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CIRCULAR BUSINESS MODEL FOR SMALLHOLDER FARMERS: UTILIZING BANANA FARMING WASTE FOR TEXTILE PRODUCTION

Ana Paula Provin *, Ana Regina de Aguiar Dutra, José Baltazar Salgueirinho Osório de Andrade Guerra and Anelise Leal Vieira Cubas

Centre for Development Research-Unisul (GREENS/Unisul), University of Southern Santa Catarina (Unisul), Brazil

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ABSTRACT

Sustainability, aligned with the principles of the Circular Economy, emerges as an alternative for waste reduction and the mitigation of environmental impacts. In the banana cultivation sector, large quantities of pseudostems are discarded after harvest, representing not only an environmental challenge but also an opportunity for the production of sustainable textile fibers. Simultaneously, the textile industry, one of the most polluting in the world, demands innovative solutions to reduce the consumption of natural resources, as well as the emission of pollutants and greenhouse gases. Based on an integrative literature review, this study examines the feasibility of a Circular Business Model (CBM) designed for smallholder farmers, utilizing banana crop residues for textile production. The final review portfolio consisted of 46 scientific articles, selected based on relevance, temporal scope, and methodological rigor. The results indicate that this approach can mitigate environmental impacts, create new income opportunities, and strengthen the circular bioeconomy. Furthermore, the adoption of this model fosters symbiosis between sectors, promoting integration between agriculture and the textile industry in the pursuit of more sustainable solutions. Ultimately, the transition toward a more responsible production model aligns with international initiatives and regulations that promote biomaterials and reduce dependence on synthetic fibers.

1. INTRODUCTION

Sustainability in both agriculture and the textile industry has become a central theme in discussions surrounding innovative, circular, and inclusive business models. The emergence of the Circular Economy (CE) as an alternative to the linear model of production and consumption has driven new approaches to resource management and waste reduction. In the context of banana cultivation, a globally significant agricultural sector, the generation of waste, such as the disposal of tons of pseudostems after harvest, may pose a significant environmental challenge (Brühl et al., 2023). However, such residues can also be repurposed as inputs for the production of biomaterials, including more sustainable textile fibers (Anafack et al., 2023; Fiallos-Cárdenas et al., 2022).

The food industry is one of the main drivers of environmental degradation, contributing to impacts such as deforestation, water resource depletion, and greenhouse gas emissions. Intensive food production generates large volumes of waste and organic residues, and their improper disposal contributes to soil and water contamination (Ghosh & Pramanik, 2023). Moreover, global food waste accounts for approximately one-third of all food produced, representing not only a failure in the distribution system but also a significant source of environmental pollution and biodiversity loss (Abdullah et al., 2023).

Although the environmental impacts of agriculture and the textile industry have been widely discussed, practical strategies that link small-scale farming with sustainable textile production remain underexplored in the literature. This study addresses this gap by proposing a circular business model that utilizes banana cultivation residues, specifically the pseudostem, for the production of textile fibers. The model is designed to support smallholder farmers and aims to foster resource circularity, environmental mitigation, and social inclusion in rural areas. This approach has the potential to contribute to waste reduction, resource optimization, and the generation of employment and income in vulnerable rural communities (Korsunova et al., 2022). Furthermore, the use of banana fibers in the textile industry offers advantages such as high tensile strength, durability, and biodegradability, thereby reducing dependence on synthetic fibers and minimizing the sector's environmental impact (Subash & Perumalsamy, 2024).

* Corresponding author:
Ana Paula Provin
email: ana.provin12@gmail.com

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The development of appropriate Business Models (BMs) helps transform environmental challenges into economic and social opportunities. According to Cullen and De Angelis (2021), a well-structured BM functions as a bridge between innovation and value creation, enabling the identification of promising opportunities. While traditional business models describe how a company creates, delivers, and captures value, encompassing elements such as value proposition, customer segmentation, distribution channels, and revenue streams (Dembek et al., 2022; Vatankhah et al., 2023), the implementation of such models in rural communities requires adaptations that consider local socioeconomic and cultural factors (Iheanachor et al., 2021).

The Circular Business Model (CBM) represents a promising approach grounded in the principles of the Circular Economy, aiming to maximize resource value through the reuse, recycling, and recovery of materials within a regenerative system (Daou et al., 2020; Rosa et al., 2019). When applied to banana cultivation, this concept enables the conversion of agricultural residues into textile fibers, contributing to the mitigation of environmental impacts in the sector while creating economic opportunities for smallholder farmers.

An illustrative example can be found in agricultural cooperatives that repurpose crop residues into biomaterials or textile fibers, representing tangible cases of CBMs. Such initiatives demonstrate how shifting from traditional to regenerative practices can simultaneously generate economic value and reduce environmental impact (Korsunova et al., 2022).

It is also noteworthy that the literature highlights a gap in the practical application of the circular economy, particularly within the context of rural entrepreneurship (Maher et al., 2023). Therefore, this research also aims to address this gap by proposing a circular business model focused on smallholder farmers, promoting a more sustainable and equitable approach to natural resource management. To this end, an integrative literature review will be conducted to consolidate knowledge and evidence regarding the potential use of banana cultivation residues for textile production.

2. METHOD

The approach of this article consisted of an integrative literature review, aimed at providing new theoretical and conceptual insights derived from existing syntheses or critiques (Annosi et al., 2022). According to Torraco (2005, 2016), integrative reviews are a specific review method that summarizes empirical or theoretical literature to offer a more comprehensive understanding of a particular phenomenon, while simultaneously reviewing, critiquing, and synthesizing the representative literature on a topic, thereby generating new frameworks and perspectives on the subject.

It is noteworthy that, despite being widely used in scientific studies, the integrative literature review does not yet have a standardized protocol. Therefore, the next step involved employing the PRISMA method, an important tool to enhance the eligibility of selected studies as well as to ensure transparency, reproducibility, credibility, and efficiency (Costa et al., 2020; Oliveira Neto et al., 2023), as demonstrated in Figure 1.

