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A systematic literature review on business models for the base of the pyramid from banana farming waste

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Abstract: *This article reports the results from systematic research on business models at the base of the pyramid (BOP) using banana farming waste as a raw material. Bananas are cultivated at a very large scale, and it leads to a high quantity of waste. The waste generated by banana farming activities includes pseudostems, leaves, and peels. It is thus evident that the opportunities for further value addition and business model development that meets the need of the poorest have been highlighted through the exploration of the banana farming waste and its potential uses. This review aims at identifying potential inclusive business models in banana farming for the base of the pyramid and initiatives through which banana farming waste could be utilized in the production of marketable products, services innovation, or alternative sources of energy. Information from the databases of ScienceDirect, Scjsion, and documents provided by the Food and Agriculture Organization (FAO), Brazilian Agricultural Research Corporation (Embrapa), Brazilian Textile Industry Association (ABIT), and The World Bank. As a result, 48 articles were used for the present literature review. Some of the uses with banana farming waste that could have a business model include getting adsorbents for effluent treatment, biocomposites, biofilm clothing fabrics, biofuels, activated charcoal, and biomass for vermicomposting. This review would be able to seed new ideas among all those interested in creating innovative business models, while maintaining the principles of the circular economy aimed at promoting social inclusion at the base of the pyramid.*

Keywords: *Base of the pyramid. Banana farming. Banana waste. Business model.*

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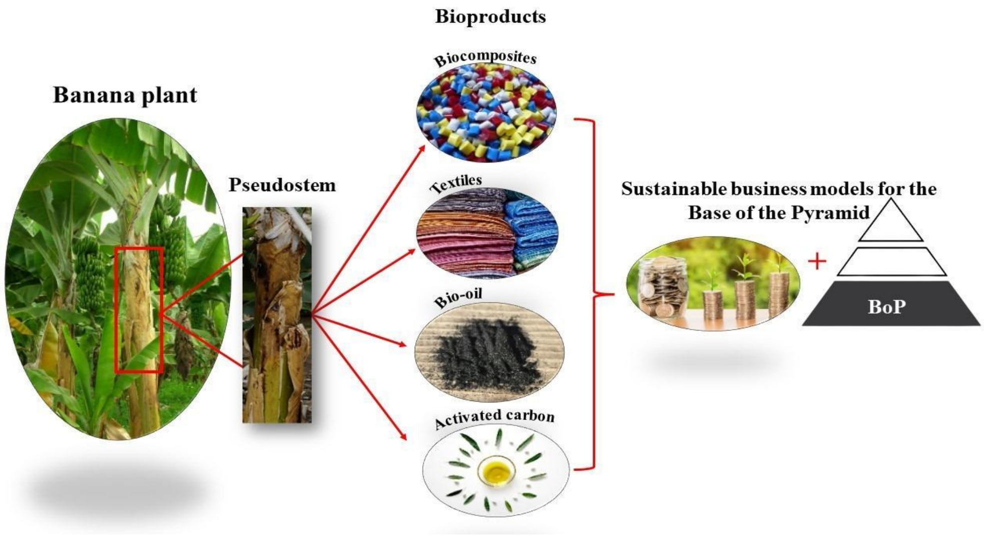
Graphical Abstract



I. Introduction

The bottom of the pyramid (BOP) was identified as the base that housed intense consumer and entrepreneurial potential in the economic landscape (Prahalad and Hart 2002). Prahalad essentially focuses his arguments on poverty alleviation through profit and thus claims that including the BOP in the economic scene is an important means to foster entrepreneurship and encourage the emergence of innovations at the bottom level. Therefore, business models at the BOP are regarded as an entrepreneurial way of deriving profit and opening opportunity based on the meeting of the needs of the low-income population, which until now was considered as both socially and economically invisible and unreached (Singh 2015).

Prahalad (2005), defines the bottom of the pyramid as representing the low-income population that earns below $2 a day. The term is used to denote more than 4 billion people around the world and who are indeed the majority in terms of population; however, they are often left ignored by traditional markets.

One view is to imbibe the BOP market into the socio-economic panorama. The viewpoint describes how private business initiatives stimulate new investments with growth, sustainable innovation in BOP, and local empowerment, jobs, and a range of new products and services suited to the particular needs of the poor (Verwaal et al. 2022).

Business models that integrate and innovate sustainability will have objectives with far-reaching aims to provide value to the customers and society at large. Access to serve low-income customers. This meant that the implementation of business models for the base of the pyramid was oriented not only towards the basic satisfaction of these people's needs but, moreover, to create business opportunities that would be executive and generate positive social impact.

One such area that provides vast opportunities in this regard is the area of banana farming, which happens to be a commonly practiced activity throughout the world. Banana production contributes much to waste, such as those from pseudostems, leaves, and peels. The leaves and pseudostem are left in the field after fruit harvest, producing large amounts of greenhouse gases. It is the general trend that from each parent banana plant, only one bunch is produced, and after the removal of that single bunch, the parent plant is cut down to make way for another (Motta et al. 2022).

That is something which certainly puts management in a very tough challenge, but from the other side, it offers them doors for the creation of innovative and sustainable business models. In fact, most of the production in the hands of micro and small-scale producers is consolidated, and according to the Food and Agriculture Organization of the United Organization (2023) (FAO), even dominated. The criticality lies in supporting this producer segment so that millions of producers all over the world can survive, grow, and be profitable. It is noteworthy that bananas are produced in more than 130 countries.

Around 20% of the total world production of bananas is meant for international markets (Al-Dairi et al. 2023). The major producers of bananas, in approximate numbers to total world production, include India (33%), China (10%), Philippines (9%), Brazil (8%), and Ecuador (5%) (Panigrahi et al., 2021). According to The World Bank (2023), data the rate of poverty these countries are registering is at 10% in India, 0.1% in China, 3.0% in the Philippines, 5.8% in Brazil, and 3.6% in Ecuador. These percentages were poverty rates; in other words, the amount of people who lived by up to $2.15 a day was represented by these percentages. This heavily approximates over 3.2 billion, accounting for about 160 million people being poverty-stricken between the two nations. They should also be further studied, contributing to the alleviation of poverty with innovation using business models that focus on the utilization of waste generated from growing bananas. A new product or service that reduces deprivation or the exclusion of the BOP population while at the same time increases their capabilities for income-earning is deemed inclusive innovation (Ramani et al. 2023)

From this perspective, this article suggests an integrative systematic review of business models whose purpose is to utilize the generated banana waste from banana farming for ventures seeking the base of the pyramid. The information will be presented in regard to the potential uses of residues in different forms of business opportunities, from them deriving socioeconomic and environmental benefits.

