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INNOVATIVE PACKAGING AND LABELING SOLUTIONS FOR PRESERVATIVE-FREE READY-TO-EAT MEALS: ENHANCING SHELF LIFE AND SUSTAINABILITY - STUDY CASE ROMANIA

Gabriela BERECHET[1], Carmen NICOLAE[1], Angela MORGANS[2]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]APTAR - Food protection, Head of North American Fiber Packaging, SUA

Corresponding author email: angela.morgans@aptar.org

Abstract

The increasing consumer demand for healthier ready-to-eat (RTE) meals with fewer or no preservatives has created a pressing need for innovative packaging and labeling solutions that maintain product quality and extend shelf life. This study investigates advanced packaging technologies, including active packaging, modified atmosphere packaging (MAP), and nanotechnology-based materials, to minimize microbial growth and preserve sensory attributes. Additionally, the integration of intelligent labeling systems, such as time-temperature indicators (TTIs) and freshness sensors, is explored to enhance consumer confidence and reduce food waste. The review also evaluates the environmental implications of these solutions, prioritizing sustainable materials and design. By synergizing cutting-edge packaging methods with transparency in labeling, this study aims to develop a comprehensive framework for enhancing the safety, quality, and sustainability of RTE meals. Particularly, some good practices related with enhancing shelf life and sustainability for RTE meals in Romania are addressed in this paper.

Key words*: ready-to-eat meals, active packaging, intelligent labeling, shelf-life extension, sustainable materials.*

INTRODUCTION

Innovative packaging solutions are emerging to extend the shelf life of ready-to-eat (RTE) meals and improve sustainability. Active packaging technologies, such as antimicrobial films using natural compounds like turmeric and red ginger, can significantly prolong the shelf life of RTE meat products (Dharma, 2023). Intelligent packaging systems provide information on product quality and safety (Janjarasskul and Suppakul, 2017). Vacuum-sealed packaging in retort pouches enhances food safety against microbial contamination (Dharma, 2023). Sustainable or "green" packaging using edible or biodegradable materials, plant extracts, and nanomaterials can reduce environmental impacts (Han et al., 2018). These technologies can work synergistically to create multipurpose food-packaging systems (Han et al., 2018). For cook-chill foods, various compatible packaging systems and active packaging strategies are designed to increase shelf life (Clodoveo et al., 2021). These innovations address consumer demands for safe, high-quality, and environmentally friendly food products.

Recent research highlights innovative packaging technologies to extend shelf life and improve the safety of ready-to-eat (RTE) and home meal replacement (HMR) products. Active packaging strategiescan prolong product shelf life (Bumbudsanpharoke et al., 2022; Clodoveo et al., 2021). Specific examples include using turmeric and red ginger as antimicrobial film coatings for RTE meat products, potentially extending shelf life up to 30 days at room temperature (Dharma, 2023). Intelligent packaging technologies, like colorimetric indicators and RFID labels, enable real-time monitoring of food conditions (Bumbudsanpharok et al., 2022). Future packaging innovations aim to address food waste reduction, food safety, and environmental concerns in a circular economy context by utilizing biodegradable polymers from agro-food waste residues (Guillard et al., 2018). Mathematical modeling of mass transfer and reactions in food/packaging systems is emerging as a valuable tool for designing and

validating new packaging solutions (Guillard et al., 2018).

MATERIALS AND METHODS

A thorough literature review was systematically carried out by sourcing peer-reviewed journal articles from a range of reputable scientific databases. The review process prioritized methodological rigor and relevance, focusing on studies that explored innovative packaging and labeling solutions specifically for ready-to-eat (RTE) meals.

Key selection criteria included research centred on antimicrobial packaging technologies, biodegradable material innovations, intelligent labeling systems, and strategies for extending product shelf life. Emphasis was placed on recent advancements and sustainability-oriented approaches, with particular attention to case studies and findings relevant to Romania's experience as part of the European Union.

The demand for ready-to-eat (RTE) meals has increased significantly due to changing consumer lifestyles. However, ensuring food safety, extending shelf life, and maintaining sustainability remain critical challenges. Modern packaging solutions integrate active components and intelligent labeling to address these concerns. This review highlights the latest advancements in packaging and labeling technologies and their implications for the food industry.

While looking for cutting-edge packaging methods the review compiles the latest and most advanced technologies and techniques used in packaging to improve the functionality, sustainability, and overall quality of packaging solutions. These methods go beyond traditional packaging and leverage innovation to meet the evolving demands of consumers, the environment, and the market, presented in Table 1.

