of agro-industrial waste, which contributes to sustainability through alternative uses that minimize environmental impact. In addition, it provides ideas for the development of value-added business units. The results are useful for policymakers, entrepreneurs, and researchers interested in implementing sustainable practices. A systematic analysis of 100 research articles published between 2017 and 2024 was conducted using the PRISMA tool to identify trends, progress, and benefits associated with the circular economy in relation to agro-industrial waste. The findings demonstrate the potential for repurposing these by-products, with applications in the production of bioenergy, the development of materials, and the extraction of compounds with utility across a range of industries, including agriculture, cosmetics, pharmaceuticals, and food production. In conclusion, the use of agro-industrial waste materials encourages the adoption of responsible practices and makes a substantial contribution to a sustainable future.

1. INTRODUCTION

The global production model follows the linear economy model, which is characterized by the extraction, manufacturing, consumption, and discarding of resources. This model has been used by the agroindustrial sector in its various activities, resulting in negative economic, social, and environmental impacts (Cury et al., 2017). The generation of waste occurs at all stages of the production process, including the transformation and commercialization of products. In the absence of an effective management plan, this waste presents significant challenges in its final disposal. It is imperative to transition from a linear economy model to a circular one that is based on the principles of reduction, reuse, recycling, repurposing, remanufacturing, and redesign (Romero-Sáez, 2022; García, 2022; Afteni et al., 2021), becoming a global priority as a strategy to dynamize territories (Khanna et al., 2022; Zheng et al., 2025).

Agro-industry is the set of activities aimed at the industrialization and commercialization of value-added products produced from waste converted into raw materials derived from food production processes (Peñaranda et al., 2017; Aguiar et al., 2022a; 2021b). It is estimated that approximately one-third of the world's food for human consumption is discarded, resulting in the generation of waste throughout the entire supply chain, from the cultivation of raw material to its commercialization. However, the amount and type of waste are influenced by a few factors, including GDP, average income, and population consumption. In some countries like Colombia, India, Ecuador, Mexico, and Paraguay, waste originates in agriculture, given that their economies are primarily based on this sector and the activities that comprise it (Peñaranda et al., 2017).

Aware of these issues, the appropriate management of waste is imperative to mitigate environmental damage (Alazaiza, 2025). It is necessary to reassess the linear economy model and consider more sustainable alternatives (Özkan & Yücel, 2020). The circular economy model offers a transformative approach to natural resource and waste management, aiming to ensure long-term sustaina-

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Detritus / Volume 31 - 2025 / pages 45-61
https://doi.org/10.31025/2611-4135/2025.19491

bility. It involves designing products for multiple life cycles, efficient resource utilization, and minimizing the generation of hazardous waste that could harm the planet (Silva y Oliveira, 2021).

Due to the above, research is being conducted with the aim of identifying sustainable solutions to minimize the problem. Potential solutions include the recovery and use of waste generated in the sector, where the production of biofuels (Golato et al., 2017; Delgado et al., 2023), bioplastic (Azmin et al., 2020; Henao and Salazar, 2018), compost (Moises et al., 2022; Chia et al., 2020), and renewable energy (Torres and Quintero, 2019) are examples of how to transform waste into valuable resources, representing a promising path for reducing environmental pollution.

A systematic review was conducted to demonstrate the productive utilization of agro-industrial residues as a sustainable solution. The objective of this study was to analyze existing research on the use of fruit and vegetable waste as raw material, identify trends and advances, and assess environmental, social, and economic benefits associated with this practice. The search focused on the use of agro-industrial residues for the development of new products, including fuels, animal feed, biomass, construction materials, compost, among others.

The results show the existence of productive initiatives that are moving toward a sustainable circular economy. Likewise, alternative uses for agroindustrial waste were identified, including the generation of bioenergy, the development of materials, and the extraction of compounds with potential applications in various industries such as agriculture, cosmetics, pharmaceuticals, and food. In conclusion, the use of agroindustrial waste promotes responsible practices and contributes significantly to a more sustainable world, especially in countries that rely on this sector for their economies.

The document targets those interested in the transformation of raw materials, including waste at technological and agricultural levels. It is also intended for professionals in industrial engineering, chemistry, construction (cement companies), and anyone focused on environmental quality and climate change improvement through agro-industrial consumption.

2. MATERIALS AND METHODS

2.1 Methodology

The objective of the research was to investigate the feasibility of contributing to sustainability and pollution abatement by transitioning from a linear to a circular economy model. The research employs an exploratory mixed approach, utilizing the systematic analysis method (Jeong et al., 2024; Codina, 2024; Castillo et al., 2024). The review encompassed 1,785 articles, which were subjected to a process of refinement based on pre-defined exclusion and inclusion criteria. The study period comprises articles published during the years 2017 and 2024. The analysis is conducted from a theoretical and documentary perspective, identifying trends, advances, and the utilization of agroindustrial waste. This evidence advances in this field, particularly regarding the practices and productive bets from a circular economy that allows contributions to environmental, social, and economic sustainability.

The search strategy was structured according to four main axes: topic, approach, context, and applications (Table 1). For each axis, key terms were defined and linked using Boolean operators (AND, OR, and NOT) since their use produces better results when searching for information (Aliyu, 2017; Bramer et al., 2018; Villegas, 2023). To begin, the search equation included either subjects such as agro-industrial residues, wastes, and by-products: ("agro-industrial residues") OR ("agro-industrial wastes") OR ("agro-industrial by-products"). Subsequently, the search was refined by defining the approach, which incorporated concepts such as recovery, valorization, reuse, and the circular economy: ("utilization") OR ("valorization") OR ("reuse") OR ("transformation") OR ("circular economy") OR ("sustainability"). As the literature on this subject is vast, it was necessary to establish a comprehensive context for the studies, with a particular focus on the agro-industrial, food, cosmetic, and pharmaceutical sectors: ("agro-industry*") OR ("agricultural sector") OR ("food industry") OR ("cosmetics industry") OR ("pharmaceutical industry"). Finally, to refine the search, applications were limited to bioenergy, materials development, and sustainable practices: ("bioenergy") OR ("materials development") OR ("compound extraction") OR ("responsible practices") OR ("sustainable solutions").