The objective of this systematic review will be to bring knowledge of the current business models designed for the Base of the Pyramid and their current landscape and future prospects using banana farming waste. From this thematic research, we expect to give an impulse to a number of ideas and the implementation of innovative solutions aimed at ensuring inclusive economic development and a more efficient use of available resources.

II. Methodology

The methodology is a integrative systematic review of business models derived from banana farming for low-income families. An integrative review, therefore, is one that uses synthesis in the summarization of the current scientific literature with regard to a certain phenomenon, in terms of research articles among other types of documents, such as official organization files, book chapters, among others. Its purpose will be developing a rich and comprehensive understanding of the issue that results in new frameworks and perspectives on the subject.

The review is based on information collected using Scopus, ScienceDirect, SpringerLink, and other information collected from the official sites of organizations such as the Food and Agriculture Organization (FAO), Brazilian Agricultural Research Corporation (Embrapa), The Brazilian Textile Industry Association (ABIT), and The World Bank.
The aim of this article is to propose conceptions in a sequence and definitions that contribute to the reduction of solid waste, proposing improvements in the lives of families that have the lowest income. For that, there has been built a review of the literature with the involvement of five combinations of terms used in writing the items. Figure 1 reflects the search method.

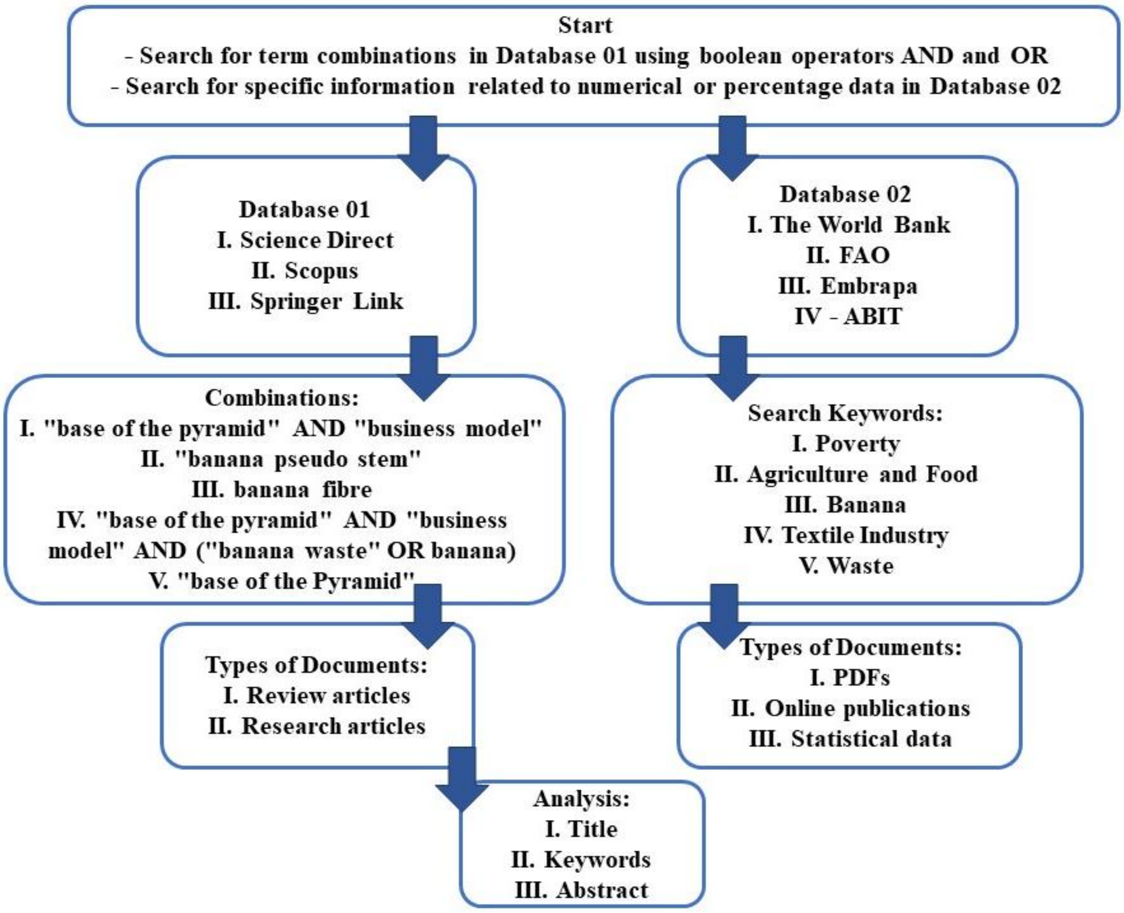


Figure 1. Flowchart of the method used for selecting research articles. Source: Authors, 2024.

Articles in Database 1 were searched using the filters "document type" (review articles and research articles), without a time constraint due to the limited literature found. The selection and exclusion criteria used were readings of the title, abstract, and keywords, selecting only articles compatible with the research theme. Database 2 was used as a complementary source to provide current data on the discussed topic.

For a better understanding of the topic, the results and discussions of this review article are structured as follows:

a) Section 4 - Results: This section presents the quantitative results obtained for the elaboration of this review article, including data from the findings recorded in the databases to the geographical scope of the countries involved in the respective publications.

b) Section 5 - Discussion: The discussion of the results is divided into two topics: i) Section 5.1 - Banana farming waste and its potential uses: This topic aims to emphasize the variety of uses that can be attributed to these wastes; ii) Section 5.2 - Possibilities of using banana farming waste as a business model for the base of the pyramid: This topic aims to address the main uses of the waste in order to propose a business model for base-of-the-pyramid families.

III. Results

The results of the searches for the combinations used in the literature research correspond to review articles and research articles. It was chosen not to use any time constraints in order to explore all research involving the topic, from the beginning. The combinations, when isolated, yielded many results, but more specific combinations related to the theme, such as "base of the pyramid" AND "business model" AND ("banana waste" OR banana), had very few results in the investigated databases.

The database that yielded the most results was ScienceDirect, with 6854 items, followed by SpringerLink and Scopus, with 3013 and 1659 items, respectively. Table 1 shows the results found for each combination of words used on March 10, 2024.

Tabela 1 - Comparison of search results across databases.

