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# Sustainable Bioeconomy Development in the Global South

Volume II Bioeconomy Techniques





# Processing Techniques for Bio-based Products in the Global South

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## Abstract

This chapter delves into the processing techniques for bio-based products in the Global South, emphasizing the intersection of traditional methods and modern advancements. The analysis begins with defining bio-based products and their importance in the context of sustainable development and environmental conservation. It explores the historical background and common traditional methods, particularly focusing on fermentation techniques prevalent in West Africa. The chapter then transitions to modern processing techniques, highlighting their potential to enhance efficiency and product quality while addressing challenges such as economic constraints and technical difficulties. The socioeconomic impacts of these processing activities are examined, noting their influence on small-scale farmers, gender dynamics, and the broader community. The discussion also encompasses the environmental benefits of adopting sustainable practices. The chapter concludes by identifying opportunities for innovation and growth in the bio-based products sector, advocating for policies and investments that support sustainable processing practices. Through this comprehensive analysis, the chapter provides insights into the challenges and opportunities within

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the processing of bio-based products, offering a pathway toward sustainable development in the Global South.

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**Keywords**

Bio-based products · Global South · Traditional processing techniques · Fermentation · Sustainable development

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**Abbreviations**

FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
ICT	Information and Communication Technology
SDGs	Sustainable Development Goals
SMEs	Small and Medium-sized Enterprises
GMO	Genetically Modified Organisms
HPP	High-Pressure Processing
SFE	Supercritical Fluid Extraction
UAE	Ultrasound-Assisted Extraction
R&D	Research and Development

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**1 Introduction****1.1 Definition and Importance of Bio-based Products**

Bio-based products are derived from biological materials and renewable sources such as plants, animals, and microorganisms (Salazar Sandoval et al., 2024). Unlike conventional products that rely on fossil fuels, bio-based products offer a sustainable alternative, reducing dependency on nonrenewable resources and mitigating environmental impacts. These products span a wide range of industries, including agriculture, pharmaceuticals, textiles, energy, and consumer goods (Moreno et al., 2020). Examples include biofuels, biodegradable plastics, natural fibers, and biopharmaceuticals.

Bio-based products play a crucial role in promoting environmental sustainability by significantly reducing carbon footprints and mitigating climate change (Andrew & Dhakal, 2022). Unlike fossil fuel-based products, bio-based products are derived from renewable resources such as plants, animals, and microorganisms. This shift to renewable resources helps conserve biodiversity and maintain natural ecosystems, as it reduces reliance on nonrenewable, polluting resources (Singh, 2024). Furthermore, the use of bio-based products in various industries can lower

greenhouse gas emissions, contributing to global efforts to address climate change and fostering a more sustainable future.

The bioeconomy, centered around bio-based products, is a powerful driver of economic development, especially in rural areas of the Global South (Taron & Gebrezgabher, 2024). By creating new markets and job opportunities, it can boost incomes for farmers and entrepreneurs involved in the sector. This economic stimulation can lead to broader rural development, reducing poverty and improving living standards in these communities. The diversification of income sources through the production and sale of bio-based products can also make local economies more resilient to external shocks, such as market fluctuations and environmental changes (Delgado et al., 2024).

In addition to environmental and economic benefits, bio-based products enhance resource efficiency by utilizing agricultural residues, organic waste, and other biomass that would otherwise go to waste (Agoh et al., 2024; Kosoe & Ogwu, 2024; Ogwu et al., 2024). This approach supports a circular economy where materials are reused and recycled, minimizing waste and making the most of available resources. The development and production of bio-based products drive innovation in biotechnology, materials science, and industrial processes, leading to technological advancements with broad applications (Ramchuran et al., 2023). These innovations not only improve the efficiency and sustainability of production methods but also open new possibilities for creating high-value products from renewable resources, further solidifying the importance of bio-based products in addressing critical global challenges.

## 1.2 Overview of the Global South Context

The term “Global South” refers to regions encompassing Africa, Latin America, Asia, and Oceania, which are generally characterized by lower income levels, less industrialization, and varied socioeconomic development compared to the Global North. The Global South is home to a significant portion of the world’s biodiversity and biomass resources, making it a crucial player in the bio-based economy (Rawat et al., 2023).

In the context of the Global South, several key factors shape the landscape for bio-based products (Mandree et al., 2023). Firstly, many countries in this region boast vast agricultural lands and favorable climates for growing a wide range of crops. This agricultural abundance provides a rich supply of raw materials necessary for the development of bio-based products. The diversity of crops grown across these regions supports a variety of bio-based industries, from biofuels to biodegradable materials, offering significant potential for growth and diversification within the local economies (Holland & Shapira, 2024).

Secondly, the Global South is home to a wealth of indigenous and traditional knowledge systems that offer valuable insights into sustainable resource management and processing techniques (Ogwu & Osawaru, 2022). These traditional practices, honed over generations, can enhance the development of bio-based products

by providing environment-friendly and culturally appropriate methods. Leveraging this knowledge can lead to innovations that are not only sustainable but also deeply rooted in local contexts, thereby increasing acceptance and effectiveness within communities.

However, despite these advantages, many regions in the Global South face significant economic challenges that hinder the development and commercialization of bio-based products (Mengal et al., 2018). Limited access to capital, inadequate infrastructure, and insufficient market access pose major barriers. Additionally, there is often a technological divide between the Global South and the more industrialized Global North. Bridging this gap requires substantial investments in education, research, and technology transfer. Government policies and regulatory frameworks are also crucial in either supporting or hindering the growth of the bio-based sector (Philippidis et al., 2024). Policies promoting renewable energy, sustainable agriculture, and innovation can drive progress, while unfavorable regulations can stifle development. Social dynamics, including gender roles and community structures, further influence the adoption and impact of bio-based products (Garmendia-Lemus et al., 2024). Empowering marginalized groups, such as women and small-scale farmers, is essential for maximizing the socioeconomic benefits of the bio-based economy.

