UNIVERSIDADE FEDERAL DO ESTADO DO RIO DE JANEIRO - UNIRIO
CENTRO DE CIÊNCIAS BIOLOGICAS E DA SAÚDE – CCBS
PROGRAMA DE PÓS-GRADUÇÃO EM ALIMENTOS E NUTRIÇÃO – PPGAN

ANDREZA SALLES BARONE

ADVANCING BIODEGRADABLE FOOD PACKAGING: INTERCONNECTIONS AMONG INNOVATION, CONSUMERS AND CIRCULAR ECONOMY POLICIES

Rio de Janeiro

2026

Andreza Salles Barone

ADVANCING BIODEGRADABLE FOOD PACKAGING: INTERCONNECTIONS AMONG INNOVATION, CONSUMERS AND CIRCULAR ECONOMY POLICIES

Tese de Doutorado apresentada ao Programa de Pós-Graduação em Alimentos e Nutrição (PPGAN) da Universidade Federal do Estado do Rio de Janeiro (UNIRIO), como parte dos requisitos necessários à obtenção do título de Doutora em Alimentos e Nutrição.

Orientadora: Profª Drª Ana Elizabeth Cavalcante Fai

Rio de Janeiro

2026

Andreza Salles Barone

ADVANCING BIODEGRADABLE FOOD PACKAGING: INTERCONNECTIONS AMONG INNOVATION, CONSUMERS AND CIRCULAR ECONOMY POLICIES

Tese de Doutorado apresentada ao Programa de Pós-Graduação em Alimentos e Nutrição (PPGAN) da Universidade Federal do Estado do Rio de Janeiro (UNIRIO), como parte dos requisitos necessários à obtenção do título de Doutora em Alimentos e Nutrição.

Aprovada em: 30 / 07 / 2026

BANCA EXAMINADORA

Profª Drª Ana Elizabeth Cavalcante Fai
Universidade do Estado do Rio de Janeiro – UERJ
Programa de Pós Graduação em Alimentos e Nutrição - PPGAN/UNIRIO

Profª Drª Bianca Chieregato Maniglia
Instituto de Química de São Carlos – Universidade de São Paulo (USP)

Prof Dr. Ricardo Schmitz Ongaratto
Escola de Química – Universidade Federal do Rio de Janeiro (UFRJ)

Drª Julia Rabelo Vaz Matheus
Instituto de Nutrição – Universidade do Estado do Rio de Janeiro (UERJ)

Prof Dr. Otniel Freitas Silva
Programa de Pós Graduação em Alimentos e Nutrição - PPGAN/UNIRIO
Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)

À todos que partilharam comigo desta trajetória, me auxiliando e incentivando em todos os momentos, em especial ao meu avô, Adelino Fernandes (*in memoriam*) e à toda minha família.

AGRADECIMENTOS

É com profunda alegria que encerro mais um importante capítulo da minha trajetória acadêmica e profissional.

Em primeiro lugar, agradeço a Deus. Tudo o que sou e tudo o que conquistei devo a Ele. Sua presença foi o que restaurou minha mente, trouxe equilíbrio, paz e renovou diariamente a certeza de que valeria a pena continuar. Sem Sua direção, eu não teria chegado até aqui.

Ao PPGAN/UNIRIO, agradeço pela oportunidade de realizar este doutorado e por todo o aprendizado proporcionado ao longo dessa trajetória. À CAPES, agradeço pelo apoio financeiro, fundamental para o desenvolvimento desta pesquisa.

Ao meu marido, Yuri, minha mais profunda gratidão. Obrigada por caminhar ao meu lado em todos os momentos, por acreditar em mim, mesmo quando eu já não conseguia acreditar, por tornar nossa rotina mais leve e por nunca me deixar desistir. Você é a rocha da nossa família, e sou imensamente grata por dividir a vida com você.

Aos meus pais, Sandro e Simone, meus maiores incentivadores, obrigada por todo amor, apoio e pelos inúmeros sacrifícios feitos para me proporcionar a melhor educação possível. Vocês me ensinaram a perseverança, a determinação e a acreditar que nenhum sonho é grande demais. À minha família, meus avós, tios, primos, sogros e cunhada, obrigada por estarem sempre presentes. O carinho e o apoio de cada um fizeram parte desta conquista, e sou muito feliz por compartilhar esta caminhada com vocês.

Aos meus amigos Hanna, Dany, Manu, Fernanda, Quedma, Vitor e Amanda, obrigada por tantos anos de amizade, pelo incentivo, pelas conversas, pelas risadas e por permanecerem presentes ao longo dos anos. Às minhas amigas de trabalho, Noor, Elisha, Astrid e Jewel, vocês transformaram os dias difíceis em dias mais leves. Obrigada pelos inúmeros "you got this", pelo apoio nos momentos de frustração e por fazerem do ambiente de trabalho um lugar onde sempre encontrei acolhimento.

À minha orientadora, Profª Drª Ana Elizabeth Fai, minha eterna gratidão. Nossa história começou ainda na graduação, na UERJ, quando despertou em mim o interesse pela Ciência de Alimentos. Foi você quem me incentivou a buscar novas oportunidades, escreveu minha carta de recomendação para o tão sonhado intercâmbio na Espanha, e desde então seguimos juntas por mais de dez anos, entre graduação, mestrado e doutorado. Obrigada pela confiança, pela paciência, pela parceria e por acreditar no meu potencial em cada etapa desse processo. Espero que este seja apenas um "até logo", pois tenho certeza de que ainda construiremos muitas histórias juntas.

A todos os professores, pesquisadores e colaboradores que contribuíram para esta tese, em especial as alunas Carollyne Maragoni, Julia Matheus, Camila Cortat, Tatiana Lopes, Dayanandra Pereira e ao Prof Dr. Ricardo Schmitz. Agradeço pela generosidade na troca de conhecimentos, pelas orientações e por todo o apoio durante esta jornada. Cada contribuição foi essencial para minha formação científica e profissional e teve um papel importante na construção deste trabalho.

"Quando considero quantas e quão maravilhosas coisas o homem compreende, pesquisa e consegue realizar, então reconheço claramente que o espírito humano é obra de Deus, e a mais notável."

Galileu Galilei

RESUMO

Esta tese teve como objetivo desenvolver uma análise integrada sobre o desenvolvimento e as perspectivas das embalagens de base biológica e biodegradáveis para alimentos, articulando inovação tecnológica, percepção dos consumidores e políticas de Economia Circular. Investigaram-se as interconexões entre esses três eixos a partir de duas frentes complementares: uma análise tecnológica, baseada em 63 patentes recuperadas na base Derwent World Patents Index (2013–2025), com foco em embalagens de origem biológica e biodegradáveis aplicadas a alimentos; e uma análise comparativa das percepções dos consumidores e das políticas de Economia Circular em Brasil, Alemanha e Itália, com abordagem bibliométrica, conduzida segundo as diretrizes PRISMA utilizando dados das bases Scopus e Web of Science, resultando em 9 documentos incluídos na análise final. Os resultados tecnológicos demonstraram crescimento consistente da atividade inventiva nos últimos doze anos, com a China como principal país depositante. Entre as principais tendências identificadas estão matérias-primas vegetais, blendas poliméricas, fibras nanocompósitas e aditivos naturais voltados à melhoria de propriedades mecânicas e de barreira, além de tecnologias emergentes como o método de eletrofiação. O *casting* destacou-se como técnica predominante, associado ao fato de 65% das invenções serem originadas em universidades, sugerindo estágio inicial de desenvolvimento e limitações de escalabilidade industrial. A predominância de aplicações em alimentos perecíveis reforça o potencial funcional desses materiais, cujos compostos bioativos podem prolongar sua vida útil. Quanto à percepção dos consumidores em relação a este tipo de embalagem, a comparação entre os três países revelou padrões nacionais distintos, evidenciando que fatores econômicos, culturais e institucionais estão associados a este comportamento e a implementação de estratégias de Economia Circular, confirmando que a maturidade tecnológica, isoladamente, não garante adoção. Conclui-se que, apesar da ampla disponibilidade de matéria-prima de origem biológica disponível e do elevado potencial de aplicação, o desenvolvimento técnico ainda é incipiente e concentrado no meio acadêmico, o que, somado aos custos de produção, dificulta a transição industrial. Sua difusão efetiva depende da superação do hiato entre intenção e comportamento do consumidor e da construção de um ambiente regulatório alinhado ao contexto de cada população, condição essencial à implementação da Economia Circular no setor de embalagens alimentícias.

Palavras-chave: Embalagens biodegradáveis; Economia Circular; Inovação tecnológica; Comportamento do consumidor; Análise de patentes; Políticas públicas; Embalagens para alimentos.

ABSTRACT

This thesis aimed to develop an integrated analysis of the development and prospects of bio-based and biodegradable food packaging, articulating technological innovation, consumer perception, and Circular Economy policies. The interconnections among these three axes were investigated through two complementary approaches: a technological analysis based on 63 patents retrieved from the Derwent World Patents Index (2013–2025), focusing on bio-based and biodegradable packaging applied to food; and a comparative analysis of consumer perceptions and Circular Economy policies in Brazil, Germany, and Italy, using a bibliometric approach conducted according to PRISMA guidelines, with data from the Scopus and Web of Science databases, resulting in 9 documents included in the final analysis. The technological results showed consistent growth in inventive activity over the past twelve years, with China as the leading depositing country. Among the main trends identified are plant-based raw materials, polymeric blends, nanocomposite fibers, and natural additives aimed at improving mechanical and barrier properties, in addition to emerging technologies such as the electrospinning method. Casting stood out as the predominant technique, associated with the fact that 65% of the inventions originated from universities, suggesting an early stage of development and known limitations regarding industrial scalability. The predominance of applications in perishable foods reinforces the functional potential of these materials, whose bioactive compounds can extend food shelf life. Regarding consumer perception of this type of packaging, the comparison among the three countries revealed distinct national patterns, showing that economic, cultural, and institutional factors are associated with this behavior and with the implementation of Circular Economy strategies, confirming that technological maturity alone does not guarantee adoption. It is concluded that, despite the wide availability of bio-based raw materials and the high application potential, technical development remains incipient and concentrated in academia, which, combined with production costs, hinders the transition to industrial scale. Effective diffusion depends on bridging the gap between consumer intention and behavior, as well as building a regulatory environment aligned with each population's context — an essential condition for implementing Circular Economy practices in the food packaging sector.

Key-words: Biodegradable packaging; Circular Economy; Technological innovation; Consumer behavior; Public policies; Patent analysis; Food applications.

LISTA DE FIGURAS

CAPÍTULO I

Figure 1. Examples of stratagies to mitigate plastic pollution around the world 32
Figure 2. Certified sustainability 51

CAPÍTULO II

Figure 1. Prisma flowchart of the patent review on biodegradable packaging for food application 76
Figure 2. Annual patent publications by country (2014–2025) based on patents retrieved from the Derwent Innovation database 77
Figure 3. Correlation between processing technique and raw material based on patent analysis 83
Figure 4. Quantitative analysis of packaging types identified in patents 84
Figure 5. Research trends in biodegradable food packaging derived from qualitative analysis of patents 88

CAPÍTULO III

Figure 1. Prisma flowchart of the search and screening process 110
Figure 2. Circular Economy strategies from Brazil, Germany and Italy 125
Figure 3. Applied Circularity Triangle representation 130

LISTA DE TABELAS

CAPÍTULO I

Table 1. Some biodegradable packaging produced at a commercial level 39

Table 2. Recent patents on the use of renewable sources as a feedstock for biodegradable packaging materials in the last 10 years 42

CAPÍTULO III

Table 1. Publications on consumer behavior and purchase intentions: demographic and socioeconomic factors 113

SUMÁRIO

1. INTRODUÇÃO 13
REFERÊNCIAS 16
2. OBJETIVOS 18
2.1 GERAL 18
2.2 ESPECÍFICOS 18
CAPÍTULO I 19
Rethinking single-use plastics: Innovations, polices, consumer awareness and market shaping biodegradable solutions in the food industry
ABSTRACT 20
1. Introduction 21
2. Methodology 24
3. Single-use plastic waste: environmental threats and challenges in global waste management 25
4. Actions against single-use plastics: worldwide public policies towards a more circular economy 29
5. Biodegradable packaging: technological innovation, market trends, and regulatory frameworks 35
6. From intention to action: Consumer awareness and attitudes towards biodegradable packaging 48
9. Conclusions and perspectives 52
FUNDING 54
CONFLICT OF INTEREST 54
REFERENCES 55
CAPÍTULO II 69
Biodegradable Food Packaging Derived from Food Matrices and By-Products: Patent Landscape and Qualitative Analysis
ABSTRACT 70
1. Introduction 71
2. Methodology 74
3. Results and discussion 77
3.1 Patent technical performance 77
3.2 Patent analysis: Gaps and trends 82
3.2.1 Raw material 82
3.2.2 Processing technologies 84
3.2.3 Challenges and technical solutions 87
3.2.4 Food packaging applications 90
4. Conclusions 93
FUNDING ACKNOWLEDGEMENTS 95
CONFLICT OF INTEREST 95
AUTHOR CONTRIBUTIONS 95
REFERENCES 96

CAPÍTULO III
Toward an Applied Circularity Triangle: Perspectives on Consumers and Circular Economy Policy for Biodegradable Food Packaging in Brazil, Germany, and Italy 103
ABSTRACT 104
1. Introduction 105
2. Methodology 108
3. Results and discussions 112
3.1 Consumer Profiles and Socioeconomic Factors 112
3.2 Consumer Behavior and Packaging Preferences 120
3.3 National Circular Economy Strategies 123
3.4 Proposal: Applied Circularity Triangle 128
4. Conclusions 132
FUNDING ACKNOWLEDGEMENTS 133
AUTHOR CONTRIBUTIONS 133
CONFLICT OF INTEREST 133
DECLARATION OG GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION PROCESS 133
REFERENCES 134
3. CONCLUSÃO GERAL E PERSPECTIVAS 139
Anexo 1 - Material Suplementar do Capítulo II 141

1. INTRODUÇÃO

Atualmente, a preocupação com a produção e a geração de resíduos plásticos vem ganhando protagonismo: estimativas indicam que, até 2050, a produção mundial de plásticos deverá atingir cerca de 1,8 bilhão de toneladas, considerando os atuais padrões de consumo (GANGULY et al., 2025). Entre os setores que mais contribuem para esse cenário, destaca-se a indústria de alimentos e bens de consumo, uma vez que as embalagens plásticas representam o maior mercado consumidor de plástico virgem, respondendo por cerca de 40% de todo o plástico utilizado na Europa (PLASTICS EUROPE, 2023).

