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DEPARTMENT NAME	**LIFE SCIENCE & BIOTECHNOLOGY**
SUBJECT NAME	**PLANT BIOCHEMISTRY**
COURSE	**M.Sc. BIOCHEMISTRY**
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SUBTOPIC NAME	**Primary cell wall, organisation, role of cell wall**
CONTENT TYPE	**PDF**
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PLANT CELL WALL

M.Sc. Biochemistry 2nd sem

CSJM University, Kanpur.

Pre-requisites: Basic knowledge about plant cell.

Objectives

- To make the students aware of the structure and organisation of primary cell wall.
- To make the students aware of the structure and organisation of secondary of cell wall and its role.

- **Content**:

1. Introduction
2. Primary cell wall
2.1 Hypothetical model & Composition of primary cell wall
2.2 Cellulose
2.3 Hemicellulose
2.4 Pectins
2.5 Proteins
2.6 Middle lamella
3. Organisation of secondary cell wall
2.1 Cellulose and lignin
2.2 Hypothetical model of biogenesis of secondary cell wall
3. Structure of secondary cell wall
3.1 Pits
4. Role of secondary cell wall

Plant Cells Are Surrounded by Rigid Cell Walls

•A fundamental difference between plants and animals is that each plant cell is surrounded by a rigid extracellular matrix known as **cell wall.**

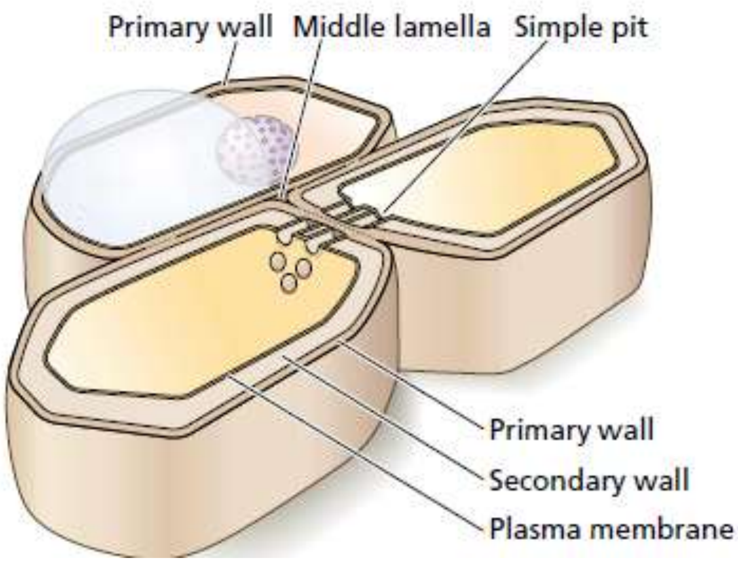
• Functions of cell wall:

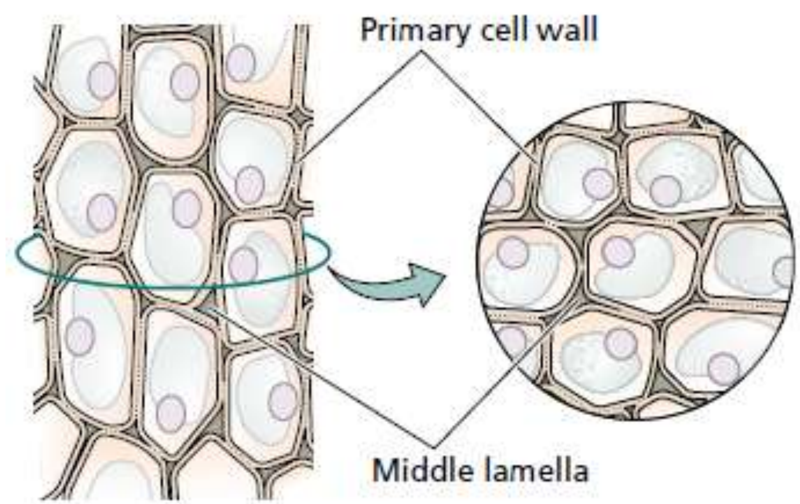
1. Cell wall plays multiple roles in plant growth, development and defence responses.
2. Cell wall plays important role in regulating cell volume and determining cell shape.
3. Cell wall is responsible for tensile strength and limited plasticity of the cell.
4. It is essential for many processes in plant growth, development and reproduction.
5. It acts as diffusion barrier for large molecules and as structural barrier to pathogen invasion.

•Electron Microscopic observations & use of different stains indicate that plant cells have two types of walls: ***Primary cell walls*** (walls deposited during active growth and relatively unspecialized) and ***secondary cell wa*****lls** (formed after cell growth during differentiation).

•Cell wall is permeated by small membrane lined channels called as plamodesmata.

