

LA PARETE CELLULARE

IL MONDO DEI VIVENTI

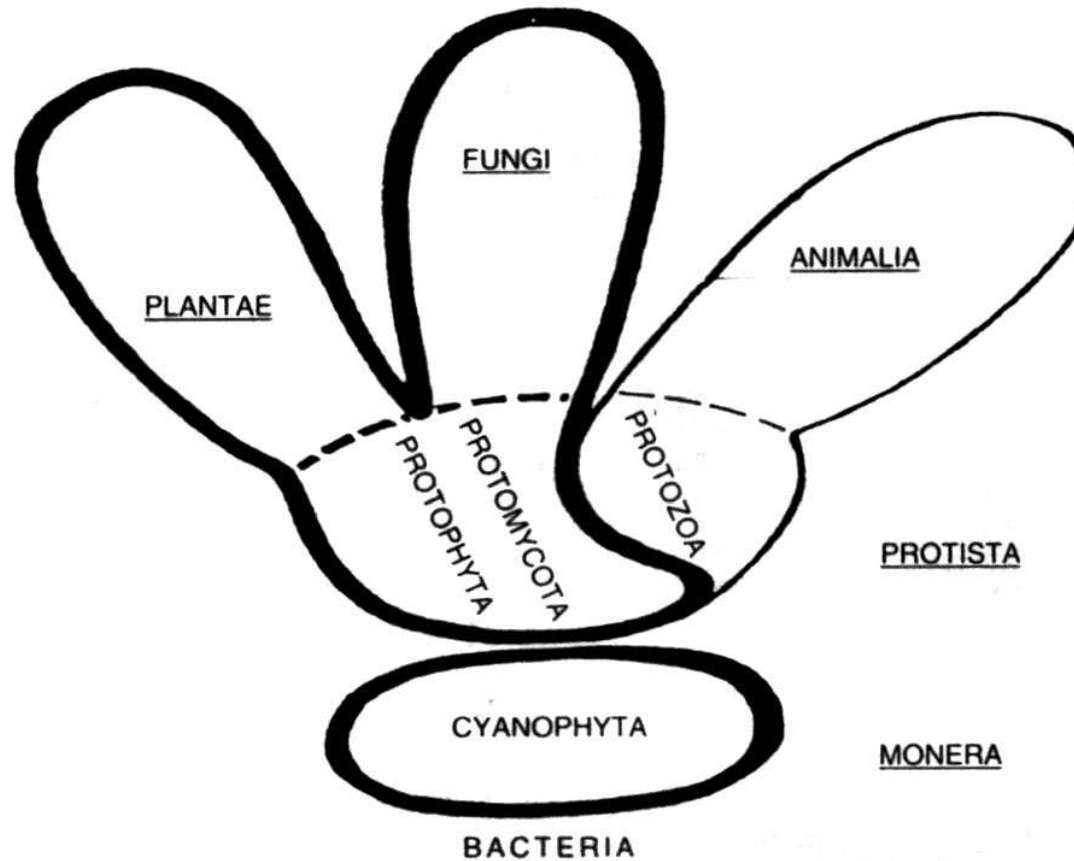


Fig. 11.2. Il mondo dei viventi è classificato in cinque regni in accordo con lo schema di Whittaker. Sono riportati in grassetto i regni i cui appartenenti posseggono pareti cellulari. (Modificato da Bartnicki-Garcia).

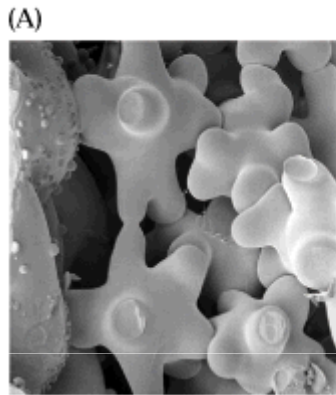
La **parete cellulare** è una struttura che circonda la cellula vegetale all'esterno della membrana plasmatica

Composta principalmente da **polisaccaridi**, **proteine** e **composti fenolici**

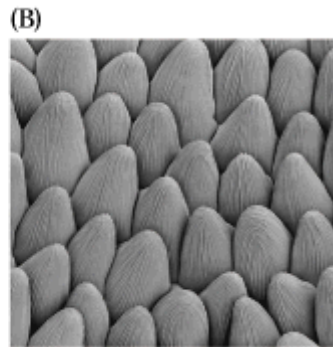
Spessore da 0,1 a 100 μm

FUNZIONI DELLA PARETE CELLULARE

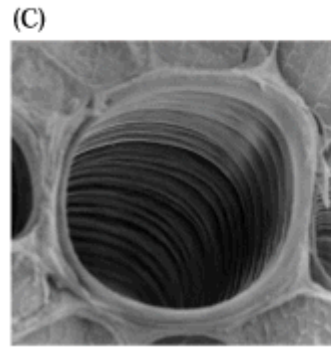
mantenimento della forma



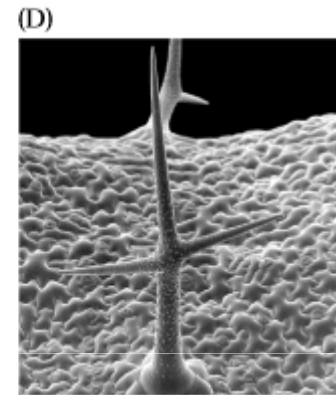
**parenchima
fogliare**



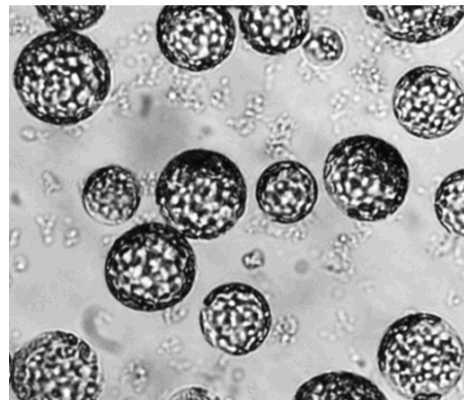
**epidermide
petali**



tracheide



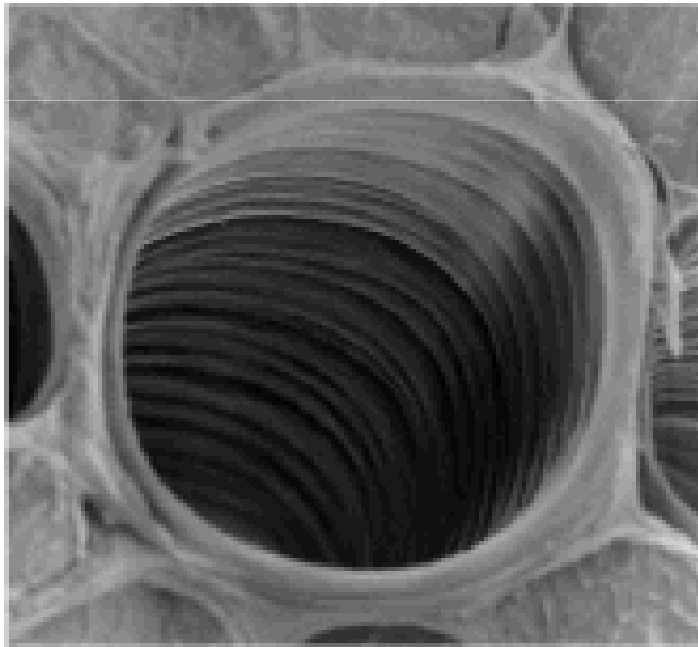
tricoma



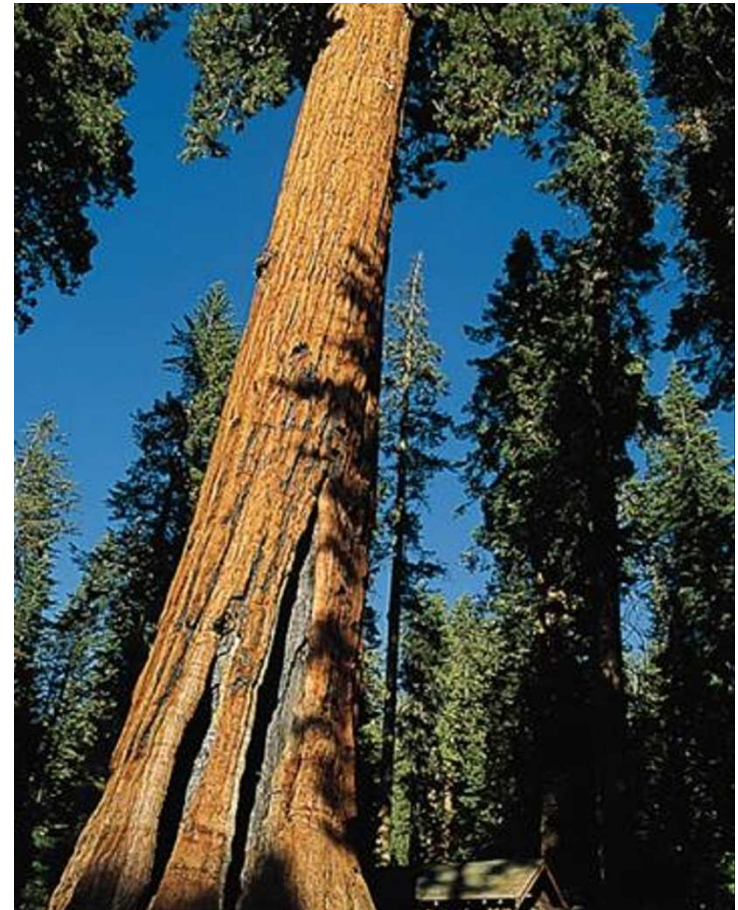
protoplasti

FUNZIONI DELLA PARETE CELLULARE

conferimento della forza meccanica



tracheide



FUNZIONI DELLA PARETE CELLULARE

controllo dell'espansione



la parete permette lo sviluppo
della pressione di turgore



FUNZIONI DELLA PARETE CELLULARE

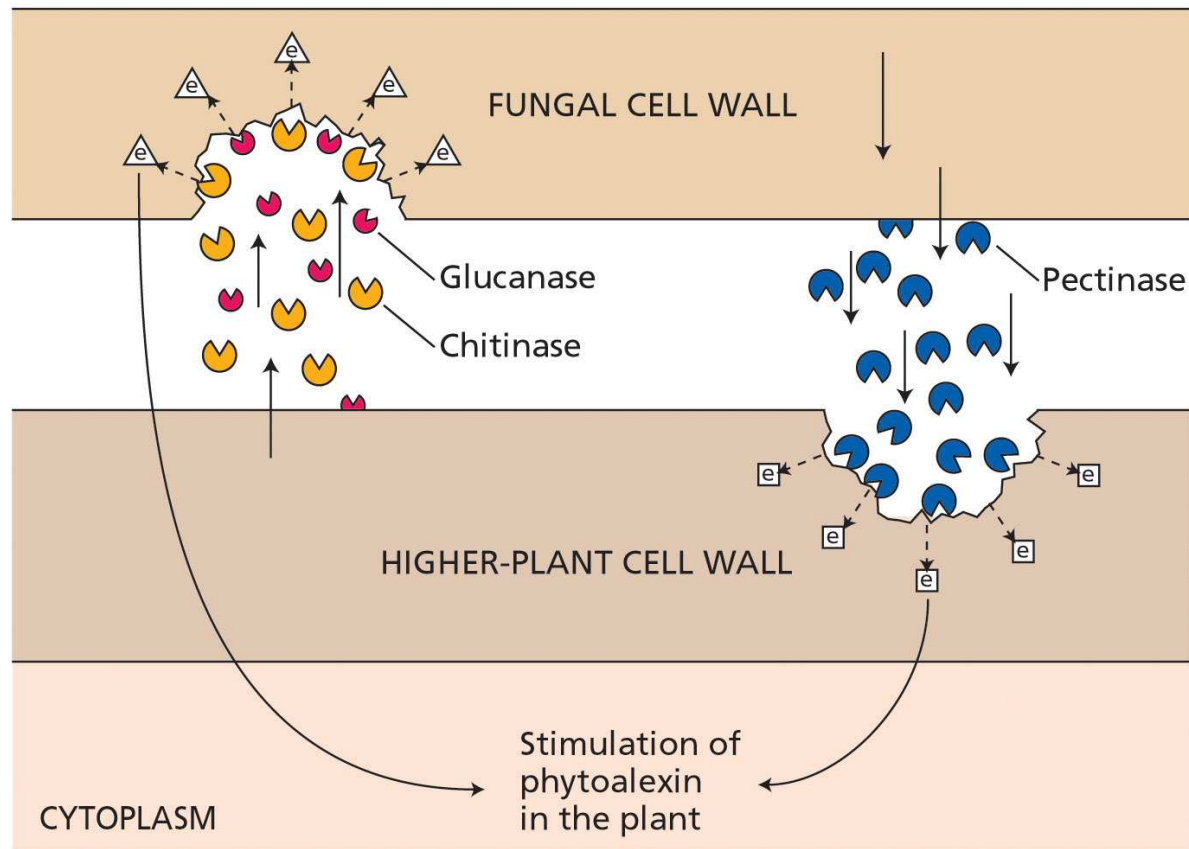
protezione da microorganismi patogeni



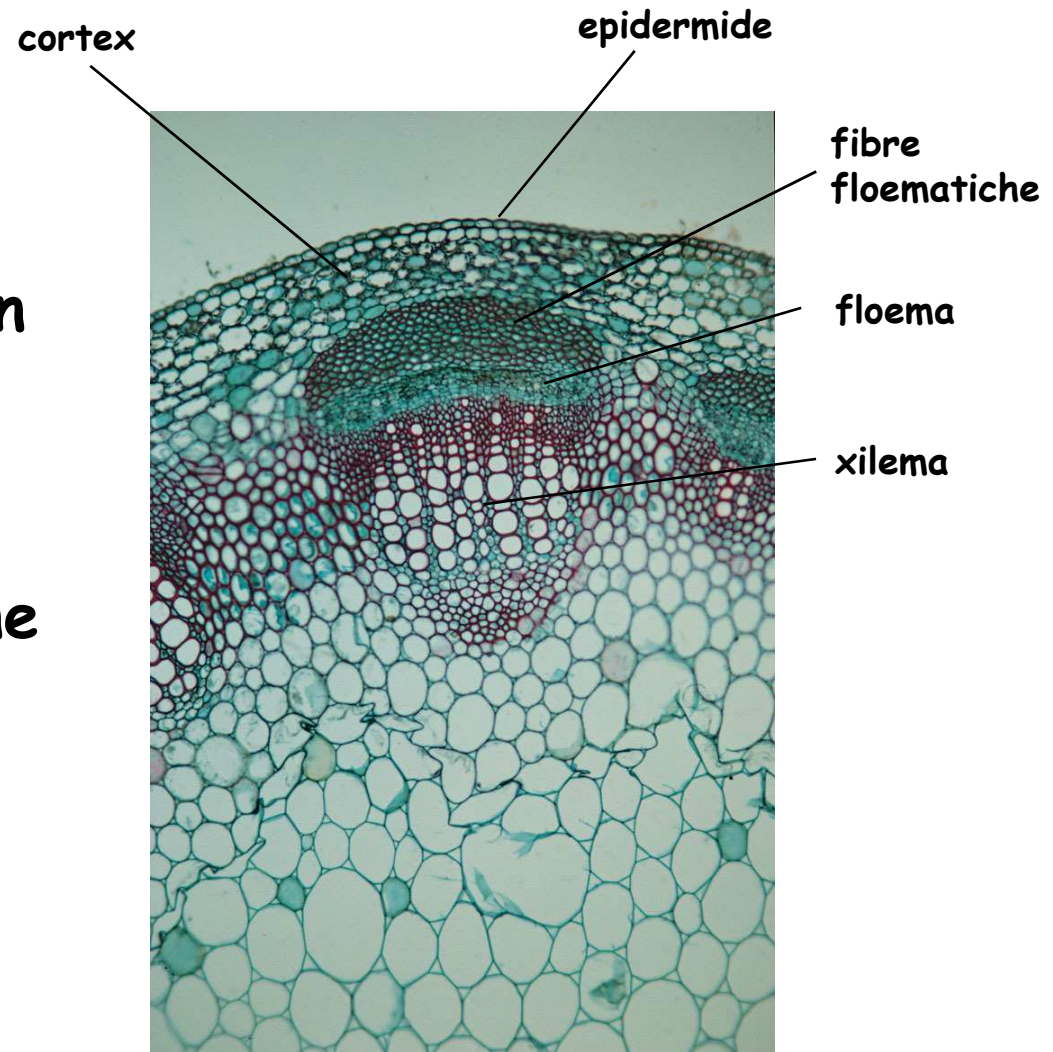
Phytophthora infestans

FUNZIONI DELLA PARETE CELLULARE

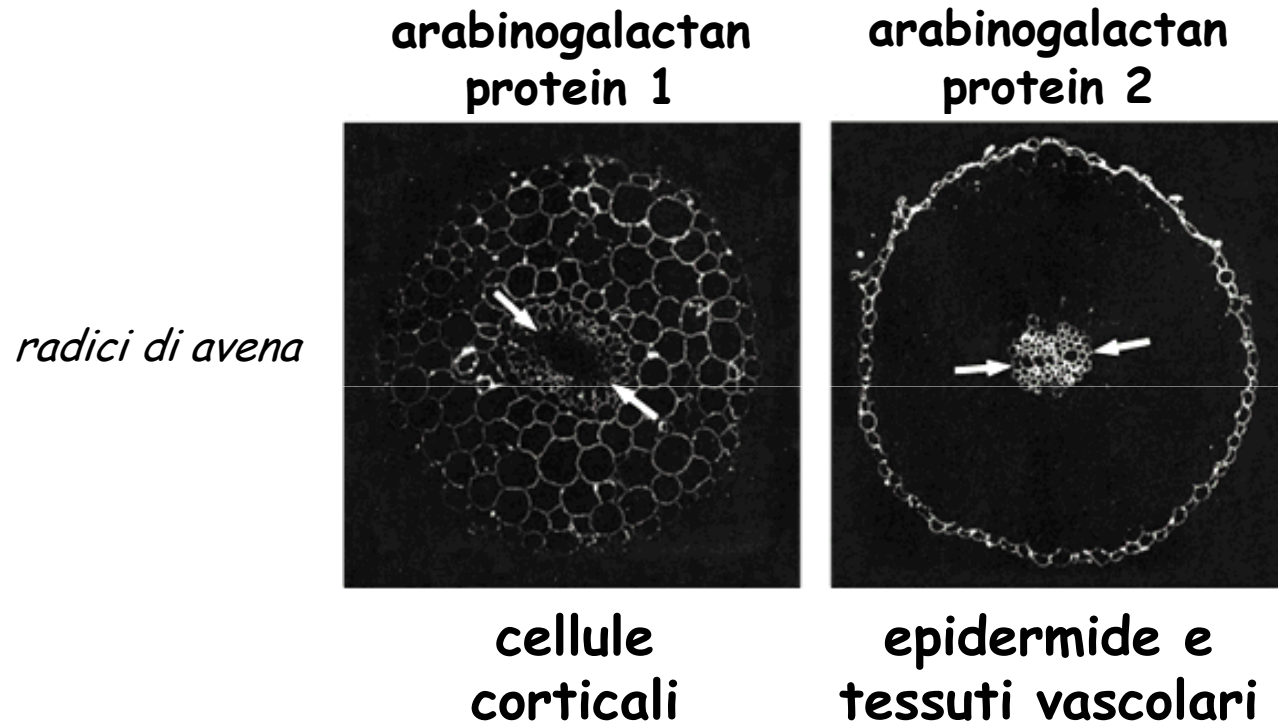
produzione di molecole segnale



la parete cellulare non è una struttura uniforme, ma varia notevolmente in aspetto e composizione nelle varie cellule

