Biopolymers Derived from Agricultural Waste and the Axiological Reconfiguration of Technological Efficiency: A Hermeneutic Analysis in Contrast to Synthetic Polymers

Fuentes Molina Natalia[1]* Salinas Epiayu Alexander A.[2] and Daza Ortiz Yorleidis M[3].

[1,2,3] Members of the research group Semi-arid Territory of the Caribbean, Environmental Engineering, Faculty of Engineering, Universidad de La Guajira, Km 3+354 vía Maicao, Riohacha La Guajira Colombia 440003. nnfuentes@uniguajira.edu.co

Abstract
Biopolymers derived from agricultural waste occupy a growing place in scholarly discussions on sustainability and technological development. Beyond their instrumental performance, these materials enable a critical examination of the values that orient agricultural production and shape the relationships between technology, nature, and culture. From this perspective, sustainability is understood as a guiding horizon that structures technological decisions and configures situated ways of inhabiting productive systems. This study advances an axiological analysis of porous biopolymers obtained from agricultural waste and applied in agricultural contexts under water stress conditions, interpreting them as mediators of a technological rationality oriented toward resource care, material circularity, and environmental responsibility. The adopted approach integrates the analysis of material configurations with a critical interpretation of the cultural and normative assumptions underpinning their development and use, articulating technical evidence with philosophical reflection on technological meaning. The results indicate that the structural and functional organization of biopolymers aligns with values associated with waste valorization, ecological coherence, and integration with soil cycles. Within this framework, material innovation acquires relevance insofar as it expresses a transformation in productive narratives, in which technology is oriented by care and intergenerational responsibility. Overall, the study contributes to understanding biopolymers as culturally situated mediators in the axiological reconfiguration of contemporary agricultural technology.
Keywords: biopolymers; sustainability; agricultural waste; philosophy of culture, axiology of technology.

INTRODUCTION

The sustained expansion of synthetic polymers in today's production systems is one of the most representative features of the modern technological paradigm, characterized by functional efficiency, material standardization, and the externalization of environmental costs; this understanding has shaped production practices that, especially in the agricultural field, have reorganized the relationship between technology and nature, prioritizing immediate functionality and operational stability. However, this same rationality has contributed to the emergence of persistent ecological imbalances, whose manifestation in soils, water bodies, and biogeochemical cycles reveals the cultural and value-laden dimension underlying technical decisions (Islam et al., 2024; Campanale et al., 2024; Wang et al., 2024).

Within the framework of current research on sustainability and technological development, biopolymers derived from agricultural waste have gained relevance as material expressions of a shift in production narratives. Beyond their functional potential, these materials introduce a redefinition of residual matter, which ceases to be understood as surplus and is instead incorporated into value chains guided by principles of circularity and environmental stewardship (Muhammad et al., 2023; Ali et al., 2024; Anjaly et al., 2023). This shift is not limited to a substitution of inputs, but implies a rearticulation of the meanings attributed to the residue, the soil and the natural cycles in which agricultural systems are inscribed. However, the specialized literature warns that the incorporation of biopolymers into production systems often operates under an instrumental notion of sustainability, in which material change is conceived as a sufficient solution to deeper structural problems; in this approach, sustainability is presented as a quantifiable technical attribute, while the logics of linear production, intensive consumption and externalization of impacts remain unaltered. Several studies underline that even materials of biological origin can reproduce these dynamics when inserted into production frameworks that prioritize economic efficiency over ecological and cultural coherence (Ahmed et al., 2024; Islam et al., 2024; Sevil et al., 2024).

From a hermeneutic perspective, this tension reveals that technology cannot be understood solely as a set of means, but rather as a sphere in which specific ways of understanding the world manifest themselves. Materials, as technical structures, actively participate in shaping these understandings by embodying values, expectations, and ways of relating to nature. In this sense, biopolymers can be interpreted as mediators of meaning, whose relevance lies not only in their functional performance, but also in the technological rationality they make visible and the ethical commitments they entail (Feenberg, 2002; Jonas, 1984). Within this context, recent research has extensively documented the transformation of diverse agricultural wastes such as rice hulls, sugarcane bagasse, banana pseudostems, fruit peels, and horticultural by-products into biodegradable polymeric materials with mechanical and functional properties relevant to agricultural and environmental applications (Bilo et al., 2018; Li et al., 2022; Karimi Sani et al., 2023); These approaches demonstrate an effort to reconfigure residual materiality within alternative production circuits; however, they also reveal that the substitution of synthetic polymers for biopolymers is not a transition free of ambiguities. Other studies indicate that certain biopolymers, even when they exhibit biodegradability under controlled conditions, can fragment into persistent micro and nanopolymers, with still uncertain biological effects in agricultural soils and aquatic environments (Wang et al., 2024; Tao et al., 2024; Pinaeva et al., 2024). These dynamics raise questions about the environmental coherence of bio-based materials when their degradation is incomplete or dependent on idealized conditions, shifting the discussion towards actual performance throughout the life cycle (Folino et al., 2023; Sevil et al., 2024; Rasheed et al., 2024).

