

A Effects of Plastic Use in the Food Processing Industry and Sustainable Substitutes: A Review

Naresh Golla^{1*}, Vikas Chikmagalur Manjunath², Yashraj S B³,
Pranav Gowda N G³.

¹ Nottingham Trent University, Nottingham, United Kingdom. ² University of Nottingham, Nottingham, United Kingdom. ³ Bapuji Institute of Engineering and Technology, Davangere, Karnataka, India.

ABSTRACT

The lightweight, inexpensive, chemically resistant, formable, sealable and useful barriers against moisture, oxygen and contamination make plastic materials ubiquitous throughout the food processing and distribution chain. They have benefits in terms of support for food safety, convenience and shelf-life extension but their widespread use raises environmental and resource-management issues. This review discusses the effects of plastic use in food processing industries, practical substitutes and reduction strategies. A literature-based review was conducted of peer-reviewed research, food-safety guidance and regulatory documents with particular emphasis on environmental impacts, food-contact safety, material performance, end-of-life management and alternative packaging technologies. It follows from the reviewed evidence that the environmental burden associated with plastic packaging is more determined by material selection, pack weight, protective properties, transportability, reuse, recyclability and disposal than just the material itself. Plastic food contact materials may also be of concern in terms of possible migration of substances or in case of micro- and nano-plastic pollution; such concerns require a risk-based approach instead of considering all plastic packaging potentially harmful. The alternative materials can include glass, metals, paper and paperboard, molded fiber, cellulose films, starch-based products, polylactic acid (PLA), polyhydroxyalkanoates (PHA), chitosan films and reusable packages. However, there is no one-to-one substitution since the alternative materials may be heavier, use more energy, be sensitive to moisture, costlier or more vulnerable to breakage than the plastic ones. The best way out appears to be using a hierarchy involving reduction, reuse, recyclability, safety of recycled content, renewable or biodegradable materials if appropriate and better waste management practices.

KEY WORDS: Food processing; plastic packaging; food-contact materials; micro-plastics; biopolymers; sustainable packaging.

INTRODUCTION

Processing transforms the produce from agriculture into food items that can be safely preserved, transported, marketed, and consumed. This process includes packaging, which is an important component because it serves as a carrier of food, protector of food from mechanical damage

and contamination, preservation of food quality, source of communication, and may increase the shelf life of food items. In their study, Marsh and Bugusu highlighted that the packaging must strike a balance between the protection and preservation of food, on the one hand, and material, energy, cost, and environmental factors, on the other[1].

The benefits of plastic as a packaging material are especially relevant to the food processing industry of today. Polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyamide (PA), and other polymers offer various strengths and combinations of strength, transparency, sealability, chemical resistance, and barrier properties[2]. In their work, Siracusa noted that the permeability of polymers to gases, water vapor, and organic substances is an important engineering property for food packaging because it affects the quality and shelf life of the food item.

Nevertheless, large volumes of plastic manufacturing and high levels of resistance of traditional plastics are causing significant waste problems. According to the findings by Geyer, Jambeck and Law, 6.3 billion tones of plastic wastes had been produced worldwide until 2015; 9% of them were recycled while significant portions of the remaining material were stored at landfills or accumulated in the environment. Plastic packaging for foods is more problematic due to its low density, contamination by food leftovers and multi-layer structure making it hard to recycle[3].

Thus, the current review attempts to answer two related questions: what are the main consequences of plastics use in food processing industries and which materials/strategies may replace the use of conventional plastics or limit their use? Environmental issues, food-contact safety, processing features, alternatives to plastics and other aspects will be taken into account. It should be noted that the purpose of the review is not to define a universal alternative but rather to provide a theoretical framework to choose an appropriate material or system[4].

