ISSN:
3091-1796
Vol. 4 No. 10 PP. 127-145

DOI:
https://doi.org/10.56519/r001qm43
Agosto 2026

VALORIZACIÓN BIOTECNOLÓGICA DE RESIDUOS AGROINDUSTRIALES ECUATORIANOS PARA BIOINSUMOS Y BIOPRODUCTOS: REVISIÓN APLICADA CON MATRIZ DE DECISIÓN

BIOTECHNOLOGICAL VALORIZATION OF ECUADORIAN AGROINDUSTRIAL RESIDUES FOR BIOINPUTS AND BIOPRODUCTS: AN APPLIED REVIEW WITH A DECISION MATRIX

Carlos Jamil Bastidas Sánchez[1]

{cbastidass@unemi.edu.ec[1]}

Fecha de recepción: 08/07/2026 / Fecha de aceptación: 13/08/2026 / Fecha de publicación: 25/08/2026

RESUMEN: La agroindustria ecuatoriana genera subproductos asociados a las cadenas de banano, cacao, arroz, caña de azúcar, maíz, cítricos y camarón, muchos de los cuales se descartan sin aprovechamiento. Estos materiales contienen fibras, carbohidratos, proteínas, compuestos fenólicos, pectinas, polisacáridos y quitina susceptibles de transformación mediante rutas biotecnológicas. Se desarrolló una investigación documental, no experimental, de alcance descriptivo-comparativo, orientada a analizar su potencial para obtener bioinsumos y bioproductos. La búsqueda reproducida en Scopus para 2022–2026 recuperó 459 resultados en la interfaz y 455 registros únicos en el archivo exportado; el corpus final integró 45 fuentes científicas seleccionadas por pertinencia y trazabilidad. La información se organizó en una matriz de decisión con cinco criterios: disponibilidad del residuo, potencial biotecnológico, diversidad de productos, aplicabilidad productiva y aporte ambiental. Los residuos se agruparon en materiales lignocelulósicos, subproductos con contenido funcional relevante y residuos acuícolas orientables hacia biopolímeros. Banano y cacao alcanzaron la mayor prioridad; caña de azúcar, camarón, cítricos y arroz también se clasificaron como de prioridad alta, mientras que maíz obtuvo prioridad media. Se concluye que los residuos agroindustriales ecuatorianos presentan un potencial de valorización diferenciado; dentro del alcance documental y de la matriz empleada, banano y cacao constituyen las alternativas iniciales más favorables, aunque su implementación debe confirmarse mediante caracterización local y evaluaciones técnicas, económicas y ambientales.

Palabras clave: Biotecnología industrial, biomasa residual, economía circular, fermentación, biofertilizantes, sostenibilidad productiva

[1]Facultad Ciencias de la Ingeniería, Universidad Estatal de Milagro, Ecuador, https://orcid.org/0000-0003-1018-6956; 0997003130

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

ABSTRACT: Ecuadorian agroindustry generates by-products from banana, cocoa, rice, sugarcane, maize, citrus and shrimp chains, many of which are discarded without recovery. These materials contain fibers, carbohydrates, proteins, phenolic compounds, pectins, polysaccharides and chitin that can be transformed through biotechnological routes. A non-experimental documentary study with a descriptive-comparative scope was conducted to analyze their potential for producing bioinputs and bioproducts. The reproducible Scopus search for 2022–2026 retrieved 459 results in the interface and 455 unique records in the exported file; the final corpus comprised 45 scientific sources selected for relevance and traceability. The information was organized in a decision matrix using five criteria: residue availability, biotechnological potential, product diversity, productive applicability and environmental contribution. Residues were grouped into lignocellulosic materials, by-products with relevant functional content and aquaculture residues suitable for biopolymer production. Banana and cocoa achieved the highest priority; sugarcane, shrimp, citrus and rice were also classified as high priority, whereas maize obtained medium priority. It is concluded that Ecuadorian agroindustrial residues have differentiated valorization potential; within the documentary scope and the matrix applied, banana and cocoa are the most favorable initial alternatives, although their implementation requires local characterization and specific technical, economic and environmental assessments.

Keywords: Industrial biotechnology, residual biomass, circular economy, fermentation, biofertilizers, productive sustainability

INTRODUCTION

Dentro de la estructura productiva del Ecuador, la agroindustria vinculada al banano, cacao, arroz, caña de azúcar, maíz, cítricos y camarón genera, además de sus productos comerciales, una cantidad significativa de subproductos que no ingresan a ningún canal de aprovechamiento posterior. Cáscaras, bagazos, cascarillas, pseudotallos, raquis, pulpas, mucílagos y exoesqueletos quedan fuera del producto final en cada ciclo productivo. Aunque su manejo habitual los sitúa como material de descarte, análisis fisicoquímicos de estos subproductos revelan la presencia de fibras, carbohidratos, proteínas, compuestos fenólicos, pectinas y polisacáridos cuya utilidad en procesos agrícolas e industriales ha sido confirmada en distintos estudios (1,2).

When a recovery mechanism is not established, this biomass can affect soils and water sources or be lost without its components having a subsequent use.. The linear scheme of extraction, processing and disposal of waste maintains environmental pressures in productive areas. This problem has been described in international and regional literature on agroindustrial waste and its transformation into resources (2–4).

The proportion and characteristics of the waste vary depending on the production chain, the fraction of the material processed and the technological level used. In Ecuador, rice husks, sugarcane bagasse, cocoa shells and other biomasses have been studied; However, these works usually analyze a residue or a route in isolation, which makes a joint comparison difficult(1–3,5,6).

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

Among the documented alternatives to modify this situation, applied biotechnology has gained relevance because it allows, through controlled biological processes, to convert waste materials into products with a specific application. Routes such as solid state fermentation, submerged fermentation, enzymatic hydrolysis, anaerobic digestion and microbial bioconversion have shown the capacity to generate biofertilizers, biopesticides, enzymes, biopolymers, bioethanol, biogas and antioxidant compounds from different types of biomass. The choice of one or another route does not only respond to the type of waste available, but is also conditioned by its physicochemical stability, the regularity with which it can be obtained and the intended use for the final product (7–10).