Diante desse cenário, os Objetivos de Desenvolvimento Sustentável (ODS) das Nações Unidas constituem uma estratégia global para o enfrentamento de desafios econômicos, ambientais e sociais que demandam atenção urgente. Dentre essas metas, o ODS 12 concentra-se especificamente no Consumo e na Produção Responsáveis, destacando a importância da redução do desperdício de recursos e o incentivo a soluções sustentáveis de produção (UNITED NATIONS, 2015; OLIVEIRA et al., 2025).

Frente a esse contexto, mudanças no atual modelo linear de produção tornam-se uma necessidade cada vez mais evidente. A lógica de "produzir, usar e descartar", antes amplamente normalizada, vem gradualmente perdendo aceitação, à medida que se reconhece que os resíduos plásticos não desaparecem após o descarte, apenas diminuem de tamanho ao longo dos anos, tornando-se contaminantes ambientais persistentes na forma de micro e nanoplásticos (ELLEN MACARTHUR FOUNDATION, 2019). Torna-se necessário, portanto, repensar práticas de produção e consumo capazes de manter produtos e materiais em circulação pelo maior tempo possível, preservando seu valor ao longo de sucessivos ciclos técnicos e biológicos (BARONE et al., 2021). Essa mudança de paradigma busca desacoplar o crescimento econômico de um modelo extrativista, deslocando-o para uma lógica regenerativa, abordagem conhecida como Economia Circular (EC) (ARIJENIWA, 2024).

Neste sentido, as embalagens de origem biológica e biodegradáveis para alimentos surgem como uma alternativa promissora aos plásticos convencionais. Pesquisas demonstram que esses materiais apresentam potencial para benefícios ambientais relevantes e que os avanços no desenvolvimento de biopolímeros têm permitido obter propriedades mecânicas e de barreira cada vez mais próximas às dos plásticos de origem fóssil, ampliando seu potencial de aplicação comercial (LEAL FILHO et al., 2025; MATHEUS et al., 2023). Além disso, a utilização de biomassa e resíduos agroindustriais como matéria-prima reduz a dependência de

recursos fósseis e promove a valorização de subprodutos da indústria alimentícia, convertendo-os em materiais de maior valor agregado, com potencial bioativo e capacidade de conferir funcionalidades adicionais aos alimentos embalados (VERMA et al., 2026). Dessa forma, essas embalagens representam uma estratégia alinhada aos princípios da economia circular.

A partir dessa perspectiva, o avanço das embalagens biodegradáveis para alimentos deve ser compreendido considerando a interação entre inovação tecnológica, comportamento do consumidor e políticas públicas de Economia Circular. Em particular, as patentes constituem uma importante fonte de evidência do desenvolvimento inventivo por refletirem os avanços tecnológicos mais próximos da aplicação comercial (SEDITA et al., 2025). Entretanto, a inovação tecnológica, por si só, não garante a adoção dessas soluções: tecnologias promissoras podem não se consolidar no mercado sem o engajamento dos consumidores e um ambiente regulatório favorável (CLICERI et al., 2026; TEIXEIRA et al., 2025). Da mesma forma, embora consumidores frequentemente demonstrem atitudes positivas em relação às embalagens biodegradáveis, essas percepções nem sempre se traduzem em comportamento de compra, evidenciando um hiato entre intenção e ação influenciado por fatores socioeconômicos, culturais e institucionais (DUARTE et al., 2024; CHIRILLI et al., 2022). Nesse processo, políticas públicas de Economia Circular podem atuar como elementos estruturantes da inovação e da adoção dessas tecnologias, reforçando a necessidade de compreender essas três dimensões de forma integrada.

Portanto, esta tese está estruturada em três capítulos, escritos sob forma de artigo científico, que abordam os avanços das embalagens de origem biológica e biodegradáveis para alimentos e suas interconexões com a inovação, os consumidores e as políticas de Economia Circular. O primeiro capítulo intitulado: **"*Rethinking single-use plastics: Innovations, polices, consumer awareness and market shaping biodegradable solutions in the packaging industry*"**, é uma revisão bibliográfica sobre os desafios ambientais associados aos plásticos de uso único e discute a transição para embalagens biodegradáveis para alimentos; abordando a relação entre inovação tecnológica, comportamento do consumidor, políticas de Economia Circular e tendências tecnológicas identificadas por meio da análise de patentes. **Este artigo foi aceito e publicado pela revista Trends in Food Science & Technology (ISSN: 1879-3053) (DOI: 10.1016/j.tifs.2025.104906).**

O segundo capítulo intitulado: ***"Biodegradable Food Packaging Derived from Food Matrices and By-Products: Patent Landscape and Qualitative Analysis"***, apresenta um estudo sobre o panorama tecnológico das patentes relacionadas ao desenvolvimento de embalagens de

origem biológica e biodegradáveis para alimentos produzidas a partir de matrizes alimentares e subprodutos agroindustriais. O trabalho realiza uma análise qualitativa da atividade inventiva, identificando os principais domínios tecnológicos, a evolução temporal das inovações e as tendências emergentes em materiais, processos de fabricação e soluções técnicas desenvolvidas ao longo dos últimos 12 anos. Ao explorar as patentes como fonte primária de informação tecnológica, o estudo oferece uma visão abrangente do estado da técnica e das principais direções de desenvolvimento desse campo. **Este artigo está submetido na revista Journal of Food Engineering (ISSN: 1873-5770).**

Por fim, o terceiro e último capítulo intitulado: ***"Toward an Applied Circularity Triangle: Perspectives on Consumers and Circular Economy Policy for Biodegradable Food Packaging in Brazil, Germany, and Italy"***, apresenta um estudo de perspectiva desenvolvido com o objetivo de compreender a percepção dos consumidores sobre embalagens biodegradáveis para alimentos e estratégias de Economia Circular no Brasil, na Itália e na Alemanha. O trabalho propõe uma análise empírica das interconexões entre realidades socioeconômicas, políticas públicas e diferentes níveis de maturidade da Economia Circular, buscando compreender como esses fatores influenciam o comportamento do consumidor e a implementação de estratégias circulares. **Este artigo será submetido para a revista Journal of Cleaner Production (ISSN: 1879-1786).**

REFERÊNCIAS

ARIJENIWA, V. F. Closing the loop: A framework for tackling single-use plastic waste in the food and beverage industry through circular economy: A review. *Journal of Environmental Management*, v. 359, p. 120816, 2024. Disponível em: https://doi.org/10.1016/j.jenvman.2024.120816.

BARONE, A. S.; MATHEUS, J. R. V.; SOUZA, T. S. P. de; MOREIRA, R. F. A.; FAI, A. E. C. Green-based active packaging: Opportunities beyond COVID-19, food applications, and perspectives in circular economy: A brief review. *Comprehensive Reviews in Food Science and Food Safety*, v. 20, n. 5, p. 4881-4905, 2021. Disponível em: https://doi.org/10.1111/1541-4337.12812.

CHIRILLI, C.; MOLINO, M.; TORRI, L. Consumers' awareness, behavior and expectations for food packaging environmental sustainability: Influence of socio-demographic characteristics. *Foods*, v. 11, n. 16, p. 2388, 2022. Disponível em: https://doi.org/10.3390/foods11162388.

CLICERI, D.; PEDROTTI, M.; PEÑALVA, C.; GASPERI, F.; ENDRIZZI, I. The bioplastic paradox: Unpacking consumer acceptance and the disposal challenge of home compostable packaging. *Future Foods*, v. 13, p. 101006, 2026. Disponível em: https://doi.org/10.1016/j.fufo.2026.101006

DUARTE, P.; SILVA, S. C.; ROZA, A. S.; DIAS, J. C. Enhancing consumer purchase intentions for sustainable packaging products: An in-depth analysis of key determinants and strategic insights. *Sustainable Futures*, v. 7, p. 100193, 2024. Disponível em: https://doi.org/10.1016/j.sftr.2024.100193.

ELLEN MACARTHUR FOUNDATION. *The circular economy in detail*. Cowes, 2019. Disponível em: https://www.ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive. Acesso em: 13 jul. 2026.

GANGULY, A.; KAIBARTA, R.; DAS, S.; KUNDU, R.; PARAMANIK, S.; MOHAPATRA, S.; MUKHERJEE, S. K.; MITRA, D.; CHATTERAJ, S. Biodegradation and valorisation of plastic based food packets: A microbial solution for sustainability and circular economy. *Discover Sustainability*, v. 6, p. 447, 2025. Disponível em: https://doi.org/10.1007/s43621-025-01257-y.

LEAL FILHO, W.; BARBIR, J.; VENKATESAN, M.; SALVIA, A. L.; DOBRI, A.; BOŠKOVIĆ, N.; EUSTACHIO, J. H. P. P.; INGRAM, I.; DINIS, M. A. P. Policy gaps and opportunities in bio-based plastics: Implications for sustainable food packaging. *Foods*, v. 14, n. 11, p. 1955, 2025. Disponível em: https://doi.org/10.3390/foods14111955.

MATHEUS, J. R. V.; FARIAS, P. M. de; SATORIVA, J. M.; ANDRADE, C. J. de; FAI, A. E. C. Cassava starch films for food packaging: Trends over the last decade and future research. *International Journal of Biological Macromolecules*, v. 225, p. 658-672, 2023. Disponível em: https://doi.org/10.1016/j.ijbiomac.2022.11.129.

OLIVEIRA, J. S.; OLIVEIRA, J. P.; OLIVEIRA, C. P.; VELOSO, C. M. Circular economy as a tool for the valorization of agro-industrial residues and the development of biodegradable and sustainable packaging: A bibliometric review from 2015 to 2024. *Cleaner and Circular Bioeconomy*, v. 12, p. 100188, 2025. Disponível em: https://doi.org/10.1016/j.clcb.2025.100188

PLASTICS EUROPE. *Plastics – The fast facts 2023: An analysis of European plastics production, demand and waste data*. Brussels, 2023. Disponível em: https://plasticseurope.org/knowledge-hub/plastics-the-fast-facts-2023/. Acesso em: 13 jul. 2026.

SEDITA, S. R.; DI MARIA, E.; MAZZONI, L.; BEKELE, N. A. Decoding the biobased blueprint: Key players and evolutionary trends in materials innovation. *Polymers*, v. 17, n. 2, p. 177, 2025. Disponível em: https://doi.org/10.3390/polym17020177.

TEIXEIRA, S. C.; OLIVEIRA, T. V. de; SOARES, N. F. F.; RAYMUNDO-PEREIRA, P. A. Sustainable and biodegradable polymer packaging: Perspectives, challenges, and opportunities. *Food Chemistry*, v. 470, p. 142652, 2025. Disponível em: https://doi.org/10.1016/j.foodchem.2024.142652.

UNITED NATIONS. *Transforming our world: The 2030 Agenda for Sustainable Development*. New York: United Nations, 2015. Disponível em: https://sdgs.un.org/2030agenda. Acesso em: 13 jul. 2026.

VERMA, P.; KUMAR, A.; CHOUDHARY, R. et al. Recent advances in agro-food waste valorization in line with the United Nations Sustainable Development Goals. *International Journal of Environmental Science and Technology*, v. 23, p. 112, 2026. Disponível em: https://doi.org/10.1007/s13762-025-06856-w.

2. OBJETIVOS

2.1 GERAL

Desenvolver uma análise integrada sobre o desenvolvimento e as perspectivas das embalagens de origem biológica e biodegradáveis para alimentos, articulando inovação tecnológica, consumidores e políticas de economia circular.

2.2 ESPECÍFICOS

- Realizar uma revisão bibliográfica sobre os aspectos ambientais das embalagens de uso único (SUP) e o potencial de embalagens biodegradáveis para alimentos, considerando aspectos tecnológicos, mercadológicos, socioeconômicos e regulatórios no contexto da Economia Circular;
- Realizar uma prospecção tecnológica de embalagens de origem biológica e biodegradáveis para alimentos derivadas de matrizes alimentares e subprodutos agroindustriais nos últimos 12 anos por meio da análise quantitativa e qualitativa de documentos de patente;
- Analisar a relação entre características sociodemográficas, a percepção e o comportamento do consumidor em relação às embalagens biodegradáveis para alimentos, comparando diferentes contextos nacionais e sua convergência com políticas e estratégias de economia circular.

CAPÍTULO I

Este artigo foi aceito e publicado pela revista Trends in Food Science & Technology (ISSN: 1879-3053) (DOI: 10.1016/j.tifs.2025.104906)

Rethinking single-use plastics: Innovations, polices, consumer awareness and market shaping biodegradable solutions in the food industry

Andreza Salles Barone[1]; Carollyne Maragoni-Santos[1]; Patricia Marques de Farias[2]; Camila Marcolongo Gomes Cortat[3]; Bianca Chieregato Maniglia[4]; Ricardo Schmitz Ongaratto[5]; Sungil Ferreira[6]; Ana Elizabeth Cavalcante Fai[1,3*]

[1] Food and Nutrition Graduate Program, Federal University of Rio de Janeiro State (UNIRIO), Rio de Janeiro/RJ, Brazil.