2.1.1 Data acquisition

The search for articles was conducted using databases that covered visualization in different contexts, including Scopus, SciELO, DOAJ, and Latindex. The selection of databases was based on their coverage of scientific literature in the fields of agroindustry and waste management. It should be noted that the databases consulted have blind peer review, which ensures the quality of the documents, in addition to having search tools that allow users to find relevant information based on specific keywords.

A search engine was used to generate keywords related to the purpose of the study, which were then classified into six blocks: agricultural waste utilization, animal feed pro-

TABLE 1: Search equation.

Topic	Search terms
Subject	("agro-industrial residues") OR ("agro-industrial wastes") OR ("agro-industrial by-products")
Approach	("utilization") OR ("valorization") OR ("reuse") OR ("transformation") OR ("circular economy") OR ("sustainability")
Context	("agro-industry*") OR ("agricultural sector") OR ("food industry") OR ("cosmetics industry") OR ("pharmaceutical industry")
Applications	("bioenergy") OR ("materials development") OR ("compound extraction") OR ("responsible practices") OR ("sustainable solutions")

TABLE 2: Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Articles published between 2017 and 2024	Articles published before 2017 or after 2024
Studies on the use of agro-industrial wastes	Studies that do not focus on agro-industrial wastes
Research demonstrating practical applications such as bioenergy, materials development, compound extraction	Research that only mentions the waste problem without proposing solutions
Studies that relate the use of waste to the circular economy and sustainability	Studies that focus exclusively on waste generation without addressing waste utilization
Publications in peer-reviewed scientific journals	Research that does not provide clear methodological details
Studies published either in English or Spanish	Publications in languages other than English or Spanish
Open Access studies	Paid studies (Not Open Access)

duction, bioenergy production, extraction of compounds, materials processing, and organic fertilizers, as well as other related topics.

Inclusion and exclusion criteria (Table 2) were established to ensure the relevance and quality of the selected studies. Articles were included if they were published in the defined period between 2017 and 2024 and were included in the four axes. Moreover, they should specifically address the use of waste from agro-industrial processes, with practical applications and a focus on circular economy or sustainability. Priority was also given to Open Access publications in English or Spanish. Studies that did not focus on agro-industrial process waste or that only mentioned the problem without proposing solutions were excluded, as were articles without clear methodological data and articles published in restricted access journals.

2.1.2 Systematic review

A bibliographic matrix was constructed according to category, thus allowing the texts to be documented for analysis and discrimination. This allowed for the identification of trends, the number of publications per year, authors, citations, journals, topics addressed, advances, and practices related to the use of residues derived from agroindustrial processes. Figure 1 illustrates the process flow.

The figure illustrates how the equation and search engines were used to identify 1,785 articles. Following the implementation of the exclusion and inclusion criteria, a

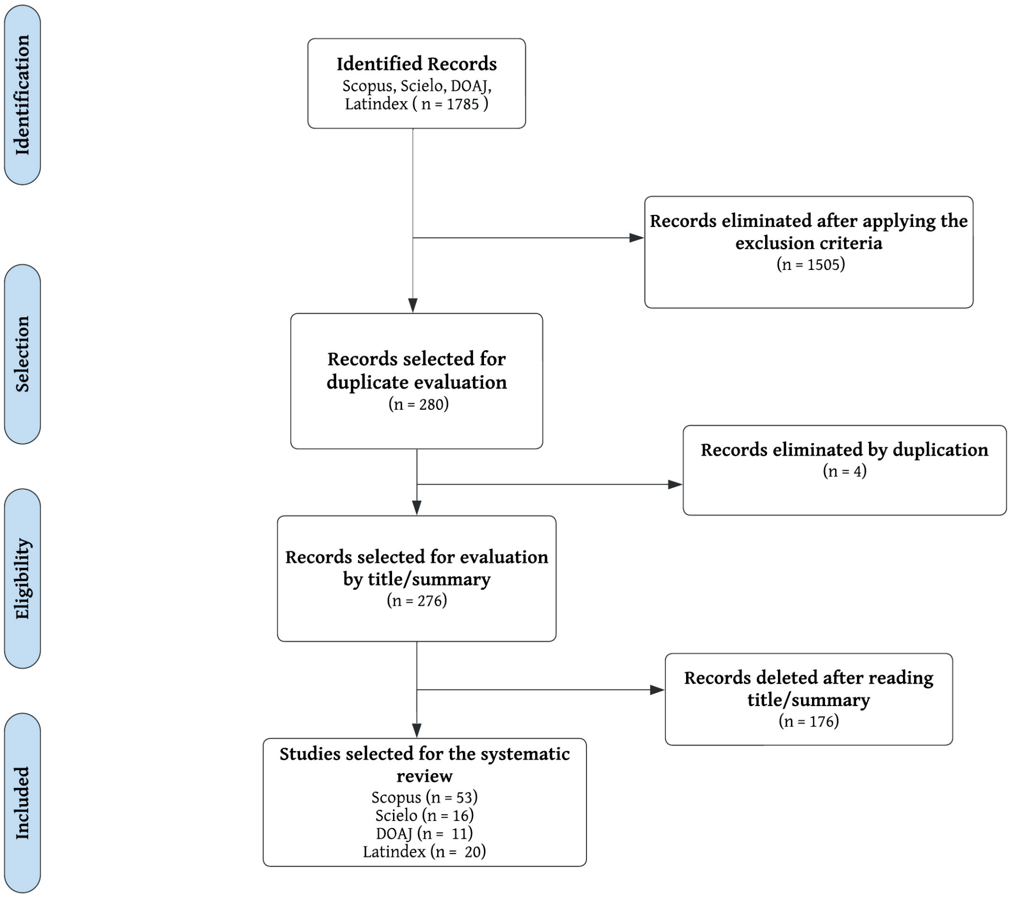

FIGURE 1: Selection process flowchart.

total of 1,505 records were deemed to be non-pertinent and were subsequently eliminated from the analysis. The inclusion criteria included: articles published between 2017 and 2024, studies focusing on the utilization of agro-industrial byproducts, research that elucidates practical applications such as bioenergy, material development, and compound extraction, studies that delineate the utilization of waste in relation to the circular economy and sustainability, publications in peer-reviewed scientific journals, and studies published in either English or Spanish, along with open access studies. Then, records were examined for duplicity, resulting in the removal of 4 duplicates. The remaining 276 records were evaluated by reviewing their titles and abstracts to verify their relevance, resulting in 100 articles, and were classified into the following areas: agricultural waste utilization, animal feed production, bioenergy production, extraction of compounds, materials processing, and organic fertilizers, as well as other related topics. The database of origin for each article is as follows: 53 articles from Scopus, 16 articles from Scielo, 11 articles from Doaj, and 20 articles from Latindex.

