REPORT ON DELIVERABLE 6.1

RISK MANAGEMENT STRATEGIES & MARKET OPPORTUNITIES FOR COMMERCIALISATION OF NEW BIOPOLYMER PRODUCTION TECHNOLOGIES

Proof of Principle fly larvae biorefinery for biopolymer plastic production

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. EXECUTIVE SUMMARY

This report provides a comprehensive overview of risk management strategies and market opportunities for the commercialization of new biopolymer production technologies. To ensure a broad and informed perspective, data was collected through a combination of extensive literature reviews, interviews, and workshops with key stakeholders. The objectives were multifaceted: (1) to identify the primary industry and consumer barriers to biopolymer commercialization outlined in the literature; (2) to gather stakeholders' individual and collective perceptions regarding bioplastics, focusing on business models, risks, challenges, market opportunities, and strategic recommendations; and (3) to provide insights into effective risk management strategies to address these barriers, while facilitating discussions on how to overcome them and enable the successful commercialisation of biopolymer production technologies.

Our findings reveal that the commercialization of biopolymers encounters several barriers, including technological challenges in scaling production, high production costs, a complex regulatory landscape, and consumer misconceptions. In response, we identified several key risk management strategies: fostering technological innovation to enhance production performance and scalability; fostering multidisciplinary and transdisciplinary approaches to overcome technological and knowledge limitations in biopolymer production; implementing cost-reduction measures through government incentives and private investment; harmonizing regulatory frameworks to create a supportive environment for commercialization; improving consumer awareness and product labelling to address misconceptions, build trust, thereby encouraging greater adoption of bioplastics.

The strategies discussed aim not only to mitigate existing challenges but also to unlock significant market opportunities. The growing environmental consciousness worldwide presents a promising avenue for international market expansion and innovation. Advancements in biopolymer technology enhance applicability across various industries, particularly in packaging, agriculture and biomedical sectors, all of which are actively pursuing sustainable materials. Furthermore, international market expansion and the promotion of circular economy practices present additional avenues for integrating bioplastics into sustainable production and waste management systems.

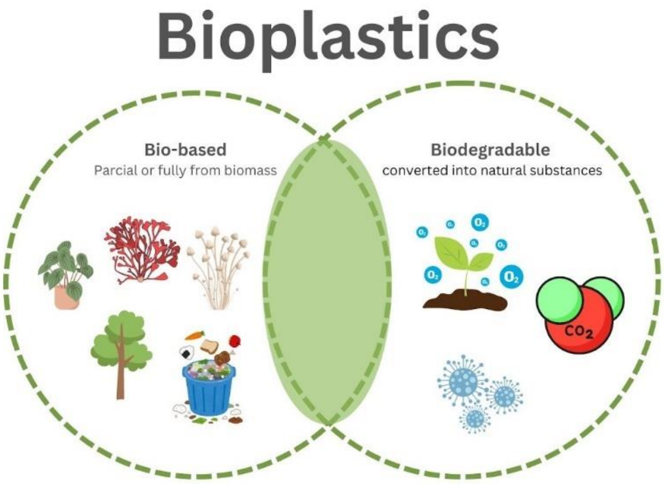
Our results indicate that by effectively navigating these challenges and capitalizing on market opportunities, the biopolymer industry has the potential to become a catalyst for transformative change, fostering the circular economy and a more environmentally responsible future.

2. INTRODUCTION

Bioplastics can be defined as plastics that are either bio-based, biodegradable, or both bio-based and biodegradable (Figure 1; Atiwesh et al., 2021; Bioplastics Europe, n.d.; European Bioplastics, 2022; European Commission, n.d.). On the one hand, "bio-based" means that the raw material used to produce the plastic is at least partially or fully derived from biomass. For example, these raw materials can be derived from plants, trees, fungi, algae, molluscs, crustaceans, bacteria, insects, as well as from organic waste through the action of several organisms (Baranwal et al., 2022). On the other hand, "biodegradable" means that the plastic can be converted into natural substances such as water, carbon dioxide and compost by different naturally occurring organisms (e.g., microbes). It should be noted that the term "biodegradable" does not specify neither the time frame nor the environmental conditions which are necessary for the natural degradation of the material (Bioplastics Europe, n.d.). For example, in the industrial context, biodegradable often refers to processes that take place in proper industrial composting facilities (Atiwesh et al., 2021).

Figure 1

Bioplastics as bio-based, biodegradable, or both

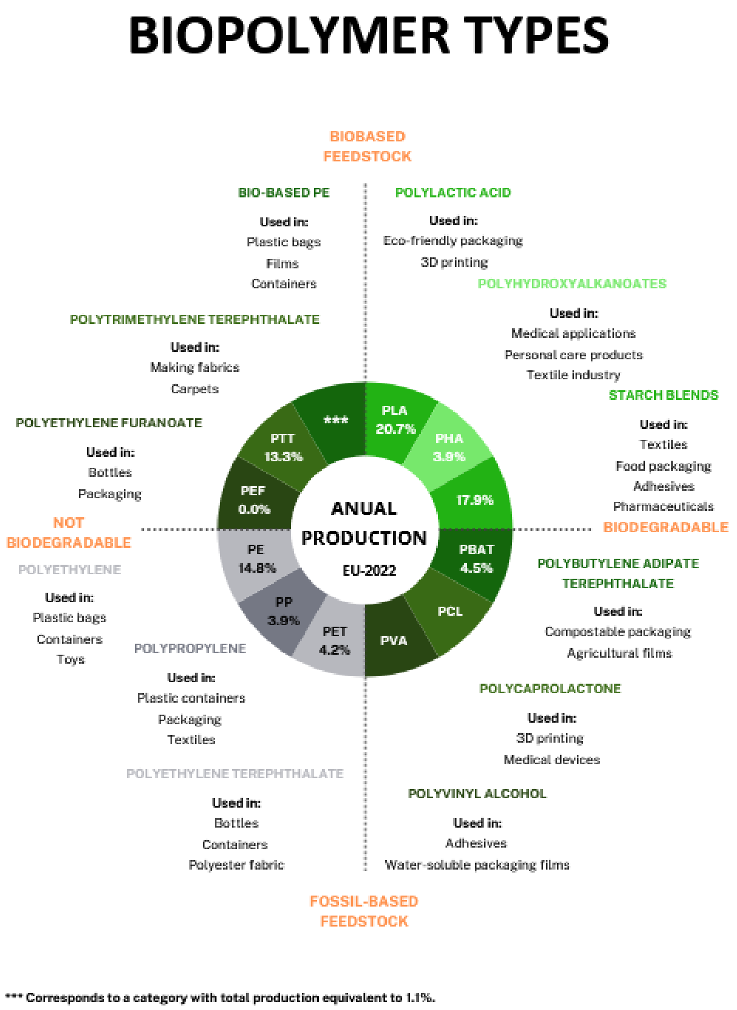


According to the European Bioplastics (2022), the main advantages of bioplastics compared to their conventional alternatives is the economy of fossil resources by using "renewable" biomass instead, and the unique potential for carbon neutrality, whereas biodegradability is an add-on property of certain types of bioplastics, offering additional means of recovery at the end of product life. In that regard, bioplastics should not be seen as a solution for inappropriate waste management or littering.

Focusing on bio-based and potentially biodegradable plastics, understanding the concept of biopolymer is also important. There are many types of biopolymers (see Figure 2). These are natural polymers produced by the cells of living organisms (Baranwal et al., 2022; Singh et al., 2021). These organic molecules can be produced from different biological sources, which include: 1) plants (e.g., starch, cellulose, alginate, carrageenan, wheat, soy, zein, natural rubber); 2) animals (e.g., collagen, gelatine, silk, chitosan and hyaluronic acid); 3) microorganisms (e.g., polyhydroxyalkanoates [PHA], chitosan, bacterial cellulose, glucan, xanthan and pullulan; and 4) renewable raw materials (e.g., lignin, tannin, and pectin; Lisitsyn et al., 2021; Luft et al., 2020). Biopolymers can also refer to molecules that are synthesised chemically but are derived from biological starting materials such as amino acids, sugars, natural fats, or oils, including polylactic acid (PLA), polycaprolactone (PCL), polybutylene succinate (PBS) and polyvinyl alcohol (PVA; Omerović et al., 2021).

Figure 2

Different types of biopolymers



The increased potential for biocompatibility, biodegradability, and reduced carbon footprint of biopolymers offers a compelling incentive to shift away from conventional plastics (Chaudhary et al., 2022; Guzman et al., 2011; Singh et al., 2021). Furthermore, the number of applications of biopolymers is countless. Many of these applications can be found in the medical industry, including drug delivery systems, wound healing, and scaffolds for tissue engineering (Chavooshi et al., 2023; Holland et al., 2019). Other applications can be found in the food and packaging industry (Salgado et al., 2021; Zhang et al., 2022); in the agriculture sector (Panoutsou et al., 2022; Pires et al., 2022); in the textile and fashion industry (Provin et al., 2021; Rognoli et al., 2022); in the technology manufacturing industry, including the medical, automotive, and aerospace and industry (Cherrington et al., 2022; Kamarudin et al., 2022); in the field of civil construction and engineering (Sáez-Pérez et al., 2020; Shyamala et al., 2020); and in the forest, water, energy, paper, and environment industries (Popp et al., 2021; Yaashikaa et al., 2023).

In this context, bioplastics, that are both bio-based and biodegradable, are emerging as promising alternatives to traditional petroleum-based polymers. In recent years, these have gained relevance due to their central role in the strategy to tackle the linear plastics challenge (European Commission, 2022; Mujtaba et al., 2022; Rendón-Villalobos et al., 2016; Shevchenko et al., 2022), and as a possible solution to mitigate or even solve some of the negative impacts that conventional plastics have on the environment (Notaro et al., 2022). Moreover, bioplastics have the added value of reducing the dependency on fossil raw materials, while promoting a shift towards circular economy and cradle-to-cradle principles (Bhagwat et al., 2020). For example, they unlock the ability to tap into the large amounts of waste (e.g., food waste) produced worldwide, that frequently ends in landfills, transforming it into new consumer goods. The circular nature inherent to the concept of bioplastics aligns with the European Union Circular Economy Package (Briassoulis, 2019), and it is seen as a main driver to foster the European Union's circular economy (European Commission, 2022).

As seen by the definition, bioplastics are a complex topic, not only for researchers working in the field (Baranwal et al., 2022; Weinrich & Herbes, 2023), but also for industry members and consumers that must deal with seemingly conflicting, unclear and uncertain information, and with concepts that are more difficult to understand than one may think (Filho et al., 2022; Weinrich & Herbes, 2023). The market success of bio-based and biodegradable plastics faces several challenges that co-occur at different levels (e.g., industry and consumer levels) and frequently interact and influence each other. For bioplastics to succeed such challenges and barriers need to be identified and overcome.

2.1. AIM

Given the central role that bioplastics have in the strategy to tackle the linear plastics challenge and on the transition to circular economy business models, it is important to understand the challenges inherent to industry and consumer acceptance.

Promoting industry and consumer acceptance of bioplastics also requires that researchers, industrials, policymakers, and other stakeholders working in the field of bioplastics, as well as those seeking to enter the field, have easy access to evidence-based overviews highlighting the main business challenges, as well as recommendations on how to overcome such challenges. This has the added value of enabling quick reference and identification of research necessities and business opportunities to overcome common pitfalls still found in theory and practice.

In that regard, we aim to compile and summarise in one comprehensive report existing information on barriers and recommendations to promote consumer demand for bioplastics and identify business and research opportunities. As such, we aim to identify and summarise: 1) potential risk factors for industry and consumer acceptance of bioplastics; 2) risk management strategies of business operators; and 3) market opportunities for commercialisation of biopolymer technologies.

2.2. APPROACH

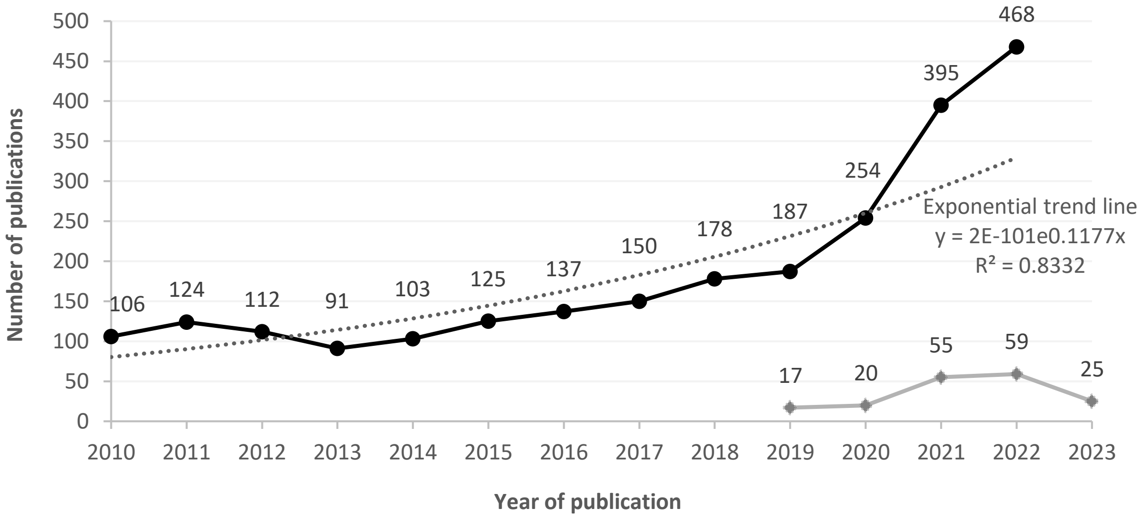
With the goal of identifying and summarising potential risk factors for industry and consumer acceptance of bioplastics, risk management strategies of business operators, and market opportunities for commercialisation of biopolymer technologies we implemented a set of research approaches, including literature reviews, semi-structured interviews, and co-production workshops with relevant stakeholders operating in the field of bioplastics. On the one hand, we conducted a systematic literature review (176 papers) on supply-side barriers for commercialization of new biopolymer production technologies, enabling the identification of risk factors for industry acceptance. On the other hand, we conducted an umbrella review (97 papers: 41 literature reviews and 56 context-specific publications) on barriers and recommendations to consumer demand for bioplastics, enabling the identification of risk factors for consumer acceptance. This was further complemented with interviews and a workshop with relevant stakeholders operating in the field of bioplastics production, commercialization and management, further enabling the identification of risk management strategies of business operators and market opportunities for commercialisation of biopolymer technologies. Specific procedures for each research approach are detailed next.

2.2.1. Systematic Literature Review Procedures

Firstly, a preliminary literature search was conducted using Google Scholar, Scopus, and by consulting with team members to create a benchmark list of studies on supply-side barriers for commercialization of new biopolymer production technologies. This helped in identifying relevant keywords and building a comprehensive search string for use in the systematic review process. The search string design was based on the PICO framework (see Richardson et al., 1995) and focused on stakeholders in the field of biopolymer production (population), barriers for commercialization (intervention), and qualitative and quantitative insights about these barriers (outcome). This search string was then used between June to July 2023 to search for papers on barriers for commercialization of new biopolymer production technologies in four scientific databases (Web of Science, SCOPUS, PubMed, IEEE Xplore). The detailed search string used in each of the four scientific databases can be seen in Annex I (pp. 55-58). The search targeted literature from 2010 to 2023, yielding 3546 documents. After removing duplicates, 2627 documents remained. Subsequently, an inclusion criterion was set based on language, document type, and publication year. As such, only English-language peer-reviewed papers published between 2019 to 2023 were included. This timeframe was chosen due to the introduction of the European Green Deal in December 2019, which may have had an impact in the increase of related publications (see Figure 3).

Figure 3

Distribution of articles on biopolymer production over years 2010 to 2023



Note. ♦ Publications considered for the present systematic review, retrieved from 2019 to 2023. ● Publications retrieved from 2010 to 2023 July. Since the documents were retrieved without the year of 2023 concluded, we did not include the number of publications of 2023 (n = 197) in the exponential trend line, since it does not reflect the total of publications of the entire year.

This was followed by a screening process focusing on title and abstract levels. Screening criteria used for this task was first pre-tested by three independent reviewers on 10% of papers identified, achieving acceptable levels of interrater agreement (k = .66). The title and abstract screening criteria was then applied to the remaining papers, ending the process with 207 papers retained. Next, three team members conducted a full-text screening and critical appraisal of the retained papers, evaluating internal validity (sample size, methodological rigor, reported data) and external validity (sample types, identification of supply-side barriers for biopolymer commercialization). The critical appraisal criteria used in this step was first refined using a random sample comprised by 10% of the retained papers. After addressing inconsistencies, two raters appraised the remaining studies, resulting in the 176 documents included in the final review. The full list of studies can be found in Annex II (pp. 59-79). The systematic review protocol was pre-registered at INPLASY.