As shown in Figure 1, after searching the databases and applying filters alongside the inclusion and exclusion criteria, 46 research articles comprised the final portfolio for the development of this integrative review article. It is noteworthy that the Scopus and Web of Science databases were selected due to their extensive multidisciplinary

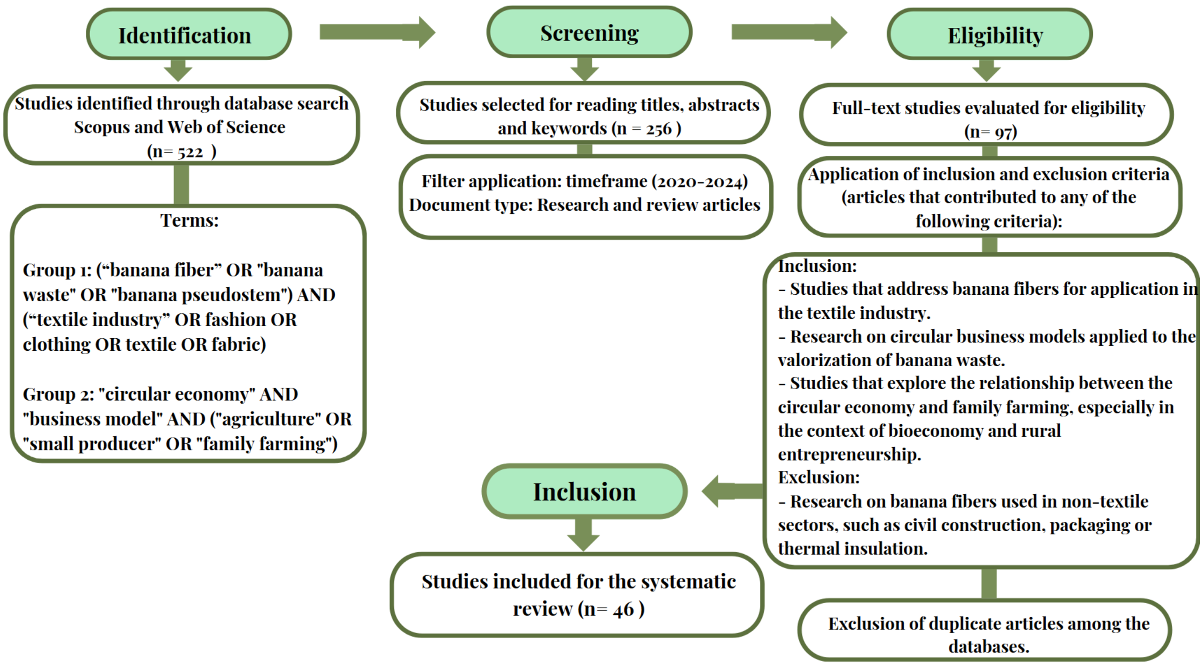

FIGURE 1: Selection and evaluation of studies using the PRISMA method. Source: Authors, 2025.

TABLE 1: Search Results in Scopus and Web of Science Databases.

Term Groups	Initial Search	1st Filter: Time Frame	2nd Filter: Document Type
("banana fiber" OR "banana waste" OR "banana pseudostem") AND ("textile industry" OR fashion OR clothing OR textile OR fabric)	Scopus: 278 Web of Science: 156	Scopus: 160 Web of Science: 103	Scopus: 114 Web of Science: 90
"circular economy" AND "business model" AND ("agriculture" OR "small producer" OR "family farming")	Scopus: 67 Web of Science: 21	Scopus: 56 Web of Science: 19	Scopus: 34 Web of Science: 18

Source: Authors, 2025

coverage and rigorous indexing, ensuring the inclusion of studies with high scientific relevance.

However, it is important to emphasize that an integrative literature review allows for the inclusion of supplementary documents to enrich the findings obtained from the databases. Therefore, in addition to scientific articles, the following documents were used to support Section "4. Discussions": 1) A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society, and Environment; 2) Circular Economy Action Plan: For a Cleaner and More Competitive Europe; 3) BIT II Bioeconomy in Italy; 4) Economic Instruments for the Circular Economy in Italy; 5) Sustainable Bioeconomy Action Plan (PABS - original acronym); 6) Decree No. 12,044, dated June 5, 2024, which establishes the National Bioeconomy Strategy in Brazil, and Decree No. 12,082, dated June 27, 2024, which establishes the National Circular Economy Strategy in Brazil; 7) National Program for Strengthening Family Farming, Brazil; and 8) the book The Fortune at the Bottom of The Pyramid: Eradicating Poverty through Profits by C. K. Prahalad.

3. RESULTS

3.1 Search and Selection of Articles in Databases

Regarding the search for research and review articles in the Scopus and Web of Science databases, Table 1 presents the number of documents identified through the two sets of terms, both in the initial search without applying filters and after applying the pre-established filters.

A greater number of results was observed with the first group of terms, with the Scopus database accounting for the highest number of retrieved publications for both the first and second groups of descriptors. After applying the defined filters, a total of 256 documents were identified across the two databases. Subsequently, titles, abstracts, and keywords were screened, resulting in the selection of 97 articles for full-text reading. Following this stage, 46 studies were identified as consistent with the topic according to the inclusion and exclusion criteria and were included in the final portfolio of the present integrative literature review.

3.2 Analysis and Classification of Articles

Data from the 46 articles comprising the final portfolio were collected, considering the countries with the highest number of publications on the topic and the year with the greatest number of publications, respecting the time frame established between 2020 and 2024. Figure 2 presents the countries with the highest number of publications on the subject, as well as the year with the highest concentration of studies within the analyzed period.