Table 1. Cutting edges methods of packaging RTE-meals

Method	Scope	Effect
Active packaging	Involves incorporating materials or components into the packaging that interact with the contents to improve shelf life or preserve food quality and includes: - oxygen scavengers (absorb oxygen to prevent oxidation and spoilage); - moisture regulators (control moisture levels to prevent bacterial growth); - antimicrobial agents (release antimicrobial substances to prevent microbial growth).	- maintains product freshness; - improves shelf life; - helps reduce food waste.
Modified Atmosphere Packaging (MAP)	Changes the air inside the packaging using gases like nitrogen, oxygen, and carbon dioxide to slow down the deterioration of perishable goods. Commonly used for fresh produce, meats, and dairy products.	- slows microbial growth; - reduces oxidation; - preserves texture, color, and flavor of food.
Nanotechnology-based packaging	Uses nanotechnology to create thin, strong packaging materials with enhanced properties. Includes: - smart packaging (detects environmental changes like temperature or microbial contamination); - active coatings (antimicrobial surfaces).	- improved barrier properties (resistant to oxygen, moisture, and light); - extends shelf life.
Intelligent packaging	Integrates technology to provide real-time information about the product's condition inside the packaging, such as: - time-temperature indicators (TTIs) that change color to show exposure to improper temperatures; - freshness sensors that detect spoilage and alert consumers.	- enhances consumer confidence - reduces food waste; - provides accurate, real-time information.

Method	Scope	Effect
Sustainable packaging	Focuses on reducing environmental impact by using materials and technologies that are eco-friendly, such as: - minimalist packaging (reducing excess packaging to decrease resource consumption and waste).	- biodegradable materials (made from renewable sources like PLA); - reduces environmental impact; - edible packaging (can be consumed along with the product); - recyclable and reusable packaging.
3D Printing in packaging	Creates custom packaging solutions using 3D printing technology. Includes: - less material usage (optimizes packaging materials, reducing waste)	- on-demand production (reduces excess waste and storage costs); - customizable shapes.
Smart labels and QR codes	Enhances consumer engagement through technology like QR codes, providing access to product information, such as: - tracks product freshness (real-time data on product storage conditions); - enhances branding.	- provides detailed product information (origin, nutritional value, production processes).
Lightweight packaging	Focuses on reducing the weight of packaging materials. Includes: - eco-friendly alternatives (thinner plastics or paper that are easier to recycle or compost).	- reduces transportation costs (lower fuel consumption and carbon emissions); - lowers material costs.

(Adapted after Guillard V. et al., 2018, Janjarasskul T. et al., 2017)

Cutting-edge packaging methods are transforming the way we think about product preservation, sustainability, and consumer interaction. By using advanced materials and technologies like active packaging, intelligent labeling, nanotechnology, and sustainable alternatives, these innovations aim to not only enhance product quality and safety but also contribute to a more environmentally responsible future. The goal is to provide consumers with better, fresher products while reducing waste and improving the sustainability of packaging materials.

These innovations are reshaping industries and will continue to play a vital role in meeting the growing demands of modern consumers and the global environment.

RESULTS AND DISCUSSIONS

After careful consideration of all the collected data and good practices, the results related with innovative packaging and labeling solutions for preservation-free RTE-meals in the world, but also, some of them, with great implementation in Romania, are concluded in the following most efficient solutions:

1. Active and IP (intelligent packaging) technologies

Active packaging systems incorporate substances interacting with food or the surrounding environment to prolong shelf life. Examples include antimicrobial films (Fadiji et al., 2023), oxygen scavengers (Han et al., 2018), and ethylene absorbers (Janjarasskul, T. et al., 2017). Intelligent packaging, such as time-temperature indicators (Bumbudsanpharoke et al., 2022) and freshness sensors (Janjarasskul, Suppakul, 2017), helps consumers to monitor storage conditions, reducing food waste.

2. Sustainable and biodegradable packaging

With increasing environmental concerns, sustainable packaging solutions such as edible films (Trajkovska et al., 2021) and biodegradable polymers (Guillard et al., 2018) are gaining traction. These materials aim to replace traditional plastics while maintaining functional properties.

Sustainable packaging for RTE meals is crucial in addressing environmental concerns while meeting the growing consumer demand for healthier, more responsible options (Gutierrez et al., 2017).