### 1.3 Objectives of the Chapter

This chapter aims to provide a comprehensive understanding of processing techniques for bio-based products in the Global South by examining both traditional and modern methods. It highlights the advantages, limitations, and applicability of these techniques in various contexts. Sustainable practices are a key focus, exploring methods that minimize environmental impact, enhance resource efficiency, reduce waste, and conserve energy. By discussing the economic, technical, and social challenges faced in developing bio-based products, the chapter identifies opportunities for innovation, investment, and collaboration. The socioeconomic impacts on local communities, particularly small-scale farmers and gender dynamics, are assessed through illustrative case studies.

Additionally, the chapter reviews the role of government policies, international aid, and partnerships in supporting the bio-based sector, highlighting successful frameworks and initiatives that can be adapted or replicated. It explores emerging technologies and trends in bio-based processing, identifying potential areas for future research and development to drive the growth of the bioeconomy in the Global South. By addressing these objectives, the chapter offers a holistic view of the current state and prospects of bio-based processing techniques, providing valuable insights for researchers, policymakers, and practitioners in the field.

## 2 Traditional Processing Techniques

### 2.1 Historical Background

Traditional processing techniques for bio-based products have deep roots in the cultural and historical contexts of the Global South (Cuestas-Caza et al., 2024). These methods have been developed and refined over centuries, often passed down through generations as part of indigenous knowledge systems. Historically, traditional processing techniques were not only a means of producing goods but also a way to preserve food, create materials for everyday use, and maintain cultural practices and rituals (Long, 2024). These methods reflect the ingenuity and adaptability of local communities who, in the absence of modern technology, found effective ways to utilize natural resources for their daily needs.

In many communities, these techniques are intimately linked with local biodiversity and ecological systems, reflecting a deep understanding of and respect for the natural environment (Egboduku et al., 2024; Reyes-García et al., 2024). For instance, in various parts of Africa, Asia, and Latin America, traditional practices are tailored to the specific types of crops and natural resources available in each region. This relationship between traditional processing methods and local biodiversity ensures that these techniques are sustainable and environment-friendly (Onwuka & Adu, 2024). For example, the use of native plant species for food, textiles, and medicinal preparations not only provides for the community's needs but also encourages the conservation of local flora.

The reliance on locally available resources and simple tools makes traditional processing techniques both accessible and sustainable (Kibria et al., 2024). These methods typically require minimal external inputs and are adapted to local conditions, making them resilient in the face of economic and environmental changes. For example, sun drying, a common preservation method, uses the natural heat from the sun to reduce moisture content in fruits, vegetables, and grains. This process requires no electricity or sophisticated equipment, making it an ideal solution for communities with limited access to modern technology.

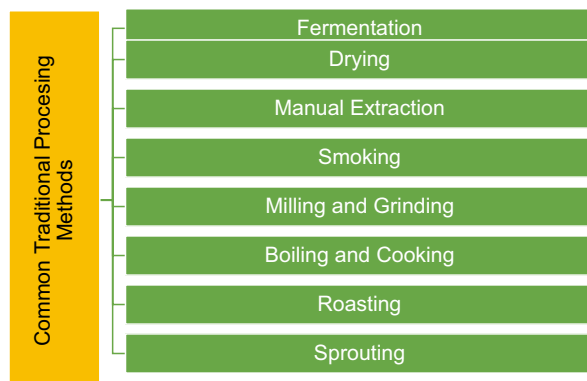
Moreover, traditional processing techniques often involve communal activities, reinforcing social bonds and cultural heritage (Ardana et al., 2024). The knowledge and skills required for these methods are usually shared among community members, ensuring that everyone, including future generations, can benefit from this collective wisdom. This communal aspect not only helps in the efficient management of resources but also strengthens community ties (Akinola et al., 2020). For example, in many African and Asian communities, the production of fermented foods or the extraction of plant oils is often a collective effort, with different members contributing to various stages of the process. This collaborative approach not only distributes the labor but also fosters a sense of unity and shared purpose.

## 2.2 Common Traditional Methods

Traditional food processing methods in the Global South encompass a variety of techniques that have been developed over generations to maximize the nutritional value, flavor, and preservation of local foods (Naika et al., 2024). These methods are deeply intertwined with the cultural practices and ecological knowledge of different ethnic groups across the country. They leverage locally available resources and simple, often low-tech tools, making them accessible and sustainable for rural and urban communities alike. The primary goal of these methods is to ensure food safety and longevity, while also enhancing the sensory qualities of food to suit local tastes and dietary preferences. These traditional techniques are not only a testament to the ingenuity of Nigerian culinary practices but also play a crucial role in maintaining food security and cultural heritage (Swinbank & Swinbank, 2021). Some of the common traditional methods are shown in Fig. 1 and explained below.

- (i) *Fermentation*: Fermentation is one of the most ancient and widespread traditional processing techniques (Sionek et al., 2023). It involves the biochemical transformation of organic substrates by microorganisms, such as bacteria, yeast, and fungi. In the Global South, fermentation is used to produce a variety of foods and beverages. For instance, in West Africa, traditional fermentation techniques are used to produce products like gari (fermented cassava), *Ogi* (fermented cereal porridge), and palm wine. These methods not only enhance the nutritional value and digestibility of foods but also improve their shelf life.
- (ii) *Drying*: Sun drying is another traditional method commonly used to preserve fruits, vegetables, grains, and fish (Arslan & Alibaş, 2024). This technique involves exposing food items to direct sunlight for extended periods, reducing their moisture content and inhibiting the growth of spoilage microorganisms. Sun drying is widely practiced in regions with hot and dry climates, such as parts of Africa and South Asia (Elsamanoudy et al., 2024). It is an energy-efficient method that requires minimal infrastructure and costs.