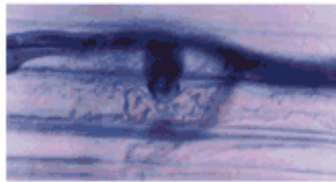


la composizione della parete varia da tessuto a tessuto



le cellule possono rispondere a patogeni con alterazioni della loro parete

(A) **MAIS**



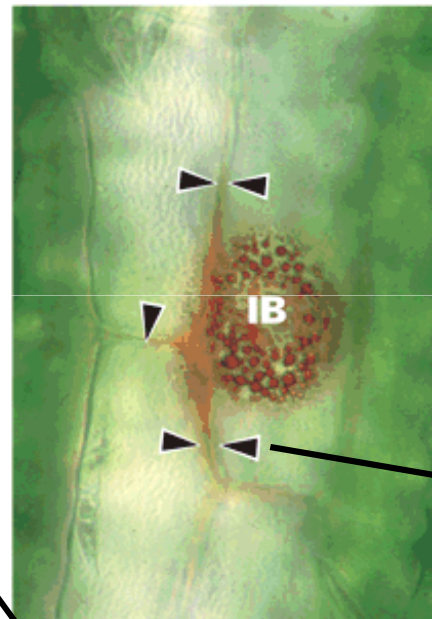
(B)



(C)



(D) **SORGO**



(A) blu= ifa fungina (*Colletotrichum*)

(B) lignina (col.specifico)

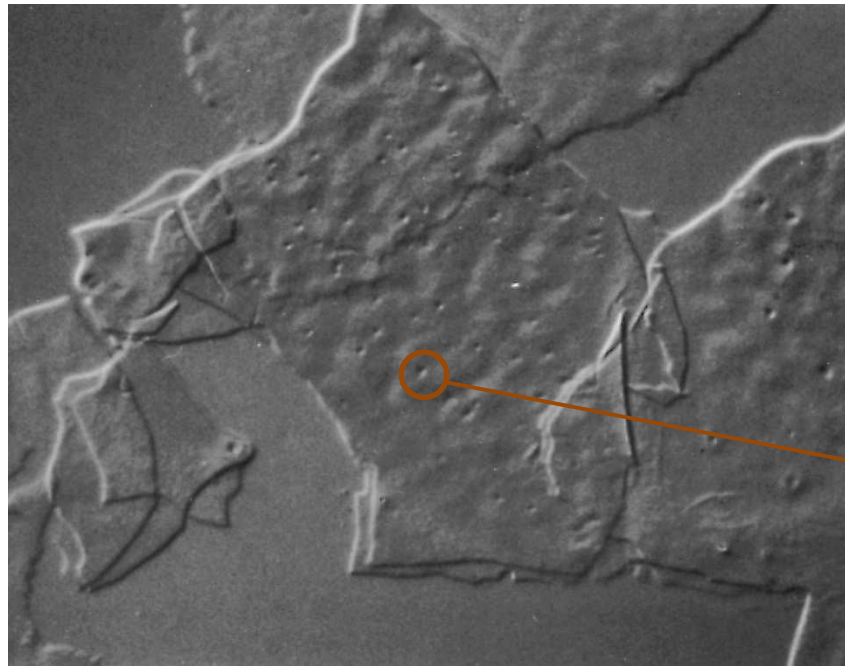
(C) lignina (siringaldeide: attività laccasi)

(D) corpi di inclusione con fitoalessine

composti fenilisoprenoidi

papilla (callosio e lignina)

pareti primarie di parenchima di cipolla



plasmodesmi

LA PARETE CELLULARE

LAMELLA MEDIANA

Si forma nelle fasi finali della mitosi ed è comune a cellule contigue

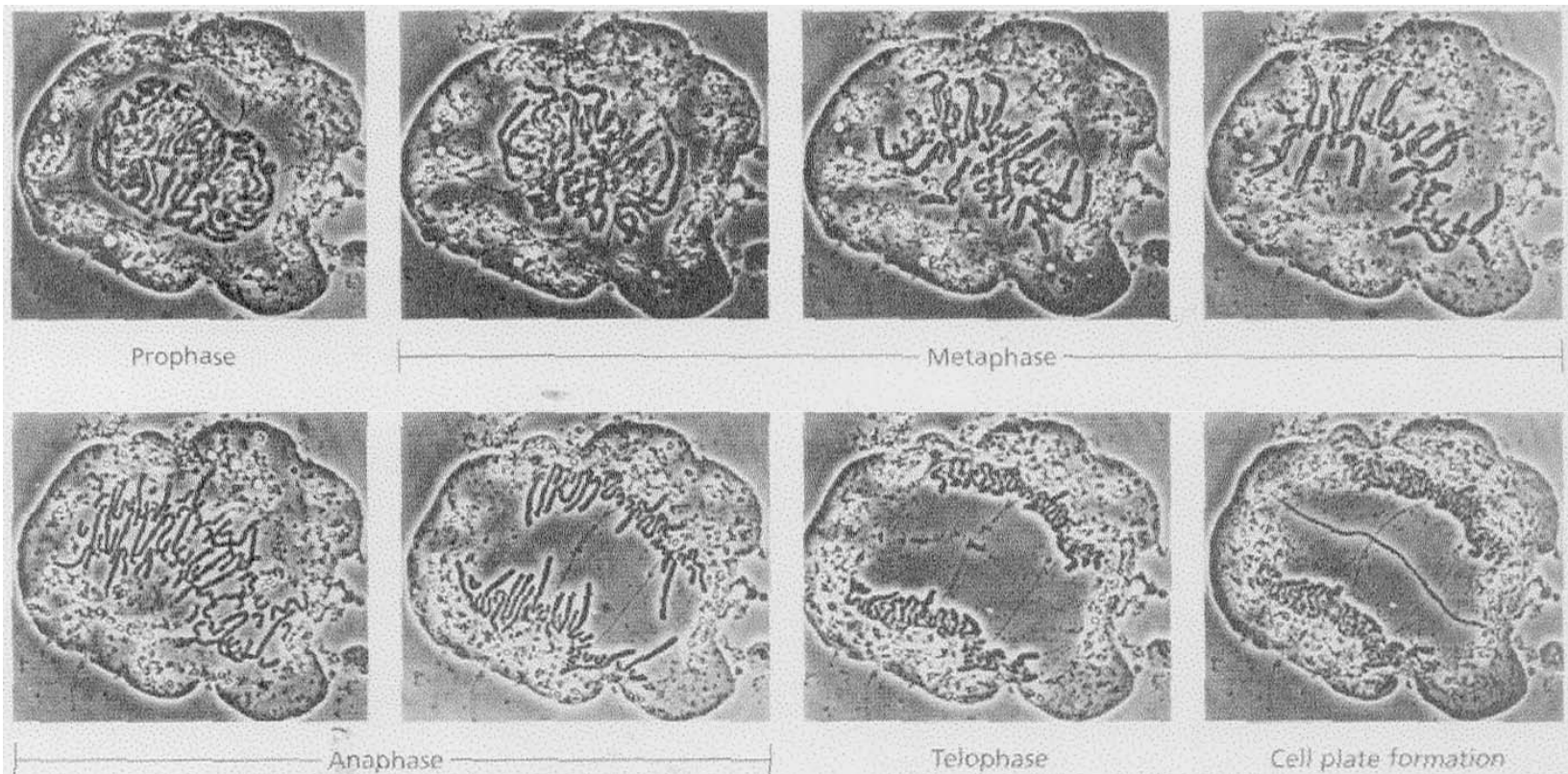
PARETE PRIMARIA

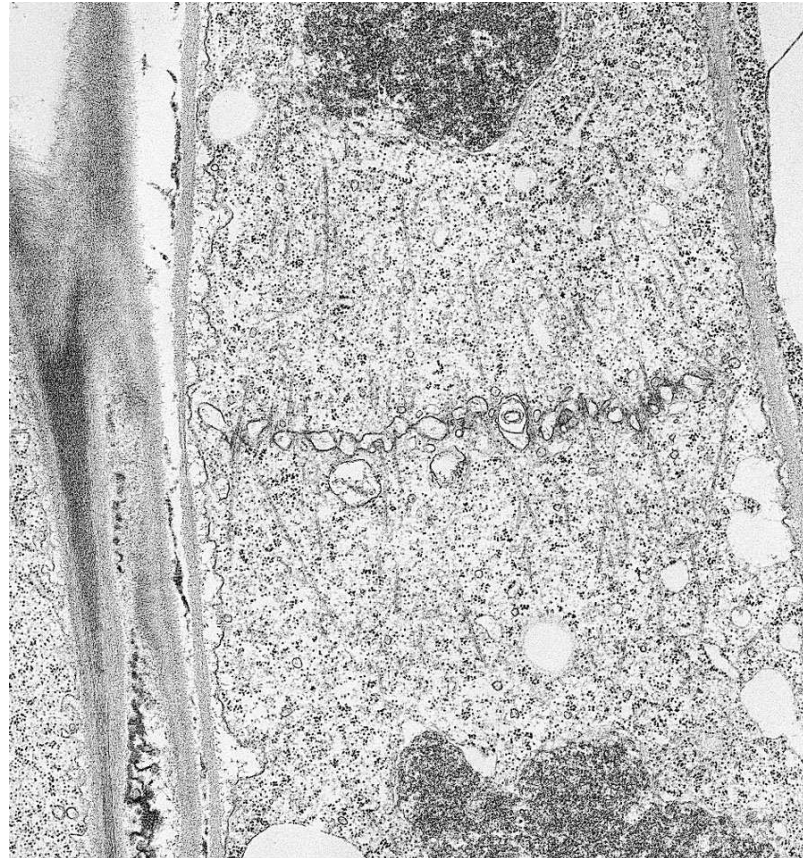
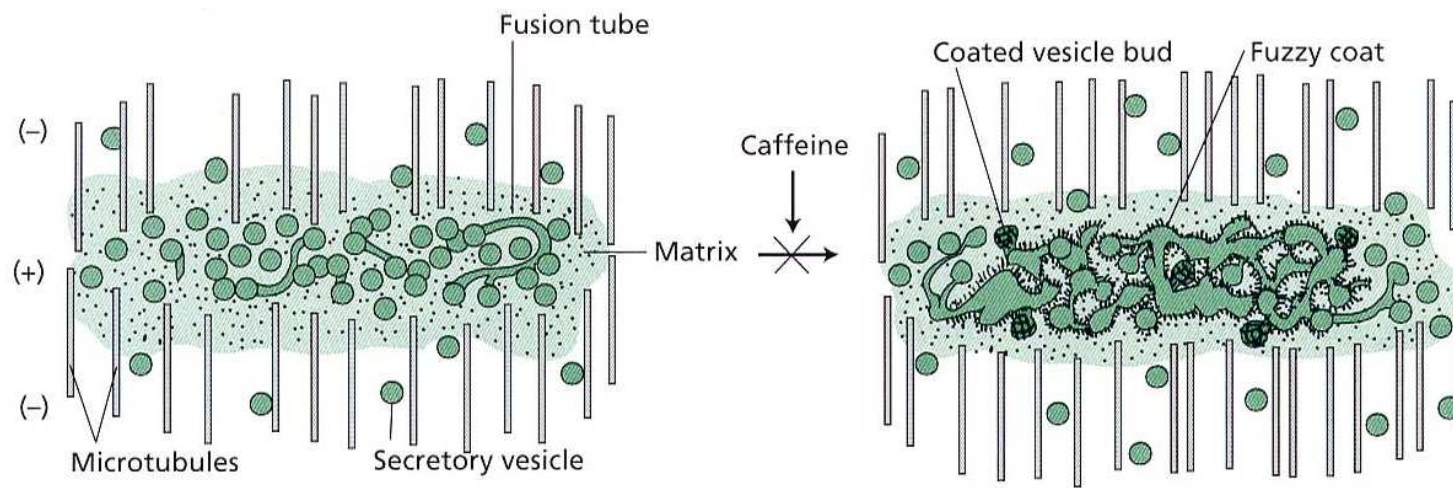
Si forma nelle cellule in crescita
Struttura simile in tutte le cellule
Spessore da 0.1 μm a 1 μm

PARETE SECONDARIA

Tipica delle cellule che hanno completato il processo di sviluppo
È formata da più strati
Ha una composizione e struttura altamente variabile

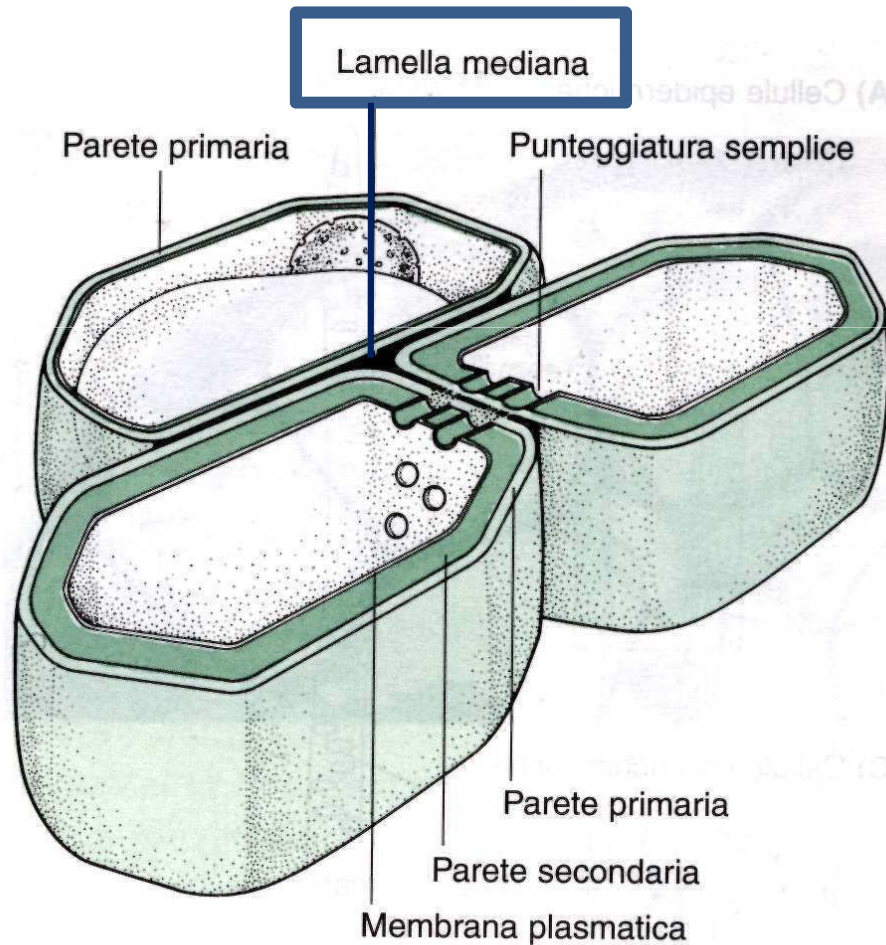
Le pareti cellulari sono assemblate durante la citochinesi





LAMELLA MEDIANA

LA PIANTA: UNA PANORAMICA SULLA STRUTTURA 11

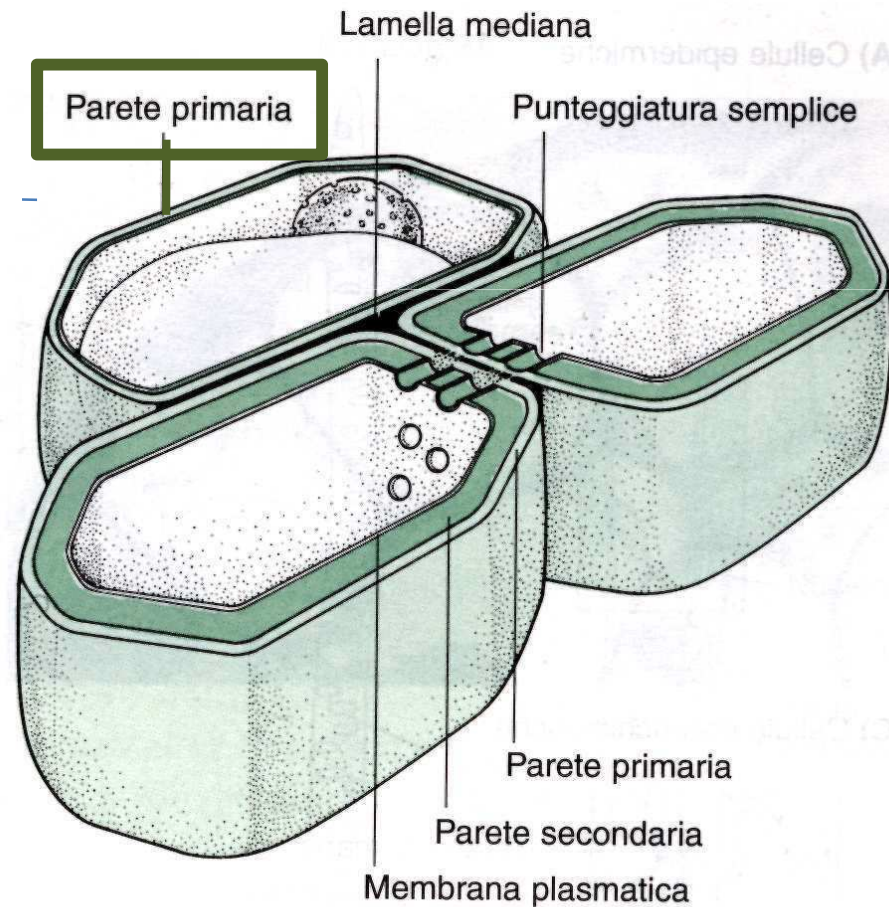


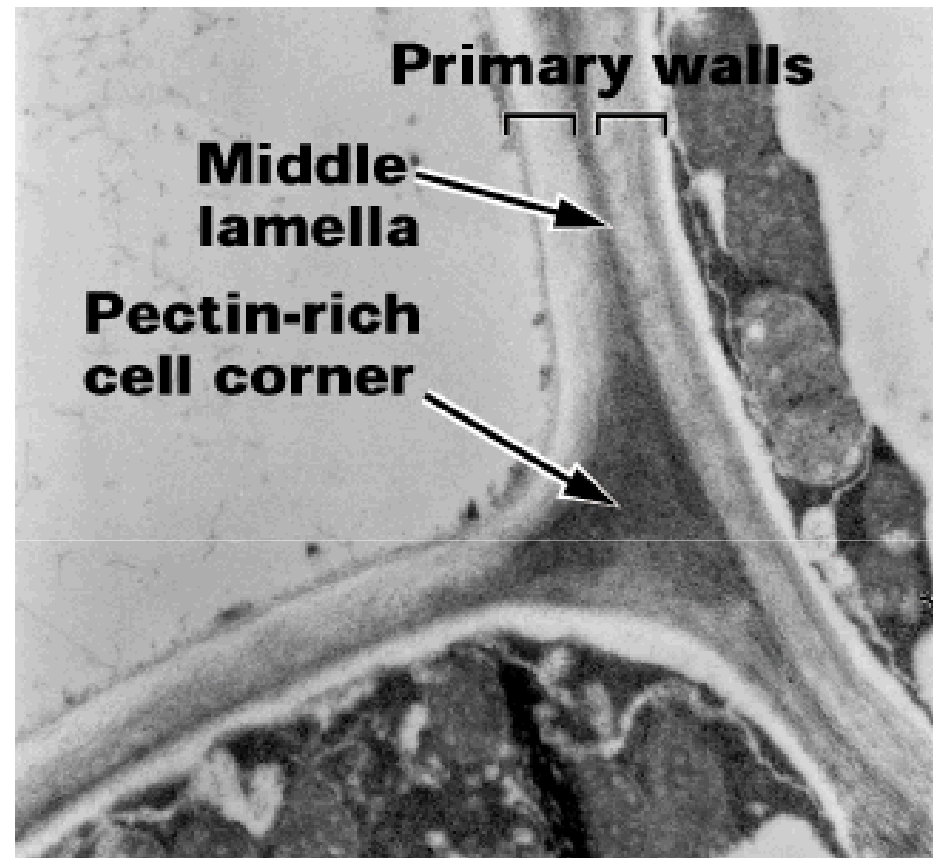
- ✓ strato più esterno
- ✓ unisce cellule adiacenti
- ✓ composta principalmente da pectine
- ✓ spessore circa 30 nm

