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Editorial: Biochemical/biomaterial production from lignocellulosic biomass

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Editorial on the Research Topic
Biochemical/biomaterial production from lignocellulosic biomass

Lignocellulosic biomass, as the largest amount of carbohydrate forms on our planet, has great potential as a feedstock for sustainable chemical and material production. However, its conversion is still challenging due to its rigid structure and complicated composition. It is mainly composed of cellulose, hemicellulose, and lignin. Cellulose is a linear polymer consisting of glucose linked by β-(1,4)-glycosidic bonds. Hydrogen and van der Waals bonds link those cellulose long chains together to form microfibrils. Hemicelluloses are branched heteropolysaccharides composed of pentoses, hexoses and sugar acids. Lignin is a complex phenolic macromolecule cross-linked with aromatic units.

A common practice in biomass conversion is degrading cellulose and hemicellulose into their monomer sugars. Then the sugars can be fed into microbial fermentation processes for biochemical and biomaterial production. However, biomass has its intact recalcitrance factors like lignin. In nature, lignin is the safeguard of a plant cell wall, which protects carbohydrates in the plant cell walls from microbial attacks. Therefore, the effective conversion of cellulose and hemicellulose typically needs preprocessing. Pretreatment breaks biomass's rigid structure and enhances the enzyme accessibility to cellulose and hemicellulose. A variety of pretreatment methods has been studied, which can be categorized into three groups: physical, biological, and chemical methods. Physical methods such as milling (Zakaria et al., 2014), microwave (Li et al., 2016), ultrasound (Wang et al., 2018), pulse-electric field (Kovacic et al., 2021), and plasma (Gao et al., 2014) enhance the accessibility of biomass. Biological methods apply microorganisms (Ferdeş et al., 2020) or enzymes (Zieminski et al., 2012) to degrade lignin. Chemical methods use certain chemicals and solvents to extract unwanted components and/or modify the structure of biomass. Various chemicals such as acid (Rezania et al., 2020), alkali (Hossain et al., 2022), organic solvents (Rostagno et al., 2015; Tang et al., 2017), ionic liquids (Usmani et al., 2020), deep eutectic solvents (Wang et al., 2021), and biomass-derived solvents (Meng et al., 2020). Kim and Yoo provided a brief review of recent chemical pretreatment approaches using organic co-solvents, acid hydrotropes, ionic liquids, and deep eutectic solvents. These solvent pretreatments have the advantages of biocompatibility, bio-derivability, and recovery of high-quality lignin compared to the conventional solvent processes. They also pointed out the future directions for solvent pretreatment, including feedstock-agnostic solvents, lignin first separation, hemicellulose valorization, and computational aiding. Diaz et al. developed an OrganoCat pretreatment process, which uses a biogenic solvent (2-methyltetrahydrofuran) and catalyst (oxalic acid). The formation of undesirable humins from sugar degradation was minimized with a certain degree of delignification. A set of genetic variations of rapeseed lines were treated by OrganoCat pretreatment, and the most suitable lines were reported based on their yield and characteristics of pulps.

The pretreated biomass is still not directly fermentable; therefore, another subsequential step called enzymatic hydrolysis is necessary for the depolymerization of cellulose and hemicellulose into fermentable sugars using cellulase and hemicellulase cocktails. However, byproducts can be generated during pretreatment and inhibit the enzyme activity. Kim et al. studied the impacts of NaOH and H_2O_2 pretreatment on the enzymatic hydrolysis of soybean straw. NaOH hydrolysate showed a higher inhibitory effect on enzyme activities (mainly β-glucosidase) compared to H_2O_2 liquid. The inhibition effects mainly come from lignin-derived phenols. The concentration of phenols suppresses the susceptibility and accessibility of enzymes to cellulose. Even a small variation in the phenols-enzyme protein ratio resulted in a pronounced effect on the efficient hydrolysis of cellulose. Therefore, a detoxification step between pretreatment and enzymatic hydrolysis could be beneficial for effective biomass conversion.

The obtained monosaccharides from pretreatment and enzymatic hydrolysis are used in microbial fermentation processes for various products. A variety of biofuels, biochemicals, and biomaterials has been produced from lignocellulosic biomass, such as ethanol (Kukielski et al., 2023), butanol (Li et al., 2019), methyl ketones (Dong et al., 2019), polyhydroxyalkanoates (Hossain et al., 2022), etc. Among the various products, 2,3-butanediol (2,3-BDO) is a platform chemical that can be converted to a wide array of products ranging from bio-based materials to sustainable aviation fuel. Stoklosa et al. studied the 2,3-BDO production by *Paenibacillus polymyxa* from pretreated sweet sorghum bagasse. They found that oxygen-limited conditions favored the 2,3-BDO accumulation, although it slowed the growth of *Paenibacillus polymyxa*. A common problem when using biomass hydrolysates in the fermentation processes is the toxicity of the hydrolysates. Besides sugars, the pretreatment and enzymatic hydrolysis process may generate some byproducts which may inhibit the growth of microorganisms. Therefore, detoxification may be needed before fermentation. Stoklosa et al. used activated carbon to detoxify the hydrolysates and significantly improved 2,3-BDO yield.

Conventional biomass processes including pulping process consider lignin as a byproduct and typically burn it as an energy source. However, 10%–30% of the lignocellulosic biomass is lignin; therefore, if lignin can be successfully valorized, the overall utilization of biomass can be significantly improved. However, lignin conversion is more challenging compared to carbohydrates because of its complicated crosslinked structure and limited knowledge about its biological degradation. Rodriguez et al. summarized the lignin conversion utilizing isolated or synthetic microbial consortia, which is what nature uses for lignin degradation. They indicate significant challenges to obtaining efficient processes for the microbial conversion of lignin, such as limitations in methods and tools available for systematically assembling and assessing microbial communities. They also pointed out that when engineering the consortia, it may be desirable to have organisms that do not consume the depolymerized fragments but some other carbon sources. Organic solvents are commonly used for lignin separation from biomass. Diaz et al. used 2-methyltetrahydrofuran to dissolve lignin from rapeseed straw, while Chotirotsukon et al. applied 70% ethanol to extract lignin from sugarcane bagasse. Chotirotsukon et al. also performed thermal treatment to further alter phenolic hydroxyl group. Application of the modified lignin at 3% in a base cream formulation resulted in enhancement of the anti-UV activity to exceed SPF 50 with increasing antioxidant activity, which points in a promising direction for lignin valorization. Based on recent progress in biomass utilization strategies including the aforementioned studies, lignocellulosic biomass is a promising future feedstock in sustainable and renewable biochemicals and biomaterials.

Author contributions

JD: Conceptualization, Writing–original draft. DK: Writing–review and editing. CY: Writing–original draft, Writing–review and editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Publisher's note

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