Figure 2 presents the countries with the highest participation in the analyzed publications, with India being the most recurrent, contributing ten articles, followed by Brazil (8), Italy (5), and Germany (5). For the country count, all institutional affiliations of the authors in each article were considered, regardless of authorship order or corresponding author status. Thus, each country represented among the co-authors was counted once per article, reflecting col-

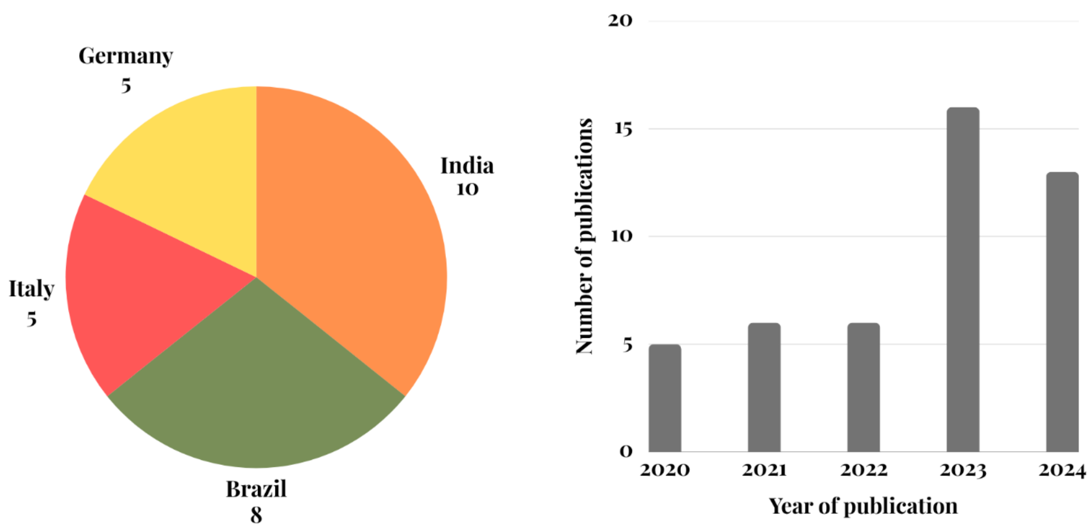

FIGURE 2: Distribution of the Number of Publications by Country and Year (2020–2024). Source: Authors, 2025.

laborative and multinational participation in scientific production. This approach acknowledges the contribution of all involved authors and enhances the representativeness of the data.

The predominance of India and Brazil may be related to the fact that both are among the world's largest banana producers, in addition to having extensive rural areas and significant socio-environmental challenges related to agricultural waste management. As developing countries, both have also been investing in sustainable and accessible solutions that promote income generation in rural areas.

The presence of European countries such as Italy and Germany may reflect academic and technological interest in circular economy models, biomaterials, and sustainable innovations, despite these countries not being major banana producers. Regarding temporal distribution, there is a marked increase in publications starting in 2022, peaking in 2023 (16 articles), and continuing this trend in 2024 (13 articles), demonstrating an intensification of academic debate on circular business models, particularly in the context of the bioeconomy and rural sustainability.

A co-occurrence term analysis was also conducted using the VOSviewer software, applied to the 46 selected articles, as shown in Figure 3. This tool is widely used in the scientific field due to its ability to map and visualize networks of keywords, authors, institutions, and other bibliometric elements based on data extracted from publications. The analysis enabled the identification of the most recurring terms within the analyzed corpus, contributing to the recognition of thematic patterns.

In Figure 3, it can be observed that the terms "circular economy," "sustainability," "bioeconomy," and "banana" form the most robust conceptual core, indicating the centrality of these themes in scientific discussions related to the reuse of agricultural residues. The direct connection between "circular economy" and terms such as "biowastes," "apparel," and "banana" demonstrates the growing relevance of utilizing agricultural by-products in the textile industry. Furthermore, although some terms appear isolated or with low connectivity, such as "family agriculture," "family farm," "bottom-of-the-pyramid," and "rural development", they indicate potential gaps and opportunities for greater integration of social and economic aspects in the academic debate.

The sparse presence of these concepts reinforces the need to expand discussions on circular business models aimed at small producers and rural communities. In this context, the adoption of two distinct groups of search terms is justified: (1) "banana fiber" OR "banana waste" OR "banana pseudostem" combined with "textile industry" OR fashion OR clothing OR textile OR fabric; and (2) "circular economy" AND "business model" AND ("agriculture" OR "small producer" OR "family farming"). This strategy allowed the identification of studies aligned with the proposal of this article, promoting a linkage between research involving sustainability, social innovation, and valorization of agricultural residues. Additionally, it highlights the lack of interdisciplinary approaches that systematically integrate these thematic axes.

Finally, it was observed that the proposal of a circular business model for small farmers based on the use of banana cultivation residues has great potential to transform environmental challenges into sustainable economic solutions, as shown in Figure 4.

Although banana production residues serve as an example, this model could be adapted to other food waste

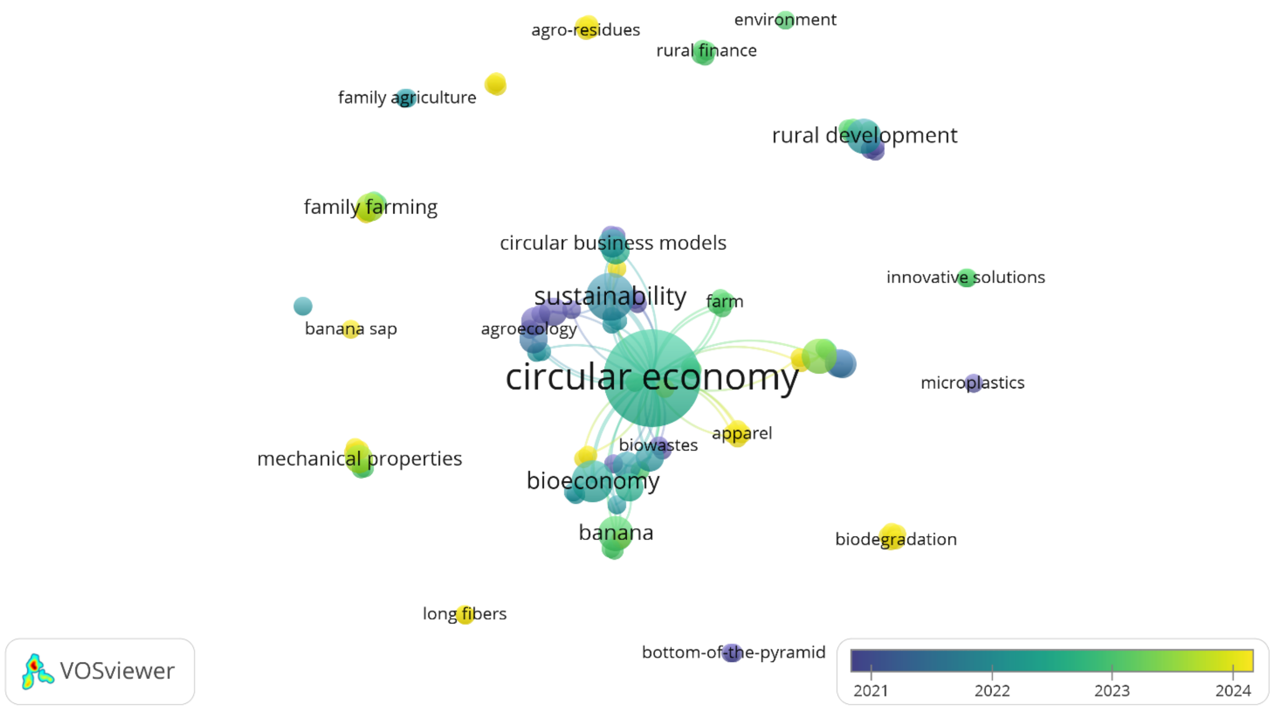

FIGURE 3: Term co-occurrence map in the 46 analyzed articles. Source: Authors, 2025.

