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Review of lignin extraction and isolation processes: from lignocellulosic biomass to ad-value materials

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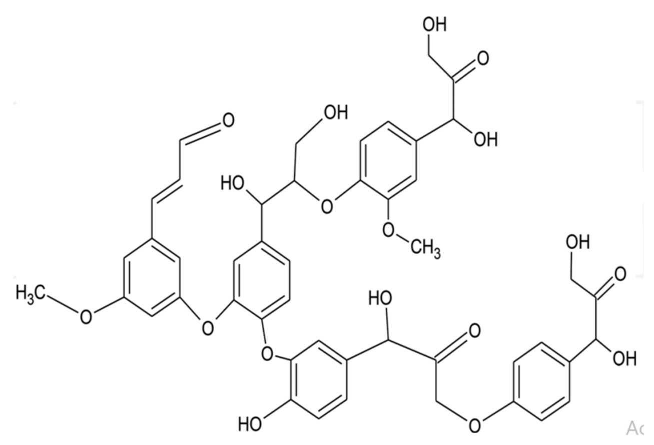
INTRODUCTION

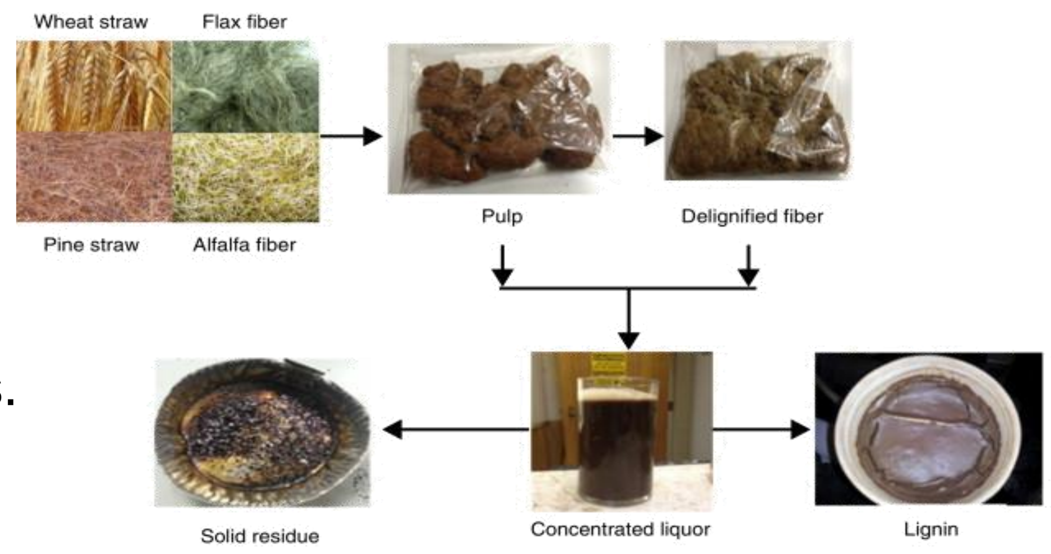
- Lignin is one of the three major components of the cell wall of lignocellulosic biomaterials. It is often chemically associated with cellulose and hemicellulose within the cellular structures of plants. Furthermore, lignin stands as the second most abundant polymer in nature after cellulose.
- Its aromatic constituents exhibit unique properties and significant bioactive effects for advanced applications: making lignin a crucial material in various advanced applications:
  - Antioxidant activity
  - Antibacterial properties
  - UV-absorbing capacity,
  - Biocompatibility and low cytotoxicity



- To fully exploit the beneficial properties of lignin, it is imperative to advance and optimize the methodologies for its extraction and isolation.

LIGNIN EXTRACTION PROCESSES

- Lignin can be isolated through various extraction processes and is classified as sulfur-containing or sulfur-free technical lignin's.
- Extracting raw lignin from lignocellulosic biomass typically leads to fragmented mixtures, and various chemical, physicochemical, and enzymatic pre-treatments have been developed to isolate and recover lignin.
- Various methods for further lignin fractionation have been investigated, including:
  - Organosolv processes;
  - Alkaline treatment;
  - Ionic liquids;
  - Deep eutectic solvents.



PROCESS	REACTION MECHANISM	ADVANTAGES	DISADVANTAGES
Kraft Process	Dissolution of lignin in sodium hydroxide and sodium sulfide at ~170°C and pH 13-14 for 2 hours. Lignin isolated via acid precipitation.	High lignin removal, low ash, good solubility in alkali and polar solvents.	Long reaction time, high carbohydrate content in black liquor.
Sulfite Process	Reaction between lignin, sulfur dioxide, and metal salts at 120-180°C for 1-5 hours. Lignosulfonate is produced.	Soluble lignosulfonate in water and solvents, works well for wood materials.	High sulfur content, affects lignin structure, non-selective.
Alkaline Process	Lignin extraction using alkaline solutions (e.g., sodium, ammonium hydroxide) at 140-170°C.	Efficient delignification, low ash content, low inhibitor formation.	Alters lignin structure, high carbohydrate content, costly catalysts.
Organosolv Process	Treatment of biomass with organic solvents (ethanol, methanol, acetic acid) with acid or base catalysts at 170-190°C. Lignin recovered via precipitation or evaporation of solvents.	No sulfur, efficient process, low reaction time, soluble lignin.	High solvent costs, additional recovery steps required.
Hydrolysis Process	Biomass subjected to acidic or enzymatic hydrolysis, and lignin is recovered after carbohydrates dissolve.	Sulfur-free lignin, high glucose yield, non-energy-intensive process.	Long process, high equipment cost, formation of inhibitors.
Ionic Liquid Extraction	Use of ionic liquids to dissolve lignocellulosic biomass, improving lignin and carbohydrate dissolution. Ionic liquids consist of inorganic anions and organic cations.	Low melting points, high thermal stability, low toxicity, reusable.	High ionic liquid cost, additional steps for regeneration and recovery.
Deep Eutectic Solvent	New green solvent combining hydrogen bond donor and acceptor (e.g., choline chloride and amines). Used for high biomass loading.	Biodegradable, low cost, non-toxic, high lignin purity, green solvent.	Requires solvent recovery and recycling.

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