Waste does not behave in the same way when it comes to its use, since its response depends on the composition of each waste. Materials such as bagasse, husk, straw and pseudostems, of a lignocellulosic nature, can be used as fermentation substrates or as a source for energy generation (4,11,12). However, using them directly is inefficient due to the recalcitrance that characterizes the lignocellulosic matrix. Within these materials, cellulose is arranged in microfibrils whose crystalline areas are held together by a network of hydrogen bonds, and all of this is embedded in a matrix formed by hemicellulose and lignin. This structural organization decreases the porosity of the material and makes it difficult for microorganisms and hydrolytic enzymes to reach the glycosidic bonds. Added to this is that lignin operates as a physical barrier and can cause enzymes to adsorb in a non-productive way. For these reasons, these biomasses usually require physical, chemical or biological pretreatments and subsequent hydrolysis, so that their carbohydrates can be efficiently transformed into fermentable sugars (1,4,11–13).

Cocoa and citrus peels present a different profile: they highlight the presence of bioactive compounds, pectins and antioxidant fractions with possible pharmacological and agri-food applications. In the case of cocoa mucilage, its soluble portion is composed mainly of glucose, fructose and sucrose, low molecular weight molecules that yeasts and bacteria can assimilate without extensive depolymerization. This availability facilitates fermentation, although the high water content, rapid microbiological deterioration and composition variability can complicate storage and standardization of the process (14,15).

The waste from the shrimp industry offers a different panorama. The chitin, proteins and minerals present in them allow us to obtain chitosan, protein hydrolysates and biomaterials useful in agriculture, food and water treatment. Chitin is a linear polysaccharide of N-acetyl-D-glucosamine with β-(1→4) bonds, high crystallinity and low solubility. In the exoskeleton it is associated with proteins and calcium carbonate, so its recovery requires demineralization and deproteinization; Deacetylation is subsequently applied to obtain chitosan or hydrolysis to generate oligomers and amino sugars. These procedures consume reagents and energy and can generate effluents that must be treated (16–19). Thus, while mucilage can be used as a fermentation substrate with less conditioning, shrimp residue requires separation and structural modification.

Ecuador presents favorable conditions because several chains generate byproducts for a good part of the year and some waste is concentrated in packing plants, mills, pilers

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

or processing plants. However, operational availability is not uniform: it depends on seasonality, humidity, territorial dispersion and storage capacity. Banana and cocoa offer a relatively regular generation, while corn and citrus present more marked variations that must be incorporated into the sizing of the processes (5,20–23).

The problem persists at another level. The information available on the use of these wastes appears distributed in research that addresses specific materials or processes, without there yet being a synthesis that allows linking the type of biomass with the applicable technology and the product that can be obtained. For those who make decisions in the productive sector or design lines of research, this dispersion represents a specific obstacle when establishing priorities.

Starting from this gap, this work maintains that agroindustrial waste from Ecuador presents a potential for biotechnological valorization differentiated according to its composition and the technologies available for each type of biomass. For this purpose, the available scientific literature on transformation processes applicable to different types of residual biomass was reviewed and a comparative tool was built that allows each waste to be related to its processing route and the products that can be obtained from it. The results seek to support the identification of priority alternatives, guide future lines of research and provide concrete elements for the design of circular economy strategies within the Ecuadorian agroindustry.

MATERIALS AND METHODS

A descriptive and comparative documentary review was carried out to identify biotechnological recovery routes applicable to banana, cocoa, rice, sugar cane, corn, citrus and shrimp waste. These chains were selected for their productive relevance, recurrent generation of byproducts and availability of scientific evidence on their transformation (3,5,7,16,21,22,24–30).

The literature search was updated and reproduced in Scopus on July 14, 2026. The following equation was run on the title, abstract, and keyword fields:

TITLE-ABS-KEY(("agro-industrial waste" OR "agroindustrial residue*" OR "agricultural by-product*" OR "residual biomass") AND (banana OR cocoa OR cocoa OR rice OR sugarcane OR maize OR corn OR citrus OR shrimp) AND ("biotechnological valorization" OR bioconversion OR fermentation OR "enzymatic hydrolysis" OR biofertilizer* OR biopolymer* OR chitosan OR pectin OR bioethanol OR biogas)) AND PUBYEAR > 2021 AND PUBYEAR < 2027 AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re")) AND (LIMIT-TO(LANGUAGE,"English") OR LIMIT-TO(LANGUAGE,"Spanish"))*

The search was limited to the period 2022-2026, to original articles and reviews published in scientific journals, in their final state and written in English or Spanish. With these parameters, 459 records were recovered.

The query returned 459 results in the Scopus interface. The exported CSV contained 455 unique titles; 454 had DOI and EID, and one lacked both identifiers. Comparison by DOI,

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

EID, and title showed no duplicates. Documents without directly extractable information on composition, process, product, performance or application, as well as thematically redundant ones, were excluded from the synthesis.

The comparison between the export and the bibliography identified 16 publications in the final corpus from the reproduced search. 29 sources were added from previous searches and retrospective tracing to cover Ecuadorian context, multi-criteria analysis and experimental performances. The final corpus brought together 45 unique sources, organized by residue, composition, process, product, performance and application (1,7).

Traceability was verified using the source consistency index (SCI), defined as:

$$\mathrm{ICF}_k = \frac{D_k + T_k + F_k + R_k + E_k}{5} \quad 1)$$

In the equation, D_k indicated the presence of DOI or persistent identifier; T_k, the fulfillment of the time interval; F_k, the final publication in a scientific journal; R_k, the direct relationship with the object studied; and E_k, the availability of extractable information. Each component received 0 or 1 and $ICF_k \geq 0.80$ was required. Forty-one sources reached 1.00; The references (21.31–33) obtained 0.80 for being before 2022, but were retained for their quantitative balances. The ICF evaluated documentary traceability, not risk of bias.