FIGURE 4: Diagram of the circular model for the valorization of banana cultivation residues in the textile industry. Source: Authors, 2025.

streams and implemented symbiotically with different industries, creating new opportunities for the circular bioeconomy. In addition to reducing pollution and waste, this approach can strengthen local production chains and promote more equitable and resilient rural development.

4. DISCUSSION

4.1 The Rural Base of the Pyramid and Family Farming as Drivers of Sustainability

The strengthening of family farming has been identified as one of the strategies to reduce social inequalities and improve the quality of life in rural areas. The United Nations (UN) emphasizes the importance of family farming for global food security and its contribution to reducing hunger and poverty. However, the need for innovation and productive diversification emerges as a critical agenda to ensure the economic sustainability of small-scale producers (Zahaikevitch et al., 2022).

The base of the pyramid is predominantly found in developing countries, encompassing both urban and rural areas. Prahalad (2005), in his work The Fortune at the Bottom of the Pyramid: Eradicating Poverty Through Profits, addresses the issue of rural communities and argues that poverty is a major challenge to be tackled by businesses and organizations. He highlights the importance of directing efforts toward this neglected segment, recognizing its potential for socioeconomic development.

Cui et al. (2023) emphasize that approximately 698 million people live below the global poverty line, predominantly in rural areas. In these regions, poverty manifests as economic vulnerability and a lack of resilience, making the strengthening of these capacities crucial for achieving rural revitalization and sustainable development. In this context, the promotion of self-development and resilience of rural communities in the face of economic, social, and environmental transformations is imperative.

It is important to note that the rural base of the pyramid is predominantly located in developing regions, characterized by populations with limited access to adequate infrastructure, markets, and financial services (Cui et al., 2023). According to Villalba et al. (2023), smallholder farmers face challenges such as limited credit availability, high transaction costs, and vulnerability to market fluctuations. Access to appropriate credit is identified as a key factor to improve agricultural efficiency and liquidity; however, many development programs overlook the resources necessary to ensure their long-term viability. Furthermore, studies on Financial Service Agents (FSAs) indicate that a significant portion of these initiatives operate beyond the financial sector, extending into commercial activities, and highlight the need for alternative channels to provide financial services in rural areas, emphasizing low-cost solutions and qualified professionals (Iheanachor et al., 2021).

It is worth recalling that the rural population at the base of the pyramid is also composed of family farmers. Thus, it is highlighted that family farming is responsible for approximately 80% of the food consumed in major urban centers (Zahaikevitch et al., 2022). However, despite its importance, structural challenges persist, such as rural succession and the exodus of young people from rural areas. The intense rural-to-urban migration remains a global concern, as pointed out by the United Nations 2030 Agenda, affecting the continuity of rural communities and the sustainability of family farms. The lack of successors represents a critical challenge to the future viability of family farming (Foguesatto et al., 2020).

Thus, it is believed that a circular business model that adds value to agricultural residues can contribute to income generation and sustainable development in these regions. For instance, Moreira-Dantas et al. (2023) note that although Brazil is a major agro-exporting power, this economic growth does not equitably extend to areas predominantly inhabited by family farmers, who face shortages of inputs, limited market access, and stagnant productivity.

Thus, supporting family farmers through public policies and financial incentives can be a key factor to ensure the success of initiatives based on the circular economy.

In Brazil, the National Program for Strengthening Family Farming (Pronaf) represents the main public policy aimed at providing microcredit and encouraging sustainable production (Pronaf, 2019). According to Coelho de Souza et al. (2023), family farming is characterized by the integration between production and social reproduction, which underscores the importance of policies that consider this dynamic.

It is noteworthy that some regional initiatives have already demonstrated the transformative potential of family farming, such as the Agrotourism Association "Acolhida na Colônia," the Ecovida Agroecology Network, the National Rural Learning Service (SENAR), and the Slow Food movement. All of these initiatives focus on valuing local and sustainable production and can serve as examples for other global regions (Coelho de Souza et al., 2023).

It is worth highlighting that the history of rural development is intrinsically linked to the pursuit of innovative solutions in the face of resource scarcity and persistent environmental and economic challenges. Rural entrepreneurs have adopted innovative approaches to add value to their production and strengthen the local economy (Hossain et al., 2023a). Hossain et al. (2023) further emphasize the role of community enterprises and informal institutions as catalysts for social transformation. The adoption of innovative technologies and approaches has contributed to expanding access to markets, employment, and essential services in rural areas, thereby promoting the achievement of the Sustainable Development Goals (SDGs).

However, Verger and Le Bars (2024) caution that many studies on food systems still fail to address the real needs of smallholder farmers, as they are often conducted without the direct participation of these stakeholders. The promotion of participatory and sustainable projects that incorporate local knowledge is essential to ensure the effectiveness of proposed solutions and to build resilient family farming systems.

To this end, circular economy initiatives should prioritize mechanisms that actively engage farmers in the design, implementation, and monitoring of solutions. Approaches such as co-design workshops, participatory action research, and community-based pilot projects can serve as effective strategies to involve smallholder farmers as co-creators of innovation. These participatory methods enhance the relevance and acceptance of proposed models, promote knowledge exchange, and strengthen social cohesion (Cavicchi et al., 2022).

