Cell Walls in Biotechnology: Applications, Innovation and Prospects

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ABSTRACT

Cell wall (CW) is present in all organisms such as bacteria, yeast, red algae, fungi, and plants except animals. It provides mechanical support, structural stability and protects the cell's internal structures. The CWs have a wide variety of applications in biotechnology, agriculture, paper & food industries, healthcare and biofuel production.

Summary : Cell walls have many biotechnological applications beneficial to agriculture & man and require further investigations and immense potential for innovations.

INTRODUCTION

Robert Hooke (1665) observed the cork cells under a primitive microscope and named those cells 'cellula', later called 'cells' and subsequently cell wall (CW). The plant CW is an elaborate extracellular matrix that encloses each cell. The CWs are made up of thin cells, referred to as primary cell walls (PCWs) and later they mature and develop thickening due to the deposition of lignin, referred to as secondary cell walls (SCWs) (Alberts *et al*., 2002; Delmer *et al*., 2024).

Composition: Plant CWs are primarily composed of >90% polysaccharides such as cellulose and pectin along with non-cellulosic or hemicellulose (callose, β-1,3:1,4-glucan, xylan, xyloglucan and mannan), phenolic components and water, wall-associated proteins (proteins, glycoproteins, proteoglycans) (Delmer *et al*., 2024).

Cellulose is the abundant insoluble polysaccharide macromolecule involved in maintaining the structural integrity of the walls.

Pectin is a heteropolysaccharide involved in expansion, adhesion, porosity, signalling and strength.

Hemicellulose provides mechanical support.

Bacterial CWs consist of peptidoglycan, a network of multiple units of *N*-acetylglucosamine and *N*-acetylmuramic acid (MurNAc) cross-linked with MurNAc residues through short peptide bridges. The fungal CWs (FCWs) are made up of several layers of fibrils. The compositions vary depending on species, however, they consist primarily (1→ 3)/(1→6)-*β* -glucan, (1→3)-*α* -glucan, chitin and glycoproteins. It consists of 80-90% glycoproteins, lipids and other minor components. The yeast CWs are made up of (1→ 3)/ (1→6)-*β*-glucan, mannoproteins and chitin. The red algae contain galactan heteropolymers with sulphite residues along with minor components like methylated sugars, mannose, arabinose and ribose. However, the basic building block is aldobiouronic acid 3-*O*-(α-d-glucopyranosyluronic acid)-l-galactopyranose disaccharide

Structure: The CW surrounds plants' plasma membrane, providing tensile strength and protection against mechanical and osmotic stress allowing cells to develop pressure of the cell contents against the CW (turgor pressure) (Figure 1).

Functions: The primary functions of the SCWs are to withstand loss of turgor, protect against water loss and diseases, transport water and minerals. It behaves as a skeletal system for the cell supporting internal contents (Alberts *et al*., 2002). Similarly, WAPs govern growth and development, cell expansion, division, signalling, embryogenesis, vascular and gametophyte development, biotic and abiotic stress-mediated responses (Delmer *et al*., 2024). The FCWs protect cells from osmotic pressure, environmental stresses and maintain cell shape.

Diagrammatic representation of cell walls of A) Plants and B) Bacteria showing the comparison of the structural details of the cellulose fibrils & pectin and lipopolysaccharide & peptidoglycan layers, respectively. (**Figure 1)**

Significance of cell walls in biotechnology

As CWs contain cellulose and hemicellulose with the deposition of phenolic polymer, lignin forms a complex and rigid structure that provides mechanical strength. Properties of CWs like abundance, diversity, carbon-neutral and non-edibility make them industry suitable. Lignocellulosic biomass accounts for ~60%–80% of dry matter yields in grasses and is primarily composed of SCWs made of cellulose (~25%–55%), hemicellulose (~20%–50%) and lignin (~10%–35%) (Bhatia *et al.*, 2017) (Figure 2).

Figure 2: Applications of cell walls in different fields.

Applications of cell walls in biotechnology

1) **Energy and fuel production:** The bioengineering strategy for the modification of CWs primarily relies on i) reprogramming of gene regulatory networks of lignocellulose biosynthesis ii) remodelling the chemical structure of CW polysaccharides and iii) expressing lignocellulose degrading and/or modifying enzymes. Polysaccharides harboured by plants are a good source for biofuel which is sustainable and renewable due to the abundance of lignin content (Bhatia *et al*., 2017). The lignin biosynthesis genes are downregulated to reduce the lignin deposition and to alter SCWs composition (Table 1).

