SmartPack Finder: Bridging the Gap Between Sustainable Packaging and Food Product Needs

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The essay aims to develop a packaging solution to address the food waste problems caused by mismatching between sustainable packaging materials and food product requirements from the food science viewpoint. The solution focus on food packaging materials and environments providing academia and existing market evidence to support the needs. The essay begins by outlining the key challenges in food packaging, followed by an overview of existing solutions currently available in the market. However, these existing solutions cannot solve the foundation problem: the improper pairing of packaging materials with food requirements which contributes to food waste. Therefore, to address the problem, a new solution, SmartPack Finder, is proposed to help food producer to find out the suitable sustainable packaging materials for their food product. Finally, the potential impact of the SmartPack Finder on society, the environment, and various stakeholders will be narrated.

Background of the problem

Food packaging plays a critical role in ensuring the safety, quality, and shelf life of food products. It functions as a protective barrier against external factors such as moisture, oxygen, and contaminants that can lead to spoilage, nutrient loss, and diminished product (Marsh and Bugusu).

The effectiveness of a packaging material is largely determined by its permeability properties as well as the mechanical properties. Key permeability metrics like the water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) are essential for maintaining food quality. Different food characteristic requires vary permeability and mechanical properties. High-fat foods like cheese require low oxygen permeability to prevent lipid oxidation (Tyagi et al.), while fresh produce benefits from higher gas transmission rates to support post-harvest respiration (Trinh et al.). As for mechanical properties, fresh produce needs moderate tensile strength to prevent damage during handling while allowing flexibility to accommodate moisture fluctuations, while frozen food needs high tensile strength to withstand low temperatures and handling stresses without cracking or puncturing. Without packaging tailored to these needs, product damage and food waste during the transportation may occur.

Currently, there is an urgent shift toward sustainable packaging alternatives to reduce the environmental impact, including reusable, recyclable, and biodegradable materials, because plastics dominate the food packaging market, with approximately 95% of packaging materials derived from petroleum-based materials, contributing significantly to environmental degradation (The New Plastics Economy).

Knowledge Gap and Problems Statement

Over the past decade, research into sustainable packaging materials and characterizing food shelf-life and quality requirements have increased substantially. However, these two streams remain disconnected. Limited studies have mapped how specific material properties, such as barrier performance and mechanical strength, align with the preservation needs of particular food products. Building this bridge to

this gap is nothing short of transformative. The connection between two streams empowers food producers to select eco-friendly packaging that both meets functional requirements and maintains product quality, thereby reducing waste and achieving sustainability goals.

Nonetheless, bridging this gap is challenging because some biopolymer alternatives often exhibit inferior barrier properties and mechanical properties. Particularly under high humidity, the permeability of the sustainable materials increases significantly, making them less effective at preserving food quality compared to conventional plastics(Ivanković et al.; Sangroniz et al.). In the absence of a systematic overview of sustainable materials against food-specific requirement, manufacturers are left to choose the materials by trial and error, too often time-consuming and perpetuating unnecessary spoilage.

Objectives

To close this gap, the solution proposes the development of an integrated, data-driven framework that maps the key physical and barrier properties of sustainable packaging materials with the functional requirements of various food categories. More than a theoretical model, our goal is to translate that framework into a **practical decision-support tool** for food manufacturers, particularly SMEs and startups, select suitable sustainable packaging with confidence and ease.

Current Solutions and Their Limitations

Currently, several sustainable packaging materials have shown potential to replace the conventional plastics, as they can offer comparable even surpass permeability and mechanical properties of traditional packaging (Owoyemi et al.; Wenche Aale Hægermark). However, identifying the right material for a specific food product remains a challenge. Existing tools, such as the Sustainable Packaging Compass developed by the Netherlands Institute for Sustainable Packaging (KIDV), and the Packaging Assessment and Comparison Tool (P-ACT), primarily assess packaging based on recyclability, circularity, and environmental footprint. These tools require users to **pre-select materials and lack guidance on material functionality** in relation to food-specific needs.

This presents a fundamental limitation: **the tools evaluate the sustainability of packaging but do not assist in selecting the appropriate materials based on technical food requirements**. As a result, food producers must first conduct their own in-depth research to identify viable materials, an approach that is time-consuming, resource-intensive, and often inaccessible for smaller companies.

Proposed Solution: SmartPack Finder

To address this fundamental limitation, we propose a data-driven decision-support tool, **SmartPack Finder,** that matches sustainable packaging materials with food-specific requirements based on functional properties. Unlike existing tools, SmartPack Finder does not require users to have prior knowledge of materials. Instead, it automatically identifies suitable packaging options based on the barrier and mechanical needs of different foods.

By combining scientific data on material performance with sustainability assessments, SmartPack Finder empowers food producers to make fast, evidence-based decisions. It streamlines the selection process, reduces food waste, and accelerates the industry's transition to more sustainable practices.