3. RESULTS AND DISCUSSIONS

The first stage of analysis identifies all published research studies during the specified period. Figure 2 shows that most publications (52%) occurred in 2020, 2021, and 2023. 2024 only encompasses the first quarter, indicating a promising trend in publication activity, except in 2022.

Secondly, the journals that disseminate the research are analyzed, as well as the number of publications and citations during the period of study. The results indicate that the topic is of interest with a growing trend and diversity of research. A total of 3960 citations were found, with 60% concentrated in the first ten journals shown in Table 3.

Regarding the assessment of recurrent terminology across the articles, Figure 3 provides a representation of the thematic interconnections network, with two focal points: sustainability and fuels. Three clusters were identified: the first (red) pertains to animal feed, food waste, and fermentation; the second (green) is concerned with biofuels, biomass, and fossil fuels; and the third (blue) is centered on agriculture. The connecting lines between nodes represent the strength of bibliometric relationships. It was found that there is a close relationship between "biofuels-biomass" and "food waste-fermentation." Also, the "sustainable development" node acts as a central point of convergence, connecting aspects of agricultural waste management with bioenergy production.

Likewise, Figure 4 offers a visual representation of the articles consulted, classified by country of study origin during the period of study. This figure illustrates the geographical distribution of consulted articles, indicating a concentration of publications in countries with a productive economy based on agricultural products. The analysis is focused on the nine countries that account for 60% of the total number of publications.

The most frequently cited articles on this topic during the period of study were also identified. Three of the most frequently cited articles were identified in the Scopus database. 1. The article "Agro-industrial wastes and their utilization using solid-state fermentation: a review" in Bioresources and Bioprocessing (2018) has been referenced 807 times, while the article "Towards transparent valorization of food surplus, waste, and loss: clarifying definitions, food waste hierarchy, and role in the circular economy," published in the journal Science of The Total Environment (2020), has been cited 257 times. The third article, "Biofuels and their sources of production: A review on cleaner, sustainable alternatives against conventional fuel in the framework of the food and energy nexus" published in the journal Energy Nexus (2021), has been referenced 113 times.

Furthermore, additional articles were identified in other databases, including Latindex, which yielded the article "Use of Agro-Industrial Waste to Improve Environmental

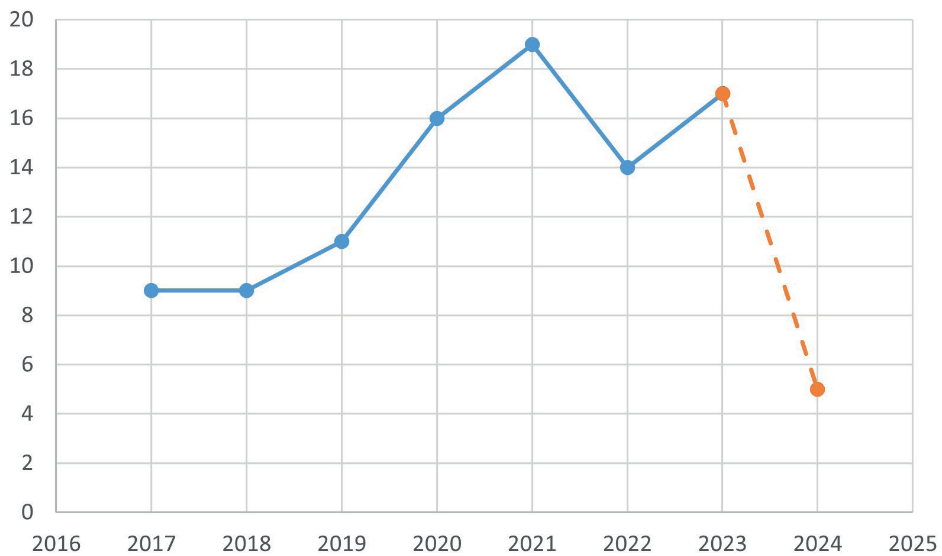

FIGURE 2: Number of articles published per year.

TABLE 3: Journal and citations.

Journal	Number of articles	Publications %	Total citation	Average number of citations
Bioresources and Bioprocessing	1	1%	804	804
Revista Facultad de Ciencias Básicas, Universidad Militar Nueva Granada	2	2%	382	191
Science of The Total Environment	2	2%	257	129
Revista De Investigación Agraria Y Ambiental	1	1%	194	194
Revista Colombiana de Ciencia Animal	1	1%	171	171
Energy Nexus	1	1%	158	158
Journal of Bioresources and Bioproducts	1	1%	140	140
Environmental Pollution	1	1%	103	103
Fuel	3	3%	102	34
Foods	1	1%	95	95
Orinoquia	1	1%	88	88
Dominio de las Ciencias	1	1%	83	83
Journal of Environmental Chemical Engineering	1	1%	81	81
PLOS ONE	1	1%	79	79
Ain Shams Engineering Journal	1	1%	78	78
Revista Ingeniería Industrial	1	1%	69	69
Annals of Agricultural Sciences	1	1%	68	68
Journal of Materials Research and Technology	1	1%	51	51
Bioresource Technology	1	1%	45	45
Heliyon	2	2%	45	23
Molecules	2	2%	45	23
CIENCIA ergo-sum	1	1%	44	44
Agriculture	1	1%	39	39
Materials Science for Energy Technologies	1	1%	37	37
Biomass Conversion and Biorefinery	1	1%	33	33
Scientia et Technica	1	1%	32	32
Animals	2	2%	31	16
Ingenierías USBMed	1	1%	31	31
Avances en Ciencias e Ingeniería	1	1%	27	27
Industrial Crops and Products	1	1%	27	27
Revista Mexicana de Ciencias Agrícolas	1	1%	24	24
Investigación e Innovación en Ingenierías	1	1%	23	23
Sustainable Energy Technologies and Assessments	1	1%	23	23
Revista Cubana de Quimica	1	1%	21	21
TecnoLógicas	1	1%	21	21
Polo del Conocimiento	1	1%	20	20
Axioma	1	1%	18	18
Case Studies in Chemical and Environmental Engineering	1	1%	18	18
Biomass and Bioenergy	2	2%	17	9
Journal of Thermoplastic Composite Materials	1	1%	17	17
Energies	1	1%	16	16
Meat Science	1	1%	16	16
Revista Iberoamericana de Tecnología Postcosecha	1	1%	15	15
Archives of Microbiology	1	1%	14	14
Cuadernos del Tomás	1	1%	14	14
RIINN - Revista Ingeniería e Innovación	2	2%	14	7

