UNIVERSITY OF LIFE SCIENCES ”KING MIHAI I” FROM TIMISOARA
”YOUNG PEOPLE AND MULTIDISCIPLINARY RESEARCH IN APPLIED LIFE SCIENCES”

05-06 November 2026



Agro-Food By-Products for Biodegradable Active and Intelligent Food Packaging: A Review and Research Framework

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Abstract: Petroleum-based food packaging has increased interest in biodegradable materials obtained from agro-food by-products. This review and research framework examine biodegradable active and intelligent films based on whey proteins, orange peel pectin, chitosan, red onion skins, tomato pomace, residual potato starch, coffee grounds and anthocyanin-rich extracts. The synthesis compares raw-material recovery, formulation, processing and film characterization, including physical, mechanical, barrier, structural, thermal, antioxidant, antimicrobial and food-contact performance. Protein- and polysaccharide-based matrices can form cohesive films, while phenolic extracts, anthocyanins, fibres and lipid-rich fractions may provide antioxidant, antimicrobial, reinforcing, hydrophobic or pH-responsive functions. Anthocyanin-based systems can support colourimetric freshness monitoring of protein-rich foods. Key challenges include raw-material variability, polymer incompatibility, moisture sensitivity, pigment degradation, migration and limited real-food validation.

Keywords: biodegradable packaging; active packaging; intelligent packaging; agro-food by-products; whey proteins; pectin; chitosan; anthocyanins; potato starch; coffee grounds

• Introduction

- Conventional petroleum-based packaging contributes to persistent waste and motivates the transition to renewable, biodegradable materials.
- Agro-food by-products can supply proteins, polysaccharides, fibres, phenolics, pigments and lipid-rich fractions for packaging applications.
- Whey proteins, pectin and chitosan may form the biodegradable matrix; red onion skins, tomato pomace, potato residues and coffee grounds may add active or structural functionality.
- Anthocyanins from red cabbage, red onion skins and grape pomace can act as pH-responsive colour indicators for intelligent packaging.
- Biodegradability alone is insufficient: mechanical performance, barrier properties, migration, food safety and real-food validation must also be demonstrated.



• Results and discussions

- Whey proteins provide a cohesive film-forming matrix with promising oxygen-barrier behaviour.
- Orange peel pectin and chitosan can improve matrix formation, biodegradability and antimicrobial functionality.
- Red onion skin extracts may provide antioxidant activity and pH-dependent colour changes for freshness monitoring.
- Tomato pomace and potato-derived fractions may reinforce films and modify hydrophobicity, while coffee-ground extracts may supply phenolic antioxidants.

• Conclusions

Combining film-forming biopolymers with phenolic, anthocyanin-rich or fibre-rich fractions can create multifunctional materials

Sequential optimization, full characterization, migration testing and real-food validation are required before practical application.

The proposed systems represent research strategies for sustainable packaging, not yet validated commercial food-contact materials.