INTRODUCTION – PLASTIC USE IN FOOD PROCESSING

Plastic is used in several steps of food processing instead of being limited to the consumer packaging. Some examples are liners, films, pouches, trays, bottles, tubs, caps, shrink films, pallet wraps, disposable gloves and some parts of processing and handling equipment. In the applications where it is in contact with food, the plastic should not lose its integrity under the expected temperature, acidity, fat content, moisture and mechanical stress[5]. Multi-layered

packaging might involve combinations of plastics with metals such as aluminium, paper and adhesives in order to achieve barrier properties that cannot be gained through a single material[6].

Functional role of packaging is a crucial point when considering its impact on the environment. Packaging protects food from air, moisture, light, microorganisms and mechanical injuries and preserves the advantages of the processing process[7]. According to FAO, packaging keeps the food fresh, safe and minimises food loss and wastage. This way, a comparison based solely on weight of packaging waste becomes irrelevant since the lighter package can actually result in significantly lower amount of food wastage than a heavy one. Life-cycle assessment becomes valuable for comparing the alternatives in a consistent functional perspective[8].

The use of plastic also has a food-contact aspect. Food contact materials have the potential to migrate their compounds into food, with the probability and amount of the process depending on the material properties, food composition, additives, temperature, and other factors[9]. The EU food contact legislation provides particular restrictions on the substances used in plastics and migration limits[10]. In India, the Food Safety and Standards (Packaging) Regulations, 2018, lay down the standards for food contact packaging, among which there are migration limits for plastic materials[11]. This demonstrates a very significant principle: when replacing a material, one should not lower the environmental impact at the cost of food safety[12].

Recent studies have drawn attention to micro-plastics and nano-plastics[13]. Reviews of the heat sensitive food packaging highlight the possible release pathways related to the use of plastic materials and the need for further improvements in terms of detection, exposure assessment, and risk assessment[14]. While such information calls for strict control of processing and packaging conditions, it cannot serve as proof that every food contact application of plastic results in hazardous exposure[15].

MAJOR EFFECTS OF PLASTIC USE

Area	Positive function	Main concern
Food protection	Barrier against moisture, gases, contamination and physical damage	Waste generation after short use
Processing efficiency	Lightweight, sealable, formable and compatible with automated lines	Dependence on fossil-derived polymers and additives
Food safety	Can provide hygienic, closed food-contact systems	Migration of some substances must be controlled
Shelf life	Can reduce deterioration and food loss	Multilayer and contaminated packages may be difficult to recycle
Logistics	Low weight and high strength-to-weight ratio	Litter and leakage into the environment if waste systems fail
Convenience	Easy opening, portioning	High volume of

	and resealing	single-use items
--	---------------	------------------

From the table, it is evident why substitution is a systems problem. Material may be environmentally better in some applications while not fit for others due to different barrier, mechanical or thermal properties[16]. Therefore, the process of material selection should start by understanding the needs of the food first[17].

EXPERIMENTAL/COMPUTATIONAL DETAILS

In this case, the literature-review methodology was used rather than laboratory experiment. The provided methods section is to give a description of the experimental/computational work in sufficient details[18]; however, in this review the corresponding methodological approach is the identification, screening and synthesis of evidence and food safety guidance documents. Sources were selected with regard to five topics:

- Packaging functionality and materials,
- Packaging environmental impact and plastic waste,
- Food migration and micro/nano-plastic safety,
- Alternative materials and biopolymers,
- Regulations and implementation considerations.

The literature review included both peer-reviewed reviews and scientific articles as well as official guidance from bodies responsible for food safety and environmental management[19]. The evidence from 2007 to 2026 was used with exceptions for sources published before, when they include foundational data regarding packaging functionality or world-wide plastic production[20]. The information on current regulations was verified using relevant official sources, such as FSSAI and European Commission. Qualitative synthesis of evidence was performed due to differences in foods, packaging types, functional units, system boundaries and environmental indicators used in studies[21].