**Fig. 1** Common traditional processing methods



- (iii) *Manual Extraction*: Manual extraction methods are used to obtain oils, fibers, and other valuable components from plants and animals (Bhatia et al., 2024). For example, traditional methods for extracting coconut oil in Southeast Asia involve grating the coconut, extracting the milk, and then heating it to separate the oil. Similarly, in parts of Africa, shea butter is traditionally extracted by crushing and roasting shea nuts, followed by boiling and skimming off the butter.
- (iv) *Smoking*: Smoking is used to preserve meat and fish. This method involves exposing food to smoke from burning wood or other plant materials, which imparts a distinct flavor and helps to prevent microbial growth (Nizio et al., 2023). Traditional smoking techniques vary widely but are commonly used in coastal and riverine communities in the Global South.
- (v) *Milling and Grinding*: Manual milling and grinding of grains and seeds have been practiced for millennia. These techniques involve the use of simple tools like stones, mortars, and pestles to process raw materials into flours and pastes. This is a critical step in the preparation of staple foods such as maize flour in Latin America and millet flour in parts of Africa.
- (vi) *Boiling and Cooking*: Boiling and cooking are fundamental techniques used to prepare a variety of Nigerian dishes (Omoniyi & Cosmas, 2024). These methods are employed to soften foods, improve their flavor, and make them safe for consumption. For instance, yams, a staple tuber, are often boiled or pounded to make “pounded yam,” a popular dish served with various soups. Boiling is also essential in the preparation of “beans,” which are cooked until tender and often mashed or stewed (Oyeneye et al., 2023). Cooking techniques in Nigeria often involve the use of traditional earthenware pots and open fires, which impart distinct flavors to the food.
- (vii) *Roasting*: Roasting is another traditional method used to enhance the flavor and texture of foods. This technique involves cooking food over an open flame or hot coals (Chobot et al., 2024). In Nigeria, plantains and maize are commonly roasted as street foods. Roasting is also used in the preparation of “groundnuts” (peanuts), which are roasted to create a popular snack and ingredient in various dishes. The roasting process not only improves the taste but also reduces moisture content, thereby extending the shelf life of the food.
- (viii) *Sprouting*: Sprouting is a technique used to improve the nutritional value of grains and legumes. By soaking and allowing seeds to germinate, enzymes are activated that increase the availability of vitamins and minerals. In Nigeria, sprouted grains are used to make traditional beverages like “malt drinks,” which are enjoyed for their refreshing taste and nutritional benefits. Sprouting also enhances the digestibility of grains, making them more suitable for consumption by children and the elderly (Miyahira et al., 2021).

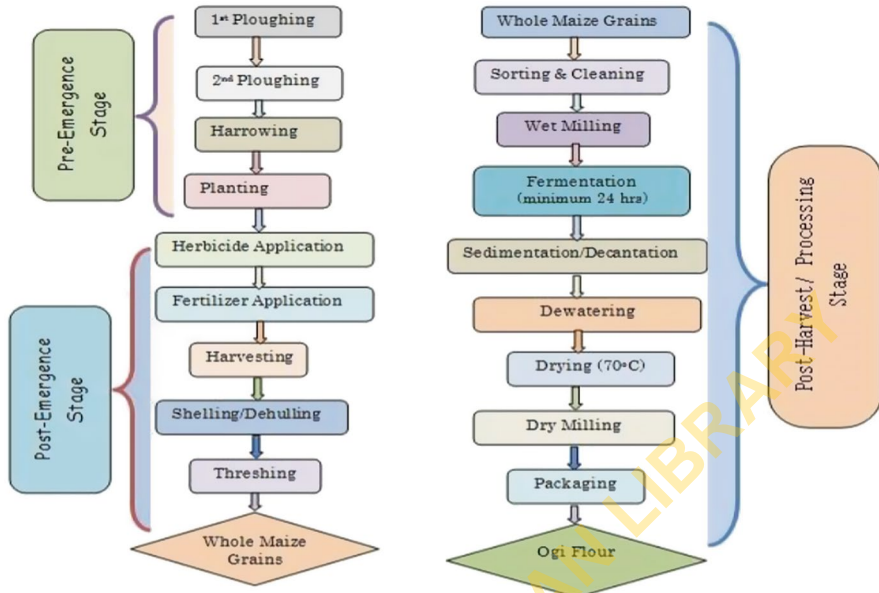
### 2.3 Case Study: Fermentation Techniques in West Africa

In West Africa, traditional fermentation techniques are integral to the region's food culture and economy. Fermentation is used to process a variety of staple foods, enhancing their flavor, nutritional value, and shelf life (Murali et al., 2024). One prominent example is the production of *gari*, a fermented and roasted product made from cassava.

**Gari Production** The process begins with peeling and washing cassava roots, which are then grated into a pulp. The grated cassava is placed in bags and left to ferment for several days. During fermentation, naturally occurring lactic acid bacteria break down the carbohydrates in the cassava, producing lactic acid and other compounds that contribute to the distinctive sour taste of *gari*. After fermentation, the cassava pulp is pressed to remove excess water, sieved to remove fibrous materials, and then roasted in large pans until it becomes dry and crispy. The final product is a coarse flour that can be stored for long periods and is used to prepare various dishes. The unit operations involved in *gari* production are shown in Fig. 2.



**Fig. 2** Gari production processes ([Goodwaychina.com](http://Goodwaychina.com))



**Fig. 3** Production stages of *Ogi* (Tulagha et al., 2021)

**Ogi Production** Ogi is another traditional fermented product made from grains such as maize, sorghum, or millet. The grains are soaked in water for several days to initiate natural fermentation. After soaking, the grains are wet-milled and the resulting slurry is sieved to remove husks. The liquid obtained is allowed to ferment further until it forms a thick, sour paste. Ogi is typically cooked into a smooth porridge and is a staple food for infants and adults alike. The production line of Ogi is shown in Fig. 3.

