Valorizing the Whole Potato Plant: From Leaves to Tubers – Sustainable Products, Benefits, and Key Applications

"All changes in nature are such that inasmuch is taken from one object insomuch is added to another. So, if the amount of matter decreases in one place, it increases elsewhere. This universal law of nature embraces laws of motion as well, for an object moving others by its own force in fact imparts to another object the force it loses."
~ Mikhail Lomonosov

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Abstract

The imperative for sustainable and safe ingredients in the bioeconomy has driven innovative biorefinery designs that prioritize Generally Recognized as Safe (GRAS) products from renewable biomass. This article explores the valorization of the entire potato plant (Solanum tuberosum)—from leaves and stems to peels and tubers—into GRAS-compliant compounds, using a Community BioRefinery (CBR) in Wisconsin as a case study. Key products include phenolic acids like chlorogenic acid (CGA) for antioxidants, glycoalkaloids like α-chaconine for biopesticides, polysaccharides like pectin for prebiotics, proteins and amino acids for nutrition, vitamins for fortification, and fatty acids for health supplements. The global potato protein market, a proxy for these bioproducts, is valued at approximately USD 220 million in 2025 and projected to reach USD 330-350 million by 2030 at a CAGR of 6-8%, driven by demand for clean-label ingredients. Traditional sourcing faces challenges like toxicity and waste, but advanced methods ensure safe, scalable production. This approach yields economic benefits, reduces environmental impact (e.g., diverting waste to cut CO2 emissions by up to 20-30 tons per 1,000 tons processed), and complies with FDA regulations, advancing circular bio-economies.

Introduction

The bioeconomy leverages biological processes to convert renewable resources into fuels, chemicals, and materials, tackling climate change and scarcity. Biorefineries integrate these conversions for efficiency. Wisconsin's potato industry produced about 26.4 million hundredweight (cwt)—equivalent to roughly 1.32 million short tons—in 2024, with 2025 expected to be similar, providing ample biomass for upcycling.

Background on the Whole Potato Plant: Safety and Biological Functions

Processed potato components are GRAS-affirmed, as in peel and tuber extracts. Phenolics like CGA in peels neutralize reactive oxygen species (ROS), curbing oxidative stress. Glycoalkaloids (e.g., α-chaconine) in leaves and berries defend against microbes but need detoxification. Polysaccharides like pectin in peels act as prebiotics for gut health. Proteins in leaves provide essential amino acids (up to 20% dry weight), vitamins (e.g., C, B-complex) in peels boost immunity, fatty acids from peels reduce inflammation, and fibers from stems lower

cholesterol. Research highlights valorization, turning waste into functional products while averting runoff and eutrophication.

Market Dynamics and Sourcing Challenges

Potato-derived compounds propel markets in supplements, foods, cosmetics, and pharmaceuticals. The potato protein segment grows from USD 220 million in 2025 to USD 330-350 million by 2030 at 6-8% CAGR, spurred by plant-based trends. Challenges include toxicity in green parts, seasonal supply, and instability. Biorefineries counter these with microbial engineering, green extraction, and enzymatic detoxification for stable GRAS outputs.

CBR's Valorization Process

Biorefineries like CBR ensure GRAS compliance and scalability. Employing zero-waste processes, CBR converts the plant into antioxidants from peels, prebiotics from stems, and biofuels from residuals, with residuals feeding subsequent steps for closed-loop efficiency.

Table 1 summarizes components, products, benefits, and applications:

Plant Part	Key Compounds	Benefits	Applications
Leaves & Stems	Proteins, Amino Acids (e.g., tryptophan, leucine)	Nutritional support, muscle repair	Plant-based foods, supplements
Peels	Phenolics (e.g., CGA, caffeic acid), Flavonoids (e.g., quercetin), Polysaccharides (e.g., pectin), Vitamins (e.g., C, B6)	Antioxidant, anti-inflammatory, prebiotic	Nutraceuticals, cosmetics, preservatives
Tubers	Starches, Fatty Acids	Energy source, heart health	Biofuels, health oils

This expands portfolios into higher-value GRAS products.

Background on Biofuel Production

CBR generates biofuels like bio-acetone, bio-butanol, bio-ethanol, and bio-hydrogen from tuber starches and residuals, powering operations and cutting fossil fuel use.

Feasibility, Benefits, Challenges, and Implementation

CBR's modular design supports diversified outputs, blending GRAS compounds with biofuels. Benefits include economic gains from premium products, sustainability via waste diversion (reducing CO_2 by 20-30 tons per 1,000 tons biomass), scalability for growth, and innovation in bioeconomy practices. Challenges like glycoalkaloid toxicity are addressed through enzymatic protocols. Implementation covers planning, engineering, and budgeting for compliant, efficient facilities.

Case Studies

Industry examples integrate potato processing for phenolics and biofuels. Boise State University (BSU) research under Dr. Owen McDougal aligns with zero-waste models. A 2025 poster on "Upcycling Potato Waste to High-Value Products" optimized starch and protein extraction with partners like Genesis Organics, boosting yields by 4-8% via PEF and SiccaDania methods. Another 2025 project, "Valorizing Potato Juice and Oat Pulp," used PEF for maximal recovery. BSU's 2022-2023 wildfire smoke studies noted yield reductions in Russet Burbank, aiding resilient practices. At Boise State University, the master's work by Kylie Johnson on dimethyl ether extraction enhances peel recovery. The 2025 Undergraduate Research Showcase included "Diverting Campus Waste for Sustainable Energy," which is relevant to biomass valorization. These initiatives support integrated models like CBR's.

Future Outlook

Synthetic biology and AI-driven extraction could boost yields by 20-30%, lowering costs. As climate impacts intensify, focusing on resilient varieties will sustain supply, enabling biorefineries to meet escalating demand for eco-friendly products—echoing Lomonosov's conservation principle in modern contexts.

Conclusion

Valorizing the whole potato plant exemplifies sustainable manufacturing, redirecting matter into safe, valuable products. Biorefineries foster circular economies, harmonizing economic, environmental, and health imperatives.

Explanation of Biofuel Production and GRAS Status

Biofuel production at CBR yields bio-acetone, bio-butanol, bio-ethanol, and bio-hydrogen from residuals. These achieve GRAS status:

- Bio-Ethanol: Beverages/extracts.
- Bio-Acetone: Processing solvent.
- Bio-Butanol: Flavors.
- Bio-Hydrogen: Food processing. They reduce carbon footprints, enabling integration.

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