•In plants, each walled cell and its neighbour are cemented together by a **middle lamella.**





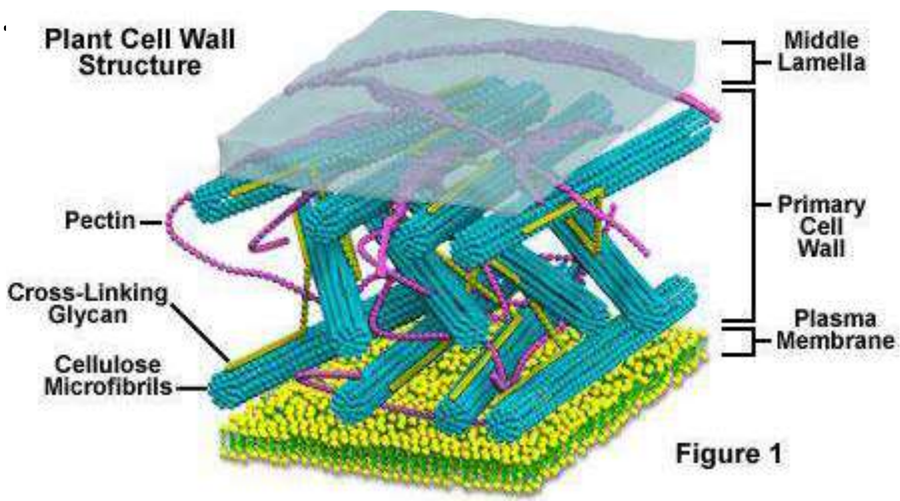
Primary cell walls are typically thin (<1 µm) and are characteristic of young, growing cells. **Secondary cell walls are thicker and stronger** than primary walls and are deposited when most cell enlargement has ended. Secondary Cell Walls owe their strength & toughness to **lignin,** a brittle, gluelike material.

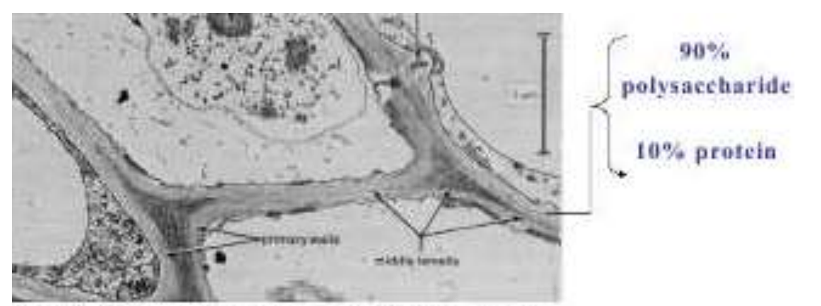
The evolution of lignified secondary cell walls provided plants with the structural reinforcement necessary to grow vertically above the soil and to colonize the land. Bryophytes, which lack lignified cell walls, are unable to grow more than a few centimeters above the ground.

Composition of Primary cell wall:

•It is the first wall laid down at the end of cell division many times referred as **phragmoplast**. It surrounds the growing cells in the young tissue, meristematic cells and present in all types of tissues. It is composed of 90% carbohydrates and 10% proteins.

•3 classes of polysaccharides make up the primary walls namely ***cellulose, hemicellulose and pectins***.





from *Katherine Esau, Anatomy of Seed Plants, 1977*

Hypothetical model for structure of primary cell wall

•The primary cell walls can be divided into two types:
•**Type I primary walls** are present in all flowering plants except the grass family. These show presence of: cellulose, hemicellulose (xyloglucan), pectin (~ 22-35%, homogalacturonan, HGA, Rhamnogalacturonan, RG I, and Rhamnogalacturonan II, RG II).

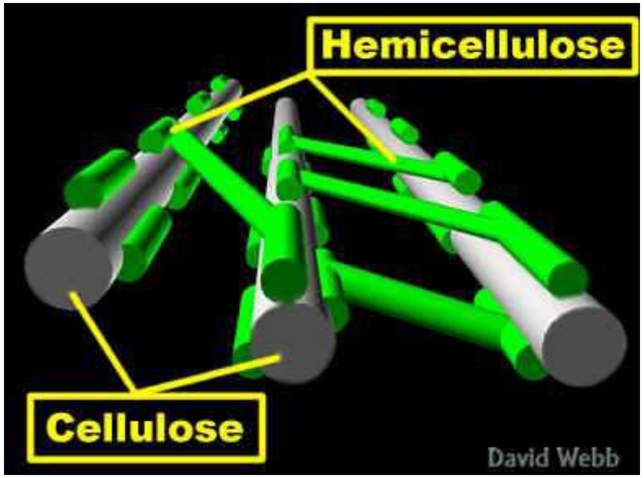
•**Type II Primary walls** are reported from grass family Poaceae. These show presence of: cellulose, hemicellulose (galacturonoarabinoxylan), pectin (~10%, homogalacturonan, HGA, Rhamnogalacturonan I, RG-I, and Rhamnogalacturonan II, RG II).