**Palm Wine Production** Palm wine is a traditional alcoholic beverage deeply embedded in the cultural and social fabric of many communities in Nigeria and other parts of West Africa (Adebola, 2024). This unique drink is made from the sap of various species of palm trees, such as the oil palm (*Elaeis guineensis*), date palm (*Phoenix dactylifera*), and raffia palm (*Raphia hookeri*). The process begins with the skillful tapping of the tree, which involves making a careful incision on the trunk or the flower stalk to access the sap. Collectors typically use a sharp, sterilized tool to ensure the sap flows freely into containers, often fashioned from natural materials like calabashes or more modern plastic containers. The sap begins to flow almost immediately, often yielding several liters in a single day. The collected sap undergoes natural fermentation, driven by wild yeasts and bacteria present in the environment and on the tree itself. This spontaneous fermentation starts almost as soon as the sap is collected, causing the sugar-rich liquid to transform into a mildly alcoholic beverage within hours. Palm wine is traditionally consumed fresh due to its

rapid fermentation process, which continues to change its taste and alcohol content over time. When freshly tapped, palm wine is sweet, with a relatively low alcohol content and a slightly effervescent quality. As fermentation progresses, the drink becomes more sour and alcoholic, sometimes reaching significant potency if left to ferment for several days. This variability in taste and strength makes palm wine a versatile beverage enjoyed at different stages of fermentation. Fresh palm wine is often consumed in social gatherings, rituals, and ceremonies, symbolizing hospitality, and community. The drink's deep cultural significance, coupled with its unique and evolving flavor profile, makes palm wine a cherished part of the culinary heritage in Nigeria and beyond.

These traditional fermentation techniques illustrate the ingenuity and adaptability of West African food processing methods. They not only provide essential nutrients and flavors but also offer economic opportunities for small-scale producers. The production and sale of fermented products like gari and palm wine are vital sources of income for many rural communities. Furthermore, these techniques are environmentally sustainable, as they rely on locally available materials and natural processes. By preserving and enhancing traditional fermentation methods, there is significant potential to improve food security and economic resilience in West Africa.

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### 3 Modern Processing Techniques

Modern processing techniques represent a departure from traditional methods, incorporating innovative technologies and advanced equipment to improve efficiency, quality, and scalability (Kolasani, 2024). These methods harness the power of science and engineering to address contemporary challenges such as food security, sustainability, and economic development. Unlike traditional techniques, which often rely on manual labor and natural processes, modern methods leverage automation, precision, and data analytics to optimize production processes and ensure consistency in product quality.

#### 3.1 Integration of Technology in Processing

The integration of technology in processing has revolutionized the way bio-based products are manufactured, enabling faster production, better quality control, and reduced environmental impact (Adeleke et al., 2024). Automation and robotics play a significant role in modern processing facilities, streamlining repetitive tasks and minimizing human error. For example, in the production of biofuels, automated systems are used to monitor fermentation processes, control temperature, and pH levels, and harvest microorganisms with precision. Additionally, advances in sensors and monitoring devices allow for real-time tracking of key parameters, ensuring optimal conditions throughout the production process (Arinze et al., 2024).

Furthermore, modern processing techniques often incorporate renewable energy sources and sustainable practices to minimize carbon footprint and resource consumption (Ninduwezuor-Ehiobu et al., 2023). For instance, solar drying technologies are increasingly being adopted in the Global South to preserve agricultural products such as fruits, vegetables, and grains. Solar dryers harness the energy from sunlight to heat and dehydrate food items, reducing moisture content and preventing spoilage. This method not only extends the shelf life of perishable goods but also reduces dependency on fossil fuels and mitigates greenhouse gas emissions. The integration of solar drying technology exemplifies the convergence of modern processing methods with sustainable solutions, highlighting the potential for innovation in addressing pressing global challenges (Ukoba et al., 2024). Some common modern processing techniques and their description are shown in Table 1.

These modern processing techniques represent advancements in science and technology that enable more efficient, sustainable, and innovative approaches to manufacturing and production across different industries.

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## 4 Challenges and Opportunities

### 4.1 Economic Constraints

Economic constraints present formidable challenges to the advancement of processing techniques for bio-based products in the Global South (Hassan et al., 2019). One of the primary hurdles is the limited access to capital, financing, and investment opportunities, especially for small-scale producers and entrepreneurs. These individuals often lack the collateral or credit history required to secure loans from traditional financial institutions. As a result, they face difficulties in obtaining the necessary funding to establish or expand processing facilities, purchase equipment, or invest in technology upgrades. This financial barrier stifles innovation and growth in the bio-based processing sector, particularly among marginalized communities who are most in need of economic opportunities.

Moreover, the high upfront costs associated with equipment, infrastructure, and technology upgrades exacerbate the financial challenges faced by bio-based product manufacturers in the Global South (Moshood et al., 2021). Investing in modern processing technologies and facilities requires substantial capital investment, which may be prohibitive for many small and medium-sized enterprises (SMEs). Without access to affordable financing options, these businesses struggle to modernize their operations or scale up production to meet growing demand (Gürsu, 2024). Additionally, fluctuating market prices, inadequate market infrastructure, and limited market access further compound the economic constraints faced by bio-based product manufacturers. Uncertainties in market conditions make it challenging for businesses to forecast revenues and plan for long-term sustainability.

Addressing economic constraints in the bio-based processing sector necessitates the implementation of innovative financing mechanisms, public-private partnerships, and supportive policies (Lange et al., 2021). Innovative financing

**Table 1** Modern processing techniques

S/N	Modern processing technique	Description
1.	Biotechnology	Biotechnology involves the manipulation of biological systems and organisms to develop products or processes. This can include genetic engineering to create genetically modified organisms (GMOs) for improved crop yields or the production of enzymes for industrial applications
2.	Nanotechnology	Nanotechnology involves the manipulation of materials at the nanoscale (typically 1–100 nanometers) to create new properties or functionalities. In food processing, nanotechnology may be used to enhance packaging materials for better preservation or to develop nanoemulsions for improved delivery of nutrients or flavors
3.	High-pressure processing (HPP)	HPP is a nonthermal processing technique that uses high-pressure water to deactivate microorganisms and enzymes in food products. This method preserves the nutritional quality and sensory attributes of foods while extending shelf life
4.	Extraction technologies	Modern extraction technologies such as supercritical fluid extraction (SFE) and ultrasound-assisted extraction (UAE) use advanced methods to extract bioactive compounds from raw materials. These techniques offer higher extraction efficiencies and reduced processing times compared to traditional solvent extraction methods
5.	Membrane separation	Membrane separation processes, including microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, are used to separate components in liquid or gas streams based on molecular size and properties. These processes are commonly used in the food and beverage industry for concentration, purification, and fractionation of products
6.	Electrospinning	Electrospinning is a technique used to produce nanofibers from polymer solutions or melts by applying an electric field. These nanofibers have a high surface area-to-volume ratio and can be used in various applications, including food packaging, tissue engineering, and drug delivery systems
7.	Microwave and radio frequency heating	Microwave and radio frequency heating technologies use electromagnetic waves to generate heat within food products. These methods offer rapid and uniform heating, making them suitable for thawing, drying, and pasteurization processes in the food industry
8.	Enzyme engineering	Enzyme engineering involves the modification or design of enzymes to improve their catalytic activity, stability, or substrate specificity. Engineered enzymes are used in various industrial processes, including food processing, biofuel production, and pharmaceutical manufacturing, to enhance efficiency and reduce environmental impact

