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PROTEINS AS FUNCTIONAL FILLERS IN THERMOPLASTIC ELASTOMER BLENDS: A DESIGN STRATEGY AGAINST PROCESSING-INDUCED DENATURATION

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Introduction

Bio-based fillers such as cellulose, lignocellulosic fibers, starch or biochar are well documented in polymer compounds, whereas proteins are rarely used as functional fillers in thermoplastics, and reports on thermoplastic elastomers (TPEs) such as styrene-butadiene-styrene (SBS) and styrene-ethylene-butylene-styrene (SEBS). Proteins are not inert organic powders: their properties depend on a hierarchical structure (α-helices, β-sheets, tertiary and quaternary folding) sensitive to temperature, shear, moisture and pH. Melt processing may induce denaturation, unfolding, aggregation and disulfide rearrangement, which could be exploited when the goal is a protein-based plastic [1] but are detrimental when the protein must carry a function into the composite. Moreover, hydrophobic thermoplastic elastomers (TPE) matrices favour protein–protein over protein–polymer interactions, leading to agglomeration, voids and loss of ductility, as filler–filler networking governs dispersion in elastomers [3]. This communication proposes a strategy for obtaining TPE–protein composites in which the protein acts as a filler with function.

The framework compares protein-based thermoplastics obtained by extrusion [1]; protein-filled polyolefins (soy/polyethylene(PE), soy/polypropylene(PP) with glycerol and PP-graft maleic anhydride (MA), PE with up to 50 wt% feather keratin); and elastomeric systems based on styrene-butadiene copolymers with 1.5–2.5 wt% collagen-functionalized graphene oxide. The key question is which protein-derived property can survive melt processing, and under which conditions.

Methodological approach

Peer-reviewed studies ([2005–2026]) were retrieved from Google Scholar, ScienceDirect, SpringerLink and Consensus using protein, matrix and processing terms (e.g., soy, keratin, collagen; SBS, SEBS, SBR, polyolefin; extrusion, compatibilizer). Only melt-processed systems with post-compounding structural or functional data were included. Protein functions were classified by the structural level they require (composition, supramolecular self-assembly or native conformation) and linked to preservation routes.

Results and conclusions

Most reported examples use proteins as structural fillers: soy in polyolefins raises modulus but lowers strength and elongation; keratin fibers reinforce PE through the interface, not through native structure; collagen in styrene butadiene rubber (SBR) aggregated already at 2.5 wt%. The first step of the strategy is therefore to decide whether the protein is a structural or a function-retaining filler. The second is to rank the target function by its resistance to processing (Table 1), which dictates how gentle processing and compatibilization must be.

Table 1 - Protein functions ranked by resistance to melt processing

Protein function (tier)	Examples	Survival	Recommended route
I – based on amino-acid composition	N functionality, polarity, char formation	High	Standard melt compounding; reactive coupling (MA-grafted polymers) acceptable
II – based on supramolecular morphology	Elasticity, self-assembly, water binding, fibrillar reinforcement	Partial	Controlled moisture, low-temperature processing, post-processing reorganization (annealing, rehydration)
III – based on tertiary/ quaternary structure	Enzymatic activity, selective binding, specific bioactivity	Low	Protein–polymer conjugation, microencapsulation, coating before compounding or post-processing immobilization

Third, the processing window is set by the protein: melt temperature stays below the DSC denaturation onset (at compounding moisture), with short residence time, late protein addition and low-shear mixing.

Fourth, compatibilization follows the tier. Reactive agents (MA-grafted polymers, isocyanates, epoxides, silanes) bind protein functional groups and may block active sites, so they suit Tier I only. Tiers II–III require physical compatibilization, encapsulation or protein–polymer conjugation [2]. Resilin, whose elasticity matches the TPE target, is a promising Tier II candidate.

Finally, retained function must be quantified (FTIR amide I, residual DSC endotherm, function-specific assays), not only mechanical and thermal properties.

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References

[1] Verbeek, C. J. R.; et al. Extrusion processing and properties of protein-based thermoplastics. *Macromolecular Materials and Engineering* 295 (2010), 10-21. https://doi.org/10.1002/mame.200900167.

[2] Pritzlaff, A.; et al. Conserved protein-polymer interactions across structurally diverse polymers underlie alterations to protein thermal unfolding. *ACS Central Science* 9 (4) (2023), 685-695. https://doi.org/10.1021/acscentsci.2c01522.

[3] Bokobza, L. Elastomer Nanocomposites: Effect of Filler–Matrix and Filler–Filler Interactions. *Polymers* 15(13), (2023), 2900. https://doi.org/10.3390/polym15132900.