Combinations	**Science Direct**	**Scopus**	**Springer Link**
"base of the pyramid" AND "business model"	295	79	120
"banana pseudo stem"	292	171	984
"banana fibre"	1390	840	782
"base of the pyramid" AND "business model" AND ("banana waste" OR banana)	04	01	02
"base of the Pyramid"	4873	568	1125
Total	6854	1659	3013

Source: Authors, 2024.

For the selection of articles, the first step involved reading the title, abstract, and keywords of each database. Publications relevant to the theme were selected, resulting in 48 documents. Despite the large number of publications displayed, the vast majority were not relevant to the theme. Many of the publications were present in all three databases searched, resulting in many duplicate articles. Figure 2 illustrates the distribution of references by year, used in the writing of each section of the results.

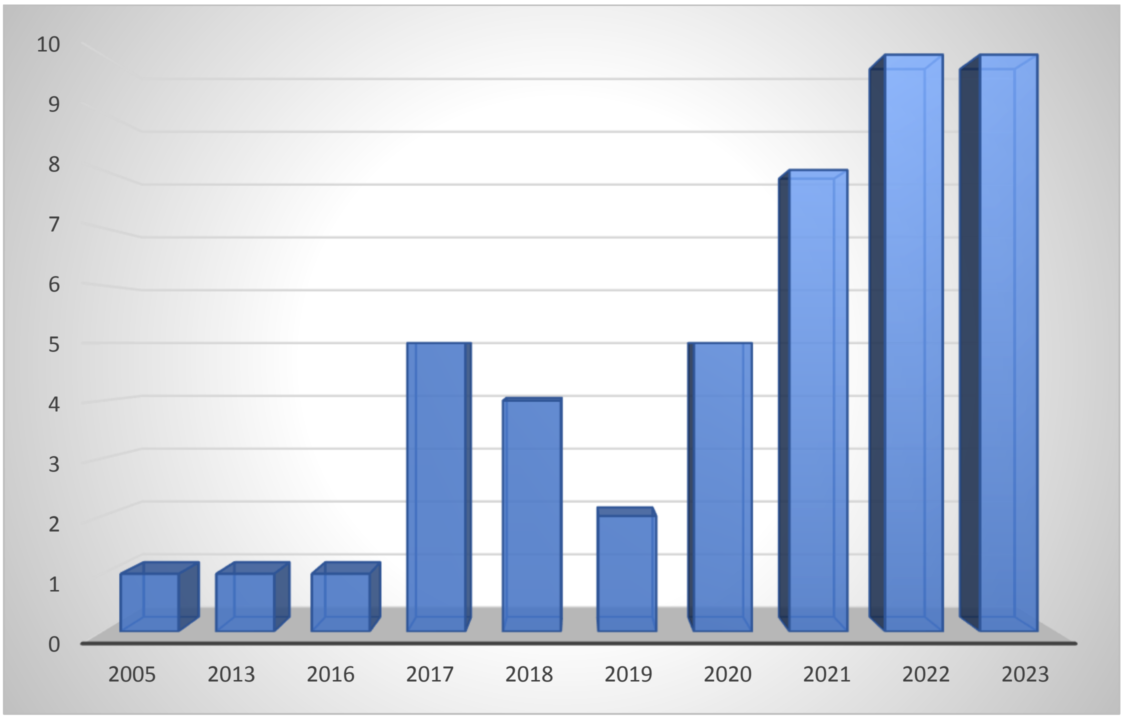


Figure 2. Analysis of the articles cited in this review by year of publication. Source: authors, 2024.

The highest number of articles published containing at least one of the main keywords, such as "Base of the Pyramid," "Business Model," and "banana," was in the year 2022/2023. It can be considered that the number of researches on the topic has been increasing since 2017. When analyzing the ScienceDirect database (the database that yielded the most results) and selecting the keyword "banana fiber," which had the highest number of publications specifically related to bananas, we have the distribution of publications by year, as shown in Figure 3.

We can conclude that interest in the topic has been significantly growing over the years. The first articles on the use of banana fiber as reinforcement in composites appeared in 2000. There was a considerable increase in the number of publications in 2003, and from 2009 onwards, publications have been steadily increasing over the years.

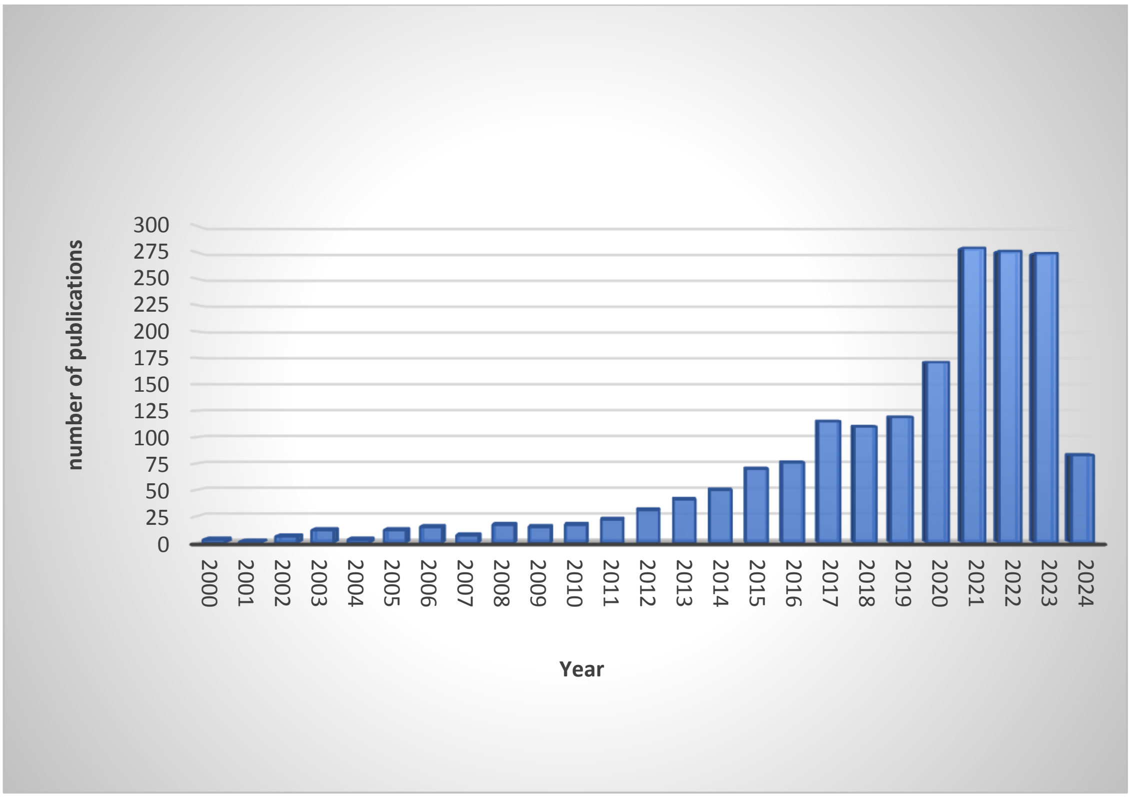


Figure 3. Analysis of the number of articles published per year in the ScienceDirect database with the keywords "banana fiber" in March 2024. Source: Authors, 2024.