PARETE PRIMARIA

- ✓ depositata da cellule in accrescimento
- ✓ cellulosa 25%, emicellulose 25%, sostanze pectiche 35%, proteine 1-8%
- ✓ spessore da 0,1 a 1 μm

LA PIANTA: UNA PANORAMICA SULLA STRUTTURA 11



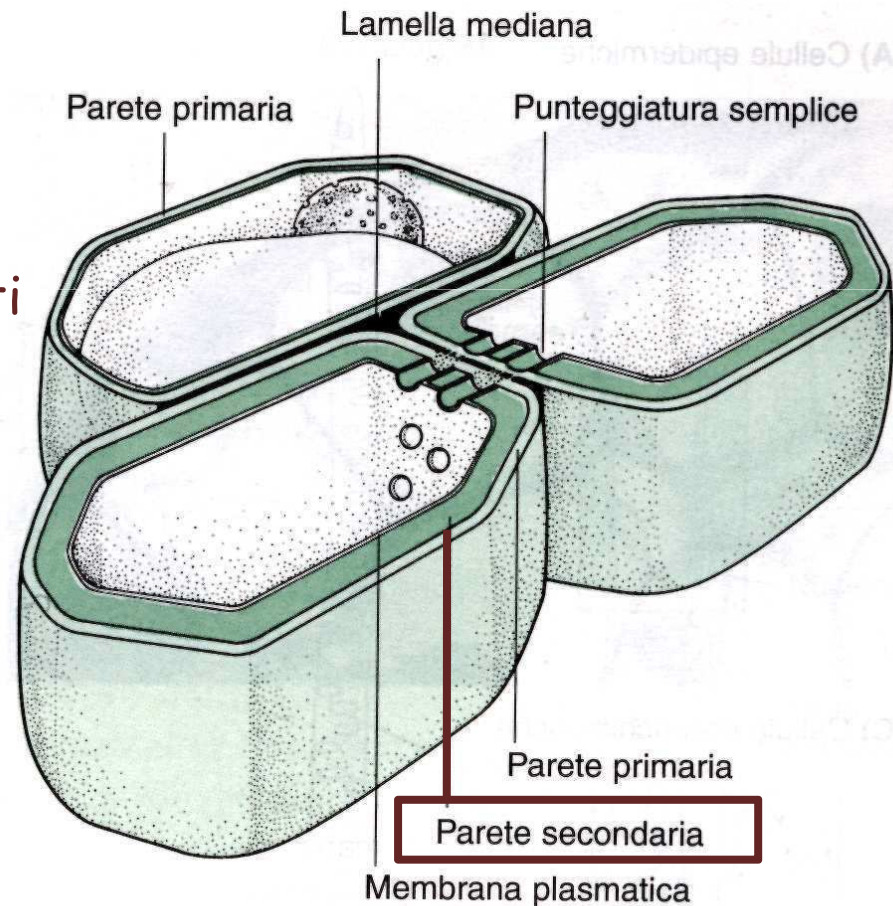


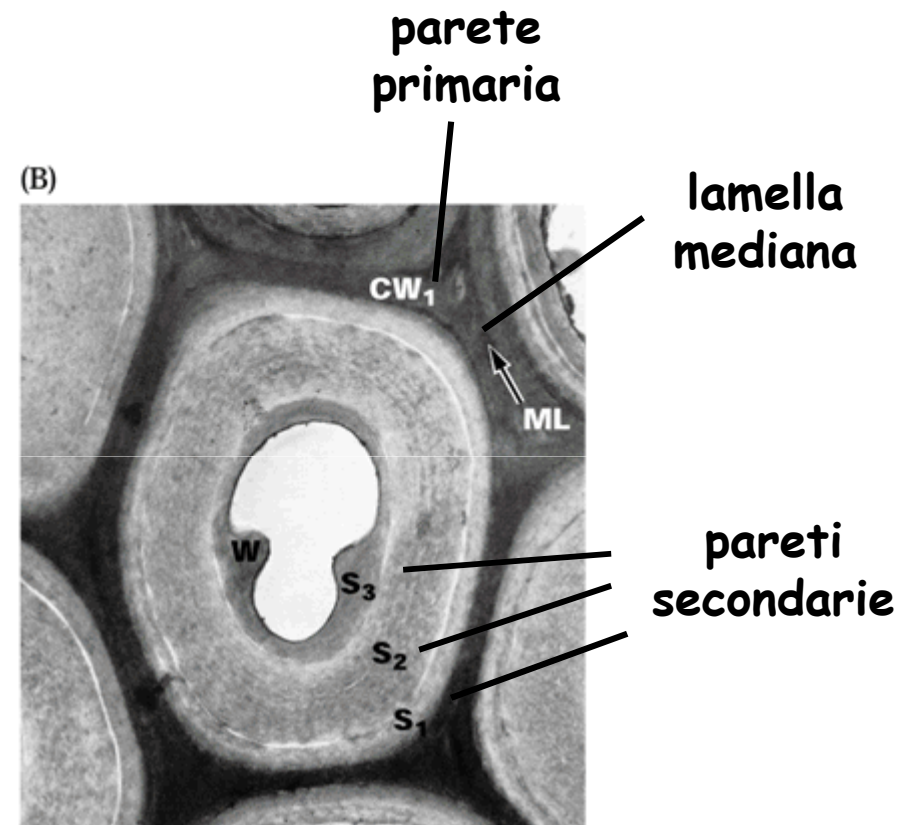
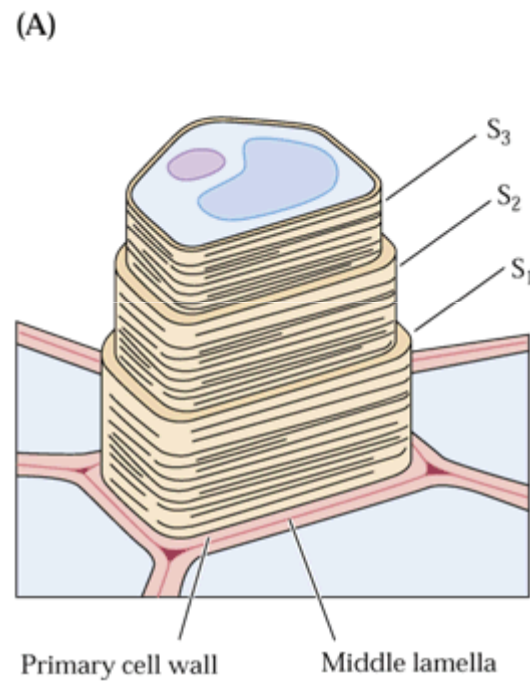
Tutte le cellule vegetali possiedono lamella mediana e parete primaria

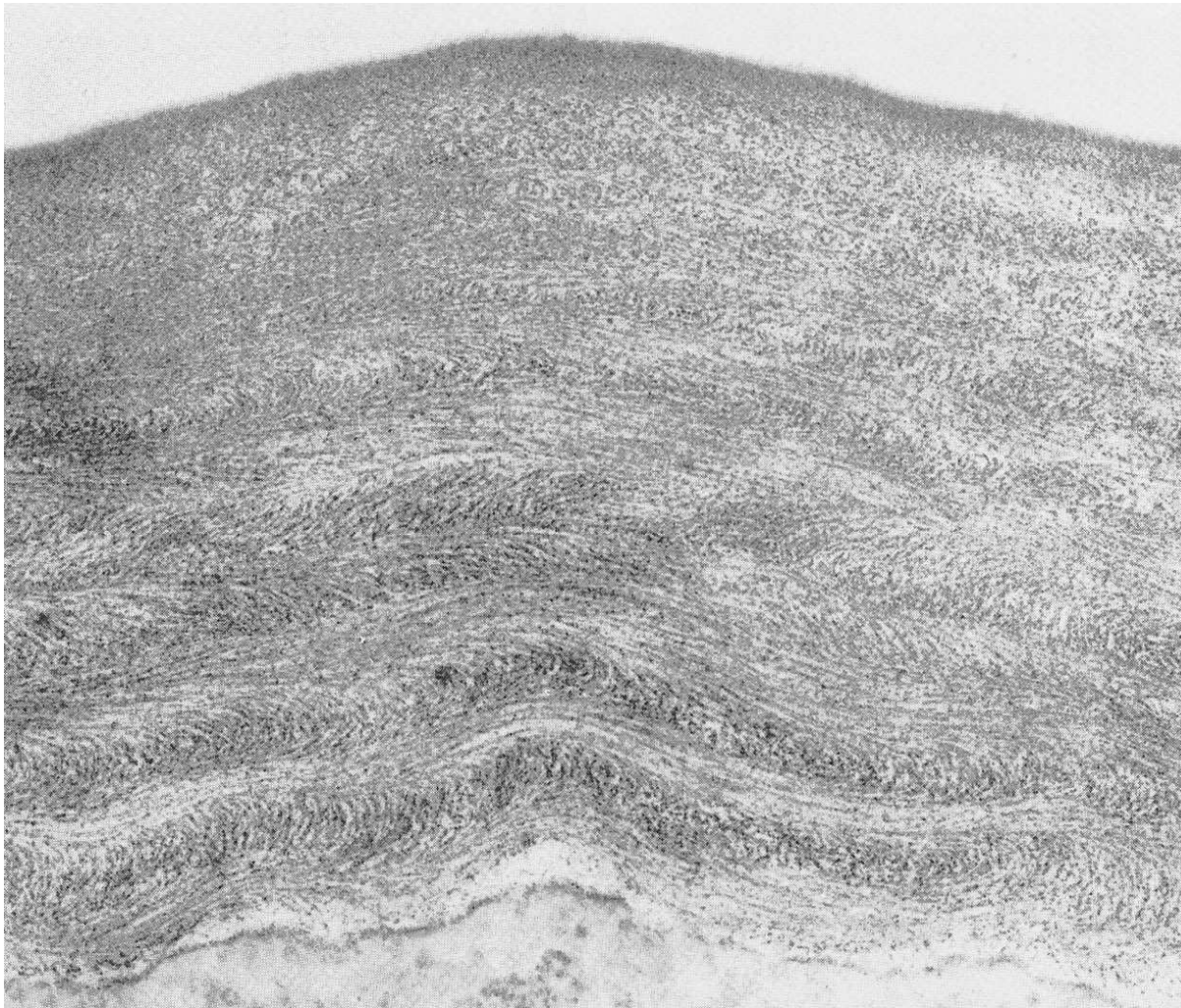
PARETE SECONDARIA

- ✓ depositata tra parete primaria e membrana plasmatica
- ✓ depositata dopo che l'espansione cellulare è completa
- ✓ spesso costituita da strati distinti
- ✓ ha funzione di supporto
- ✓ può contenere un'elevata proporzione di cellulosa e lignina
- ✓ può contenere suberina, cutina e cere

LA PIANTA: UNA PANORAMICA SULLA STRUTTURA 11







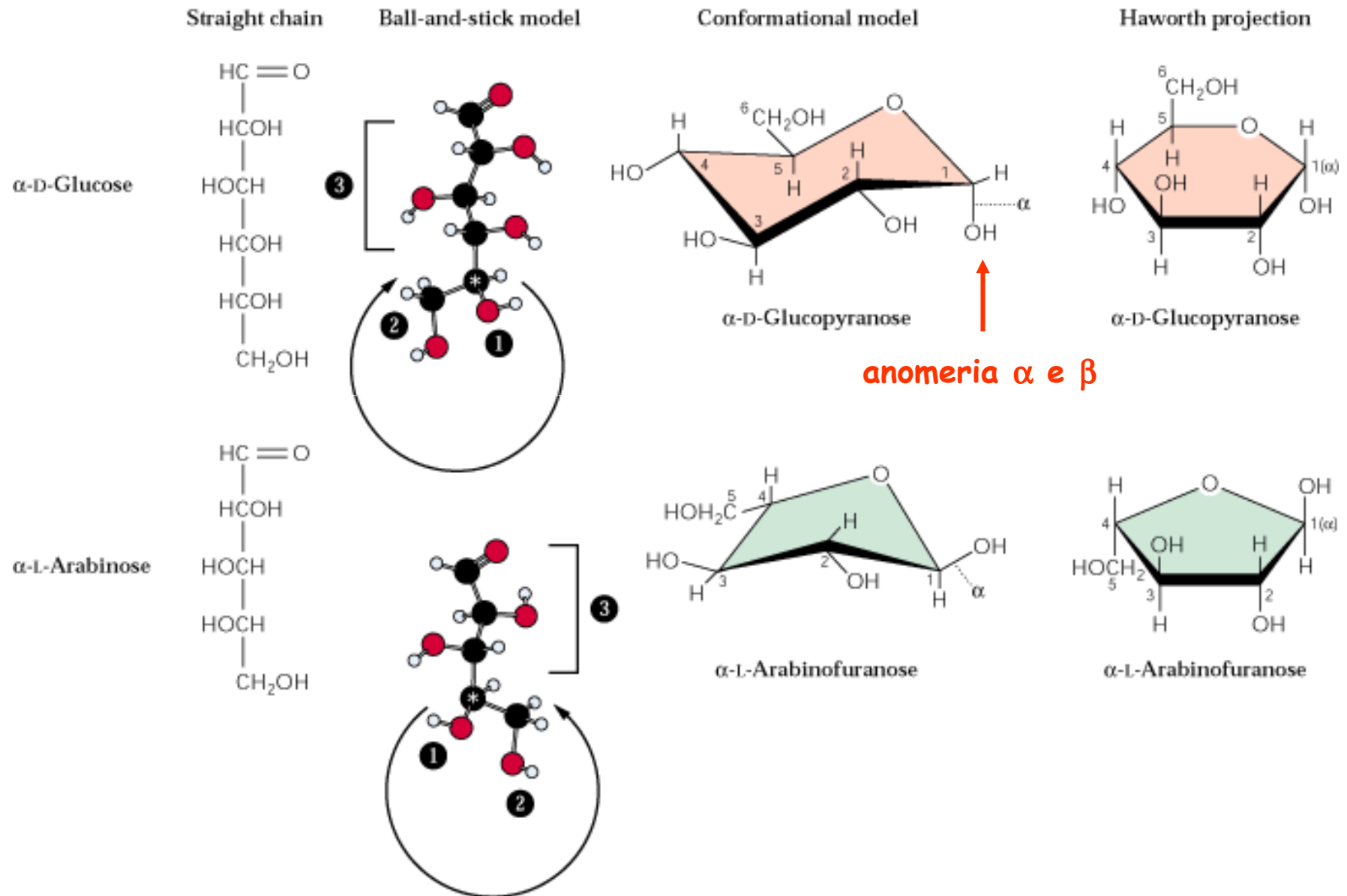
strati esterni

strati interni

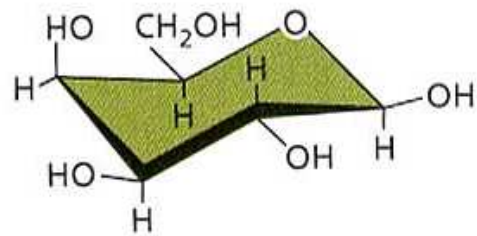
I componenti della parete primaria.