Basic structure of primary cell wall shows presence of cellulose microfibrils embedded in highly hydrated matrix. Matrix consists of hemicellulose, pectins and small amount of structural proteins. Matrix is a highly hydrated gel phase in which cellulose microfibrils are embedded.

Cellulose molecules provide tensile strength to the primary cell wall. Each molecule consists of a β1 4 linked linear chain of at least 500 glucose residues that are covalently linked to one another to form a ribbon like structure, which is stabilized by hydrogen bonds within the chain.
Intermolecular hydrogen bonds between adjacent cellulose molecules cause them to adhere strongly to one another in overlapping parallel arrays, forming a bundle of about 40 cellulose chains, all of which have the same polarity. These highly ordered crystalline aggregates, many micrometers long, are called **cellulose microfibrils, and they have a very high tensile strength.**

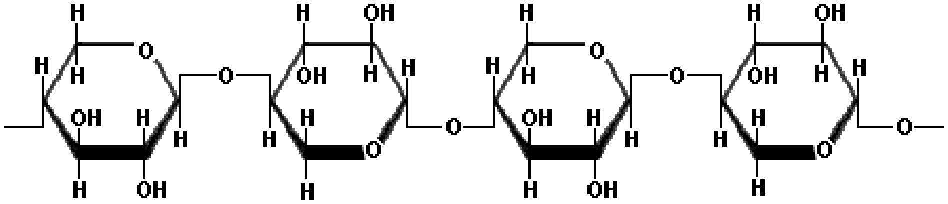
Hemicellulose shows presence of highly branched long chains of glucose (xyloglucans, arabinoxylans, glucoronoxylans, galactomannans). Cellulose microfibrils are coated with the fibrous hemicellulose like xyloglucans. They are usually connected by hydrogen bonds with cellulose. Xyloglucans, in turn, chemically bonded to another hemicellulose that serves as a cross-link between pectin molecules.

Model showing long Cellulose Microfibrils with attached, interconnecting Hemicelluloses. These are held together by weak Hydrogen Bonds. However, there are so many of these bonds that the overall structure is very stable.



There are different hemicelluloses with different functions:

Xyloglucans: Xylans are a family of structurally diverse plant polysaccharides with a backbone composed of 1,4-linked β-D-xylosyl residues.



Xylan

Xyloglucans bind to cellulose microfibers through non-covalent (H-Bonding) interactions, coats and cross-links adjacent microfibers and serves as loadbearing glycans in primary cell wall. They serve as a source of signal molecules:

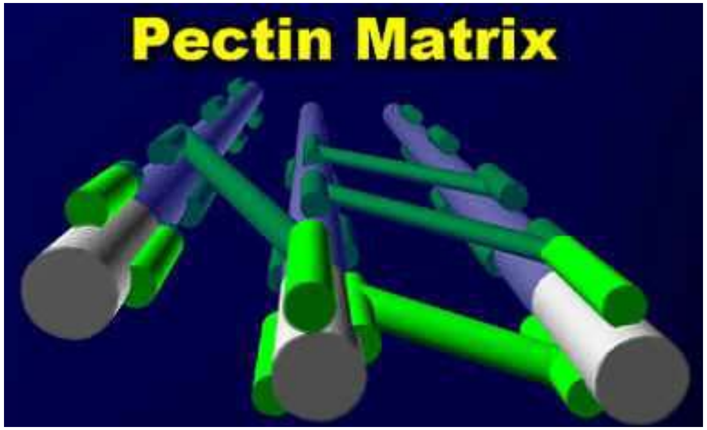
XXFG counteracts auxin-induced cell expansion and also as seed storage carbohydrate

Arabinoxylans: These are the predominant hemicellulose of grasses. In these hemicelluloses, Larabinofuranose is attached randomly by 1α→2 and/or 1α→3 linkages to the xylose units throughout the chain. Also, side chains containing arabinosyl, galactosyl, glucosyluronic acid, and 4-O-methyl glucosyluronic acid residues have been identified.

Glucuronoxylans: These are major components of the secondary cell walls of dicots (15%-30%). These show α (1, 2)-linked D-glucuronyl (GlcA) 4-O-methyl-GlcA (MeGlcA) residues attached to C-2 ∼every 10 Xyl residues. It is observed that approximately 70% of glucuronoxylans contain one O-acetyl group at C-2 or C-3. These are seen to contain a distinct "glycosyl sequence" at the reducing end and are devoid of -Ara units.

Galactomannans: Galactomannans are food reserve polysaccharides in endosperm of legume seeds & in endosperm walls and cell lumens. These reserve carbohydrates are used during seed germination, protect the seed from desiccation, and are used as thickeners and stabilizers in the food industry. Galactomannans are β1,4-linked mannans substituted by α1,6-linked Gal.