The specialized literature offers more detailed exploration of how eco-friendly packaging being developed for RTE meals, such as:

2.1. ***Biodegradable and compostable packaging***

One of the most significant advancements in eco-friendly packaging is the use of biodegradable and compostable materials. For RTE meals, this can include:

- Plant-based polymers: Materials like polylactic acid (PLA), which are derived from renewable resources like corn starch or sugarcane, can be used to create containers, wraps, and trays for meals. PLA is compostable in industrial composting facilities and can break down without leaving harmful residues (Baneshi et al., 2024);
- Mushroom packaging: This innovative packaging material is made from mycelium (the root structure of mushrooms), which is biodegradable and compostable. It can be used as a protective layer for RTE meals, reducing plastic waste (Verma et al., 2023);
- Seaweed packaging: Some companies are exploring seaweed-based packaging, which is biodegradable and can even be edible in some cases. Seaweed has a minimal environmental footprint and grows quickly, making it a renewable resource for packaging (Kajla et al., 2024).

2.2. ***Edible packaging***

In some innovative RTE meal products, edible packaging is being developed to minimize waste. For example:

- Cereal and legume protein edible films: These can be used to wrap meals, and consumers can either consume the packaging with the meal or dispose of it in an environmentally friendly way (Linares-Castañeda et al., 2023);
- Gelatin and kitosan films: These materials can be used to encase food in a way that is both functional and edible, offering a sustainable solution to reduce the need for plastic packaging (Ștefănescu et al., 2022).

2.3. ***Recyclable materials***

For RTE meals, recyclable packaging is a priority in reducing the environmental impact of food packaging. Key trends include:

- Recyclable plastic trays and containers: companies are designing trays, bowls, and containers from recyclable plastics like polyethylene (PE) or polypropylene (PP), which can be processed and reused in the recycling system. Accordingly, with the life cycle assessment of food, the recyclable plastic trays and containers increased with 30% reaching 70% when properly manufactured and manipulated (Molina-Besch et al., 2018);
- Glass containers: while heavier and more costly, glass is an excellent recyclable material. Some RTE meals, especially those in higher-end or premium markets, use glass jars or containers that are fully recyclable and reusable (futuremarketinsights, 2025).

2.4. ***Minimalist and reduced packaging***

Sustainability in packaging often means reducing the amount of material used overall. In the case of RTE meals, this can involve:

- Streamlined packaging designs: fewer layers or unnecessary components, such as plastic wraps or excessive labels, to reduce waste and lower the carbon footprint of production and shipping;
- Smaller portion sizes: in some cases, reducing portion sizes for certain products can lead to smaller, more efficient packaging, reducing material usage;
- Slimmer packaging: Using thinner layers or smaller containers to hold the same amount of food reduces the amount of material used, which also lowers waste.

2.5. ***Reusability and refill options***

Another way to improve sustainability in RTE meal packaging is by focusing on reusable packaging systems:

- Reusable containers: Instead of single-use packaging, companies can offer RTE meals in containers designed to be reused. Consumers can bring these containers back for refills or to store other food items, cutting down on waste.
- Refill stations: Some innovative systems allow customers to buy RTE meals in reusable containers that can be refilled at designated stores, much like refillable beverage containers. This not only reduces single-use packaging but also encourages sustainable consumer behavior.

2.6. *Smart packaging for reduced waste*

Smart packaging plays an essential role in reducing food waste by helping consumers understand the product's condition and encouraging proper use. For RTE meals, these smart technologies can be used to:

- Time-temperature indicators (TTIs): These indicators change color based on exposure to temperature, showing whether a meal has been stored improperly. This can help consumers avoid consuming spoiled food, reducing food waste (Waldhans et al., 2025);
- Freshness sensors: Some packages contain sensors that monitor the freshness of the meal inside, signaling when the product is still at its best or when it may have gone past its optimal freshness.

2.7. *Sustainably sourced materials*

Using materials that are sustainably sourced is a key component of eco-friendly packaging for RTE meals, such as:

- Recycled paper and cardboard: Packaging made from recycled paper or cardboard is a more eco-friendly option compared to virgin paper materials. These can be used for outer packaging or as a protective layer inside containers.
- Sustainably sourced pulp: Packaging made from tree-free, sustainably sourced pulp (such as agricultural waste, bamboo, or sugarcane bagasse) reduces the reliance on virgin wood pulp and helps protect forests.
- Forest Stewardship Council (FSC) certified paper: For any paper or cardboard packaging, choosing FSC-certified materials ensures that they come from responsibly managed forests, supporting biodiversity and sustainable forestry practices.