Fase	Componenti	
microfibrillare	cellulosa	(β 1,4–glucano)
matrice	pectine	ramnogalatturonano I ramnogalatturonano II arabinano galattano arabinogalattano I omogalatturonano
	emicellulose	xilano glucomannano mannano galattomannano glucuromannano xiloglucano callosio (β 1,3–glucano) arabinogalattano II
	proteine	estensine arabinogalattanoproteine proteine ricche di glicina proteine ricche di prolina proteine enzimatiche

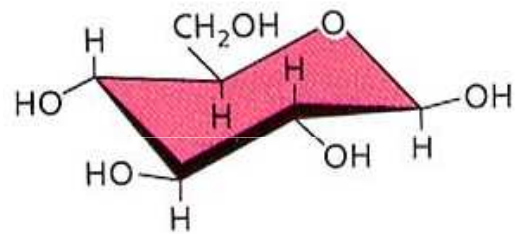
GLI ZUCCHERI



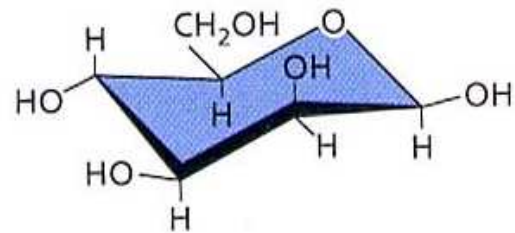
(A) Hexoses



β -D-Galactose

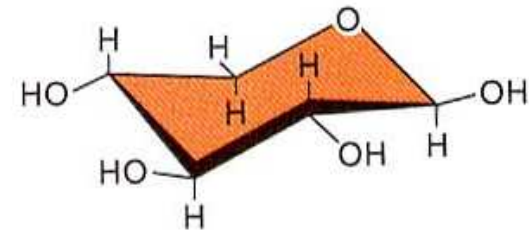


β -D-Glucose

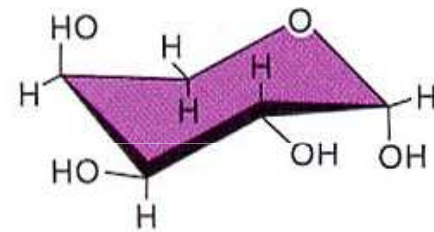


β -D-Mannose

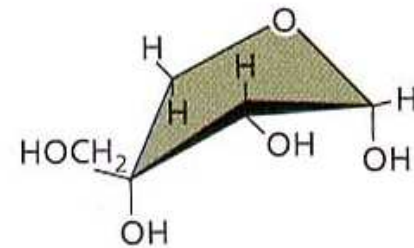
(B) Pentoses



β -D-Xylose

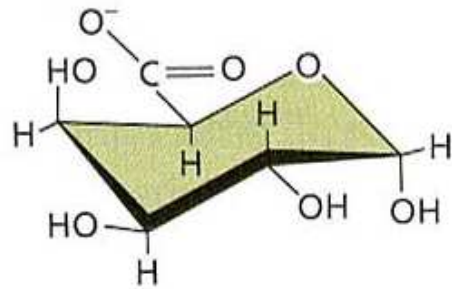


β -L-Arabinose

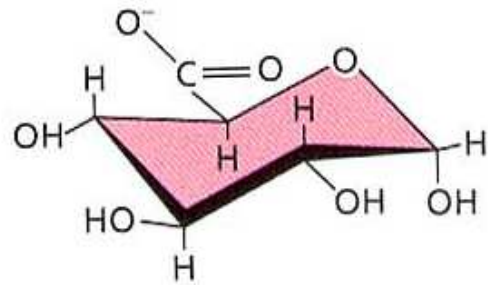


α -D-Apiose

(C) Uronic acids

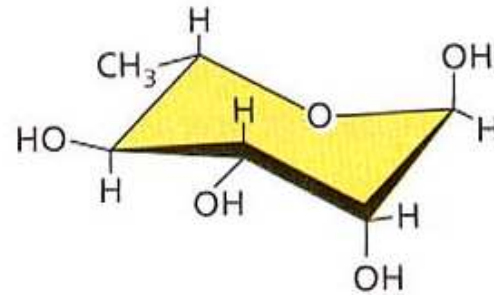


α -D-Galacturonic acid (GalA)

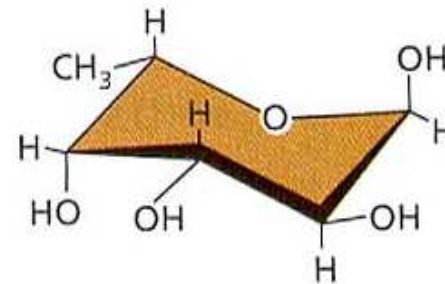


α -D-Glucuronic acid (GlcA)

(D) Deoxy sugars



α -L-Rhamnose (Rha)



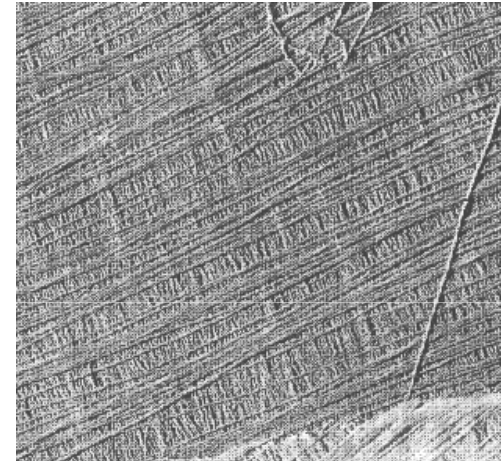
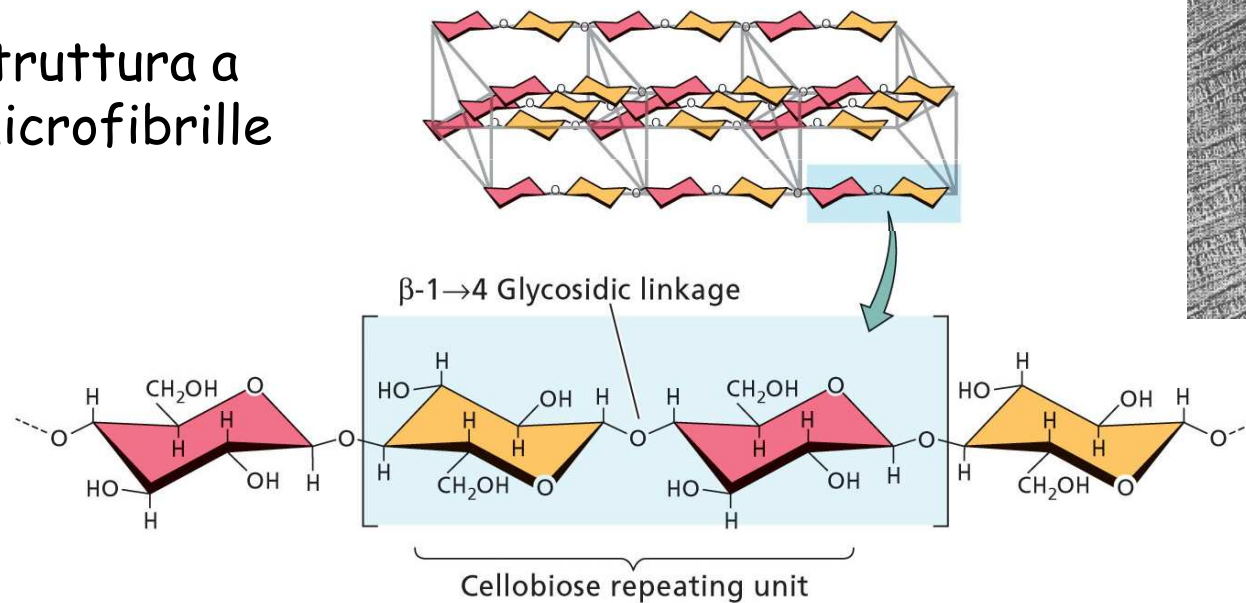
α -L-Fucose (Fuc)

CELLULOSA

costituisce circa il 30% del peso delle pareti primarie

polimero lineare di D(+)-glucosio in legame $\beta(1 \rightarrow 4)$

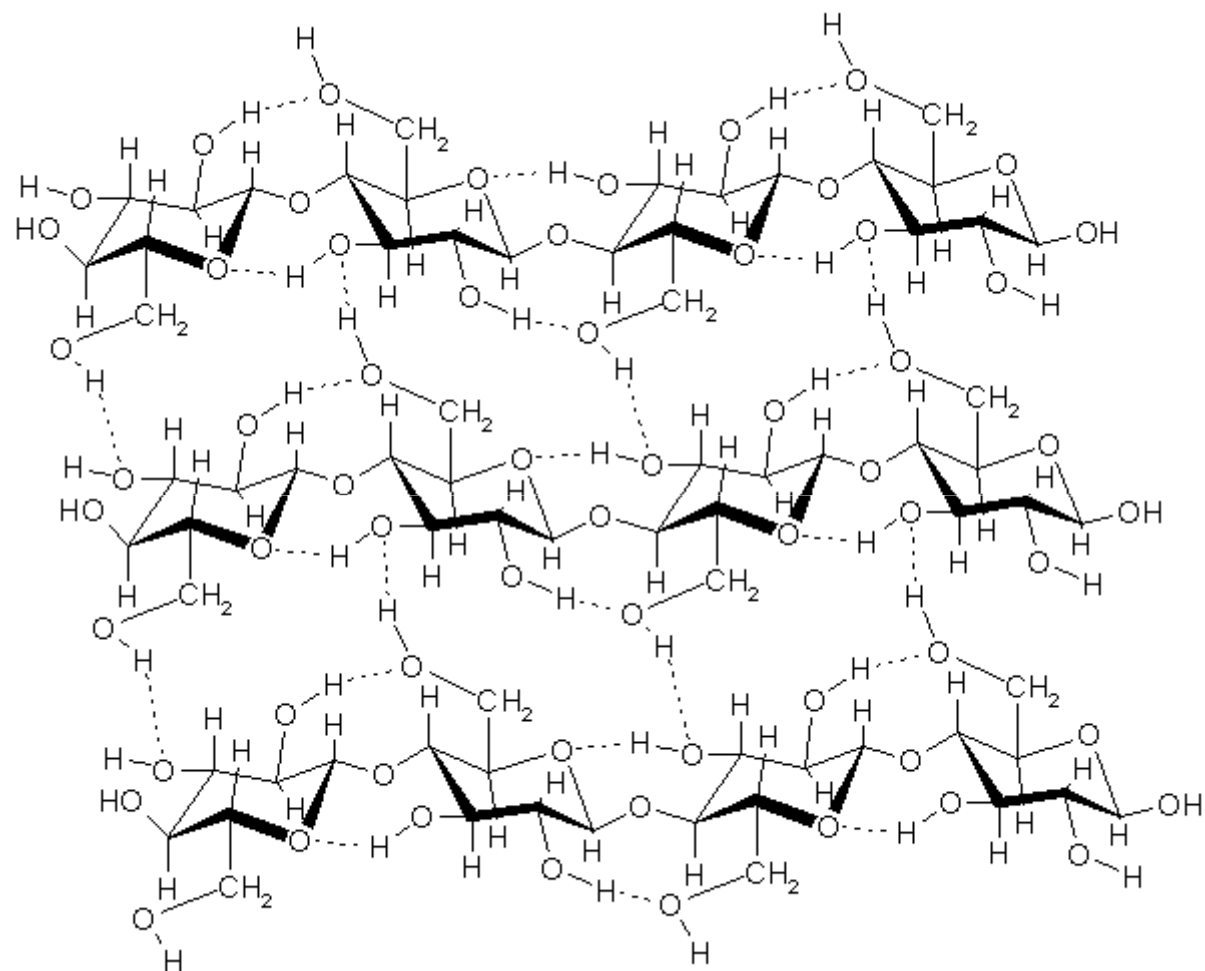
struttura a microfibrille

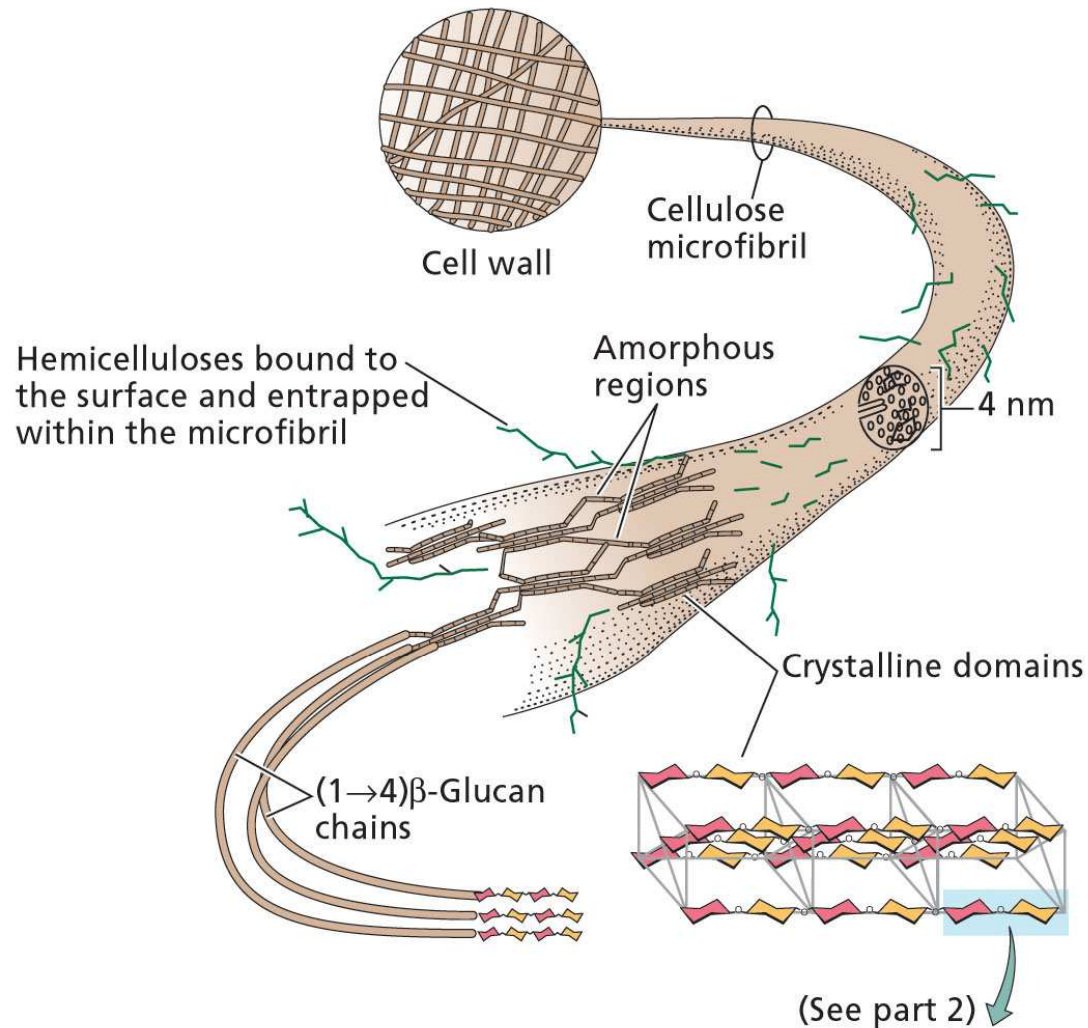


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FORZA TENSILE COME L'ACCIAIO

Legame idrogeno tra glucani adiacenti





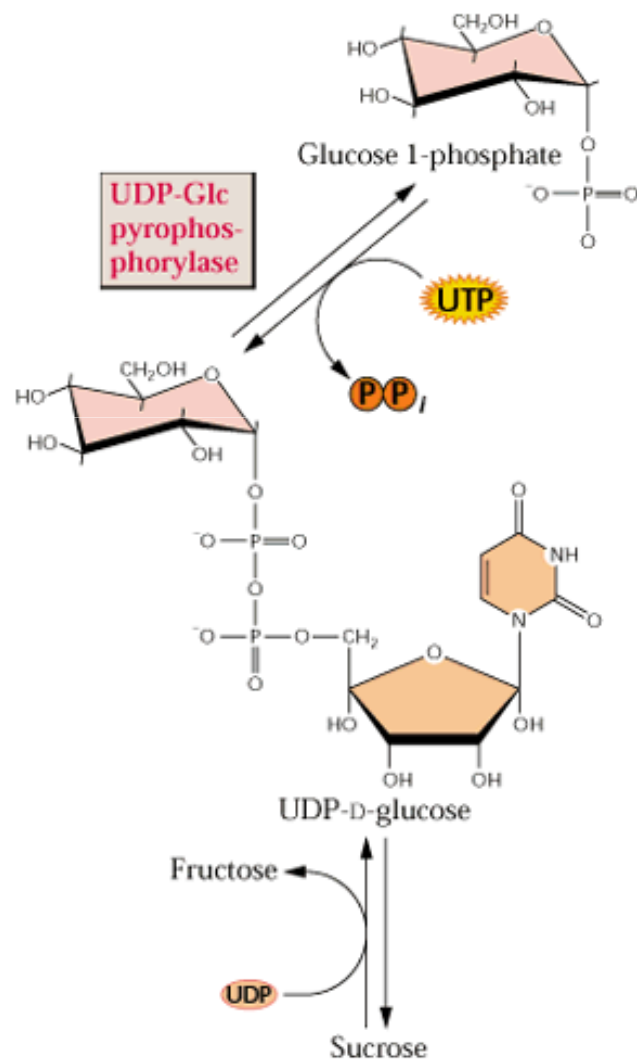
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lunghezza catene: da
circa 2000 a circa
20000 residui di glucosio

dimensioni microfibrille:
da circa 30 catene
(alghe) a circa 200
catene
Diametro 4-15 nm

il grado di cristallizzazione e polimerizzazione è più
elevato nelle pareti secondarie

LA CELLULOSA È SINTETIZZATA DA UDP-GLUCOSIO

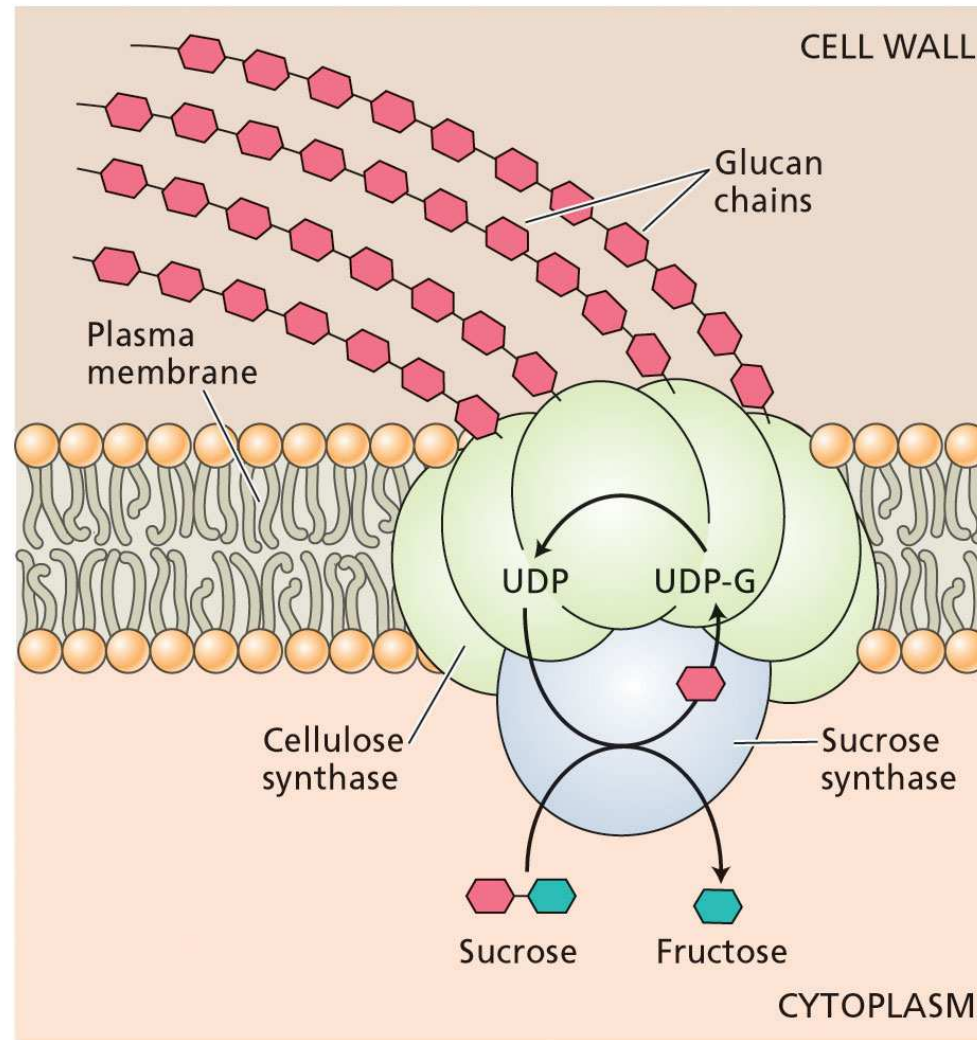


sio sintasi

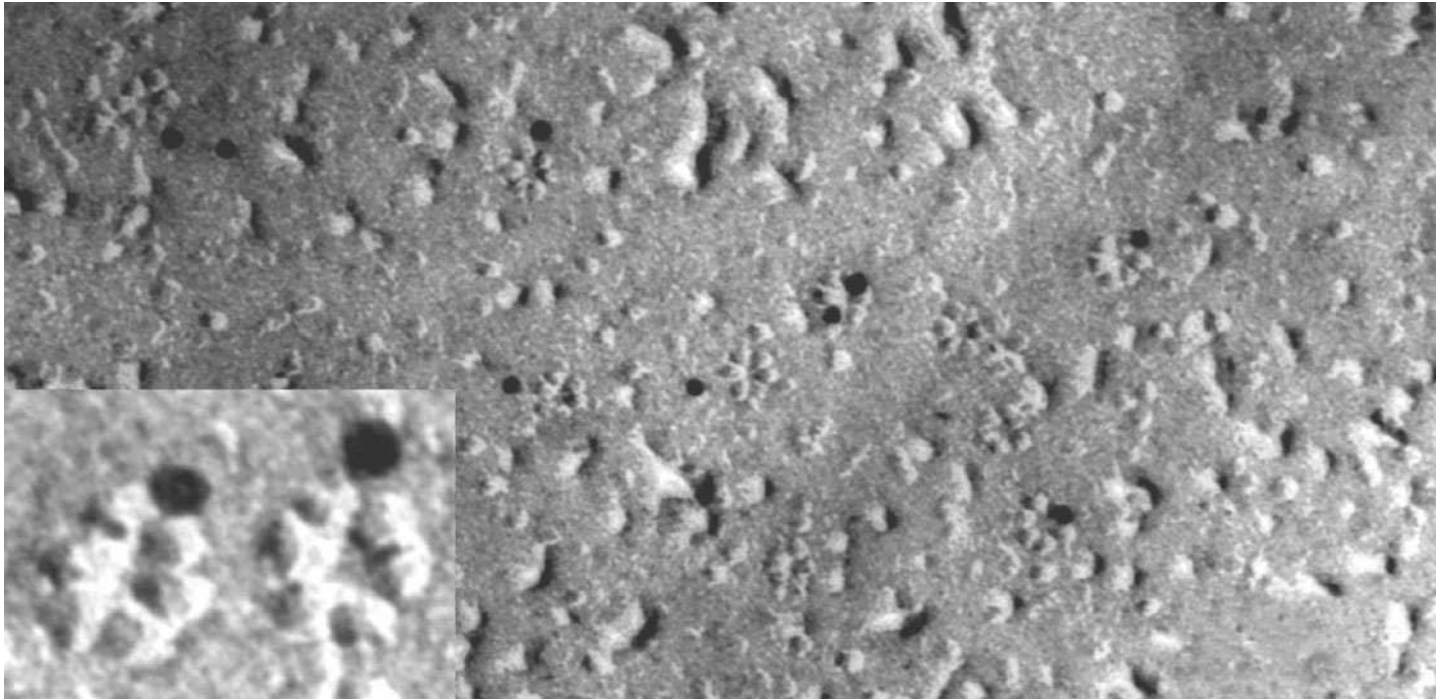
COMPLESSO ENZIMATICO DELLA CELLULOSA SINTASI