In this context, the proposed circular business model directly addresses the challenges faced by smallholder farmers, creating new economic opportunities through the valorization of agricultural residues. By converting banana pseudostems into commercially viable textile fibers, the model reduces dependence on external inputs and enhances land-use efficiency by leveraging already cultivated banana plantations, thus avoiding the need for land-use change or deforestation to support new income-generating activities. It also encourages the development of localized value chains and promotes income diversification. Furthermore, it enables cooperative organization and integration into sustainable value chains, potentially improving access to markets, financial services, and technological resources.

4.2 Circular Economy and Valorization of Banana Crop Residues

The textile and food industries stand out as major sectors responsible for environmental impacts on a global scale. The textile industry, in particular, is characterized by intensive use of natural resources such as water and energy, in addition to requiring large volumes of chemicals used in processes such as dyeing, washing, and fabric finishing. This combination renders textile production one of the most polluting industrial activities today. Furthermore, the improper disposal of textile waste, especially that derived from synthetic fibers, significantly contributes to the release of microplastics into the environment, negatively affecting aquatic and terrestrial ecosystems (Provin et al., 2024; Xu et al., 2020).

Simultaneously, the food industry, especially the tropical fruit agro-industry, generates substantial quantities of organic waste which, if not managed appropriately, constitute significant sources of greenhouse gas emissions and can lead to serious environmental problems such as soil and water contamination, in addition to the loss of biomass with high valorization potential (Provin et al., 2024).

Di Fraia et al. (2024) indicate that global food waste may reach 2.2 billion tons by 2025, highlighting the urgent need to implement sustainable solutions for the valorization of such residues and the promotion of efficient resource use. In this context, the circular economy emerges as a strategic approach to mitigate the environmental impacts of these sectors.

Based on the principles of reduction, reuse, and recycling, the circular economy advocates the creation of regenerative production systems that keep resources in use for the longest possible time and eliminate waste generation whenever feasible. The valorization of residues from banana cultivation represents a promising example of the practical application of these principles, integrating agro-industrial waste into new sustainable production chains. Global banana production, in addition to being significant in volume, also generates substantial amounts of waste. For every ton of harvested bananas, approximately four tons of residues are estimated to be produced, including peels, leaves, roots, and primarily the plant's pseudostem (Abdullah et al., 2023).

Traditionally discarded after harvest, the pseudostem holds significant potential for utilization, particularly for the extraction of natural fibers with textile applications. This reuse represents an opportunity to transform an environmental liability into a productive asset while simultaneously contributing to the reduction of demand for conventional and fossil-based raw materials. Fibers extracted from the banana pseudostem have attracted attention from researchers and industry due to their mechanical and structural properties, which make them suitable for use in sustainable textile products. Numerous studies indicate that these fibers exhibit tensile strength, flexibility, and absorption capacity comparable to or exceeding those of other commonly used natural fibers such as hemp, flax, and sisal (Pan et al., 2020; Daou et al., 2020).

Moreover, unlike synthetic fibers, banana fibers are biodegradable and renewable, underscoring their suitability for circular production models. The incorporation of these fibers into the textile sector can play a pivotal role in replacing non-biodegradable synthetic fibers such as polyester and nylon, whose production relies on fossil resources and is associated with high carbon emissions. The use of natural banana fibers enables a reduction in the environmental footprint of textile products, as well as a decreased dependence on non-renewable inputs. Additionally, these fibers require less water and energy during processing compared to conventional fibers such as cotton, whose production chain is also associated with significant environmental impacts (Subash & Perumalsamy, 2023).

From a socioeconomic perspective, the valorization of banana cultivation residues for textile purposes can promote the inclusion of small producers and rural communities in sustainable value chains. In banana-producing countries such as Brazil, India, the Philippines, and Ecuador, the establishment of micro and small industries focused on the processing of natural fibers may stimulate regional development by generating employment and income in rural areas. Thus, beyond the direct environmental benefits, this strategy can contribute to the strengthening of local economies and the promotion of more equitable and resilient business models (Shirvanimoghaddam et al., 2020; Pan et al., 2020).

It is worth highlighting that banana plant residues also hold potential for various other industrial applications, such as the production of bioplastics, bioethanol, paper, biodegradable packaging, and other bioproducts. These possibilities broaden the positive impact of valorizing these residues, contributing to economic diversification and the transition toward a circular bioeconomy based on the efficient use of biological resources (Sawarkar et al., 2022).

Despite the significant environmental and socioeconomic potential, the valorization of banana fiber still faces major barriers to scalability. Among the main challenges are the absence of standardized extraction processes, the scarcity of specific machinery for fiber processing, and the lack of structured value chains that effectively integrate these materials into the conventional textile market. Additionally, logistical issues related to the collection, transportation, and storage of biomass are particularly pressing in regions with limited rural infrastructure (Sarangi et al., 2023).

Overcoming these obstacles requires targeted investments in research and development (R&D) focused on improving extraction techniques, enhancing fiber quality, and reducing production costs. The establishment of pilot units and public–private partnerships can significantly contribute to testing technical feasibility and attracting commercial interest. Case studies reveal varying experiences regarding the implementation of such solutions (Sarangi et al., 2023).

In the Philippines, for instance, the company Bananatex® developed a line of fabrics made from banana pseudostem fibers by engaging local cooperatives and promoting high-value-added exports. The material was created by the Swiss bag brand QWSTION, in collaboration with a spinning expert and a weaver, both based in Taiwan. The collaboration among these three actors aimed to generate a positive impact on the planet's future, resulting in a next-generation fabric that is biodegradable in both industrial and marine environments (in compliance with EN 13432 and ISO 14851) and developed according to Cradle to Cradle principles (Bananatex®, 2025).

In contrast, experiences in Latin America, such as in Colombia, face consolidation difficulties due to the lack of continued technical support. According to Montoya Berrio et al. (2024), approximately 70% of banana cultivation output is discarded as waste after harvest, largely due to poor management and underutilization of materials such as the pseudostem, which holds significant potential for fiber extraction. In addition, technical challenges persist in the production and treatment of these fibers, including the definition of appropriate drying parameters (temperature and methods), which are essential to preserve or enhance their mechanical and chemical properties and ensure their viability as a reinforcing material in composites, textiles, and other products.