2.2.2. Umbrella Review Procedures

The umbrella review procedure enables the aggregation of findings from recently published systematic reviews on consumer demand for bioplastics, particularly focusing on barriers and recommendations, and complements it with context-specific publications (Grant & Booth, 2009). A preliminary Google Scholar search showed evidence of several existing systematic reviews around the topic (e.g., see Findrik & Meixner, 2023; Ruf et al., 2022; Weinrich & Herbes, 2023). To provide a systematized and replicable approach, we first designed a search string, based in the PICO framework (see Richardson et al., 1995), to identify published systematic reviews (outcome) on consumer (population) demand (comparator) for bioplastics (intervention). The search string included synonymous and commonly used expressions for each PICO framework identifier. For example, bioplastics are often referred as bio-based, biodegradable, and even as sustainable or green products, so these different ways of referring to bioplastics were also included in the search string. This search string was then used on Web of Science and SCOPUS to identify published systematic reviews on the topic and can be seen in Annex III (pp. 80-83). Search was limited to English-language peer-reviewed papers published between 2019 to 2024. Similarly to the work conducted in the systematic review on supply-side barriers for commercialization of new biopolymer production technologies, this timeframe was chosen due to the introduction of the European Green Deal in December 2019. The list of 41 systematic reviews identified can be seen in Annex IV (pp. 84-92). Additional context-specific publications directly connected to the systematic reviews reviewed were also included. These publications were identified through title and author searches on Google Scholar, Web of Science, and

Scopus. To provide transparency, the list of the 56 publications considered in this review, in addition to the systematic reviews, together with a brief description and goals of the publication, can be found in Annex V (pp. 93-104). The barriers and recommendations identified in the reviewed literature were coded following qualitative thematic analysis procedures, using categories based on the Hierarchy of Effects Theory (Lavidge & Steiner, 1961). Such approach was selected for being a familiar framework already used in previous literature, thus offering a more objective, structured, and theory-based orientation for categorising the identified barriers and recommendations.

2.2.3. Stakeholder Interview Procedures

We conducted interviews to understand the challenges associated with producing and commercialising biopolymer production technologies. Our approach involved engaging with key players across the entire value chain, including researchers, suppliers, producers, policymakers, researchers and retailers within this sector. The aim is to explore their business models, identify barriers, and determine recommendations and strategies for overcoming these obstacles.

To facilitate this process, we developed an internal document that supports the ongoing identification and engagement of key stakeholders and companies with significant roles in the biopolymer production market. We created this list of stakeholders through continuous research since the project's inception, to reach out to relevant players for valuable insights. The identified stakeholders were then contacted via LinkedIn and personal email. Contact efforts began on March 6, 2024. As of now, we have successfully conducted four interviews with Portuguese stakeholders and four interviews with international stakeholders. On total we conducted eight interviews with stakeholders from industry organisations associated with the development, production, management, and commercialization of bioplastics.

The interview protocol (see Annex VI, pp. 105-107) was composed by 6 general questions, guided by subtopics, that aimed to collect stakeholders' individual and socially shared perceptions and beliefs about bioplastics: 1) business models; 2) risks, challenges, and solutions; and 3) market opportunities and recommendations. Interviews were automatically transcribed using an online transcription tool (Dropbox transcription plugin) and verified for transcription accuracy by one of the team members, that listened to the full audio and compared with the obtained transcript, correcting any identified inaccuracy or error. This was followed by a thematic content analysis procedure, where the content of the interviews was coded by two independent judges into categories of successful business models, risk perceptions of business operators, and market opportunities.

2.2.4. Workshop Procedures

The workshop took place on May 9, 2024, from 10:00 a.m. to 1:00 p.m. It was planned as a three-part hybrid event (i.e., in-person and online) with a duration of three hours. Participants were mainly recruited following a stakeholder mapping procedure aimed at identifying key actors in bioplastic production and commercialization, as well as key actors on bioplastic research and development, feedstock production, and waste management. Following this list, identified actors were contacted by the research team via e-mail and invited to participate in a workshop on "Bioplastics in a Sustainable World". Additionally, contacts were made with business centres, incubators, and associations, universities and research centres, policy making representatives, journalists working in the field of sustainability, and public and citizen associations with focus on sustainability issues. Following these contacts a total of 31 actors registered for the event. Twenty registered to participate online and eleven registered to participate in-person. From these 21 participated in the workshop (71.4% female), 6 in-person (83.3% female) and 15 online (66.7% female). Table 1 shows information on the number of participants by activity sector present in the workshop, both in-person and online.

Table 1

Number of participants by activity sector present in the workshop, both in-person and online

		In-Person		**Online**	
Field/Sector	***n* (%)**	***M***	***F***	***M***	***F***
Bioplastics Production	8 (38.1)	-	3	2	3
Bioplastics Commercialization	2 (9.5)	1	-	1	-
Bioplastics Research	2 (9.5)	-	1	-	1
Bioplastics Waste Management	4 (19.1)	-	1	-	3
Public Sector	2 (9.5)	-	-	-	2
Other	3 (14.3)	-	-	1	2
Totals	21 (100)	1	5	5	10

The first part of the workshop was planned to last one hour and twenty minutes. It started with an introduction to the workshop followed by a keynote session. In this session, a keynote speaker delivered a twenty-minute presentation on the topic of "Circular Economy" followed by a ten-minute session of questions and answers. After the keynote session there was a thirty-minute session focused on presenting research results on the identification of barriers to production and commercialization of bioplastics. The first part of the workshop ended with a ten-minute coffee break. The second part of the workshop was planned to last one hour and ten minutes and involved a co-production task on solutions and recommendations to the previously identified barriers. In this task, both online and in-person participants jointly co-produced solutions and recommendations for each identified barrier by suggesting potential solutions and recommendations and discussing such suggestions with each other. To record the outputs of the co-production process and to ease the interaction between in-person and online participants a virtual white board with sticky notes was used. Each contribution co-produced by the participants was registered in this virtual white board by a member of the research team. In the end there was a ten-minute period to wrap-up the co-production task and guide participants into the third part of the workshop. After the co-production task, the third part of the workshop was planned to last thirty minutes and aimed to join all participants to discuss the co-produced output. This was followed by a five-minute closing session. After the workshop the global output from the co-production and discussion session was compiled and returned to the participants for validation and additional feedback.

3. FINDINGS

3.1. BARRIERS TO BIOPOLYMER COMMERCIALIZATION

In this section we firstly report the findings emerging from the systematic literature review on supply side barriers for commercialization of new biopolymer production technologies, and from the umbrella review on barriers and recommendations to consumer demand for bioplastics.

3.1.1. Supply-Side Barriers to Biopolymer Commercialization

Following the systematic review procedures, the majority (82%) of the documents mentioned more than one barrier. This finding reflects the common presence of multi-level barriers and the complex interaction between the different challenges that emerge in the commercialization of biopolymer technologies. The main barriers identified were technological, knowledge, economical, regulatory, supply-stability, and behavioural related (Table 2).

Table 2

Supply-side barriers to biopolymer commercialization identified in the systematic literature review

Barriers	Description	E.g.,	%
Technological	Limited biopolymer properties, specialized equipment availability, and the need for diverse technical expertise	Chaudhary et al., 2022; Cristofoli et al., 2023	83.0
Knowledge	Limited research, gaps in farming techniques, lack of collaboration and multidisciplinary approaches	Dini, 2022; Luft et al., 2020	56.8
Economic	High production costs and limited access to financial capital for research, development, and commercialization	Agarwal et al., 2023; Duran et al., 2022	47.7
Regulatory	Inconsistent policies, and unique regulatory landscapes that complicate cross-border knowledge transfer	Ma et al., 2022; Panoutsou et al., 2022	43.8
Supply-stability	Limited raw material availability, seasonal variations, and resource management challenges	Oulkhir et al., 2023; Rehman et al., 2023	33.5
Behavioural	Resistance to change, intention-behaviour gaps, market uncertainty, and perceived unacceptance from the demand-side	Bos & Broeze, 2020; Clifton-Brown et al., 2023	18.2

3.1.1.1. Technological Barriers. Technological barriers were the most mentioned challenge, appearing in 83% of the documents. These papers often report biopolymer technology development and life-cycle analysis of such technologies. Barriers related with chemical properties of biopolymers, such as limited mechanical performance (e.g., observed on bamboo fibres, gelatine, PHA), thermal stability (e.g., observed on agar, PLA), and barrier properties (e.g., observed on starch, cellulose) were frequently mentioned (Chaudhary et al., 2022; Cristofoli et al., 2023; Wang et al., 2022). Physical properties of biopolymers, such as larger particle size, heterogeneity, low rate of dispersibility, odour, colour, and asymmetrical morphology were also mentioned in the literature as major limiting factors in development and production of biopolymer products (Mujtaba et al., 2022; Titirici et al., 2022). Another important category of technological challenges relates with specific applications of biopolymers. For example, in applications for pharmacological delivery systems of bioactive components, biopolymers tend to show lower bioavailability potential (i.e., the fraction of an administered drug that reaches the systemic circulation) compared to conventional solutions (Dong et al., 2021). To ensure that these bioactive ingredients are effective in providing their intended effect, several issues related to the preparation and application of biopolymer delivery systems need to be addressed (Dong et al., 2021). Biodegradation and recyclability challenges were another technological barrier identified (Maraveas et al., 2022; Omerović et al., 2021; Stark & Matuana, 2021). These barriers were often associated to low biodegradation rates of some biopolymers (e.g., PVA), limited recyclability, and waste management issues. This included the challenge of dealing with contamination from nonbiodegradable plastics and the lack of effective recycling processes (Bhola et al., 2021; Costa et al., 2023). Limited technical functionalities and production specificities were also among the technological barriers identified. Bio-based materials often have different technical functionalities compared to petrochemical plastics. Improving properties such as mechanical strength, thermal resistance, and barrier properties is challenging (Gheorghita et al., 2021). Technological barriers identified also included the lack of professionals with the technical knowledge and skills for the development and production of biopolymer-based products (Dong et al., 2022; Fiallos-Cardenas et al., 2022). This barrier often connects with the limited availability of specialized production equipment (Jamieson et al., 2021; Zhang et al., 2022), limited technological development (Pessôa et al., 2021), low technological readiness (Panoutsou et al., 2022), and lack of technical strength or outdated technology (Moshood et al., 2022). Challenges with industrial scalability of biopolymer products production were another important barrier identified. The lack of methods and technology for mass production and difficulties in scaling up from laboratory to commercial scale pose a significant barrier to biopolymer production uptake (Asim et al., 2022; Cristofoli et al., 2023). To advance biopolymer technologies production and achieve sustainable solutions. These significant technological and production challenges must be addressed.

3.1.1.2. Knowledge Barriers. Technological and industrial-scale implementation issues are closely tied to a gap between laboratory research and practical applications, marked by a clear difficulty in transforming academic knowledge into commercial products (Capodaglio, 2023; Chavooshi et al., 2023). Such results highlight not only the need to improve knowledge transfer processes, but also the processes through which knowledge is produced. This challenge is also accompanied by the need for more scientific and practical knowledge production, particularly regarding specific biopolymer production technologies, feedstock production techniques, and the economic and environmental impact of biopolymer technologies (Dini, 2022; Song et al., 2022). In that regard, evidence from the reviewed literature suggests that many biopolymer technologies are in their infancy, with insufficient information on their long-term applicability and economic sustainability.

Such uncertainty often leads to scepticism and resistance among stakeholders, which further hinders industry representatives from investing on new biopolymer technologies (Catoira et al., 2020; Khodaman et al., 2022; Ktari et al., 2022; Pessôa et al., 2021). Another important topic where current knowledge is insufficient relates with feedstock production technologies and sources. Independently of feedstock types (e.g., plant-based; waste-based), potential feedstock producers are often unfamiliarized with production techniques and sources adequate for biopolymer production, preferring those they already know (Panoutsou et al., 2022). Moreover, confusion and lack of clarity regarding how these production techniques and sources are framed and communicated further complicates investment from potential feedstock producers and the emergence of new ones (Fletcher et al., 2021). All in all, a multidisciplinary and interdisciplinary approach, emphasising research, collaboration, knowledge sharing, and co-production is essential to overcoming industry knowledge limitations and advance biopolymer production technologies (Brandolese & Kleij, 2022; Clifton-Brown et al., 2023; Geijer et al., 2022; Gheorghita et al., 2021; Kostas et al., 2021; Krujatz et al., 2022; Menossi et al., 2021).

3.1.1.3. Economic Barriers. Economic barriers were identified as the third most frequently mentioned aspect. A significant challenge in large-scale biopolymer production of some biopolymers is their high cost, with Polyhydroxyalkanoates (PHA) being a notable example (Capodaglio, 2023). Moreover, several authors have noted the lack of economically stable biopolymers for industrial production. These authors also note high production costs and labour expenses that hinder large-cale production (Agarwal et al., 2023; Bamps et al., 2022; Dalton et al., 2022; Duran et al., 2022). Comparing with synthetic polymers, biopolymers still present higher processing costs (Alves et al., 2023; Kunamaneni, 2023). Biopolymer production is frequently in early development stages (Fuentes et al., 2022) making them more susceptible to market fluctuations (Vázquez-Núñez et al., 2021). Production technologies required are also described as capital-intensive (Maraveas et al., 2022), and further hinder biopolymer production due to limited access to financial capital for research, development, and commercialization (Ktari et al., 2022; Mobtaker et al., 2021; Mossberg et al., 2021; Vlăsceanu et al., 2019). Lack of consumer incentives to encourage purchase of sustainable alternatives further aggravates this scenario (Friedrich, 2020; Salvador et al., 2022; Shevchenko et al., 2022).

3.1.1.4. Regulatory Barriers. The complex regulatory landscape of biopolymer commercialization was identified a significant barrier identified. Besides complexity, the lack of governance poses added risks to stakeholders (Panoutsou et al., 2022). To this contributes the absence of proper technical and governmental policies and regulatory guidelines, disconnections between policymaking and technology implementation, and contradictory environmental policies (Cherrington et al., 2022; Gupta et al., 2022; Ma et al., 2022; Mossberg et al., 2021; Pippa et al., 2021; Popp et al., 2021; Rathee et al., 2022; Santhosh et al., 2021). For instance, the absence of a legislative framework for collecting and cultivating seaweed impedes the sector's development (Ktari et al., 2022). Similarly, the lack of government legislation to legalize certain raw materials like hemp hinders farmers' ability to cultivate these crops (Agyekum et al., 2022). Furthermore, the sector faces challenges such as a lack of political awareness and long-term vision for the sector, and insufficient policy instruments to foster technological development (Fiallos-Cárdenas et al., 2022). This is added by pre-market approval challenges and environmental protection regulations (Goh & Potter, 2022; Massella et al., 2019). Additionally, inadequate waste management legislation and recycling practices are also highlighted as barriers (Shevchenko et al., 2022). Social and ethical issues, such as national food safety regulations, health concerns, and consumer acceptance, add to the regulatory complexities (Grama et al., 2022; Joye, 2019; Nikolic et al., 2021; Rosseto et al., 2023; Sun et al., 2021). Finally, each country's unique environmental and regulatory landscape complicates the extension of policy implementation lessons from one country to another (Clifton-Brown et al., 2023; Kostas et al., 2021). Altogether, this lack of updated global and specific regulations hinders the development of new biopolymer technologies.

3.1.1.5. Supply-Stability Barriers. The limited availability of high-quality raw materials has been identified as a significant barrier to biopolymer production. Raw material shortages, such as polyamino acids (PAAs) in biomedical applications and shortages in the supply of chitin and chitosan present notable challenges (Kordasht et al., 2021; Rehman et al., 2023). External factors that limit such availability include raw material losses due to climate (e.g., heat and droughts), social (e.g., work strikes; world conflicts), and other physical factors (e.g., diseases and pests that affect crops and other types of feedstocks). Such factors often impact product availability, quality, and pricing (Holland et al., 2019; Mazitova et al., 2021; Oulkhir et al., 2023; Panoutsou et al., 2022; Semple et al., 2022). Challenges in optimizing and scaling up production of raw materials also affect biopolymer supply chain (Rehman et al., 2023). Raw material recovery is also a challenge that threatens biopolymer production frequently depending on region-specific factors (e.g., lack of proper waste management facilities and other infrastructure). Adding to this, logistical costs often outweigh the value of biomass, leading biorefineries to opt for incineration or landfills instead of recovery (Cristofoli et al., 2023). In this scenario, market growth is limited by the presence of only a few suppliers that lack raw material alternatives (e.g., often only relying on plant-based solutions; Panoutsou et al., 2022).

3.1.1.6. Cultural and Behavioural Barriers. The commercialization of new biopolymer technologies also faces significant cultural and behavioural challenges (Fiallos-Cárdenas et al., 2022). These include resistance to changing traditional practices and production methods. In that regard, the transition to a 'bio-based society' is perceived as a major challenge (Bos & Broeze, 2020), and often relates to perceived risks, market uncertainty, high upfront investments, long-term commitments, development failures, and limited number of end-users (Clifton-Brown et al., 2023). Entrepreneurs also often lack reference business models and experiences (Kulej-Dudek, 2021). Changing market trends and technological advancements are also challenges to many organizations that struggle to stay updated in the transition to the circular economy (Jaconis et al., 2019). Individual characteristics, such as age and education level, also emerge as barriers. For example, older entrepreneurs often resist changing business models and invest in new products due to a lack of knowledge, and those with lower education levels are also less likely to participate in the circular market (Fiallos-Cárdenas et al., 2022). Difficulties in appraising the benefits of biopolymer technologies, uncertainties about their properties, and a lack of understanding about its life cycle often emerge as barriers (Abdollahiparsa et al., 2023). Such lack of knowledge and understanding extends to consumers, that are frequently unfamiliarity about the 'bio-based' concept (van Leeuwen et al., 2022). This lack of customer knowledge and interest about green products is also a significant challenge limiting market opportunities and biopolymer production growth (Ktari et al., 2022; Moshood et al., 2022). Slow market demand and consumer acceptance can lead to higher production costs, affecting product supply (Chaudhary et al., 2022). Such lack of knowledge is often accompanied by risk perceptions that often act as a powerful barrier to consumer acceptance and demand, particularly in the food industry, where consumers are concerned with product safety and security (Reshmy et al., 2021). Developing incentives to inform and promote consumer knowledge and purchase of bio-based plastics emerges as a pressing necessity (Kövilein et al., 2020; Ngwabebhoh et al., 2022; Shevchenko et al., 2022). Evidence-based and tailored communication campaigns are needed to reduce consumers perceptions of "greenwashing", increasing trust and increase public awareness about the personal benefits of new biopolymer products (Jayakumar et al., 2022; Joye, 2019; Pires et al., 2022). Such campaigns should extend to potential biopolymer producers and other stakeholders (Jamieson et al., 2021), promoting responsible innovation practices, stakeholder accountability, and community engagement (Kostas et al., 2021).