Famiglia genica
CesA (10 membri in
Arabidopsis)

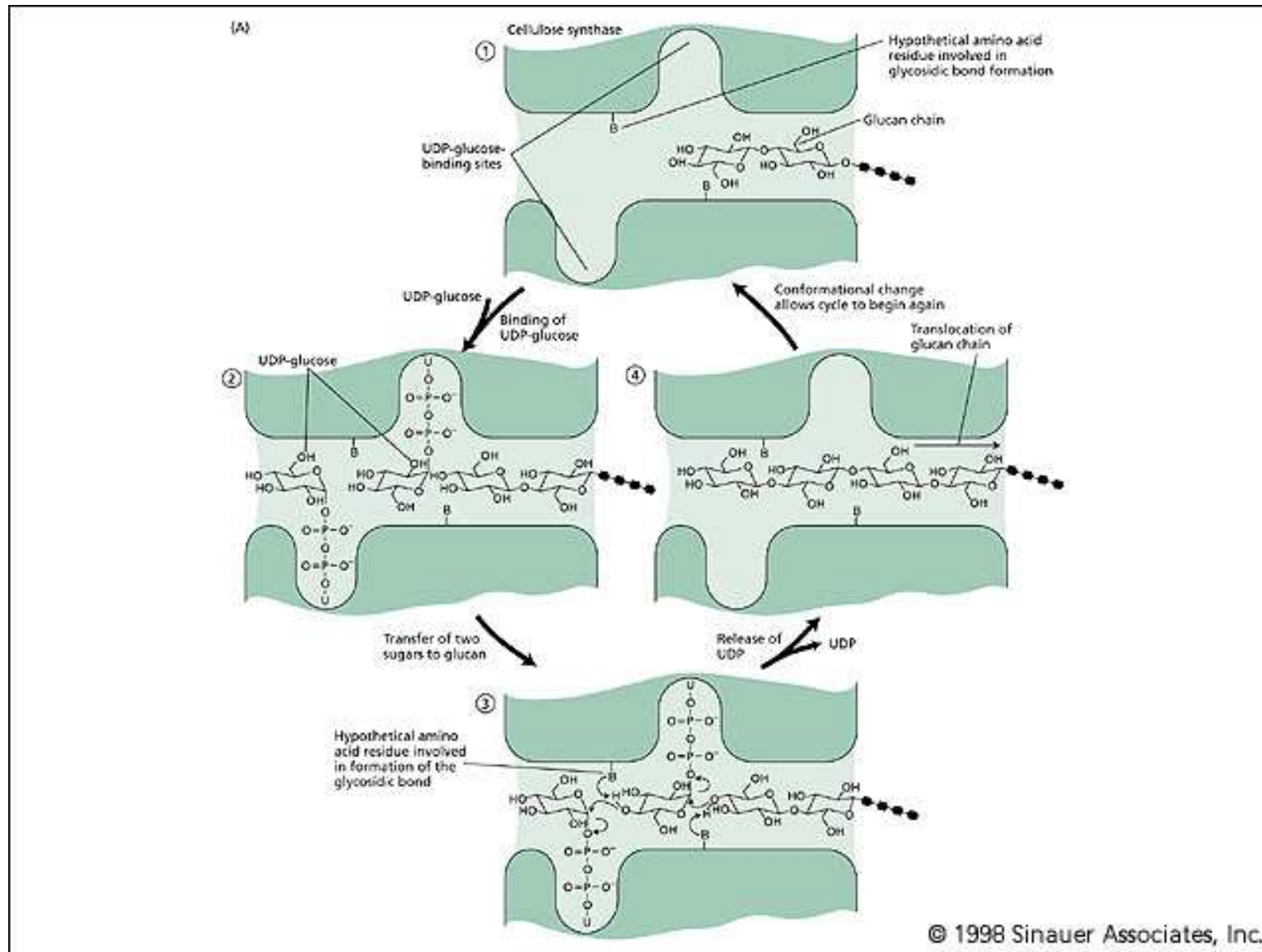
Superfamiglia *Cs/* a cui
appartengono anche geni
per la sintesi delle
emicellulose

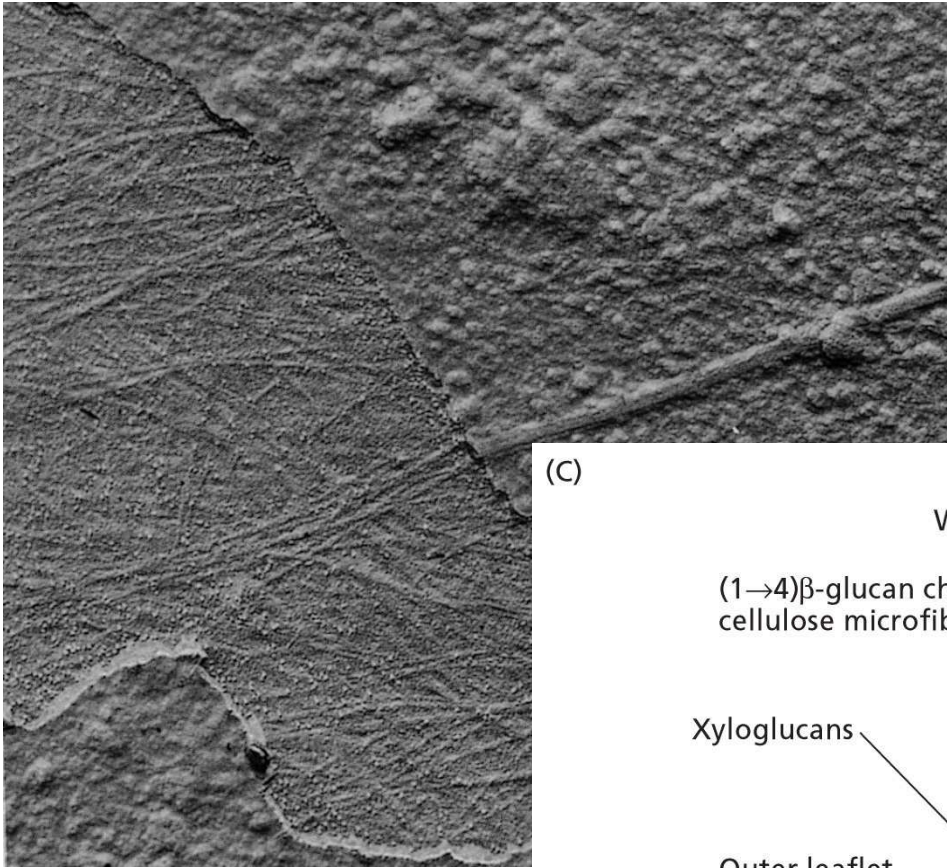


rosette o
complessi terminali

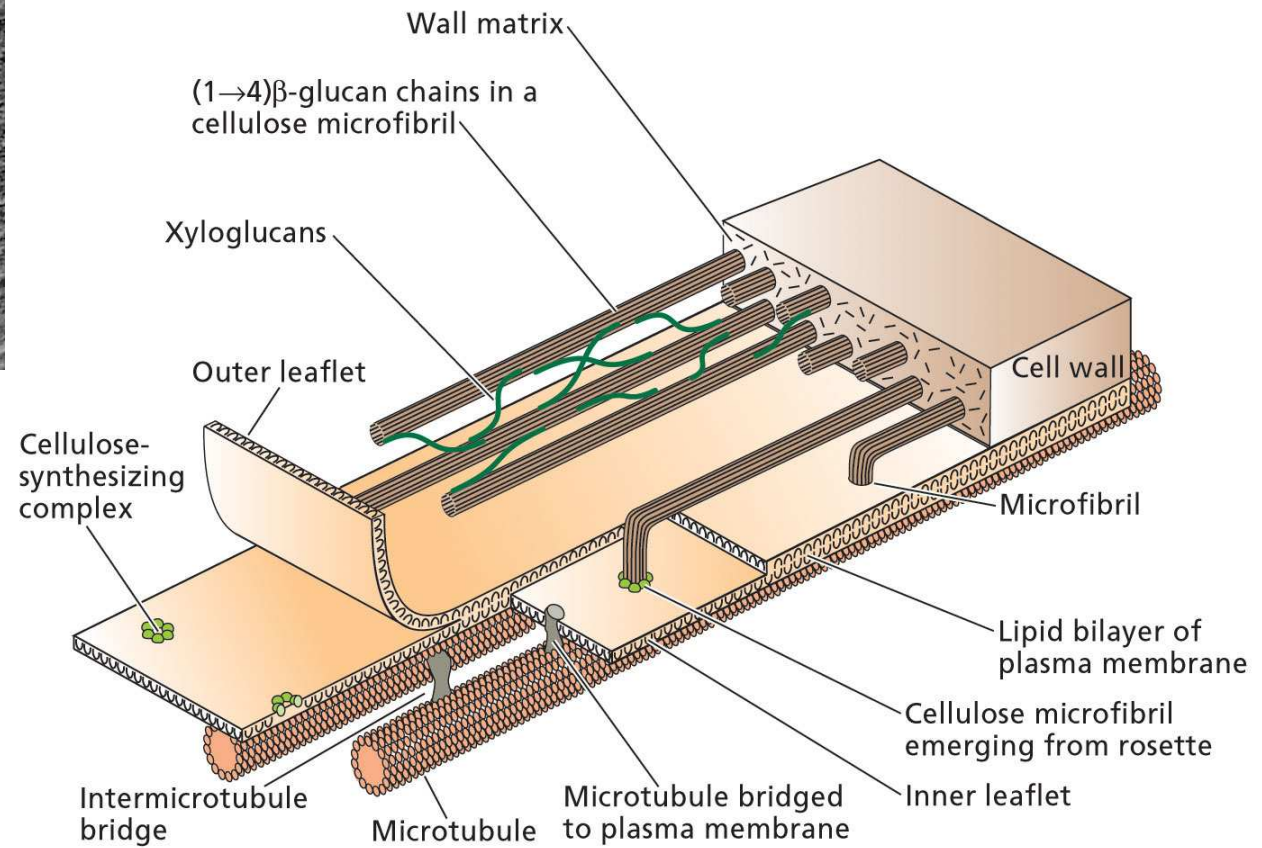


MODELLO PER LA SINTESI DELLA CELLULOSA

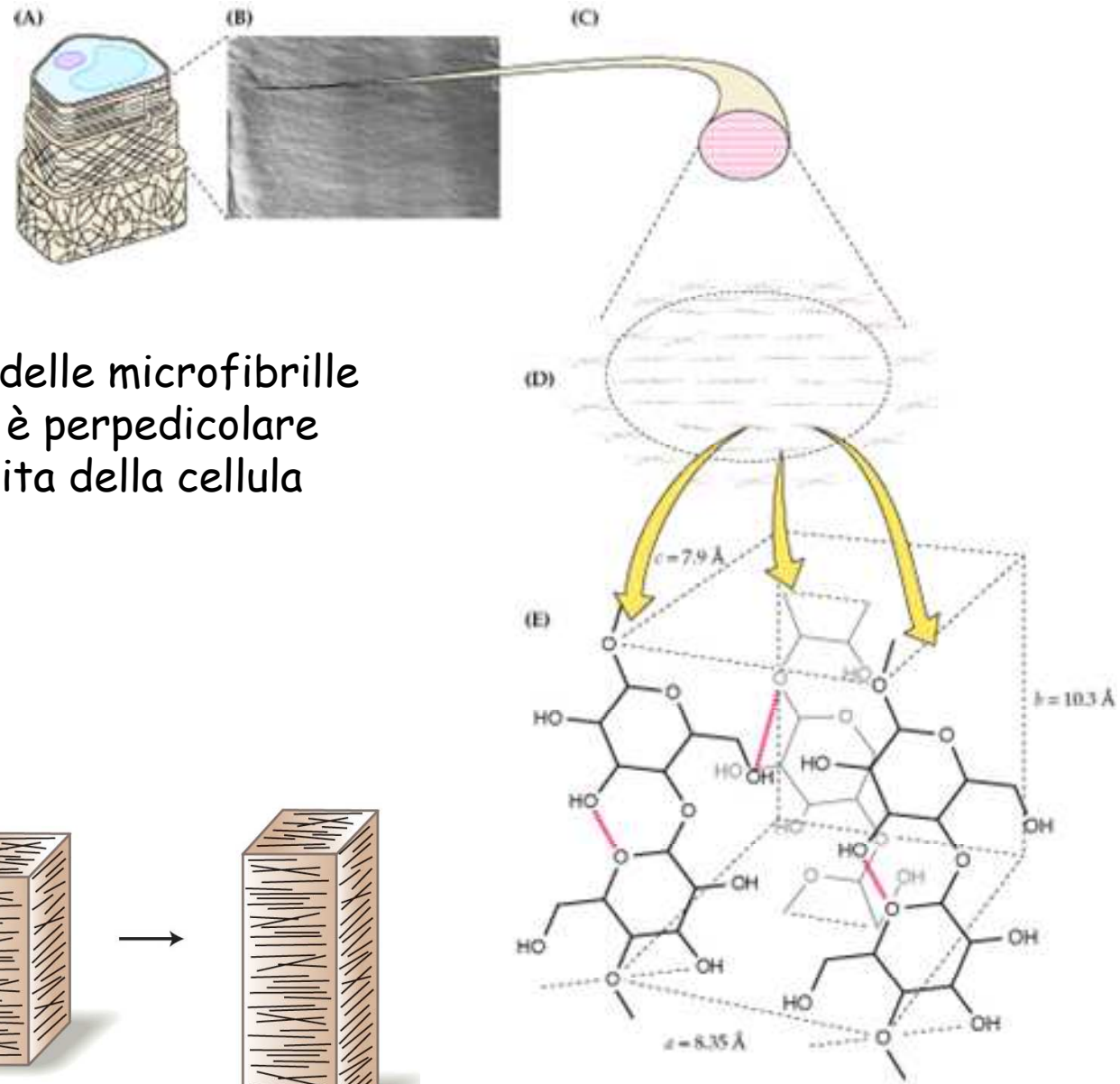
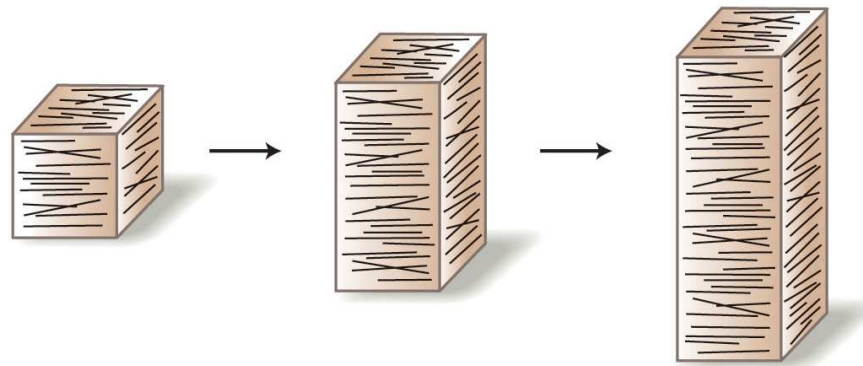




(C)



L'orientamento delle microfibrille di nuova sintesi è perpedicolare all'asse di crescita della cellula