The decision matrix included five criteria: availability, biotechnological potential, product diversity, productive applicability and environmental contribution, taking as reference multi-criteria approaches applied to agricultural waste (34,35). The s_{ij} scores were assigned on an ordinal scale from 1 to 3 according to Table 1. In the event of insufficient or contradictory evidence, the lower level was adopted.

Table 1. Criteria and operational rules used for the decision matrix.

Criterion	1 = Low	2 = Medium	3 = High
Availability	Limited, localized or irregular generation	Seasonal or regional generation	Continuous or high-scale generation, supported by documentation
Biotechnological potential	A preliminary exploitation route	Two routes or mainly laboratory evidence	Three or more differentiated routes, supported by at least two sources
Product diversity	One product family	Two or three product families	Four or more product families

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

Criterion	1 = Low	2 = Medium	3 = High
Productive applicability	One conceptual application	Application in two sectors or laboratory validation	Documented application in three or more sectors or pilot/productive evidence
Environmental contribution	Unproven benefit	A documented benefit or qualitative evidence	Two or more benefits supported by at least two sources

Source: Own elaboration based on multi-criteria and environmental approaches (34,35).

For diversity, bioethanol, biogas and bioenergy were counted as a family; chitin, chitosan and derived biomaterials were grouped as biopolymers, avoiding duplicating products from the same route.

The scores were normalized in the range of 0 to 1 using the expression:

$$z_{ij} = \frac{s_{ij} - 1}{2} \quad (2)$$

No Delphi queries were performed nor were statistical methods applied to estimate the relative importance of the criteria. Because there was not enough empirical evidence to establish a hierarchy between them, the uniform weighting vector was adopted:

$$w = (0{,}20;\ 0{,}20;\ 0{,}20;\ 0{,}20;\ 0{,}20) \quad (3)$$

The priority index of each residue was calculated by:

$$P_i = \sum_{j=1}^{5} w_j z_{ij} \quad (4)$$

High priority was established when $P_i \geq 0.70$, equivalent to an original score of 12 to 15; medium priority when $0.30 \leq P_i < 0.70$, equivalent to 8-11 points; and low priority when $P_i < 0.30$, equivalent to 7 points or less.

Stability was examined with 10,000 iterations and seed 20260714. Weights were generated uniformly between 0.16 and 0.24 and renormalized to sum to 1. The procedure was run in Python 3.12.13 with NumPy 2.3.5.

Finally, a comparative matrix was prepared that related each biomass to its transformation route, product and application. The priority was established based on documented availability, biotechnological potential, applicability and environmental contribution, within a circular economy perspective (1,7,34,35).

ISSN:
3091-1796
Vol. 4 No. 10 PP. 127-145

DOI:
https://doi.org/10.56519/r001qm43
Agosto 2026

RESULTS

The agro-industrial waste analyzed does not follow the same pattern compared to the available biotechnological recovery routes. What determines the potential of each material is its composition, the regularity with which it is generated within the production chain and the quantity of products that can be derived from it. Based on this logic, the reviewed waste was grouped into three categories: lignocellulosic materials, waste with relevant functional content and by-products of aquaculture origin that can be directed towards biopolymers.

Within the first group were cane bagasse, rice husks and straw, banana pseudostems and rachis, and corn residues. They all share a matrix based on cellulose, hemicellulose and lignin, suitable for fermentation, hydrolysis, anaerobic digestion and production of biodegradable materials. Their abundance and low cost are advantages, but they typically require pretreatments to release fermentable sugars and improve enzymatic or microbial action (1,4,7,11–13,30).

Cocoa and citrus residues made up the second group. Its peels, mucilage and albedos contain pectins, phenolic compounds, fermentable sugars and antioxidant fractions that allow obtaining functional ingredients and agri-food products (14,15,24,25,36,37). In Ecuador, cocoa shell and mucilage deserve attention due to their availability in producing areas and due to the evidence on fermentation and circular bioeconomy (14,22,38).

The third group corresponded to shrimp waste. Chitin, proteins and minerals guide them towards chitosan, protein hydrolysates and biomaterials. The processes of demineralization, deproteinization, and deacetylation differ from the energetic fermentation of lignocellulosic materials, and their products have applications in agriculture, food, and water treatment (16–19).

Table 2. Biotechnological routes identified for Ecuadorian agroindustrial waste.

String productive	Residue main	Composition predominant	Biotechnological route possible	Product expected	Application end
Banana	Pseudostem, rachis and peel	Fiber, cellulose, hemicellulose and sugars	Fermentation, hydrolysis and anaerobic digestion	Biofertilizers, bioethanol, biogas, fibers and biomaterials	Agriculture, energy and biodegradable materials
Cocoa	Shell and mucilage	Fiber, phenolic compounds, sugars and pectins	Fermentation, extraction of functional compounds and bioconversion	Antioxidants, bio-inputs, pectin and fermented products	Agribusiness, food and agriculture

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

String productive	Residue main	Composition predominant	Biotechnological route possible	Product expected	Application end
Rice	Husk and straw	Lignocellulose, silica and fiber	Pretreatment, fermentation, anaerobic digestion and thermobiological conversion	Bioenergy, biochar, adsorbent materials and substrates	Energy, environment and agriculture
Sugar cane	Bagasse and cachaça	Lignocellulose, residual sugars and organic matter	Hydrolysis, fermentation and enriched composting	Bioethanol, enzymes, biofertilizers and energy	Energy, agriculture and industry
Corn	Stubble, stubble and processing waste	Lignocellulose and residual starches	Saccharification, fermentation and composting	Bioethanol, organic acids and biofertilizers	Energy, agriculture and bioprocesses
Citrus	Peel and albedo	Pectin, essential oils, fiber and phenolic compounds	Extraction, fermentation and hydrolysis	Pectin, antioxidants, essential oils and bioethanol	Food, agribusiness and bioproducts
Shrimp	Exoskeletons, heads and processing remains	Chitin, proteins and minerals	Demineralization, deproteinization, deacetylation and hydrolysis	Chitin, chitosan, protein hydrolysates and biomaterials	Agriculture, food and water treatment

Source: Own elaboration based on bibliographic review (12–18,21–30,36–43).