(continued)

**Table 1** (continued)

S/N	Modern processing technique	Description
9.	Supercritical fluid technology	Supercritical fluids, such as carbon dioxide or water, are used as solvents in extraction, separation, and purification processes. Supercritical fluid technology offers advantages such as high selectivity, low toxicity, and minimal environmental impact compared to traditional solvent-based methods
10.	Continuous flow processing	Continuous flow processing involves the continuous movement of materials through a series of interconnected processing units, as opposed to batch processing. This approach allows for greater control over reaction conditions, higher throughput, and reduced energy and resource consumption
11.	Green chemistry	Green chemistry, also known as sustainable chemistry, focuses on the design of chemical products and processes that minimize environmental impact and maximize efficiency. Green chemistry principles are applied across various industries to develop safer and more sustainable alternatives to conventional chemical processes
12.	Hydrothermal processing	Hydrothermal processing involves the treatment of materials with hot, pressurized water or steam to facilitate chemical reactions or physical transformations. This technique is used in applications such as biomass conversion, waste treatment, and the production of functional materials
13.	Electron beam processing	Electron beam processing uses high-energy electron beams to irradiate materials for sterilization, cross-linking, or modification. This technique is employed in medical device sterilization, food irradiation, polymer modification, and semiconductor manufacturing
14.	Cold plasma processing	Cold plasma, or nonthermal plasma, is used to treat surfaces or materials for sterilization, decontamination, or surface modification. Cold plasma processing offers advantages such as rapid treatment, low energy consumption, and compatibility with sensitive materials
15.	Cryogenic processing	Cryogenic processing involves the use of very low temperatures, typically below $-150\text{ }^{\circ}\text{C}$ ( $-238\text{ }^{\circ}\text{F}$ ), to enhance the properties of materials. Cryogenic processing is used in metallurgy, electronics, and food processing to improve wear resistance, toughness, and shelf life
16.	Hybrid processing technologies	Hybrid processing technologies combine multiple techniques, such as thermal, mechanical, and electromagnetic methods, to achieve synergistic effects and improve processing efficiency. These hybrid approaches are used in materials processing, chemical synthesis, and manufacturing processes to overcome the limitations of individual techniques.
17.	Advanced sensing and control systems	Advanced sensing and control systems integrate sensors, actuators, and automation technologies to monitor and optimize process parameters in real time. These systems enable precise control over manufacturing processes, leading to improved product quality, consistency, and efficiency

mechanisms, such as microfinance initiatives, venture capital funds, and impact investment funds, can provide much-needed capital to SMEs and entrepreneurs in the Global South. Public–private partnerships can facilitate knowledge sharing, technology transfer, and capacity-building initiatives, enabling businesses to access the expertise and resources needed for growth. Supportive policies that incentivize investment in bio-based processing enterprises, particularly those operating in rural and underserved areas, are essential for creating an enabling environment for economic development and sustainable livelihoods (Virgin et al., 2022). By overcoming economic constraints, the bio-based processing sector can unlock its full potential as a driver of inclusive growth, environmental sustainability, and social resilience in the Global South.

## 4.2 Technical and Infrastructure Challenges

Technical and infrastructure challenges pose significant barriers to the efficient and effective processing of bio-based products in the Global South (Hlangwani et al., 2023). One of the primary challenges is inadequate access to reliable energy, water, and sanitation infrastructure, particularly in remote or off-grid locations where many processing facilities are situated. Without reliable access to these essential resources, processing operations are often hindered, leading to disruptions in production schedules and increased operational costs. Moreover, unreliable energy sources may limit the adoption of energy-intensive processing technologies, further impeding productivity and efficiency (Usman et al., 2024).

Additionally, insufficient technical expertise and skilled labor present significant challenges to the adoption of advanced processing technologies and techniques in the Global South (Miah et al., 2024). Many small-scale producers and entrepreneurs lack the necessary training and expertise to effectively operate and maintain modern processing equipment. This hampers their ability to implement best practices in processing, leading to issues such as inconsistent product quality, low yields, and increased waste. Furthermore, the shortage of skilled labor exacerbates the challenge of adopting innovative processing techniques, hindering the sector's ability to keep pace with technological advancements and market demands (Nizzy & Ogwu, 2024; Sima et al., 2020).

Furthermore, outdated or insufficient processing equipment and facilities constrain the capacity and capability of bio-based product manufacturers in the Global South (Gatica-Neira & Ramos-Maldonado, 2022). Many processing facilities in the region are equipped with outdated or inadequate machinery, which limits their ability to scale up production and meet growing demand. Moreover, the lack of modern processing equipment and facilities hampers the sector's competitiveness in both domestic and international markets, where quality standards and efficiency are paramount.

Addressing technical and infrastructure challenges requires a multifaceted approach that includes targeted investments in capacity building, technology transfer, and infrastructure development (Odeyemi et al., 2024). Governments,

international organizations, and development agencies can play a crucial role in providing financial support and technical assistance to upgrade existing processing facilities and build new infrastructure where needed. Moreover, fostering collaboration between industry, academia, and government institutions is essential for promoting knowledge sharing and skills development. By investing in technical capacity and infrastructure development, the Global South can unlock the full potential of its bio-based processing sector, driving economic growth, innovation, and sustainability.