Journal	Number of articles	Publications %	Total citation	Average number of citations
Sustainable Production and Consumption	1	1%	14	14
Prospectiva	3	3%	13	4
Revista Colombiana de Investigaciones Agroindustriales	1	1%	13	13
Revista Tecnología en Marcha	1	1%	13	13
Revista industrial y agrícola de Tucumán	1	1%	12	12
ALFA	1	1%	11	11
Enfoque UTE	1	1%	10	10
FIGEMPA: Investigación y Desarrollo	1	1%	10	10
Rivar	1	1%	10	10
International Journal of Biological Macromolecules	1	1%	9	9
Designia	1	1%	8	8
Journal of Environmental Management	1	1%	8	8
Resources, Conservation and Recycling	1	1%	8	8
Revista Ingeniería Agrícola	1	1%	8	8
Energy for Sustainable Development	1	1%	7	7
Journal Of Academia	1	1%	7	7
Saudi Journal of Biological Sciences	1	1%	7	7
Gestión y Ambiente	1	1%	6	6
Food Packaging and Shelf Life	1	1%	5	5
Revista Colón Ciencias, Tecnología y Negocios	1	1%	5	5
Revista Kawsaypacha: Sociedad y Medio Ambiente	1	1%	5	5
Scientia Agropecuaria	1	1%	5	5
South African Journal of Animal Sciences	1	1%	5	5
Cuadernos de Investigación UNED	1	1%	4	4
Materials Today: Proceedings	2	2%	4	2
Ciencia del suelo	1	1%	3	3
En Computer-aided chemical engineering	1	1%	3	3
Pertinencia Académica	1	1%	3	3
Química Hoy	1	1%	3	3
Chemical Engineering Research and Design	1	1%	2	2
Ciencia Latina Revista Científica Multidisciplinar	1	1%	2	2
Journal of Analytical and Applied Pyrolysis	1	1%	2	2
Minerva	1	1%	2	2
Acta Nova	1	1%	1	1
Agro Productividad	1	1%	1	1
Digital Ciencia@ UAQRO	1	1%	1	1
Agro UNS	1	1%	0	0
Anales Científicos	1	1%	0	0
Fuel Processing Technology	1	1%	0	0
LOGINN Investigación Científica Y Tecnológica	1	1%	0	0
Revista de la Facultad de Agronomia	1	1%	0	0
Revista Teinnova	1	1%	0	0
Total	100	100%	3960	

Quality" from the journal Revista Facultad de Ciencias Basicas, Universidad Militar Nueva Granada (2018). This article has received a total of 370 citations. DOAJ lists the article "Use of Agro-industrial Waste in Colombia" in the Revista De Investigación Agraria Y Ambiental (2017) with 194 citations, while CIELO lists the article "Agro-industrial

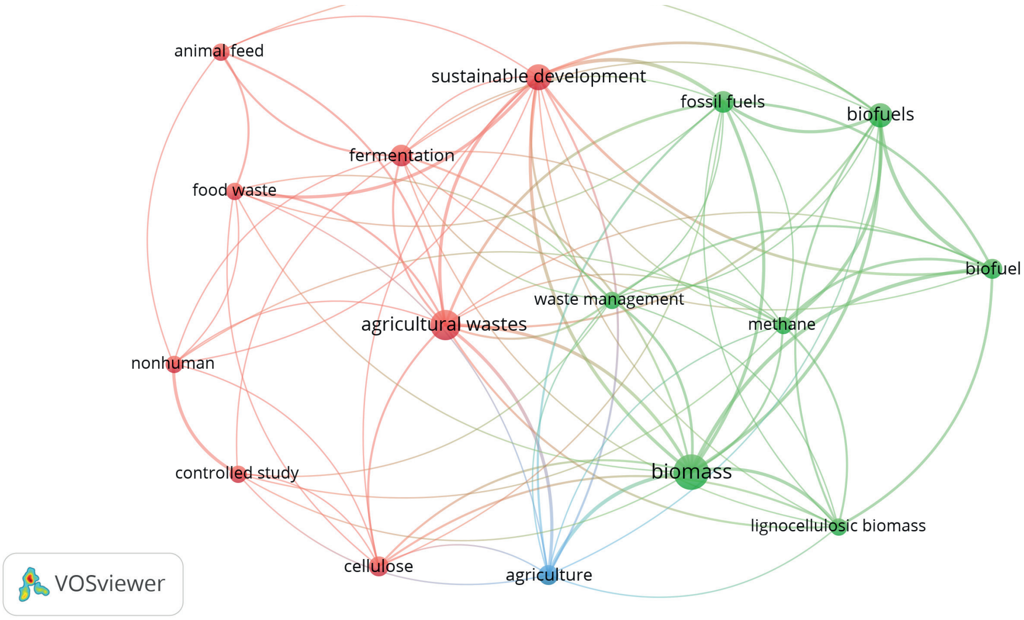

FIGURE 3: Thematic interconnections network.