In terms of the number of countries involved in the research cited in this review, Figure 4 shows the quantity of publications per country involved.

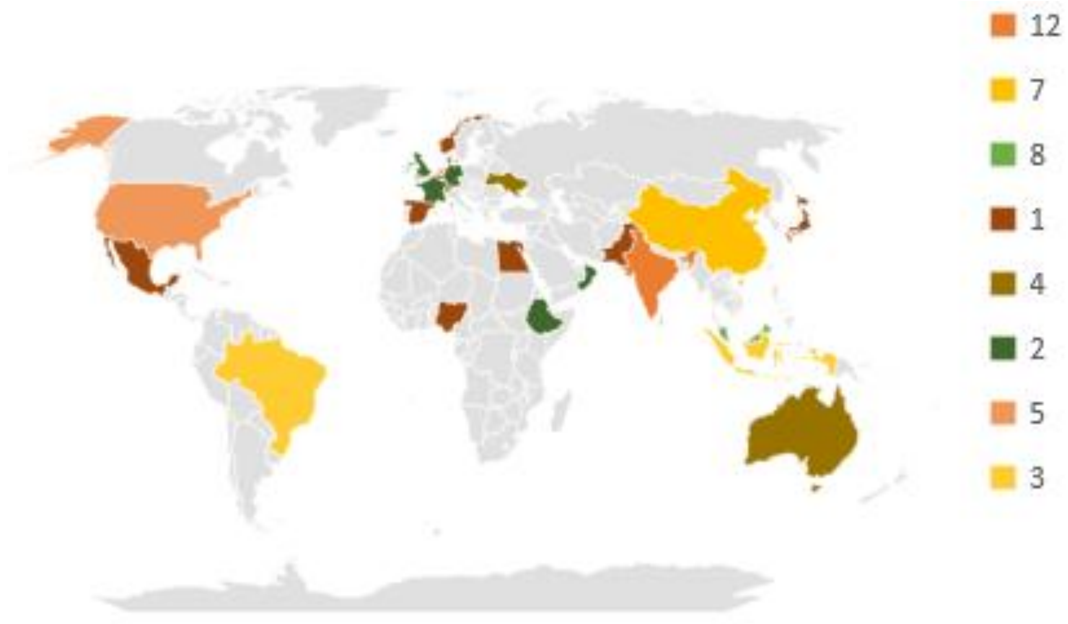


Figure 4. Countries of the authors of the articles cited in this review. Source: Authors, 2024.

In the analysis of articles published by country of authors, there is a considerably larger number of articles published in India, China, and Malaysia. It is worth noting that these countries have a strong culture of banana cultivation, which justifies the current interest in this context. According to Taib et al. (2021), Malaysia is not a major banana producer; however, bananas are widely planted in this country, covering approximately 30,455 hectares.

With a focus solely on applications of waste generated in banana farming, Table 2 shows some studies on the possibilities of product formation and the countries involved in these researches. These applications were found through a search of articles in the databases using the combinations mentioned in Table 1. This table lists the most recent results found for each application.

Table 2 - Publications on applications of waste generated in banana farming.

Authors	Title	Application	Country/ Year
Pawar et al.	Column study using modified banana pseudo stem as adsorbent for removal of Pb (II)	Adsorventes	Índia / 2023
Zhang et al.	Nanocellulose aerogels from banana pseudo-stem as a wound dressing	Curativo para feridas	China / 2023
Ab Ghani et al.	Landfill leachate treatment by activated carbon (AC) from banana pseudo-stem, iron oxide nanocomposite (IOAC), and iron oxide nanoparticles (IONPs)	Carvão ativado	Malásia, Omã, Nigéria / 2023
Sawarkar et al.	Bioethanol from various types of banana waste: A review	Bioetanol	Índia / 2022
Khan et al.	Banana agro-waste as an alternative to cotton fibre in textile applications. Yarn to fabric: An ecofriendly approach	Tecidos para vestuário	Paquistão / 2022
Taib et al.	Bio-oil derived from banana pseudo-stem via fast pyrolysis process	Bio-óleo	Malásia / 2021
Pan et al.	Evaluation of squeezing pretreatment for improving methane production from fresh banana pseudo-stems	Produção de metano	China / 2020
Othman et al.	Starch/banana pseudo-stem biocomposite films for potential food packaging applications	Filmes para embalagem de alimentos	Malásia / 2020
Hassan et al.	Optimization of tensile behavior of banana pseudo-stem (Musa acuminate) fiber reinforced epoxy composites using response surface methodology	Biocompósitos	Malásia / 2019
Bello et al.	A study on adsorption behavior of newly synthesized banana pseudo-stem derived superabsorbent hydrogels for cationic and anionic dye removal from effluents	Hidrogéis superabsorvedores	Índia / 2018
Faradilla et al.	Characteristics of a free-standing film from banana pseudo-stem nanocellulose generated from TEMPO-mediated oxidation	Filme de nanocelulose	Austrália, Indonésia / 2017
Ramdhonee & Jeetah	Production of wrapping paper from banana fibres	Papel de embrulho	Ilhas Maurícias / 2017
Baharin et al.	Production of Laminated Natural Fibre Board from Banana Tree Wastes	Chapa laminada	Malásia / 2016
Ashok Kumar et al.	Production and characterization of enriched vermicompost from banana leaf biomass waste activated by biochar integration	Biomassa para vermicompostagem	Índia, Etiópia / 2023

Fonte: autores, 2024.

The majority of the research presented in Table 2 is related to the creation of products from the banana plant's pseudostem. This becomes interesting in terms of waste management, given that leaves and peels are extensively used in crafts. On the other hand, the pseudostem is often left in the production area, in fields or along roadsides, and improper disposal can certainly lead to environmental issues (Pan et al., 2020).

It's worth highlighting that the applications mentioned in the above table were selected because they could be directed towards establishing a business model for the base of the pyramid. In subsection 4.2, we will elucidate how each application can serve as the foundation for a business model.