MATRICE

fase amorfa della parete

alto contenuto in H_2O

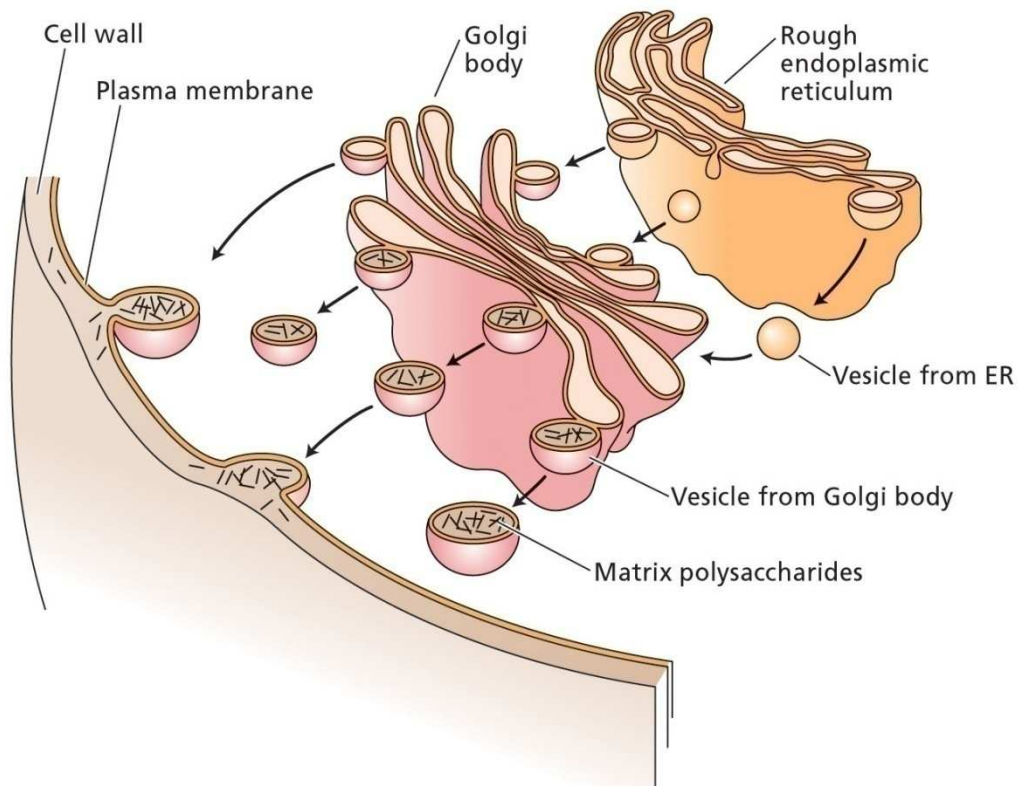
polisaccaridi

EMICELLULOSE
PECTINE

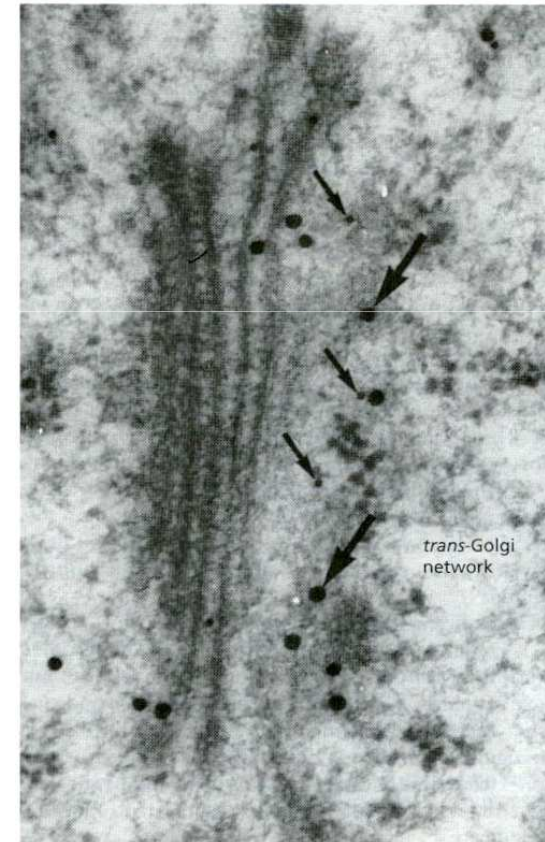
proteine

HRGP (ESTENSINE)
GRP
PRP
AGP

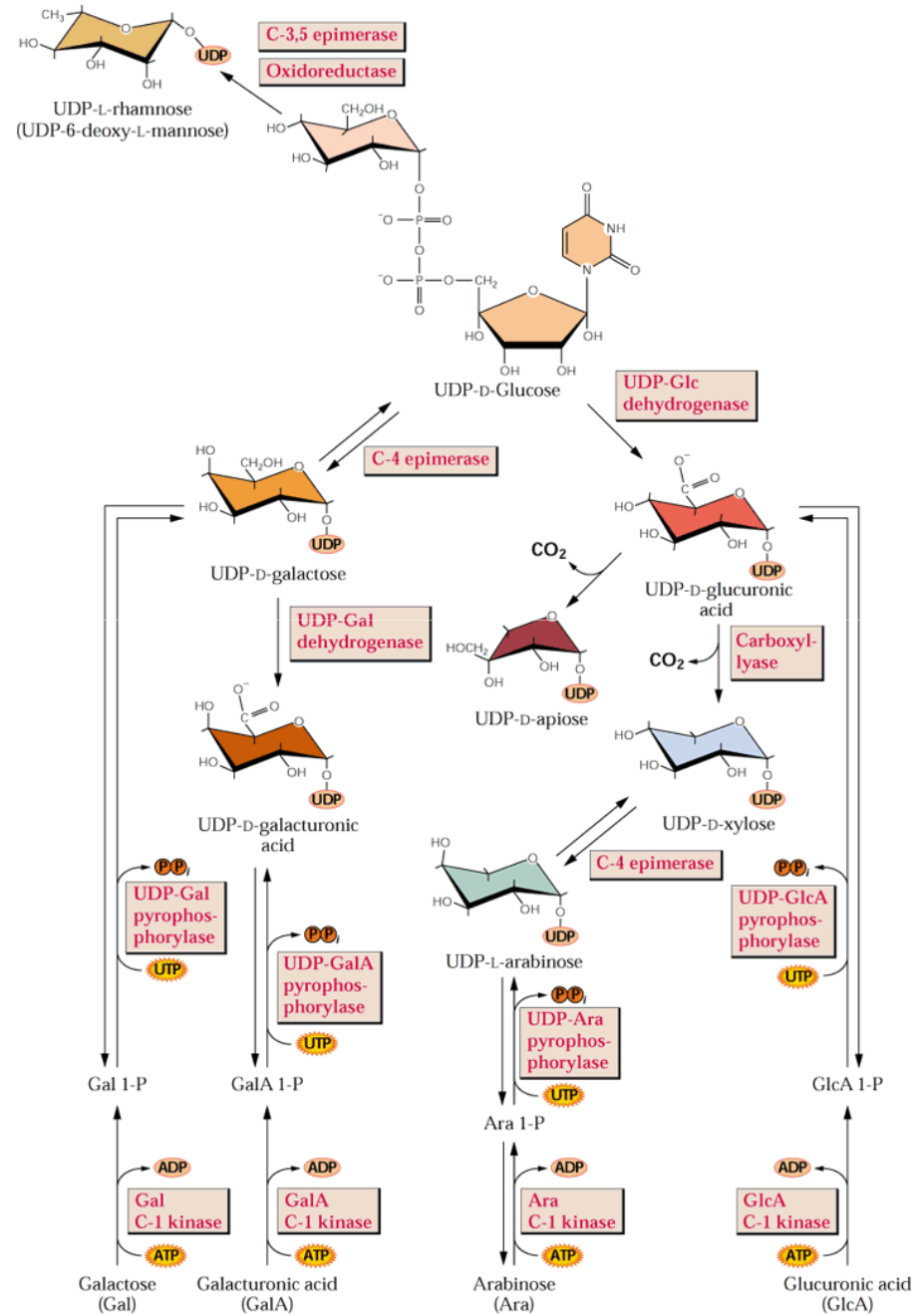
i polisaccaridi della matrice sono sintetizzati nel Golgi ad opera di *zucchero-nucleotide polisaccaride glicosiltransferasi*



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Sintesi degli UDP-zuccheri



EMICELLULOSE

gruppo eterogeneo di polisaccaridi
alta variabilità (tessuti, specie)

XILOGLUCANI

XILANI

β GLUCANI

MANNANI

GLUCOMANNANI

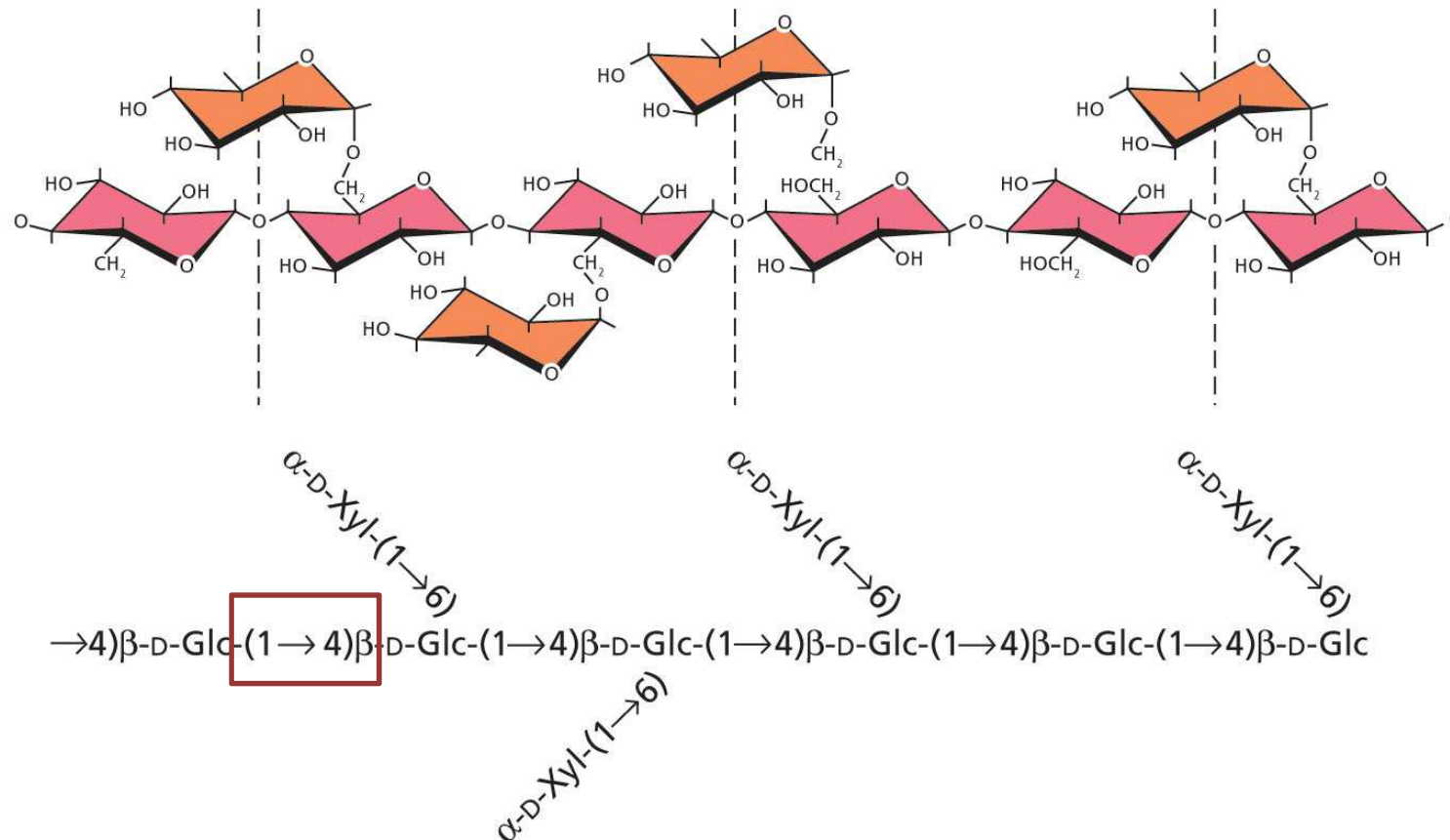
EMICELLULOSE

XILOGLUCANI

9-3000 kDa

20% peso secco dicotiledoni
2% peso secco monocotiledoni

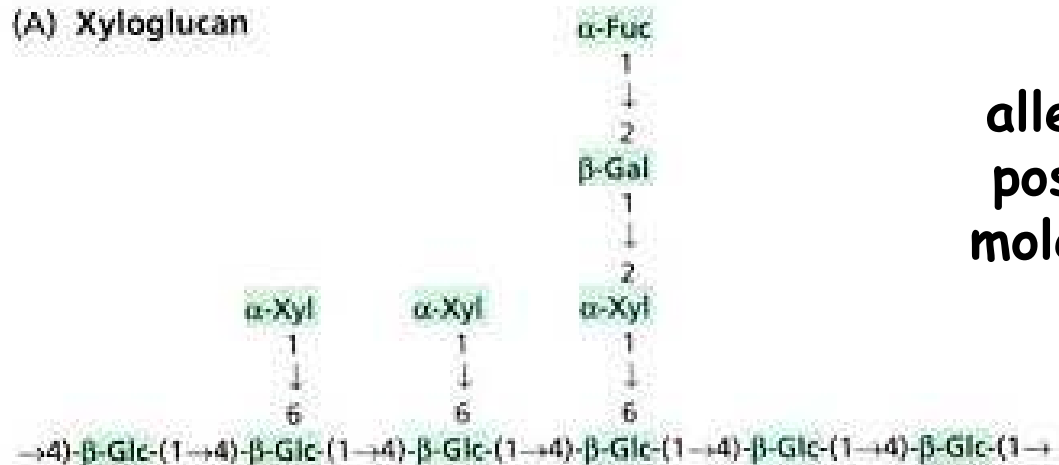
(A) Xyloglucan



EMICELLULOSE

XILOGLUCANI

(A) Xyloglucan



alle molecole di xilosio
possono essere legate
molecole di galattosio e
fucosio

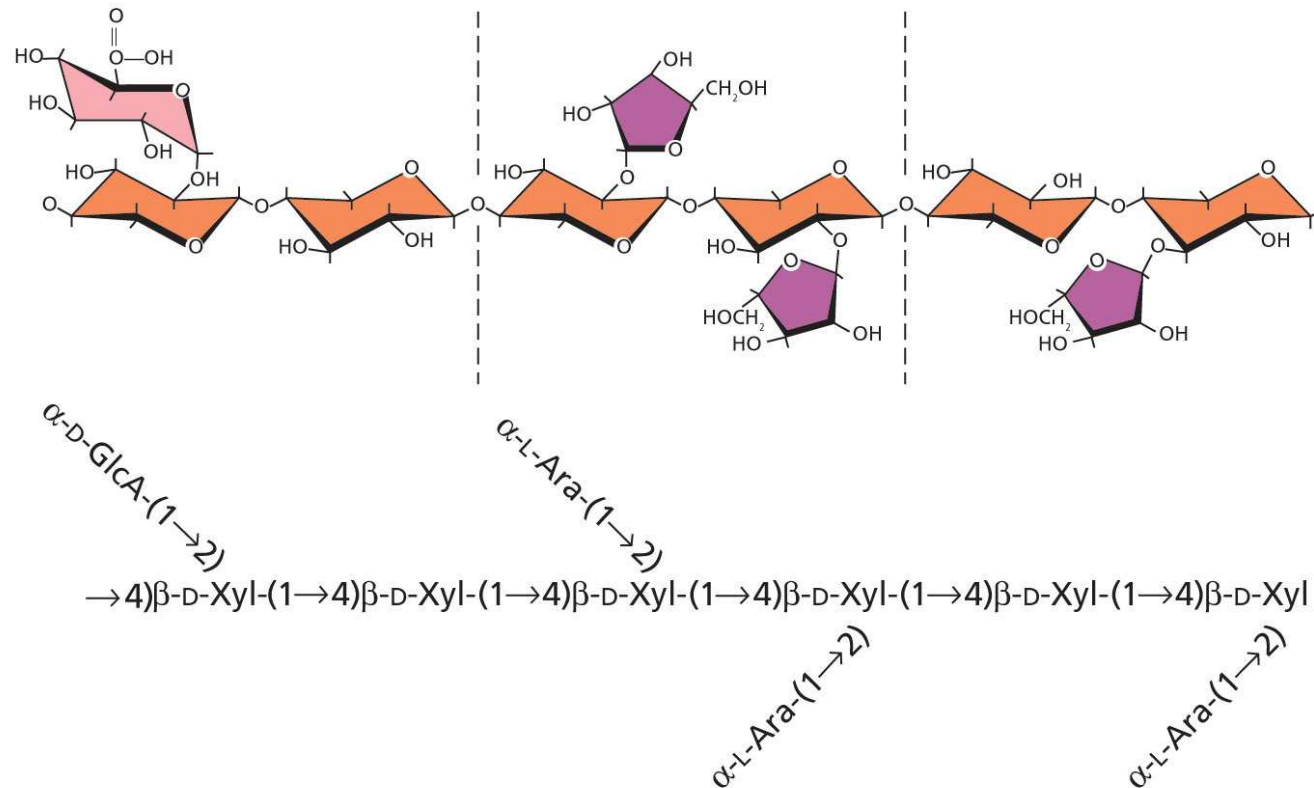
le monocotiledoni non contengono
fucosi terminali e posseggono meno
xilosio e galattosio

EMICELLULOSE

XILANI

emicellulose più abbondanti nella parete primaria delle monocotiledoni

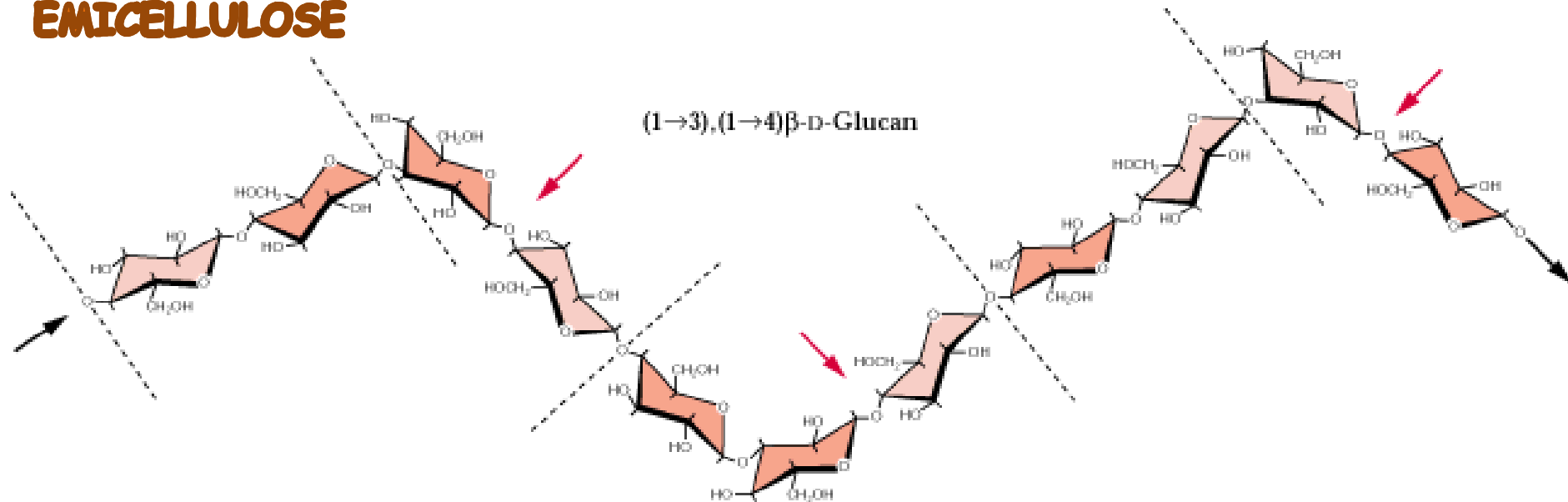
(B) Glucuronoarabinoxylan



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- polimero lineare di D-xilosio in legame $\beta(1\rightarrow4)$
- catene laterali in posizione O-2 e O-3 (arabinosio e acido 4-ossi-metil glucuronico)

EMICELLULOSE



$\rightarrow 4)\beta$ -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$ 3) β -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$ 3) β -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$ 3) β -D-Glc-(1 $\rightarrow$ 4) β -D-Glc-(1 $\rightarrow$

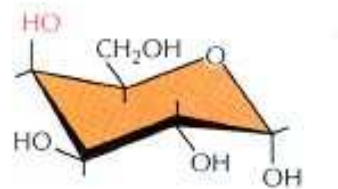
β GLUCANI

tipici delle graminacee

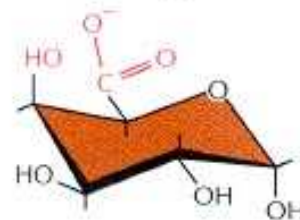
polimeri di D(+)-glucosio
legame $\beta(1\rightarrow3)$ e $\beta(1\rightarrow4)$