Table 2 confirms that there is no single valuation path. Banana, cane, rice and corn converge in lignocellulosic use; cocoa and citrus allow the recovery of functional compounds and pectins; and shrimp is oriented towards biopolymers. This differentiation forces each biomass to be related to the process it can sustain according to its composition (4,11–18,22,24,25,27–30,36–38).

To complement this qualitative comparison, a theoretical-documentary mass balance per ton of waste was constructed. In the lignocellulosic routes, the theoretical mass of ethanol was estimated by the expression:

$$m_{\mathrm{EtOH,teórico}} = M(0{,}568 f_C + 0{,}581 f_H) \qquad 5)$$

where M represents the dry mass of the residue and fC and fH correspond to the mass fractions of cellulose and hemicellulose. The coefficients 0.568 and 0.581 are obtained by considering the stoichiometric hydration of glucan to glucose (180/162) and of xylan

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

to xylose (150/132), followed by the theoretical yield of 0.511 kg of ethanol per kilogram of monosaccharide. The effective yield was expressed as:

$$m_{\mathrm{EtOH,efectivo}} = m_{\mathrm{EtOH,teórico}} \times \eta_p \times \eta_h \times \eta_f \quad 6)$$

where ηp, ηh and ηf represent the efficiencies of pretreatment, hydrolysis and fermentation. To convert the mass of ethanol to volume, a density of 0.789 kg L^{-1} was used. In cocoa mucilage, the conversion of directly fermentable sugars was considered. For pectin and chitosan, the following was applied:

$$m_{\mathrm{producto}} = M \times Y_{\mathrm{extracción}} \quad 7)$$

The equations were used as a theoretical reference; The values in Table 3 correspond to performances documented in the original sources (14,19,20,30–33,44,45).

Because the publications did not provide equivalent time profiles for all seven chains, it was not possible to calculate a common kinetic constant. When the studies reported the final concentration and processing time, an average productivity was calculated using:

$$Q_P = \frac{C_P}{t} \quad 8)$$

In the other cases, the overall yield per unit of residue was maintained, without assuming kinetic behaviors that had not been demonstrated experimentally.

Table 3. Mass balances and documentary yields by agroindustrial chain.

Chain	Base of the balance	Condition processing	Performance documented	Equivalent per ton	Main limitation
Banana	1 t of dried pseudostem	Simultaneous saccharification and fermentation for approximately 72 h	112 L of ethanol t^{-1}; approximate specific productivity of 1.56 L t^{-1} h^{-1} (20)	112 L or 88.4 kg of ethanol	The high humidity of the fresh pseudostem increases the mass transported and the energy required for stabilization.

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

Chain	Base of the balance	Condition processing	Performance documented	Equivalent per ton	Main limitation
Cocoa	1 t of fresh mucilage; approximate density of 1 kg L^{-1}	Fermentation with Saccharomyces cerevisiae at 25 °C for 96 h	71.91 g L^{-1} ethanol; average productivity of 0.75 g L^{-1} h^{-1} (14)	Approximately 71.9 kg or 91 L of ethanol	The concentration of sugars changes with the variety, maturity and post-harvest handling.
Rice	1 t dry straw	Combined pretreatment, enzymatic hydrolysis and fermentation	214 mg ethanol g^{-1} biomass and bioconversion efficiency of 72.5 % (33)	214 kg or approximately 271 L of ethanol	The presence of silica and lignin determines the efficiency of the pretreatment.
Sugar cane	1 t of dried bagasse	Acid pretreatment, hydrolysis and fermentation of C5 and C6 sugars	191.96 kg of ethanol; pentose fermentation yield of 86.11% (44)	243.3 L ethanol	The balance depends on the recovery and co-fermentation of hexoses and pentoses.
Corn	1 t of dry stubble	Pretreatment, saccharification and fermentation	480 L t^{-1} theoretical maximum; 240 L t^{-1} as a process estimate and 45 L t^{-1} in an experimental study (31,45)	Between 45 and 240 L compared to a theoretical maximum of 480 L	The yield changes with the cultivar, humidity, harvest and hydrolysis efficiency.
Citrus fruits	1 t of pulverized dry peel	Acid extraction at 80 °C, pH 2, for 90 min	21.63% pectin in orange peel and 32.53% in lime peel (32)	Between 216 and 325 kg of pectin	The yield depends on species, maturity, drying, acid and extraction time.
Shrimp	1 t of dried exoskeleton	Demineralization, deproteinization and deacetylation; approximately 52 h of chemical contact	13.96 % chitosan relative to the dry shell (19)	139.6 kg per dry ton	The species, humidity, mineral content and degree of deacetylation affect the performance.

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

Source: Own elaboration based on experimental results and documentary balances (14,19,20,31–33,44,45).

The balance sheets show that a high stoichiometric potential does not ensure an equivalent effective performance. In lignocellulosics, losses during pretreatment, hydrolysis and fermentation explain the distance between the theoretical maximum and the recovered product. 112 L of ethanol per dry ton of banana pseudostem, 243.3 L t^{-1} of sugarcane bagasse and approximately 271 L t^{-1} of rice straw were documented (20,33,44).