2) **Engineering for the food industry:** Plant CWs are added to food as dietary fibres to improve health (Harris and Smith, 2006). Such polysaccharides are obtained from cotton and wood cellulose, dicotyledons pectin, cereals β-glucans and arabinoxylans, galactomannans, legume xyloglucans and pectic rhamnogalacturonan I non-lignified SCWs.

3) **Applications of bacterial cell wall hydrolases**: Hydrolases control foodborne spoilage and detect bacterial pathogens.

4) **Hemicellulose for different industries:** The converted polymers used in thermoplastics, papermaking, coatings, pharmaceutics, cosmetics, hydrogels and fuels. These products are obtained through the hydrolysis of hemicellulose and produce intermediate products like hexoses and pentoses that gets modified into many high-value polymers such as 5-hydroxymethylfurfural, polylactates etc.

5) **Yeast:** YCW is used in pharmaceuticals, bioremediation, enzyme immobilization, veterinary, wine production, cosmetics and hydrogel production.

6) **Microalgal:** They have been used as antioxidants, broncho-dilating agents, plant growth stimulants & antimicrobial agents eg. (1→3,1→6)-β-d-glucan from *Isochrysis galbana* show antitumor properties by inhibiting human leukemic monocyte lymphoma cell lines (U937).

Manipulation of cell wall composition for varied purposes

With the advances in identifying the genes involved in the biosynthesis of CWs, the manipulation of genes is of great interest in exploring their applicability in various fields (Figure 2).

Gene	Organism/Plant	Remark
CesA	Transgenic aspen (*Populus tremuloides*)	Resulted in the silencing of both transgene and endogenous genes and thereby resulted in reduced levels of cellulose
fs2 (brittle stem mutant)	Barley	The mutant (*fs2*) contains a retroelement in its first intron, *HvCesA4* which interfered with the transcription and reduced the levels thus impacting cellulose crystallinity and stem strength
Brittle stem mutant	Rice	The mutant interfered with the levels of the gene, *OsCesA4* thereby lowering the levels of cellulose but higher nutrition levels for ruminants.
anisotropy1 (single amino acid mutant of *CesA*)	*Arabidopsis*	Normal levels of cellulose but reduced plant height and CW crystallinity
HvCslF6 + *35S*	Transformation of barley with transgenic lines	(1,3;1,4)-β-glucan content in leaves increased from 3-fold to 4-fold
gux1gux2	*Arabidopsis*	Reduced overall

		xylan
HvCslF6 + endosperm-specific oat globulin promoter	Barley	(1,3;1,4)-β-glucan content

Table 1: Manipulation of CW components for different purposes.

CONCLUSION AND FUTURE PROSPECTS

Cell wall modifications tend to increase the amorphous density and depth of cellulose microfibrils providing a solution to both biomass recalcitrance and plant strength (lodging resistance) through the co-expression and/or silencing of different types of genes for biomass production.

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Annexures

Figure 1

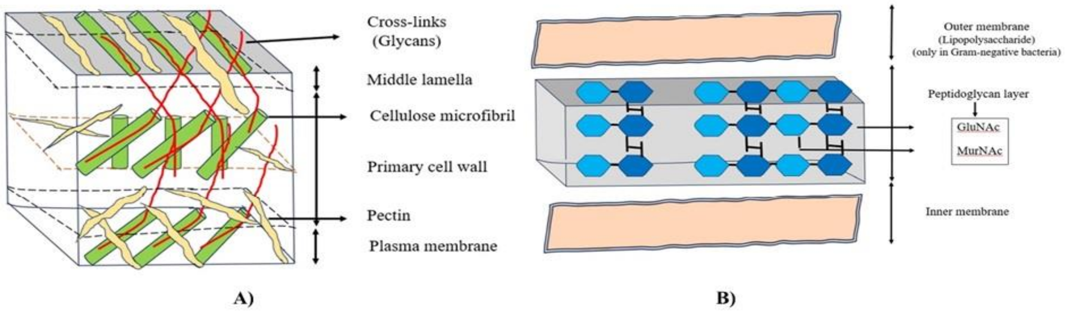

Figure 2