Pectins are a family of complex carbohydrates found in all plant primary walls that play structural and informational roles in plant cells. These heterogeneous group of branched polysaccharides contain many negatively charged galacturonic acid units. Because of their negative charge, pectins are highly hydrated and associated with a cloud of cations. Cellulose and hemicellulose are embedded in cellulose-hemicellulose network with pectins.



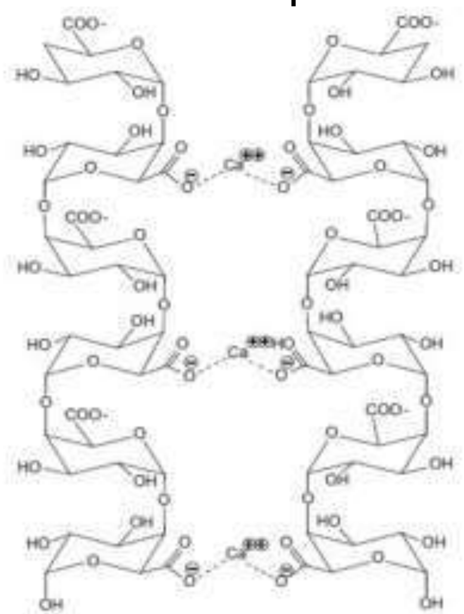
Pectins are hydrophilic & are 75% water.

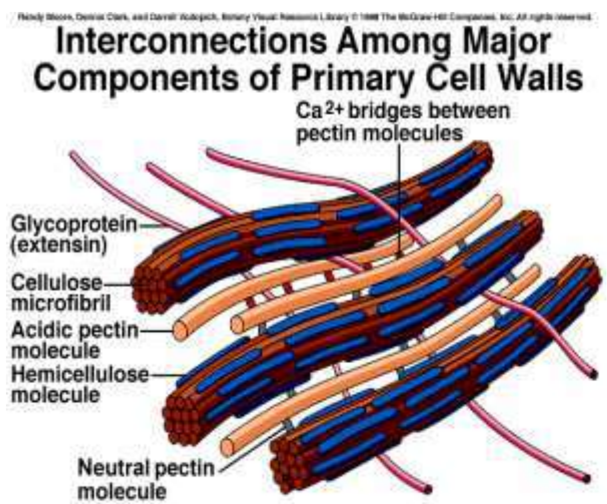
Types of pectins: In plants different types of pectins have been reported. Some of them are as follows:

- Homogalacturonan (HG)
- Xylogalacturonan (XGA)
- Apiogalacturonan (AGA)
- Rhamnogalacturonan I (RGI)
- Rhamnogalacturonan II (RGII)

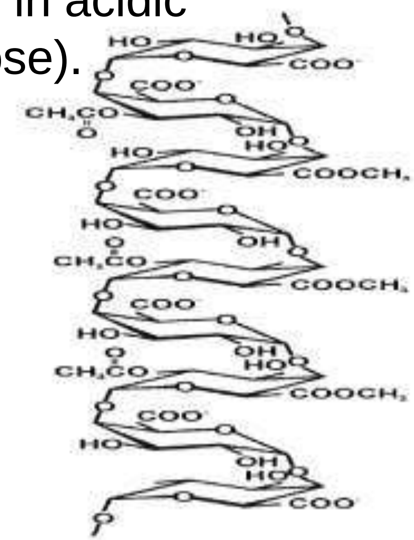
Homogalacturonan: (HG): HG is the the most abundant pectic polysaccharide, is a homopolymer of α1,4-linked galacturonic acid that may be methylesterified at C6 and acetylated or xylosylated at C3. X-ray diffraction studies indicated that HG adopts a 3(4.45) right-handed helix

Pectin forms gels in the presence of divalent cations (e.g. Ca++) or in acidic conditions in the presence of high solute concentrations (e.g. sucrose).





calcium helps in bridging pectin molecules



HG

Proteins: In addition to the two polysaccharide-based networks that are present in all plant primary cell walls, proteins contribute up to about 5% of the wall's dry mass. There is presence of Structural and enzyme proteins (~10% dry weight).