Lastly, Figure 5 illustrates the correlation between the banana plant's pseudostem and its potential applications in various contexts. Note that Figure 5 was constructed using the VOSviewer software, widely utilized for analyzing and visualizing networks of terms, co-citations, co-occurrences, collaborations, and other complex structures found in bibliometric and scientific data.

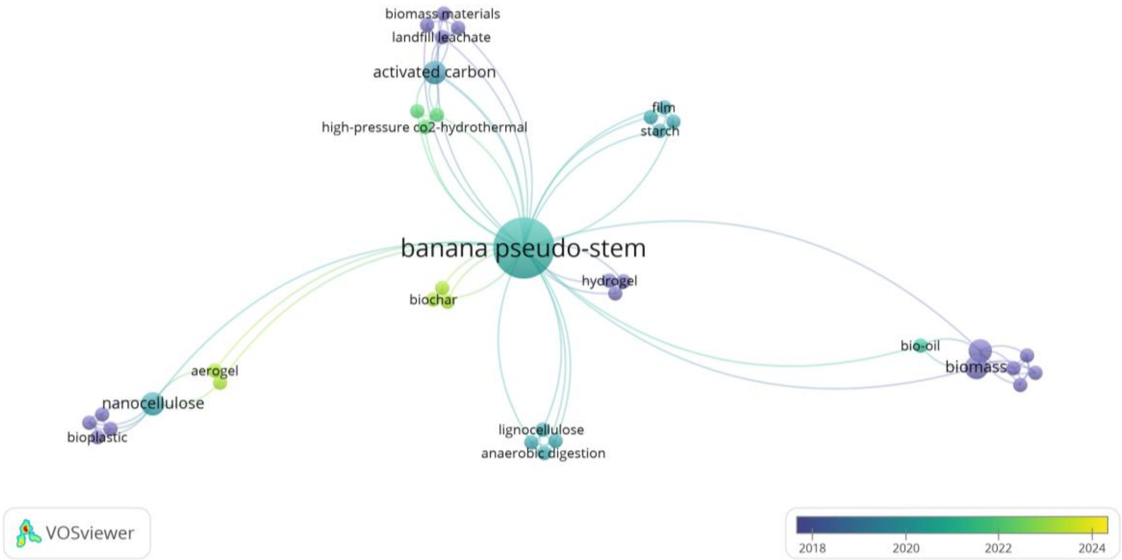


Figure 5. Potential applications of banana plant's pseudostem as found in the 48 analyzed articles. Source: Authors, 2024.

In Figure 5, the significant potential of the banana plant's pseudostem as a valuable resource is evident. The analysis of the 48 articles revealed its interconnections with various meaningful co-occurrences, as indicated by the following clusters: hydrogel, biochar, film starch, lignocellulose, anaerobic digestion, bio-oil, biomass, aerogel, nanocellulose, bioplastic, high-pressure CO2 hydrothermal, activated carbon, landfill leachate, and biomass materials.

The diversity of these co-occurrences reflects the versatility of the banana plant's pseudostem resource, spanning from advanced material technologies to renewable energy production and sustainable waste management. Moreover, the presence of terms like "hydrogel," "biochar," and "bioplastic" may suggest a shift towards more sustainable and innovative approaches, potentially leading to avenues for future research suggestions.

IV. Discussion

5.1. Banana farming waste and potential uses

Bananas are the most exported fresh fruit in the world (US$ 10 billion/year), being an essential source of income for thousands of rural families in developing countries (Food and Agriculture Organization of the United Organization 2023). In Brazil, banana trees are cultivated in all states of the country, and besides being the largest consumer worldwide, Brazil is the fourth largest producer, with 6.6 million tons produced in 455 thousand hectares, half originating from family farming. The sector generates US$ 2.8 billion in revenue per year and creates 500 thousand direct jobs (Embrapa 2023).

Approximately 4 tons of waste are generated for every ton of harvested banana (Abdullah et al. 2023). Large quantities of peel, leaf, pseudostem, and stem are generated (Fernandes et al. 2013). These residues have traditionally been used in different conventional ways. For example, fresh leaves can be used for food wrapping, and pseudostems can be processed into ropes, crafts, fabric, paper, and cardboard (Taib et al. 2021).

The planting and harvesting cycle lasts from 10 to 15 months to harvest the fruits from the planting day. After harvesting, the mother plant dies and needs to be cut to reuse the same land for replanting. It is estimated that 114.08 metric tons of banana waste are produced annually worldwide (Khan et al. 2022)

Managing this agricultural waste is a serious challenge, and attempts have been made to deal with this waste by using it as a renewable source of energy. However, burning this waste is an unsustainable process that leads to various climate problems. Disposal also leads to issues such as fungal proliferation and methane emission, contributing to greenhouse gas emissions and serious ecological problems (Khan et al. 2022)

On the other hand, these residues contain a large amount of fibers, which are one of the most utilized parts in obtaining new products and can be classified as coarse or fine. The coarse and strong fibers are located on the outer part of the leaf sheaths, while the fine and silky fibers are available on the inner part of the leaf. The main part of the plant, which extends from the roots to the end of the pseudostem, is composed of fine white fibers. The fruit stalks contain coarse-quality fibers, while the central veins of the leaves can produce a fiber of remarkable strength and durability if processed correctly (Ramdhonee and Jeetah 2017).

Given this scenario, the large amount of waste generated in banana farming has driven the development of various works to find uses for them and thus contribute to reducing environmental impact. Harnessing these residues for the production of inputs or turning them into a true commodity would reduce environmental pollution and add value to banana farming (Fernandes et al. 2013). Therefore, business models using banana farming waste as the main raw material are extremely interesting, especially if targeted at the low-income community. In addition to generating income for the base of the pyramid, the utilization of these residues has a strong sustainable appeal.

In addition to conventional uses, the waste produced in banana farming can be utilized for various purposes, such as Pb adsorbents for residual water (Pawar et al. 2023), production of activated carbon from the pseudostem for leachate treatment (Ab Ghani et al. 2023), nanocellulose aerogels from the pseudostem as wound dressings (Zhang et al. 2023), paper production from banana fiber (Ramdhonee and Jeetah 2017), bioethanol production (Sawarkar et al. 2022), preparation of optimized biocomposites for fiber-based packaging of banana pseudostem (Pei Pei et al. 2023), vermicomposting of banana farming residues (Khatua et al. 2018; Mago et al. 2021; Kumar et al. 2022), among other functionalities described in various research works. Figure 6 illustrates the various types of materials that can be derived from a banana plant.