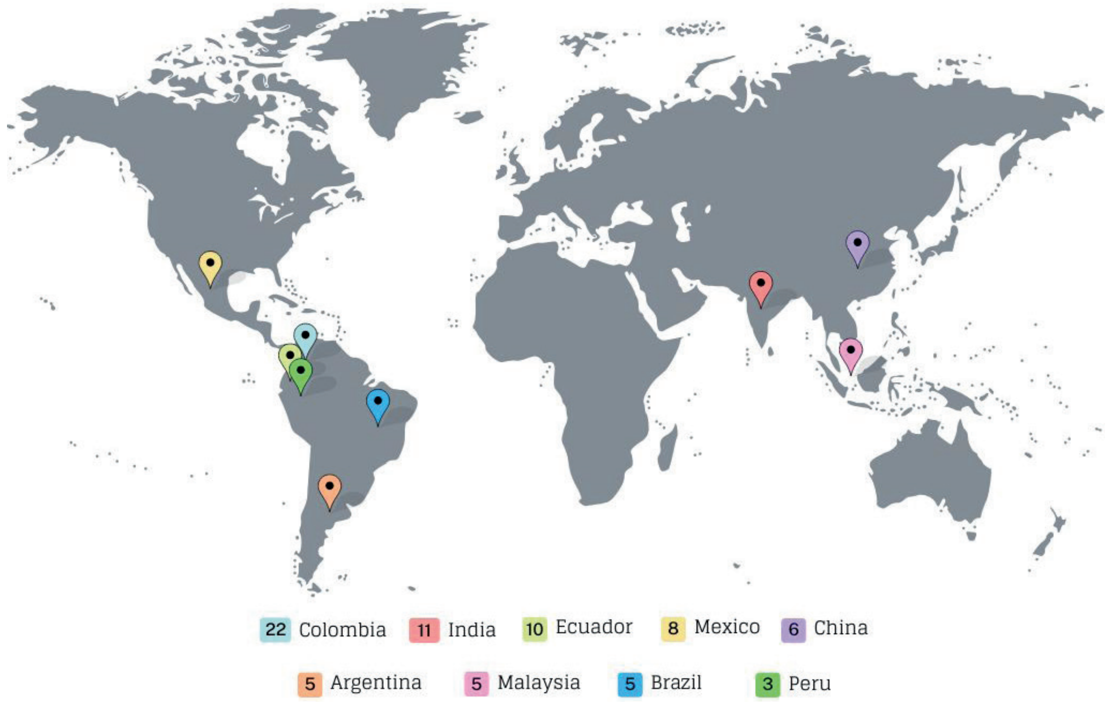

FIGURE 4: Country of study origin.

Waste Impact, Management and Utilization" in the Revista Colombiana de Ciencia Animal (2017) with 171 citations.

It can be stated with a reasonable degree of certainty that there is now sufficient evidence to affirm that in the world there is an increased awareness of change towards a circular economy production model. This is evidenced by the fact that productive bets are being generated using agroindustrial waste on different fronts that were classified in six categories, and the participation is as follows: production of animal feed with 14%; generation of bioenergy with 27%; elaboration of materials with 14%; extraction of valuable compounds with 16%; production of fertilizers with 10%; and other applications with 18%.

The objective of this article was to identify productive practices that involve the use of agroindustrial wastes as part of the transition from a linear to a circular economy model, with a view to contributing to sustainability. Through a systematic review, the state of the art was obtained, with particular attention paid to trends in the use of agroindustrial wastes. This revealed the production of animal feed, bioenergy, materials and extraction compounds, materials, fertilizers, and other applications such as food for human consumption and cosmetics.

3.1 Animal Feed

It is possible to produce animal feed (for ruminants, pigs, and poultry) from agro-industrial residues. For example, the stems and leaves have a high fiber content but a low protein content. In contrast, husks, seeds, and bran of grains, such as wheat, are rich in protein but have less fiber. Combining and blending is necessary to formulate compound feeds that provide animals with the nutritional value necessary for their development (Yang et al., 2021).

However, it should be noted that some residues contain toxic elements tolerated by ruminants but not by other species. This makes it necessary to subject the residues to physical, chemical, or biological treatment processes to degrade or eliminate the toxic factors, guaranteeing food safety (Yafetto et al., 2023). Furthermore, it is evident that this type of research is being pursued in a multitude of geographical contexts. For example, in Ghana, the lack of feed supply for the livestock industry has led most farmers to use agricultural residues derived from groundnut, cassava, pigeon pea, yam, corncob, and rice in their raw state as livestock feed. In order to achieve an effective valorization of these residues, Yafetto et al. (2023) suggest the biological processing of these residues, taking full advantage of their nutritional potential.

In Mexico, Alarcón-Rojo et al. (2019) conducted a study that demonstrated that the inclusion of fermented apple pomace in lamb diets resulted in improved meat quality. Similarly, the study by Mizael et al. (2020) in Brazil indicated that the introduction of fermented tomato pomace in the diet of lactating goats resulted in remarkable improvements in both milk production and milk composition. These findings underscore the beneficial effects of incorporating agro-industrial residues in animal feed.

Likewise, the implementation of standards for the use of agro-industrial residues is required. In fact, the environmental and economic benefits are well-documented; however, the necessity of implementing regulations aimed at sustainable practices is a matter of debate. The establishment of treatment protocols and quality certifications would ensure food safety and promote confidence in these inputs, thereby encouraging their adoption by producers and promoting a more sustainable model in the livestock industry (Table 4).

3.2 Bioenergy

Another potential application of agro-industrial waste is its use in bioenergy generation as an alternative and a new commitment to sustainability. Lignocellulosic biomass, such as rice husks, coffee husks, banana leaves, and corn straw, can be converted into biofuels through biochemical and thermochemical processes (Alves et al., 2023; Cherwoo et al., 2023; Wang et al., 2023). These processes produce bio-oil, biochar, biodiesel, bioethanol, and biogas, contributing to cleaner energy alternatives.

The manufacture of bio-oil utilizes a variety of agricultural by-products, including rice husk residues, coffee husk, banana leaves, and oat and corn straw (AlMallahi et al., 2023; Bieniek et al., 2023; Ma et al., 2024). Husk, fiber, and residual leaves from coconut processing are promising sources for obtaining biochar (Duangkham and Thuadaij, 2023; Ighalo et al., 2023). Also, in bioethanol production, orange peel, seed and pulp residues, as well as coffee pulp residues, can be used as feedstock (Acevedo et al., 2021; Manrique, 2018). Furthermore, rice straw, sunflower stalk and head, together with sugarcane bagasse, are viable sources for obtaining biogas (Hashemi et al., 2019; Zhou et al., 2017; Zhurka et al., 2019). The use of these residues for biofuel production not only contributes to reducing greenhouse gas emissions, but also offers sustainable energy solutions (Sharmila et al., 2024; Mahapatra et al., 2021; Coello et al., 2021).