3.1.2. Demand-Side Barriers to Biopolymer Commercialization

The umbrella review on barriers and recommendations to consumer demand for bioplastics enabled the identification of risk factors for consumer acceptance of bioplastics. Table 3 summarises barriers to consumer demand for bioplastics, as well as drivers and recommendations to overcome such barriers found in the reviewed literature.

Table 3

Summary of barriers and recommendations to consumer demand for bioplastics found in the literature

Barriers	Recommendations
Awareness and Recognition	
- Limited availability of bioplastic products - Lack of public awareness and reluctance to new technologies - Bioplastic products are relatively new and unknown to consumers, particularly those that are not plant-based - Difficulty in recognizing bioplastic products, and differentiating bioplastics from other plastic products - Absence of clear labelling systems that catch consumers' attention	- Promote awareness, interaction, and familiarity with bioplastic products - Highlight the personal benefits of bioplastics - Promote brand and product involvement, while delivering products that live up to marketing claims - Use clear labelling systems that can enable quick and automatic identification of bioplastic products and their characteristics - Carefully design and test communication materials with target group consumers
Knowledge and Information	
- Limited or low consumer knowledge and understanding about bioplastics - Complexity of bioplastic concepts and terminology - Lack of clear and trustworthy information sources - Low knowledge about bioplastic material sources, biodegradability, and disposal methods - "Simply" providing knowledge and information without following up on consumers' needs	- Understand what consumers already know and what they still need to know about bioplastics to make informed decisions - Tailor knowledge dissemination and communication activities to identified knowledge and information gaps - Focus on what consumers still need to know rather than on the redundancy of what they already know - Diversify knowledge dissemination and information activities, tailored to different social contexts and target groups - Coproduce knowledge about bioplastics joining together relevant stakeholders and consumer groups

	- Select appropriate and diversified knowledge dissemination channels, while building and maintaining consumers trust in such channels - Test knowledge sharing materials and interventions, and monitor their effects on consumers knowledge
Perceptions, Beliefs, and Misconceptions	
- Negative and ambivalent perceptions of bioplastics - Perception of high cost, lower durability, and poor performance of bioplastics - Beliefs and misconceptions about bio-based and biodegradable properties - Perceptions of greenwashing and feelings of deception - Perceptions of risk and concerns about the safety and origin of feedstock and final products	- Assess perceptions and beliefs about bioplastics beforehand and identify problematic perceptions and misconceptions - Concisely and systematically addressed problematic perceptions and misconceptions as they are identified - Reinforce existent positive perceptions and accurate beliefs - Frame communications to avoid the perception of exaggerated or false claims - Make accurate, relevant, and truthful, claims backed up by sound measurements based on approved and certified standards - Minimize the perception of losses by highlighting both the performance aspects that are personally relevant to consumers and the eco-friendliness of bioplastics - Test communication materials beforehand, and monitor their effects on consumers perceptions and beliefs
Attitudes, Preferences, and Expectations	
- Positive attitudes driven mainly by environmental friendliness alone - Preferences for locally produced and plant-based bioplastics	- Focus on bioplastics and product characteristics that align with consumers attitudes, preferences, and expectations

- Preference for 100% bio-based, with products with lower percentages of bio-based content being perceived as greenwashing attempts - Emphasis on preference for biodegradability over bio-based content - High expectations about technical and environmental performance	- Assess consumers' attitudes, preferences, and expectations towards different types of bioplastics - Build and maintain positive attitudes, and manage consumers' preferences and expectations - Promote meaningful and positive interactions with different types of bioplastics, focusing on quality, safety, and environmental performance - Implement social marketing activities across a diverse range of contexts and consumer groups - Test communication materials and interventions, and monitor their effects on consumers attitudes, preferences, expectations, and behaviours
Identity, Values, and Social Influence	
- Contexts of lower green self-identity, environmental concern, and pro-environmental values - Heightened environmental concern of specific social groups and with increase exploitation of animals and land use - Contexts of absence of social norms towards sustainability, particularly pro-environmental norms, and low social pressure to preserve the environment - Mass media and social media amplification of controversies and misleading or false information about bioplastics	- Target environmentally conscious and concerned consumers, with a green self-identity and pro-environmental values - Design Marketing campaigns that are transparent, interactive, and aligned with broader societal values - Promote consumers' green self-identity and pro-environmental values - Be aware of common pitfalls when leveraging green self-identity, pro-environmental goals and values, and social norms - Monitor how emerging environmental and social issues influence consumer responses to bioplastic products

	- Build information sharing partnerships with media outlets, particular those with sections on innovative and green technologies - Strengthen online presence, and foster trustworthy online resources and online communities to coproduce knowledge - Monitor communication, dissemination, and marketing activities effects on consumer behavioural and psychological responses
Policy and Regulatory	
- Lack of clear and uniformized policies and regulations - Lack of policies and regulations that encourage or support consumers to purchase bioplastic products - Inadequate labelling systems and incentives - Misleading labelling, signs, and disposal instructions - Lack of universally accepted biodegradability standards - Need for certification and labelling programs	- Develop and implement shared cross-cultural definitions, that counter identified misconceptions arising from current bioplastics definition - Create uniformized, consistent, and shared certification and labelling programs ratified by government agencies from different countries - Create visible mechanisms to ensure product compliance with policy and regulation, focusing on safety and quality assurance - Regulate the use of "attractive labelling strategies" that can mislead consumers - Governments can set incentives for consumers when buying, reusing, and recycling bioplastics

3.1.2.1. Awareness and Recognition Barriers. The reviewed literature clearly emphasises that Bioplastic products availability is still limited, and these products are relatively unknown to consumers (Filho et al., 2022; Ruf et al., 2022; Zwicker et al., 2020). Unawareness is particularly stronger for bioplastics that are not plant-based. Lack of public awareness and reluctance towards new technologies were also reported to act as barriers to consumer demand for bioplastics (Filho et al., 2022; 2021; de Marchi et al., 2020; Notaro et al., 2022; Scarpi et al., 2021; Sijtsema et al., 2016). Such unawareness extends to properties, benefits, life cycle, and end-of-life options of bioplastics. Without clear marketing and labelling, bioplastics are often indistinguishable from conventional plastics, making it harder for consumers to recognize and properly dispose these products, which undermines their environmental benefits (Dilkes-Hoffman et al., 2019). Altogether, low awareness and difficult recognition makes it hard for consumers to classify their interactions with bioplastics, build meaning, and use their experiences with such products to attest their quality, safety, and functionality, while building trust. Increasing public awareness and recognition of bioplastic products, through clear labelling and improved marketing, can enhance consumer acceptance and demand (Findrik & Meixner, 2023; Ruf et al., 2022).

3.1.2.2. Knowledge and Information Barriers. With some exceptions (see Filho et al., 2022) the literature on consumer research about bioplastics consistently shows that, across countries, consumers have limited knowledge about bioplastics (Findrik & Meixner, 2023). Consumers generally lack understanding of basic concepts (e.g., bio-based and biodegradability) and disposal methods associated to bioplastics (Filho et al., 2022; Klein et al., 2019; Weinrich & Herbes, 2023). Limited knowledge is further amplified by unclear and inconsistent terminology used by experts, making it harder for consumers to build accurate meaning about bioplastics (Fletcher, 2022). Studies also reveal that most people do not know about bioplastics biodegradability particularities (e.g., shared belief that all bioplastics are biodegradable and degrade naturally and fast in the environment), about the different feedstocks that can be used to produce bioplastics, about how they should be discarded, and about their potential environmental impacts (i.e., both positive and negative; Blesin et al., 2017; Dilkes-Hoffman et al., 2019; Sijtsema et al., 2016). For example, misconceptions such as equating "bio-based" with "biodegradable" are common. This lack of knowledge and understanding hinders the adoption of bioplastic products (Filho et al., 2022). To promote bioplastic use, it is crucial to provide clear and trustworthy information, tailored to consumers' existing knowledge and informational needs. However, merely providing information is insufficient, and addressing misconceptions and understanding consumers' perceptions and beliefs is essential. Misalignment between factual knowledge and existing perceptions can lead to distrust and hinder consumer demand for bioplastic products.

3.1.2.3. Perceptions, Beliefs, and Misconceptions Barriers. The literature shows that consumers have varied perceptions and frequent misconceptions about bioplastic products (Findrik & Meixner, 2023; Onwezen et al., 2017; Zwicker et al., 2020). While bioplastics are often perceived as environmentally friendly and sustainable products (Blesin et al., 2017; Boz et al., 2020; Dilkes-Hoffman et al., 2019; Filho et al., 2022; Karachaliou et al., 2017; Lynch et al., 2017; Yeh et al., 2015), they are also perceived as more expensive and with lower quality than conventional plastics, which often hinders consumer demand (Findrik & Meixner, 2023; Karana, 2012; Ketelsen et al., 2020; Magnier & Crié, 2015; Sijtsema et al., 2016; Yue et al., 2010a). Misunderstandings about terms like "bio-based" and “biodegradable” lead not only to incorrect disposal practices but also create doubts about environmental benefits, often resulting in perceptions of greenwashing (Findrik & Meixner, 2023; Herbes et al., 2018; Taufik et al., 2020; Zwicker et al., 2021). Despite often being perceived as relatively safe products, bioplastics also evoke risk perceptions frequently connected to concerns about land use, food security, and cross-contamination (Cammarelle et al., 2021; Herbes et al., 2018; Koenig-Lewis et al., 2014; Weinrich & Herbes, 2023). These perceptions, coupled with a lack of knowledge, create negative and ambivalent feelings, reducing consumer acceptance and demand for bioplastics.

3.1.2.4. Attitudes, Preferences, and Expectations Barriers. Research suggests that consumers have mixed attitudes towards bioplastics, driven by beliefs in their environmental benefits (Friedrich, 2021; Klein et al., 2020; 2019; Testa et al., 2021; Zwicker et al., 2021) but hindered by misconceptions and broader systemic barrier such as regulatory (e.g., lack of public policies that encourage consumer demand for bioplastics), cultural (e.g., inherent consumer and market resistance to change frequently guided by cultural values, particularly towards waste-based products), and institutional (e.g., industry’s difficulty in increasing bioplastics visibility and attracting consumer attention; Boz et al., 2020; Fletcher, 2022; Ketelsen et al., 2020; Niedermeier et al., 2021; Rudolph, 2018; Testa et al., 2021). Positive attitudes tend to stem from perceptions of environmental friendliness and environmental values, whereas negative attitudes tend to stem from perceptions of high cost, low quality and performance, and lower social status attributed to repurposed or recycled products. Research also suggests that there still exists a significant gap between positive attitudes and actual purchasing behaviour. Consumers tend to prefer locally produced bioplastics from local feedstocks and plant-based bioplastics over waste-based ones (Filho et al., 2022; Findrik & Meixner, 2023; Klein et al., 2020; Scherer et al., 2018; 2017; Sijtsema et al., 2016). They have high expectations for bioplastics to outperform conventional plastics in all aspects, including quality and biodegradability, which often leads to feelings of deception when bioplastics do not meet these expectations (Bhagwat et al., 2020; Blesin et al., 2017; Falcone & Imbert, 2018; Fletcher, 2022; Laborda et al., 2023; Mehta et al., 2021; Yue et al., 2010b; Zwicker et al., 2021). Consumers also tend to overlook the circular economy benefits of bioplastics, focusing instead on their beginning and end-of-life characteristics (Bhagwat et al., 2020; Herbes et al., 2018). This limited understanding and the clash between high expectations and technical limitations of bioplastics pose significant challenges to their acceptance and demand.

3.1.2.5. Identity, Values, and Social Influence Barriers. The literature also provides evidence that consumer acceptance and demand for bioplastic products are influenced by various personal and social factors. Consumers with a strong green self-identity, environmental concern, nature relatedness, and health consciousness tend to favour bioplastics more, showing higher willingness to pay and intention to purchase (Confente et al., 2020; Findrik & Meixner, 2023; Herbes et al., 2018; Ruf et al., 2022; Russo et al., 2019; Scarpi et al., 2021; Scherer et al., 2017; Weinrich & Herbes, 2023). Conversely, those without or with lower identification with these traits and values tend to show lower acceptance and demand for bioplastic products. However, caution is needed as higher green values and environmental concern does not always result in positive views of bioplastics. For example, certain sub-groups, such as vegetarians and vegans, may oppose bioplastics made from animal waste (Mehta et al., 2021), hidering consumer demand for bioplastics or even promoting the appearance of social movements that advocate against such products. In that regard, social norms and mass media also play significant roles in shaping consumer perceptions and behaviours (Weinrich & Herbes, 2023). For example, pro-environmental norms can nudge consumers towards bioplastics (Cruz et al., 2022; Notaro et al., 2022; Onwezen et al., 2017; Osburg, 2016; Weinrich & Herbes, 2023), but negative media coverage, confusing and uncertain information, and misinformation can hinder consumer demand (Grebitus et al., 2020; Neves et al., 2020). Clear, trustworthy information and communication strategies emphasising environmental benefits are crucial for promoting bioplastic products.

3.1.2.6. Policy and Regulatory Barriers. Research also shows that policy and regulation play a crucial role in promoting consumer demand for bioplastic products, mainly by providing clear principles, regulations, guidance, and incentives. Research indicates that the absence of uniform policies and regulations hinders consumer awareness and demand (Cruz et al., 2022; Fletcher, 2022; Karachaliou et al., 2017; Mehta et al., 2021; Theinsathid et al., 2011; Weinrich & Herbes, 2023; Yeh et al., 2015). Key issues include the lack of clear and trustworthy regulations, labelling systems, and consumer incentives, often leading to consumer misinformation and confusion (Fletcher, 2022; Koenig-Lewis et al., 2014). Evidence shows that there is still lack of universally accepted biodegradability parameters and standards for end-of-life usage, as well as of strict policies and regulations to ensure consumer protection from abusive use of labelling and marketing strategies (Bhagwat et al., 2020; Klein et al., 2019). Effective policies should establish universal biodegradability standards, strict labelling regulations, and incentives for reusing and recycling bioplastics (Herbes et al., 2018; Klein et al., 2020; Scherer et al., 2017). Certification and labelling programs can help define bioplastics clearly, enhance consumer awareness, and build trust, thereby facilitating informed purchase decisions (Scherer et al., 2017).

3.2. RISK MANAGEMENT STRATEGIES OF BUSINESS OPERATORS

Informed by the systematic literature review and the umbrella review, and focusing on data collected in the interviews and the workshop conducted with relevant stakeholders operating in the field of biopolymers, this section reports on the risk managed strategies identified.

3.2.1. Evidence from Literature Reviews

Considering the evidence found in the systematic literature review and the umbrella review previously reported, limited public awareness, difficulty in differentiating bioplastics from conventional plastics, low knowledge and misleading information, negative perceptions and misconceptions about bioplastics characteristics, marked feedstock and material preferences, misaligned product expectations, lower consumer identification with green products, lack of green values, social amplification of controversies and misleading information, and regulatory aspects were identified as important barriers to consumer demand for bioplastics. Nevertheless, identifying barriers to consumer demand for bioplastics is just a first step. For those working in the field of designing, developing, producing, and commercializing bioplastics, more than simply knowing the barriers, it is important to have evidence-based recommendations and best practices on how to overcome such barriers. In that regard, several drivers, recommendations and best practices were identified in the reviewed literature, such as promoting direct interaction and familiarity with bioplastics (Findrik & Meixner, 2023; Klein et al., 2020; Weinrich & Herbes, 2023), understanding what consumers already know and what they still need to know about bioplastics (Friedrich, 2021; Klein et al., 2020; 2019; Testa et al., 2021; Zwicker et al., 2021), addressing consumers' inaccurate perceptions and beliefs (Mehta et al., 2021; Steenis et al., 2017), building positive attitudes, managing preferences and expectations (Confente et al., 2020; Notaro et al., 2022; Russo et al., 2019; Weinrich and Herbes, 2023), targeting favourable social groups for initial market penetration (Confente et al., 2020; Findrik & Meixner, 2023; Herbes et al., 2018; Ruf et al., 2022; Russo et al., 2019; Scarpi et al., 2021; Scherer et al., 2017; Weinrich & Herbes, 2023), making accurate and truthful claims backed up by certified standards (European Bioplastics, 2017; Notaro et al., 2022), and developing clear definitions, standards, and labels (Bhagwat et al., 2020; Klein et al., 2019; Meeks et al., 2015; Notaro et al., 2022; Yeh et al., 2015), and finally the need for policies and investments that encourage consumers purchase of bioplastics (Filho et al., 2022).