In the agricultural sector, biodegradable mulch films have been extensively studied as alternatives to conventional polymers, with significant advances in their structural design, processability, and field performance (Ryu et al., 2025; Campanale et al., 2024). However, the literature also highlights persistent tensions between agronomic performance, costs, effective biodegradability, and long-term ecological effects, especially under conditions of water stress and intensive soil management (Yang et al., 2024; Campanale et al., 2024). These tensions make it clear that the evaluation of agricultural biopolymers is not limited to technical parameters, but refers to the values that guide their adoption and legitimization. From this perspective, biopolymers derived from agricultural waste become relevant not only for properties such as porosity, biological compatibility and capacity for integration with the soil, but also for the axiological shift they embody by reconfiguring waste as a resource and by inscribing themselves in a technological rationality oriented towards sustainability, circularity and intergenerational responsibility (Ahmed et al., 2024; Qian et al., 2025; Zhang et al., 2025). An axiological analysis of the development of biopolymers thus allows us to shift the focus from the question of efficient substitution to the question of the values that guide technical action; this analysis makes it possible to understand sustainability not as an external criterion applied a posteriori, but as a horizon of meaning that structures material decisions from their conception. In the agricultural field, this horizon is particularly linked to the care of the soil as a living system and to responsibility towards future generations, dimensions that give bio-based materials a cultural significance that exceeds their immediate function; from this interpretative framework, the research starts from the hypothesis that the development and use of biopolymers derived from agricultural waste in agricultural contexts expresses an axiological shift in the dominant technological rationality, in which material decisions incorporate values of circularity, care of the soil and intergenerational responsibility, configuring an alternative form of relationship between technology, nature and sustainability. In accordance with this hypothesis, the research is guided by an analytical strategy that articulates the understanding of the materiality of biopolymers with the interpretive analysis of the values that guide their design and application. This approach allows us to place the materials at the crossroads between technique and culture, and opens the way for an evaluation that considers both their material configurations and the meanings they mobilize in contemporary production systems.

METHODOLOGY

The methodological configuration of this study is based on the recognition that all technical practice is inscribed within an axiological and hermeneutical horizon that guides, explicitly or implicitly, the selection of materials, processes, and evaluation criteria; in accordance with the critical philosophy of technology, which understands biopolymers as material crystallizations of social rationalities and value systems (Feenberg, 2002; Verbeek, 2011; Winner, 1986), The methodology was deliberately designed to avoid a purely instrumental approach focused on material performance or functional optimization. Instead, a perspective was adopted that integrates environmental responsibility, strong sustainability, and care for the soil as a living system, understood not only as technical variables but also as normative categories that guide the research. This methodological stance also aligns with the principle of responsibility formulated by Jonas (1984), This requires anticipating the long-term effects of technological interventions on vulnerable natural systems. In this regard, methodological decisions prioritized processing, characterization, and evaluation pathways capable of minimizing persistent environmental impacts and promoting material reintegration into soil ecological cycles. This approach is consistent with recent perspectives that question the ethical neutrality of technological innovation and underscore the importance of incorporating criteria of care, precaution, and shared responsibility into materials design. Contemporary studies in the ethics of technology and nanoinnovation highlight the need to integrate ethical, environmental, and social dimensions into technological design and development practices, guiding innovation toward sustainable and responsible ends (Tien et al., 2025; Atausinchi Masias et al., 2025; Grunwald, 2011).

From this perspective, each stage of the methodological design, from the selection of residual biomass to the comparative evaluation against conventional synthetic mulches, was approached as a value judgment aimed at examining the technical feasibility of porous biofilms and their consistency with principles of ecological sustainability, material circularity, and responsible resource use. This approach responds to the recommendations of Islam et al. (2024) y Pinaeva et al. (2024), who warn that biopolymers can produce significant environmental impacts if analyzed exclusively from functional criteria, without a comprehensive reading of the life cycle and their insertion into intensive production systems; likewise, the incorporation of indicators associated with soil-material interaction and degradation in an agricultural context aligns with the approaches of Campanale et al.

(2024), that emphasize the need to go beyond immediate agronomic performance and consider the ecological and cultural effects of using biodegradable mulches.

Selection and preparation of residual biomass

Representative agricultural residues from tropical production systems were used, such as cassava peel (Manihot esculenta), sugarcane bagasse (Saccharum officinarum L.) and corn bagasse (Zea mays L.), selected for their high availability, agro-industrial relevance and content of biodegradable polymer fractions, including starch, hemicelluloses and structural cellulose; these biomasses were considered within the framework of waste valorization and circular economy strategies, in which agricultural by-products are transformed into functional polymer matrices (Muhammad et al., 2023; Ahmed et al., 2024; Ali et al., 2024). The biomasses were subjected to physical conditioning processes such as cleaning, drying and size reduction, followed by controlled chemical pretreatments, aimed at facilitating the release and reorganization of the constituent polymeric fractions. These procedures aimed at the exhaustive isolation of cellulose, and the preparation of integrated polymeric systems, preserving the functional interaction between the different polysaccharides present in the biomass (Anjaly et al., 2023; Rasheed et al., 2024; Mostafa et al., 2018).

Obtaining and shaping polymeric matrices

The polymeric matrices were obtained through mild thermal and chemical treatments, designed to promote gelatinization, structural disorganization and subsequent molecular rearrangement of the polysaccharides present in the biomass; in this process, cellulose acts as a reinforcing structural component within the matrix, while other polymeric fractions contribute to the formation of continuous phases and the cohesion of the biopolymer. Variables such as temperature, pH, and processing time were controlled in order to modulate intermolecular interactions, mainly hydrogen bonds, responsible for the mechanical integrity and stability of the final material, obtaining homogeneous polymer dispersions explicitly aimed at the production of biodegradable materials, rather than the isolated study of their constituent components (Ahmed et al., 2024; Qian et al., 2025; Zhang et al., 2025; Qian et al., 2025). The biopolymers obtained by pouring and controlled drying techniques, modulating physicochemical parameters such as solids concentration, evaporation rate and environmental conditions of the process, these variables were adjusted to favor the formation of continuous films with mechanical and functional behavior comparable to that of synthetic polymers used in agricultural applications. Its formation was conceived as a decisive stage in the axiological configuration of the material, insofar as it articulates technical properties such as flexibility, structural stability and degradability with values associated with the responsible use of the land and the integration of the material with natural cycles (Campanale et al., 2024; Ryu et al., 2025).

