Protein-based bio-plastics: formulation, processing, properties and applications

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Introduction

Recently, research on protein based bioplastics has been boosted as a result of the fresh interest in renewable and biodegradable raw materials [1,2,3].

Many industrial sources of proteins can be used as raw materials to produce films, molded materials, and various hollow items either by "casting" techniques or by "thermo-plastic processing". Plant proteins are generally inexpensive, widely available and relatively easy to process. Animal proteins are more expensive, but sometimes have no functional advantages. Combining proteins with natural fibres, paper or biodegradable polymers is very promising to form biodegradable composites with take advantage of the barrier and mechanical properties of each component. Using nano-illite to form nanocomposites has also been shown to be interesting to improve properties. Production, with low transformation cost, of protein based materials to form biodegradable materials with controlled functional properties for food uses, medical use, packaging, agriculture, controlled release systems, etc. is discussed.

Formulation, processing and related properties

The heterogeneous structure of proteins provides many reaction sites for potential cross-linking or chemical grafting. It facilitates modification of the material-forming properties and end-product properties. Protein-based materials are cross-linked via heat treatments, or radiation treatments (UV, gamma, etc.) form insoluble and infusible networks, characterized by elastic or thermoplastic thermo-mechanical behavior according to the polymer cross-linking density. It is important to notice that physically induced treatments has similar effects on protein structure (cross-linking degree) than chemically induces ones. (e.g. thermal cross-linking of wheat gluten matrix can be as important as formaldehyde one). In addition the activation energy of thermally induced cross-linking is strongly reduced when mechanical energy is applied [4].

The mechanical mixing/curing strongly effects the the properties of composite materials, especially when mechanical energy is applied. [5,6]

Formulation of blends, composites and nanocomposites have been used to modulate protein based materials mechanical and transport properties. The functional properties (especially optical, barrier and mechanical) of these protein-based materials are often specific and unique, and they could be used as raw materials for bioplastics with a wide range of agricultural, agro-food, pharmaceutical and medical industry application.

Protein-based materials have slightly lower mechanical properties than reference materials such as low-density polyethylene or plastered PVC [7], but the addition of fibres (composite materials) can considerably improve them. The thermoplastic properties of proteins and their water resistance (for inedible proteins) are especially interesting for natural raw uses to produce particleboard type materials [8].

The water permeability of protein-based films is very high (water permeability around 5.10^-12 mol.m-1.s-1.Pa-1) but affected by crosslinking density and material formulation. The high water permeability is especially attractive for cheese, fruit and vegetable packaging, and for agricultural material and cosmetic applications. The gas barrier (CO2, O2 and ethylene) properties of protein-based materials are highly interesting as they are exceptionally low under low relative humidity conditions. CO2 permeability (around 1.0 mol.m-1.s-1.Pa-1) properties are close to those of EVOH (0.2 mol.m-1.s-1.Pa-1) and much lower than those of low density polyethylene (1000 amo1.m-1.s-1.Pa-1) The gas barrier properties are closely dependent on the material structure, relative humidity and temperature. The CO2/KC2 selectivity coefficient, which can rise from 3 to more than 50 when the relative humidity increases from 0 to 100% and the temperature rises from 510 to 45°C. This property can be utilized in designing selective or active materials for modified atmosphere packaging of fresh products such as fruit, vegetables, cheese, etc. [9].

Solute retention properties (especially antimicrobial and antimicrobial agents) have been studied and modeled, thus paving the way for potential applications involving controlled release of beneficial agents (pharmaceutical, bioactive compounds, ...). For food, agriculture (e.g. coated seed), pharmacy (drug delivery) and cosmetic industries [10].

Environmental performance and applications

The environmental performance of wheat gluten materials was considered following the life cycle analysis methods of the ISO 14000 family [11]. The results were very positive (energy use<10KJ/kg and emission of green house gases<72 kg CO2 eq/kg). Both values were very low compared to starch or PLA based biodegradable polymers. This with any chemical additives. Mechanical properties can then be adjusted from thermoplastic material with high elongation at break up to elastomeric like material. Barrier properties can also be designed for the controlled release of entrapped solutes (pharmaceutical, bioactive compounds, ...). Whatever the physical treatment severity performed (and the important corrosive change in the protein network structure) gluten materials were fully degradable (after ISO 14852) within days and no microbial inhibit due to toxic metabolites during the naturalization process was observed. In vitro enzymatic digestion tests confirmed that a decrease of the protein network hydrolysis rate became significant only at high gluten covalending degree [12].

References