Alfalfa Field Residue: A Sustainable Resource for Biodegradable Packaging Films

Sandeep Paudel, South Dakota State University
Srinivas Janaswamy, South Dakota State University

Plastic packaging is widely used but poses environmental and health risks due to its persistence and fragmentation into micro- and nano-plastics. While biopolymers such as starch and proteins are being explored as alternatives, their use may compete with food resources. In contrast, cellulose derived from non-food biomass offers a sustainable solution. Alfalfa field residue, which accounts for approximately 25% of total biomass yield, represents an underutilized lignocellulosic resource with strong potential for value-added applications. In this study, lignocellulosic and cellulosic fractions were extracted from alfalfa residue using alkaline treatments (20% and 50% NaOH) and bleaching. Film formulations were optimized using a Box–Behnken design based on tensile strength (TS), elongation at break (EB), and water vapor permeability (WVP). Films were prepared using $ZnCl_2$ dissolution, calcium crosslinking, and sorbitol plasticization. Functional performance was evaluated through mechanical, barrier, optical, and biodegradability analyses, as well as application testing for strawberry shelf-life extension. Cellulose-based films exhibited superior mechanical properties (TS: 16.9 MPa; EB: 10.1 ± 0.3%) and improved barrier performance (WVP: 0.47×10^{-10} g·m^{-1} · s^{-1} · Pa^{-1}) compared to lignocellulose films. Blending with carrageenans and starches further enhanced tensile strength by up to 130%. Lignocellulose films demonstrated stronger UV-blocking properties, and all films biodegraded within 25–40 days at 24% soil moisture. Notably, cellulose-based films extended strawberry shelf life by two days compared to conventional plastic packaging. These findings demonstrate the feasibility of converting alfalfa field residue into high-performance biodegradable packaging materials. This approach supports the development of a circular bioeconomy and provides an additional potential revenue stream for alfalfa producers, estimated at $5.4–6.1 billion per year.