The difference was greater for corn: compared to a theoretical maximum of 480 L t^{-1} of dry stubble, the process estimates and the revised experimental result were 240 and 45 L t^{-1}, respectively (31.45). For other chains, cocoa mucilage produced 71.91 g L^{-1} of ethanol after 96 h; dried citrus peel allowed recovery of 216–325 kg of pectin per ton; and the dry shrimp exoskeleton reached 139.6 kg t^{-1} of chitosan (14,19,32).

To organize this information and establish priorities, the decision matrix defined in the methodology was applied, evaluating five criteria per residue: availability, biotechnological potential, product diversity, productive applicability and environmental contribution. The normalized results are shown in Tables 4a and 4b.

Table 4a. Scoring of the criteria for prioritizing Ecuadorian agroindustrial waste.

Residue agroindustrial	Available bility	Potential biotechnological	Diversity of products	Applicability productive	Contribution environmental	Score total
Banana waste	3	3	3	3	3	15
Cocoa waste	3	3	3	3	3	15
Sugar cane waste	3	3	2	3	3	14
Shrimp waste	3	3	2	3	3	14
Citrus waste	2	3	3	3	3	14
Waste rice	3	2	2	3	3	13
Corn waste	2	2	2	2	2	10

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

Source: Own elaboration. Scores were assigned using the operating rules in Table 1.

Table 4b. Normalized index, priority and backup sources per residue.

Agroindustrial waste	Pi Index	Priority	Supporting Sources
Banana Residues	1,00	High	(20,21,23,39,40)
Cocoa Residues	1,00	High	(14,15,22,24)
Sugarcane Residues	0,90	High	(12,13,26,41,44)
Shrimp Residues	0,90	High	(16–19)
Citrus residues	0,90	High	(25,32,36–38)
Rice residues	0,80	High	(27,33,42,43)
Corn residues	0,50	Medium	(28–31,43,45)

Source: Own elaboration from the sources indicated for each chain

Banana and cocoa topped the classification with 15 points and Pi = 1.00. Sugar cane, shrimp and citrus reached 14 points and Pi = 0.90; rice obtained 13 points and Pi = 0.80; and corn was located in medium priority with 10 points and Pi = 0.50. The scores do not represent national experimental measurements, but rather an ordinal synthesis of the evidence cited in the last column of Table 4b.

The sensitivity analysis maintained the priority category of the seven residues in 100% of the 10,000 iterations. Banana and cocoa remained at Pi = 1.00; cane and shrimp varied between 0.868 and 0.926; citrus, between 0.871 and 0.926; rice, between 0.756 and 0.841; and corn remained at Pi = 0.50. Therefore, the classification was stable against small variations in the weights, although this robustness does not replace technical and economic validation.

Yearly availability is not equivalent to a consistent monthly offer. Corn and citrus have greater seasonality and dispersion; On the other hand, bagasse, rice husks and shrimp exoskeletons are usually concentrated in processing facilities. Humidity, low bulk density, collection distance, and the need for stabilization can reduce the viability of a technically promising route. Therefore, the matrix should be interpreted as an initial technological prioritization and not as a demonstration of profitability.

DISCUSSION

The results confirm that the biotechnological valorization of Ecuadorian agroindustrial waste cannot be proposed through a uniform route. The potential of each biomass depends on its composition, the way it is generated and the relationship between the

ISSN: 3091-1796
Vol. 4 No. 10 PP. 127-145
DOI: https://doi.org/10.56519/r001qm43
Agosto 2026

transformation process and the expected product. This interpretation coincides with studies that indicate that waste acquires value when its chemical and structural characteristics are linked to specific technologies and applications (1,2,7–9,34,35). The matrix allowed these differences to be ordered, although its scores should be understood as a documentary prioritization and not as a demonstration of industrial feasibility.

Bananas and cocoa achieved the highest priority, but for different reasons. Banana pseudostems, rachises, and peels combine availability with routes to fibers, nanocellulose, bioenergy, biofertilizers, and biodegradable materials (20,21,23,39,40). However, its lignocellulosic structure requires conditioning, pretreatment and hydrolysis. For reference, one ton of dried pseudostem could generate around 112 L of ethanol through simultaneous saccharification and fermentation (20); This figure should not be applied to fresh material, whose high water content increases transportation and conditioning needs. Cocoa responds to a functional logic: the shell and mucilage contain phenolic compounds, pectins and fermentable sugars (14,15,22,24). In the mucilage, 71.91 g L^{-1} of ethanol were reported after 96 h, equivalent to approximately 91 L per fresh ton (14). Its advantage is the direct availability of sugars; Its limitations are microbiological deterioration and composition variability.

Sugarcane and rice also showed high priority, although their use is conditioned by lignocellulosic recalcitrance. For sugarcane bagasse, 191.96 kg of ethanol per dry ton were documented, equivalent to 243.3 L, when hexoses and pentoses are recovered and fermented (44). In rice straw, 214 mg of ethanol per gram, approximately 271 L per dry ton, was recorded after combined pretreatment (33). These yields show the potential of both chains, but depend on the efficiency of pretreatment, hydrolysis, enzyme consumption, and the microbial capacity to use the released fractions (12,13,26,27,33,41–44).

Corn was placed in medium priority because evidence shows a gap between theoretical potential and achievable yield. For dry stubble, a maximum of close to 480 L of ethanol per ton was estimated, compared to a process estimate of approximately 240 L t^{-1} and an experimental result of 45 L t^{-1} (31.45). These differences respond to the composition, humidity, pretreatment and microorganisms used. Although there are also routes to biosurfactants, cellulosic materials and biohydrogen (28–30,43), it is still necessary to define which waste and process would be most appropriate for Ecuadorian conditions.

Citrus fruits and shrimp show that valorization should not be limited to energy production. The acid extraction of citrus peels allowed the recovery of between 21.63 and 32.53% of pectin on a dry basis, equivalent to 216–325 kg per ton (32), in addition to there being alternatives for essential oils, packaging and functional compounds (25.36–38). In shrimp waste, a chitosan yield of 13.96% was reported with respect to the dry shell, equivalent to 139.6 kg per dry ton (19). However, obtaining it requires demineralization, deproteinization and deacetylation, with consumption of reagents and generation of effluents that must be incorporated into the environmental evaluation (16–19).