2.8. *Eco-friendly inks and labels*

In addition to sustainable materials, packaging for RTE meals also needs to consider the inks and labels used. For an eco-friendly approach:

- Water-based inks: These inks are made without petroleum-based chemicals and can be used for printing on packaging materials like paper, cardboard, or bioplastics. They are less harmful to the environment compared to traditional oil-based inks;
- Plant-based labels: Labels made from plant-based materials like soy or corn starch can reduce environmental impact, especially when they are designed to be biodegradable;
- Minimalist labeling: Reducing the size of labels or printing information directly on the packaging material can reduce waste and the need for additional packaging layers.

2.9. *Carbon footprint reduction in packaging production*

Reducing the carbon footprint of packaging production is another way to make RTE meal packaging more eco-friendly. Innovations in the manufacturing process, such as:

- Energy-efficient production methods: Using renewable energy sources in the production of packaging materials can significantly reduce the carbon footprint of the packaging process;
- Local production: Manufacturing packaging materials closer to where RTE meals are produced can help reduce transportation emissions, thus decreasing the overall environmental impact.

3. Shelf-life extension strategies for RTE meals

Recent studies emphasize the role of coatings and modified atmosphere packaging in extending food shelf life. The use of turmeric and red ginger coatings (Dharma, 2023) and the impact of packaging on ready-to-eat meals (Clodoveo et al., 2021) demonstrate effective strategies for prolonging product freshness. Modified atmosphere packaging (MAP) is particularly useful in preventing microbial growth and oxidation, thereby preserving food quality (Kontominas et al., 2021).

4. Study case Romania – good practice in extending the shelf life of RTE meals

Several noteworthy practices and innovations have been identified in Romania, as documented and analyzed in Table 2.

Future packaging methods with increasing interest from the Romanian RTE producers are presented in Table 3.

Table 2. Modern RTE packaging in Romania

Practice/Technology	Description	Reference
Micvac Technology	Caroli Foods Group introduced a range of chilled ready meals under their Maestro brand using Micvac's in-pack cooking and pasteurization technology. This method allows meals to retain flavor and nutrition for up to 60 days without additives or preservatives.	Caroli Foods Group launches range of ready meals using Micvac technology (www.foodanddrinktechnology.com)
Biobased and Biodegradable Packaging	BFG Packaging produces 100% biobased and biodegradable single-use rigid takeaway packaging made entirely from FSC-certified wood fiber. This eco-friendly packaging is oil and water-resistant, heat-retaining, and heat-sealable, aligning with EU regulations promoting ecological packaging.	Biobased and biodegradable single use rigid takeaway packaging now produced in Romania (www.bfgpackaging.com)
Aseptic Carton Packaging	Tetra Pak Romania offers aseptic carton packages that protect perishable foods, such as milk and juices, for up to 12 months without refrigeration or preservatives. The multi-layered design safeguards contents from light, oxygen, and moisture, preserving quality and safety.	Food protection by Tetra Pak Romania (www.tetrapak.com)
Vacuum Skin Packaging (VSP)	VSP technology involves sealing the product with a transparent film that conforms to its shape, removing air and extending shelf life. This method enhances product presentation and freshness, making it suitable for various food items, including RTE meals. However, this method is one of the oldest methods of packaging with the purpose of enhancing shelf life of RTE meals.	How Vacuum Skin Packaging Can Increase Your Product Shelf Life & Sales (www.zonesone.com/ro)
Tetra Pak's eBeam Technology at Simultan	In January 2025, Tetra Pak installed its advanced eBeam technology at Simultan, Romania's largest locally-owned dairy processor. This innovative packaging line utilizes electron beam technology for sterilization, reducing environmental impact and enhancing the shelf-life of dairy products.	packagingreporter.com/food-beverage/tetra-pak-and-simultan
CHEP's Circular Logistics Solutions	CHEP Romania has implemented circular logistics solutions by providing reusable pallets for product transportation. This approach reduces waste and carbon footprint, contributing to a more sustainable supply chain in the FMCG and retail sectors.	FMCG and Retail Sectors drive Romania's transition to the Circular Economy (www.chep.com/ro/en/fmcg-and-retail-sectors-drive-romanias-transition-circular-economy)
Tetra Recart® Packaging	Tetra Pak Romania offers Tetra Recart®, an innovative carton-based packaging solution suitable for shelf-stable foods like vegetables, soups, and ready meals. This packaging extends shelf life without refrigeration and has a lower climate impact compared to traditional packaging methods.	Food packaging by Tetra Pak Romania (www.tetrapak.com)