These variations also underscore the importance of adequate political and institutional frameworks for the success of such initiatives. Public policies play a decisive role in creating a favorable environment for the development of a circular bioeconomy. In Brazil, although there are programs focused on family farming and technological innovation, such as the National Bioeconomy Program (PNB), its implementation still lacks integration with the textile sector and circular economy policies (Brazil, 2024a). Colombia, despite having strategies for both the Circular Economy and the Bioeconomy since 2020, still faces several challenges, as observed in the studies by Montoya Berrio et al. (2024).

Conversely, India and the Philippines have adopted more integrated approaches, featuring tax incentives, targeted financing mechanisms, and technical assistance tailored to the valorization of agricultural residues. Examples include India's National Policy for Management of Crop Residues (NPMCR) and the Philippines' Action Plan for Sustainable Consumption and Production, alongside the National Innovation Agenda. According to Sarangi et al. (2023), well-designed public policies can play a strategic role in enabling the large-scale adoption of circular and bioeconomic solutions. Analyzing these regional disparities helps clarify how political and institutional contexts shape the viability of circular business models based on agro-industrial residues.

4.3 Circular Business Models for the Rural Base of the Pyramid

The transition to Circular Business Models (CBMs) has emerged as a promising strategy to promote sustainable agriculture practices, particularly within rural communities and among small-scale producers. Traditionally, agricultural residues were incinerated or disposed of in landfills, resulting in air and soil pollution. However, there has been growing recognition of the potential of these residues as raw materials for high-value-added products such as textile fibers, biofertilizers, biomaterials, and energy sources (Haque et al., 2023; Nesterov et al., 2024).

In this context, CBMs present tangible opportunities for income diversification and social entrepreneurship. In the case of banana cultivation, the conversion of residues into textile fibers represents an innovative alternative that integrates sustainability with value creation in the rural economy (Straub et al., 2023). By fostering the establishment of cooperatives and decentralized production networks, these models enable greater economic independence and resilience for smallholder farmers in the face of market instabilities (Fedele & Formisano, 2023).

The literature further evidences that agroindustrial cooperatives play a significant role in structuring these more sustainable models. They enhance efficiency within the agri-food supply chain, strengthen access to technologies, and encourage collaborative practices and industrial symbiosis, particularly through the sharing of residues among producers and companies aimed at their transformation into new resources (Barros, de Jesus, et al., 2023). This synergy contributes to reinforcing environmental and social sustainability in rural areas.

However, Schiavon et al. (2021) caution that, although most studies and innovations focus on agribusiness and the food industry, initiatives targeting family farming and small rural entrepreneurs remain scarce. In this context, agroecology emerges as a strategic approach, promoting practices that integrate various factors of the agri-food system and seek to overcome the negative impacts of conventional agriculture. The rise of methods such as organic farming, permaculture, and agroforestry reinforces the development of self-sufficient agricultural ecosystems that are more resilient to market transformations.

To support the implementation of circular business models, various tools and frameworks have been proposed, such as Ecocanvas, which incorporates environmental, social, and governance aspects into the business model structure (Daou et al., 2020). Additionally, the integration of Industry 4.0 and innovative technologies can enhance process efficiency, reduce waste, and support the creation of competitive bio-based products. Factors such as logistics, cooperation, geographic proximity, institutional support, and social acceptance are equally critical for the success of these models (Donner et al., 2021).

According to Cavicchi et al. (2022), practical examples such as the use of a high-tech hydroponic system that recovers water and utilizes CO_2 generated by a biogas cogeneration system illustrate how the Circular Economy can be effectively applied. Specifically at the base of the pyramid, notable cases include the Indian company Boond, which provides clean energy and essential services to low-income communities, and Mitticool, a manufacturer of clay refrigerators that operate without electricity, both demonstrating how circular business models can integrate innovation, affordability, and sustainability in rural contexts. Another example is Jayaashree, which develops low-cost biodegradable sanitary pads aimed at women in rural areas, promoting menstrual health, income generation, and waste reutilization. It is emphasized that these models are considered frugal innovations and demonstrate the viability of inclusive circular solutions at the base of the pyramid (Hossain et al., 2023b; (Sarkar & Mateus, 2022) ; (Mcphee et al., 2018).

In terms of metrics, measuring circularity remains a challenge. Although there is no globally accepted standard, evaluation initiatives are based on frameworks encompassing categories such as design, production, use, and end-of-life. Three levels of circularity can be identified: within the rural property, among neighboring properties, and through integration with the agroindustrial cooperative. This approach enables economic gains such as energy consumption reduction and resource reutilization (Barros, de Jesus, et al., 2023).

Silva and Morais (2022) conducted a study with companies in the textile and fashion industry in developing countries that have been adopting different circular business models, classified as Adopters and Holders. The authors observed that while Adopters operate based on linear structures and gradually implement circular strategies, prioritizing low-risk solutions with higher financial returns, Holders are inherently guided by circular economy principles, adopting innovative practices such as upcycling and textile banks. The business models of Holders demonstrate greater integration of economic, social, and environmental criteria, reflecting stronger commitments to circularity. Furthermore, they differ in management profiles: Adopters tend to outsource competencies, whereas Holders invest in internal capacity building and maintain their own infrastructure to support sustainable operations.

Beyond environmental and productive benefits, circular economy practices in agriculture also stand out for their social impact. Food waste reduction, which currently accounts for approximately one-third of total global production, is a strategic priority with the potential to mitigate hunger and significantly reduce greenhouse gas emissions (Scarano et al., 2022). Initiatives that transform waste into new products, such as biogas and textile fibers, also provide employment opportunities for youth and foster the development of green markets (Çaloğlu & Binay, 2023; Koul et al., 2022).

Despite its potential, many small producers and SMEs still face challenges related to access to financing and the necessary technological infrastructure. Cavicchi et al. (2022) emphasize the importance of establishing collaborative networks among companies, public institutions, and investors, aiming to strengthen the economic and technical viability of the circular transition.

Finally, progressing towards an agricultural system based on circularity requires, as a first step, the selection of appropriate approaches for waste conversion, the use of specific machinery or the reutilization of existing compatible equipment, the understanding of end-use applications, and the detailed characterization of raw materials. In this regard, an alignment of technology, knowledge, and cooperation is observed, whereby circular business models become a powerful tool to transform the environmental and social challenges of agriculture into sustainable and innovative opportunities for the sector's future (Haque et al., 2023).