The assessment involved the use of functional-requirement approach. First, the target application was categorized on the basis of the properties of the food items and processing parameters[22]. Secondly, the necessary packaging functions were identified including containment, mechanical protection, oxygen and moisture barrier, thermal stability, seal-ability, visibility, hygienic and shelf-life performance[23]. Thirdly, potential alternatives were evaluated on the basis of suitability for food contact, environmental impacts, recyclable or compostable, availability and price[24]. Lastly, trade-offs were assessed from life-cycle perspective. Biodegradable, bio-based and paper-based alternative were not considered better by default[25].

SELECTION CRITERIA FOR PLASTIC SUBSTITUTES

Criterion	Questions for assessment
Food safety	Is the material suitable for the intended food and contact conditions? Are migration limits and compliance

	requirements met?
Functional performance	Does it provide the required barrier, strength, sealing, thermal and mechanical properties?
Environmental performance	What are the material, manufacturing, transport and end-of-life impacts?
Circularity	Can the package be reduced, reused, recycled or composted within a realistic local system?
Economic feasibility	Are raw materials, conversion equipment and
	supply chains available at acceptable cost?
Consumer and industry use	Can the material be handled, stored, labelled and disposed of correctly?

One major limitation in the methodology is that studies related to lifecycle have a high level of applicability. A 2026 systematic review on the lifecycle assessment of packaging for food showed great variability among functional units and methodologies used; as such, the conclusion was made that a universal ranking per unit for the materials based on the existing research is impossible. As a result, the results provided below are offered as a comparative framework only.

RESULTS

The current literature suggests that plastic is an important material from a technical perspective due to its low density and various desirable characteristics, such as barriers, mechanical, and processing characteristics[26]. Plastic food packaging can be produced fast, heat-sealed and combined with automated filling lines. Plastic can also lower the weight during transportation compared to heavy materials[27].

ENVIRONMENTAL EFFECTS

The first major environmental problem is that of persistent plastic waste. Geyer et al. provided a picture of plastic production historically and the very small amount of plastic that was recycled up to 2015[28]. Food packaging becomes an environmental issue due to the variety of types of packaging, which can be used for a limited time period and disposed for a long time. Flexible films and multilayer laminates become very hard to recycle economically when they become thin, dirty or incompatible.

It is also necessary to pay attention to the environmental issues that occur even before the waste stage[29]. Most conventional plastics are obtained from fossil-based feedstocks, so the extraction of raw material, polymer production, processing and transportation cause energy consumption and greenhouse gas emissions. But the environmental impact varies when considering weight of the packaging, food loss, efficient transportation and reuse. In a recent systematic review of food-packaging LCAs, it was

shown that global warming potential was the most common impact category considered in such studies[30].

FOOD SAFETY AND FOOD-CONTACT EFFECTS

Food contact plastics are made to satisfy certain specifications in performance characteristics, but their compounds may migrate into foods when proper conditions are met[31]. The extent of migration is based on polymer type, additives, food simulant, temperature, and time of contact. Regulations have been developed for the approval of the substances allowed in plastics as well as their migration. Food Safety Standards Authority of India's packaging regulation defines the specifications of food-grade plastics as well as the limits of migration of plastics meant to come into contact with food[32].

Studies related to micro-plastics and nano-plastics are yet another avenue of exploration. In a study published in 2025, worries about potential particles' emission from heat-sensitive packaging of food were raised, and the need for improved methods of detection and exposure assessment was discussed.

PLASTIC WASTE MANAGEMENT

The use of recycled plastics may help avoid the usage of virgin polymers, although there are some special requirements regarding food contact recycling. In particular, the present-day framework of recycled plastic for food contact developed by the European Commission implies the implementation of certain control measures concerning recycling technology and processes. There is even the experience in this area from India with respect to recycled PET[33].

RESULTS – POTENTIAL SUBSTITUTES

Several material types were found to be suitable for use as an alternative to plastic for some food-processing applications. These vary widely in their appropriateness depending on the particular product being processed and various other factors.