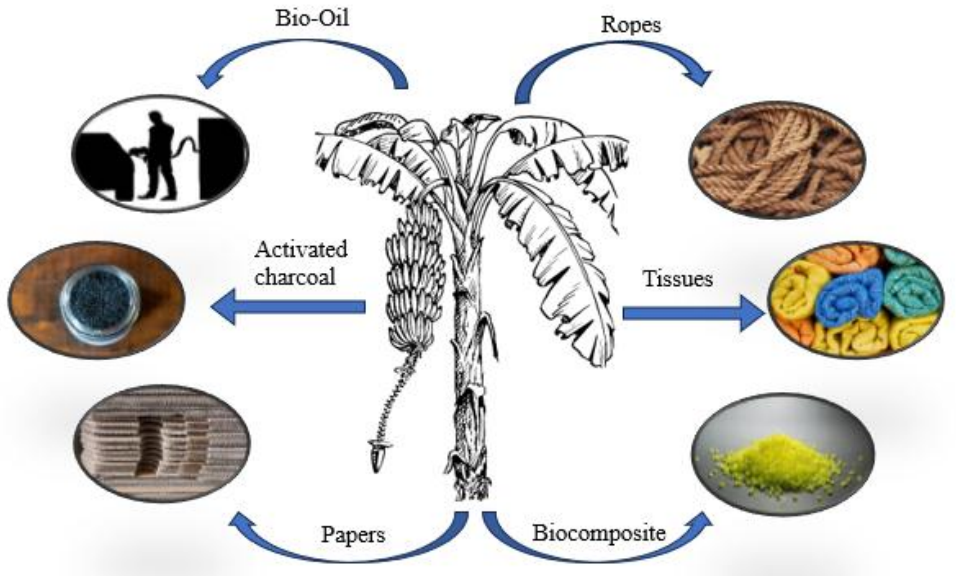


Figure 6**. Products that can be generated from the banana plant. Source: Authors, 2024.**

In this context, these bioresidues can be considered potential resources for the development of new products and thus be part of the circular economy process and also of new economically and environmentally viable business models for low-income families. An innovative and attractive example of using these residues is in the production of fabrics derived from banana fiber. In the literature, the work of Khan et al. (2022), describes the possibility of banana fiber as an alternative to cotton fiber in clothing applications.

Today, commercially, there is a fabric called Bananatex®, made exclusively from banana plants. Bananatex® was developed by the Swiss bag and material innovators QWSTION in collaboration with a yarn expert and a weaving partner, both based in Taiwan. In Brazil, MusaFiber® is a company in the business of producing ecological fabrics made from banana fiber from the pseudostem. The fiber is transformed into fabric, which can be applied in various forms, from carpets to clothing pieces (MusaFiber 2023).

Banana fibers can be an alternative to replace synthetic fibers due to several advantages, such as being renewable, biodegradable, abundantly available, and low cost. Additionally, banana fiber has shown that polyester composites reinforced with natural fiber are the right alternative to replace synthetic fiber materials (kalangi et al. 2022).

The polyester fiber begins its production chain with petroleum refining and obtaining naphtha. The use of fossil fuel makes it the fiber champion in greenhouse gas emissions. Additionally, polyester releases microplastics, which have been found in drinking water, fish served at the table, and various organs of the human body (Melgert 2021). Synthetic textile fibers are one of the most resilient types of microplastic waste, with an annual production of 60 million metric tons, which accounts for 16% of the world's plastic pollution (Gasperi et al. 2018).

Given this information, a business model focused on environmental issues related to synthetic fibers becomes interesting, considering that (I) bananas are the most exported fruit in the world; (II) 4 tons of waste are generated for every ton of harvested bananas; (III) it is possible to produce fibers derived from banana plants; (IV) synthetic textile fibers have a high degree of pollution, and (V) it is an option for a business model that can benefit low-income families, considering that they are the main stakeholders in banana cultivation.

5.2 Business Model Possibilities for the Base of the Pyramid Using Banana Cultivation Waste

The individuals belonging to the base of the pyramid, as per Prahalad and Hart (2002), live on an annual income ranging from $1,500 to $2,000, while data from The World Bank defines a threshold below $2.15 per person per day. The population living at the base of the pyramid is numerous and, due to their extremely low income, they allocate most of their expenses to food and lack access to basic services and products to meet human needs. The challenges faced by people at the BOP have long been known, but it was only in the early 21st century that they began to envision the BOP as a new business opportunity (Palomares-Aguirre et al. 2018).

According to The World Bank data, currently, about 700 million people live below the poverty line. It is estimated that by 2030, there will still be about 7% of the world's population living in these conditions. Agricultural development is one of the most powerful tools to end extreme poverty, as growth in this sector is two to four times more effective in increasing income among the poorest compared to other sectors (The World Bank 2023)

Given this data, the significant potential of agriculture in reducing extreme poverty worldwide is evident. This potential also extends to the utilization of agri-food waste generated in these activities. Currently, there is ongoing interest in proposing sustainable and inclusive business models to meet the needs of the poorest (Derks et al. 2022).

Currently, commonly used tools to reduce poverty include foreign aid, microcredit, social entrepreneurship, BOP initiatives, property rights, and industrialization (Kumar et al. 2022). The central idea of a business model focused on the BOP is to make this social group potential consumers or producers in the value chains of large businesses (Prahalad 2005).

In summary, the BOP approach is based on the principles of inclusion and mutual value. Inclusion brings markets to the poorest and allows them to participate in these markets. It also makes the business sector thrive by involving local communities in creating business models that simultaneously generate economic, social, and environmental value (Dembek et al. 2020).

Business models are built through a process of adaptation to their context represented by potential customers, established institutions, and competitors (Ausrød et al. 2017). The Base of the Pyramid offers a suitable context for exploring business model projects because companies are instructed to adapt to their context and build upon local conditions. By including people from the BOP in the market economy, entrepreneurs can generate profits while also assisting the poorest population (Hart and London 2005).

Business models focused on agriculture become compelling as it is the fastest-growing sector globally (The World Bank 2023). In addition to the planting, harvesting, and consumption cycle, there is also the issue of bio-waste generated in these activities, which often can be utilized to create a new product. Agri-food waste comprises non-food product outputs from agricultural production and processing and includes animal waste, food processing waste, crop residues, and hazardous or toxic waste (Ahmad and Danish 2018; Bello et al. 2018; Pawar et al. 2023).