### 4.3 Potential for Innovation and Growth

Despite the myriad challenges, the bio-based processing sector in the Global South holds significant potential for innovation and growth (Stark et al., 2022). The region's rich biodiversity, abundant natural resources, and diverse agricultural landscapes offer fertile ground for the development of novel bio-based products and processing techniques. With unique raw materials at their disposal, entrepreneurs and researchers have the opportunity to explore innovative solutions that can address local needs while also catering to global markets.

Advancements in biotechnology, nanotechnology, and green chemistry further bolster the potential for innovation in bio-based processing (Wagh et al., 2024). These cutting-edge fields offer new avenues for enhancing the efficiency, sustainability, and value proposition of bio-based products. For instance, biotechnology enables the development of genetically engineered crops with improved traits for processing, while nanotechnology facilitates the creation of nanostructured materials with enhanced properties for various applications.

Moreover, the growing consumer demand for sustainable and eco-friendly products presents favorable market conditions for innovation and growth in the bio-based processing sector (Liu et al., 2024). Consumers are increasingly seeking alternatives to conventional products that are derived from fossil fuels and contribute to environmental degradation. Bio-based materials offer a promising solution, as they are renewable, biodegradable, and often have lower environmental footprints compared to their synthetic counterparts.

Additionally, there is a growing recognition of the environmental and social benefits of bio-based materials, further driving interest and investment in the sector. Governments, businesses, and civil society organizations are increasingly embracing bio-based solutions as part of their sustainability strategies, creating a conducive environment for innovation and growth (Sadhukhan et al., 2023). To fully harness the potential of the bio-based processing sector in the Global South, it is essential to leverage indigenous knowledge, traditional practices, and local resources. Strategic investments in research and development, coupled with supportive policies and partnerships, can catalyze innovation and drive economic development, environmental sustainability, and social inclusion in the region. By embracing innovation and fostering collaboration, the Global South can position itself as a leader in bio-based processing, contributing to a more sustainable and resilient future.

## 5 Socioeconomic Impacts

### 5.1 Impact on Small-Scale Farmers

The socioeconomic impacts of bio-based processing in the Global South present a complex interplay of opportunities and challenges, particularly for small-scale farmers (Stark et al., 2022). On the one hand, bio-based processing opens up new avenues for income generation by providing markets for agricultural produce. Through the transformation of raw materials into value-added products like biofuels, bio-based chemicals, or natural fibers, small-scale farmers can effectively capture more value from their crops and augment their incomes. This added value enhances the economic viability of farming activities and contributes to the financial sustainability of rural livelihoods.

Moreover, bio-based processing enables small-scale farmers to diversify their income sources, thereby reducing their dependency on a single crop or commodity (Feleke et al., 2021). By branching out into processing activities, farmers can mitigate the risks associated with fluctuations in market prices and demand for raw agricultural produce. Diversification also serves as a means of hedging against crop failures or adverse weather conditions, enhancing the resilience of small-scale farming enterprises in the face of economic uncertainties.

However, despite the potential benefits, small-scale farmers encounter various challenges in engaging with bio-based processing (Gontard et al., 2018). Access to markets remains a significant hurdle, particularly for those located in remote or underserved areas with limited transportation infrastructure. Many farmers lack the necessary resources and technical knowledge to invest in processing equipment, storage facilities, and transportation networks. Moreover, the transition to bio-based processing often necessitates acquiring new skills and knowledge, which may not be readily available or accessible to small-scale farmers. Additionally, navigating competitive global markets, which prioritize economies of scale and stringent quality standards, poses further barriers for small-scale producers seeking to market their processed products internationally (Mukherjee, 2018).

Addressing these challenges requires a holistic approach that combines targeted investments in infrastructure, capacity building, and market access with supportive policies and interventions. By empowering small-scale farmers with the resources, skills, and opportunities needed to engage in bio-based processing, policymakers, development agencies, and other stakeholders can unlock the full potential of the sector to drive economic development, enhance food security, and promote sustainable livelihoods in the Global South.

### 5.2 Gender Dynamics in Processing Activities

Gender dynamics play a pivotal role in shaping the landscape of bio-based processing activities in the Global South, influencing the participation, roles, and outcomes of both men and women (Bhujel & Joshi, 2024). While women are often heavily

involved in agricultural production and processing activities, their contributions tend to be undervalued and overlooked compared to their male counterparts. Despite being actively engaged in tasks such as harvesting, sorting, and processing crops, women typically receive lower wages and have fewer opportunities for advancement within the agricultural value chain.

Moreover, women in the Global South face additional hurdles in accessing resources critical for engaging in bio-based processing activities (Mandal et al., 2024). Factors such as limited access to land ownership, credit facilities, and training opportunities hinder women's ability to fully participate in and benefit from bio-based processing initiatives. These disparities not only perpetuate economic inequalities but also constrain the overall potential for inclusive growth and sustainable development in rural communities.

Furthermore, entrenched gender norms and stereotypes contribute to the unequal division of labor and decision-making processes within households and communities. Women are often burdened with unpaid care work, including childcare and household chores, which can significantly limit their time and opportunities for engaging in income-generating activities such as bio-based processing (Lightman & Kevins, 2021). Additionally, cultural and social barriers may further restrict women's mobility and participation in public spaces, hindering their access to markets, training, and information relevant to bio-based processing ventures.

Addressing gender disparities and promoting gender equality in bio-based processing necessitates targeted interventions aimed at dismantling structural barriers and empowering women to fully participate in economic activities. This includes initiatives to improve women's access to resources such as land, credit, and training, as well as efforts to challenge traditional gender roles and norms that limit women's economic agency. By ensuring equitable access to resources and opportunities for both men and women, bio-based processing initiatives can contribute to more inclusive and sustainable development outcomes in the Global South.