How It Works: AI-Powered Matching for Precision & Sustainability

The core innovation behind the SmartPack Finder lies in an algorithm that leverages the existing academic research and machine and deep learning technique to match food packaging requirements with sustainable material properties, barrier and mechanical properties. The matching concept is inspired by the Trinh's study, which showed barrier requirements ranges for specific foods found in standard packaging.

The matching algorithm consists of three key steps, illustrated in Figure 1.

1. Building a Comprehensive Database: The tool firstly compiles and organizes a database of sustainable material barrier and mechanical properties sourced from academic research, as well as allows user input of food requirements.
2. Material Clustering and Matching: Using permeability and mechanical properties as key parameters, the algorithm clusters packaging materials into groups, ensuring precise matching. The system matches food packaging needs to optimal material choices based on functional performance.
3. Sustainability Assessment & Decision Support: Sustainability is more than just functionality, so SmartPack Finder integrates Life Cycle Assessment (LCA) scores and carbon footprint (CO_2e) data in multi-criteria decision analysis. By weighing functional and environmental factors, the tool generates a set of optimized packaging recommendations, enabling food producers to make smarter, more sustainable choices with confidence.

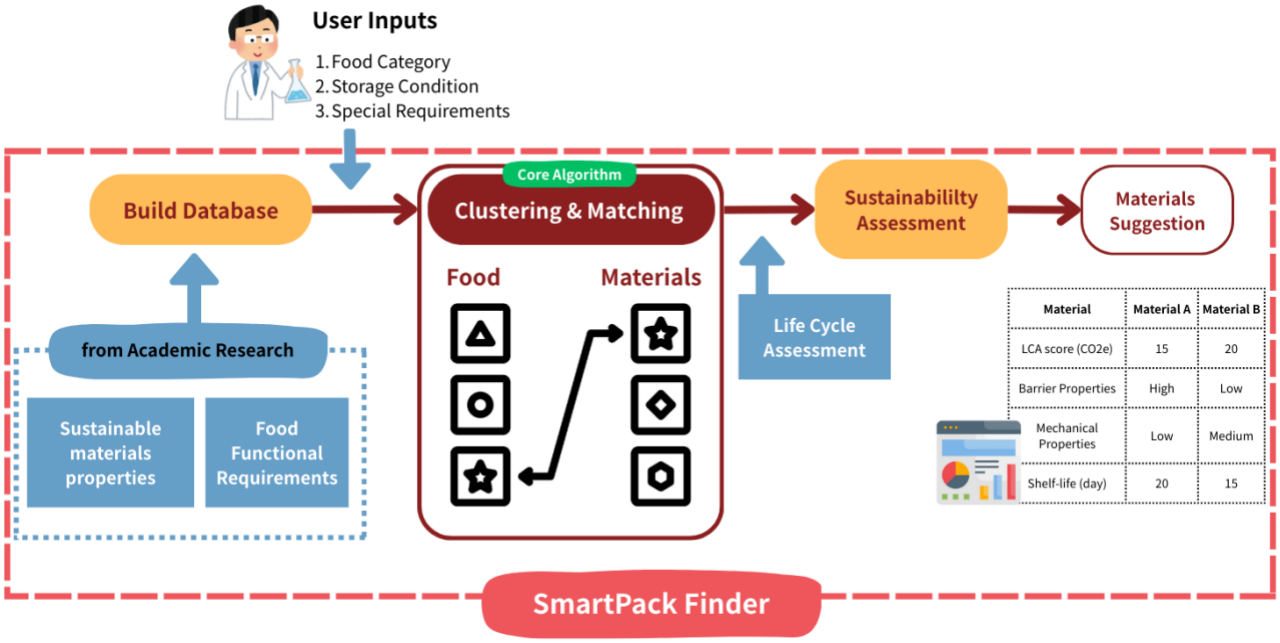

Figure 1. Schematic Workflow of SmartPack Finder

Effortless Decision-Making: A Holistic Sustainability Assessment

With SmartPack Finder, users only need to input their food product category, storage conditions and special requirements. The tool delivers tailored sustainable packaging recommendations, complete with LCA scores and CO_2e impact data, simplifying what was once a complex and time-consuming process. By utilizing, the users are able to find out the most suitable sustainable materials in terms of functional aspect and also knowing their sustainability with little effort.

Potential Impact

By eliminating research bottlenecks, reducing decision fatigue, and promoting sustainability**,** SmartPack Finder is set to transform how food producers adopt sustainable, making the process more efficient, informed and impactful. The tool creates possible value across three stakeholders, food producer, academia and society because it significantly can reduce research time for food producers, leverages existing academic research, and creates a valuable database. Ultimately, SmartPack Finder aligns with broader sustainability goals by accelerating the transition to eco-friendly packaging solutions, helping reduce food waste, and supporting a circular economy in the food industry.

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