Taking advantage of agricultural residues in the production of bioenergy not only contributes to solving environmental problems related to waste management and the use of highly polluting fuels but also allows obtaining high

TABLE 4: Animal feed.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Yafetto et al. (2023)	General (agricultural waste)	Alemania	2023
Sun et al. (2024)	General (agricultural waste)	Colombia	2024
Quintero-Herrera et al. (2023)	General (agricultural waste)	Países bajos	2023
Mizael et al. (2020)	Residual tomato pulp	Reino unido	2020
Alarcon-Rojo et al. (2019)	Apple pulp waste	Países bajos	2019
de Evan et al. (2020)	Cauliflower stems	Países bajos	2020
Aruna et al. (2017)	Yam peel	Reino unido	2017
Jais et al. (2017)	Banana peel	Reino unido	2017
Yang et al. (2021)	General (agricultural waste)	Reino unido	2021
Camacho Villa & Grande Tovar (2021)	Malt bagasse	Países bajos	2021
Aguiar et al. (2021)	Agro-industrial waste	Ecuador	2021
Nobre et al. (2020)	Guava agro-industrial waste	Brasil	2020
Romero-Sáez (2022)	Agro-industrial waste	Colombia	2022

value-added products from residues (Casoni et al., 2018; Fit, 2025; Rashid & Malik, 2023).

A fundamental aspect of the production of bioenergy, derived from agroindustrial waste, is the need to enhance the efficiency and profitability of conversion processes. Technologies are crucial in achieving this, as they can lead to cost reductions. From a public policy perspective, it is necessary to establish incentives for the utilization of bioenergy in the industrial and transport sectors in order to mitigate climate change (Table 5).

3.3 Material and extraction compounds

The recovery of bioactive compounds and materials, including the extraction of valuable compounds from agro-industrial waste, presents a promising opportunity. For example, lignocellulose biomass, an agro-industrial and forestry waste, when dissolved with ionic liquids, yields cellulose, lignin, and hemicellulose, which are compounds used as biofuel feedstock, biochemicals, and bioplastics (Norfarhana et al. 2024). Likewise, cellulose, a component of plants,

TABLE 5: Bionergy.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Khan et al. (2023)	General (agricultural waste)	Malasia	2023
Sharmila et al. (2024)	General (agricultural waste)	Colombia	2024
Duangkham & Thuadaij (2023)	Rice straw and banana peel	Argentina	2023
Aruwajoye et al. (2020)	Mixed starchy agricultural waste	México	2020
Acevedo et al. (2021)	Coffee waste	Argentina	2021
Gómez-Castro et al. (2022)	Fruit and vegetable waste	Chile	2023
Gómez Manrique (2018)	Citrus waste	Colombia	2018
Golato et al. (2017)	Sugarcane waste	Colombia	2017
Delgado Alvarado et al. (2023)	General (agricultural waste)	Colombia	2022
Gil Aguilar et al. (2022)	General (agricultural waste)	Ecuador	2022
Vargas Corredor & Peréz Pérez (2018)	General (agricultural waste)	Bolivia	2018
Reyes Suárez et al. (2020)	Tomato waste	Ecuador	2020
Ighalo et al. (2023)	Coconut waste	México	2023
Torres Pérez & Quintero Lopez (2019)	African palm waste	México	2019
Sadh et al. (2018)	General (agricultural waste)	India	2018
Mahapatra et al. (2021)	Algae, biomasses	Colombia	2021
Rojas-González & López-Rodríguez	Agro-industrial waste - Fruits - Pineapple	Colombia	2019
Morales Apaza et al. (2021)	Pineapple waste	Bolivia	2021
Ginni et al. (2021)	Agro-industrial waste	India	2021
Anvari et al. (2024)	Agro-industrial waste	Tunisia	2024
Zhang et al. (2023)	Agro-industrial waste	China	2023
Kabir Ahmad et al. (2022)	Coconut waste	Malasia	2022
Bot et al. (2023)	Banana peels, rattan waste, coconut shells, and sugarcane bagasse	Camerún	2021
Zinla et al. (2021)	Rice straw, rice husk, coffee husk, and cocoa pod husk	Costa de Marfil	2021
Aristizábal-Marulanda et al. (2022)	Cut coffee stems	Colombia	2022
Teigiserova et al. (2020)	Food waste	Dinamarca	2020
Alves et al. (2023)	African palm waste	Brasil	2023
Cherwoo et al. (2023)	General (agricultural waste)	India	2023
AlMallahi et al. (2023)	Biochar and bio-oil	Emiratos Árabes Unidos	2023
Bieniek et al. (2023)	Oats and corn straw	Polonia	2023
Ma et al. (2024)	Biochar and bio-oil	China	2024
Sajad Hashemi et al. (2019)	Sugarcane waste	Iran	2019
Zhou et al. (2017)	Rice straw	China	2017
Zhurka et al. (2019)	Sunflower seeds	Grecia	2019
Casoni et al. (2018)	Sunflower seed shell	Argentina	2018
Gallipoli et al. (2021)	Citrus fruit waste		2021

has a variety of applications, including the reinforcement of composite materials and the production of biomaterials. It can be extracted from residues such as straws, husks, and stems, as well as from pineapple residues, by enzymatic hydrolysis or advanced chemical treatments (Presenda-Geronimo et al., 2020).

However, the use of agro-industrial waste to obtain bioactive compounds not only promotes sustainability but also fosters innovation across diverse industry sectors, thereby reducing the reliance on conventional sources and minimizing environmental impact. Moreover, this approach generates economic opportunities for the agro-industrial sector.

The food, cosmetic, and pharmaceutical industries are interested in bioactive compounds such as bromelain, as well as phenolic compounds, due to their biological properties, antioxidant, anticancer, and antimicrobial capacity. These valuable compounds can be extracted from pineapple peel, which highlights the importance of utilizing available resources for various industrial applications (Campos et al., 2020; Paz Arteaga, S. 2022).