The matrix also showed that annual abundance does not equate to operational availability. Corn and citrus fruits have greater seasonality and dispersion, while bagasse, rice husks and shrimp exoskeletons tend to be concentrated in sugar mills, mills or processing plants. Humidity, low bulk density, collection distance, and the need for stabilization can reduce the benefit of a technically viable route (3,5,22,23). This interaction explains why selection must simultaneously consider productive, technological and environmental variables, as proposed by multi-criteria approaches applied to agricultural waste (34,35).

The stability observed in the sensitivity analysis supports the general classification against small variations in the weights, but does not eliminate the limitations of the study. The collected yields come from different experimental conditions and calculation bases, so they function as orders of magnitude and not as industrial predictions for Ecuador. Nor were costs, monthly availability or impacts evaluated through life cycle analysis. Consequently, banana and cocoa constitute initial alternatives of greatest interest, while the implementation of any of the routes must be confirmed with local characterization, mass balances, techno-economic evaluation and laboratory and pilot scale tests.

CONCLUSIONS

The evaluated Ecuadorian agroindustrial waste does not present a uniform potential for biotechnological recovery. Its use depends on the composition of the material, the regularity with which it is generated, the technological complexity of the transformation route and the type of final product that can be obtained. Lignocellulosic waste, such as sugarcane bagasse, rice husks and straw, banana pseudostems and rachis, show potential for fermentative processes, bioenergy, biofertilizers and biomaterials; However, its transformation may require pretreatments that condition technical and economic feasibility. On the other hand, cocoa and citrus residues are better oriented towards the recovery of functional compounds, pectins, antioxidant fractions and molecules of industrial interest. Shrimp waste follows a different logic, focused on obtaining chitin, chitosan and protein hydrolysates from the exoskeleton.

The decision matrix made it possible to organize dispersed information and establish an initial prioritization based on comparable criteria. Banana and cocoa obtained the highest scores, although for different reasons: banana stood out for its availability, diversity of residual fractions and breadth of possible routes, while cocoa stood out for the functional value of its by-products. Sugar cane, shrimp, citrus fruits and rice were also placed in high priority, but their use requires a more precise selection of the process, the final product and the operating conditions. Corn was classified as medium priority, not due to lack of potential, but due to the need to better define the type of waste, the biotechnological route and the expected application.

The biotechnological valorization of agroindustrial waste should not be interpreted only as a waste management strategy, but as a productive, environmental and technological opportunity within chains already consolidated in the country. However, the abundance of biomass does not by itself guarantee the feasibility of its use. The decision on which

waste to prioritize must also consider transformation barriers, conditioning costs, product stability, potential demand and local processing capabilities.

In this sense, the comparative matrix and the theoretical-documentary balances constructed in this work constitute initial guidance tools to select waste and recovery routes with greater relevance for the Ecuadorian context. The balances allow establishing orders of magnitude for bioethanol, pectin and chitosan, but should not be interpreted as yields obtained directly in national facilities. The next steps should focus on trials with waste collected in Ecuador and pilot tests that allow evaluating composition, humidity, effective performance, stability, scalability, collection and operation costs, reagent consumption and environmental impact of the prioritized routes.

REFERENCES

1. Prado-Acebo I, Cubero-Cardoso J, Lu-Chau TA, Eibes G. Integral multi-valorization of agro-industrial wastes: A review. Waste Management. 2024 Jun 30;183:42–52. doi:10.1016/j.wasman.2024.05.001
2. Bala S, Garg D, Sridhar K, Inbaraj BS, Singh R, Kamma S, et al. Transformation of Agro-Waste into Value-Added Bioproducts and Bioactive Compounds: Micro/Nano Formulations and Application in the Agri-Food-Pharma Sector. Bioengineering. 2023 Feb;10(2):152. doi:10.3390/bioengineering10020152
3. Weldesemayat Sileshi G, Barrios E, Lehmann J, Tubiello FN. An organic matter database (OMD): consolidating global residue data from agriculture, fisheries, forestry and related industries. Earth System Science Data. 2025 Feb 3;17(2):369–91. doi:10.5194/essd-17-369-2025
4. Escudero-Curiel S, Giráldez A, Pazos M, Sanromán Á. From Waste to Resource: Valorization of Lignocellulosic Agri-Food Residues through Engineered Hydrochar and Biochar for Environmental and Clean Energy Applications—A Comprehensive Review. Foods. 2023 Jan;12(19):3646. doi:10.3390/foods12193646
5. Bermúdez JMS, Varela GAZ, Cedeño REC, Riera MA. Estudio de residuos biomásicos agrícolas para la instalación de una biorefinería de pequeña escala. La Granja. 2025 Aug 26;42(2):136–53. doi:10.17163/lgr.n42.2025.09
6. Nicolás García M, Borrás Enríquez A, González Escobar J, Calva Cruz O, Pérez Pérez V, Sánchez Becerril M. Phenolic Compounds in Agro-Industrial Waste of Mango Fruit: Impact on Health and Its Prebiotic Effect – a Review. Pol J Food Nutr Sci. 2023 Feb 21;5–23. doi:10.31883/pjfns/159361
7. Ezeorba TPC, Okeke ES, Mayel MH, Nwuche CO, Ezike TC. Recent advances in biotechnological valorization of agro-food wastes (AFW): Optimizing integrated approaches for sustainable biorefinery and circular bioeconomy. Bioresource Technology Reports. 2024 Jun 1;26:101823. doi:10.1016/j.biteb.2024.101823
8. Burbano-Cuasapud JM, Solarte-Toro JC, Restrepo-Serna DL, Cardona Alzate CA. Process Sustainability Analysis of Biorefineries to Produce Biofertilizers and Bioenergy from Biodegradable Residues. Fermentation. 2023 Sep;9(9):788. doi:10.3390/fermentation9090788
9. Yafetto L, Odamtten GT, Wiafe-Kwagyan M. Valorization of agro-industrial wastes into animal feed through microbial fermentation: A review of the global and