PECTINE

Gruppo eterogeneo di polisaccaridi contenenti uno zucchero acido, l'acido galatturonico, e residui di ramnosio, arabinosio, galattosio e xilosio



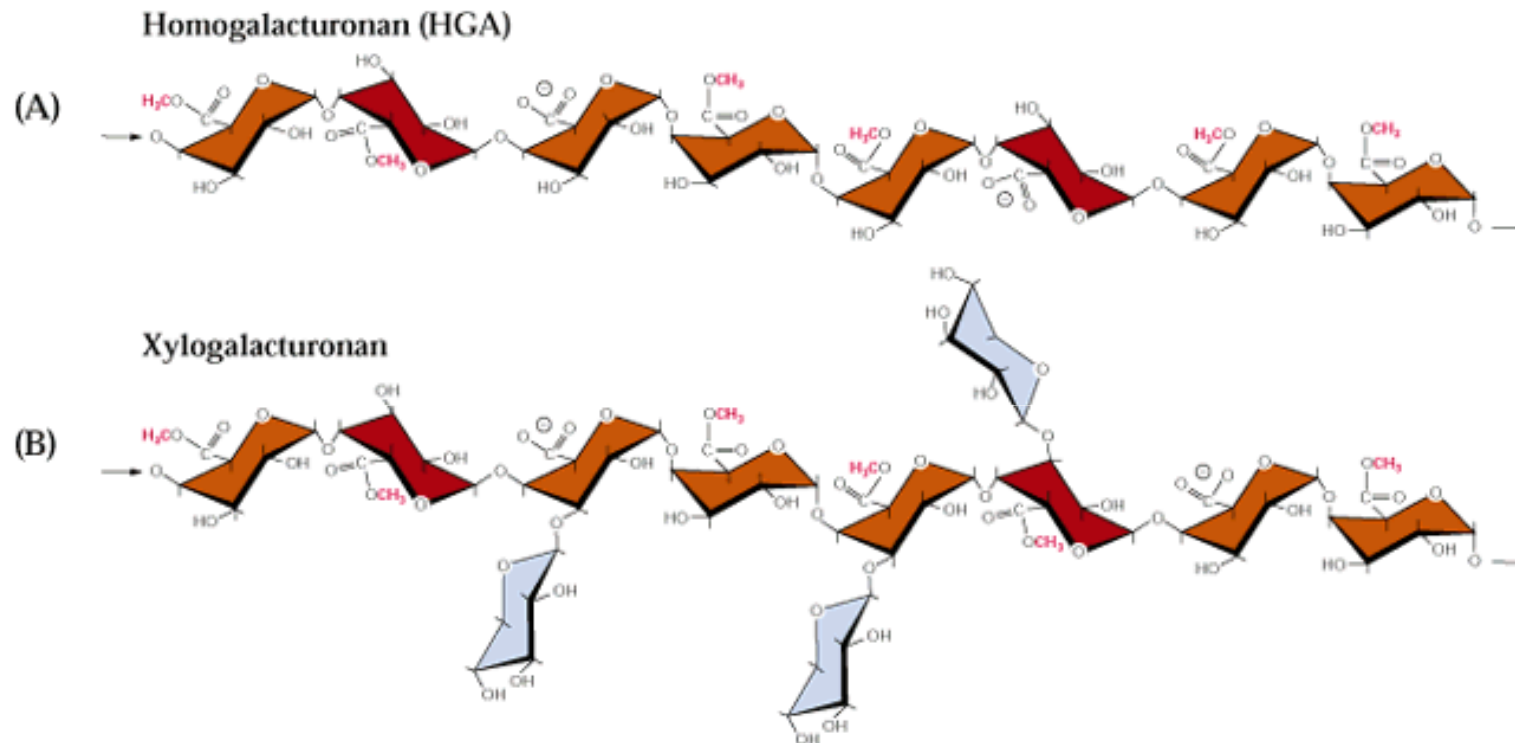
α -D-Galactose (Gal)



α -D-Galacturonic
acid (GalA)

OMOGALATTURONANO

polimero lineare di unità di acido α -D galatturonico
 unite da legami 1-4 (circa 200 unità, 100 nm)

**XILOGALATTURONANO**

unità di α -D xilosio legate in posizione O-3 a circa
 la metà dei residui di acido galatturonico

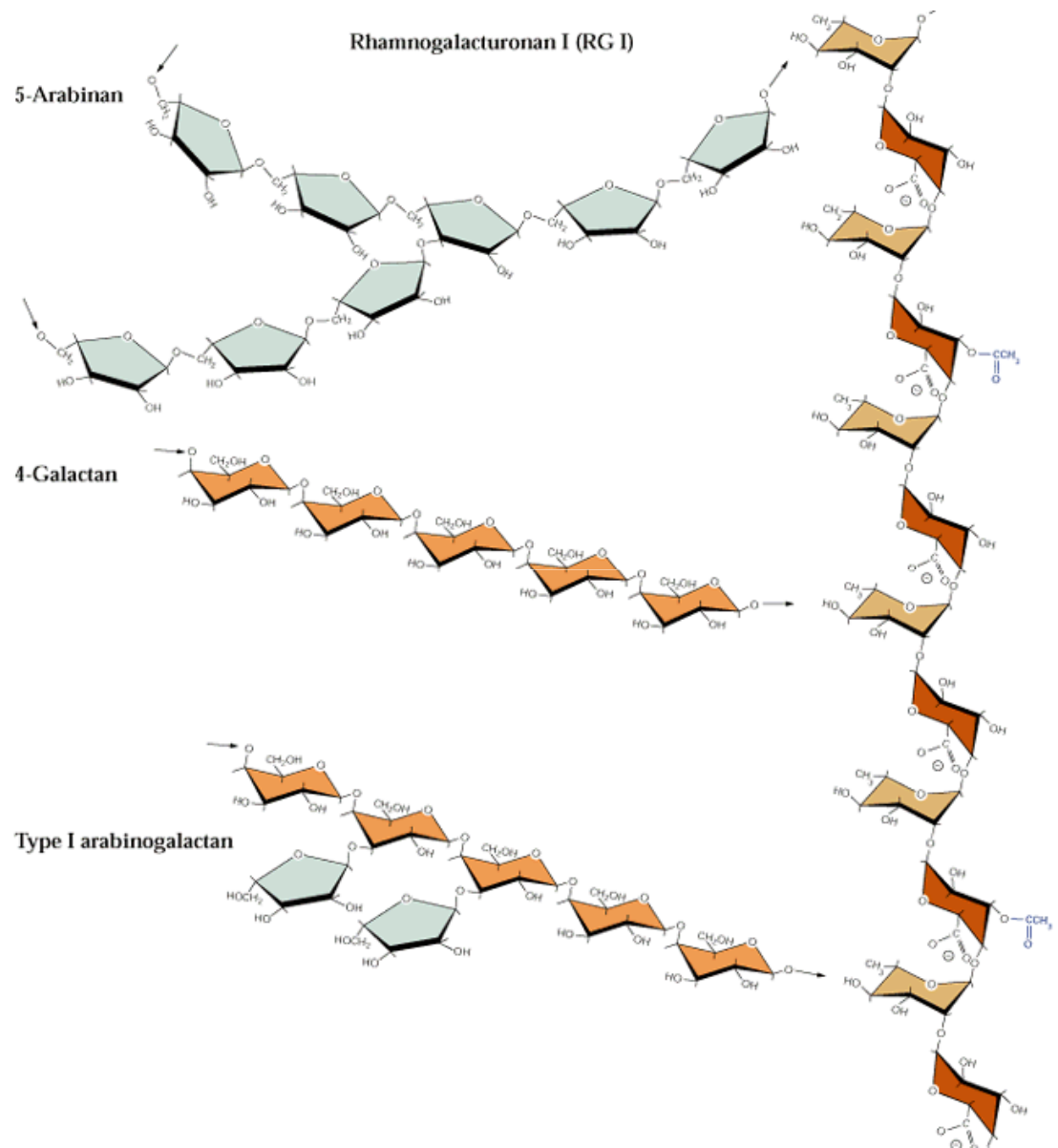
PECTINE

RAMNOGALATTURONANO

Tipo I

è la pectina più abbondante. Polimero composto da unità ripetute del disaccaride $(1 \rightarrow 2)\alpha\text{-D-Rha}-(1 \rightarrow 4)\alpha\text{-D-GalA}$

tre tipi di catene laterali legate al Rha $(1 \rightarrow 5 \text{ o } 1 \rightarrow 4)$



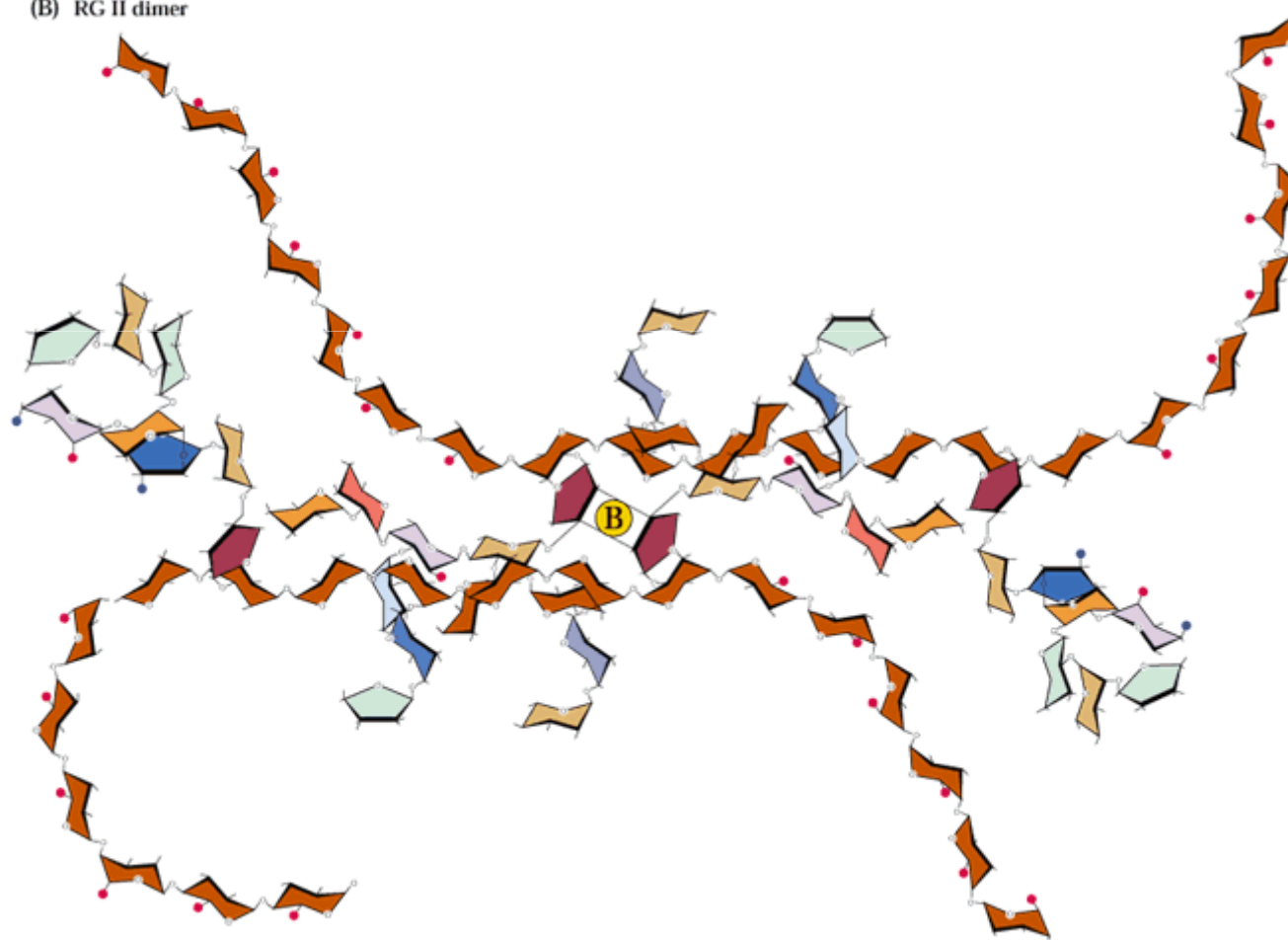
RAMNOGALATTURONANO

Tipo II

struttura molto complessa

- almeno 10 zuccheri differenti (funzione segnale?)
- forma dimeri (legami con il Boro)

(B) RG II dimer



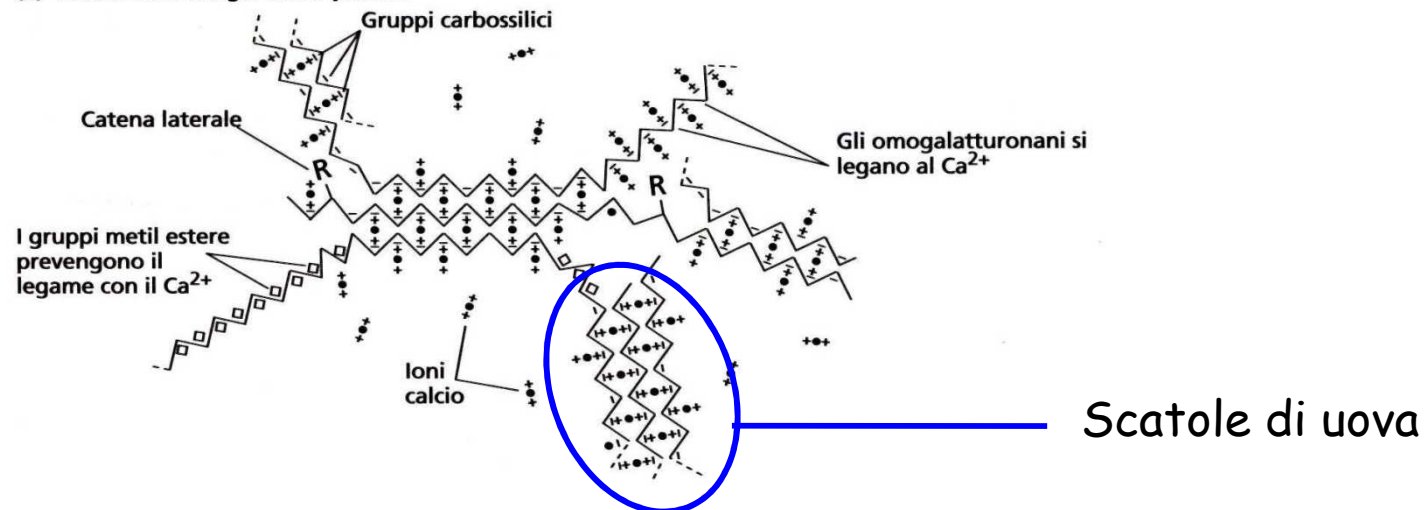
PECTINE

I gruppi COO^- dell'omogalatturonano, quando non sono metilati, possono formare legami ionici con ioni Ca^{++} e Mg^{++} formando "egg boxes"



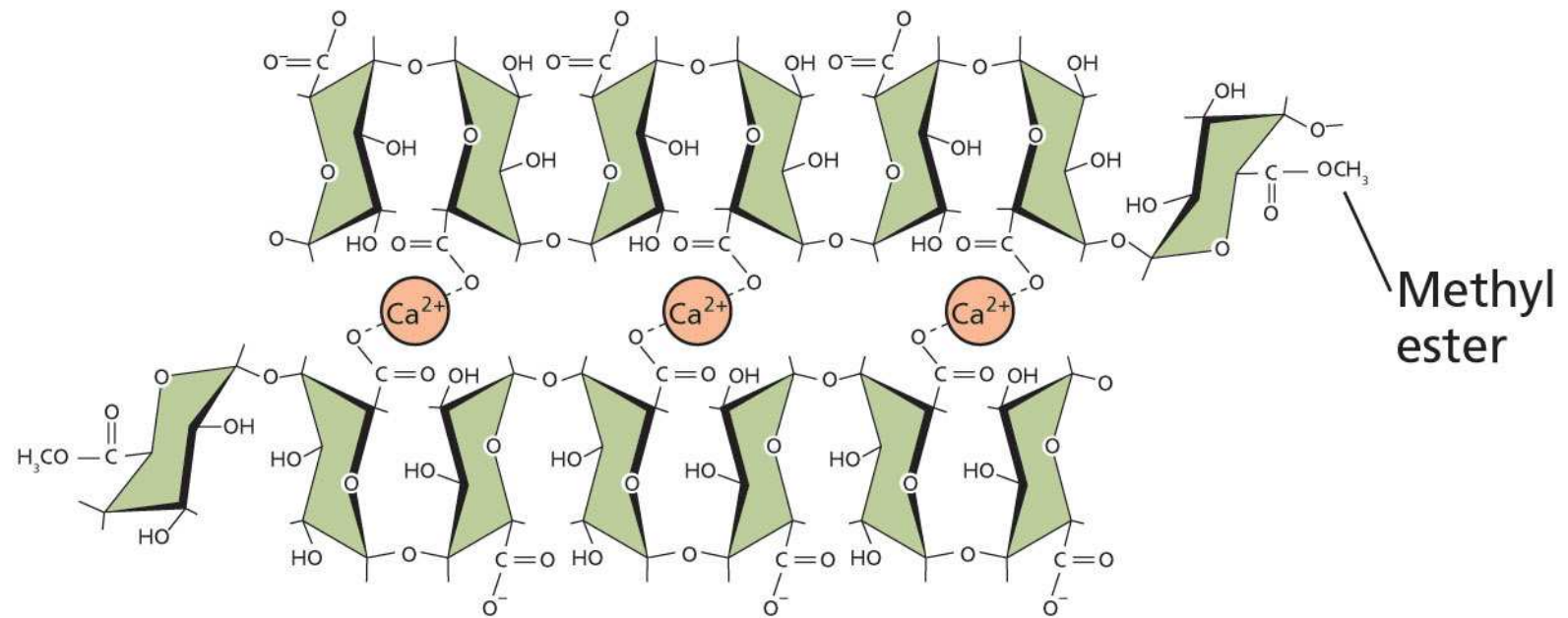
Formazione di gel

(B) Formazione del gel calcio-pectina



(B) Ionic bonding of pectin network by calcium

PECTINE

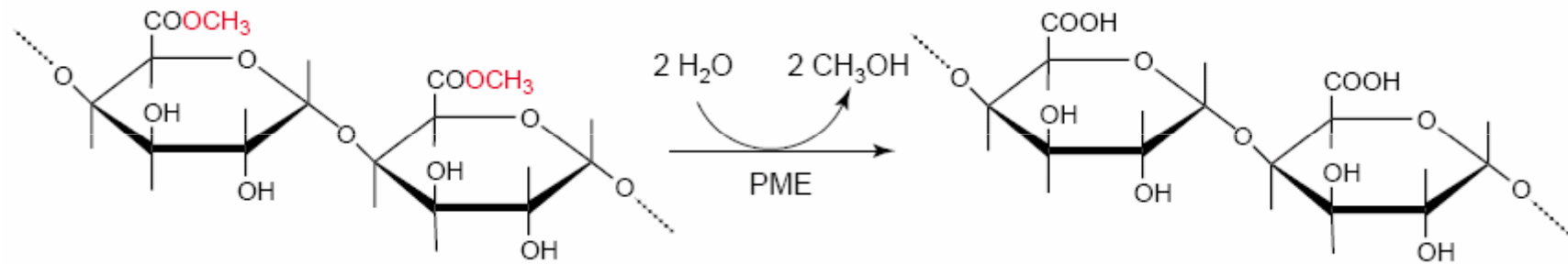


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Il Ca^{2+} favorisce la formazione dell'intreccio gelificato