Alternative	Potential applications	Advantages	Limitations
Glass	Beverage bottles, jars, sauces	Excellent barrier; reusable; established recycling	Heavy; breakage; higher transport weight
Aluminium metal	Cans, trays, closures	Strong barrier; high recycling value; thermal processing compatibility	Energy-intensive primary production; forming/coating needs
Paper, paper board	Cartons, secondary packs, dry foods	Renewable fibre feedstock; printable; lightweight	Moisture/grease barrier often needs coatings
Molded fibre	Trays, bowls,	Potentially	Water and oil

	food-service items	renewable and recyclable/compostable in suitable systems	resistance can be challenging
Cellulose films	Dry foods, wraps, specialty films	Bio-based; useful film properties	Moisture barrier and cost limitations
PLA	Cups, trays, films, selected food packaging	Bio-based; industrially compostable in suitable systems	Heat resistance and end-of-life infrastructure limitations
PHA	Films, coatings, containers	Biodegradable/compostable potential; bio-derived	Cost, scale and processing challenges
Chitosan/starch	Coatings and active films	Renewable; can carry functional additives	Moisture sensitivity; mechanical limitations

According to recent literature, despite the promising features of biodegradable polymers such as PLA and PHA, there are still some problems concerning their costs, effectiveness and end-of-life disposal facilities[34]. PHA seems to be of special interest due to its microbial origin, which allows having biodegradable and compostable properties; the main areas of research include processing, barrier and economic efficiency improvement. The systems based on starch, cellulose and chitosan may also have beneficial film-forming and coating properties[35].

REUSABLE AND REDUCTION STRATEGIES

Material substitution is not the whole answer. Packaging reduction may include light-weighting, removal of unnecessary layers, concentrated products, refills and package redesign[36]. Returnable packaging, whether it be pallets, containers or food-service ware, will minimize single use packaging when there is an efficient collection, wash and reverse logistics system. However, reuse does have its water, detergent, energy and transportation costs associated with it, and there are issues with hygiene. Therefore, in certain circumstances, the environmentally preferable choice will depend on the situation.

Recycling is yet another method to consider. One made out of a single compatible polymer can be more readily sorted and recycled than the multi-material construction, as long as it satisfies the performance and food contact specifications of the final product[37]. Proper material identification, closures, labels and adhesives will help with the sorting process. In any case, the package design must be consistent with the chosen end-of-life solution.

DISCUSSION

The evidence suggests that plastic used in food processing should not be considered a homogenous category. Various plastics and different packaging designs have various functions, effects and post-consumption destinations[38]. The core issue is about retaining the food safety and shelf life benefits of packaging while minimizing the material use and generation of persistent waste. That is why the life cycle and functional analysis approach is more helpful than simply asking whether plastic is to be substituted[39].

First, the emphasis needs to be put on the reduction of unnecessary material use where it goes beyond the essential functions performed by packaging[40]. The light-weighting of products allows decreasing the material consumption rate without altering the essence of packaging design. Second, there is a place for reuse wherever it is possible in terms of technology and hygiene[41]. Third, recycling is achievable through the development of packaging designs fitting existing systems for collection and processing[42].

Material substitution by biopolymers appears to be viable where the role of the plastic is served by an environmentally friendly or biodegradable polymer without increasing the life-cycle impact. According to a review published in 2025, packaging by biopolymers is able to decrease environmental impacts relative to conventional plastics, yet it faces high costs and poor recycling capacity issues[43]. In another review released in 2026, biodegradable polymers proved to have significant prospects, but their barrier and mechanical properties need to be improved as well as advanced processing techniques used.

WHY A SINGLE REPLACEMENT IS NOT SUFFICIENT

While glass materials may offer good barrier properties and reusability and recyclability, their heaviness due to high density and fragility are issues that need to be considered[44]. Metals can be subjected to high temperature processing and can be good barrier materials; however, their production involves significant amounts of energy and most of food containers need coatings made of polymers. Paper and molded fibre may have the advantage of renewable origin, however, they may need coatings which can protect from water, grease and oxygen. The presence of complicated composite structure can hinder recycling process[45].