Ghanaian case. Heliyon. 2023 Apr 1;9(4):e14814. doi:10.1016/j.heliyon.2023.e14814
10. Sundaram T, Govindarajan RK, Vinayagam S, Krishnan V, Nagarajan S, Gnanasekaran GR, et al. Advancements in biosurfactant production using agro-industrial waste for industrial and environmental applications. Front Microbiol. 2024 Feb 5;15:1357302. doi:10.3389/fmicb.2024.1357302
11. Jayanthi B, Vinoth S, Hariharan M, Raja RK, Kamaraj C, Narayanan M. Valorization of agro-industry wastes for nanocellulose fabrication and its multifunctional applications. Biocatalysis and Agricultural Biotechnology. 2024 Apr 1;57:103124. doi:10.1016/j.bcab.2024.103124
12. Matsueda Y, Antunes E. A review of current technologies for the sustainable valorisation of sugarcane bagasse. Journal of Environmental Chemical Engineering. 2024 Dec 1;12(6):114900. doi:10.1016/j.jece.2024.114900
13. Kamboj A, Sadh PK, Yadav B, Kumari A, Kumar R, Surekha, et al. Unravelling the potential of sugarcane bagasse: An eco-friendly and inexpensive agro-industrial waste for the production of valuable products using pretreatment processes for sustainable bio-economy. Journal of Environmental Chemical Engineering. 2024 Dec 1;12(6):114461. doi:10.1016/j.jece.2024.114461
14. Zambrano A, Cobos V, Luna T, Duarte J, Barzallo D. Optimization of Bioethanol Production from Cocoa Mucilage (Theobroma cacao) Using a Commercial and a Genetically Modified Strain of Saccharomyces cerevisiae. International Journal of Agriculture and Biosciences. 2026 Feb 12. doi:10.47278/journal.ijab/2026.039
15. Guzmán-Armenteros TM, Guerra LS, Ruales J, Ramos-Guerrero L. Ecuadorian Cacao Mucilage as a Novel Culture Medium Ingredient: Unveiling Its Potential for Microbial Growth and Biotechnological Applications. Foods. 2025 Jan;14(2):261. doi:10.3390/foods14020261
16. Pérez WA, Marín JA, López JN, Burgos MA, Rios LA. Development of a Pilot-ecofriendly Process for Chitosan Production from Waste Shrimp Shells. Environmental Processes. 2022 Sep 2;9(3):55. doi:10.1007/s40710-022-00605-8
17. Lakshmi DS, Ravindran L, Mary PJM, Rathika G, Sreekala MS, Munisamy S. Valorization of Crustacean Shells: Preparation, Characterization, and Chemical Modification of Nano-Chitin Biopolymer Membrane for Application in Water Purification. Waste Biomass Valor. 2024 Nov 1;15(11):6067–90. doi:10.1007/s12649-024-02601-5
18. Bautista-Hernández I, Gómez-García R, Martínez-Ávila GCG, Pintado M. Solid state fermentation (SSF) on marine biomasses and their by-products - a new research biorefinery frontier for the obtention of innovative and novel value-added compounds towards industrial applications. Journal of Environmental Management. 2026 Jun 15;410:129973. doi:10.1016/j.jenvman.2026.129973
19. Aberoumand A, Chabavi M. Extraction and Quality Control of Chitin and Chitosan from Shrimp (Vanami) Litophenause Vanamei Shells Wastes. Natural Product Communications. 2024 Oct 1;19(10):1934578X241291383. doi:10.1177/1934578X241291383
20. Guerrero AB, Ballesteros I, Ballesteros M. The potential of agricultural banana waste for bioethanol production. Fuel. 2018 Feb 1;213:176–85. doi:10.1016/j.fuel.2017.10.105