[2] Sustainable Packaging Institute SPI, Faculty of Life Sciences, Albstadt-Sigmaringen University, Anton-Gu€nther-Str. 51, Sigmaringen, 72488, Germany.

[3] Basic and Experimental Nutrition, Institute of Nutrition, Rio de Janeiro State University (UERJ), Rio de Janeiro/RJ, Brazil.

[4] São Carlos Institute of Chemistry, University of São Paulo – USP, São Carlos, SP, Brazil.

[5] Chemistry School, Federal University of Rio de Janeiro (UFRJ), Rio de Janeiro, Brazil.

[6] Department of Food Science, University of Arkansas System – Division of Agriculture, Fayetteville, AR, USA.

* Corresponding author: FAI, A.E.C. Email: bethfai@yahoo.com.br

Abstract

Background

The production of single-use plastics (SUP) is increasing and has become one of the most pressing environmental problems.

Scope and approach

This review assesses the environmental aspects of SUP in the food packaging, considering challenges, impacts and global policies. The focus is on biodegradable packaging alternatives, certification standards, consumer behavior, and the critical role of R&D and patents in moving towards a circular economy. This report integrates discussions on bans and taxes on SUP worldwide and proposes comprehensive strategies, including extended producer responsibility and consumer education. The technological status and trends in biodegradable plastics are addressed. The impact of certification standards and patents are examined. Consumer demand for eco- friendly packaging is explored, highlighting the complexity of purchasing behavior influenced by demographic and economic factors as well as marketing strategies. The phenomenon of greenwashing and the importance of transparent environmental labeling are also addressed.

Key findings and conclusions

Global efforts to curb SUP have led to a 68% reduction in polyethylene bags in some regions. Legislative action against SUP is essential, especially for packaging, which accounts for 53% of SUP. Biodegradable plastics currently account for 0.5% of the 400 million tons of plastics produced annually and 44% of global patents filed for biodegradable polymers relate to packaging. Their growth depends on strict standards, transparent certifications and the priority of environmental integrity over the market. The growing demand for biodegradable packaging based on sugar cane, cassava and corn starch reflects consumer awareness. Real progress is impeded by the mismatch between consumer intentions and behavior, economic constraints and greenwashing. A solid legal framework, eco-labeling and environmental education are essential.

Keywords: Sustainability, food packaging, bio-based materials, circular economy, consumer perception.

1. Introduction

Since the 1950s, global plastic production has skyrocketed, mainly due to single-use plastics (SUPs), which now account for more than two-thirds of total production. This trend, exacerbated by urbanization, changing lifestyles and the COVID-19 pandemic, underscores the urgent need for sustainable strategies to combat plastic pollution and promote effective waste management solutions (UNEP, 2023; Barone et al., 2021). In numbers, global plastic production has increased from 335 million metric tons (MMt) in 2016 to 367 MMt in 2020 (Plastics Europe 2021), partly due to single-use plastics (SUP) and medical plastic waste from the COVID-19 pandemic (Barone et al., 2021). Currently, 430 MMt of plastics are produced globally per year, with about 36% used for packaging, including single-use plastic products for food and beverage containers. Of this, only about 25% is recycled (UNEP, 2022).

The United Nations (UN) has recognized the urgency of tackling plastic pollution through its Sustainable Development Goals (SDGs), which are directly or indirectly linked to at least 6 of the 17 SDGs. Nevertheless, progress towards full implementation of the 2030 Agenda remains uncertain (Shah et al., 2024). Recent global efforts to curb single-use plastics (SUP) through bans and regulations have gained momentum, as demonstrated by initiatives in countries such as Brazil, the US, Australia and Rwanda. For example, some cities in these countries have banned the use of plastic straws, discouraged the use of single-use plastic bags and imposed an environmental levy on all imported goods packaged in plastic material or SUP items (Uche, 2023; Lima et al., 2022a; Macintosh et al., 2020; Taylor & Villas-Boas, 2015). Legislative measures are indeed important, but they can only address the overall plastic pollution crisis to a limited extent. This underscores the need for comprehensive strategies that include consumer behavior, improving recycling and innovative waste management practices (Sharma et al., 2021).

The commercial use of biodegradable plastics has been promoted as a more environmentally friendly alternative (Campanale et al., 2024). Research shows that these plastics offer promising environmental benefits compared to conventional plastics, particularly with regard to climate change (Filiciotto & Rothenberg, 2020). However, the limited presence of biodegradable plastics on the market, accounting for only 0.5% of global production, further emphasizes this point (European Bioplastics, 2023). Promoting biodegradable alternatives is important not only to complement regulatory efforts, but also to meet the urgent need for sustainable packaging materials, which account for more than half of the plastic waste generated (UNEP, 2018). While the potential of biodegradable plastics for the development of environmentally friendly packaging has been explored, it is crucial to incorporate these innovations into a holistic approach that includes effective consumer engagement and improved recycling infrastructure (Otto et al., 2021; Moshood et al., 2021). However, the complex structures of conventional plastics such as biphasic polymers, multilayer films and flexible PVC pose major challenges for recycling, making efficient recovery difficult. Even in industrialized countries, recycling has proven to be inefficient relative to the amount of plastic consumed, making it an "imperfect solution" (Vuppaladadiyam et al., 2024; Rafey & Siddiqui, 2021). Although circular economy strategies have evolved to extend the life cycle of plastics through practices such as upcycling, the issues of natural resource depletion and the significant increase in atmospheric CO_2 emissions due to the production and incineration of this material remain pressing and are also gaining consumer attention (Kittithammavong et al., 2023).

The growing popularity among the public and the increasing research activities have led to an increasing number of peer-reviewed publications and patent applications and have stimulated the growth and investment of large companies in this sector (OECD, 2022). Furthermore, studies suggest that while consumers are aware of the use of greener

packaging, they have a limited understanding of its definitions and functions, which consequently affects their purchasing decisions (Uehara et al., 2023; Notaro et al., 2022). Price, material, quality and origin attributes are also important factors that influence consumers' final decision (Wu et al., 2021). This discrepancy highlights the importance of understanding the complexity of consumer behavior, as well as the need for robust industry standards and transparent communication. Bridging this gap is critical to make real progress in the adoption of biodegradable packaging in the fast-moving consumer goods industry and ensuring the long-term viability and credibility of the market (Donato & D'Aniello, 2021).

This review assesses the environmental aspects of SUP in the packaging industry, taking into account challenges, impacts and global policies. The focus is on biodegradable packaging alternatives, certification standards, consumer behavior and the crucial role of R&D and patents on the road to a circular economy.

2. Methodology

The peer-reviewed articles listed in ScienceDirect and Scopus were evaluated in this bibliographic review using a qualitative approach. The search strategy was designed to find experimental and review studies that were relevant to the topic of the study on the screen and related exclusively to the topics covered. Titles and abstracts of studies were screened by the reviewers, then articles eligible for full-text screening were independently reviewed. The inclusion criteria included full-text articles that were available in English language, without restrictions on publication date.

For the patent analysis, the data was obtained from patent documents indexed in the electronic database Derwent World Patents Index (DWPI). The queries combined various keywords for the type of packaging, the raw material and the characteristics of interest were combined in the queries. Keywords for packaging type included composite, packaging, film, polymer and bioplastic. Keywords for raw material included fruit, vegetable, by-product, food, waste, peel, seed and cake. Keywords for packaging characteristics included biodegradable, edible and sustainable. The inclusion criteria included biodegradable/edible packaging or packaging materials with applications in the food sector, and the publication date was limited to the period between December 2013 and December 2023.

3. Single-use plastic waste: environmental threats and challenges in global waste management

Since the 1950s, global plastic production has increased by an average of 9% per year, from 1.7 million metric tons (MMt) in 1950 to 343 MMt in 2018, and is expected to triple by 2060 (UNEP, 2023; Chen et al., 2021). The United Nations Environment Programme (UNEP) points out that the current production of durable plastics is shifting towards single-use plastics (SUP). This type of material already accounts for 40% to 60% of all plastic packaging produced worldwide (UNEP, 2023; Plastics Europe, 2021). Although these materials are versatile, durable and commonly used in items such as bottles and packaging, they have short commercial lifecycles and are non-biodegradable, with their economic value decreasing by more than 95% after a single use (Dey et al., 2020).

The COVID-19 pandemic has exacerbated the use of SUPs and increased the demand for personal protective equipment and packaging, leading to remarkable growth in the plastics industry and generating more than 8 million tons of waste, mainly affecting Asia, Europe and America (Tiwari et al., 2023). The continued growth in the production and use of SUPs is also linked to changing lifestyles, population growth and urbanization (Barone et al., 2021), leading to a significant increase in the amount of plastic waste polluting land, rivers and oceans (Ilechukwu et al., 2024). These residues pose threat to wildlife, human health and the balance of natural systems (Ilechukwu et al., 2024).

Researchers in China investigated the long-term effects of the accumulation of plastic waste in soil and its impact on plant productivity, biodiversity and the multifunctionality of terrestrial ecosystems. The results of this study indicate that the shape of plastic fragments has a greater influence on the structure and function of bacterial communities in the soil than the concentration of the waste and affects the biogeochemical cycle and soil metabolism. The addition of small and medium-sized fragments also significantly reduces

the multifunctionality of the soil, such as its nitrogen storage capacity, and causes disruptive changes in the structure of soil aggregates and its hydrothermal state (Zhao et al., 2024; Wang et al., 2023). These effects lead to a gradual reduction in permeability, which restricts the movement of water and nutrients as well as the vertical growth of roots, and ultimately affects crop yields (Koskei et al., 2021). It is now estimated that less than 0.3 MMt of plastic is floating on the ocean surface, threatening the lives of more than 800 marine species (MacLeod et al., 2021). Ortega-Borchardt et al. (2024) investigated the presence and distribution of plastic pollution at three beaches in the Gulf of California between 2021 and 2022 due to the improper disposal of personal protective equipment (PPE) during the COVID-19 pandemic. The data analysis showed that the density of PPE per m^2 on the beaches was significantly lower in 2022 due to the gradual relaxation of restrictive measures, while face masks were the most widespread type of PPE with a 96% share. According to Shashoua et al. (2024), the presence of plastic litter drastically alters the marine environment and coastal regions by affecting thermal inputs and outputs, e.g. through the absorption of infrared radiation, which affects the temperature of the sediments and consequently heats up the sand on the beaches.

By 2025, the annual release of plastic waste into rivers and lakes is expected to reach 46 MMt (MacLeod et al., 2021). Idowu et al. (2024) determined average microplastic concentrations of over 9,500 particles/liter in the waters at five sites along the Osun River (Nigeria), ranging from 3,791 to 22,079 particles/liter, while levels found in the sediments were between 392 and 1,590 particles/kg. This is the highest level ever reported for a river water worldwide. Higher concentrations of microplastics were found in water samples collected in the city center than in more remote areas, which is associated with increasing urbanization, indiscriminate use and disposal of SUP-type plastics and inefficiency of local waste policies (Idowu et al., 2024). This highlights that plastic pollution in river systems is

also responsible for negative impact on the quality of surface waters used for human consumption, domestic activities, recreational purposes and fishing (Angnunavuri et al., 2023).

Solid waste management is a complex system that has significant social, environmental and economic impacts (Lima et al., 2022b). Despite ongoing efforts, estimates by the World Bank (2019) predict that the amount of municipal solid waste will reach 3.4 billion tons by 2050 (Ye et al., 2023). Although these materials are considered a valuable by-product in an optimal circular economy, the recovery rate through recycling is low, especially in developing countries where organic and inorganic solid waste are constantly mixed during collection, transportation and disposal (Xin et al., 2020). Studies indicate that the largest proportion of incorrectly disposed plastic waste comes from Asian countries, which account for about 46.3% of the total, followed by Europe with 23.8%, South America with 16.4%, North America with 5.6%, Africa with 7.9% and Oceania with less than 0.1% (Vuppaladadiyam et al., 2024). In general, countries still face major challenges in terms of infrastructure, execution and implementation of climate change mitigation measures have been questionable as few concrete measures have been effectively put into practice (Rafey & Siddiqui, 2021).

SUP packaging waste accounted for about one-third of Canada's municipal solid waste (household non-household) in 2020, or 8 million tons, and only 20% of this is recovered for recycling (Diggle & Walker, 2020). The cost of collecting and processing post-consumer plastics varies widely, while the production of recycled plastics is still not economically competitive compared to the production of virgin plastics, which is heavily subsidized by the government (OECD, 2018). In addition, the impact of the 2017 import ban on post-consumer plastics on the world's largest importer of recycled plastic – China – posed an even greater challenge to solid waste management in Canada, which was forced to

implement several strategies to increase domestic recycling capacity, such as Extended Producer Responsibility (EPR) (Diggle & Walker, 2020; Filiciotto & Rothenberg, 2020).

SUPs account for 86% of packaging in German households, where 25 kg/person/year of SUP-type household waste was generated in 2017 (Schmidt & Laner, 2021). Although Germany is considered an example of success due to its significant improvements in the recovery and recycling of various materials, it currently faces challenges related to the need to improve technologies/processes, the recyclability of products and legislation towards a true circular system (Azevedo et al., 2021). Strategies to address these issues are important, but they are not sufficient to achieve the recycling targets for municipal solid waste proposed by the European Union, highlighting that a systemic perspective is crucial to achieve significant effects in waste management (Ríos & Picazo-Tadeo, 2021). The multidimensional impacts of SUP strategies highlight the importance of understanding the systemic impacts of circular economy strategies on waste management systems in order to find optimized solutions from a waste resource perspective.