Biopolymer materials such as PLA or PHA may help to reduce the reliance on fossil-based polymers in some applications, but their environmental benefits will depend on feedstock, production process, package weight and the way of disposal. Biodegradable or compostable packages do not add any environmental benefit when they are disposed into the landfill or contaminate the recycling process. Thus, such claims as 'biodegradable' or 'compostable' should be connected with particular standards and conditions[46].

FOOD SAFETY MUST REMAIN THE PRIMARY DESIGN CONSTRAINT

Food is protected by packaging against any form of contamination, and hence, wrong substitutions can result in spoilage or food safety threats[47]. The latest work by the Food and Agriculture Organization of the United Nations

regarding recycled and innovative food contact materials stresses the importance of analyzing the risks posed by chemicals that are able to migrate from recycled or innovative materials to food products.

DISCUSSION – IMPLEMENTATION FRAMEWORK

A practical transition for the food-processing industry could be done in the following way. First, the company would need to identify all plastic applications including primary packaging, secondary packaging, transport packaging, and processing aids[48]. Second, each application will have a function specification associated with it. Third, the plastic that is not necessary would need to be minimized. Fourth, other applications should be evaluated on whether they could be reused, redesigned, have recycled content or substitute material used.

Stage	Action	Expected outcome
1. Audit	Measure plastic types, quantities, applications and disposal routes	Baseline plastic inventory
2. Function	Define barrier, strength, temperature, hygiene and shelf-life requirements	Performance specification
3. Reduce	Lightweight, eliminate unnecessary components and optimize dimensions	Lower material demand
4. Reuse	Assess returnable crates, containers and refill systems	Lower single-use consumption
5. Redesign	Prefer compatible mono-material or readily separable structures where feasible	Improved recyclability
6. Substitute	Test glass, metal, fibre, cellulose or biopolymers for suitable applications	Reduced dependence on conventional plastic

7. Validate	Conduct food-contact, shelf-life, mechanical and life-cycle assessments	Evidence-based selection
8. Monitor	Track waste, recycling rate, product loss and cost	Continuous improvement

ROLE OF POLICY AND INDUSTRY

Regulation can help in creating a safe system through food contact specifications, recycled-content regulations, responsibility of producers and waste management requirements. FSSAI has the Food Safety and Standards (Packaging) Regulations and has also provided updates on recycled PET for use as food contact material[49]. Similarly, the Plastic Waste Management rules and amendments are with the Ministry of Environment, Forest and Climate Change. This shows that substitution and circular economy will need collaboration between the producers, packaging converters, food companies, recyclers, regulators and consumers.

The industry can help through developing packaging suitable for realistic recycling process, minimizing unnecessary variation in materials used and working together with collection and recycling partners. Food companies should provide performance data on their packaging using metrics such as packaging weight per kilogram of food, recycled content, portion recyclable or reusable, food loss, energy consumed and greenhouse gas emission. Such metrics are more effective than claiming a material to be 'green'.

FUTURE RESEARCH NEEDS

- Life cycle assessment techniques that allow comparison of food packaging systems through standardization of their functions and boundary conditions[50].
- Improving barrier properties and mechanical properties of fiber-based packaging and biodegradable packaging under humid and high-temperature conditions[51].
- Reliable analytical methods and exposure methods for micro plastics and nano-plastics in food contact materials.
- Processes that recycle food-safe food contact polymers after their consumer use.
- Economic models that correlate the material costs of alternative materials with the recycling infrastructure costs.
- Research related to application specific studies of Indian food products.

These areas of research are in line with the existing literature, as it highlights performance, cost, regulations and end-of-life infrastructure as important barriers to substitution.

CONCLUSIONS

Plastic is well entrenched in food processing due to its ability to combine several qualities – lightness, processability, sealability, mechanical resistance and barrier

performance – which cannot be matched with any single material. The main issues that plastic poses relate to the persistence of most traditional plastics, relatively short usage time of certain types of packaging, leakage in waste management systems and difficulty of recycling contaminated and multi-layered products. It is also necessary to consider food contact safety, as there is migration of substances from packaging to foods, as well as developing research on micro/nano plastic release.