3.2.2. Evidence from Interviews

A set of Interviews were conducted with experts from the academia, industry, production and commercialization with the goal of identifying several significant barriers and risks in the production and commercialization of bioplastics, as well as risk management strategies to overcome them. Here we report on the risk management strategies that emerged on those interviews.

3.2.2.1. Risk Management Strategies for Technological Barriers. Key challenges in the production of bioplastics stem from high production costs when compared to traditional plastics. These elevated costs are often due to the specialized materials and processes required to manufacture bioplastics, which can discourage investment. Moreover, technical difficulties in scaling up production processes from small-scale laboratory settings to large industrial operations can present significant obstacles. These scaling issues may include inefficiencies in production, unanticipated equipment failures, and the need for specialized skills or knowledge. Additionally, the complex separation and extraction methods necessary for producing bioplastics can further complicate the technological landscape. These processes are not only time-consuming but also require advanced technology that may not be readily available to all manufacturers. To address these challenges, experts mentioned how innovation plays a crucial role. Companies can invest in research and development to explore new production techniques that utilize waste products as raw materials. Finally, developing more efficient extraction methods was reported as vital for reducing overall costs and improving scalability.

3.2.2.2. Risk Management Strategies for Knowledge Barriers. A notable barrier to the successful commercialization of bioplastics mentioned by our participants was the lack of consumer awareness and acceptance. Many potential users and consumers are unfamiliar with bioplastics, their environmental benefits, and how they compare to traditional plastics. This knowledge gap can impede market growth and hinder the adoption of bioplastics in various applications. To mitigate these knowledge barriers, targeted educational and awareness campaigns were identified as possible solutions that can be launched to inform consumers about the advantages of bioplastics. These campaigns can clarify misconceptions (e.g., about biodegradability), and inform consumers about bioplastics reduced environmental impact and the innovative processes behind their production. By increasing public awareness and understanding, companies can foster a more favourable perception of bioplastics, ultimately encouraging adoption.

3.2.2.3. Risk Management Strategies for Economic Barriers. Economic barriers significantly affect the bioplastics industry, with market competitiveness being a key concern in the field. Traditional plastics often dominate the market due to lower prices, which can make it challenging for bioplastics to compete. Additionally, the experts believe that regulatory uncertainties can create a complicated landscape for businesses, making it difficult to navigate market entry and growth. To overcome these economic challenges, effective policies and regulations were considered as essential. Governments can support the development and commercialization of bioplastics by providing clear guidelines, financial incentives, and support for sustainable practices. This can include, for example, tax breaks for companies producing bioplastics, grants for research, or subsidies to reduce production costs. By creating a more favourable economic environment, policymakers can help level the playing field for bioplastics.

3.2.2.4. Risk Management Strategies for Regulatory Barriers. Regulatory barriers were also mentioned as obstacles to the growth of the bioplastics market. Unclear or inconsistent regulations can lead to uncertainty among manufacturers and investors, discouraging them from entering the bioplastics sector. Effective regulatory frameworks were mentioned as necessary to support the development of bioplastics and ensure they meet safety and environmental standards. To manage these regulatory challenges, participants mentioned that it is essential to foster collaboration between industry stakeholders and regulatory bodies. Engaging in dialogue can help shape policies that support innovation while ensuring consumer safety and environmental protection. Clear and transparent regulations will not only reduce uncertainty but also enhance the credibility of bioplastics in the marketplace.

3.2.2.5. Risk Management Strategies for Supply Stability Barriers. Supply stability is another critical concern for the bioplastics industry. Variability in the availability of raw materials, particularly those derived from renewable sources, can impact production continuity. Fluctuations in supply can arise due to factors such as climate change, agricultural practices, and market demand. Moreover, interviewed stakeholders mentioned they often face competition from other sectors (e.g., pharmaceutical) when acquiring bio-based feedstocks for bioplastic production. To address supply stability risks, businesses can develop diversified sourcing strategies. By establishing relationships with multiple suppliers and investing in alternative raw materials, companies can reduce their dependency on a single source. Additionally, fostering collaborations not only with agricultural partners, but also with waste-management partners and emerging companies exploring new feedstock possibilities (e.g., algae) can be key for securing a reliable supply of bio-based feedstocks that can help stabilize the supply chain.

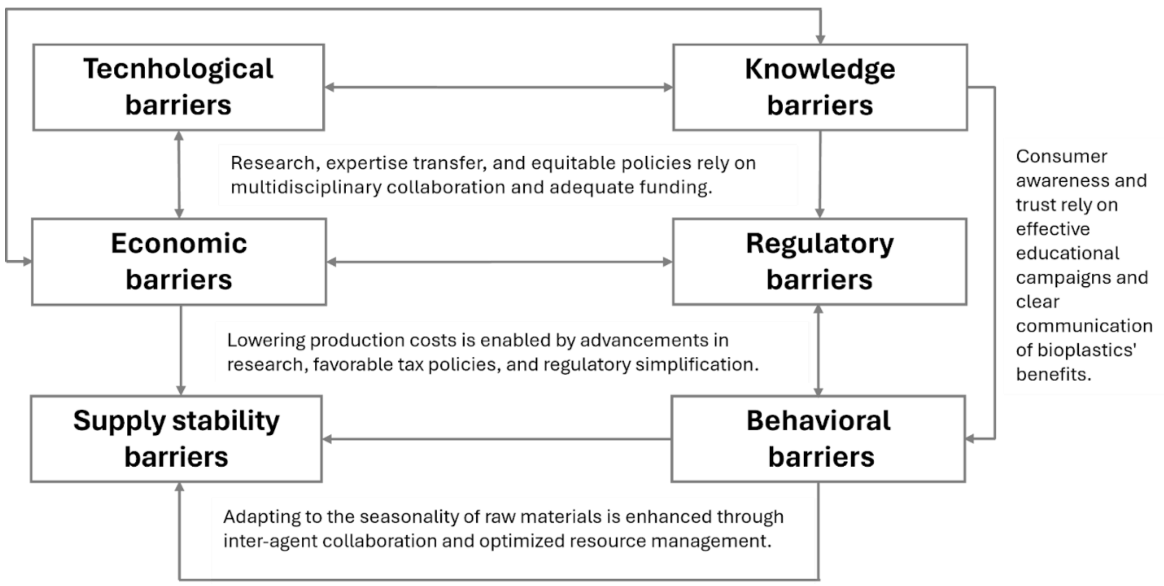
3.2.2.6. Risk Management Strategies for Behavioural Barriers. Finally, our participants revealed to be aware how behavioural barriers can pose significant challenges to the adoption of bioplastics. Misconceptions about the performance and benefits of bioplastics, as well as resistance to change among manufacturers and consumers, can hinder market acceptance. Stakeholders may be hesitant to transition to bioplastics due to concerns over quality, performance, or reliability. To counter these behavioural barriers, they said it is important to address misconceptions head-on through comprehensive educational and awareness initiatives. Companies should provide clear, evidence-based information about the performance of bioplastics in comparison to traditional materials. Encouraging trial use through pilot projects or demonstrations can also help build confidence in bioplastics and showcase their benefits, ultimately driving wider understanding and acceptance in the market.

3.2.3. Evidence from Workshop

Evidence from the workshop conducted with relevant stakeholders operating in the field of bioplastics production and commercialization enabled the identification of risk management strategies for technological, knowledge, economic, regulatory, supply stability, and behavioural barriers highlighted by those professionals based on their professional experience. Figure 4 shows the interconnection between barriers and the co-created risk management strategies identified in the workshop.

Figure 4

Barriers and co-created risk management strategies for the production and commercialization of bioplastics identified in the workshop



3.2.3.1. Risk Management Strategies for Technological Barriers. Participants highlighted the importance of promoting the development of specialized equipment and technology. They suggested providing tax benefits to companies that promote good practices, scaling models to industrial levels, and transitioning academic models and transferring expertise and know-how to the industry. As we address the technological barriers, it's essential to support companies through incentives and ensure the scalability of innovations from academia to industry. Additionally, participants identified the need to overcome challenges in hiring skilled technical personnel. They recommended fostering interest among students and the younger generation in research and science, enabling companies to generate profit to achieve scalability, and providing specialized assistance to industries and companies (e.g., legal advice, planning, management, etc.). Furthermore, addressing the skills gap involves inspiring the next generation and equipping businesses with the necessary support to grow and sustain their operations.

3.2.3.2. Risk Management Strategies for Knowledge Barriers. The workshop participants emphasized the necessity to promote research and fill gaps in bioplastics production techniques. They suggested attracting funding for research in this area through collaboration among various stakeholders, focusing more on European projects and increasing investment in national projects, and simplifying the processes related to funding and expenditures. Bridging knowledge gaps requires a concerted effort to secure funding and streamline administrative processes to facilitate more effective research and development. Moreover, the participants stressed the importance of promoting collaboration among all stakeholders involved in the production and commercialization of bioplastics. They recommended educating consumers, focusing on universities and younger demographics, increasing outreach through media and social networks, encouraging interaction and collaboration across different knowledge areas, overcoming the "fear" of sharing knowledge, and promoting collaboration. They also highlighted the need to appeal for private funding as a solution to common problems faced by academia and industry. Enhancing collaboration and knowledge sharing among stakeholders can significantly boost innovation and acceptance of bioplastics in the market.

3.2.3.3. Risk Management Strategies for Economic Barriers. Participants identified the reduction of production costs of certain bioplastics as a critical area. They proposed investing more in research on efficient production methods, providing greater support to researchers and assistance in project applications, offering specialized support to establish industry partnerships, and implementing strategies to reduce costs through strategic planning. Tackling economic barriers involves improving production efficiency and forming strategic partnerships to reduce overall costs. They also discussed the importance of increasing access to funding for new projects. Suggestions included introducing tax benefits or carbon footprint-based taxation to encourage bioplastics production, organizing and planning as a society, establishing directives aligned with strategic programs to motivate investments, and simplifying funding processes in the research and education sector. Increasing funding accessibility can be achieved through targeted incentives and streamlined processes, encouraging more investment in bioplastics.

3.2.3.4. Risk Management Strategies for Regulatory Barriers. During the workshop, participants advocated for promoting fair production and commercialization policies and standards. They recommended adapting European regulations to the internal market, ensuring technical honesty in the creation of standards and legislation, integrating bioplastics into existing regulatory flows, and standardizing procedures. To overcome regulatory barriers, policies need to be fair, transparent, and adapted to both European and local markets, ensuring smooth integration of bioplastics into the existing framework. They also emphasized the need to promote regulatory standards harmonization between countries. This includes fostering multidisciplinary collaboration among legislators, researchers, and industry in drafting legislation, establishing specific regulations for bioplastics (vs. those equating plastics with bioplastics), better defining and categorizing bioplastics (including bio-based, biodegradable, and biocompatible), communicating clearly and based on accurate evidence, and developing accessible documents summarizing existing information on various types of bioplastics, life cycle analysis, advantages, and disadvantages. Harmonizing regulatory standards globally will facilitate smoother trade and adoption of bioplastics, fostering international collaboration and clearer guidelines.

3.2.3.5. Risk Management Strategies for Supply Stability Barriers. Workshop participants underscored the importance of optimizing resource management. They advocated for encouraging collaboration among organizations instead of competition, using waste as raw material, and adapting technology to the seasonality of raw materials. Ensuring a stable supply of bioplastics requires innovative resource management and technological adaptations to maintain production levels year-round. Additionally, participants discussed making the bioplastics business more attractive. They suggested creating representative associations for the sector, providing training and capacity building for new economic units, exploring forests and forest production for cellulose extraction, and promoting consumption and effective communication about bioplastics. Attracting businesses to the bioplastics sector can be achieved through industry representation, training, and effective marketing strategies that highlight the benefits of bioplastics.

3.2.3.6. Risk Management Strategies for Behavioural Barriers. Participants identified reducing the gap between intention and actual production of bioplastics as a key focus. They recommended dispelling misconceptions about disadvantages through awareness and educational campaigns, focusing on younger demographics, providing incentives for the recycling of plastics, utilizing by-products from agriculture and agro-food industries in bioplastics production, investing in consumer confidence through reliable information, certification, and legislation, engaging in multidisciplinary efforts to reduce this gap, involving various stakeholders across distribution/retail chains, and attracting raw material producers through more technical and behavioural research to understand the best communication strategies to promote pro-environmental behaviours. Addressing behavioural barriers requires a multifaceted approach involving education, incentives, and clear communication to bridge the gap between intention and production. Lastly, participants discussed promoting consumer acceptance and reducing perceptions of risk. They suggested communicating information clearly and accessibly about the benefits of bioplastics, confronting the perception of low durability with scientific evidence, using credible tools to reinforce consumer confidence, and adjusting prices to encourage pro-environmental behaviours. Promoting consumer acceptance involves transparent communication, addressing misconceptions, and providing incentives to encourage environmentally friendly choices.

3.3. MARKET OPPORTUNITIES FOR COMMERCIALISATION OF BIOPOLYMER TECHNOLOGIES

This section reports on a set of market opportunities for commercialisation of biopolymer technologies. Opportunities identified in the systematic literature review and the umbrella review are mainly inferences based on pressing topics identified on those. This is because the literature review did not focus on directly on the identification of market opportunities, but instead on the identification of barriers to commercialization of biopolymers. As such, the identification of market opportunities for commercialisation of biopolymer technologies is complemented with data collected from the interviews and the workshop with relevant stakeholders working in the field of production and commercialization of bioplastics.

3.3.1. Evidence from Literature Reviews

The biopolymer and bioplastic market presents substantial opportunities due to their potential for promoting sustainability and reducing reliance on fossil fuels. One of the key market opportunities lies in advancing the technology and production methods for biopolymers. This includes overcoming existing technological and knowledge barriers through increased research and development (Chaudhary et al., 2022; Luft et al., 2020). By addressing these technical challenges, the industry can enhance the performance and scalability of biopolymer products, making them more competitive with conventional plastics. Economic opportunities are also significant. Investing in the development and commercialization of biopolymer technologies can lead to new business ventures and job creation in the green technology sector. However, this requires addressing economic constraints such as limited access to financial resources for research, development, and scaling up production (Agarwal et al., 2023). Regulatory frameworks present another opportunity for market growth. Developing clear and supportive regulations can facilitate the adoption of biopolymers by providing manufacturers with the guidelines needed to comply with environmental standards (Panoutsou et al., 2022). This regulatory support, coupled with incentives for adopting bioplastics, can drive consumer acceptance and market expansion (Fiallos-Cardenas et al., 2022). Additionally, there are opportunities related to supply chain improvements. Utilizing organic waste and other sustainable raw materials not only supports waste management but also contributes to a circular economy (Bos & Broeze, 2020). This approach can enhance the stability and sustainability of the biopolymer supply chain, creating a more resilient and environmentally friendly production system (Rehman et al., 2023). Furthermore, there is a need for increased public awareness and consumer education regarding bioplastics (Findrik & Meixner, 2023; Weinrich & Herbes, 2023). Informational campaigns and clear labelling practices can build consumer trust and promote the benefits of biopolymers (Bhagwat et al., 2020; Klein et al., 2019; Meeks et al., 2015; Notaro et al., 2022; Yeh et al., 2015). Collaborative efforts among researchers, industry experts, and policymakers are essential to address the barriers and drive market growth effectively (Omerović et al., 2021). In summary, the biopolymer market holds significant opportunities for growth and innovation. By focusing on technological advancement, economic investment, supportive regulations, supply chain improvements and increasing consumer awareness and engagement with bioplastics, the industry can overcome current challenges and capitalize on the potential of biopolymers to advance sustainability and circular economy goals.

3.3.2. Evidence from Interviews

Despite the challenges to biopolymer commercialization previously identified, experts that participated in the interviews highlighted that there are promising market opportunities. In that regard, they mentioned that there is a growing consumer demand for sustainable products, driven by increasing environmental awareness. This shift in consumer preferences creates a favourable market environment for bioplastics, as more individuals seek eco-friendly alternatives to traditional plastics. Moreover, they mentioned that technological advancements are also contributing to the sector's potential, with innovations in production methods and new types of bioplastics enhancing their viability. For instance, using waste products as raw materials not only reduces costs but also makes bioplastics more attractive. Opportunities from emerging applications across various industries were also mentioned in the interviews. For example, packaging, agriculture, and automotive sectors, are expanding the use cases for bioplastics, thereby supporting market growth. The rise of bioplastic startups, which often drive innovation, also presents significant growth opportunities and can act as catalysts for broader industry adoption. Additionally, international market expansion offers further growth potential as global environmental consciousness rises. Often mentioned by the interviewed stakeholders are the need for supportive policies and regulations that promote sustainable practices and offer incentives for bioplastic use are crucial for fostering a positive development environment. Although this constitutes a challenge, it also highlights potential opportunities for promoting the commercialisation of biopolymer technologies, particularly for companies that can drive and adapt to the development new regulatory frameworks. Addressing production costs, increasing consumer awareness, and leveraging technological advancements will be key to unlocking the full market potential. These create opportunities for companies aiming to establish themselves as industry benchmarks.