4.4 Benefits and Challenges of Model Implementation

The adoption of agro-industrial residues for sustainable textile production represents a promising opportunity to mitigate the negative impacts of these industries. Ali et al. (2024) highlight the conversion of organic waste into bioplastics as an environmentally viable solution aligned with the principles of the circular bioeconomy. Recent studies indicate that banana fiber may be a viable alternative to reduce dependence on petroleum-derived synthetic fibers, contributing to a more sustainable production system and aligned with circular economy principles (Provin et al., 2024).

Regarding the use of banana cultivation residues for textile production, this approach faces certain technical and commercial challenges. The feasibility and quality of the resulting textile products are affected by the availability, purity, and composition of banana residues, which can vary considerably. To overcome these challenges, comprehensive research is required to address various issues related to this process (Kee et al., 2021).

Chaves et al. (2024) Chaves et al. (2024) emphasize that the valorization of these residues can drive new sustainable business models and strengthen local economies, particularly in farming communities that rely on the diversification of their income sources. Khan et al. (2024) demonstrate that the processing of banana pseudostems can enable the production of high-quality yarns and fabrics, contributing to the development of a sustainable supply chain. Venkatesh and Kumar (2024) explore the physical properties of fabrics made from banana fiber, highlighting their viability for innovative applications in the textile sector.

However, the production of fibers derived from banana cultivation still faces challenges related to process efficiency and industrial scalability. As noted by Akatwijuka et al. (2022), the techniques currently employed for fiber extraction are relatively costly and may cause negative environmental impacts if not properly managed. Therefore, it is necessary to develop and invest in the adoption of more efficient and environmentally sustainable technologies and machinery. Furthermore, the demand for banana fibers remains limited when compared to other widely used natural fibers, which poses a barrier to their economic viability in large-scale production contexts.

Beyond financial and technical challenges, cultural and market acceptance of products derived from the circular economy represents a critical factor for the success of this approach. It is important to raise awareness among consumers and businesses regarding the environmental and social benefits of adopting sustainable textiles, promoting the value of these products through certifications and awareness campaigns (Korsunova et al., 2022b).

According to Subash and Perumalsamy (2023), banana fibers are durable, biodegradable, and exhibit high tensile strength. Their properties—such as spinnability and structural resilience—make them suitable for fabric production. When properly processed and treated, these fibers can also serve as substitutes for non-biodegradable synthetic fibers, thereby contributing significantly to the reduction of environmental impact.

However, despite the existence of established concepts, models, and ongoing research, there are still considerable challenges to be addressed. Overcoming regulatory barriers and public policy constraints that hinder the expansion of Circular Business Models (CBMs) requires a logic of scaling. In particular, the deep scaling logic, which aims to transform cultural values and beliefs, is essential for shifting from a traditional, linear, and fast fashion model toward an industry grounded in circular business practices. Despite growing acceptance of circular strategies, challenges such as uncertain market demand, limited knowledge of circularity, and a lack of trust in new collaborative partners continue to impede progress toward greater circularity in the fashion sector (Sandberg & Hultberg, 2021).

In some developing countries, agricultural cooperatives have improved the performance of smallholder farms by facilitating access to new technologies, sustainable practices, and agricultural product marketing. The emphasis on collaboration, knowledge sharing, and inter-cooperation highlights the potential of industrial symbiosis in transforming agricultural waste into valuable resources for various industries. A strong commitment to sustainability, including environmental protection and social development, is a defining characteristic of these cooperatives, promoting responsible business practices and offering solutions to both economic and environmental challenges in rural areas (Barros, Salvador, et al., 2023).

Basu et al. (2021) emphasize that the Base of the Pyramid (BoP) market encompasses billions of low-income consumers in developing countries, who possess limited purchasing power and are often overlooked by companies. Both social and commercial organizations can address this demand not only as a business opportunity but also as a means to contribute to the improvement of these consumers' living conditions. However, engagement in this market must occur responsibly and sustainably, taking into account its cultural, economic, and social specificities.

Within this context, family farming faces challenges in adopting sustainable and circular practices. Among these, the need to develop basic elements to strengthen the domestic market stands out, along with tackling the economic, social, and environmental complexities involved. A holistic model may facilitate a better understanding of the strategic structure and organizational value of sustainable family farming. This model enables the visualization of interactions among various dimensions, such as globalization, technology, and changes in market demand, thereby supporting the coordination of marketing strategies and necessary organizational adaptations (Schiavon et al., 2021).

Cavicchi et al. (2022) underscore the importance of the circular economy for small and medium-sized enterprises (SMEs) in the agricultural sector, particularly concerning the implementation of circular business models. However, the financial feasibility of clean production practices and sustainable agricultural technologies requires economic incentives. Examples such as hydroponic systems that reuse water and utilize CO_2 generated from biogas cogeneration illustrate how the circular economy can be efficiently applied. Nevertheless, a lack of financial and technical resources limits many SMEs. Therefore, the establishment of collaborative networks among companies, public institutions, and investors is recommended to strengthen financial and technical capacity and facilitate the adoption of circular innovations.

Finally, despite the challenges in implementing circular practices, such as greenwashing or deceptive marketing strategies claiming sustainability, there are also significant opportunities. The fashion industry, for example, can benefit by adopting a circular approach, enhancing its sustainability and responding to increasing demands for more responsible practices (Tsironis & Tsagarakis, 2023). Hellström and Olsson (2024) point out that while digital technologies may enable innovation, they are not the true drivers of transformation. Rather, consumer centrality is identified as the primary catalyst for transitioning toward circularity, requiring a profound cultural and strategic shift within organizations.

4.5 Bioeconomy, Circularity, and International Regulations

The transition to a more sustainable economic model has become a global priority, and the intersection between the bioeconomy and the circular economy has emerged as a strategic pathway to reduce waste and environmental impact across various sectors, including the textile industry. In this context, both international and national documents have established guidelines to support this transition by promoting the efficient use of renewable resources and encouraging sustainable practices across different productive contexts, including family farming and its integration into more sustainable value chains.