Nevertheless, advanced techniques such as enzymatic hydrolysis, fermentation, and extraction allow for the production of premium-quality compounds with a multitude of applications across diverse sectors, including food, pharmaceuticals, energy, and materials. Consequently, the recovery of valuable compounds from agro-industrial waste represents a promising path for fostering a sustainable and efficient future, particularly in terms of waste management, which represents a shift to a regenerative circular economy (Pal, 2024).

The development of materials such as bioplastics and biorefinery from agro-industrial waste represents a cutting-edge approach in the pursuit of sustainable solutions (Table 6).

3.4 Materials

By employing innovative processes, a range of agricultural residues, including cucumber peels, tubers, pineapple, cocoa, orange peels, straw, and crop residues, are subjected to controlled degradation treatments or fermentation processes to extract valuable compounds, an eco-friendly alternative to conventional plastics derived from non-renewable resources (Caliskan, 2025). In the case of bioplastics, the cellulose obtained from these residues can be transformed into biodegradable polymers, offering an environmentally friendly alternative to conventional plastics derived from non-renewable resources.

TABLE 6: Material and extraction compounds.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Norfarhana et al. (2024)	General (lignocellulosic biomass)		2024
Paul et al. (2023)	Coconut fiber		2023
Nurika et al. (2020)	Rice straw		2020
Pattnaik et al. (2022)	Sugarcane waste		2022
Camacho-Oviedo et al. (2020)	Potato peel		2020
Presenda-Gerónimo et al. (2020)	Pineapple waste		2020
Valle Alvarez et al. (2019)	Waste from palm oil production	Ecuador	2019
Zambrano Zambrano et al. (2021)	Rice husk		2021
Montoya-Pérez et al. (2017)	Pineapple waste		2017
Cabascango et al. (2021)	General (agricultural waste)		2021
Del Rio Osorio & Grande-Tovar (2021)	Cassava waste	Colombia	2021
Diaz-Uribe et al. (2020)	Waste from the peel of Vaccinium meridionale fruit (antioxidant)	Colombia	2020
Matiacevich et al. (2023)	General (agricultural waste)	Chile	2023
Aguiar Novillo et al. (2022)	Agro-industrial waste	Ecuador	2022
Vargas y Vargas et al. (2019)	Fruit peel	México	2019
Flórez Montes & Rojas González (2018)	Agro-industrial waste	Colombia	2019
Campos et al. (2020)	Pineapple waste	Portugal	2020
Coello-Pisco et al. (2021)	Coffee waste	Colombia	2021
Sudarsan et al. (2023)	Rice straw	China	2023
Ilangovan et al. (2019)	Coffee husk	India	2019
Penkhrue et al. (2020)	Pineapple waste	Tailandia	2020
Azmin et al. (2020)	Cocoa husk and sugarcane bagasse	Malasia	2020
Kharb & Saharan (2023)	Cucumber peel	India	2023
Santos et al. (2023)	Orange peel and pulp residues	Brasil	2023
Yaradoddi et al. (2022)	Orange peel	India	2022

In addition, biorefining also harnesses the diversity of compounds in agro-industrial waste to produce biofuels, chemicals, and advanced materials. This integrated approach not only reduces dependence on fossil resources but also helps to mitigate the environmental impacts associated with inefficient waste management. Ultimately, the transformation of agro-industrial waste into advanced materials highlights the potential of the circular economy and demonstrates how innovation and sustainability can converge to effectively address today's challenges (Kharb and Sahara, 2023; Santos et al., 2023; Lema, 2021; Azmin, 2020) (Table 7).

3.5 Fertilizers

Agro-industrial waste composting is a sustainable practice that contributes to reducing the environmental impact of agricultural and food production. This process transforms organic waste into compost, a nutrient-rich product that can be used as fertilizer. The benefits of composting include reducing the use of chemical fertilizers, improving soil quality, and helping to reduce greenhouse gas emissions. Composting is also an effective way to treat agricultural waste and produce organic fertilizer, achieving waste minimization and stabilization. Internal and external parameters, such as moisture content, temperature, pH, ventilation, and external additives, are some of the factors that influence the composting process (Xie et al., 2023; Vargas-Pineda, 2019) (Table 8).

Finally, there are other applications, such as in construction, where rice straw is presented as a substitute for additives in concrete, promoting cost-effective and environmentally friendly construction practices while reducing dependence on traditional materials (Sudarsan et al., 2023b). Similarly, in the cosmetics industry, passion fruit seeds provide a source for oil extraction and the production of beneficial exfoliants for skin care (Proaño et al., 2020). Mango seeds can be used to produce wholemeal flour, which diversifies the supply of nutritional products and efficiently uses food resources (Velasco & Cuesta González, 2019). However, implementation requires advances in waste processing technologies, regulatory support, and industry collaboration. To maximize the efficiency and scalability of agro-industrial waste utilization, the use of innovative biotechnological approaches such as enzymatic hydrolysis, microbial fermentation, and biorefining processes is essential.

3.6 Food for human consumption

Mango seeds have the potential to be used to produce wholemeal flour, diversifying the supply of nutritional products and making efficient use of food resources (Velasco & Cuesta González, 2019). However, its implementation requires advances in waste treatment technologies, regulatory support, and industry collaboration. To achieve maximum efficiency and scalability in the utilization of agro-industrial waste, there is a need for innovative bio-

TABLE 7: Materials.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Haro-Velasteguí et al. (2017)	Banana waste	Ecuador	2017
Lema Vera (2021)	Cocoa shell and sugarcane bagasse	Colombia	2021
Hernández Chaverri & Prado Barragán (2018)	Banana waste	Costa Rica	2018
Henao Díaz & Salazar Perdomo (2017)	General (agricultural waste)	Colombia	2018
Marlon Fernando et al. (2021)	Banana waste	Colombia	2021
Riera et al. (2018)	General (agricultural waste)	Ecuador	2018
Buraglia Osorio (2021)	General (agricultural waste)	Colombia	2021
Peñaranda Gonzalez et al. (2017)	Fruit peel	Colombia	2017
Cury R et al. (2017)	Agro-industrial waste	Colombia	2017

TABLE 8: Fertilizers.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Xie et al. (2023)	General (organic waste)	China	2023
Chia et al. (2020)	General (organic waste)	Malasia	2020
Vargas-Pineda et al. (2019)	Food waste	México	2019
Duval et al. (2019)	Soybean oil waste	Argentina	2019
Méndez-Matías et al. (2018)	General (organic waste)	México	2018
Moisés et al. (1983)	General (organic waste)	Argentina	2022
Vargas Corredor & Peréz Pérez (2018)	General (organic waste)	Colombia	2018
Romero-Sáez (2022)	Agro-industrial waste	Colombia	2022
Alvarado Dávila & Rangel Zambrano (2020)	Agro-industrial waste	Colombia	2020
Oliveira Vieira et al. (2022)	Agro-industrial waste	Brasil	2022

technological approaches such as enzymatic hydrolysis, microbial fermentation, and biorefining processes.