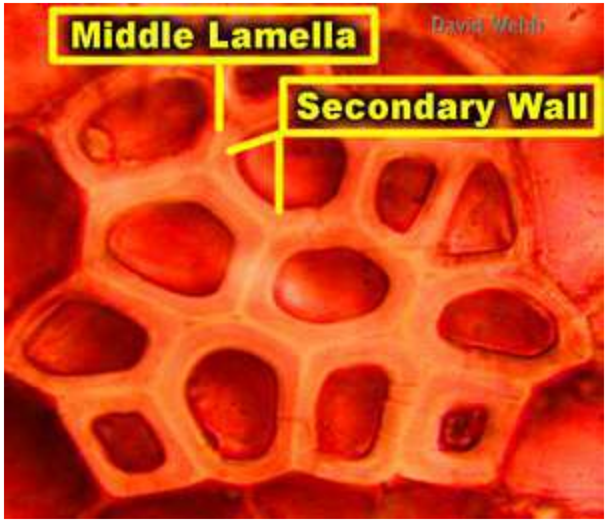
Structural proteins: These are the major part of cell wall proteins. Their functions are considered to be contribution to the cell wall strength, control cell wall assembly, expansion, hydration and permeability. They also serve as possible nucleation sites for lignification and as sources of signaling molecules.

Based on the enrichment in specific amino acids and the presence of repeated sequence motifs, they can be classified into two groups: (1) glycine-rich proteins (GRPs) and (2) hydroxyproline-rich glycoproteins (HRGPs). HRGPs is shown to be the major components of structural cell wall proteins. They all are glycosylated and contain hydroxyproline (Hyp).

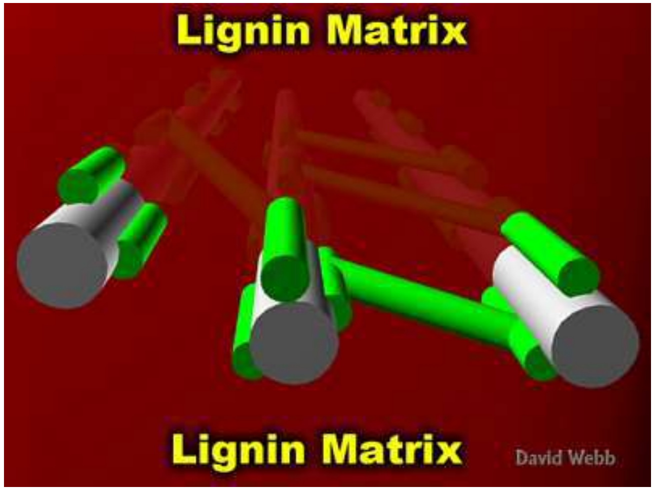
Protein class	% Protein	% Sugar	Peptide periodicity	Hyp-Oglycosylation	Repetitive units
Proline-rich proteins (PRPs)	80~100	0~20	Highly periodic	Lightly glycosylated	Pro-Hyp-Val-Tyr-Lys motif
Extensins	~45	~55	Periodic	Moderate glycosylated	Ser-Hyp4 motif
Arabinogalactan proteins (AGPs)	1~10	90~99	Least periodic	Highly glycosylated	Ser-Hyp-Hyp-Ara-Pro-Ara-Pro or Ara-Hyp motif

•**Enzyme proteins**: Enzymes like Peroxidases, celluloses, pectinases, kinases, phosphatases are associated with wall and are responsible for wall turnover and remodeling, particularly during growth. These proteins are thought to strengthen the wall, and they are produced in greatly increased amounts as a local response to attack by pathogens.

•**The middle lamella** cements together primary wall of two adjacent cells. It is mainly pectic in nature but often becomes lignified in older cells (lignin: a complex chemical compound, polymer, gives rigidity) Middle lamella (region between cells) is composed of pectin and glues cells together. It is hydrophilic (holds up to 65% water in primary walls) in nature.



These Cells are called Fibers. They have thick Secondary Walls. The Middle Lamella is visible as the Yellow Lines that occur where adjacent Cell Walls meet. The red colour indicates the presence of Lignin in the Secondary Walls.

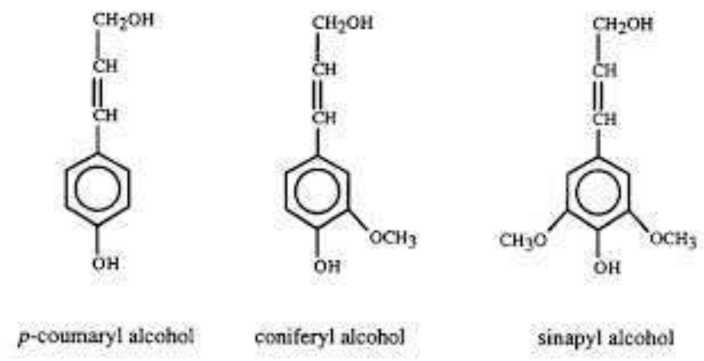


Pectins can be replaced by Lignin which is impervious to water. Lignin adds tremendous amount of strength to Cell Walls and also makes them inflexible.