4. Actions against single-use plastics: worldwide public policies towards a more circular economy

The introduction of bans or taxes on certain products such as plastic bags and straws is common practice in many countries such as Brazil (Lima et al., 2022a), the USA (Taylor & Villas-Boas, 2015), Canada (Baxter et al., 2022) Kenya (Uche, 2023) and Australia (Macintosh et al., 2020). These measures aim to reduce the demand for SUP plastic and encourage the adoption of more sustainable alternatives, such as reusable bags and biodegradable utensils (Taylor & Villas-Boas, 2015). In 2018, the US, the European Commission, the UK and Chile banned the use of SUP products, directly impacting supermarkets and stores that have had to phase out plastic bags, for example (Dey et al., 2020). Taylor & Villas-Boas (2015) showed that these policies reduced the demand for single-use bags and led to a significant increase in the consumption of paper and reusable bags.

In Brazil, 14 states have already banned the use of plastic straws. In a broader perspective, Rio de Janeiro has been the pioneer state in the implementation of legislative projects that include the ban of other single-use plastic materials in stores. In this sense, biodegradable materials have gained more and more space through specific laws in Brazil, such as Law Project No. 92 of 2018, currently under consideration in the National Congress, on the use of biodegradable plastics for disposable utensils such as plates, cups, cutlery and others (Lima et al., 2022b). In Australia, a study found that in the first seven years (2011 to 2018) of implementing the SUP ban, there was a reduction in the consumption of around 2,600 tons of polyethylene bags and the acceptance and support of these measures by the population was 68% in 2018 (Macintosh et al., 2020). In Canada, for example, Baxter et al. (2022) assessed the country's measures to curb single-use plastic using brand audits and beach cleanup data in 4 different cities (Vancouver, Toronto, Montreal, Halifax) and one

remote island (Sable Island). Bottle caps and packaging make up the majority (between 36 and 54%) of plastic waste found in Canada, with food packaging accounting for 27% of waste collected. As a disincentive tool used by the Canadian government, plastic bags, toothpicks, wrapping rings, straws and cutlery are among the banned single-use materials. However, additional strategies are needed to address other common categories of collected waste and more effectively mitigate the impact on the environment.

Alternative proposals or guidelines that promote structural practices and a fair regulatory framework are becoming increasingly important. A ban on single-use plastics (SUP) can lead to a reduction in global coastal plastic waste. Estimates suggest that this reduction could be between 4 and 7% on European coasts and 2 to 6% at sampling sites in Germany (Kiessling et al., 2023). It is estimated that the ban on SUP products, included in the Single Use Plastics Directive (SUPD), will reduce marine pollution in the European Union by around 5.5% (Herberz et al., 2020). Although these measures represent a positive trend, strategies to mitigate the problem of single-use plastic pollution need to go beyond banning its use and charging fees. These results indicate that improvements can be observed. However, they underline the need for a comprehensive and effective intervention against plastic pollution in the future that goes beyond bans.

The European multidisciplinary model of determinations is important for supporting policies that go beyond taxes and bans in several countries. These include strict monitoring and penalties for improper waste disposal, regulating the minimum amount of packaging material required to ensure food safety and hygiene, and prioritizing the promotion of public education to achieve changes in consumer behavior. In addition, product labeling in the European Union seems to inspire other countries, as labels include information on plastic content, appropriate disposal methods and the environmental damage caused by this type of material (Baxter et al., 2022).

The Extended Producer Responsibility (EPR) approach is a concept that has gained prominence in the field of environmental protection against plastic pollution. Originally defined as a strategy to address the environmental impact of products throughout their life cycle, EPR aims to extend the responsibility of manufacturers beyond the production phase to the post-consumer phase. This means that responsibility, both physical and economic, is transferred from local authorities to manufacturers. It also provides incentives to incorporate environmental aspects into the design of their products (Rubio et al., 2019). EPR and return/deposit schemes are expected to play a crucial role in the European Union's new recycling target for plastic packaging (50% by 2025 and 55% by 2030) (Bassi et al., 2020). Portugal and Spain have succeeded in promoting the reduction of material consumption, in particular through the introduction of the Green Dot tax scheme, and have seen an increase in recycling activities in line with the targets set by the European Union (Rubio et al., 2019).

Other strategies to mitigate plastic pollution include education and information campaigns aimed at consumers (Rabiu & Jaeger-Erben, 2024). One example is Plastic Free July®, which contributes to the growing anti-plastic movement by encouraging participants to take on a personal challenge to reduce their plastic consumption. The official program was created to encourage behavior change by offering ideas, solutions and stories to help people make small changes in their plastic-related behavior. Although the Challenge is focused on July, it has become a globally recognized brand with wide reach and participation (Borg et al., 2022). In addition, deposit-refund systems are an effective way to prevent plastic pollution by incentivizing the return of plastics or their waste by refunding the surcharge levied on the price of potentially polluting products. A classic example is the payment of a deposit to the retailer when purchasing a PET (polyethylene terephthalate) beverage, which is refunded to the consumer when the empty container is returned (Calabrese et al., 2021).

In fact, the awareness among countries has been steadily increasing in terms of reducing the production and sale of single-use plastics. **Figure 1** shows interventions carried out in several countries.

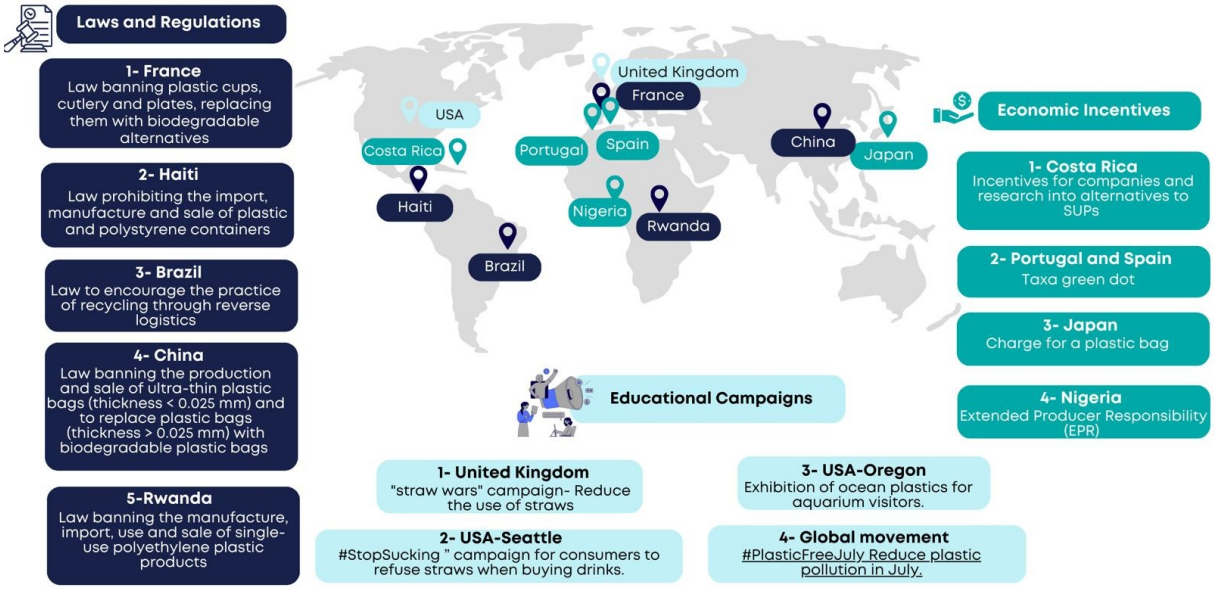


Figure 1. Examples of strategies to mitigate plastic pollution around the world.

During the pandemic, the mandatory use of face masks in many countries posed a challenge to traditional waste disposal and may have contributed to an increase in plastic pollution. COVID-19 has also hindered the implementation of laws against SUPs, and recycling efforts have been halted due to transmission risks (Najafighodousi et al., 2024).

Since the COVID-19 pandemic, several countries have adopted policies that help restrict the use of this type of material (Najafighodousi et al., 2024), focusing on what is already considered “the most significant green agreement since the 2015 Paris Agreement" (GLOBO, 2022). This is the approval of the basic text of the UN Pact against Plastics and aims to establish legal barriers to the production and commercialization of plastics, especially single-use or disposable plastics (UNEP, 2024). In March 2022, all 193 UN member states reached an important milestone at the United Nations Environment Assembly (UNEA-5) in Nairobi by deciding to put an end to plastic pollution. This decision was formalized by a legally binding international agreement, the fifth session of which took

place in the Republic of Korea in December 2024, and negotiations are scheduled to resume in 2025 (UNEP, 2024). The agreement aims to tackle the problem of plastic pollution by starting with the reduction of problematic and unnecessary plastic consumption. This requires a redesign of the system, products and their packaging, combined with a market transformation towards a circular economy for plastics. This approach can be achieved by accelerating three key changes: Reuse and diversification, reuse and recycling, and the implementation of measures to tackle the legacy of plastic pollution (UNEP, 2023).

Despite recent legislative efforts aimed at achieving a circular and sustainable economy, it remains difficult to identify and measure the effectiveness of the policy frameworks implemented in all these regions. Government action is important to promote actions to reduce the consumption and improper disposal of SUP. However, this strategy cannot be the only effective one to control the impacts caused by plastic waste when the applicability of other solutions is questionable (Dey et al., 2020). In the Brazilian scenario, the National Solid Waste Policy (PNRS), introduced more than 10 years ago, includes information on the most diverse interrelated issues, such as reverse logistics, selective collection, composting and energy use, and requires the public and private sectors to be transparent in the management of their waste. This resulted in some innovations, such as the principle of shared responsibility in waste management and the inclusion of informal waste collectors in the process of recovering these materials (Política Nacional de Resíduos Sólidos, 2010). In 2021, China published the "Plastic Pollution Control Action Plan", which sets the goal of reducing plastic pollution by 2025. The plan includes measures to strengthen the management of plastic products in the production, distribution and consumption stages, as well as to promote plastic alternatives and improve detoxification treatment capacity. In recent years, China has collected and reused about 19 million tons of different types of plastics annually. Although progress has been made in the efficiency of waste processing,

the country still faces challenges in improving the efficiency of the collection process (Hayashi, 2023).

Achieving resilient economic growth entails several challenges. Policy makers must not only think about protecting national economies during a crisis but also take decisive steps towards a broader and more robust structural transformation against future global threats (Dey et al., 2020). To meet current needs and preserve development rights for future generations, a set of waste management strategies that integrate the concept of sustainable development must be developed (Sharma et al., 2021).

5. Biodegradable packaging: technological innovation, market trends, and regulatory frameworks

Biodegradable plastics currently account for around 0.5% of the more than 400 million tons of plastics produced annually (European Bioplastics, 2023). According to the European Bioplastics Industry Association, biodegradation is a chemical process in which microorganisms present in the environment convert materials into natural substances such as CO2, biomass and water. This process and the degradation time depend on the environmental conditions, the material and the application. Furthermore, biodegradability is inherent to the chemical structure of the material and not to the resource/raw material (Nizamuddin et al., 2024). In this context, not all biodegradable plastics are biobased, and some biobased plastics may not be biodegradable. Although these terms are often used interchangeably, they are not synonymous (Nizamuddin et al., 2024). To determine and define biodegradable polymeric materials, certifications such as EN 13432, ASTM D6400, AS 4736, GreenPla or ISO 17088 establish a set of standards for biodegradability and compostability in different exposure environments. These standards generally describe definitions, test guidelines, time limits, procedures, conditions, limits and the interpretation of results (Zhong et al., 2020).

The largest area of application for biodegradable materials is the packaging segment with a share of around 53% (Mangaraj et al., 2018). Due to their versatility, these materials are used in various sectors, e.g. in the medical-pharmaceutical industry for applications such as surgical sutures (Mukherjee et al., 2023), in agricultural plastic films, in construction and in the field of electronic devices, e.g. as thermal insulators, solar cells, bio-batteries, sensors and displays (Liu et al., 2021; Liu et al., 2020; Barkhad et al., 2020). With the growing environmental awareness of the importance of biodegradable materials, several industries are trying to incorporate eco-friendly options into their production lines. Major companies

from different segments such as Cargill Incorporated, Mitsubishi Chemical Corporation and NatureWorks are leading this trend in the biodegradable plastics industry (Moshood et al., 2021).

The biodegradable packaging market was estimated to reach USD 105.26 billion in 2024, with an expected annual growth rate of 5.97% between 2024 and 2029 (Mordor Intelligence, 2019). Due to growing environmental concerns and government initiatives to reduce the use of conventional plastics, global production of this type of material is also showing growing interest from the packaging industry, reaching a production volume of 2.11 million tons in 2019, with a focus on countries in Asia (45%), Europe (25%), North America (18%) and South America (12%) (Shaikh et al., 2021).

The European Union supports approaches such as the circular economy and the bioeconomy to promote the development and innovation of this material, with the aim of ensuring the efficient use of resources. A circular economy consists of following the 6R concept (Rethink, Refuse, Reduce, Reuse, Repair and Recycle), a sustainable production and consumption of resources (Yildiz et al., 2023). These sustainable mechanisms for the production and management of new polymeric materials are very much in line with the strategies and actions defined by the United Nations Sustainable Development Goals (SDGs) and the European Strategy for a Circular Economy (Rameshkumar et al., 2020). According to a report by the Nova Institute, the global production capacity for biodegradable plastics would grow significantly, with Europe occupying the first position in the research and development of these polymers and Asia being the main center of production and consumption (Rameshkumar et al., 2020). In Brazil, one of the most important associations in the sector, the Brazilian Association of Compostable Biopolymers and Composting (ABICOM), believes that the country offers a favorable environment for the development of biodegradable packaging. What makes the Brazilian scenario attractive

is the national agricultural production, which mostly uses agro-industrial materials as a first choice and low-cost raw material (Souza, 2022).