Nevertheless, we also found that stakeholders were not often comfortable at discussing biopolymer commercialization opportunities. As such, they often expressed hesitancy and resistance when discussing such opportunities. This reluctance may reflect broader market uncertainty, as businesses weigh the risks associated with adopting newer, market unproven technologies. This reflected participants' concerns over production costs, scalability, and the long-term viability of bioplastics compared to traditional plastics. Additionally, they reported that while consumer interest in sustainable products is rising, translating this demand into consistent, large-scale commercial success may take time. As a result, interviewed stakeholder opinion is that organizations appear to be adopting a more optimistic but cautious approach, waiting for more stable market conditions, clearer regulatory frameworks, and further technological advancements in this industry. In this scenario, interviewed actors agree that companies that can follow market trends and accompany technological developments will be at the forefront of the biopolymer commercialization business.

3.3.3. Evidence from Workshop

The workshop with key stakeholders in the bioplastics industry revealed several market opportunities tied to overcoming existing barriers in the production and commercialization of biopolymers. Stakeholders emphasized the need for specialized equipment and technology that can bridge the gap between academic research and industrial applications. Companies that focus on developing industrial-scale solutions for bioplastic production can benefit from fiscal incentives while playing a crucial role in scaling innovative technologies. Similarly, addressing the shortage of skilled labour in the industry presents an opportunity for training institutions and businesses that provide specialized workforce development programs, particularly for younger generations, to fill technical roles in the bioplastics field.

Another significant market opportunity identified by stakeholders involves improving cost-efficiency in bioplastics production. There is a clear demand for innovations that reduce production costs, such as using waste or agricultural by-products as raw materials, which could also support circular economy models. Additionally, regulatory harmonization across countries was highlighted as a critical need, creating space for companies specializing in regulatory consulting to help bioplastics firms navigate complex local and international frameworks. Establishing specific regulatory standards for bioplastics, distinct from conventional plastics, was seen as essential for market growth. This, along with clearer consumer education campaigns and credible certification schemes, could enhance trust and promote broader consumer acceptance of bioplastics, opening further commercial opportunities.

Lastly, stakeholders pointed out the potential for collaboration between academia, industry, and policymakers to attract funding for bioplastics research. Companies that facilitate these collaborations and advocate for streamlined funding processes could benefit from an influx of investment aimed at making bioplastics more competitive. By tackling these barriers through innovation and partnerships, businesses can tap into a growing demand for sustainable materials while contributing to the industry's long-term viability.

4. DISCUSSION

The importance of developing and commercializing biopolymer production technologies cannot be overstated, particularly in the context of increasing environmental concerns and the urgent need for sustainable alternatives to traditional plastics (Atiwesh et al., 2021; de Souza Machado, 2018; Nielsen et al., 2020; Teixeira et al., 2023; Villarrubia-Gómez, 2018). As global awareness of the ecological impact of plastic pollution grows, the biopolymer sector presents a promising solution that aligns with both consumer demands for greener products and regulatory pressures for more sustainable practices (Bhagwat et al., 2020; Briassoulis, 2019; Notaro et al., 2022). This report delved into the risk management strategies and market opportunities essential for the successful commercialization of biopolymer technologies.

To achieve a comprehensive perspective, we employed a robust methodology that included extensive literature reviews, interviews with industry experts, and workshops with key stakeholders. Firstly, our work aimed to identify the primary industry and consumer challenges to biopolymer commercialization. Secondly, it aimed to gather insights into stakeholders' perceptions regarding bioplastics, focusing on business models, risks, challenges, market opportunities, and strategic recommendations. Finally, it aimed to provide actionable insights into effective risk management strategies aimed at overcoming these barriers and facilitating the successful commercialization of biopolymer production technologies.

Our findings highlight significant barriers to the commercialization of biopolymers, including technological challenges in scaling production processes and optimizing product performance (Chaudhary et al., 2022; Cristofoli et al., 2023; Dijkstra et al., 2020; Wang et al., 2022). High production costs further complicate the market landscape (Agarwal et al., 2023; Bamps et al., 2022; Dalton et al., 2022; Duran et al., 2022), compounded by a complex regulatory framework (Fiallos-Cárdenas et al., 2022; Panoutsou et al., 2022) and widespread consumer misconceptions regarding bioplastics were also identified (Findrik & Meixner, 2023; Onwezen et al., 2017; Zwicker et al., 2020).

In response to these challenges, we found several key risk management strategies. We found that promoting technological innovation is critical for improving production efficiency and scalability (Asim et al., 2022; Cristofoli et al., 2023). Furthermore, adopting multidisciplinary and transdisciplinary approaches can help bridge gaps in technology and knowledge within the biopolymer production process (Brandolese & Kleij, 2022; Clifton-Brown et al., 2023; Geijer et al., 2022; Gheorghita et al., 2021; Kostas et al., 2021; Krujatz et al., 2022; Menossi et al., 2021). Cost-reduction measures through government incentives and private investment are also essential to alleviate financial burdens on producers (Herbes et al., 2018; Klein et al., 2020; Scherer et al., 2017). Harmonizing regulatory frameworks will also foster a more supportive environment for commercialization, simplifying compliance and encouraging market entry (European Bioplastics, 2017; Filho et al., 2022; Notaro et al., 2022). Moreover, enhancing consumer awareness, improving product labelling, and ensuring clear and trustworthy communication are vital for addressing misconceptions about bioplastics (Findrik & Meixner, 2023; Klein et al., 2020; Weinrich & Herbes, 2023). By building trust and raising engagement, these initiatives can facilitate greater consumer adoption and acceptance of biopolymer products (Dijkstra et al., 2020; Findrik & Meixner, 2023; Jayakumar et al., 2022; Joye, 2019; Pires et al., 2022; Ruf et al., 2022; Scherer et al., 2017).

The strategies discussed not only aim to address existing challenges but also unlock significant market opportunities. The increasing global emphasis on environmental sustainability provides a favourable backdrop for bioplastics, creating avenues for international market expansion and innovation (Blesin et al., 2017; Boz et al., 2020; Filho et al., 2022; Mahmud et al., 2024; Rehman et al., 2023). Advancements in biopolymer technology are enhancing applicability across various sectors, particularly in agriculture, packaging, and biomedical fields, all of which are actively seeking sustainable alternatives (Chavooshi et al., 2023; Getahun et al., 2024; Holland et al., 2019; Panoutsou et al., 2022; Pires et al., 2022; Salgado et al., 2021; Zhang et al., 2022). Additionally, the promotion of circular economy practices offers further opportunities to integrate bioplastics into sustainable production and waste management systems, aligning with global sustainability objectives (Bos & Broeze, 2020). This is complemented with the emergence of new companies seeking to explore novel feedstock sources (e.g., algae; Cinar et al., 2020).

Our results indicate that by effectively navigating these challenges and capitalizing on market opportunities, the biopolymer industry can serve as a catalyst for transformative change. This sector has the potential to drive innovations that contribute to a more environmentally responsible future, significantly impacting the transition towards a circular economy focused on sustainable material usage. As the industry continues to evolve, ongoing collaboration and co-production of knowledge among industry stakeholders, dedicated research, policymakers, and consumers, will be crucial in realizing the full potential of biopolymers in meeting both environmental and economic goals.

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ANNEX I

Detailed Search String for the Systematic Review on Industry Barriers to Biopolymer Commercialization

Database	Search string
Web of Science	TS=("supply-side" OR "supply-chain" OR "supply" OR "supplier*" OR "developer*" OR "stakeholder*" OR "shareholder*" OR "producer*" OR "manufacter*" OR "industry") AND TS=("biopolymer*" OR "biobased polymer*" OR "biodegradable polymer*" OR "sustainable polymer*" OR "renewable polymer*" OR "green polymer*" OR "biomaterial*" OR "bio-based material*" OR "bioproduct*" OR "biodegradable material*" OR "sustainable material*" OR "green material*") AND TS=("commercialization" OR "market" OR "market entry" OR "market adaptation" OR "market penetration" OR "entrepreneurship" OR "business model" OR "business" OR "industry" OR "adoption" OR "consumption") AND TS=("new*" OR "novel*" OR "innovat*") AND TS=("barrier*" OR "obstacle*" OR "challenge*" OR "difficult*" OR "problem*" OR "impediment*" OR "limitation*" OR "constraint*" OR "bottleneck*")
SCOPUS	TITLE-ABS-KEY ("supply-side" OR "supply-chain" OR "supply" OR "supplier*" OR "developer*" OR "stakeholder*" OR "shareholder*" OR "producer*" OR "manufacter*" OR "industry") AND TITLE-ABS-KEY ("biopolymer*" OR "biobased polymer*" OR "biodegradable polymer*" OR "sustainable polymer*" OR "renewable polymer*" OR "green polymer*" OR "biomaterial*" OR "bio-based material*" OR "bioproduct*" OR "biodegradable material*" OR "sustainable material*" OR "green material*") AND TITLE-ABS-KEY ("commercialization" OR "market" OR "market entry" OR "market adaptation" OR "market penetration" OR "entrepreneurship" OR "business model" OR "business" OR "industry" OR "adoption" OR "consumption") AND TITLE-ABS-KEY ("new*" OR "novel*" OR "innovat*") AND TITLE-ABS-KEY ("barrier*" OR "obstacle*" OR "challenge*" OR "difficult*" OR "problem*" OR "impediment*" OR "limitation*" OR "constraint*" OR "bottleneck*") AND TITLE-ABS-KEY ("technolog*" OR "technical" OR "innovation" OR "r&d" OR "research" OR "development" OR "limited knowledge" OR "limited expertise" OR "specialized equipment" OR "limited availability" OR "limited research" OR "design" OR "engineering" OR "prototyping" OR "manufacturing" OR "scale-up" OR "process" OR "productivity" OR "efficiency" OR "performance" OR "standardization" OR "quality controls" OR "automation" OR

	"regulatory" OR "pre-market" OR "approval" OR "legal" OR "polic*" OR "compliance" OR "standards" OR "certification" OR "permitting" OR "licensing" OR "environmental" OR "waste management" OR "waste disposal" OR "waste reduction" OR "waste minimization" OR "health" OR "safety" OR "liability" OR "intellectual property" OR "trade" OR "customs" OR "taxation" OR "funding" OR "capital" OR "financial" OR "cost" OR "economic" OR "budget" OR "investment" OR "financial return" OR "uncertainty in return" OR "risk management" OR "market demand" OR "market entry" OR "market penetration" OR "consumption" OR "consumer*" OR "supply-stability" OR "supply" OR "stability" OR "manufacturing" OR "production" OR "resource* availability" OR "raw material* availability" OR "supply interruptions" OR "supply problems" OR "supply chain disruptions" OR "supply shortages" OR "production limitations" OR "production issues" OR "distribution" OR "supply chain uncertainties" OR "seasonal" OR "skilled labor" OR "skilled human resources" OR "cultural" OR "social" OR "organizational" OR "management" OR "leadership" OR "human" OR "psychological" OR "attitud*" OR "behavio*" OR "beliefs" OR "perception" OR "motivat*" OR "decision-making" OR "communication" OR "collaboration" OR "networking" OR "resistance to change" OR "traditional practices" OR "learning" OR "education" OR "knowledge" OR "training" OR "awareness" OR "expertise" OR "competency" OR "skills" OR "capacity" OR "information" OR "availab*") AND (LIMIT-TO (PUBYEAR,2023) OR LIMIT-TO (PUBYEAR,2022) OR LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR,2015) OR LIMIT-TO (PUBYEAR,2014) OR LIMIT-TO (PUBYEAR,2013) OR LIMIT-TO (PUBYEAR,2012) OR LIMIT-TO (PUBYEAR,2011) OR LIMIT-TO (PUBYEAR,2010))
PubMed	(("supply-side"[Title/Abstract] OR "supply-chain"[Title/Abstract] OR "supply"[Title/Abstract] OR "supplier*"[Title/Abstract] OR "developer*"[Title/Abstract] OR "stakeholder*"[Title/Abstract] OR "shareholder*"[Title/Abstract] OR "producer*"[Title/Abstract] OR "manufacter*"[Title/Abstract] OR "industry"[Title/Abstract]) AND ("bioplastic*"[Title/Abstract] OR "biopolymer*"[Title/Abstract] OR "biobased polymer*"[Title/Abstract] OR "biodegradable polymer*"[Title/Abstract] OR "sustainable polymer*"[Title/Abstract] OR "renewable polymer*"[Title/Abstract]

	OR "green polymer*"[Title/Abstract] OR "biomaterial*"[Title/Abstract] OR "bio-based material*"[Title/Abstract] OR "bioproduct*"[Title/Abstract] OR "biodegradable material*"[Title/Abstract] OR "sustainable material*"[Title/Abstract] OR "green material*"[Title/Abstract])) AND ("commercialization"[Title/Abstract] OR "market"[Title/Abstract] OR "market entry"[Title/Abstract] OR "market adaptation"[Title/Abstract] OR "market penetration"[Title/Abstract] OR "entrepreneurship"[Title/Abstract] OR "business model"[Title/Abstract] OR "business"[Title/Abstract] OR "industry"[Title/Abstract] OR "adoption"[Title/Abstract] OR "consumption"[Title/Abstract]) AND ("new*" [Title/Abstract] OR "novel*" [Title/Abstract] OR "innovat*" [Title/Abstract]) AND ("barrier*"[Title/Abstract] OR "obstacle*"[Title/Abstract] OR "challenge*"[Title/Abstract] OR "difficult*"[Title/Abstract] OR "problem*"[Title/Abstract] OR "impediment*"[Title/Abstract] OR "limitation*"[Title/Abstract] OR "constraint*"[Title/Abstract] OR "bottleneck*"[Title/Abstract]) AND (2010:2023[Date - Publication])
IEEE Xplore	(("All Metadata":bioplastic OR biopolymer OR biobased polymer OR biodegradable polymer OR sustainable polymer OR renewable polymer OR green polymer OR biomaterial OR bio-based material OR bioproduct OR biodegradable material OR sustainable material OR green material) AND ("All Metadata":commercialization OR market OR market entry OR market adaptation OR market penetration OR entrepreneurship OR business model OR business OR industry OR adoption OR consumption)) AND ("All Metadata":new OR novel OR innovat*) AND (("All Metadata":barrier OR obstacle OR challenge OR difficult OR problem OR impediment OR limitation OR constraint OR bottleneck OR technology OR innovation OR r&d OR research OR development OR knowledge OR expertise OR skills OR capacity) AND ("All Metadata":technolog* OR technical OR innovation OR r&d OR research OR development OR limited knowledge OR limited expertise OR specialized equipment OR limited availability OR limited research OR design OR engineering OR prototyping OR manufacturing OR scale-up OR process OR productivity OR efficiency OR performance OR standardization OR quality controls OR automation OR regulatory OR pre-market OR approval OR legal OR polic* OR compliance OR standards OR certification OR permitting OR licensing OR environmental OR waste management OR waste disposal OR waste reduction OR waste minimization OR health OR safety OR liability OR intellectual property OR

trade OR customs OR taxation OR funding OR capital OR financial OR cost OR economic OR budget OR investment OR financial return OR uncertainty in return OR risk management OR market demand OR market entry OR market penetration OR consumption OR consumer OR supply-stability OR supply OR stability OR manufacturing OR production OR resource* availability OR raw material* availability OR supply interruptions OR supply problems OR supply chain disruptions OR supply shortages OR production limitations OR distribution OR supply chain uncertainties OR seasonal OR skilled labor OR skilled human resources OR cultural OR social OR organizational OR management OR leadership OR human OR psychological OR attitude OR behavior OR belief OR perception OR motivation OR decision-making OR communication OR collaboration OR networking OR resistance to change OR traditional practices OR learning OR education OR knowledge OR training OR awareness OR expertise OR competency OR skills OR capacity OR information OR availability))

ANNEX II

Full List of studies included in the Systematic Review on Industry Barriers to Biopolymer Commercialization

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ANNEX III

Search String Used on Web of Science and SCOPUS to Identify Published Systematic Reviews on Barriers to Consumer Demand for Bioplastics