Similarly, coconut fiber, rice straw, and sugarcane bagasse are agroindustrial residues that can be employed in the manufacture of biovanilla, an alternative aromatic compound to the synthetic vanilla that is commonly utilized in the food and cosmetic industries (Paul et al., 2023; Nurika et al., 2020; Pattnaik et al., 2022).

Furthermore, the design and development of policies that encourage waste recovery and circular economy initiatives is critical to foster a sustainable industrial ecosystem (Paul et al., 2023; Nurika et al., 2020; Pattnaik et al., 2022) (Table 9).

3.7 Cosmetics

Similarly, in the cosmetics industry, passion fruit seeds provide a source for oil extraction and the production of beneficial exfoliants for skin care (Proaño et al., 2020) (Table 10).

4. CONCLUSIONS

These days, there are still businesses that persist in operating within the limits of the linear economy model, thus resulting in the generation of waste without taking advantage of it or the mitigation of adverse environmental impacts. This review attempts to identify which are the most common uses of agro-industrial waste as a sustainable solution. In order to achieve this, a systematic review was conducted to identify trends and opportunities in the utilization of agroindustrial waste that contributes to sustainability. This review comprised blind peer review articles from indexed open access journals, aiming to classify the by-products, with applications in the production of bioenergy, the development of materials, and the extraction of compounds with utility across a range of industries, including agriculture, cosmetics, pharmaceuticals, and food production.

The use of agro-industrial waste represents an opportunity to move towards a circular economy model, with implications for different sectors and economic activities. In the food sector, the use of waste, once transformed, generates nutrients and minerals for human and animal consumption. Similarly, the production of bioenergy from lignocellulosic biomass (bioethanol and biogas) reduces greenhouse gas emissions and becomes a sustainable alternative to fossil fuels (Silva and Oliveira, 2021; Kharb and Sahara, 2023; Santos et al., 2023; Lema, 2021; and Azmin, 2020). This transition is emerging as a global priority as a strategy to promote dynamism in territories (Bag et al., 2021; Khanna et al., 2022; Zheng et al., 2025). It is important to note production sectors such as animal feed, bioenergy, bioplastics, and specialty composites can achieve both economic and environmental benefits through the transformation and integration of waste. Sustainable agro-industrial waste management contributes to reducing waste accumulation and environmental degradation and promotes the efficient use of natural resources.

On the other hand, the recovery of bioactive compounds and the development of materials indicate the potential for the generation of value-added products applicable in the food, pharmaceutical, and cosmetic industries. Likewise, the extraction of compounds such as phenols and bromelain, as well as biomass for the creation of bioplastics and biomaterials, demonstrates the impact of technological innovation on the comprehensive utilization of these resources. Furthermore, it underscores the potential for utilization as fertilizers in crops, thereby facilitating the implementation of balanced and environmentally conscious agricultural practices (Paul et al., 2023; Nurika et al., 2020; Pattnaik et al., 2022). These applications reinforce the principles of

TABLE 9: Food for human consumption.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Coral Velasco & Cuesta González (2019)	Mango seed	Cuba	2019
López Ráez et al. (2021)	Mango waste	Colombia	2021
Camacho Villa & Grande Tovar (2021)	Malt bagasse	Colombia	2021
Duval et al. (2019)	Soybean waste	Argentina	2019
Sanz M. et al. (2021)	Mango seed	Colombia	2021
Preciado-Saldaña et al. (2022)	General (agricultural waste)	Mexico	2022

TABLE 10: Cosmetics.

Authors	Usable waste / Recoverable waste	Country	Year of publication
Proaño et al. (2020)	Passion fruit waste	India	2020
Presenda-Gerónimo et al. (2020)	Pineapple waste	México	2020
Mejia (2018)	General (agricultural waste)	Colombia	2018
Filippín et al. (2017)	Olive and oilseed residues	Colombia	2017
Vera Raza et al. (2022)	Lignocellulosic waste		2017
Suárez Ramos & Ubillus Ascarza (2022)	Lucuma waste	México	2022
Soto-Regalado et al. (2021)	Soybean waste	Argentina	2022
Rojas Romaní et al. (2021)	Seeds and shell of Passiflora tripartita fruit	Venezuela	2021

sustainability by minimizing reliance on fossil fuels, synthetic chemicals, and environmentally harmful materials.

From a broader perspective, the comprehensive utilization of agro-industrial waste is presented as a fundamental element in the development of a sustainable future. This integrated approach not only aims to ensure responsible waste management practices but also promotes environmentally sustainable activities that contribute to the advancement of communities and industrial sectors.

In turn, the use of agro-industrial waste fosters innovation, mitigates climate change impacts, and enhances economic resilience by creating new value chains and promoting sustainable business models. In order to optimize the potential of these resources, it is crucial to address the issues associated with waste management through the implentation of policy frameworks and research.

Ultimately, the continued development of innovative strategies for the use of agro-industrial waste is essential to shape a more sustainable and resource-efficient future, ensuring environmental management while fostering economic growth and social welfare.

This study illustrates how the topic has gained prominence and generated awareness globally, offering sustainable solutions through the utilization of agro-industrial waste, underscoring its role in the transition to a circular and sustainable economy (Kharb and Sahara, 2023; Santos et al., 2023; Lema, 2021; Azmin, 2020). This research demonstrates the development of strategies that address challenges such as waste management and climate change while simultaneously fostering innovation and sustainability. As a result, agro-industrial waste has emerged as a crucial resource in the transition to a more sustainable future.

It is recommended that future research should focus on the optimization of transformation processes, the assessment of the economic feasibility of large-scale implementation, and the consolidation of interdisciplinary collaborations between academia, industry, and policymakers.

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