Approaches to developing biodegradable packaging on a commercial scale have received considerable attention in the chemical industry, as shown in **Table 1**. The Bio-Based Industries (BBI) consortium, in partnership with the European Union (EU), is investing around US$4.1 billion in large-scale projects to advance new technologies for the production of monomers and polymers based on biomass residues and/or renewable resources. As one of the specific impacts of the BBI program is to replace at least 30% of fossil feedstocks with bio-based feedstocks by 2030, the potential scope for manufacturing processes for these materials is predicted for the next decade (Rameshkumar et al., 2020). Asia also offers several opportunities for the growth and development of the sector, such as Thailand, which in 2022 announced the extension of a 25% tax exemption for companies producing bioplastics to promote the country as a major center for the production of this material. In addition, Malaysia has excelled in the production of palm oil, from which around 19.8 million tons of by-products are extracted annually. Researchers have found opportunities to convert the hemicellulose contained in this waste into biodegradable films for green packaging (Mordor Intelligence, 2023).

In the Brazilian scenario, large industries are investing in the sector, such as the American company Earth Renewable Technologies (ERT), which has already invested around US$ 3 million in the construction of its factory in the south of the country and is expected to double this investment in the next 3 years, reaching a production volume of 15 thousand tons of biopolymers per year, as the Brazilian market represents around 17% of the company's total sales (ERT, 2023). The Chilean startup BioElements, which has partnerships with universities and research institutions in Brazil (Federal University of Rio de Janeiro - UFRJ) and Latin America, is promoting expansion in the Brazilian market and

evaluating the growth and commercialization potential of its products in industry, e-commerce and retail (Ann Thomas, 2022). In addition, two pioneering companies in the production of these materials in Brazil should be highlighted, such as Braskem and PHB Industrial, which produce biodegradable packaging from sugar cane (Lima et al., 2022a).

Table 1. Some biodegradable packaging produced at a commercial level

Source	Manufacturer, country	Commercial launch	Certification	Reference
Sugar cane	Earth Renewable Technologies (ERT), USA	2019	TUV Austria USDA Certified Biobased BPI Compostable	(ERT, 2023)
Corn, sugar cane, palm leaf and cassava	Vegware, Scotland	2006	EN 13432 Certified ASTM D6400	(Vegware, 2022)
Starch	Já fui Mandioca, Brazil	2019	ASTM D6400 EN 13432 Certified ABNT-NBR 15.448-2	(Já fui Mandioca, n.d)
Avocado pit	Biofase, Mexico	2002	TUV Austria SGS	(BIOFASE, n.d)
Starch	Kompuestos, Spain	2018	TUV Austria	(Kompuestos, 2020)
Mushroom roots	Ecovative, USA	2007	ASTM D6868 USDA Certified Biobased	(Ecovative, 2019)
Cassava, sugar cane and corn	PTT MCC Biochem, Thailand	2012	BPI Compostable USDA Certified Biobased	(PTT MCC Biochem, n.d)

			TUV Austria GreenPLA	
Corn and sugar cane	Carbiolice, France	2006	TUV Austria ASTM D6400	(Carbiolice, 2019)
Starch, cellulose and vegetable oils	Novamont, Italy	1992	TUV Austria EN 13432 Certified Compostable CIC BPI Compostable	(Novamont, 2017)
Starch/PLA	NatureWorks, USA	2002	TUV Austria USDA Certified Biobased	(NatureWorks, n.d)

TUV Austria: compostability and biodegradability certification; BPI Compostable: compostability certification; USDA Certified Biobased: Certification for bio-based materials; ASTM D6400: Testing for compostability and biodegradability standards; EN 13432 Certified: European Standard for compostability and biodegradability testing; SGS: compostability and biodegradability certification; ASTM D6868: Standards for products that have compostable coatings combined with other compostable substrates; GreenPLA: Japanese biodegradability certification; Compostable CIC: Italian compostability and biodegradability certification; ABNT-NBR 15.448-2: Brazilian standard for compostability and biodegradability standards.

While the industry is focusing on the production and commercialization of new innovative biodegradable materials, Research and Development (R&D) activities are expected to exceed the sector's expectations. Around 70 - 80% of existing technological information is disclosed exclusively through patents. These are intellectual property rights that grant the owner the right to the exclusive use of an invention in a specific region for a certain period of time. Patent analysis is used to identify current technological trends, predict emerging technologies and find technical alternatives. In addition, patent information can have a valuable influence on strategic R&D decisions as well as on product or process development, acquisitions or licensing (Elvers et al., 2016). The European Patent Office (EPO) estimates that the use of existing technological information could reduce R&D costs by 30% and points out that around 20 billion US dollars are wasted annually in Europe due to duplicate inventions (Nordkvist & Kalo, 2010).

The analysis of patents shows that patent activity in the field of biodegradable materials has increased significantly overall, especially in the last ten years. Of the total number of patents filed for biodegradable polymers, 44% relate to packaging, 35% to biotechnology, 7% to the pharmaceutical industry, 4% to the medical field, 4% to the chemical industry and 6% to other applications (de Santana et al., 2018). In the period 2006-2010, most patent applications were filed in Japan, China, the USA, Korea and Europe, while the largest holders of this technology are concentrated in the USA, Japan and Germany, which clearly demonstrates the prominent position of industrialized countries in this sector (Elvers et al., 2016).

Depending on the source, different raw materials and methods have been used to produce biodegradable packaging from renewable resources, as can be seen from the patent documents listed in **Table 2.**

Table 2. Recent patents on the use of renewable sources as a feedstock for biodegradable packaging materials in the last 10 years

N°	Title	Patent No.	Publication Date	Country	Raw Material
1	The production of biodegradable biofilm for food packaging involves soaking sorghum in sodium hydroxide	MX2012010024-A1	25/02/2014	Mexico	Sorghum Starch
2	Edible asparagus sugar powder film and method of preparation thereof	CN103937041-A	23/07/2014	China	Asparagus powder and gum arabic
3	A photo-biodegradable environmental plastic film and its preparation method	CN104910435-A	16/09/2015	China	Cornstarch and peanut oil
4	Grape skin edible food packaging material and preparation method thereof	CN105924680-A	07/09/2016	China	Grape skin
5	Methods for preparing film materials for food packaging	CN105924984-A	07/09/2016	China	Sorghum starch and peanut protein
6	Protein edible film and film technology	CN106118074-A	16/11/2016	China	Whey Protein Concentrate
7	Preparation method of edible instant packaging film for seasoning bag production	CN106243398-A	21/12/2016	China	Corn starch, carboxymethyl cellulose and Houttuynia extract

8	Edible starch film for instant food and preparation method thereof	CN106674619-A	17/05/2017	China	Seaweed silk and starch
9	Preparation of anthocyanin-modified protein edible film	CN107151338-A	12/09/2017	China	Soy protein isolate and anthocyanins
10	Manufacturing process of biodegradable packaging with antimicrobial function and resulting product	BR102016005619-A2	19/09/2017	Brazil	Sugarcane bagasse
11	Biodegradable film made from avocado seed starch	BR102014027807-A2	27/02/2018	Brazil	Avocado seed
12	Use of edible films based on vegetable hemicelluloses and wax in fruit preservation	BR102016013399-A2	27/02/2018	Brazil	Carnauba wax and *Caesalpinea pulcherrima* extract
13	Food packaging film useful for preserving aquatic products preservative	CN107955215-A	24/04/2018	China	Bamboo by-products and chitosan
14	Types of food, dietary fiber, method of preparing the paper film	CN108484944-A	04/09/2018	China	Cassava
15	Edible film made of bacterial cellulose from sago liquid waste and manufacturing method	ID201900180-S	22/02/2019	Indonesia	Bacterial Cellulose and Sago Waste

16	A type of edible film made of gelatin and sodium caseinate and its preparation method	CN110878172-A	13/05/2020	China	Gelatin and casein solution
17	Biodegradable, bacteriostatic and self-improving bio-based polyester alloy material used for disposable food packaging	CN111334016-A	26/06/2020	China	Poly lactic acid (PLA) and chitosan
18	A smart indication of the use of edible film	CN112661997-A	16/04/2021	China	Corn/wheat starch and zein
19	Use of the granules to produce compostable films, as well as films made from the granules	DE202021102591-U1	22/07/2021	Germany	Potato starch and pectin
20	A preparation method for edible anthocyanin film from chitosan and blueberry	CN114409975-A	22/04/2022	China	Chitosan and blueberry
21	An edible film composed of flaxseed polysaccharide and sodium alginate and its preparation method	CN114752117-A	15/07/2022	China	Linseed polysaccharide
22	A type of starch-modified plastic film production method	CN114773664-A	22/07/2022	China	Modified starch and protein

23	Intelligent visual indication film for the freshness of low temperature formed pork and its preparation and application method	CN114805875-A	29/07/2022	China	Sodium alginate and gelatin solution
24	Xerogel nanocomposite film based on edible biopolymer and method of its manufacture	IN202231069691-A	30/12/2022	India	Banana shoot extract, edible mushroom and chitosan
25	Methods for preparing low-cost thermosetting bioplastics	IN202331003021-A	03/02/2023	India	Rice starch
26	A thermoreversible gel of tamarind seed polysaccharide and its preparation	CN115819801-A	21/03/2023	China	Tamarind seed
27	Biodegradable packaging film made from biorefinery waste and its production method	IN202241037898-A	26/05/2023	India	Jackfruit waste and chitosan
28	Biodegradable tableware and packaging solutions from plant waste biomass and method of production thereof	IN202341027258-A	26/05/2023	India	Coffee, rice starch and tapioca by-products
29	A biodegradable tomato cling film for preserving strawberries	CN116218248-A	06/07/2023	China	Tomato
30	Method of preparing fully biodegradable (self-degradable) edible seaweed plastic film	CN116515148-A	01/08/2023	China	Edible seaweed

Table 2 shows that China is the most important producer and holder of patents for emerging technologies, accounting for 66% of the documents analyzed. Studies confirm that China has been actively working to overcome the hegemony previously dominated by companies from industrialized countries. China's rise in the field of patents has been evident since the first two decades of this century, as data from the EPO and USPTO show. This progress is also reflected in the Global Innovation Index (CICC Research, 2024; Godinho & Simões, 2023). This progress is the result of robust intellectual property protection policies, significant investment in research and development and a learning dynamic that promotes innovation (Godinho & Simões, 2023). One notable example is the fast-track patent application system formally introduced by the China National Intellectual Property Administration (CNIPA) in 2012. This system mainly focuses on patents related to green innovation, shortens the examination time for qualified applications and extends the theoretical protection period, which promotes the development of green technologies (Liu et al., 2023).

Also noteworthy is the predominant use of polysaccharides, which account for 73% of the documents analyzed, as the raw material of first choice in the development of technologies for this type of material. Among the polysaccharides, starch and polylactic acid (PLA) are the most frequently mentioned. Academic studies confirm the constant use of polysaccharides in the production of bioplastics, which have gained significant importance in the 2000s (Matheus et al., 2023; Barone et al., 2023). In terms of technology, PLA has already reached an advanced stage of maturity. However, from a market perspective, this polymer has great potential for food packaging due to its relatively low cost, high production capacity, good transparency and strong market acceptance. Other polymers such as polyhydroxyalkanoates (PHA) and polyglycolides (PGA), on the other hand, still have considerable potential for future research due to their high barrier properties,

adjustable mechanical properties and attractive biodegradability, which is the most interesting characteristic of PHA (Wu et al., 2021; Rameshkumar et al., 2020; Elvers et al., 2016). In addition, there is a growing interest in the use of protein materials, despite their limitations. With the development of commercial products based on whey proteins and chitosan, these materials are becoming increasingly important in the industry. These advances indicate a promising trend in the field of bioplastics, expanding the possibilities for applications and innovation (Al-Hilifi et al., 2023).

6. From intention to action: Consumer awareness and attitudes towards biodegradable packaging

Increasing awareness of the environmental impact of conventional plastic packaging has led to greater concern about the waste generated by these products in the fast-moving consumer goods industry (Herbes et al., 2018). This has led to a growing consumer demand for environmentally friendly packaging solutions, including a greater willingness to buy unpackaged food or food in traditional packaging materials such as glass and paper instead of plastic packaging (Otto et al., 2021). Consequently, companies such as Nestlé, PepsiCo, Mars, Unilever, The Coca-Cola Company and Danone are increasingly embracing the concept of corporate social responsibility and drawing attention to the development of reusable and 100% biodegradable packaging. This strategy not only strengthens the competitive position, but also facilitates the sale of these products (Phelan et al., 2022).

Nevertheless, consumers' positive perceptions and intentions to act more sustainably may not match the actual results achieved, due to various factors including individual and demographic characteristics, marketing and pricing strategies, environmental awareness, cost, quality and packaging characteristics (Chirilli et al., 2022). Findings from studies on consumers' sustainable choices show that various factors influence the intention to purchase sustainable food packaging. The results suggest that consumers who have a positive attitude towards environmental protection are more likely to consider sustainable packaging options. Furthermore, the data shows that respondents slightly prefer products packaged with plant-based, biodegradable materials (Cammarelle et al., 2021). Gender has been shown to be an important determinant of both interest in sustainability and consumer behavior. Italian women, for example, are more environmentally aware and make more careful and selective consumption choices than men. This is particularly evident in their attitude towards the use of packaging and selective collection (Chirilli et al., 2022). Product quality also plays an

important role. Although consumers perceive biodegradable materials as high-quality products due to the perceived properties of the material, they also consider them to be inferior due to their lower durability and fragility compared to conventional plastic (Wu et al., 2021). In the UK, consumer surveys have shown that the biodegradability, reusability or recyclability of packaging significantly influences their perception of its environmental friendliness and has a direct impact on their purchasing decisions. However, research suggests that not all consumers are willing to pay for these environmentally friendly materials (Norton et al., 2022).