Web of Science Search String

(TI=((bioplastic*) OR (bio-plastic*) OR ((bio)plastic*) OR (biobased) OR (bio-based) OR ((bio)based) OR (biopolymer*) OR (bio-polymer*) OR ((bio)polymer*) OR (“sustainable plastic*”) OR (“sustainable material*”) OR (“sustainable packaging”) OR (“sustainable food packaging”) OR (“sustainable container*”) OR (“sustainable product*”) OR (“sustainable purchase*”) OR (“biodegradable plastic*”) OR (“biodegradable material*”) OR (“biodegradable packaging”) OR (“biodegradable food packaging”) OR (“biodegradable container*”) OR (“biodegradable product*”) OR (“environmentally-friendly plastic*”) OR (“environmentally-friendly material*”) OR (“environmentally-friendly packaging”) OR (“environmentally-friendly food packaging”) OR (“environmentally-friendly container*”) OR (“environmentally-friendly product*”) OR (“environmentally-friendly purchase*”) OR (“environmentally friendly plastic*”) OR (“environmentally friendly material*”) OR (“environmentally friendly packaging”) OR (“environmentally friendly food packaging”) OR (“environmentally friendly container*”) OR (“environmentally friendly product*”) OR (“environmentally friendly purchase*”) OR (“ecological plastic*”) OR (“ecological material*”) OR (“ecological packaging”) OR (“ecological food packaging”) OR (“ecological container*”) OR (“ecological product*”) OR (“ecological purchase*”) OR (“eco-designed plastic*”) OR (“eco-designed material*”) OR (“eco-designed packaging”) OR (“eco-designed food packaging”) OR (“eco-designed container*”) OR (“eco-designed product*”) OR (“eco designed plastic*”) OR (“eco designed material*”) OR (“eco designed packaging”) OR (“eco designed food packaging”) OR (“eco designed container*”) OR (“eco designed product*”) OR (“eco-innovative plastic*”) OR (“eco-innovative material*”) OR (“eco-innovative packaging”) OR (“eco-innovative packaging”) OR (“eco-innovative container*”) OR (“eco-innovative product*”) OR (“eco innovative plastic*”) OR (“eco innovative material*”) OR (“eco innovative packaging”) OR (“eco innovative food packaging”) OR (“eco innovative container*”) OR (“eco innovative product*”) OR (“bio-waste plastic*”) OR (“bio-waste material*”) OR (“bio-waste packaging”) OR (“bio-waste food packaging”) OR (“bio-waste container*”) OR (“bio-waste product*”) OR (“bio waste plastic*”) OR (“bio waste material*”) OR (“bio waste packaging”) OR (“bio waste food packaging”) OR (“bio waste container*”) OR (“bio waste product*”) OR (“zero-waste plastic*”) OR (“zero-waste material*”) OR (“zero-waste packaging”) OR (“zero-waste food packaging”) OR (“zero-waste container*”) OR (“zero-waste product*”) OR (“zero waste plastic*”) OR (“zero waste material*”) OR (“zero waste packaging”) OR (“zero waste food packaging”) OR (“zero waste container*”) OR (“zero waste product*”) OR (“circular plastic*”) OR (“circular material*”) OR (“circular packaging”) OR (“circular food packaging”) OR (“circular container*”) OR (“circular product*”) OR (“waste based plastic*”) OR (“waste based material*”) OR (“waste based packaging”) OR (“waste based food packaging”) OR (“waste based container*”) OR (“waste based product*”) OR (“waste-based plastic*”) OR (“waste-based material*”) OR (“waste-based packaging”) OR (“waste-based packaging”) OR (“waste-based container*”) OR (“waste-based product*”) OR (“organic plastic*”) OR (“organic material*”) OR (“organic packaging”) OR (“organic food packaging”) OR (“organic container*”) OR (“organic product*”) OR (“plant based plastic*”) OR (“plant based material*”) OR (“plant based packaging”) OR (“plant based food packaging”) OR (“plant based container*”) OR (“plant based product*”) OR (“plant-based plastic*”) OR (“plant-based material*”) OR (“plant-based packaging”) OR (“plant-based food packaging”) OR (“plant-based container*”) OR (“plant-based product*”) OR (“green plastic*”) OR (“green material*”) OR (“green packaging”) OR (“green food packaging”) OR (“green container*”) OR (“green product*”) OR (“green purchase*”) OR (“renewable plastic*”) OR (“renewable material*”) OR (“renewable packaging”) OR (“renewable food packaging”) OR (“renewable container*”) OR (“renewable product*”))) AND (TI=((review) OR (meta-analysis) OR (overview) OR (state-of-the-art) OR (“state of the art”) OR (“evidence synthesis”) OR (“literature synthesis”) OR (“synthesis of literature”) OR (“systematic map”) OR (“systematic search”) OR (“literature search”) OR (“search of literature”))) AND (AB=((consumer*) OR (public) OR (stakeholder*) OR (customer*) OR (“end user*”) OR (“end-user*”) OR (market) OR (commerc*) OR (citizen*) OR (user*))) AND (AB=((impact*) OR (challenge*) OR (aware*) OR (preference*) OR (perce*) OR (attitud*) OR (know*) OR (driver*) OR (barrier*) OR (concern*) OR (intent*) OR (purchas*) OR (accept*) OR (scenario*) OR (choice*) OR (response*) OR (behavio$r*) OR (“willing* to pay”) OR (“willingness-to-pay”) OR (norm*) OR (expectation*) OR (evaluation*) OR (belief*) OR (value*) OR (consideration*) OR (future*) OR (innovation*) OR (recommend*) OR (“best practice*”) OR (“best-practice*”) OR (progress*) OR (decision*) OR (motiv*) OR (solution*) OR (adopt*) OR (demand*) OR (commercialization*) OR (commercialisation*) OR (purchase*))) AND PY=((2019) OR (2020) OR (2021) OR (2022) OR (2023) OR (2024)) AND LA=((English)) AND DT=((REVIEW) OR (ARTICLE))

SCOPUS Search String

(TITLE ((bioplastic*) OR (bio-plastic*) OR ((bio) plastic*) OR (biobased) OR (bio-based) OR ((bio) based) OR (biopolymer*) OR (bio-polymer*) OR ((bio) polymer*) OR ("sustainable plastic*") OR ("sustainable material*") OR ("sustainable packaging") OR ("sustainable food packaging") OR ("sustainable container*") OR ("sustainable product*") OR ("sustainable purchase*") OR ("biodegradable plastic*") OR ("biodegradable material*") OR ("biodegradable packaging") OR ("biodegradable food packaging") OR ("biodegradable container*") OR ("biodegradable product*") OR ("environmentally-friendly plastic*") OR ("environmentally-friendly material*") OR ("environmentally-friendly packaging") OR ("environmentally-friendly food packaging") OR ("environmentally-friendly container*") OR ("environmentally-friendly product*") OR ("environmentally-friendly purchase*") OR ("environmentally friendly plastic*") OR ("environmentally friendly material*") OR ("environmentally friendly packaging") OR ("environmentally friendly food packaging") OR ("environmentally friendly container*") OR ("environmentally friendly product*") OR ("environmentally friendly purchase*") OR ("ecological plastic*") OR ("ecological material*") OR ("ecological packaging") OR ("ecological food packaging") OR ("ecological container*") OR ("ecological product*") OR ("ecological purchase*") OR ("eco-designed plastic*") OR ("eco-designed material*") OR ("eco-designed packaging") OR ("eco-designed food packaging") OR ("eco-designed container*") OR ("eco-designed product*") OR ("eco designed plastic*") OR ("eco designed material*") OR ("eco designed packaging") OR ("eco designed food packaging") OR ("eco designed container*") OR ("eco designed product*") OR ("eco-innovative plastic*") OR ("eco-innovative material*") OR ("eco-innovative packaging") OR ("eco-innovative packaging") OR ("eco-innovative container*") OR ("eco-innovative product*") OR ("eco innovative plastic*") OR ("eco innovative material*") OR ("eco innovative packaging") OR ("eco innovative food packaging") OR ("eco innovative container*") OR ("eco innovative product*") OR ("bio-waste plastic*") OR ("bio-waste material*") OR ("bio-waste packaging") OR ("bio-waste food packaging") OR ("bio-waste container*") OR ("bio-waste product*") OR ("bio waste plastic*") OR ("bio waste material*") OR ("bio waste packaging") OR ("bio waste food packaging") OR ("bio waste container*") OR ("bio waste product*") OR ("zero-waste plastic*") OR ("zero-waste material*") OR ("zero-waste packaging") OR ("zero-waste food packaging") OR ("zero-waste container*") OR ("zero-waste product*") OR ("zero waste plastic*") OR ("zero waste material*") OR ("zero waste packaging") OR ("zero waste food packaging") OR ("zero waste container*") OR ("zero waste product*") OR ("circular plastic*") OR ("circular material*") OR ("circular packaging") OR ("circular food packaging") OR ("circular container*") OR ("circular product*") OR ("waste based plastic*") OR ("waste based material*") OR ("waste based packaging") OR ("waste based food packaging") OR ("waste based container*") OR ("waste based product*") OR ("waste-based plastic*") OR ("waste-based material*") OR ("waste-based packaging") OR ("waste-based packaging") OR ("waste-based container*") OR ("waste-based product*") OR ("organic plastic*") OR ("organic material*") OR ("organic packaging") OR ("organic food packaging") OR ("organic container*") OR ("organic product*") OR ("plant based plastic*") OR ("plant based material*") OR ("plant based packaging") OR ("plant based food packaging") OR ("plant based container*") OR ("plant based product*") OR ("plant-based plastic*") OR ("plant-based material*") OR ("plant-based packaging") OR ("plant-based food packaging") OR ("plant-based container*") OR ("plant-based product*") OR ("green plastic*") OR ("green material*") OR ("green packaging") OR ("green food packaging") OR ("green container*") OR ("green product*") OR ("green purchase*") OR ("renewable plastic*") OR ("renewable material*") OR ("renewable packaging") OR ("renewable food packaging") OR ("renewable container*") OR ("renewable product*"))) AND (TITLE ((review) OR (meta-analysis) OR (overview) OR (state-of-the-art) OR ("state of the art") OR ("evidence synthesis") OR ("literature synthesis") OR ("synthesis of literature") OR ("systematic map") OR ("systematic search") OR ("literature search") OR ("search of literature"))) AND (ABS ((consumer*) OR (public) OR (stakeholder*) OR (customer*) OR ("end user*") OR ("end-user*") OR (market) OR (commerc*) OR (citizen*) OR (user*))) AND (ABS ((impact*) OR (challenge*) OR (aware*) OR (preference*) OR (perce*) OR (attitud*) OR (know*) OR (driver*) OR (barrier*) OR (concern*) OR (intent*) OR (purchas*) OR (accept*) OR (scenario*) OR (choice*) OR (response*) OR (behavio$r*) OR ("willing* to pay") OR ("willingness-to-pay") OR (norm*) OR (expectation*) OR (evaluation*) OR (belief*) OR (value*) OR (consideration*) OR (future*) OR (innovation*) OR (recommend*) OR ("best practice*") OR ("best-practice*") OR (progress*) OR (decision*) OR (motiv*) OR (solution*) OR (adopt*) OR (demand*) OR (commercialization*) OR (commercialisation*) OR (purchase*))) AND PUBYEAR > 2018 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

ANNEX IV

List of Systematic Reviews Identified for the Umbrella Review on Barriers to Consumer Demand for Bioplastics

List of systematic reviews reviewed and brief description of the publication

Reference	Brief Description / Goal
Abrha, H., Cabrera, J., Dai, Y., Irfan, M., Toma, A., Jiao, S., & Liu, X. (2022) *Bio-based plastics production, impact and end of life: A literature review and content analysis*. Sustainability, 14(8), 4855. https://doi.org/10.3390/su14084855	Reviews bio-based plastics production, impact and end of life, including impact on the environment, economy, and society, and barriers to consumer demand and recommendations.
Adeyanju, G. C., Augustine, T. M., Volkmann, S., Oyebamiji, U. A., Ran, S., Osobajo, O. A., & Otitoju, A. (2021). Effectiveness of intervention on behaviour change against use of non-biodegradable plastic bags: a systematic review. *Discover Sustainability, 2*(13). https://doi.org/10.1007/s43621-021-00015-0	Examines various government regulations targeted at changing behaviour against plastic bags consumption, including their effectiveness in reducing such consumption for other alternatives.
Atiwesh, G., Mikhael, A., Parrish, C. C., Banoub, J., & Le, T. T. (2021). Environmental impact of bioplastic use: A review. *Heliyon, 7*, e07918. https://doi.org/10.1016/j.heliyon.2021.e07918	Reviews the environmental impact of different bioplastics currently in commercialization or under development, with implications for consumer acceptance.
Bangsa, A. B., & Schlegelmilch, B. B. (2020). Linking sustainable product attributes and consumer decision-making: Insights from a systematic review. *Journal of Cleaner Production, 245*, 118902. https://doi.org/10.1016/j.jclepro.2019.118902	Presents a systematic review of research into relationships between sustainable product attributes and consumer decision-making over the past decade (2008-2018).

Barbu, A., Catană, S-A., Deselnicu, D. C., Cioca, L-I., & Ioanid, A. (2022). Factors influencing consumer behavior toward green products: A systematic literature review. International Journal of *Environmental Research and Public Health, 19*(24), 16568. https://doi.org/10.3390/ijerph192416568	Reviews consumer behaviour and identifies important factors that interfere with consumer behaviour toward green products, including bioplastics.
Basbasan, A. J., Hararak, B., Winotapun, C., Wanmolee, W., Leelaphiwat, P., Boonruang, K., Chinsirikul, W., & Chonhenchob, V. (2022). Emerging challenges on viability and commercialization of lignin in biobased polymers for food packaging: *A review. Food Packaging and Shelf Life, 34*, 100969. https://doi.org/10.1016/j.fpsl.2022.100969	Reviewed the effects of incorporation of lignin into biobased polymers, including insights about pressing issues for judgment and buying decision that influence consumer acceptance.
Bos, P., Ritzen, L., van Dam, S., Balkenende, R., & Bakker, C. (2024). Bio-based plastics in product design: the state of the art and challenges to overcome. *Sustainability, 16*(8), 3295. https://doi.org/10.3390/su16083295	Explores the current state of the art of bio-based plastic use in durable consumer products and the opportunities and barriers encountered by product developers in adopting these materials, including consumer acceptance barriers.
Boz, Z., Korhonen, V., & Sand, C. K. (2020). Consumer considerations for the implementation of sustainable packaging: A review. *Sustainability, 12*, 2192. https://doi.org/10.3390/su12062192	Summarizes previous consumer research on sustainable packaging and highlights literature gaps, opportunities, and future research needs.
Camilleri, M. A., Cricelli, L., Mauriello, R., & Strazzullo, S. (2023). Consumer perceptions of sustainable products: A systematic literature review. *Sustainability, 15*(11),8923. https://doi.org/10.3390/su15118923	Reviews factors influencing consumers' perception of sustainable products, which apply to bioplastic products.

Cao, Y. (2022). "Green products": A review with the consumer buying process framework. *Journal of Environmental Management and Tourism, 14*(1), 52-66. https://doi.org/10.14505/jemt.v13.1(65).06	Synthesizes several factors contributing to low purchase of green products from the consumer perspective, which apply to bioplastics, providing understanding of consumer decision-making process
Corona, B., Tunn, V. S. C., & van den Broek, K. L. (2024). Integrating consumer behaviour into the environmental assessment of circular packaging: A scoping review. *The International Journal of Life Cycle Assessment, 29*, 80-98. https://doi.org/10.1007/s11367-023-02218-1	Explores the integration of behavioural insights from consumer behaviour sciences into Life-Cycle-Assessment of circular packaging, including consumer-side barriers and enablers for the success of circular and sustainable packaging.
Corrêa, R. S., de Oliveira, U. R., Abdalla, M. M., & Fernandes, V. A. (2022). Systematic literature review on sustainable products: Impact on organizations, research opportunities and future perspectives. *Cleaner Waste Systems, 1*, 100003. https://doi.org/10.1016/j.clwas.2022.100003	Presents the state of the art on sustainable products and analyses how this content impacts organizations, including consumer's behaviour regarding products with eco-labels, such as bioplastics.
Dey, B., Prabhakar, M. R., Jayaraman, S., Gujjala, L. K. S., Venugopal, A. P., & Balasubramanian, P. (2024). Biopolymer-based solutions for enhanced safety and quality assurance: A review. *Food Research International, 191*, 114723. https://doi.org/10.1016/j.foodres.2024.114723	Reviews key topics in biopolymer-based solutions, including factors that can increase consumer acceptance and purchase.

Dijkstra, H., van Beukering, P., & Brouwer, R. (2020). Business models and sustainable plastic management: A systematic review of the literature. *Journal of Cleaner Production, 258*, 120967. https://doi.org/10.1016/j.jclepro.2020.120967	Reviews the scientific literature of business models for sustainable plastic, including insights into consumer barriers and drivers for bioplastics acceptance.
Fatemi, H., Leijerholt, U., Rezvani, Z., & Schnittka, O. (2023). Consumer responses to sustainable product branding strategies: a literature review and future research agenda. *Baltic Journal of Management, 18*(4), 525-542. https://doi.org/10.1108/BJM-11-2022-0412	Synthesises the research on various sustainable product branding activities, including bioplastics, and their impact on consumer responses to sustainable products and brands.
Ferreira-Filipe, D. A, Paço, A., Duarte, A. C., Rocha-Santos, T., & Silva A. L. (2021). Are biobased plastics green alternatives? – A critical review. *International Journal of Environmental Research and Public Health, 18*(15), 7729. https://doi.org/10.3390/ijerph18157729	Provides a critical review on the recent advances in biobased polymers, including barriers and recommendations to consumer acceptance.
Findrik, E., & Meixner, O. (2023). Drivers and barriers for consumers purchasing bioplastics – A systematic literature review. *Journal of Cleaner Production, 410*, 137311. https://doi.org/10.1016/j.jclepro.2023.137311	Summarizes the state of the art regarding consumers’ response to bioplastics.
Jayakumar, A., Radoor, S., Siengchin, S., Shin, G. H., & Kim, J. T. (2023). Recent progress of bioplastics in their properties, standards, certifications and regulations: A review. *Science of the Total Environment, 878*, 163156. http://dx.doi.org/10.1016/j.scitotenv.2023.163156	Reviews several key aspects about bioplastics, such as: terminology, major sources, properties, management and recovery options, standards and certifications, and challenges and limitations.