Table 1. Methodological stages, axiological categories and theoretical references

Methodological stage	Technical dimension: physical, chemical, and functional	Axiological categories involved	Value category analyzed	References

Selection and chemical pretreatment of residual biomass	Selection of polymeric sources: cassava peel (Manihot esculenta), sugarcane bagasse (Saccharum officinarum L.) and corn bagasse (Zea mays L.). Cleaning, drying, size reduction and controlled chemical treatments	Sustainability, circularity, environmental responsibility Soil conservation, technological prudence	The selection of agricultural waste redefines waste as a resource, displacing an extractive logic with a rationality oriented towards responsible use and the circular economy. Moderation in pretreatments expresses an ethic of technical intervention aimed at minimizing impacts and preserving the ecological integrity of the material.	Muhammad et al., 2023; Ali et al., 2024; Anjaly et al., 2023 Ahmed et al., 2024; Rasheed et al., 2024; Jonas, 1984
Obtaining and shaping polymeric matrices	Gelatinization and molecular rearrangement of polysaccharides with cellulose as structural reinforcement Pouring and controlled drying to obtain continuous films	Ecological coherence, systemic integration Intergenerational responsibility, responsible land use	The integrated matrix avoids reductionist approaches and reflects a technical rationality inspired by the interdependence of natural systems. The shape of the material is defined by its interaction with the soil and its degradation, prioritizing long-term impacts over immediate efficiency.	Mostafa et al., 2018; Qian et al., 2025; Zhang et al., 2025 Campanale et al., 2024; Ryu et al., 2025; Feenberg, 2002

Physical, chemical, structural and functional characterization	Thermal, mechanical, and morphological evaluation Comparative analysis against synthetic polymers	Reflective technological rationality Contextual relevance, strong sustainability	Characterization seeks to understand limits and environmental compatibility rather than maximize performance. Functionality is evaluated under real-world conditions, recognizing the ecological and cultural complexity of the agricultural system.	Ahmed et al., 2024; Yang et al., 2024; Sevil et al., 2024 Campanale et al., 2024; Islam et al., 2024
Axiological analysis and interpretive framework	Critical interpretation of the values embodied in the materials	Ethics of technology, responsibility, care	Biopolymers are understood as matrices that carry values and not as technically neutral objects.	Feenberg, 2002; Jonas, 1984; Islam et al., 2024
Methodological triangulation	Integration of technical evidence, comparative analysis, and axiological reflection	Epistemological coherence, hermeneutic understanding	Triangulation articulates empiricism and interpretation, avoiding technical or normative reductionism.	Pinaeva et al., 2024; Rasheed et al., 2024

Physical, chemical, structural and functional characterization of biopolymers

The shaped biopolymers were subjected to a physicochemical and structural characterization aimed at understanding the relationship between their material configuration and their functional performance in agricultural contexts.Chemical characterization allowed the identification of thermal stability and resistance to degradation processes induced by temperature and humidity, fundamental aspects to evaluate its behavior under conditions of water stress and environmental exposure. These analyses were performed considering that the stability of biopolymers depends on the chemical composition, type and intensity of the intermolecular interactions that structure the polymer matrix, particularly those associated with hydrogen bond networks and semicrystalline domains (Ahmed et al., 2024; Qian et al., 2025). From a structural point of view, the surface morphology and internal organization of the polymer films were evaluated in order to analyze their continuity, porosity and homogeneity, properties directly related to their interaction with the soil and with the flows of water and gases in the soil environment. The functional characterization included the evaluation of relevant mechanical properties such as flexibility, strength and dimensional stability, as well as tests aimed at analyzing its behavior in agricultural applications, particularly its performance as a soil cover material compared to conventional synthetic polymers, which are widely documented in the literature (Yang et al., 2024; Campanale et al., 2024; Sevil et al., 2024).

Axiological analysis and interpretive framework

The axiological analysis of the study was based on the premise that materials and technological processes are not axiologically neutral, but rather embody values, rationalities, and specific forms of relationship with the natural environment (Feenberg, 2002; Jonas, 1984). In this sense, biopolymers derived from agricultural waste were interpreted not only as technical solutions, but as material expressions of an alternative technological rationality, guided by principles of sustainability, environmental responsibility and care for the soil as a living system. The interpretative framework made it possible to contrast the dominant paradigm of synthetic polymers characterized by durability, standardization and immediate productive efficiency with the material logic of biopolymers, in which properties such as biodegradability, residual origin and ecological compatibility acquire a central axiological meaning.This reading was supported by recent studies that warn that the evaluation of biodegradable materials requires considering not only their functional performance, but also the cultural and normative values that guide their development and implementation in contemporary production systems (Islam et al., 2024; Pinaeva et al., 2024; Rasheed et al., 2024).