Secondary cell wall: As cell wall expansion stops at the end of growth, cell continues to synthesize secondary cell wall. Secondary cell wall is thick and provides mechanical support Secondary cell wall Surround the cells that differentiate to form specialized functions (e.g. wood elements like xylem cells, bark cells) and mature cells. They have altered polysaccharide composition as compared to primary cell walls. They often are lignified. Secondary cell wall is multilayered and differs in structure and composition. For example secondary wall of wood shows high proportion of cellulose and xylans, show specific alignment of cellulose microfibrils which are impregnated with lignin.

Organization of secondary cell wall: Two main components of secondary cell wall are ***cellulose and lignin***. Cellulose deposition continues from development of primary cell wall and it gets impregnated with lignin

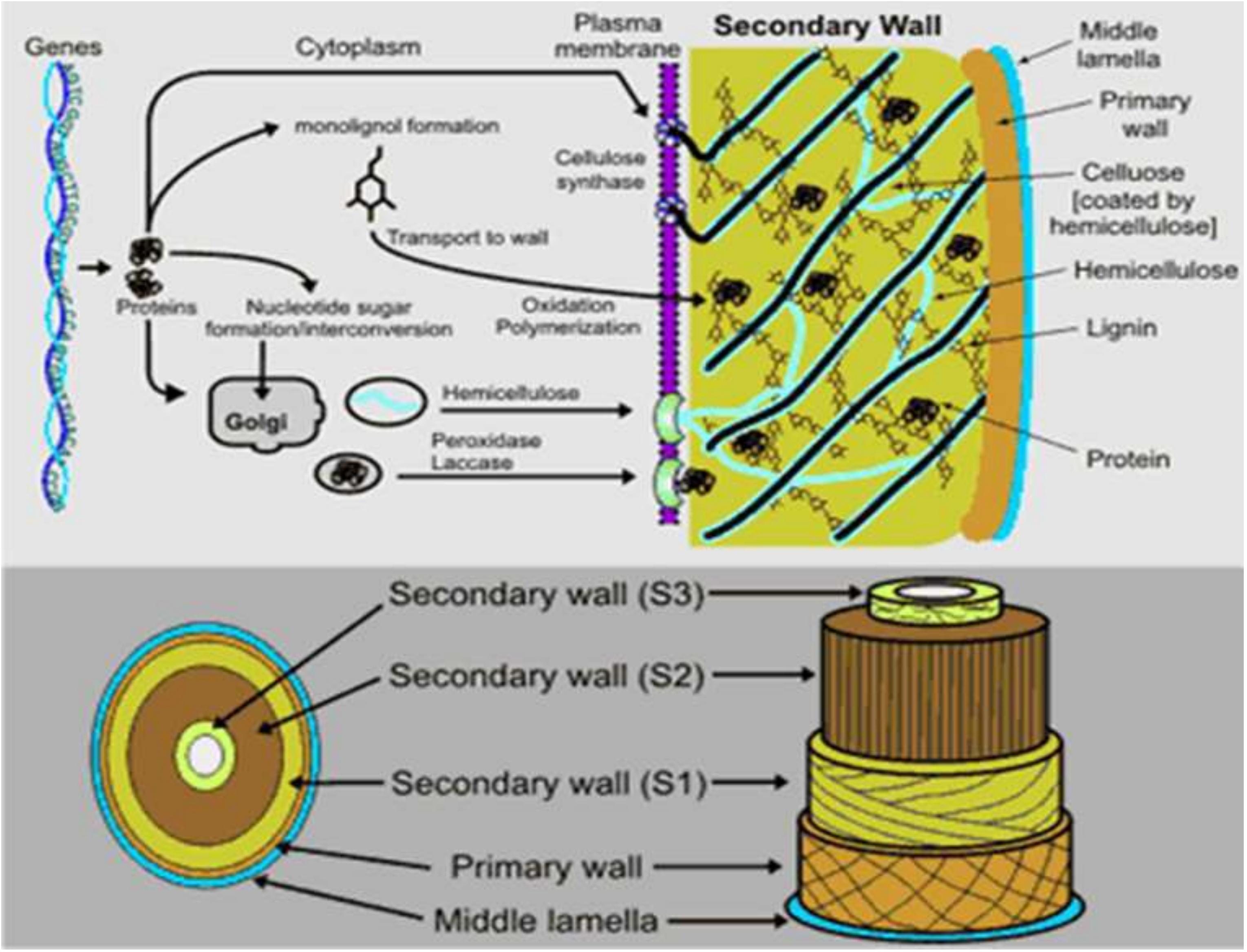
Lignin: It is a phenolic polymer with a complete pattern of linkages with aromatic alcohol subunits. These three aromatic alcohol subunits namely p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol are synthesized from phenyl alanine and deposited in the wall. Lignin provides significant mechanical strength to the wall and reduces susceptibility of walls to pathogen attack, Lignin deposition exhibits specific pattern depending on pattern of wall expansion.



Phenylpropanoid precursors of lignin.