Table 3. Emerging packaging methods for enhancing RTE meals' shelf-life

Method	Functionality	References
Active Packaging Using Agri-Food Waste	- active packaging incorporating activated carbon derived from agri-food waste. This packaging effectively adsorbs ethylene, delaying the ripening of fruits and vegetables and extending shelf-life. .	Fadiji et al., 2022
Copper-Infused Packaging	- packaging method that incorporates copper microparticles, exhibiting biocidal properties against microorganisms. This technology extends the shelf-life of various food products by up to 30 days.	Gopinath et al., 2024, https://packagingeurope.com/news/copper-infused-masterbatch
Microencapsulation of Extra Virgin Olive Oil (EVOO)	- microencapsulation of EVOO in dietary fiber, resulting in breaded foods with up to 90% less fat and an extended shelf-life of up to three weeks. This technology offers a healthier alternative to traditional frying methods and prolongs product freshness.	Calvo et al., 2012; Başyiğit et al., 2021

Innovative packaging and labeling solutions for RTE meals present significant benefits, including enhanced food safety, waste reduction, and improved consumer transparency. However, challenges such as cost-effectiveness, regulatory compliance, and material compatibility remain. Future research should focus on scaling biodegradable alternatives and integrating digital tracking technologies to improve supply chain efficiency.

Market research indicates a growing consumer willingness to transition from traditional dining habits to a ready-to-eat (RTE) meal model by 2035. This projected shift is supported by the factors outlined in Table 4, which highlight key drivers behind this behavioral change.

Table 4. Market shift 2025 to 2035 (futuremarketinginsights.com)

Factors	Behavioral change
Regulatory Landscape	Regulatory frameworks today target clean-label foods, reduced sodium and sugar, and natural preservatives. Governments worldwide promote green packaging and heightened cold chain regulation to minimize food wastage.
Technological Advancements	AI-facilitated supply chain optimization guards against minimal waste and precise demand forecasting. Smart packaging with shelf-life markers and blockchain traceability enhances food safety and transparency in RTE foods.
Consumer Preferences	Health-conscious consumers drive demand for plant-based, organically grown, and nutritionally balanced RTE food. Growth in allergen-free and keto, paleo, and high-protein meal opportunities meets niche nutritional needs.
Ingredient Sourcing & Sustainability	Growing global acceptance of regenerative farming and carbon-zero ingredient sourcing. Companies use alternative proteins, such as lab-cultured meat and plant protein, to reduce their environmental impact.
Packaging Innovations	Smart, edible, and biodegradable packaging solutions dominate, with QR codes providing in-depth sourcing and nutritional data to consumers.
E-commerce & Retail Dynamics	Direct-to-consumer (DTC) players thrive on customized meal plans. AI-powered recommendations and fast-delivery networks achieve maximum convenience and product availability.
Regional Market Trends	Regional taste creation and personalization drive market growth. Emerging markets witness a boom in fortified and nutrient-fortified RTE meals to combat malnutrition.
Market Growth Drivers	Plant-based protein innovation, sustainable production, and minimally processed, nutrient-rich RTE meal demand drive long-term growth. Flexitarian and personalized nutrition trends also drive growth.

CONCLUSIONS

The advancements in packaging and labeling solutions offer promising alternatives to conventional methods for RTE meals. Their role in food safety, quality maintenance, and sustainability is crucial in addressing global food preservation challenges. Continued research and technological integration will drive further improvements in this field.

The RTE meals industry in Romania faces a dual challenge: extending shelf life while promoting sustainability. Companies involved in the RTE meals industry in Romania are actively implementing innovative packaging solutions to enhance food preservation without compromising quality. However, these advancements come with challenges, including higher production costs, consumer acceptance of new technologies, and regulatory compliance with EU sustainability goals.

To remain competitive, the Romanian RTE meal producers must strike a balance between extending shelf life and reducing environmental impact. Sustainable solutions such as biodegradable materials, active packaging, and circular economy models (e.g., reusable packaging) are gradually being adopted. Despite the progress, more investment in research, collaboration between food technologists and packaging specialists, and consumer education will be key to ensuring long-term success.

The future of the Romanian RTE meals industry depends on innovative, cost-effective, and sustainable packaging solutions that meet both market demand and environmental standards, paving the way for a more resilient and eco-friendly food sector.

In response to the growing consumer demand for clean-label, preservative-free food products, the integration of advanced packaging

technologies emerges as a critical component in ensuring the safety, quality, and regulatory compliance of ready-to-eat (RTE) meals. The adoption of these innovations not only aligns with evolving environmental standards but also supports the development of more sustainable food preservation practices. Continued interdisciplinary research and collaboration within the industry will be instrumental in advancing the implementation and optimization of these technologies.

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