As seen in subsection 4.1, the solid waste generated in banana cultivation has significant potential to generate value-added products for commercialization. The paragraphs below will outline some of these potential uses, all of which can generate a business model for the base of the pyramid.

There is a considerable number of publications related to obtaining activated charcoal from banana pseudostems for effluent treatment. The works of A.B. Ghani et al. (2023), Abdullah et al. (2023), Ghani et al. (2017), Jiang et al. (2022), and Wang et al. (2023) highlight the production of activated charcoal from banana pseudostems. To obtain charcoal, steps involve cutting the pseudostem into small pieces, drying, and, if necessary, grinding and sieving. After these basic treatments, the semi-finished product must undergo a thermal process at high temperatures to form activated charcoal. In summary, the preparation process of activated charcoal involves simple procedures that can be easily implemented on-site at the harvesting location. The semi-finished material would then be sent to a sector responsible for converting it into activated charcoal according to the desired process.

Following the same effluent treatment line, these waste materials can also become common adsorbents for pollutant removal (Ahmad and Danish 2018; Bello et al. 2018). The procedures for obtaining adsorbents are similar to those for activated charcoal. The difference lies in the absence of thermal treatment. Simple methods such as grinding, washing, drying, and sieving are required. The goal is to obtain a fine powder that can be used in direct contact with the effluent. These techniques can easily be carried out in the cultivation area itself, making it an option for waste utilization and a potential business model idea. In addition to the generated product, the application purpose also involves sustainable aspects, such as effluent treatment.

Another example of application is the formation of composites. Composites are materials reinforced with another type of material to enhance their properties. Banana cultivation residues can easily serve as reinforcement for these materials. The literature presents several options for composite formation using different polymeric matrices with varying proportions of banana fiber (Hassan et al. 2019; Jordan and Chester 2017; kalangi et al. 2022; S. Kumar et al. 2023; Li et al. 2018; Ramanan et al. 2022; Suresh et al. 2020). Obtaining the fibers involves simple steps, where the fibers are manually extracted, washed, and sun-dried. Banana producers then have the option to extract these fibers and supply them to potential consumers in the composite industry, generating a business model where sustainability encompasses both the producer and the consumer.

The production of bio-oil and bioethanol is also possible from these residues, as evidenced by the works of (Sawarkar et al. 2022; Taib et al. 2021). While bioethanol production only requires biomass as raw material, i.e., any type of banana cultivation residue, bio-oil production requires some pseudostem treatment steps. These steps consist of cutting the pseudostem into small pieces, drying, grinding in a ball mill, and sieving. After these treatments, the fine powder obtained is sent to a fluidized bed reactor, where the fast pyrolysis process will be carried out to obtain bio-oil. A business model can easily be implemented to leverage these residues for specific consumers who make appropriate use of these treated residues or biomass.

The formation of films, as demonstrated in the works of (Ai et al. 2021; Faradilla et al. 2017), Faradilla et al. 2019; Othman et al. 2020), whether for food wrapping or not, can also be the focus of a business model. Simple operations such as cutting, drying, grinding, and sieving are performed to obtain pseudostem flour, which is the main raw material for extracting nanocellulose, with the aim of producing biofilms. Nanocellulose, or cellulose nanofiber, is cellulose fiber with one of its dimensions less than 100 nm. This material has the potential to replace non-biodegradable synthetic polymers (Faradilla et al. 2017).

Vermicomposting using banana cultivation residues has also become an interesting option for the final disposal of these residues. The works of Khato et al. (2018), Mago et al. (2021), and Kumar et al. (2023) explore the use of vermicomposting of banana pseudostems and leaves with cow dung. An increase in plant micronutrients in vermicomposts was observed, which are excellent allies in the soil fertilization process. However, these works showed that vermicomposting can be integrated into the global banana waste management plan and can also become a promising business plan, since the vermicomposting process only requires a cultivation location for the worms, cow dung, and shredded banana residues.

In addition to the aforementioned potential uses, the most attractive for establishing a business model is the production of fibers for textiles from banana fiber for the textile industry. Despite having a significant impact on a country's economy, textile industries face major environmental issues. According to the Brazilian Textile and Apparel Industry Association (Abit), in 2021, the sector generated approximately R$ 190 billion in revenue, creating approximately 1.34 million jobs. It has 22.5 thousand companies installed nationwide and is the second-largest job-generating sector, second only to the food industry (Abit 2023).

The large quantities of water used in fabric manufacturing result in equally large amounts of wastewater containing high levels of dissolved solids, organics, metals, salts, and recalcitrant dyes (Ismail and Sakai 2022). In addition to high water consumption, textile industries use a wide range of toxic chemicals in various stages of the process (Al-Tohamy et al. 2022). Among the fibers used in the textile industry, polyester is the most widely used worldwide, accounting for about 52% of the total global fiber production. The second most used is cotton with 23% of global production followed by polyamide, representing 5% of the market (Janaina et al. 2020).

Given the importance of the textile industry to a country's economy and its negative environmental impact, the possibility of making this sector sustainable is extremely compelling from environmental, social, and economic standpoints. The combination of the large quantity of waste generated and the potential for using banana fibers to produce fabrics creates a significant opportunity for a business model targeting low-income families involved in planting and harvesting. As mentioned earlier, Bananatex® (Bananatex 2023) was the first company to develop fabrics made exclusively from banana plants. Figure 7 shows some varieties of Bananatex® fabrics classified as lightweight, medium weight, and heavyweight fabrics.

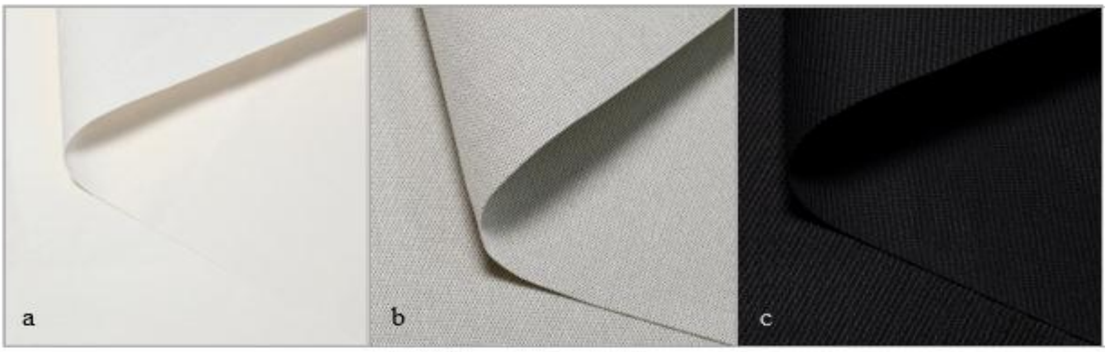


Figure 7. Samples of fabrics made exclusively from Abaca banana plants, where (a) is lightweight fabric with 230 g/m²; (b) medium-weight fabric with 430 g/m²; and (c) heavyweight fabric with 540 g/m². Source: Adapted from https://www.bananatex.info/products_EN.html.