Jha, S., Akula, B., Enyioma, H., Novak, M., Amin, V., & Liang, H. (2024). Biodegradable biobased polymers: A review of the state of the art, challenges, and future directions. *Polymers, 16*(16), 2262. https://doi.org/10.3390/polym16162262	Makes a techno-commercial analysis of biodegradable biobased polymers and includes government initiatives to facilitate the transition to these products that may impact consumer demand.
Ketelsen, M., Janssen, M., & Hamm, U. (2020). Consumers' response to environmentally-friendly food packaging – A systematic review. *Journal of Cleaner Production, 254*, 120123. https://doi.org/10.1016/j.jclepro.2020.120123	Analyses the state of the art regarding consumers' response to environmentally friendly food packaging, identifies barriers to the purchase of such products, and draws conclusions on how to overcome barriers to purchase.
Lestari, I. P., Pambekti, G. T. & Annisa, A. A. (2024). Determinant of green purchase behavior of Muslims: A systematic literature review. *Journal of Islamic Marketing*. [requested full text to author] https://doi.org/10.1108/JIMA-07-2023-0214	Reviews relevant factors that affect green purchase behaviour of Muslim consumers, with applicability in the field of bioplastics.
Luo, J., Wu, L., & Luximon, Y. (2024). A systematic literature review of sensory-related sustainable product design. *Environmental Development, 51*, 100993. https://doi.org/10.1016/j.envdev.2024.100993	Explores research on consumers sensory responses to sustainable products including barriers and recommendations to consumer acceptance in this domain, that can be applied to bioplastics.
Maior, R. Â., Oliveira Jr., E. R., Ribeiro, A. R., & Fernandes, L. M. (2022). Consumer behavioural variables in relation to green products: A systematic literature review. *Brazilian Journal of Marketing. 21*(4) 1307-1359. https://doi.org/10.5585/remark.v21i4.20016	Identifies variables influencing consumer behaviour towards sustainable products, and their application in market practices, including barriers and recommendations for bioplastics.

Manchanda, R. (2022). Exploration of green materialism framework: A review. *Indian Journal of Economics and Development, 18*(1), 189-200. https://doi.org/10.35716/IJED/21317	Reviews the concepts of materialism, environmental concern, and green marketing, including recommendations on strategies to boost green consumption appliable to bioplastics.
Marcon, A., Rbeiro, J. L. D., Dangelico, R. M., de Medeiros, J. F., & Marcon, É. (2022). Exploring green product attributes and their effect on consumer behaviour: A systematic review. *Sustainable Production and Consumption, 32*, 76-91. https://doi.org/10.1016/j.spc.2022.04.012	Analyses research to provide a comprehensive list of green product attributes, including bioplastics, and discusses the effects of different green product attributes on consumers' behaviour.
Mazhandu, Z. S., Muzenda, E., Mamvura, T. A., Belaid, M., & Nhubu, T. (2020). Integrated and consolidated review of plastic waste management and bio-based biodegradable plastics: Challenges and opportunities. *Sustainability, 12*(20), 8360. https://doi.org/10.3390/su12208360	Reviews the sustainability of some bio-based biodegradable plastics and includes recommendations to foster consumer acceptance.
Medeiros, J. F., Garlet, T. B., Ribeiro, J. L., & Cortimiglia, M. N. (2022). Success factors for environmentally sustainable product innovation: An updated review. *Journal of Cleaner Production, 345*(15), 131039. https://doi.org/10.1016/j.jclepro.2022.131039	Identified variables leading to behaviour patterns that lead to successful green products innovation, including how these contribute to consumer demand and acceptance of sustainable products such as bioplastics.
Morris, M. I. R., & Hicks, A. L. (2022). A human-centered review of life cycle assessments of bioplastics. *The International Journal of Life Cycle Assessment, 27*, 157-172. https://doi.org/10.1007/s11367-021-02001-0	Identifies gaps between human behaviour in bioplastic disposal and its environmental impact, highlighting barriers to bioplastic uptake and consumer demand.

Moshood, T. D., Nawanir, G., & Mahmud, F. (2022). Sustainability of biodegradable plastics: A review on social, economic, and environmental factors. *Critical Reviews in Biotechnology, 42*(6), 892–912. https://doi.org/10.1080/07388551.2021.1973954	Reviews biodegradable plastics regarding social, economic, and environmental sustainability, including factors that can contribute to consumer demand.
Panda, D., Singhal, D., Jena, S., & Tripathy, S. (2024). Assessment of Indian consumers' green purchase intention: an integration of theory of planned behaviour and meta-analysis. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-024-04897-8	Focusing on Indian consumers, reviews studies on consumers' green purchase intentions, identifying factors that influence consumers' decision-making towards the purchase of green products, such as bioplastics.
RameshKumar, S., Shaiju, P., O'Connor, K. E., Babu P, R. (2020). Bio-based and biodegradable polymers - State-of-the-art, challenges and emerging trends. *Current Opinion in Green and Sustainable Chemistry, 21*, 75-81. https://doi.org/10.1016/j.cogsc.2019.12.005	Reviews technologies in bioplastics manufacturing along with several challenges that can influence consumer acceptance.
Rietz, S., & Kremel, A. (2024). Consumer behavior as a challenge and opportunity for circular food packaging - A systematic literature review. *Circular Economy and Sustainability, 4*, 413-438. https://doi.org/10.1007/s43615-023-00290-1	Reviews strategies that could address concerns about waste management and littering if there is consumer acceptance and participation in circular systems, which may inform strategies to promote consumer demand for bioplastics.
Ruf, J., Emberger-Klein, A., & Menrad, K. (2022). Consumer response to bio-based products – A systematic review. *Sustainable Production and Consumption, 34*, 353-370. https://doi.org/10.1016/j.spc.2022.09.022	Reviews and analyses the current state of the art in consumer research on bio-based products and aims to identify research gaps and future research needs.

Seidu, R. K., Eghan, B., & Acquaye, R. (2024). A review of circular fashion and bio-based materials in the fashion industry. *Circular Economy and Sustainability, 4*, 693-715. https://doi.org/10.1007/s43615-023-00303-z	Investigates sustainable technological innovations within circular fashion and bio-based materials, including factors with critical role in influencing consumers to purchase bio-based materials.
Shaikh, S., Yaqoob, M., & Aggarwal, P. (2021). An overview of biodegradable packaging in food industry. *Current Research in Food Science, 4*, 503-520. https://doi.org/10.1016/j.crfs.2021.07.005	Reviews the characteristics of various biopolymers and their market potential for food packaging applications, including consumer perceptions and other issues affecting market growth.
Sharma, K., Aswal, C., & Paul, J. (2023). Factors affecting green purchase behavior: A systematic literature review. *Business Strategy and the Environment, 32*(4), 2078-2092. https://doi.org/10.1002/bse.3237	Explores the literature to identify factors that influence consumers' purchase of products with lower environmental impact, such as bioplastics, providing strategic insights to marketers.
Veerabhadrappa, N. B. B., Fernandes, S., & Panda, R. (2023). A review of green purchase with reference to individual consumers and organizational consumers: A TCCM approach. *Cleaner and Responsible Consumption, 8*, 100097. https://doi.org/10.1016/j.clrc.2022.100097	Reviews factors that influence green buying concerning B2C and B2B consumers (e.g., price sensitivity, risk perception), that are also applicable in the context of bioplastics.
Weinrich, R., & Herbes, C. (2023). Consumer research on bioplastics: A systematic review. *Q Open, 3*, 1-44. https://doi.org/10.1093/qopen/qoad013	Identifies consumer attributes and product attributes that influence consumers' purchase intention and willingness to pay.

Wijekoon, R., & Sabri, M. F. (2021). Determinants that influence green product purchase intention and behavior: A literature review and guiding framework. *Sustainability, 13*(11), 6219. https://doi.org/10.3390/su13116219	Reviews green purchase behavioural research, identifying facilitators, motives, and obstacles influencing consumers' decision-making process towards environmentally friendly products such as bioplastics.
Zhang, X., & Dong, F. (2020). Why do consumers make green purchase decisions? Insights from a systematic review. International Journal of *Environmental Research and Public Health, 17*(18), 6607. https://doi.org/10.3390/ijerph17186607	Reviews empirical research on green purchase behaviour, identifying individual factors, product attributes, marketing, and social factors influencing green purchase behaviour of products such as bioplastics.
Zhuang, W., Luo, X., & Riaz, M. U. (2021). On the factors influencing green purchase intention: A meta-analysis approach. *Frontiers in Psychology, 12*, 644020. https://doi.org/10.3389/fpsyg.2021.644020	Reviews cognitive, individual, and social factors influencing consumers' green purchase intention applicable in the context of bioplastics.

ANNEX V

List of Context-Specific Publications Reviewed for the Umbrella Review on Barriers to Consumer Demand for Bioplastics

List of context specific publications reviewed and brief description of the publication

Reference	Brief Description / Goal
Bhagwat, G., Gray, K., Wilson, S. P., Muniyasamy, S., Vincent, S. G., Bush, R., & Palanisami, T. (2020). Benchmarking bioplastics: A natural step towards a sustainable future. *Journal of Polymers and the Environment, 28*, 3055-3075. https://doi.org/10.1007/s10924-020-01830-8	Analyses international bioplastics standards, critically assess the potential shortcomings, and highlights avenues towards the reform of bioplastics regulation.
Blesin, J-M., Jaspersen, M., & Möhring, W. (2017). Boosting Plastics' Image? Communicative Challenges of Innovative Bioplastics. *e-plastory, 3.* http://e-plastory.com/index.php/e-plastory/article/view/Blesin/37	Explores, through focus groups, consumers' perceptions and knowledge on topics related to bioplastics, such as land use and genetic engineering.
Cammarelle, A., Viscecchia, R., & Bimbo, F. (2021). Intention to purchase milk packaged in biodegradable packaging: Evidence from Italian consumers. *Foods, 10*, 2068. https://doi.org/10.3390/foods10092068	Explores consumers' intentions to purchase sustainable packages made from organic waste, and the willingness to pay for them.
Chen, K-J., Marsh, T. L., Tozer, P. R., & Galinato, S. P. (2019). Biotechnology to sustainability: Consumer preferences for food products grown on biodegradable mulches. *Food Research International, 116*, 200-210. https://doi.org/10.1016/j.foodres.2018.08.013	Identifies consumer preferences and evaluates factors that determine willingness to pay for products grown in biodegradable mulches.

Confente, I., Scarpi, D., & Russo, I. (2020). Marketing a new generation of bio-plastics products for a circular economy: The role of green self-identity, self-congruity, and perceived value. *Journal of Business Research, 112*, 431-439. https://doi.org/10.1016/j.jbusres.2019.10.030

Studies what can lead to market acceptance of bioplastic from urban waste, and how consumers might respond to the introduction of products made of these PHA-based bioplastics.

Cruz, R. M., Krauter, V., Krauter, S., Agriopoulou, S., Weinrich, R., Herbes, C., Scholten, P. B., Uysal-Unalan. I., Sogut, E., Kopacic, S., Lahti, J., Rutkaite, R., & Varzakas, T. (2022). Bioplastics for food packaging: Environmental impact, trends and regulatory aspects. *Foods, 11*, 3087. https://doi.org/10.3390/foods11193087

Reviews different properties of bioplastics, mechanisms of biodegradation, regulations, future trends, and how consumers perceive bioplastics.

de Marchi, E., Pigliafreddo, S., Banterle, A., Parolini, M., & Cavaliere, A. (2020). Plastic packaging goes sustainable: An analysis of consumer preferences for plastic water bottles. *Environmental Science and Policy, 114*, 305-311. https://doi.org/10.1016/j.envsci.2020.08.014

Explores consumer preferences and willingness to pay for plastic water bottles made of conventional plastic polymer and from more sustainable plastic alternatives such as PLA.

Dilkes-Hoffman, L., Ashworth, P., Laycock, B., Pratt, S., & Lant, P. (2019). Public attitudes towards bioplastics – knowledge, perception and end-of-life management. *Resources, Conservation & Recycling, 151*, 104479. https://doi.org/10.1016/j.resconrec.2019.104479

Studies current knowledge and perceptions regarding bioplastics in a nationally representative sample of Australians.

Falcone, P., & Imbert, E. (2018). Social life cycle approach as a tool for promoting the market uptake of bio-based products from a consumer perspective. Sustainability, 10(4), 1031. https://doi.org/10.3390/su10041031

Identifies the main social impact categories and indicators that should be included in a social sustainability assessment of bio-based products, with a focus on the consumers.

Filho, W. L., Barbir, J., Abubakar, I. R., Paço, A., Stasiskiene, Z., Hornbogen, M., Fendt, M. T., Voronova, V., & Klõga, M. (2022) Consumer attitudes and concerns with bioplastics use: An international study. *PLoS ONE 17*(4), e0266918. https://doi.org/10.1371/journal. pone.0266918	Studies perceptions of bioplastics among consumers in 42 countries, including identification of levels of information and awareness, concerns, and attitudes towards bioplastics.
Filho, W. L., Salvia, A. L., Bonoli, A., Saari, U. A., Voronova, V., Klõga, M., Kumbhar, S. S., Olszewski, K., De Quevedo, D. M., & Barbir, J. (2021). An assessment of attitudes towards plastics and bioplastics in Europe. *Science of The Total Environment, 755*. https://doi.org/10.1016/j.scitotenv.2020.142732	Investigates consumer attitudes towards plastic and bioplastic consumption in Europe.
Fletcher, C. A. (2022). Is the consumer experience creating barriers for the effective uptake and disposal of bioplastics? *Clean Technologies and Recycling, 2*(4), 308-320. https://doi.org/10.3934/ctr.2022016	Explores three factors that may influence consumers' experience with bioplastics, and the impact that such factors may have on the use and disposal of bioplastics.
Fletcher, C. A., Niemenoja, K., Hunt, R., Adams, J., Dempsey, A., & Banks, C. E. (2021). Addressing stakeholder concerns regarding the effective use of bio-based and biodegradable plastics. *Resources, 10*(10), 95. https://doi.org/10.3390/resources10100095	Assesses performance and safety concerns about bioplastics and develops measures to overcome significant concerns through a series of stakeholder engagement events.
Gabriel, A., & Menrad, K. (2015). Market acceptance and consumers' willingness-to-pay for plants in biodegradable pots. *Acta Horticulturae, 1099*, 297-305. https://doi.org/10.17660/ActaHortic.2015.1099.34	Analyzes general motives, perceptions, and willingness-to pay of plant buyers and identifies possible target groups for biodegradable plant pots.

Grebitus, C., Roscoe, R. D., van Loo, E. J., & Kula, I. (2020). Sustainable bottled water: How nudging and Internet Search affect consumers' choices. *Journal of Cleaner Production, 267*, 121930. https://doi.org/10.1016/j.jclepro.2020.121930	Examines differences in consumer preferences and willingness to pay for sustainable bottled water produced with plant-based versus post-consumer waste plastics.
Herbes, C., Beuthner, C., & Ramme, I. (2018). Consumer attitudes towards biobased packaging – A cross-cultural comparative study. *Journal of Cleaner Production, 194*, 203-218. https://doi.org/10.1016/j.jclepro.2018.05.106	Examines how environmentally friendly packaging attributes influence overall evaluations of environmental friendliness, in three Western consumer cultures: Germany, France, and the U.S.
Iles, A., & Martin, A. N. (2013). Expanding bioplastics production: sustainable business innovation in the chemical industry. *Journal of Cleaner Production, 45*, 38-49. https://doi.org/10.1016/j.jclepro.2012.05.008	Examines the bioplastic businesses of three major chemical companies to understand how to address the challenges of bioplastic production and commercialization.
Karachaliou, E., Tsagaraki, E., Delioglamnis, I., & Kouzi, E. (2017). D2.2 Public perception of bio-based products. BIOWAYS. https://www.bioways.eu/download.php?f=243&l=en&key=faf3e6f477c8183036b6eb591863b6e8	Explores consumers' awareness, knowledge, understanding, and perceptions about bioplastics to promote their adoption across various EU countries.
Karana, E. (2012). Characterization of 'natural' and 'high-quality' materials to improve perception of bio-plastics. *Journal of Cleaner Production, 37*, 316-325. https://doi.org/10.1016/j.jclepro.2012.07.034	Explores determinants behind consumers' perception of bioplastic as 'natural' and/or 'high- quality' materials.

Klein, F. F., Emberger-Klein, A., & Menrad, K. (2020). Indicators of consumers' preferences for bio-based apparel: A German case study with a functional rain jacket made of bioplastic. *Sustainability, 12*, 675. https://doi.org/10.3390/su12020675

Analyzes factors influencing consumers' preferences for functional apparel made of bioplastic material.

Klein, F. F., Emberger-Klein, A., Menrad, K., Möhring, W., & Blesin, J-M. (2019). Influencing factors for the purchase intention of consumers choosing bioplastic products in Germany. *Sustainable Production and Consumption, 19*, 33-43. https://doi.org/10.1016/j.spc.2019.01.004

Studies consumers' reactions and purchase intention of bioplastics, and identifies factors influencing such intention, with focus on the German market.

Koenig-Lewis, N., Palmer, A., Dermody, J., & Urbye, A. (2014). Consumers' evaluations of ecological packaging – Rational and emotional approaches. *Journal of Environmental Psychology, 37*, 94-105. https://doi.org/10.1016/j.jenvp.2013.11.009

Investigates consumers' emotional and rational evaluations of pro-environmental packaging.