Based on the information presented in the literature review, it can be said that the most realistic scenario of transition does not include the replacement of all the plastics with any single material. In food processing industries, a hierarchy should be implemented, which includes reducing the use of plastics, reusing packaging, recyclable design, use of safe recycled content and selection of substitutes. Such materials as glass, metal, paperboard, moulded fiber, cellulose films, PLA, PHA, starches and chitosan-based materials have certain uses and limits.

These are due to both technological and environmental reasons. Poor packaging leads to higher food waste, while poor recoverability leads to higher waste. The most sustainable option is thus the one that achieves the necessary protection of food in the best way possible using the minimum amount of material with the least environmental impact in a realistic circular economy scenario. This depends on future advancements in material science, safe recycled polymers, high-performance fibres and biopolymers[53].

REFERENCES

- [1] Linda, Atinga, and Isaac Abraham. "INFLUENCE OF PACKAGING DESIGN AND MATERIAL SELECTION ON CONSUMER CHOICE, SAFETY AND QUALITY PRESERVATION OF FUGU PRODUCTS."
- [2] Sharma, Savita, Ranjit Kumar, and Hitesh Borkar. "Polymers." *Properties and Applications of Advanced Materials* (2026): 73-94.
- [3] Wijesinghe, SM Kenneth, et al. "Marine pollution: the global challenge of ocean contaminants and mitigation efforts." *Anthropocene Coasts* 9.1 (2026): 5.
- [4] Kopton, Johannes, Amelie Michalke, and Katja Schiffrers. "How to choose the functional unit for agricultural LCA? A stakeholder-centered conceptual framework." *Cleaner Environmental Systems* (2026): 100389.
- [5] Dang, Xugang, et al. "Versatile biodegradable biomass-based smart packaging with advanced mechanical properties, antimicrobial capacity, and pH responsiveness for food preservation and freshness monitoring." *Polymer* (2026): 130528.
- [6] Singh, Kundan Kumar, and Devendra Kumar. "A Review on Biobased Barrier Coating and Its Challenges for Sustainable Paper Packaging." *Polymers for Advanced Technologies* 37.4 (2026): e70581.
- [7] Renuka, V., et al. "Safety in Packaging." *Food Packaging Technology*. CRC Press, 2026. 188-207.
- [8] Fidan, Muhammed, and Tuba Şanlı. "Comparative life cycle assessment of conventional dairy products and plant-based analog and hybrid alternatives: current status and future perspectives." *Critical Reviews in Food Science and Nutrition* (2026): 1-20.
- [9] Carvalho, Otilia. "Food contact materials." (2026): 20260160693.
- [10] Feeley, M. A. R. K., et al. *Food safety implications of recycled plastics and alternative food contact materials*. Food & Agriculture Organization, 2026.
- [11] Carvalho, Otilia. "Food contact materials." (2026): 20260160693.
- [12] Ciacchella, Maria Carla, Andrea Tomassi, and Andrea Falegnami. "The Twelve Principles of Green Chemistry in Complex Industrial Systems: A Critical Analysis." *Processes* 14.5 (2026): 765.
- [13] Di Fiore, Cristina, and Pasquale Avino. "Microplastics and nanoplastics in the human diet." *Nature Health* 1.1 (2026): 48-57.
- [14] Zhu, Jingrun, et al. "Dynamic Risk Profiling of Polylactic Acid-Based Food Packaging: From Migration-Derived Toxicity Biomarkers to Green Technology-Driven Safety Optimization." *Comprehensive Reviews in Food Science and Food Safety* 25.4 (2026): e70560.
- [15] Renuka, V., et al. "Safety in Packaging." *Food Packaging Technology*. CRC Press, 2026. 188-207.