Interpretive triangulation

A methodological integration strategy was developed based on triangulation between three analytical dimensions: i. the physicochemical and structural evidence obtained from the characterization of biopolymers; ii. the comparative analysis of their functional performance against synthetic polymers used in agricultural applications; and iii. the axiological reflection aimed at interpreting the cultural and environmental meaning of these material configurations. This triangulation allowed for a coherent evaluation of the study's central hypothesis, according to which biopolymers derived from agricultural waste not only represent a technical alternative to dominant synthetic polymers, but also express an axiological shift in technological decisions associated with sustainable agriculture.

RESULTS

The results show that biopolymers derived from agricultural waste have structural and functional configurations that acquire full meaning when interpreted in an integrated way, articulating physical, chemical, mechanical properties, functional performance and axiological coherence. Rather than constituting a set of isolated metrics, the data reveal a structural correspondence between material, function and environmental context, which allows us to understand these biopolymers as technical mediators situated in agricultural production systems.

Structural and physicochemical configuration of agricultural biopolymers

Structural analysis of biopolymers made from cassava peel (Manihot esculenta), sugarcane bagasse (Saccharum officinarum), and corn bagasse (Zea mays) showed differentiated porous structures, associated with the origin and composition of the residual biomass. These differences translated into relevant functional variations, particularly in water retention capacity, mechanical stability, and interaction with the soil, central aspects in agricultural contexts subjected to water stress.

Table 2. Structural and functional analysis of biopolymers derived from agricultural waste

Polymeric matrix	Residual biomass	Structural configuration	Structural characteristics	Functional performance	Environmental implications
Biopolymer A	Cassava peel (Manihot esculenta)	Semi-continuous polymer matrix with fibrillar reinforcement	Medium-high interconnected porosity, homogeneous distribution	Medium	Progressive degradation, compatible with soil cycles
Biopolymer B	Sugarcane bagasse (Saccharum officinarum)	Dense matrix with high intermolecular cohesion	Low-medium porosity, compact structure	High	Slower degradation, integrated into the soil
Biopolymer C	Corn bagasse (Zea mays)	Heterogeneous polymer network	Variable porosity, irregular microdomains	Medium-low	Rapid degradation, high biological interaction
Synthetic polymer	Petrochemical derivative	Highly ordered homogeneous structure	Negligible porosity	Very high	High environmental persistence

The table 2 shows that the differences in the porous structure of the biopolymers respond directly to the origin and composition of the residual biomass used. From an axiological perspective, porosity is not reduced to a physical variable, but constitutes a material condition that enables interaction with the soil, water, and soil biota. In particular, the biopolymers obtained from cassava peel have a highly porous structure that favors water and gas exchange, configuring a materiality akin to dynamic ecological processes. This configuration expresses a technical rationality oriented towards systemic integration, in contrast to the logic of closure and isolation that characterizes conventional synthetic polymers. In hermeneutical terms, the structure of the biopolymer can be interpreted as a form of material openness to the environment, in which the technique is not imposed on the ground, but rather articulated with it. By integrating these results with the axiological analysis, a positive convergence was observed between functional performance, environmental sustainability, and ecological coherence in biopolymers derived from agricultural waste.

Functional performance in agricultural contexts

The comparative functional analysis indicated that biopolymers achieve performance levels compatible with agricultural applications, especially in terms of regulating soil moisture and supporting germination processes. These properties are expressed more markedly in biopolymers derived from banana pseudostems, suggesting a material affinity with small and medium-scale agricultural systems, characterized by management practices more integrated into the local environment. This convergence contrasts with the profile of conventional synthetic polymers, whose high immediate technical performance is accompanied by a low axiological value, associated with their environmental persistence and their disconnection from natural cycles. In this sense, the results confirm that technological efficiency acquires different meanings depending on the value system from which it is evaluated, and that biopolymers express a technical rationality oriented by adaptability, regeneration, and systemic integration. It is also evident that the functional performance of biopolymers is expressed differently depending on the biomass of origin, particularly in relation to water retention and compatibility with germination processes. This functional variability makes sense when it is interpreted from the notion of adaptability, central to the axiological methodology adopted. Unlike synthetic polymers, whose performance is defined by the stability and permanence of properties over time, biopolymers exhibit a dynamic functional behavior, adjusted to environmental conditions and the needs of the agricultural system; this material temporality marked by progressive degradation and reintegration into the soil constitutes a technical value in itself, by favoring the resilience of the agroecosystem in contexts of water stress.

Comparative Axiological Evaluation of Polymeric Materials

This explicitly introduces the axiological dimension of the analysis, showing that the technological valuation of materials varies substantially when criteria such as material origin, integration with natural cycles and coherence with the circular economy are incorporated in the table 3. In this framework, biopolymers derived from agricultural waste achieve a high valuation not by maximizing an isolated property, but by their ability to articulate multiple dimensions of meaning. This result confirms one of the central assumptions of the methodology: technological efficiency is not a universal and neutral attribute, but a construct dependent on the value system that guides the evaluation. While synthetic polymers focus their value on immediate performance, biopolymers express an expanded efficiency, in which environmental impact, ecological temporality, and intergenerational responsibility become central.

Table 3. Comparative axiological analysis of biopolymeric materials in their agricultural use.