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## **6 Policy and Support Mechanisms**

### **6.1 Role of Government Policies**

Government policies wield significant influence in shaping the landscape of bio-based processing activities across the Global South (Brandão & Santos, 2024). A well-crafted regulatory framework provides the foundation for fostering growth and innovation within the sector while simultaneously addressing broader socioeconomic and environmental objectives. One of the pivotal roles of government policies is the establishment of an enabling regulatory environment conducive to investment and innovation in bio-based processing. This involves the formulation of clear standards, regulations, and certification schemes aimed at ensuring the quality, safety, and environmental sustainability of bio-based products. By delineating guidelines and benchmarks, governments can instill confidence among investors,

consumers, and stakeholders in the reliability and integrity of bio-based processing practices.

Furthermore, governments can employ various financial incentives, tax breaks, and subsidies to stimulate private sector investment in bio-based processing infrastructure and technology (Srivastava, 2024). These measures serve to mitigate the upfront costs and risks associated with setting up and operating processing facilities, thereby encouraging businesses to explore and expand their engagement in bio-based processing ventures. Additionally, supportive policies that prioritize sustainable land use, biodiversity conservation, and the protection of natural resources are instrumental in safeguarding the long-term viability of bio-based processing activities (Paleari, 2024). By integrating environmental considerations into policy frameworks, governments can foster a holistic approach to bio-based processing that balances economic growth with ecological sustainability.

Moreover, government policies can play a pivotal role in fostering collaboration and partnership among stakeholders within the bio-based processing ecosystem. By facilitating knowledge exchange, technology transfer, and industry-academia linkages, governments can catalyze innovation and capacity-building efforts within the sector. Furthermore, policies aimed at enhancing market access, promoting research and development, and facilitating international trade can bolster the competitiveness of bio-based processing enterprises on both domestic and global scales. By aligning policies with broader development agendas such as poverty alleviation, food security, and inclusive growth, governments can harness the transformative potential of bio-based processing to drive socioeconomic progress and environmental stewardship in the Global South.

Government policies serve as indispensable tools for steering the trajectory of bio-based processing activities in the Global South. By fostering an enabling regulatory environment, incentivizing investment and innovation, and promoting sustainable practices, policymakers can unlock the full potential of bio-based processing to contribute to the attainment of national development goals and the realization of a more sustainable future.

## **6.2 International Support and Collaboration**

International support and collaboration play indispensable roles in advancing bio-based processing initiatives across the Global South (Tiwari, 2023). Multilateral organizations, development agencies, and international donors serve as crucial partners in providing financial assistance, technical expertise, and capacity-building support to countries within the region. Through various initiatives such as technology transfer programs, knowledge-sharing platforms, and funding schemes, these international partners contribute to bridging the technological and knowledge gaps that often impede the widespread adoption of bio-based processing technologies in the Global South.

One of the primary benefits of international support is its capacity to facilitate technology transfer and knowledge exchange between developed and developing

countries. By leveraging the expertise and resources of more advanced economies, countries in the Global South can gain access to cutting-edge technologies, innovative processes, and best practices in bio-based processing. This transfer of knowledge enables local stakeholders to enhance their technical capabilities, improve production efficiency, and adapt sustainable practices tailored to their specific contexts.

Moreover, international collaboration enables countries to leverage each other's strengths and experiences, thereby accelerating the development and deployment of sustainable bio-based processing solutions (Sierra et al., 2021). By sharing lessons learned, exchanging information, and collaborating on joint research and innovation projects, countries can collectively address common challenges and capitalize on emerging opportunities in the bio-based processing sector. This collaborative approach fosters synergies among governments, academia, research institutions, and the private sector, leading to more effective and impactful interventions.

Furthermore, international support plays a vital role in mobilizing financial resources to support bio-based processing initiatives in the Global South. Through funding schemes and investment programs, international donors and development agencies provide critical financial assistance to governments, businesses, and civil society organizations involved in bio-based processing activities. This financial support enables countries to invest in infrastructure development, capacity building, and technology adoption, thereby laying the foundation for sustainable and inclusive growth in the bio-based processing sector.

International support and collaboration are indispensable for advancing bio-based processing initiatives and promoting sustainable development in the Global South (Lange et al., 2021). By leveraging the expertise, resources, and experiences of international partners, countries can accelerate the transition toward a more sustainable and resilient bio-based economy, contributing to poverty reduction, food security, and environmental conservation across the region.

Effective policy and support mechanisms are essential for unlocking the full potential of bio-based processing in the Global South (Ding et al., 2024). By implementing supportive government policies and leveraging international support and collaboration, countries can create an enabling environment for investment, innovation, and sustainable development in the bio-based processing sector. Moreover, by aligning policies with broader development objectives such as poverty reduction, food security, and environmental sustainability, governments and international partners can ensure that bio-based processing initiatives contribute to inclusive and equitable growth in the Global South.

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## **7 Future Directions and Innovations**

### **7.1 Emerging Technologies and Techniques**

The future of bio-based processing in the Global South is marked by a promising trajectory of advancements fueled by emerging technologies and innovative

techniques (Demirel et al., 2024). The rapid evolution of biotechnology, nanotechnology, and green chemistry is reshaping the landscape of bio-based processing, presenting unprecedented opportunities for enhancing efficiency, sustainability, and product diversification. Biotechnological breakthroughs, such as genetic engineering and metabolic engineering, are empowering scientists to develop novel crops with tailored traits optimized for bio-based processing (Diankristanti et al., 2024). These advancements promise higher yields, improved disease resistance, and optimized biochemical compositions, thus revolutionizing the raw material base for bio-based industries across the Global South.

Furthermore, ongoing progress in fermentation technologies, enzymatic processes, and microbial bioproduction is broadening the horizons of biomass conversion, enabling the transformation of diverse feedstocks into a wide array of valuable products (Lopresto et al., 2018). From biofuels to biopolymers and biochemicals, these cutting-edge techniques offer scalable and sustainable solutions to meet the growing demands for renewable resources and eco-friendly alternatives to conventional products. Moreover, nanotechnology is increasingly being harnessed to enhance the performance and properties of bio-based materials, unlocking new functionalities and applications. Nanostructured materials such as nanocellulose and nanoclays exhibit superior mechanical strength, barrier properties, and biodegradability, rendering them appealing alternatives across various sectors, including packaging, construction, and healthcare.