- [16] Liu, Yong, et al. "Toward High-Thermal-Conductivity Polymer-Based Materials: Breakthroughs and Barriers." *Polymer Composites* 47.4 (2026): 2995-3038.
- [17] Drummond, Karen E., and Lisa M. Brefere. *Nutrition for Foodservice and Culinary Professionals, with eBook Access Code*. John Wiley & Sons, 2026.
- [18] Zorin, Igor A., et al. "Rational experimental-computational correlation analysis of cross-sectioning methods for residual stress evaluation." *Measurement* (2026): 123202.
- [19] Birara, Amsalu, and Achenef Motbainor. "Food Safety Legislation, Standards, and Measures in Ethiopia: A Scoping Review." *Environmental Health Insights* 20 (2026): 11786302261425324.
- [20] Wysling, Louise. "Phase-in, Phase-down, Phase-out: A More Nuanced Perspective on Firm Strategies for Phasing out Plastics in the FMCG Industry." (2026).
- [21] Jaiswal, Swarna, Nora A. Moreb, and Amit K. Jaiswal. "Regulatory, ethical, and standardization aspects of smart and intelligent food packaging." *Smart and Intelligent Food Packaging*. Academic Press, 2026. 485-510.
- [22] Said, Martina G., et al. "An Intelligent Model to Predict Functional and Non-Functional Requirements From Software Requirements Specification." *IEEE Access* (2026).
- [23] Mohammed, S. F., I. K. Gimba, and A. Ramzy. "Fundamentals of Food Packaging Science & Technology: An Illustrative Approach."
- [24] Eroglu, Ela, et al. "Edible Films and Coatings with Compostable End-of-Life Properties as Functional Alternatives to Conventional Flexible Plastics in Food Packaging." *Food Reviews International* (2026): 1-59.
- [25] Brito-Pereira, Ricardo, et al. "FreeSens: An Open-Source Multi-Criteria Environmental Sustainability Screening Platform for Sensor Design." *ACS Sustainable Chemistry & Engineering* 14.31 (2026): 14017-14030.
- [26] Quinn, Ethan C., et al. "Cracking the code of multi-layer films to promote circularity in single-use plastic packaging." *Nature Communications* 17.1 (2026): 1489.
- [27] Ramezan, Yousef, Amir Kamkari, and Hamidreza Pourramezan. "Filling and sealing." *Packaging Operations in the Food Industry*. Woodhead Publishing, 2026. 79-98.
- [28] Schmidt, Sarah, et al. "Plastic and contaminant flow dynamics in the German building and infrastructure sector: Current and future challenges and opportunities for recycling." *Resources, Conservation and Recycling* 225 (2026): 108620.
- [29] Rana, Rinku, et al. "Plastics and the environment: challenges, impacts, and pathways to sustainability." *Integrated Environmental Assessment and Management* 22.4 (2026): 997-1015.
- [30] Koblianska, Inna, et al. "Environmental impacts of food packaging: a systematic synthesis of LCA evidence." *Agricultural and Resource Economics: International Scientific E-Journal* 12.1 (2026): 309-343.
- [31] Mizuguchi-Fukase, Chiharu, et al. "Development of a Long-term Migration Test Method for Plastic Food Utensils, Containers, and Packaging." *Food Safety* 14.1 (2026): 25-36.
- [32] Yadav¹, Vishal, Madhur Kumar, and Deepanshu Yadav. "Risks from Black Plastic Packaging: Toxic Chemicals and Their Migration into Food."
- [33] Rana, Rinku, et al. "Plastics and the environment: challenges, impacts, and pathways to sustainability." *Integrated Environmental Assessment and Management* 22.4 (2026): 997-1015.
- [34] Arunkumar, Priya, et al. "Integrating additive manufacturing with biodegradable polymers for sustainable biomedical engineering: a state-of-the-art review." *International Journal of Polymeric Materials and Polymeric Biomaterials* (2026): 1-38.