Lignin is one of the most abundant organic polymers in plants, just after cellulose. It is the exclusive chemical composition of gymnosperm and angiosperm cell walls. The content of lignin in wood and Gramineae is 20–40% and 15–20 %, respectively. Variation is manifested in different species of plants, length of growing season, and different parts of the plants. Even in the different morphologies of cells of the same xylem or different cell wall layers, the structures of lignin are not the same in them.

A hypothetical model of secondary cell wall biogenesis has been proposed by workers, which is depicted in the figure below.



Structure of secondary cell wall:

Secondary wall is frequently made of three layers which are designated as follows:

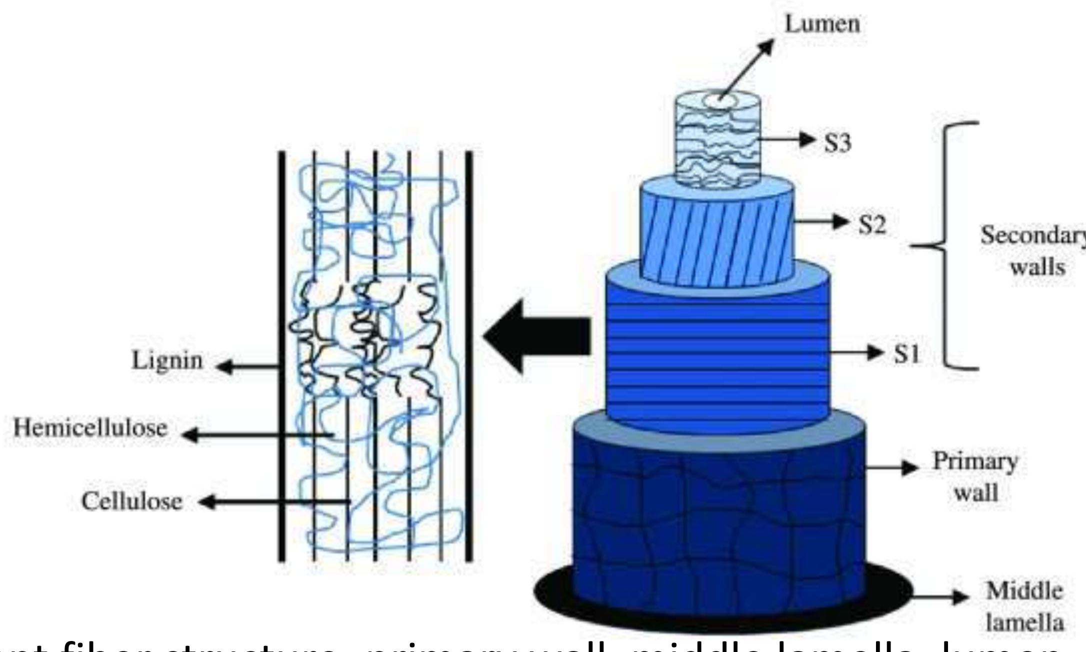
S1: medium thick, after primary cell wall

S2: the thickest and comes after S1

S3: may be very thin or lacking, some times called tertiary wall

Because the different orientations of cellulose microfibrils in the three layers which are helically oriented but with different slopes these layers can be differentiated. These are impregnated with lignin, which replaces pectin as lignin is a phenolic compound that strengthens the wall, makes it waterproof and resistant to decay and animals attack by herbivores.

The orientation of three layers is depicted in the figure below as a representation of structure of plant fiber:

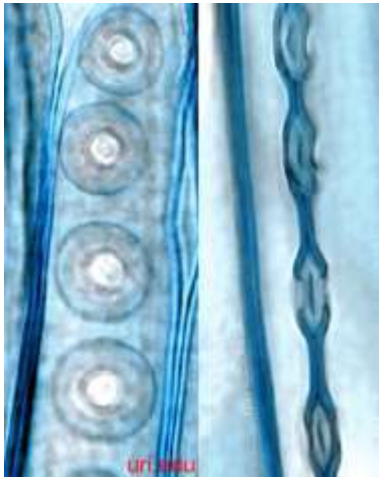


Schematic representation of plant fiber structure: primary wall, middle lamella, lumen, S1 – external secondary wall, S2 - middle secondary wall and S3 -internal secondary wall

Pits:

The primary pit field established in the primary cell wall is not covered by the secondary cell wall component, resulting in the formation of many sunken areas called pits. Sometimes, the pits can also occur in the absence of a primary pit field. Pits on the cell wall are often opposite the pits on the adjacent cell walls; the intercellular layer between the two pits and two layers of primary walls make up the pit membrane, and two opposite pits and pit membrane make up the pit pair.

Pits on the secondary wall have two types: the ***simple pit*** and the ***bordered pit***. The basic difference between them is that, in case of bordered pit, the secondary thickened wall uplifts toward the central part, hangs over the pit cavity, and forms a dome-shaped edge so that the pit aperture is significantly smaller, but this kind of dome-shaped edge does not exist in the simple pit.