21. Kumar V, Chakraborty P, Janghu P, Umesh M, Sarojini S, Pasrija R, et al. Potential of banana based cellulose materials for advanced applications: A review on properties and technical challenges. Carbohydrate Polymer Technologies and Applications. 2023 Dec 1;6:100366. doi:10.1016/j.carpta.2023.100366
22. Alava C, Moncayo S, Galarza L. Cocoa husk in the circular bioeconomy: a perspective from Ecuador and other producer countries. Front Food Sci Technol. 2025 Dec 18;5. doi:10.3389/frfst.2025.1726187
23. Hazarika U, Saikia P, Choudhury M, Das M. Unlocking the potential of banana peel waste – A multi-faceted review emphasizing its nutrient profile, extraction strategies, and prospective utility within the context of circular waste bioeconomy. Applied Food Research. 2026 Jun;6(1):101675. doi:10.1016/j.afres.2026.101675
24. Sánchez M, Laca A, Laca A, Díaz M. Cocoa Bean Shell: A By-Product with High Potential for Nutritional and Biotechnological Applications. Antioxidants. 2023 May;12(5):1028. doi:10.3390/antiox12051028
25. Sharma P, Vishvakarma R, Gautam K, Vimal A, Kumar Gaur V, Farooqui A, et al. Valorization of citrus peel waste for the sustainable production of value-added products. Bioresource Technology. 2022 May 1;351:127064. doi:10.1016/j.biortech.2022.127064
26. Ntunka MG, Makhathini TP, Khumalo SM, Bwapwa JK, Tshibangu MM. Recent Developments in the Valorization of Sugarcane Bagasse Biomass via Integrated Pretreatment and Fermentation Strategies. Fermentation. 2025 Nov;11(11):632. doi:10.3390/fermentation11110632
27. Li Z, Zheng Z, Li H, Xu D, Li X, Xiang L, et al. Review on Rice Husk Biochar as an Adsorbent for Soil and Water Remediation. Plants. 2023 Jan;12(7):1524. doi:10.3390/plants12071524
28. Nunes HMAR, Vieira IMM, Santos BLP, Silva DP, Ruzene DS. Biosurfactants produced from corncob: a bibliometric perspective of a renewable and promising substrate. Preparative Biochemistry & Biotechnology. 2022 Feb 1;52(2):123–34. doi:10.1080/10826068.2021.1929319 PubMed PMID: 34081569.
29. Gutiérrez P, Aldas M, Gavilanes D, Cadena F, Valle V. Corn cob valorization: Synthesis of a polymer based on crystalline cellulose with poly(ethylene glycol) diacrylate and N-vinylcaprolactam. Cleaner Engineering and Technology. 2025 Jul;27:101019. doi:10.1016/j.clet.2025.101019
30. Aghaei S, Karimi Alavijeh M, Shafiei M, Karimi K. A comprehensive review on bioethanol production from corn stover: Worldwide potential, environmental importance, and perspectives. Biomass and Bioenergy. 2022 Jun 1;161:106447. doi:10.1016/j.biombioe.2022.106447
31. Mensah MB, Jumpah H, Boadi NO, Awudza JAM. Assessment of quantities and composition of corn stover in Ghana and their conversion into bioethanol. Scientific African. 2021 Jul;12:e00731. doi:10.1016/j.sciaf.2021.e00731
32. Akhter MostJ, Sarkar S, Sharmin T, Mondal SC. Extraction of pectin from powdered citrus peels using various acids: An analysis contrasting orange with lime. Applied Food Research. 2024 Dec;4(2):100614. doi:10.1016/j.afres.2024.100614
33. Sawhney D, Vaid S, Bangotra R, Sharma S, Dutt HC, Kapoor N, et al. Proficient bioconversion of rice straw biomass to bioethanol using a novel combinatorial pretreatment approach based on deep eutectic solvent, microwave irradiation

and laccase. Bioresour Technol. 2023 May;375:128791. doi:10.1016/j.biortech.2023.128791 PubMed PMID: 36871702.

34. Lombardi P, Todella E. Multi-Criteria Decision Analysis to Evaluate Sustainability and Circularity in Agricultural Waste Management. Sustainability. 2023 Jan;15(20):14878. doi:10.3390/su152014878
35. Orlandella I, Fiore S. Life Cycle Assessment of the Production of Biofertilizers from Agricultural Waste. Sustainability. 2025 Jan;17(2):421. doi:10.3390/su17020421
36. Frosi I, Balduzzi A, Moretto G, Colombo R, Papetti A. Towards Valorization of Food-Waste-Derived Pectin: Recent Advances on Their Characterization and Application. Molecules. 2023 Jan;28(17):6390. doi:10.3390/molecules28176390
37. Díaz-Muñoz LL, Castañeda-Aude JE, Landín-Sandoval VJ, Lozano-Álvarez JA, Escárcega-González CE. Valorization and Harnessing Citrus Waste: Focus on Green Synthesis of Metal Nanoparticles with Antimicrobial Applications and Other Potential Uses. Food Reviews International. 2026 Mar 31;42(4):2116–61. doi:10.1080/87559129.2025.2541849
38. Revathi V, Bora S, Afzia N, Ghosh T. Orange peel composition, biopolymer extraction, and applications in paper and packaging sector: A review. Sustainable Chemistry and Pharmacy. 2025 Feb 1;43:101908. doi:10.1016/j.scp.2025.101908
39. Fiallos-Cardenas M, Gavin C, Huilcarema-Enríquez K, Cumbicus-Bravo A, Pozo F. Innovation in obtaining bacterial nanocellulose from banana rachis: Effects of ozone treatment. Case Studies in Chemical and Environmental Engineering. 2025 Jun;11:101044. doi:10.1016/j.cscee.2024.101044
40. Romero-Cárdenas E, Romero-Romero BR, Tapia-Núñez DW, Zúñiga-Santillán XL, Valenzuela-Cobos JD. Sustainable paper from agricultural residues: differentiating treatment effects in banana pseudostem fibers using X-STATIS multiblock analysis. Front Sustain. 2025 Jul 23;6:1628095. doi:10.3389/frsus.2025.1628095
41. Pérez-Contreras S, Hernández-Rosas F, Lizardi-Jiménez MA, Herrera-Corredor JA, Baltazar-Bernal O, Avalos-de la Cruz DA, et al. Sugarcane Industry By-Products: A Decade of Research Using Biotechnological Approaches. Recycling. 2025 Aug;10(4):154. doi:10.3390/recycling10040154
42. Liang D, Wei C, Liu D, Liu X, Xiao S, Wang Y, et al. Research Progress Review on the Activation of Bioactive Substances by Targeted Fermentation of Rice Bran. Foods. 2026 Jan;15(11):1881. doi:10.3390/foods15111881
43. Prado ERL, Rial RC. Biohydrogen production from residual biomass: The potential of wheat, corn, rice, and barley straw – recent advances. Bioresource Technology. 2025 Sep 1;432:132638. doi:10.1016/j.biortech.2025.132638
44. Dionísio SR, Santoro DCJ, Bonan CIDG, Soares LB, Biazi LE, Rabelo SC, et al. Second-generation ethanol process for integral use of hemicellulosic and cellulosic hydrolysates from diluted sulfuric acid pretreatment of sugarcane bagasse. Fuel. 2021 Nov 1. doi:10.1016/j.fuel.2021.121290
45. Kadam KL, McMillan JD. Availability of corn stover as a sustainable feedstock for bioethanol production. Bioresour Technol. 2003 May;88(1):17–25. doi:10.1016/s0960-8524(02)00269-9 PubMed PMID: 12573559.