- [35] Xia, Guangmei, and Peng Jia. "Preparation and Application of Cellulose-Based and Chitosan-Based Materials." *Polymers* 18.7 (2026): 812.
- [36] Yadav, Himani. *Optimization of Single-Use Plastic Packaging and Identification of Micro-nanoplastics Sources in Human Consumption*. Diss. North Dakota State University, 2026.
- [37] Bari, M. Ashnaim, et al. "Recycling of multilayer food packaging waste: Techniques, applications, and future prospects: A review." *Journal of Thermoplastic Composite Materials* (2026): 08927057261456266.
- [38] Cunha, Ana Luiza Camargo Mascarin, et al. "Closing the loop in online food delivery: a systematic literature review of consumer behavior toward post-consumption waste." *Frontiers in Sustainable Food Systems* 9 (2026): 1700028.
- [39] Ballam, Chiara, and Carlos Landaverde Alvarado. "Life cycle and behavioral analysis of single-use research laboratory plastic recycling on a college campus." *International Journal of Sustainability in Higher Education* (2026): 1-26.
- [40] Sebbe, Naiara PV, et al. "Geometric Optimization and Thickness Reduction of Metal Packaging for the Transportation of Dangerous Goods: A New Design Paradigm." *Results in Engineering* (2026): 109081.
- [41] Heddema, Femke, et al. "FAIR with FHIR: A Proposed Workflow for Retrospective FAIRification of FHIR-Compliant Health Data." *Scientific Data* (2026).
- [42] García-Arca, Jesús, et al. "Best practices in packaging design. A proposal for a model to evaluate their overall impact on sustainability." *Business Process Management Journal* 32.5 (2026): 1626-1662.
- [43] Jain, Rajul, et al. "Biopolymer-based food packaging: performance, environmental impact, and pathways toward a sustainable future." *Frontiers in Sustainable Food Systems* 10 (2026): 1941522.
- [44] Rota, Angelica. "The reuse of glass: tackling the technical, environmental and logistical challenges." (2026).
- [45] Abteu, Mulat Alubel, et al. "Recycled Cellulosic Natural Fibers and Their Reinforced Polymer Composites: Processing Methods, Applications, Challenges and Future Directions." *Sustainability* 18.5 (2026): 2500.
- [46] Chipambwa, Walter, Raphael Kanyire Seidu, and Benjamin Eghan. "Biodegradable and Compostable Fibres in the Age of Sustainability." *Sustainable Fashion Materials: Innovations and the Future of Fashion*. Singapore: Springer Nature Singapore, 2026. 123-153.
- [47] Momtaz, Mysha, Saniya Yesmin Bubli, and Mohidus Samad Khan. "Impacts of Food Adulteration and Contamination: Health, Socio-Economic, and Legislative Aspects." *Foods* 15.17 (2026): 3041.
- [48] Georgakoudis, Elias D., et al. "A Parametric Decision Support Framework for Sustainable Packaging Design: Integrating Logistics Performance, CO2 Emissions and Cost Through AHP–TOPSIS." *Applied Sciences* 16.18 (2026): 9115.
- [49] Feeley, M. A. R. K., et al. *Food safety implications of recycled plastics and alternative food contact materials*. Food & Agriculture Organization, 2026.
- [50] Marmora, Giovanni, et al. "A Comparative Life Cycle Assessment of Conventional and Reusable Packaging Systems Under Alternative Logistic Configurations." *Recycling* 11.1 (2026): 13.
- [51] Reunanen, Atte. "Potential for Advanced Measurement of Barrier Performance in Fibre-Based Packaging." (2026).
- [52] Rani, Ritu, et al. "Microbial Levan as a Biopolymer for Active Antimicrobial Food Packaging Films: Characterization, Antimicrobial Properties, and Development." *Journal of Food Science* 91.3 (2026): e70920.
- [53] Abteu, Mulat Alubel, et al. "Recycled Cellulosic Natural Fibers and Their Reinforced Polymer Composites: Processing Methods, Applications, Challenges and Future Directions." *Sustainability* 18.5 (2026): 2500.