Koutsimanis, G., Getter, K., Behe, B., Harte, J., Almenar, E. (2012). Influences of packaging attributes on consumer purchase decisions for fresh produce. *Appetite, 59*(2), 270-280. https://doi.org/10.1016/j.appet.2012.05.012

Investigates influences of packaging attributes on consumers' purchase decisions of fresh products in general and sweet cherries in particular.

Laborda, E., Del-Busto, F., Bartolomé, C., & Fernández, V. (2023). Analysing the social acceptance of bio-based products made from recycled absorbent hygiene products in Europe. *Sustainability, 15*, 3008. https://doi.org/10.3390/su15043008

Identifies key factors that might increase the social acceptance of bio-based and recycled products made from recovered flows of Absorbent Hygiene Products (AHP) waste.

Lettner, M., Schöggl, J-P., & Stern, T. (2017). Factors influencing the market diffusion of bio-based plastics: Results of four comparative scenario analyses. *Journal of Cleaner Production, 157*, 289-298. http://dx.doi.org/10.1016/j.jclepro.2017.04.077

Identifies factors influencing the market diffusion of bioplastic by considering stakeholder insights about four biopolymers (PLA, PHA, Lignin, and CNSL).

Lynch, D. H., Klaassen, P., & Broerse, J. E. (2017). Unraveling Dutch citizens' perceptions on the bio-based economy: The case of bioplastics, bio-jetfuels and small-scale bio-refineries. *Industrial Crops and Products, 106*, 130-137. https://doi.org/10.1016/j.indcrop.2016.10.035

Explores Dutch citizens' arguments for and against three selected bio-based innovations: bioplastics, bio-jetfuels, and small-scale bio-refineries.

Magnier, L., & Crié, D. (2015). Communicating packaging eco-friendliness: An exploration of consumers' perceptions of eco-designed packaging. *International Journal of Retail & Distribution Management, 43*, 350-366. https://doi.org/10.1108/IJRDM-04-2014-0048

Examines which cues of package design are more likely to inform packaging eco-friendliness and how consumers respond to such cues.

Martinho, G., Pires, A., Portela, G., & Fonseca, M. (2015). Factors affecting consumers' choices concerning sustainable packaging during product purchase and recycling. *Resources, Conservation and Recycling, 103*, 58-68. http://dx.doi.org/10.1016/j.resconrec.2015.07.012

Examines the factors that influence consumers' product purchasing behavior and their recycling behavior with respect to sustainable packaging.

Meeks, D., Hottle, T., Bilec, M. M., & Landis, A. E. (2015). Compostable biopolymer use in the real world: Stakeholder interviews to better understand the motivations and realities of use and disposal in the US. *Resources, Conservation and Recycling, 105*, 134-142. https://doi.org/10.1016/j.resconrec.2015.10.022

Identifies and explores where consumers are most likely to come into contact with compostable biopolymers, actual disposal methods, and the motivation behind compostable biopolymer use and disposal.

Mehta, N., Cunningham, E., Roy, D., Cathcart, A., Dempster, M., Berry, E., & Smyth, B. M. (2021). Exploring perceptions of environmental professionals, plastic processors, students and consumers of bio-based plastics: Informing the development of the sector. *Sustainable Production and Consumption, 26*, 574-587. https://doi.org/10.1016/j.spc.2020.12.015	Investigates the perceptions and opinions that environmental professionals, plastic processors, university students, and consumers in Belfast, Northern Ireland, have about bio-based plastics.
Neves, A. C., Moyne, M. M., Eyre, C., & Casey, B. P. (2020). Acceptability and societal impact of the introduction of bioplastics as novel environmentally friendly packaging materials in Ireland. *Clean Technologies, 2*(1), 127-143. https://doi.org/10.3390/cleantechnol2010009	Assesses factors contributing to low adoption rates of bioplastics and develops an understanding of stakeholder motivations and user behaviours, to remove barriers to the adoption of bioplastics.
Niedermeier, A., Emberger-Klein. A., & Menrad, K. (2021). Drivers and barriers for purchasing green Fast-Moving Consumer Goods: A study of consumer preferences of glue sticks in Germany. *Journal of Cleaner Production, 284*, 124804. https://doi.org/10.1016/j.jclepro.2020.124804	Investigates the drivers and barriers for purchasing green Fast-Moving Consumer Goods in Germany, with a special focus on bio-based glue sticks packaged with environmentally friendly materials.
Notaro, S., Lovera, E., & Paletto, A. (2022a). Behaviours and attitudes of consumers towards bioplastics: An exploratory study in Italy. *Journal of Forest Science, 68*(4), 121-135. https://doi.org/10.17221/26/2022-JFS	Investigates consumers' attitudes and behaviours towards bioplastic products.
Notaro, S., Lovera, E., & Paletto, A. (2022b). Consumers' preferences for bioplastic products: A discrete choice experiment with a focus on purchase drivers. *Journal of Cleaner Production, 330*, 129870. https://doi.org/10.1016/j.jclepro.2021.129870	Investigate consumers' preferences and willingness to pay for two commonly used consumer products made from bioplastic (a pack of disposable cups, and a jacket).

Onwezen, M. C., Reinders, M. J., & Sijtsema, S. J. (2017). Understanding intentions to purchase bio-based products: The role of subjective ambivalence. *Journal of Environmental Psychology, 52*, 26-36. http://dx.doi.org/10.1016/j.jenvp.2017.05.001	Explores whether subjective ambivalence increases the understanding of consumers' intentions to buy bio-based products.
Osburg, V-S. (2016). An empirical investigation of the determinants influencing consumers' planned choices of eco-innovative materials. *International Journal of Innovation and Sustainable Development, 10*(4), 339-360. https://doi.org/10.1504/IJISD.2016.079580	Investigates determinants of consumers' choices of eco-innovative materials in relation to currently established materials.
Otaki, Y., & Kyono, T. (2022). Effects of information provision on public attitudes toward bioplastics in Japan. *Frontiers in Sustainability, 3*, 927857. https://doi.org/10.3389/frsus.2022.927857	Investigates knowledge and perception concerning bioplastics in Japan, and the effectiveness of information provision in promoting willingness to use bioplastics.
Reinders, M. J., Onwezen, M. C., & Meeusen, M. J. (2017). Can bio-based attributes upgrade a brand? How partial and full use of bio-based materials affects the purchase intention of brands. *Journal of Cleaner Production, 162*, 1169-1179. https://doi.org/10.1016/j.jclepro.2017.06.126	Examines how consumers evaluate brands that use different percentages of bio-based materials, and how these evaluations influence purchase intentions.
Rudolph, K. (2018). Barriers to acceptance of bio-based substitutes: How schema incongruity can hinder the purchase of bio-based products. In W. L. Filho, D. Pociovălișteanu, P. Borges de Brito, & I. Borges de Lima (Eds), *Towards a sustainable bioeconomy: Principles, challenges and perspectives*. World Sustainability Series. Springer, Cham. https://doi.org/10.1007/978-3-319-73028-8_7	Contribute to understanding and overcoming barriers to the acceptance of bio-based products by analysing product acceptance using the schema theory.

Russo, I., Confente, I., Scarpi, D., & Hazen, B. T. (2019). From trash to treasure: The impact of consumer perception of bio-waste products in closed-loop supply chains. *Journal of Cleaner Production, 218*, 966-974. https://doi.org/10.1016/j.jclepro.2019.02.044	Explores consumers' intentions to purchase, pay for, and switch to bio-based waste products.
Sang, Y., Yu, H., & Han, E. (2022). Understanding the barriers to consumer purchasing of zero-waste products. *Sustainability, 14*(24), 16858. https://doi.org/10.3390/su142416858	Studies consumer innovation resistance to zero-waste products, extending the theoretical application of Innovation Resistance Theory to the field of sustainability research.
Scarpi, D., Russo, I., Confente, I., & Hazen, B. (2021). Individual antecedents to consumer intention to switch to food waste bioplastic products: A configuration analysis. *Industrial Marketing Management, 93*, 578-590. https://doi.org/10.1016/j.indmarman.2020.09.006	Studies how configurations of salient antecedents relate to consumers' intention to switch to bioplastics, and how firms can increase consumers' intention to switch to these products.
Scherer, C., Emberger-Klein, A., & Menrad, K. (2018). Consumer preferences for outdoor sporting equipment made of biobased plastics: Results of a choice-based-conjoint experiment in Germany. *Journal of Cleaner Production, 203*, 1085-1094. https://doi.org/10.1016/j.jclepro.2018.08.298	Using a Choice-Based-Conjoint analysis (CBC) identifies preferred consumer attributes of a bio-based plastic drink bottle for bicycles and a running shoe with a bio-based sole.
Scherer, C., Emberger-Klein, A., & Menrad, K. (2017). Biogenic product alternatives for children: Consumer preferences for a set of sand toys made of bio-based plastic. *Sustainable Production and Consumption, 10*, 1-14. http://dx.doi.org/10.1016/j.spc.2016.11.001	Identifies important product attributes and consumers' preferred characteristics of a set of bio-based sand toys for children.

Sijtsema, S. J., Onwezen, M. C., Reinders, M. J., Dagevos, H., Partanen, A., & Meeusen, M. (2016). Consumer perception of bio-based products – an exploratory study in 5 European countries. *NJAS – Wageningen Journal of Life Sciences, 77*, 61-69. http://dx.doi.org/10.1016/j.njas.2016.03.007	Explores consumers' perceptions (i.e., positive, negative, and mixed feelings) regarding the concept of 'bio-based' in general, and specific bio-based products in particular.
Taufik, D., Reinders, M. J., Molenveld, K., & Onwezen, M. C. (2020). The paradox between the environmental appeal of bio-based plastic packaging for consumers and their disposal behaviour. *Science of the Total Environment, 705*, 135820. https://doi.org/10.1016/j.scitotenv.2019.135820	Explores whether consumers' perceived environmental benefits of recyclable and compostable bio-based plastic packages match with how consumers dispose of these packages.
Testa, F., di Iorio, V., Cerri, J., & Pretner, G. (2021). Five shades of plastic in food: Which potentially circular packaging solutions are Italian consumers more sensitive to. *Resources, Conservation & Recycling, 173*, 105726. https://doi.org/10.1016/j.resconrec.2021.105726	Explores consumers' awareness of different circular economy strategies and its effect during the purchasing moment.
Theinsathid, P., Chandrachai, A., Suwannathep, S., & Keeratipibul, S. (2011). Lead users and early adoptors of bioplastics: A market-led approach to innovative food packaging films. Journal of *Biobased Materials and Bioenergy, 5*(1), 17-29. https://doi.org/10.1166/jbmb.2011.1128	Studies the perceptions of stakeholders and lead users about antimicrobial PLA films, and reports on factors that influence the commercialization and consumer demand for bioplastics.
Theinsathid, P., Chandrachai, A., Suwannathep, S., & Keeratipibul, S. (2010). Bio-based products: factors that influence their adoption. *IEEE*. https://doi.org/10.1109/ICMIT.2010.5492715	Reports on a survey that identifies factors influencing bioplastics adoption from a stakeholder perspective.

Walter, F. J. (2011). Seeking consumers for industrial biotechnology. *Industrial Biotechnology, 7*(3), 190-191. https://doi.org/10.1089/ind.2011.7.190

Discusses five public relations recommendations to help the industry better reach and influence consumer opinion on biobased products and companies.

Yeh, C.-H., Lücke, F.-K., & Janssen, J. (2015). Bioplastics: Acceptable for the packaging of organic food? A policy analysis. *Journal of Agriculture, Food Systems, and Community Development, 6*(1), 95-105. https://doi.org/10.5304/jafscd.2015.061.009

Examines the applicability of bioplastics packaging to organic food products, based on the perspectives of interviewed experts in industry and academia.

Yue, C., Hall, C. R., Behe, B. K., Campbell, B. L., Dennis, J., & Lopez, R. (2010a). Are consumers willing to pay more for biodegradable containers than for plastic ones? Evidence from hypothetical conjoint analysis and nonhypothetical experimental auctions. *Journal of Agricultural and Applied Economics, 42*(4), 757-772. https://doi.org/10.1017/S1074070800003941

Evaluates consumer preference and willingness to pay for various products, with a focus on plastic versus biobased.

Yue, C., Hall, C. R., Behe, B. K., Campbell, B. L., Lopez, R. G., & Dennis, J. H. (2010b). Investigating consumer preference for biodegradable containers. *Journal of Environmental Horticulture, 28*(4), 239-239. https://doi.org/10.24266/0738-2898-28.4.239

Studies consumers' perceived value for different biodegradable plant containers, without the influence of the plant in the container.

Zwicker, M. V., Brick, C., Gruter, G-J., & van Harreveld, F. (2023). Consumer attitudes and willingness to pay for novel bio-based products using hypothetical bottle choice. *Sustainable Production and Consumption, 35*, 173-183. https://doi.org/10.1016/j.spc.2022.10.021

Investigates psychological factors influencing preferences for three types of plastic bottles (PET plastic, PEF plastic, and paper PEF).

Zwicker, M. V., Brick, C., Gruter, G-J., & van Harreveld, F. (2021). (Not) doing the right things for the wrong reasons: An investigation of consumer attitudes, perceptions, and willingness to pay for bio-based plastics. *Sustainability, 13*(12), 6819. http://dx.doi.org/10.3390/su13126819	Investigates consumers' attitudes towards fossil and bio-based plastics, perceived importance of recycling both types of plastics, willingness to pay, and perceptions of bio-based plastics.
Zwicker, M. V., Nohlen, H. U., Dalege, J., Gruter, G-J., & van Harreveld, F. (2020). Applying an attitude network approach to consumer behaviour towards plastic. *Journal of Environmental Psychology, 69*, 101433. https://doi.org/10.1016/j.jenvp.2020.101433	Investigates which associations people have towards conventional and bio-based plastic in order to develop an empirically based approach to initiate attitude and behaviour change.

ANNEX VI

Stakeholder Interview Protocol

My name is [Interviewer's Name], and this interview will be conducted as part of the European BioLaMer project. Our aim is to understand the various experiences of professionals in the field. We estimate that the interview will last approximately [30 minutes]. We'll talk a bit about your organization's mission, focusing on the interests of the bioplastics industry, and identifying barriers and strategies to overcome potential obstacles. Can we get started?

1. **I'd like to start this interview, in a very general way, if you could introduce yourself and talk a bit about your experiences, how long you've worked in this organization, what your responsibilities are?**
    - Name of interviewee and organization?
    - How long have you been with the organization?
    - What is your role in the organization?
    - How long have you been in this position?
    - What are your responsibilities in the organization?
    - How long have you been working in this area?
    - Briefly describe your experience and knowledge in the area.

2. **Mission and values**
    - Could you describe your organization's mission?
    - What do you consider to be the main entities associated with your organization (e.g. suppliers, customers)?
    - Who is your organization's target audience? How would you describe it? [if not mentioned] What is the main focus of your organization?

3. **Integrating Bioplastics into the Business Model [Always focus on Bioplastics]**
    - What do you understand by bioplastics?
    - What kind of services related to bioplastics does your organization offer?
    - Do you have any idea what type(s) of bioplastic are most commonly used?
    - Do you have any idea what raw material(s) are most used in the production of different bioplastic(s)?

4. **Challenges and solutions**

- Which do you think are the main barriers to working with bioplastics?
- * Which do you think are the main barriers related to the production of feedstock and working with bioplastics?
- Can you share any experiences in which you faced challenges when working with bioplastics?
- * Can you share any experiences in which you faced challenges when working with bioplastics and the production of feedstock?
- What strategies or actions have been implemented by the organization in order to overcome the challenges identified?
- Are there any challenges that are being or have been more difficult to overcome?

  [If yes]

  a) Which challenge(s)?

  b) How have you dealt with these challenge(s)?
- In addition to the challenges identified, what other challenges do you see in terms of...

  a) Technological barriers (e.g., Limited biopolymer properties, specialized equipment availability, the need for diverse technical expertise)

  b) Knowledge barriers (e.g., Limited research, gaps in farming techniques, lack of collaboration and multidisciplinary approaches)

  c) Economic barriers (e.g., High production costs, limited access to financial capital for research, development, and commercialization)

  d) Regulatory barriers (e.g., Inconsistent policies, unique regulatory landscapes that complicate cross-border knowledge transfer)

  e) Supply-stability barriers (e.g., Limited raw material availability, seasonal variations, resource management challenges)

  f) Behavioural barriers (e.g., Resistance to change, intention-behaviour gaps, market uncertainty)

  g) Consumer acceptance barriers (perceived unacceptance from the demand-side)
- **[To have a quantitative measure of the importance attributed to each barrier, for each barrier category ask]**

  From 1 to 10, how much do you feel this barrier affects the commercialization of bioplastics products/services?

5. Risk perception

- In general, which do you consider to be the main risks associated with business models that focus on [the production / use / management of] bioplastics?
- What do you consider to be the most effective strategies your organization applies to deal with these risks?

6. Recommendations

- To finalize the interview, based on your experience with bioplastics, what are the recommendations and best practices that the industry should adopt?
- Do you see any future market or business opportunity in the field of bioplastics?
- In your opinion, in which bioplastics do you think companies should invest more in the future? What factors might motivate this investment?

*** Indicates questions that only appear in the interview script for stakeholders in the bioplastics production industry.**