Additionally, the principles of green chemistry are driving the development of eco-friendly processes and renewable feedstocks for bio-based processing, ushering in an era of sustainable manufacturing practices that minimize waste, energy consumption, and environmental impact (Sharma et al., 2024). By prioritizing the use of renewable resources, reducing hazardous chemicals, and optimizing production processes, green chemistry offers a pathway toward a more sustainable and circular bio-based economy in the Global South. As these emerging technologies and techniques continue to evolve and mature, they hold immense potential to catalyze transformative changes, driving economic growth, environmental stewardship, and social development across the region. Through strategic investments, collaborative research efforts, and supportive policy frameworks, countries in the Global South can harness the full potential of these innovations to chart a sustainable path forward for bio-based processing.

## 7.2 Prospects for Scaling Up Successful Models

The prospects for scaling up successful models in bio-based processing across the Global South are promising as technologies mature and demonstrate their economic viability (Singh et al., 2022). Leveraging successful case studies and best practices from diverse regions, countries have the opportunity to replicate and adapt proven models to fit their local contexts and development priorities. Community-based bio-refineries and cooperative processing units represent exemplary models for decentralized bio-based processing, particularly in rural and underserved areas. These

grassroots initiatives empower local communities, create employment opportunities, and add value to agricultural produce, thereby fostering rural development and alleviating poverty.

Moreover, public–private partnerships and cross-sector collaborations have the potential to facilitate the scaling up of bio-based processing initiatives by mobilizing resources, expertise, and networks (Tran et al., 2024). Collaboration among government agencies, research institutions, industry stakeholders, and civil society organizations can foster a conducive environment for innovation and investment, enabling countries to overcome barriers and accelerate the adoption of bio-based processing technologies at scale. By pooling resources and sharing knowledge, stakeholders can collectively address challenges related to technology transfer, infrastructure development, and market access, thus promoting the widespread adoption of sustainable bio-based processing practices.

Furthermore, international cooperation and knowledge-sharing platforms play a pivotal role in disseminating best practices and building technical capacity to support the scaling up of bio-based processing initiatives in the Global South (Sierra et al., 2021). By facilitating exchange programs, collaborative research projects, and capacity-building initiatives, international partners can help countries in the region enhance their capabilities and seize opportunities for sustainable development. By fostering innovation ecosystems and fostering a culture of collaboration and learning, international cooperation contributes to the creation of an enabling environment for scaling up bio-based processing initiatives, thereby unlocking their full potential to drive economic growth, environmental sustainability, and social progress across the Global South.

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## **8 Recommendations for Future Research and Development**

Looking ahead, strategic investments in research and development (R&D) are imperative to propel innovation and tackle critical challenges in bio-based processing. Future R&D efforts should prioritize enhancing the efficiency and sustainability of bio-based processing technologies, optimizing feedstock utilization, and valorizing waste streams. By focusing on these key areas, researchers can develop solutions that not only improve the economic viability of bio-based processing but also contribute to environmental conservation and social welfare. Additionally, interdisciplinary research that integrates insights from fields such as agronomy, biotechnology, materials science, and socioeconomic analysis is essential to develop holistic solutions that strike a balance between economic, environmental, and social considerations. By fostering collaboration and knowledge exchange among experts from diverse disciplines, researchers can leverage complementary expertise to address complex challenges and maximize the impact of R&D initiatives.

Furthermore, fostering collaboration between academia, industry, and government agencies is paramount to align R&D priorities with market needs, accelerate technology transfer, and ensure the commercialization of research outcomes. By

fostering an ecosystem of collaboration and innovation, stakeholders can collectively identify and address market gaps, regulatory barriers, and technical challenges hindering the adoption of bio-based processing technologies. Moreover, investing in human capital development, education, and skills training is critical to cultivating a skilled workforce equipped with the knowledge and expertise to drive innovation and entrepreneurship in the bio-based processing sector. By investing in education and training programs that nurture talent and foster creativity, countries in the Global South can build a pool of skilled professionals capable of leading the transition toward a more sustainable and resilient bio-based economy.

By prioritizing these recommendations for future research and development, countries in the Global South can position themselves as leaders in the transition toward a more sustainable and resilient bio-based economy. By leveraging R&D investments to drive innovation, foster collaboration, and build human capital, countries can unlock new opportunities for economic growth, environmental stewardship, and social development. Through concerted efforts to advance bio-based processing technologies and practices, countries can harness the transformative potential of bio-based resources to address pressing challenges and create a more prosperous and sustainable future for all.

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## 9 Conclusion

In conclusion, the exploration of processing techniques for bio-based products in the Global South underscores the immense potential of leveraging natural resources, traditional knowledge, and emerging technologies to drive sustainable development. Throughout this discussion, we have highlighted the multifaceted benefits of bio-based processing, ranging from environmental sustainability and economic growth to social empowerment and innovation. By tapping into the rich biodiversity and agricultural abundance of the Global South, countries in the region have the opportunity to unlock new pathways for value addition, job creation, and rural development.

Moreover, our analysis has shed light on the challenges and opportunities inherent in bio-based processing, from economic constraints and technical barriers to gender dynamics and policy imperatives. While these challenges pose formidable obstacles, they also serve as catalysts for innovation, collaboration, and transformative change. By addressing these challenges through strategic investments, supportive policies, and inclusive approaches, countries can harness the full potential of bio-based processing to drive inclusive and sustainable development.

Looking ahead, strategic recommendations for future research and development underscore the importance of continued investment in innovation, capacity building, and collaboration. By prioritizing interdisciplinary research, fostering partnerships between academia, industry, and government agencies, and investing in human capital development, countries in the Global South can position themselves at the forefront of the bio-based revolution. Through concerted efforts to advance bio-based processing technologies and practices, countries can not only enhance

their economic competitiveness but also contribute to global efforts toward a more sustainable and resilient future.

In essence, the journey toward a more sustainable and inclusive bio-based economy requires collective action, shared commitment, and visionary leadership. By embracing the principles of sustainability, equity, and innovation, countries in the Global South can chart a course toward a future where bio-based processing catalyzes prosperity, resilience, and well-being for all.

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