Axiological dimension	Biopolymer A (Manihot esculenta)	Biopolymer B (Saccharum officinarum)	Biopolymer C (Zea mays)	Synthetic polymer
Environmental sustainability	Very high	High	High	Low
Coherence with natural cycles	Very high	High	High	Very low
Material circularity	Very high	High	High	Very low
Social Responsibility	High	Medium - High	High	Very low
Polymer matrix soil integration	Very high	Medium - High	High	Low
Axiological value	Very high	High	High	Low

Systemic coherence	Very high	High	High	Low
Paradigmatic position	Ecologically situated technology	Advanced functional replacement	Adaptive technology	Dominant technoscientifi c paradigm

This result confirms one of the central assumptions of the methodology: technological efficiency is not a universal and neutral attribute, but a construct dependent on the value system that guides the evaluation. While synthetic polymers focus their value on immediate performance, biopolymers express an expanded efficiency, in which environmental impact, ecological temporality, and intergenerational responsibility become central. Figure 1 illustrates the axiological shift of technological efficiency in agricultural polymeric materials. While synthetic polymers focus on high technical performance with low axiological coherence, biopolymers derived from agricultural waste are distributed across a field of greater integration between functionality and environmental values; this shift demonstrates that technological efficiency, when evaluated from an axiological framework, ceases to be an exclusively mechanical attribute and is redefined as a relationship between material, its function, and its ecological context.

Figure 1A shows how technological efficiency is distributed in relation to the structural stability of agricultural polymeric materials. The synthetic polymer is positioned in the upper right corner, demonstrating high structural stability associated with high technological efficiency under classic production criteria. However, this deficiency appears decoupled from other dimensions of material performance considered in the study.Biopolymers exhibit a distinct configuration. Biopolymer A achieves a level of structural stability comparable to that of the synthetic polymer, while maintaining high technological efficiency, indicating a convergence between sufficient technical performance and material rationality oriented towards ecological integration. Biopolymer C is situated in an intermediate zone, combining adequate structural stability with consistent technological efficiency, while Biopolymer B presents lower relative values, without losing functional coherence within adaptive agricultural systems.

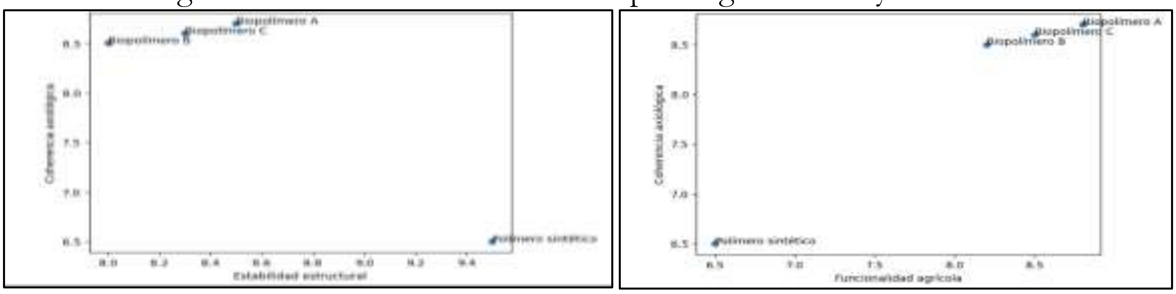

Figure 1. Axiological shift of technological efficiency in polymeric materials in agricultural uses. Convergence between structural stability (1A) agricultural functionality (1B) and axiological coherence.

From an axiological perspective, the graph shows that technological efficiency is not distributed exclusively based on maximizing structural stability, but rather shifts towards material configurations where technical sufficiency is articulated with values of degradability, ecological temporality, and compatibility with the soil. This shift confirms that stability ceases to operate as an absolute goal and is integrated as a property situated within a broader ecological and productive framework.

Meanwhile, Figure 1B further illustrates this shift by directly linking agricultural functionality with technological efficiency, highlighting the paradigmatic divergence between materials. The synthetic polymer achieves high technological efficiency despite limited agricultural functionality, reflecting an efficiency logic disconnected from the agroecosystem and focused on material persistence. In contrast, biopolymers are grouped in a region where technological efficiency is maintained along with high levels of agricultural functionality. Biopolymer A is positioned as the material with the greatest integration between both dimensions, demonstrating a technical rationale oriented towards adaptability, soil-plant interaction and water regulation; Biopolymer C reinforces this trend, while Biopolymer B, even with lower values, maintains a functional coherence aligned with smaller-scale agricultural systems and greater ecological sensitivity.

Axiological displacement of technological efficiency

This summarizes the methodological triangulation strategy, integrating technical performance, environmental impact and axiological coherence Figure 2. This integration confirms that biopolymers derived from agricultural waste do not represent a decrease in technological performance, but rather a redefinition of the very concept of performance, guided by criteria of systemic coherence and strong sustainability. From a philosophical perspective, these results allow us to affirm that biopolymers act as material mediators of a paradigmatic transition, in which agricultural technology shifts from a logic of control and durability towards a rationality based on adaptability, regeneration and care of natural resources, where the materiality of the biopolymer thus becomes a space of cultural mediation, where values, commitments and forms of relationship with the environment are inscribed.