Nevertheless, economic factors are still among the most important factors influencing the decision to purchase biodegradable packaging. Compared to the current widely used conventional plastics such as polyethylene and polypropylene, which range from $1.2–1.3/kg, the price of the cheapest biodegradable plastic, polylactide, is still higher ($1.9–2.0/kg in 2019). Other biodegradable polymers such as PBS, PBAT ($3.5/kg in 2019) and PHAs ($3.5/kg in 2018) are even more expensive (Wu et al., 2021). A study of consumers from 42 countries, including Malaysia, Estonia, Lithuania and Germany, found that the factors preventing the industry from continuing to use biodegradable plastic packaging are related to limited availability, the high cost of producing these materials, a lack of information about the products and their properties, and limited awareness of their benefits (Leal Filho et al., 2022). In Poland, consumers with higher per capita income showed a stronger propensity to purchase ecological products than consumers with lower income. This was associated with a greater willingness to pay higher prices and a stronger belief in the prestige of purchasing ecological products, reinforced by better personal circumstances (Witek & Kuźniar, 2020). In the current context, European and Asian consumers seem to be more willing to pay for more environmentally friendly and sustainable packaging than others (Ketelsen et al., 2020). In the Brazilian context, on the other hand, more than 50% of

consumers consider biodegradable packaging to be "sustainable"," "recyclable"," "ecological"," "innovative" and "not harmful to the environment" However, 20% of participants rejected the idea of paying for biodegradable bags on the market, while 60% were willing to pay more under certain price conditions (La Fuente et al., 2022). This indicates a gap between consumers' intentions and their actual behavior, known as the intention-behavior gap. These results also emphasize how the impact of these factors can change depending on the context.

Eco-labels serve as green marketing tools to increase demand for environmentally friendly products and influence conscious decisions. They serve to visually inform consumers about the sustainable characteristics of products (Donato & D'Aniello, 2021). In Europe, for example, the introduction of carbon labels has been promoted for several years to monitor the overall level of greenhouse gas emissions of different products. It was first introduced in 2007 by the British company Tesco, which decided to label its products with information on the CO2 emissions generated during their production and transportation (Liang et al., 2020). Over the past ten years, the number of ecolabels has increased worldwide. In May 2020, the Eco-label Index platform counted 458 ecolabels in 199 countries and 25 different industries listed in the global directory, as some examples in **Figure 2** show (Meis-Harris et al., 2021).

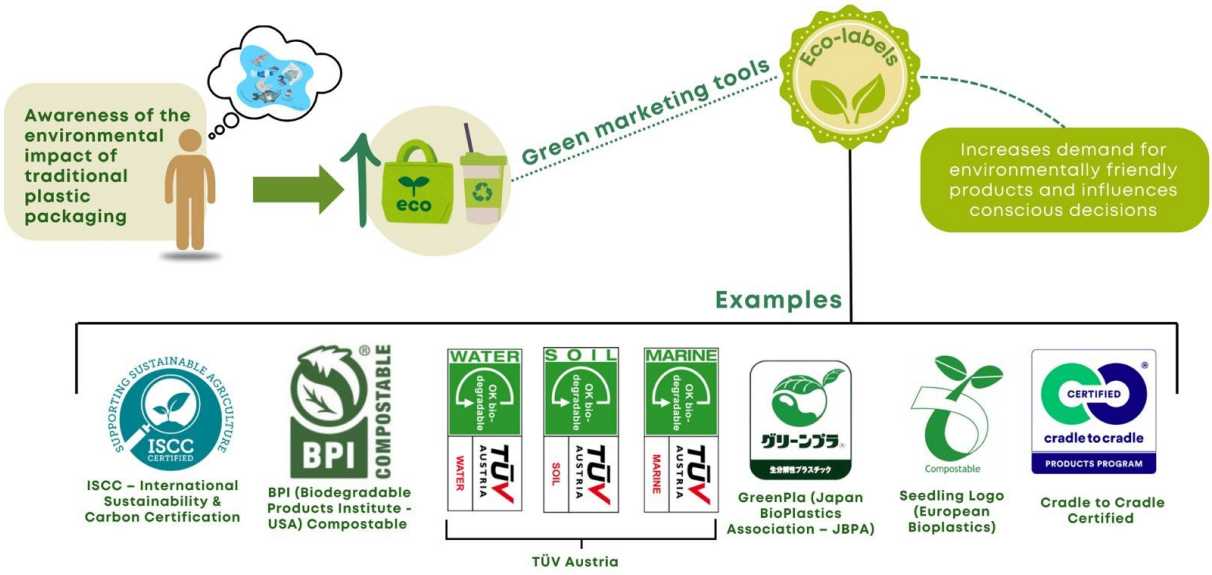


Figure 2. Certified sustainability.

However, greenwashing, which uses nature-related elements to make consumers believe that brands or products are environmentally friendly, threatens the development of a sustainable market by giving consumers a false impression of a product's environmental impact (Boncinelli et al., 2023). The lack of regulations and penalties is an important factor for greenwashing. In addition, green companies can be negatively affected by the greenwashing behavior of other companies. Therefore, environmental labeling rules and practices and country governance are crucial to ensure that labeling is trustworthy and legitimate (Boncinelli et al., 2023; Meis-Harris et al., 2021). An alternative approach could be to focus on improving consumer knowledge and understanding of the actual properties and composition of environmentally friendly and biodegradable packaging. In addition, the labeling, composition and disposal instructions for biodegradable plastics should be clearly indicated on logos and labels so that consumers can easily recognize them. This underlines the need to link logos and labels to a standardized and certified system (Boncinelli et al., 2023).

7. Conclusions and perspectives

Global plastics production is expected to triple by 2060. This follows the current alarming trend of transitioning from durable plastics to SUP. This growth, combined with the low recycling rate of SUPs, makes investment in the recycling of these materials economically uncompetitive compared to the production of virgin plastics due to government subsidies and the strong influence of the packaging industry. The ubiquitous presence of plastics affects agricultural productivity, impacts the multifunctionality of soils, threatens marine life and impacts the livelihoods of local communities. While global measures to ban and tax SUP plastics represent a positive trend towards a more circular economic model, initiatives by countries such as Spain, Rwanda and Australia highlight the need for multidisciplinary approaches to tackle this multi-faceted problem. China's ban on imports of recyclable plastics and other solid waste has been one of the major catalyst for this shift, forcing many exporting countries such as Japan, the US and Canada to rethink and strengthen their domestic waste management systems, instead of “simply exporting their waste”. Furthermore, involving the packaging industry in this issue through strategies such as Extended Producer Responsibility (EPR) shifts the responsibility for the disposal of post-consumer materials back to the producers and proves to be an effective measure by encouraging a revision of product design. In this context, biodegradable materials have proven to be a promising alternative to mitigate the environmental impact of conventional plastics and have sparked the interest of the chemical and packaging industries to invest in large-scale production technologies for renewable monomers and polymers. As a result, the number of patents in this sector has increased in recent years, shaping strategic R&D decisions and highlighting new technological trends and technical alternatives. China is a leader in the production and ownership of emerging technologies. This is the result of sound intellectual property protection policies and significant investment in research and green

innovation. The use of agro-industrial waste, especially that rich in polysaccharides, has also gained importance as it is an important raw material to produce biodegradable packaging. This could benefit agro-industrial countries such as Brazil, Thailand, Malaysia and Mexico, attracting investment from major companies such as Braskem and Earth Renewable Technologies (ERT). The growing popularity of biodegradable alternatives and consumers' increasing awareness of the environmental impact of their consumption choices have fueled demand for eco-friendly solutions. However, studies point to an "intention-behavior gap'," which states that the intention to adopt more sustainable practices does not always translate into purchasing decisions, which are influenced by socio-demographic factors, price, quality and characteristics associated with biodegradable packaging. In general, these materials are more expensive and fragile than conventional plastics, and the use of renewable resources does not guarantee sustainability per se. Therefore, a policy that prioritizes the circular economy should encourage companies to conduct comprehensive assessments of all stages of their product life cycle and invest in green marketing tools such as eco-labels to avoid greenwashing practices and facilitate more informed consumer purchasing decisions. The implementation of transparent regulatory frameworks and the adoption of global strategies such as the United Nations Global Plastics Pact underline the importance of a collaborative approach that transcends national and private economic interests and ensures a more robust and effective transition to tackle future environmental threats.

Funding: The authors would like to express their gratitude for the support from UNIRIO, UERJ, USP, UFRJ, Albstadt-Sigmaringen University, University of Arkansas System, CAPES-Humboldt Research Fellowship; CAPES (Coordination for the Improvement of Higher Education Personnel (CAPES) (001) and FAPERJ (Research Support Foundation of the State of Rio de Janeiro) (code E-26/211.985/2021; code E-26/201.428/2022; code SEI-260003/019614/2022).

Conflict of interest: There are no conflicts of interest.

References

Al-Hilifi, S. A., Al-Ibresam, O. T., Al-Hatim, R. R., Al-Ali, R. M., Namrata Maslekar, Yao, Y., & Agarwal, V. (2023). Development of Chitosan/Whey Protein Hydrolysate Composite Films for Food Packaging Application. *Journal of Composites Science*, *7*(3), 94–94. https://doi.org/10.3390/jcs7030094

Angnunavuri, P. N., Attiogbe, F., & Mensah, B. (2023). Particulate plastics in drinking water and potential human health effects: Current knowledge for management of freshwater plastic materials in Africa. *Environmental Pollution*, *316*, 120714. https://doi.org/10.1016/j.envpol.2022.120714

Ann Thomas, J. (2022). Startup chilena chega ao Brasil com bioplástico que se degrada em 20 meses. Retrieved from https://veja.abril.com.br/agenda-verde/startup-chilena-chega-ao-brasil-com-bioplastico-que-se-degrada-em-20-meses/. Accessed October 27, 2024.

Azevedo, B. D., Scavarda, L. F., Caiado, R. G. G., & Fuss, M. (2021). Improving urban household solid waste management in developing countries based on the German experience. *Waste Management*, *120*, 772–783. https://doi.org/10.1016/j.wasman.2020.11.001

Barkhad, M. S., Abu-Jdayil, B., Iqbal, M. Z., & Mourad, A.-H. I. (2020). Thermal insulation using biodegradable poly (lactic acid)/date pit composites. *Construction and Building Materials*, *261*, 120533. https://doi.org/10.1016/j.conbuildmat.2020.120533

Barone, A. S., Matheus, J. R. V., Souza, T. S. P., Moreira, R. F. A., & Fai, A. E. C. (2021). Green-based active packaging: Opportunities beyond COVID-19, food applications, and perspectives in circular economy—A brief review. *Comprehensive Reviews in Food Science and Food Safety*, *20*(5), 4881–4905. https://doi.org/10.1111/1541-4337.12812

Barone, A. S., Rabelo, J., Cláudia Leites Luchese, Regina, Maria, A., Ferreira, W. H., Felipe, R., & Elizabeth, A. (2023). Active antioxidant and aromatic films blended with persimmon

(*Diospyros kaki* L.) and orange peel flour (*Citrus sinensis*) as sustainable packaging. *Journal of Vinyl and Additive Technology*. https://doi.org/10.1002/vnl.22075

Bassi, S. A., Boldrin, A., Faraca, G., & Astrup, T. F. (2020). Extended producer responsibility: How to unlock the environmental and economic potential of plastic packaging waste? *Resources, Conservation and Recycling*, *162*, 105030. https://doi.org/10.1016/j.resconrec.2020.105030

Baxter, L., Lucas, Z., & Walker, T. R. (2022). Evaluating Canada's single-use plastic mitigation policies via brand audit and beach cleanup data to reduce plastic pollution. *Marine Pollution Bulletin*, *176*(113460), 113460. https://doi.org/10.1016/j.marpolbul.2022.113460

BIOFASE (n.d.). Nostalgia de Mexico. Retrieved from https://www.nostalgiademexico.com/biofase/ Accessed October 29, 2024.

Boncinelli, F., Gerini, F., Piracci, G., Bellia, R., & Casini, L. (2023). Effect of executional greenwashing on market share of food products: An empirical study on green-coloured packaging. *Journal of Cleaner Production*, *391*(391), 136258. https://doi.org/10.1016/j.jclepro.2023.136258

Borg, K., Lennox, A., Kaufman, S., Tull, F., Prime, R., Rogers, L., & Dunstan, E. (2022). Curbing plastic consumption: A review of single-use plastic behaviour change interventions. *Journal of Cleaner Production*, *344*(131077), 131077. https://doi.org/10.1016/j.jclepro.2022.131077

Calabrese, A., Costa, R., Levialdi Ghiron, N., Menichini, T., Miscoli, V., & Tiburzi, L. (2021). Operating modes and cost burdens for the European deposit-refund systems: A systematic approach for their analysis and design. *Journal of Cleaner Production*, *288*, 125600. https://doi.org/10.1016/j.jclepro.2020.125600

Cammarelle, A., Viscecchia, R., & Bimbo, F. (2021). Intention to Purchase Milk Packaged in Biodegradable Packaging: Evidence from Italian Consumers. *Foods*, *10*(9), 2068. https://doi.org/10.3390/foods10092068

Carbiolice (2019). Standards and legislation for compostable. Retrieved from https://www.carbiolice.com/en/composting-and-certification/ Accessed October 29, 2024.