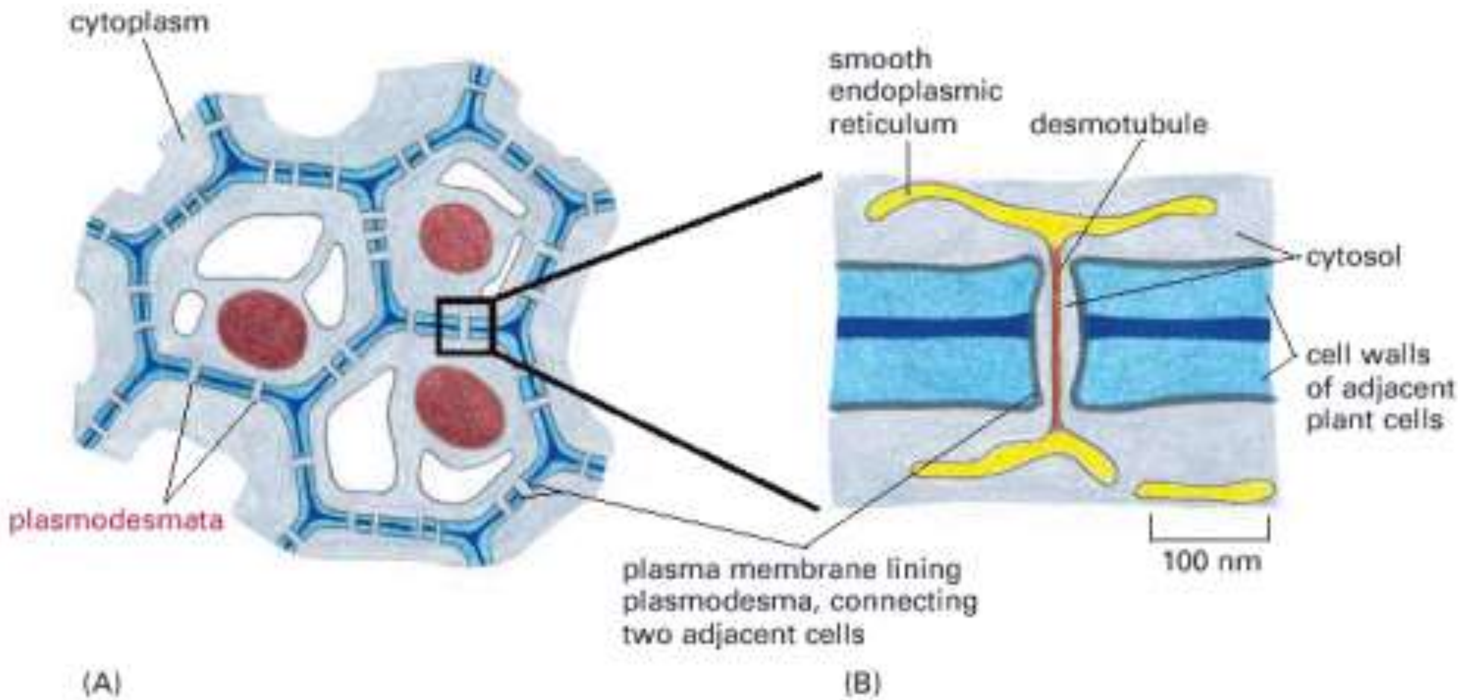
Pits: Depression occurs in secondary cell wall

Role of secondary wall:

Secondary plant cell wall thickening is vital for many aspects of plant growth as follows:

1. For the production of mechanical tissues
2. For water transport and support
3. For other aspects of mechanical force are required, for example anther dehiscence.
4. The final shape of a growing plant cell, and hence the final form of the plant, is determined by controlled cell expansion.
5. Expansion occurs in response to turgor pressure in a direction that depends in part on the arrangement or orientation of the cellulose microfibrils in the wall.
6. Each protoplasm forms its wall from outside inward. So the oldest layer of a wall is the outermost position, the most recent one is the innermost position next to protoplasm

PLASMODESMATA



- Plasmodesmata are channels in cell walls of plant cells that connect cytoplasms of adjacent cells. (Channel diameter : 20-40 nm)
- Running through center of channel is a fine tubular structure, ***plasmotubule*** **,** that is derived from smooth ER.
- These allow passage of molecules with Molecular Weight<800 (as confirmed by passage of dyes with different molecular weights).
- Some mRNA, plant viruses, infectious viral RNA can pass cell to cell through plasmodesmata.

***Disclaimer note**: All the original contributors of the concept and findings published elsewhere are gratefully acknowledged while preparing the E-content for the purpose of student reading material in convenient form for biochemistry and allied discipline.*

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