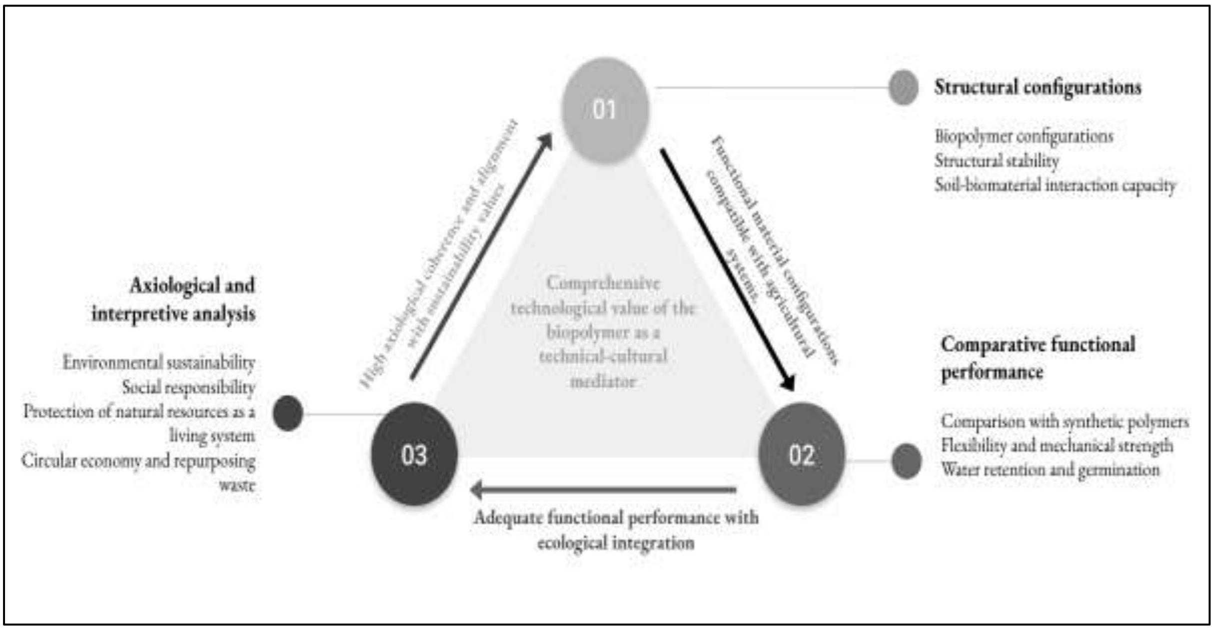

Figure 2. Methodological triangulation and axiological interpretation of biopolymers derived from agricultural waste.

DISCUSSION

The results of this research allow us to understand the evaluation of biopolymers derived from agricultural waste as an exercise that transcends functional comparison with conventional synthetic polymers and is inscribed within an expanded technological rationality, where cultural, environmental, and axiological dimensions acquire centrality; in coherence with the contemporary philosophy of technology, the materials analyzed are configured as socio-technical forms that embody values, intentions, and specific modes of productive organization, expressing a particular understanding of the relationship between technology, nature, and agricultural practice (Winner, 1980; Feenberg, 2002). From a technical point of view, biopolymers obtained from agricultural waste show porous structures, the ability to interact with the soil, and compatibility with germination processes under water deficit conditions. These properties, interpreted axiologically, manifest values associated with material circularity, ecological temporality, and environmental responsibility, configuring a coherent alternative to the paradigm of durability and persistence characteristic of dominant synthetic polymers (Muhammad et al., 2023; Ahmed et al., 2024).

Recent literature provides elements that enrich this interpretation by demonstrating that the transition to bio-based materials is strengthened when it incorporates criteria related to the life cycle, ecological interaction, and context of use. Research on micro- and nanopolymers derived from biodegradable materials has contributed to a broader understanding of the environmental impacts associated with different material configurations, highlighting the importance of integrating degradation processes into the biogeochemical cycles of soil and aquatic ecosystems. (Wang et al., 2024; Tao et al., 2024; Pinaeva et al., 2024). Within this framework, the biopolymers of residual origin analyzed in this study are part of a material logic that favors their ecological reintegration and reinforces their coherence with agricultural practices oriented towards sustainability, in line with the analyses of Campanale et al. (2024) and Ryu et al. (2025) on biodegradable materials in agriculture.

The diversity of biomasses used highlights that material selection is an axiologically situated decision, in which technical, environmental, and cultural criteria converge. Some matrices show a greater water retention capacity and a favorable biological response, linking them to resilient, locally scaled agricultural systems with strong territorial roots, where values such as adaptability, waste utilization, and soil conservation take center stage. Other matrices, characterized by greater structural stability and mechanical resistance, align with production scenarios that prioritize functionality and durability, demonstrating that different paradigmatic orientations coexist within the field of biopolymers. (Li et al., 2022; Qian et al., 2025; Zhang et al., 2025). This plurality confirms that material innovation unfolds as a space of mediation between technical needs and horizons of meaning.

From the perspective of the axiology of technology, these findings allow us to affirm that innovation is expressed in the redefinition of efficiency criteria, integrating functional performance with shared social and environmental values. As noted Feenberg (2002),Technological rationality acquires depth when it is guided by principles that articulate efficiency and responsibility. In this study, the analyzed biopolymers show the possibility of combining suitable technical properties with principles of strong sustainability, circular economy and soil care, shifting efficiency towards an ecologically situated understanding. Furthermore, the results reinforce the concept of agricultural materials as active mediators in the interactions between plant, soil and environment, as proposed by Yang et al. (2024). The ability of biopolymers to regulate soil moisture and promote germination processes under water stress introduces an ethical dimension linked to the responsible management of water in contexts of climate vulnerability, an aspect highlighted by Islam et al. (2024) and Rasheed et al. (2024). In this context, biopolymers are configured as material expressions of a cultural transition in which technology is guided by principles of care, ecological coherence and intergenerational responsibility.