Chen, Y., Awasthi, A. K., Wei, F., Tan, Q., & Li, J. (2021). Single-use plastics: Production, usage, disposal, and adverse impacts. *Science of the Total Environment*, *752*(752), 141772. https://doi.org/10.1016/j.scitotenv.2020.141772

Chirilli, C., Molino, M., & Torri, L. (2022). Consumers' Awareness, Behavior and Expectations for Food Packaging Environmental Sustainability: Influence of Socio-Demographic Characteristics. *Foods*, *11*(16), 2388. https://doi.org/10.3390/foods11162388

CICC Research, CICC Global Institute. (2024). Technological Innovation in China: Current State and Challenges. In: The Rise of China's Innovation Economy. Springer, Singapore. https://doi.org/10.1007/978-981-99-8231-8_1.

Cristi, M. A., Holzapfel, C., Nehls, M., De Veer, D., Gonzalez, C., Holtmann, G., Honorato-Zimmer, D., Kiessling, T., Muñoz, A. L., Reyes, S. N., Nuñez, P., Sepulveda, J. M., Vásquez, N., & Thiel, M. (2020). The rise and demise of plastic shopping bags in Chile – Broad and informal coalition supporting ban as a first step to reduce single-use plastics. *Ocean & Coastal Management*, *187*, 105079. https://doi.org/10.1016/j.ocecoaman.2019.105079

de Santana, M. C. C. B., da Fonseca, L. S., Tatum, C. T. S., Naziazeno Neto, L. F., & de Oliveira Júnior, A. M. (2018). *Proteínas Písceas: tendências tecnológicas em embalagens biodegradáveis através da prospecção em documentos de patentes* (Vol. 4, Issue 1, pp. 663–669).

Dey, A., Dhumal, C. V., Sengupta, P., Kumar, A., Pramanik, N. K., & Alam, T. (2020). Challenges and possible solutions to mitigate the problems of single-use plastics used for packaging food items: a review. *Journal of Food Science and Technology*, *58*(9), 3251–3269. https://doi.org/10.1007/s13197-020-04885-6

Diggle, A., & Walker, T. R. (2020). Implementation of harmonized Extended Producer Responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. *Waste Management*, *110*, 20–23. https://doi.org/10.1016/j.wasman.2020.05.013

Donato, C., & D'Aniello, A. (2021). Tell me more and make me feel proud: the role of eco-labels and informational cues on consumers' food perceptions. *British Food Journal*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/bfj-04-2021-0416

Ecovative (2019). Home | Packaging products grown from mushroom mycelium. Retrieved from https://mushroompackaging.com/ Accessed October 29, 2024.

Elvers, D., Song, C. H., Steinbüchel, A., & Leker, J. (2016). Technology Trends in Biodegradable Polymers: Evidence from Patent Analysis. *Polymer Reviews*, *56*(4), 584–606. https://doi.org/10.1080/15583724.2015.1125918

ERT, A. (2023). Curitiba terá a primeira indústria de plástico biodegradável da América Latina. ERT - Earth Renewable Technologies. Retrieved from https://ertbio.com/noticias/curitiba-tera-a-primeira-industria-de-plastico-biodegradavel-da-america-latina-4/. Accessed October 27, 2024.

European Bioplastics. (2023). Bioplastics Market Development Update 2023. European Bioplastics. Retrieved from https://www.european-bioplastics.org/bioplastics-market-development-update-2023-2/ Accessed October 27, 2024.

Filiciotto, L., & Rothenberg, G. (2020). Biodegradable Plastics: Standards, Policies, and Impacts. *ChemSusChem*, *14*(1). https://doi.org/10.1002/cssc.202002044

GLOBO (2022). ONU aprova base do pacto contra o plástico, maior acordo verde desde Paris. Um Só Planeta. Retrieved from https://umsoplaneta.globo.com/sociedade/noticia/2022/03/02/tratado-do-plastico-maior-acordo-verde-desde-paris-tera-diretrizes-reveladas.ghtml. Accessed October 31, 2024.

Godinho, M. M. & Simões, V. C. (2023). The Tech Cold War: What can we learn from the most dynamic patent classes? *International Business Review*, *32*(6), 102140–102140. https://doi.org/10.1016/j.ibusrev.2023.102140

Hayashi, T. (2023). Plastic Recycling Policy in China and the Waste Plastic Trade [Review of *Plastic Recycling Policy in China and the Waste Plastic Trade*]. In K. Fujikawa (Ed.), *Empirical Research on Environmental Policies in China* (pp. 37–57). Springer. https://link.springer.com/book/10.1007/978-981-99-5957-0

Herberz, T., Barlow, C. Y., & Finkbeiner, M. (2020). Sustainability Assessment of a Single-Use Plastics Ban. *Sustainability*, *12*(9), 3746. https://doi.org/10.3390/su12093746

Herbes, C., Beuthner, C., & Ramme, I. (2018). Consumer attitudes towards biobased packaging – A cross-cultural comparative study. *Journal of Cleaner Production*, *194*(1), 203–218. https://doi.org/10.1016/j.jclepro.2018.05.106

Idowu G.A., Oriji A.Y., Olorunfemi K.O., Sunday M.O., Sogbanmu T.O., Bodunwa O.K., Shokunbi O.S., & Aiyesanmi A.F. (2024). Why Nigeria should ban Single-use Plastics: Excessive Microplastic Pollution of the water, sediments and fish species in Osun River, Nigeria. *Journal of Hazardous Materials Advances*, *13*, 100409–100409. https://doi.org/10.1016/j.hazadv.2024.100409

Ilechukwu, I., Das, R. R., Jamodiong, E. A., Borghi, S., Manzano, G. G., Hakim, A. A., & Reimer, J. D. (2024). Abundance and distribution of marine litter on the beaches of Okinawa Island, Japan. *Marine Pollution Bulletin*, *200*, 116036. https://doi.org/10.1016/j.marpolbul.2024.116036

Já Fui Mandioca! (n.d) Bioembalagens 100% ecológicas. Retrieved from https://jafuimandioca.com.br/ Accessed October 29, 2024.

Ketelsen, M., Janssen, M., & Hamm, U. (2020). Consumers' response to environmentally-friendly food packaging - A systematic review. *Journal of Cleaner Production*, *254*(254), 120123. https://doi.org/10.1016/j.jclepro.2020.120123

Kiessling, T., Hinzmann, M., Mederake, L., Dittmann, S., Brennecke, D., Böhm-Beck, M., Knickmeier, K., & Thiel, M. (2023). What potential does the EU Single-Use Plastics Directive have for reducing plastic pollution at coastlines and riversides? An evaluation based on citizen science data. *Waste Management*, *164*, 106–118. https://doi.org/10.1016/j.wasman.2023.03.042

Kittithammavong, V., Khanitchaidecha, W., & Thongsanit, P. (2023). CO2 Emissions from Plastic Consumption Behaviors in Thailand. *Sustainability*, *15*(16), 12135–12135. https://doi.org/10.3390/su151612135

Kompuestos (2020). New Plastics Economy Global Commitment. Retrieved from https://www.kompuestos.com/en/sustainability Accessed October 29, 2024.

Koskei, K., Munyasya, A. N., Wang, Y.-B., Zhao, Z.-Y., Zhou, R., Indoshi, S. N., Wang, W., Cheruiyot, W. K., Mburu, D. M., Nyende, A. B., & Xiong, Y.-C. (2021). Effects of increased plastic film residues on soil properties and crop productivity in agro-ecosystem. *Journal of Hazardous Materials*, *414*, 125521. https://doi.org/10.1016/j.jhazmat.2021.125521

La Fuente, C. I. A., Tribst, A. A. L., & Augusto, P. E. D. (2022). Knowledge and perception of different plastic bags and packages: A case study in Brazil. *Journal of Environmental Management*, *301*, 113881. https://doi.org/10.1016/j.jenvman.2021.113881

Leal Filho, W., Barbir, J., Abubakar, I. R., Paço, A., Stasiskiene, Z., Hornbogen, M., Christin 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

Liang, T.-C., Situmorang, R. O. P., Liao, M.-C., & Chang, S.-C. (2020). The Relationship of Perceived Consumer Effectiveness, Subjective Knowledge, and Purchase Intention on Carbon Label Products—A Case Study of Carbon-Labeled Packaged Tea Products in Taiwan. *Sustainability*, *12*(19), 7892. https://doi.org/10.3390/su12197892

Lima, L. R., Gutierrez, R. F., & Cruz, S. A. (2022a). Challenges in the context of single-use plastics and bioplastics in Brazil: A legislative review. *Waste Management & Research*, *40*(7), 998–1006. https://doi.org/10.1177/0734242X21105

Lima, L. R., Gutierrez, R. F., & Cruz, S. A. (2022b). A Perspective of the COVID-19 Pandemic in the Plastic Waste Management and Cooperatives of Waste Pickers in Brazil. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-021-00130-0

Liu, E., Zhang, L., Dong, W., & Yan, C. (2021). Biodegradable plastic mulch films in agriculture: feasibility and challenges. *Environmental Research Letters*, *16*(1), 011004. https://doi.org/10.1088/1748-9326/abd211

Liu, R., Zhu, X., Zhang, M., & Hu, C. (2023). Innovation incentives and urban carbon dioxide emissions: A quasi-natural experiment based on fast-tracking green patent applications in China. *Journal of Cleaner Production*, 135444. https://doi.org/10.1016/j.jclepro.2022.135444

Liu, W., Wang, Z., Liu, J., Dai, B., Hu, S., Hong, R., Xie, H., Li, Z., Chen, Y., & Zeng, G. (2020). Preparation, reinforcement and properties of thermoplastic starch film by film blowing. *Food Hydrocolloids*, *108*, 106006. https://doi.org/10.1016/j.foodhyd.2020.106006

Macintosh, A., Simpson, A., Neeman, T., & Dickson, K. (2020). Plastic bag bans: Lessons from the Australian Capital Territory. *Resources, Conservation and Recycling*, *154*(1), 104638. https://doi.org/10.1016/j.resconrec.2019.104638

MacLeod, M., Arp, H. P. H., Tekman, M. B., & Jahnke, A. (2021). The Global Threat from Plastic Pollution. *Science*, *373*(6550), 61–65. https://doi.org/10.1126/science.abg5433

Mangaraj, S., Yadav, A., Bal, L. M., Dash, S. K., & Mahanti, N. K. (2018). Application of Biodegradable Polymers in Food Packaging Industry: A Comprehensive Review. *Journal of Packaging Technology and Research*, *3*(1), 77–96. https://doi.org/10.1007/s41783-018-0049-y

Matheus, J. R. V., de Farias, P. M., Satoriva, J. M., de Andrade, C. J., & Fai, A. E. C. (2023). Cassava starch films for food packaging: Trends over the last decade and future research. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2022.11.129

Meis-Harris, J., Klemm, C., Kaufman, S., Curtis, J., Borg, K., & Bragge, P. (2021). What is the role of eco-labels for a circular economy? A rapid review of the literature. *Journal of Cleaner Production*, *306*, 127134. https://doi.org/10.1016/j.jclepro.2021.127134

Mordor Intelligence (2019). Biodegradable Packaging Solutions Market Size & Share Analysis - Growth Trends & Forecasts (2024 - 2029) Retrieved from https://www.mordorintelligence.com/industry-reports/gobal-biodegradable-packaging-solutions-market-industry. Accessed October 27, 2024.

Mordor Intelligence (2023). Southeast Asia Bioplastics Market Size & Share Analysis - Growth Trends & Forecasts (2024 - 2029) Retrieved from https://www.mordorintelligence.com/industry-reports/southeast-asia-bioplastics-market. Accessed October 27, 2024.

Moshood, T. D., Nawanir, G., & Mahmud, F. (2021). Sustainability of biodegradable plastics: a review on social, economic, and environmental factors. *Critical Reviews in Biotechnology*, *42*(6), 1–21. https://doi.org/10.1080/07388551.2021.1973954

Mukherjee, C., Varghese, D., Krishna, J. S., Boominathan, T., Rakeshkumar, R., Dineshkumar, S., Brahmananda Rao, C. V. S., & Sivaramakrishna, A. (2023). Recent advances in

biodegradable polymers – Properties, applications and future prospects. *European Polymer Journal*, *192*, 112068. https://doi.org/10.1016/j.eurpolymj.2023.112068

Najafighodousi, A., Nemati, F., Rayegani, A., Saberian, M., Zamani, L., & Li, J. (2024). Recycling facemasks into civil construction material to manage waste generated during COVID-19. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-023-31726-8

NatureWorks (n.d) Composting. Retrieved from https://www.natureworksllc.com/sustainability/end-of-life-opportunities/composting Accessed October 29, 2024.

Nizamuddin, S., Baloch, A. J., Chen, C., Arif, M., & Mubarak, N. M. (2024). Bio-based plastics, biodegradable plastics, and compostable plastics: biodegradation mechanism, biodegradability standards and environmental stratagem. *International Biodeterioration & Biodegradation*, *195*, 105887–105887. https://doi.org/10.1016/j.ibiod.2024.105887

Nordkvist, L., & Kalo, A. (2010). How do Intellectual Property Rights help commercializing inventions in Europe? The case of the introduction of the European community patent system. Master's Thesis in Business Administration. Retrieved from https://www.diva-portal.org/smash/get/diva2:828264/FULLTEXT01.pdf. Accessed October 27, 2024.

Norton, V., Waters, C., Oloyede, O. O., & Lignou, S. (2022). Exploring Consumers' Understanding and Perception of Sustainable Food Packaging in the UK. *Foods*, *11*(21), 3424. MDPI. https://doi.org/10.3390/foods11213424

Novamont (2017). MATER-BI Certifications. Retrieved from https://novamont.it/eng/mater-bi-certifications Accessed October 29, 2024.

OECD (2018), Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, OECD Publishing, Paris, https://doi.org/10.1787/9789264301016-en

OECD (2022), Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options, OECD Publishing, Paris, https://doi.org/10.1787/de747aef-en.