The European Union has developed structured policies to integrate the bioeconomy with the circular economy. The document A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society, and the Environment proposes a holistic approach, promoting the sustainable use of biomass, the development of markets for bio-based products, and sustainable agricultural practices. These actions are directly related to circularity, as they involve converting organic waste into valuable resources and optimizing material flows within closed-loop systems. Public education and participatory governance are also emphasized, recognizing the essential role of stakeholders in shaping sustainable policy frameworks (European Commission, 2018; Dace et al., 2024; WBCSD, 2020).

The Circular Economy Action Plan: For a Cleaner and More Competitive Europe complements these initiatives by proposing guidelines for sectors with high environmental impact, such as textiles. It encourages ecodesign, the use of recycled materials, the reduction of hazardous substances, and the extension of product life cycles (European Commission, 2020). The EU Strategy for Sustainable and Circular Textiles reinforces this commitment by establishing concrete targets for 2030, such as increasing the use of recycled fibers, eliminating hazardous substances, and making the separate collection of textiles mandatory starting in 2025. Mechanisms such as Extended Producer Responsibility (EPR) and fee modulation are intended to promote more circular design models (UN, 2023; Voukkali et al., 2024).

At the national level, European countries have also implemented specific plans. In Portugal, the Action Plan for the Circular Economy (PAEC) identifies the textile sector as a priority, focusing on ecodesign, the valorization of agricultural waste, and the promotion of natural fibers to reduce the environmental impact of the production cycle. The Action Plan for a Sustainable Bioeconomy (PABS) presents ambitious goals, such as replacing fossil-based raw materials with local and renewable alternatives, increasing water and energy use efficiency, and enhancing the value of biological residues through industrial symbiosis (DGAE, 2023; Portugal, 2018).

In Italy, the document BIT II – Bioeconomy in Italy and the report Economic Instruments for the Circular Economy reinforce the integration of the bioeconomy into industrial sectors, with particular emphasis on textiles. The focus lies on transforming agricultural waste into higher value-added products, such as fibers and fabrics, and on converting industrial areas into biorefineries. The country is investing in innovation hubs, tax incentives, and public policies to promote circularity and reduce the use of non-renewable resources (Italy, 2019, 2023).

In Brazil, recent developments include the publication of the National Strategies for Bioeconomy and Circular Economy. Decree No. 12.082/2024, dated June 27, 2024, established the National Circular Economy Strategy, aimed at promoting the transition from a linear production model to a circular economy by encouraging the efficient use of natural resources and the adoption of sustainable practices throughout the production chain (Brazil, 2024b). In addition, the country has consolidated its regulatory framework on the circular economy with the adoption of the Brazilian Association of Technical Standards (ABNT) circularity standards approved in 2024, namely: a) ABNT NBR ISO 59004, which establishes vocabulary, principles, and guidelines for implementing the circular economy, offering a common reference for companies and institutions (Abnt, 2024b); b) ABNT NBR ISO 59010, which guides the transition of business models and value networks, facilitating the adoption of circularity across various productive sectors (Abnt, 2024a); and c) ABNT NBR ISO 59020, which defines criteria for measuring and assessing circularity performance, enabling the monitoring and continuous improvement of circular practices

The implementation of integrated policies demonstrates significant progress toward global sustainability. Initiatives such as Trash-2-Cash and the use of biomaterials like Piñatex highlight the transformative potential of the circular bioeconomy in the fashion industry. However, the transition still faces challenges, from regulatory barriers to infrastructure needs and technical capacity building, especially in countries with lower levels of industrialization. In this scenario, integrating the circular bioeconomy into family farming represents a strategic opportunity. The use of banana crop residues, such as the pseudostem, for textile fiber production exemplifies the articulation between social innovation, environmental sustainability, and productive inclusion. The proposed circular business model for smallholder farmers aims to convert environmental liabilities into economic resources, adding value to agro-industrial waste and connecting these producers to sustainable value chains, in alignment with both international and national regulatory frameworks (Subash & Perumalsamy, 2024).

CONCLUSIONS

This study proposed a Circular Business Model (CBM) focused on the value of banana farming residues, particularly the pseudostem, for sustainable textile production, offering an inclusive strategy to promote circularity in rural contexts. Through an integrative literature review, it identified not only the environmental benefits of reducing agro-industrial waste and synthetic fiber use, but also the socioeconomic potential to diversify income, strengthen family farming, and foster rural development.

The proposed model addresses key challenges at the rural base of the pyramid, including low resilience, lack of access to value chains, and economic marginalization of smallholder farmers. It demonstrates how agricultural residues can become strategic resources within regenerative systems, advancing climate goals and aligning with global and national policy frameworks on the circular bioeconomy.

However, despite its theoretical robustness and alignment with sustainability agendas, the implementation of this model faces significant barriers. Technological challenges include the absence of standardized and scalable fiber extraction methods, high operational costs, and limited availability of processing infrastructure, especially in regions with poor logistics and limited industrial capacity. Economically, market demand for banana fibers remains low, and smallholders often lack the financial instruments and technical support to engage in value-added activities. Culturally, there are still gaps in consumer awareness and acceptance of circular textiles, which may hinder the commercial viability of such initiatives.

In addition, this study is limited by its conceptual nature and reliance on secondary data. While literature offers substantial theoretical insight, empirical validation is necessary to assess the feasibility of the model under real conditions. Regional heterogeneity, in terms of infrastructure, governance, social capital, and institutional support, demands localized, participatory, and adaptive approaches. The transferability of the model to different contexts should not assume uniform conditions or capacities. Instead, future research must address place-based configurations, involving stakeholders through co-creation and experimentation in pilot projects.

Further studies are also needed to investigate mechanisms of cooperation between farmers, cooperatives, textile companies, and public institutions, as well as governance models that ensure fair distribution of value and environmental responsibility. The inclusion of metrics to assess circularity performance, traceability, and socioeconomic impact will be essential to evaluate outcomes and guide scaling strategies. In this sense, innovations that combine technological solutions with social design, such as frugal innovations and community-based business models, can play a key role.

Ultimately, transitioning from linear to circular production systems requires more than technical solutions. It demands a shift in cultural paradigms, consumer behavior, and institutional logic. The adoption of CBMs in banana farming is not merely a matter of technological feasibility, but of political will, stakeholder alignment, and a commitment to systemic change. By advancing in these directions, the circular valorization of agro-industrial residues can serve as a replicable model for sustainable development, social equity, and environmental regeneration.

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