CONCLUSIONS

It was possible to understand biopolymers derived from agricultural waste as material expressions of a situated way of inhabiting the technical world; in this horizon, materials are configured as spaces of mediation in which understanding, practice and meaning converge, making visible a specific relationship between human beings, nature and production systems. The transformation of agricultural waste activates a different experience of matter, in which the soil, biomass and natural cycles acquire a constitutive role in the configuration of the biopolymer, affirming a technical rationality oriented by care and belonging to an ecological and cultural framework.

From a hermeneutic perspective, the reinterpretation of waste as technological matter expresses a shift in the horizons of understanding that have historically guided material production. This interpretive movement reinscribes the residual within the realm of the meaningful and affirms circularity as a principle of intelligibility of productive activity. Innovation thus manifests itself as an interpretive event, in which material decisions and transformation processes participate in a practical rationality laden with ontological and axiological implications.

In dialogue with the philosophy of technology, it is shown that biopolymers operate as cultural mediators through which values, commitments and ways of relating to the world are expressed; the technical choices and the forms of application reveal a rationality that articulates responsibility, limits and temporal projection, placing sustainability as an orientation of meaning and not as an external criterion of evaluation. From this perspective, biopolymers are understood as material expressions of an ethic of care and intergenerational responsibility, in which technology is reinscribed in a way of living that is attentive to the finiteness of resources, the interdependence of living systems, and the need for productive relationships that are more consistent with the environments that sustain life.

Bibliographic references

1. Ahmed, M., Ashfaq, J., Sohail, Z., Channa, I.A., Sanchez, A., Ali, S. N., Chandio, A.D. .Lignocellulosic bioplastics in sustainable packaging – Recent developments in materials design and processing: A comprehensive review. Sustainable Materials and Technologies 41:e01077.(2024). https://doi.org/10.1016/j.susmat.2024.e01077

2. Ali, Z., Abdullah, M., Yasin, M. T., Amanat, K., Ahmad, K., Ahmed, I., Qaisrani M. M., & Khan, J. Organic waste-to-bioplastics: Conversion with eco-friendly technologies and approaches for sustainable environment. Environmental Research 244: 117949.(2024). https://doi.org/10.1016/j.envres.2023.117949

3. Anjaly, P., Vara, Prasad., Brajesh, Kumar., Ramkrishna, Sen., Ajit, K. Sarmah. Synthesis and commercialization of bioplastics: Organic wastes as sustainable feedstock. Science of the Total Environment, 904: 167243.(2023). https://doi.org/10.1016/j.scitotenv.2023.167243

4. Atausinchi, A., Atausinchi, D., & Contreras, R. J. Ethics and sustainability in technological innovation: a systematic review of its environmental impact.InveCom Journal 6 (1). 1-9.(2025). https://doi.org/10.5281/zenodo.15447180

5. Bilo, Fabjola., Pandini, Stefano., Sartore, Luciana., Depero, Laura., Gargiulo, Giovanna., Bonassi, Andrea., Federici, Stefania., Bontempi, Elza. A sustainable bioplastic obtained from rice straw. Journal of Cleaner Production 200: 357–368.(2018). https://doi.org/10.1016/j.jclepro.2018.07.252

6. Campanale, C., Galafassi, S., Di Pippo, F., Pojar, I., Massarelli, C., & Uricchio, V. F. A critical review of biodegradable plastic mulch films in agriculture: Definitions, scientific background and potential impacts. TrAC Trends in Analytical Chemistry 170: 117391.(2024). https://doi.org/10.1016/j.trac.2023.117391

7. Feenberg, A. Ten paradoxes of technology. Techné: Research in Philosophy and Technology, 14(1), 3–15.(2010). https://doi.org/10.5840/techne20101411

8. Folino, A., Pangallo, D., & Calabrò P. S. Assessing bioplastics biodegradability by standard and research methods:Current trends and open issues. Journal of Environmental Chemical Engineering 11: 109424 (2023). https://doi.org/10.1016/j.jece.2023.109424

9. Grunwald, A. . The hermeneutic side of responsible research and innovation. Journal of Responsible Innovation, 1(3), 274–291.(2014). https://doi.org/10.1080/23299460.2014.968437

10. Hideo, Kawaguchia., Kenji, Takadab., Taghreed, Elkasabydo., Radityo, Pangestudo., Masakazu, Toyoshimado., Prihardi, Kahardo., Chiaki, Oginodo., Tatsuo, Kanekob., Akihiko, Kondoa. Recent advances in white biotechnology of lignocellulosic biomass for bioplastics. Bioresource Technology 344: 126165.(2022). https://doi.org/10.1016/j.biortech.2022.126165

11. Ilke, Uysal., Ece, Soguta., Carolina, E. Realini., Hulya, Cakmak., Emel, Oz., Eduardo, Espinosa., Ramón, Morcillo., Fatih, Oz., Maristiina, Nurmih., Miguel, A. Cerqueirai., Kalpani, Y. Pererayo., Zehra, Ayhank., Dilhun, Keriman. Arserim., Chrysoula, Kanakakimetro. Polímeros crisócolosnorte.; Begonya Marcoso.; Milena Corrediga. Bioplastic packaging for fresh meat and fish Current status and future direction on mitigating food and packaging waste. Trends in Food Science & Technology 152: 104660.(2024). https://doi.org/10.1016/j.tifs.2024.104660

12. Islam, monjurul., Tu, Xayachak., Nawshad, Haque., Déborah, Lau., Muhammad, Bhuiyana., Kumar, Pramanika. Impact of bioplastics on environment from its production to end-of-life. Process Safety and Environmental Protection 188: 151–166.(2024). https://doi.org/10.1016/j.psep.2024.05.113

13. Jonas, H. The imperative of responsibility: In search of an ethics for the technological age. University of Chicago Press.(1984).