Ortega-Borchardt, J.A., Barba-Acuña, I.D., De-la-Torre, G. E., Ramírez-Álvarez, N., & García-Hernández, J. (2024). Personal protective equipment (PPE) pollution associated with the COVID-19 pandemic on beaches in the eastern region of the Gulf of California, Mexico. *Science of the Total Environment*, *906*, 167539–167539. https://doi.org/10.1016/j.scitotenv.2023.167539

Otto, S., Strenger, M., Maier-Nöth, A., & Schmid, M. (2021). Food packaging and sustainability – Consumer perception vs. correlated scientific facts: A review. *Journal of Cleaner Production*, *298*(1), 126733. https://doi.org/10.1016/j.jclepro.2021.126733

Phelan, A., Meissner, K., Humphrey, J., & Ross, H. (2022). Plastic pollution and packaging: Corporate commitments and actions from the food and beverage sector. *Journal of Cleaner Production*, *331*(331), 129827. https://doi.org/10.1016/j.jclepro.2021.129827

Plastics Europe. (2021). Plastics -the Facts 2021 An analysis of European plastics production, demand and waste data. Retrieved from https://plasticseurope.org/wp-content/uploads/2021/12/Plastics-the-Facts-2021-web-final.pdf. Accessed October 31, 2024.

Política Nacional de Resíduos Sólidos, N° 12.305 (2010). Retrieved from https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm. Accessed October 31, 2024.

PTT MCC BIOCHEM CO., LTD. (n.d.). Flexible Packaging. Retrieved from https://www.pttmcc.com/flexible-packaging Accessed October 29, 2024.

Rabiu, M. K., & Jaeger-Erben, M. (2024). Reducing single-use plastic in everyday social practices: Insights from a living lab experiment. *Resources, Conservation and Recycling*, *200*, 107303. https://doi.org/10.1016/j.resconrec.2023.107303

Rafey, A., & Siddiqui, F. Z. (2021). A review of plastic waste management in India – challenges and opportunities. *International Journal of Environmental Analytical Chemistry*, *103*(16), 1–17. https://doi.org/10.1080/03067319.2021.1917560

RameshKumar, S., Shaiju, P., O'Connor, K. E., & P, R. B. (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

Ríos, A.-M., & Picazo-Tadeo, A. J. (2021). Measuring environmental performance in the treatment of municipal solid waste: The case of the European Union-28. *Ecological Indicators*, *123*, 107328. https://doi.org/10.1016/j.ecolind.2020.107328

Rubio, S., Ramos, T. R. P., Leitão, M. M. R., & Barbosa-Povoa, A. P. (2019). Effectiveness of extended producer responsibility policies implementation: The case of Portuguese and Spanish packaging waste systems. *Journal of Cleaner Production*, *210*, 217–230. https://doi.org/10.1016/j.jclepro.2018.10.299

Schmidt, S., & Laner, D. (2021). The multidimensional effects of single-use and packaging plastic strategies on German household waste management. *Waste Management*, *131*, 187–200. https://doi.org/10.1016/j.wasman.2021.06.003

Shaikh, S., Yaqoob, M., & Aggarwal, P. (2021). An overview of biodegradable packaging in food industry. *Current Research in Food Science*, *4*, 503–520. Sciencedirect. https://doi.org/10.1016/j.crfs.2021.07.005

Sharma, H. B., Vanapalli, K. R., Samal, B., Cheela, V. R. S., Dubey, B. K., & Bhattacharya, J. (2021). Circular economy approach in solid waste management system to achieve UN-SDGs: Solutions for post-COVID recovery. Science of the Total Environment, 800(3), 149605. https://doi.org/10.1016/j.scitotenv.2021.149605

Shashoua, Y., Asal Peydaei, Mortensen, M. N., Kanstrup, A. B., & Gregory, D. J. (2024). Physio-Chemical Degradation of Single-Use Plastics in Natural Weather and Marine Environments. *Environmental Pollution*, *357*, 124414–124414. https://doi.org/10.1016/j.envpol.2024.124414

Sousa, T. (2022, February 11). Brasil aposta em futuro promissor para bioplástico. Agência de Notícias Brasil-Árabe. Retrieved from https://anba.com.br/brasil-aposta-em-futuro-promissor-para-bioplastico/. Accessed October 27, 2024.

Taylor, R. L., & Villas-Boas, S. B. (2015). Bans vs. Fees: Disposable Carryout Bag Policies and Bag Usage. *Applied Economic Perspectives and Policy*, *38*(2), 351–372. https://doi.org/10.1093/aepp/ppv025

Tiwari, B.R., Lecka, J., Pulicharla, R., & Brar S.K. (2023). *Microplastic pollution and associated health hazards: Impact of COVID-19 pandemic*. *Current Opinion in Environmental Science & Health*, 34, 100480-100480. https://doi.org/10.1016/j.coesh.2023.100480

Tiwari, B.R., Lecka, J., Rama Pulicharla, & Satinder Kaur Brar. (2023). *Microplastic pollution and associated health hazards: Impact of COVID-19 pandemic*. 100480–100480. https://doi.org/10.1016/j.coesh.2023.100480

Uche, O.L. (2023). Plastic Waste Regime in Rwanda, Kenya and South Africa: A Comparative Case Study. *American Journal of Law*, *5*(2), 54–85. https://doi.org/10.47672/ajl.1652

UNEP (2022). Visual Feature | Beat Plastic Pollution. United Nations Environment Programme. Retrieved from https://www.unep.org/interactives/beat-plasticpollution/?gad_source=1&gclid=EAIaIQobChMIuq2zpue5iQMVJzAIBR2JRQk0EAAYAiAAEgLtJfD_BwE. Accessed October 31, 2024.

UNEP (2023). *Turning off the Tap: How the world can end plastic pollution and create a circular economy*. United Nations Environment Programme. Retrieved from

https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy. Accessed October 31, 2024.

UNEP (2024). Plastic pollution negotiations adjourn with new text and a follow-up session planned**.** United Nations Environment Programme. Retrieved from https://www.unep.org/inc-plastic-pollution/media#PressRelease2Dec. Accessed January 30, 2025.

United Nations Environment Programme. (2018). *Single-use plastics, a roadmap for sustainability.* United Nations Environment Programme.

Vegware (2022). Vegware - plant-based compostable foodservice packaging. Retrieved from https://www.vegware.com/uk-en/ Accessed October 29, 2024.

Vuppaladadiyam, S.S.V., Vuppaladadiyam, A. K., Sahoo A., Urgunde, A., Murugavelh S., Šrámek, V., Pohořelý, M., Trakal, L., Bhattacharya, S., Sarmah, A. K., Shah, K., & Pant, K.K. (2024). Waste to energy: Trending key challenges and current technologies in waste plastic management. *Science of the Total Environment*, 169436–169436. https://doi.org/10.1016/j.scitotenv.2023.169436

Wang, P.-Y., Zhao, Z.-Y., Xiong, X.-B., Wang, N., Zhou, R., Zhang, Z.-M., Ding, F., Hao, M., Wang, S., Ma, Y., Uzamurera, A. G., Xiao, K.-W., Khan, A., Tao, X.-P., Wang, W.-Y., Tao, H.-Y., & Xiong, Y.-C. (2023). Microplastics affect soil bacterial community assembly more by their shapes rather than the concentrations. *Water Research*, *245*, 120581–120581. https://doi.org/10.1016/j.watres.2023.120581

Witek, L., & Kuźniar, W. (2020). Green Purchase Behavior: The Effectiveness of Sociodemographic Variables for Explaining Green Purchases in Emerging Market. *Sustainability*, *13*(1), 209. https://doi.org/10.3390/su13010209

Wu, F., Misra, M., & Mohanty, A. K. (2021). Challenges and New Opportunities on Barrier Performance of Biodegradable Polymers for Sustainable Packaging. *Progress in Polymer Science*, *117*(101395), 101395. https://doi.org/10.1016/j.progpolymsci.2021.101395

Xin, C., Zhang, T., Tsai, S.-B., Zhai, Y.-M., & Wang, J. (2020). An Empirical Study on Greenhouse Gas Emission Calculations Under Different Municipal Solid Waste Management Strategies. *Applied Sciences*, *10*(5), 1673. https://doi.org/10.3390/app10051673

Ye, Q., Umer, Q., Zhou, R., Asmi, A., & Asmi, F. (2023). How publications and patents are contributing to the development of municipal solid waste management: Viewing the UN Sustainable Development Goals as ground zero. *Journal of Environmental Management*, *325*, 116496. https://doi.org/10.1016/j.jenvman.2022.116496

Yıldız, N. Ç., Avunduk, Z. B. & Erdiaw-Kwasie. M. O. (2023). Circular Economy in Turkish Manufacturing Sector: The Roles of Green Manufacturing and Innovation. *Sustainable Development Goals Series*, 381–415. https://doi.org/10.1007/978-981-99-3083-8_13

Zhao, Z.-Y., Wang, P.-Y., Xiong, X.-B., Chen, Y., Tao, H.-Y., Wang, W.-Y., Song, Y., Ashraf, M., Zhu, L., Xiao, Y.-L., Li, S.-S., Yang, F.-K., Li, M.-Y., Cao, J., Fang, X.-W., Levis Kavagi, & Xiong, Y.-C. (2024). Uncollected polythene fragments size-dependently alter soil multifunctionality via mediating bacterial drivers in dryland. *National Science Review*, *11*(9). https://doi.org/10.1093/nsr/nwae281

Zhong, Y., Godwin, P., Jin, Y., & Xiao, H. (2020). Biodegradable polymers and green-based antimicrobial packaging materials: A mini-review. *Advanced Industrial and Engineering Polymer Research*, *3*(1), 27–35. https://doi.org/10.1016/j.aiepr.2019.11.002

3. CONCLUSÃO GERAL E PERSPECTIVAS

Medidas globais, como a Agenda 2030 da ONU, e nacionais, como o Marco de Referência de Sistemas Alimentares e Clima para as Políticas Públicas (MDS/Brasil) e o Plano Nacional de Economia Circular (MDIC/Brasil), reforçam a transição do modelo linear de produção e consumo para uma economia mais circular e o uso de materiais de menor impacto ao longo das cadeias produtivas, escopo no qual se inserem as embalagens de origem biológica e biodegradáveis para alimentos, que se destacam como alternativa às embalagens plásticas de uso único. Contudo, seu avanço não depende apenas do desenvolvimento de novos materiais, mas também de sua viabilidade industrial, aceitação pelo mercado e inserção em ambientes regulatórios favoráveis. A análise patentária revelou um campo tecnológico em expansão, marcado pelo predomínio de matérias-primas vegetais, pela valorização de subprodutos agroindustriais e pelo desenvolvimento de materiais com propriedades ativas, mecânicas e de barreira aprimoradas. A liderança da China reflete seus investimentos em pesquisa e inovação verde, enquanto a participação de países como Alemanha, Índia e Brasil indica que esse domínio tecnológico também pode representar uma oportunidade estratégica para nações com elevada disponibilidade de recursos agrícolas e biomassa. Apesar desses avanços, existe uma lacuna entre a geração de conhecimento e sua aplicação industrial. A elevada participação de instituições acadêmicas entre os depositantes e o uso recorrente do método de *casting* indicam que muitas tecnologias ainda permanecem em estágios laboratoriais ou iniciais de desenvolvimento. Assim, o crescimento da atividade patentária não deve ser interpretado como evidência direta de ampla disponibilidade comercial. A aplicação dessas embalagens em alimentos perecíveis demonstra o potencial de integração entre biodegradabilidade, funcionalidade ativa e aproveitamento de subprodutos ricos em compostos bioativos. Além disso, tecnologias emergentes, como a eletrofiação para encapsulação de compostos termossensíveis, ampliam as possibilidades de desenvolvimento do setor. Entretanto, a

maturidade tecnológica, isoladamente, não assegura a adoção dessas soluções. As percepções dos consumidores revelam que o preço, a qualidade percebida e a transparência sao fatores fundamentais durante a decisao de compra. Da mesma forma, a análise das políticas de economia circular mostrou que não existe um único caminho de implementação aplicável a todos os países, uma vez que as estratégias nacionais dependem de capacidades institucionais, infraestrutura, prioridades econômicas e desafios socioambientais específicos. Este estudo apresenta limitações que devem ser consideradas. A análise patentária utilizou uma única base de dados e abrangeu o período de 2013 a 2025, o que pode ter excluído documentos relevantes e sub-representado avanços recentes devido ao intervalo entre depósito e publicação. Além disso, as patentes não permitem determinar, por si só, a maturidade tecnológica, o sucesso comercial ou a adoção industrial das invenções. Nos estudos sobre percepção dos consumidores, a distribuição desigual das evidências entre os países limitou a comparabilidade dos resultados, especialmente em relação ao Brasil. Por isso, os achados devem ser interpretados como perspectivas comparativas e exploratórias, e não como representações definitivas do comportamento dos consumidores. Pesquisas futuras poderão integrar diferentes bases patentárias e indicadores de família, citações e status legal, além de incorporar análises técnico-econômicas e de ciclo de vida para avaliar desempenho, custo, escalabilidade e impacto ambiental. No campo do comportamento do consumidor, estudos experimentais com amostras representativas e metodologias padronizadas poderão reduzir vieses e permitir comparações estatísticas mais robustas entre países. Por fim, esta tese amplia a discussão ao conectar dimensões tecnológicas, ambientais, econômicas, comportamentais e regulatórias. Essa abordagem integrada pode apoiar empresas, pesquisadores e formuladores de políticas na identificação de soluções de embalagem não apenas inovadoras, mas também escaláveis, acessíveis, confiáveis e compatíveis com os princípios da economia circular.