With these three fabric varieties, hats, bags, backpacks, children's clothing, cell phone cases, and chair seats have been manufactured. Additional information regarding this biotextile can be found on the Banatex.info website. Acknowledging the significance of banana fiber and the array of products it can yield, Veera Ajay et al. (2021), published a project detailing a manually operated banana fiber extraction apparatus. Presently, fiber extraction for artisanal purposes is predominantly manual, entailing labor-intensive and protracted procedures. Figure 8 illustrates a concept of the artisanal process and machine for extracting banana fibre as mentioned in the article read.

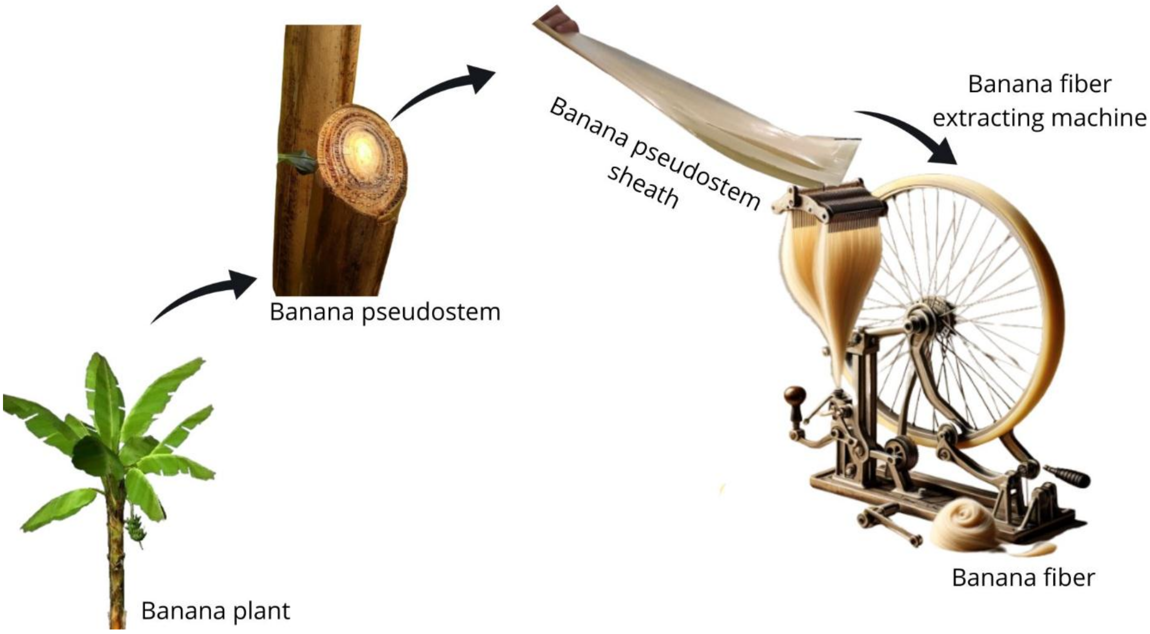


Figure 8. artisanal process and machine for extracting banana fibre. Source: Authors, 2024.

According to Veera Ajay et al. (2021), the designed machine is a commercial product that can be used by people both in rural areas and by farmers, providing them with additional income. The product was specially developed to extract fiber from the banana pseudostem. The machine's mechanism is designed in a very simple way and can be used by everyone. The main components used are structure, blade, bearing, chain, sprocket, flywheel, hard chrome blades with roller, and blunt-edged shaft.

The work of Khan et al. (2022) also explores the possibility of banana fiber as an alternative to cotton fiber in clothing applications. In addition to yarn and fabric preparation, various physical and mechanical properties of the fabrics were evaluated, leading to the conclusion that banana fibers can be used as an alternative to cotton fibers due to several inherent benefits when compared to cotton fiber.

The use of banana fiber as a proposed substitute for synthetic and natural fibers in the textile industry has emerged recently. Until then, the residues generated in banana cultivation were mostly destined for handicrafts. The leaves and other components of the pseudostem are used for the production of bags, covers, fabrics, decorative articles such as mats, curtains, rugs, baskets, items in the furniture industry, among others

(Veera Ajay et al. 2021). There is also the possibility of using the fibers for paper production for packaging, replacing traditional wood-originated paper (Ramdhonee and Jeetah 2017).

Among the many possibilities for the application of this waste, the most interesting would be those that allow for the consolidation of a business model that does not require large investments and that involve simple and easily executable techniques. All the proposals presented so far have this characteristic, with the producer capable of appropriately allocating these residues according to their purpose.

For the implementation of these business models, specific tools would be required for the adaptation of these residues to their handling, such as fiber extraction and waste shredding, as this is the most labor-intensive step. Other requirements such as labor and raw materials are available in any banana cultivation. The provision of the necessary resources for the implementation of these business models would certainly make them viable, as their agendas are based on the transformation of solid waste into a product with added value and sustainability.

V. Conclusions

There has been a significant increase in interest in investigating possible uses/final disposal of banana cultivation residues, due to its extensive global production. The growing number of publications on the topic is bringing forth various possibilities for utilization. Among the many options mentioned in this article, creating a business model for the BOP using residues generated in banana cultivation becomes feasible in all of them, and yet, complex tools are not necessary for adapting these residues to their application.

There are numerous justifications that enhance banana cultivation as a source of income and social-economic growth for the poorest segment of the population, with the most important highlighted in this review being: (I) banana cultivation is a globally extensive activity, and bananas are one of the most consumed fruits in the world; (II) A large volume of waste is generated in this activity, and without proper disposal, it causes serious damage to the environment and soil; (III) For all the presented applications, there is a need for simple treatment of the residues, such as shredding, drying, and bleaching. This facilitates the implementation of a business model for the BOP, as it does not require a large investment; (IV) The majority of banana production is concentrated in the hands of micro and small producers; (V) Sustainable development.

It is hoped that this review will reach a wide audience, and that the idea of using banana cultivation residues as a business model for low-income families becomes an increasingly recurrent path.

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