14. Karimi, Sani., Mahdieh, M. Behabadi., Mahmood, A., Halimeh, Motalebinejad., Ameena, S.M., Amirafshar, A., Hadi, E., Seyedeh, M., Farzad, M. Value-added utilization of fruit and vegetable processing by-products for the manufacture of biodegradable food packaging films. Food Chemistry 405: 134964 (2023).https://doi.org/10.1016/j.foodchem.2022.134964

15. Li, H., Zhou, H., Ahmed, Yagoub. Mohammed., Chen, L., & Zhou, C. From fruit and vegetable waste to biodegradable bioplastic films and advanced materials: a review. Sustainable Chemistry and Pharmacy 30: 100859.(2022). https://doi.org/10.1016/j.scp.2022.100859

16. Mostafa, N., Awatef, A., Hala, M., Aghareed, M. Production of biodegradable plastic from agricultural wastes. Arabian Journal of Chemistry 11: 546–553.(2018).https://doi.org/10.1016/j.arabjc.2015.04.008

17. Muhammad, Mujtaba., Fernandes, Leonardo., Mahyar, Fazeli., Sritama, Mukherjee., Susilaine, M. Savassa.,Araujo, Gerson., Pereira, Anderson., Sandro, D., Mancinido, Juha, Lipponenb., Vilaplanad, Francisco. Lignocellulosic biomass from agricultural waste to the circular economy: a review with focus on biofuels, biocomposites and bioplastics. Journal of Cleaner Production 402: 136815.(2023). https://doi.org/10.1016/j.jclepro.2023.136815

18. Pinaeva, L., & Noskov, A. Biodegradable biopolymers: Real impact on environmental pollution. Science of the Total Environment 947: 174445.(2024). https://doi.org/10.1016/j.scitotenv.2024.174445

19. Qian, Y., Qin, C., Zhang, J., Shi, B., Wei, Y., Wang, C., Niu, J., Kang, S., Chen, G., & Liu, Y. Sustainable, biodegradable and recyclable bioplastics derived from renewable carboxymethylcellulose and waste walnut shells. International Journal of Biological Macromolecules 299: 140130.(2025). https://doi.org/10.1016/j.ijbiomac.2025.140130

20. Rasheed, T., Vattathurvalappil, S., Shaukat, M., Theravalappil, R., Alia, U., Chennampilly, U., Bin Saleem, M., Jaseer, E., & Imran, M. Recent updates on biodegradability and recyclability of bioplastics: Towards a new era of sustainability. Sustainable Materials and Technologies 41: e01051.(2024) https://doi.org/10.1016/j.susmat.2024.e01051

21. Ryu, Y., Bouharras, F., Chao, M., Mudondo, J., Kim, Y., Ramakrishnan, A., Shin, S.,Yungchang, W., Lee, W., Siyoung, J., Junyong, C., Yunho, S., Gil, Chae., Ahn, D., Kim, S., & Kim, H. Recent advances in the evolution, production, and degradation of biodegradable mulch films: A review. Environmental Research 277: 121629. (2025).. https://doi.org/10.1016/j.envres.2025.121629

22. Sevil, V. Afshar., Boldrina, Alessio., Astrup, Thomas., Daugaard, Anders., Hartmanna, Nanna., Degradation of biodegradable plastics in waste management systems and the open environment: A critical review. Journal of Cleaner Production 434:140000. (2024). https://doi.org/10.1016/j.jclepro.2023.140000

23. Tao, S., Lian, T., Li, M., Yang, S., Shen, M., & Liu, H. Advances in research on the toxicity of micro-/nanoplastics derived from biodegradable plastics in the environment: A review. Science of the Total Environment 916: 170299.(2024). https://doi.org/10.1016/j.scitotenv.2024.170299

24. Tien, J., Kenny, K., Broom, A., Motion, A., & Bartlett, S. Ensuring Responsible Nanotechnology Innovation. Nanoethics 19: 14 (2025). https://doi.org/10.1007/s11569-025-00478-9

25. Verbeek, P. Materializing morality: Design ethics and technological mediation. Science, Technology & Human Values, 31(3), 361–380.(2006). https://doi.org/10.1177/0162243905285847

26. Wang, D., Xiong, F., Wu, L., Liu, Z., Xu, K., Huang, J., Liu, J., Ding, Q., Zhang, J., Pu, Y., & Sun, R. A progress update on the biological effects of biodegradable microplastics on soil and ocean environment: A perfect substitute or new threat?. Environmental Research 252: 118960.(2024).

27. Yang, B., Feng, W. , & Qilin. Emerging research trends in plant-plastic interactions: A thorough analysis. Current Plant Biology 39:100375.(2024). https://doi.org/10.1016/j.cpb.2024.100375

28. Zhang, S., Li, H., Zhang, B., Ai, S., Shan, Y., & Ding, S. Noncovalent in situ self-assembly of fruit peel waste into eco-friendly pectocellulosic bioplastics with high strength, flexibility, and processability. Chemical Engineering Journal 504: 158697.(2025). https://doi.org/10.1016/j.cej.2024.158697