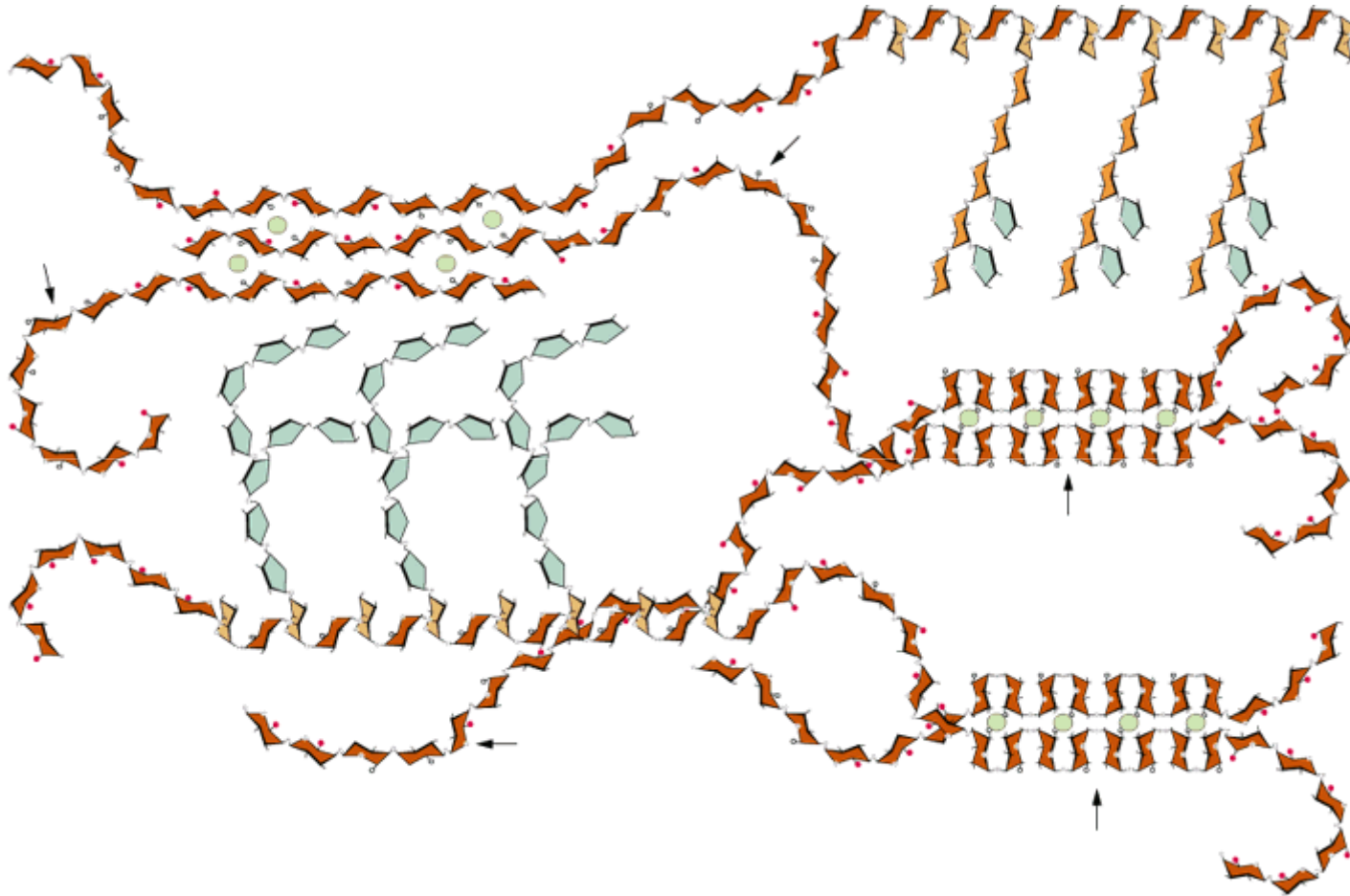
L'esterificazione, che avviene nel Golgi, previene la formazione dei ponti ionici con il Ca^{2+} riducendo il carattere di gel della pectina

Le pectine possono essere de-metilate
da **PECTINA-METILESTERASI (PME)**

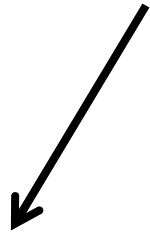


PECTINE

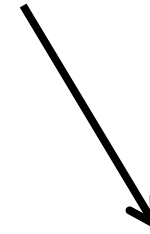
La pectina determina la porosità della parete



PROTEINE DI PARETE



strutturali



non strutturali

PROTEINE STRUTTURALI DI PARETE

TABLE 15.2
Structural proteins of the cell wall

Class of cell wall proteins	Percentage carbohydrate	Localization typically in:
HRGP (hydroxyproline-rich glycoprotein)	~55	Phloem, cambium, sclereids
PRP (proline-rich protein)	~0–20	Xylem, fibers, cortex
GRP (glycine-rich protein)	0	Xylem

ESTENSINA (HRGP)

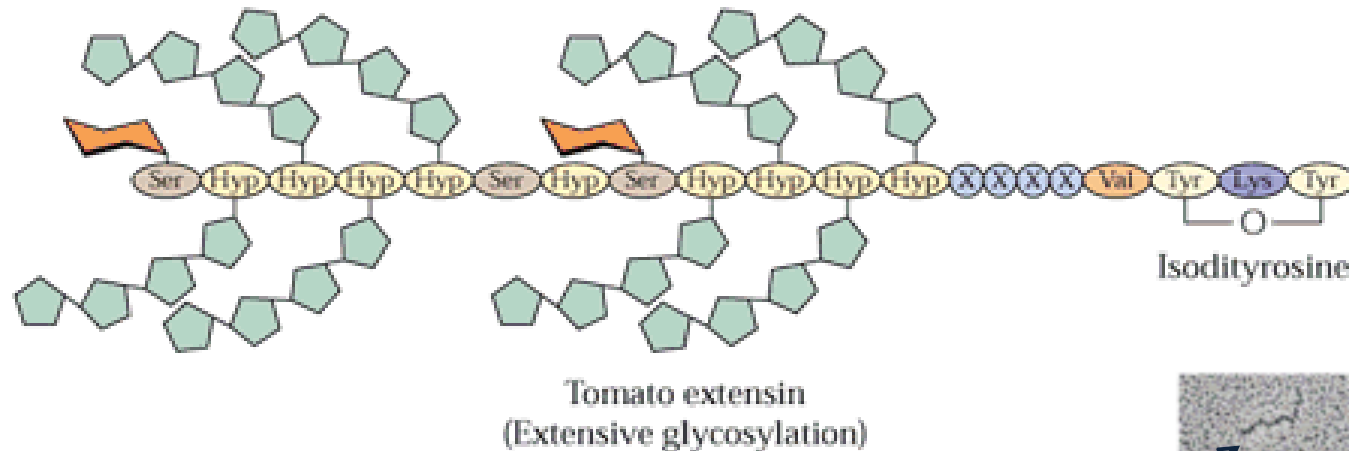
motivo Ser-(Hyp)₄

residui di idrossiprolina glicosilati (arabinosio)

alcune serine glicosilate (galattosio)

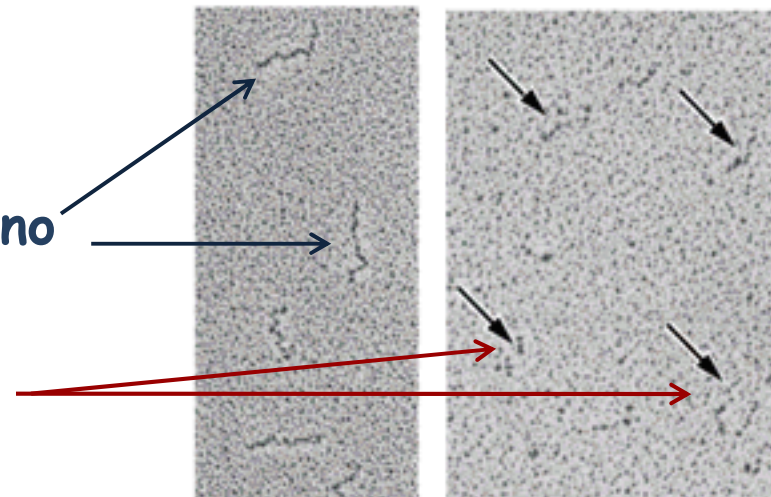
forma legami intermolecolari → insolubile

(A)



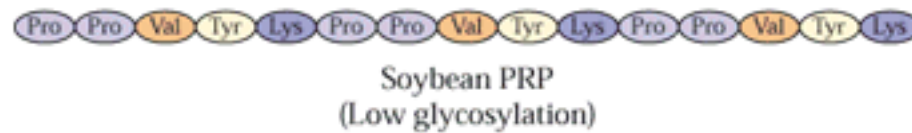
Tipica struttura a bastoncino

La rimozione degli arabinosidi
comporta la perdita della
struttura a bastoncino



PRP

unità ripetute tipo Pro-Pro-X-X-Lys



non hanno motivi ripetuti contenenti gruppi ossidrilici

La struttura non è nota ma si pensa abbiano forma bastoncellare

GRP

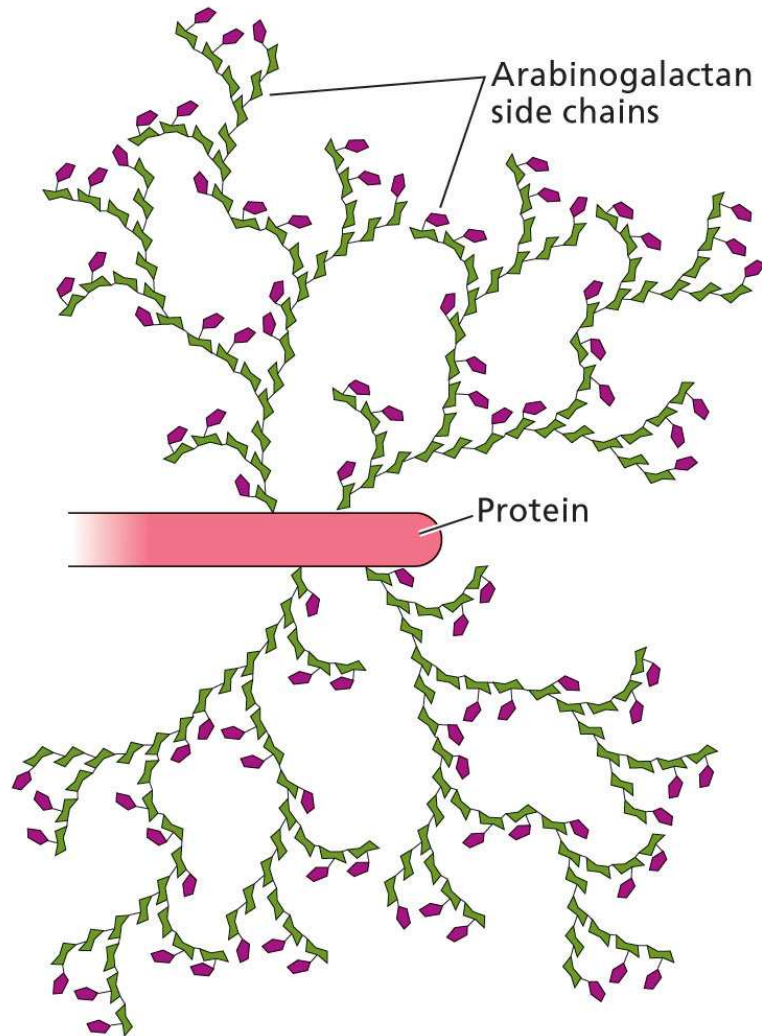
struttura primaria formata da elementi ripetitivi contenenti circa il 70% di glicina

foglietti β antiparalleli

funzione ignota: punti di nucleazione per lignificazione?



Petunia GRP
(No glycosylation)



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AGP

ARABINO GALATTAN PROTEINE

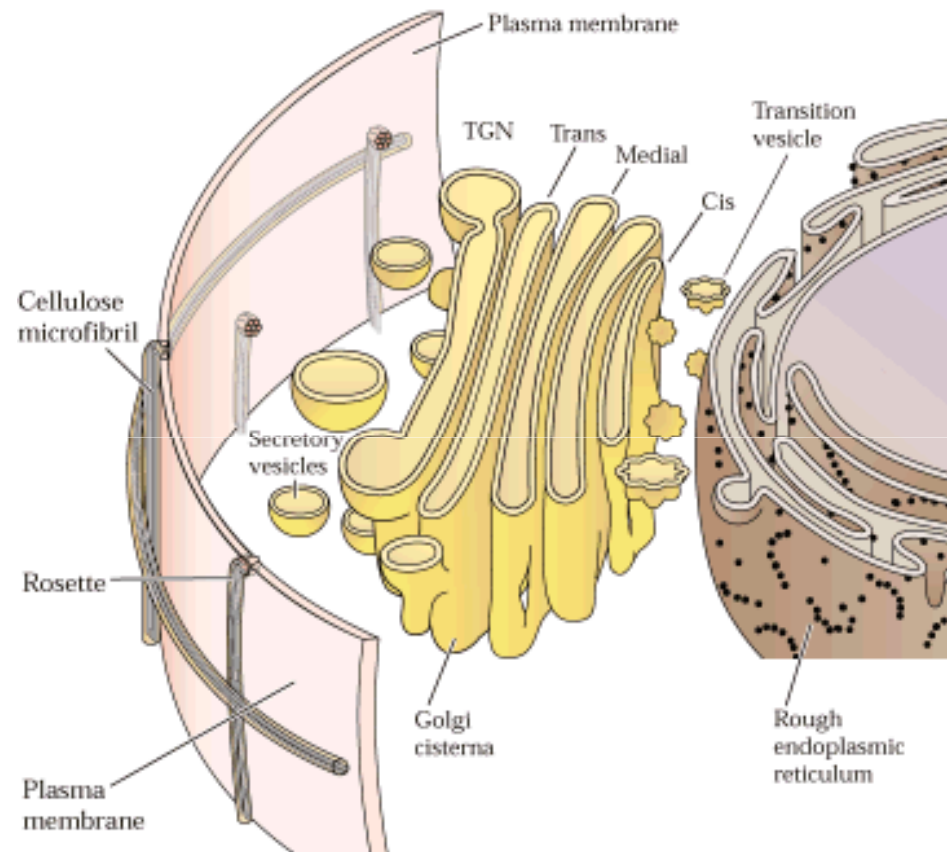
altissimo contenuto in zuccheri (fino al 90%)
galattosio e arabinosio

(PROTEOGLICANI)

sono ricche di Pro(Hyp), Ala, Ser/Thr, ma
molte non hanno correlazione tra loro

funzione non nota: siti di nucleazione per
l'assemblaggio della parete

(A)



Site of synthesis for:
Cellulose
Callose

Site of synthesis for:

Pectins
HGA
RG I
RG II

Cross-linking glycans
Xyloglucan
Glucuronoarabinoxylan
 β -Glucan
Galactomannan

Site of glycosylation of:

HRGPs
AGPs
Modified glycoproteins

Site of synthesis for:

Cell wall proteins
HRGPs
PRPs
GRPs
AGPs

Enzymes
Hydrolases
Esterases
Peroxidases
Polysaccharide
synthase

ARCHITETTURA DELLA PARETE

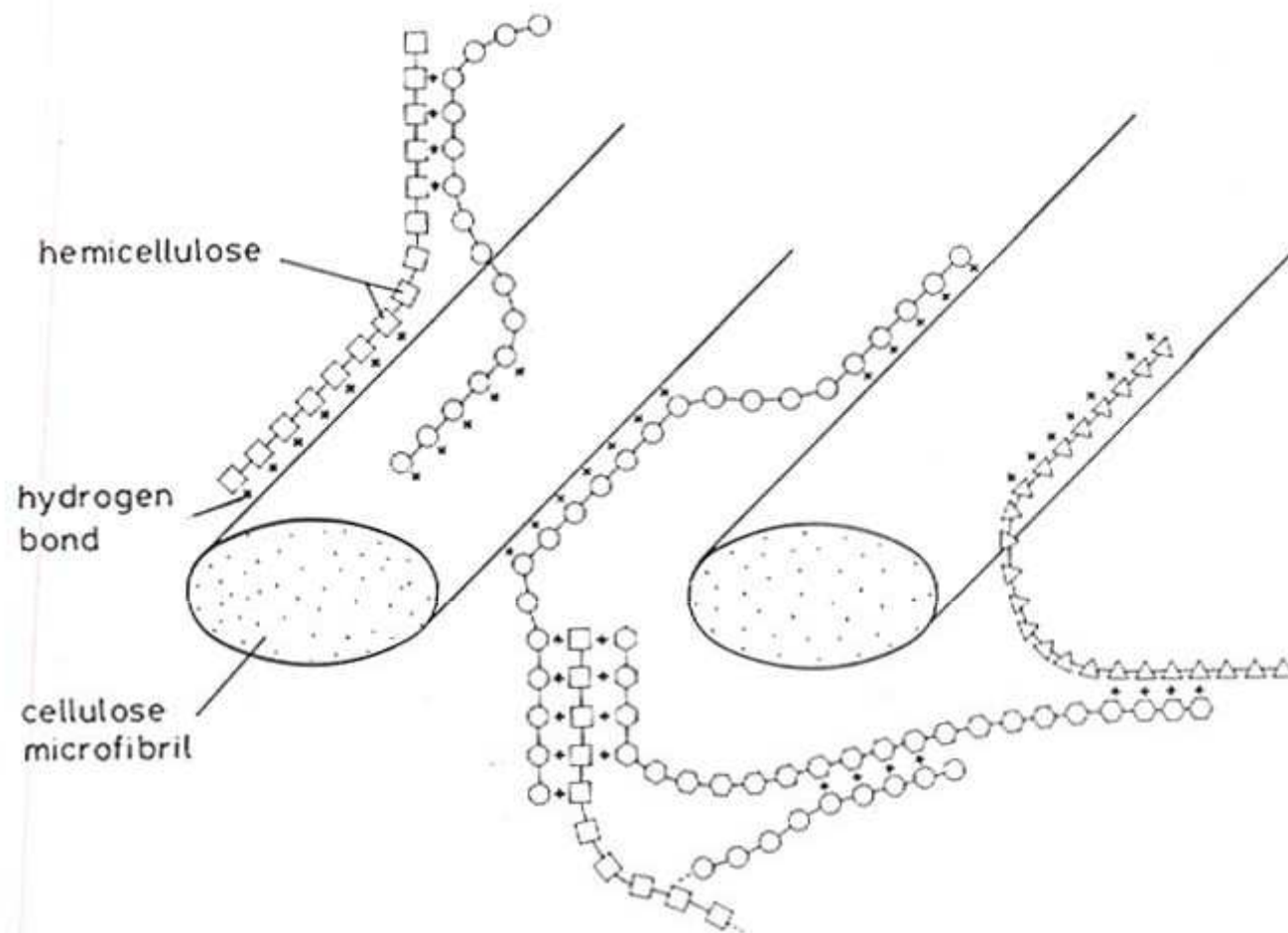
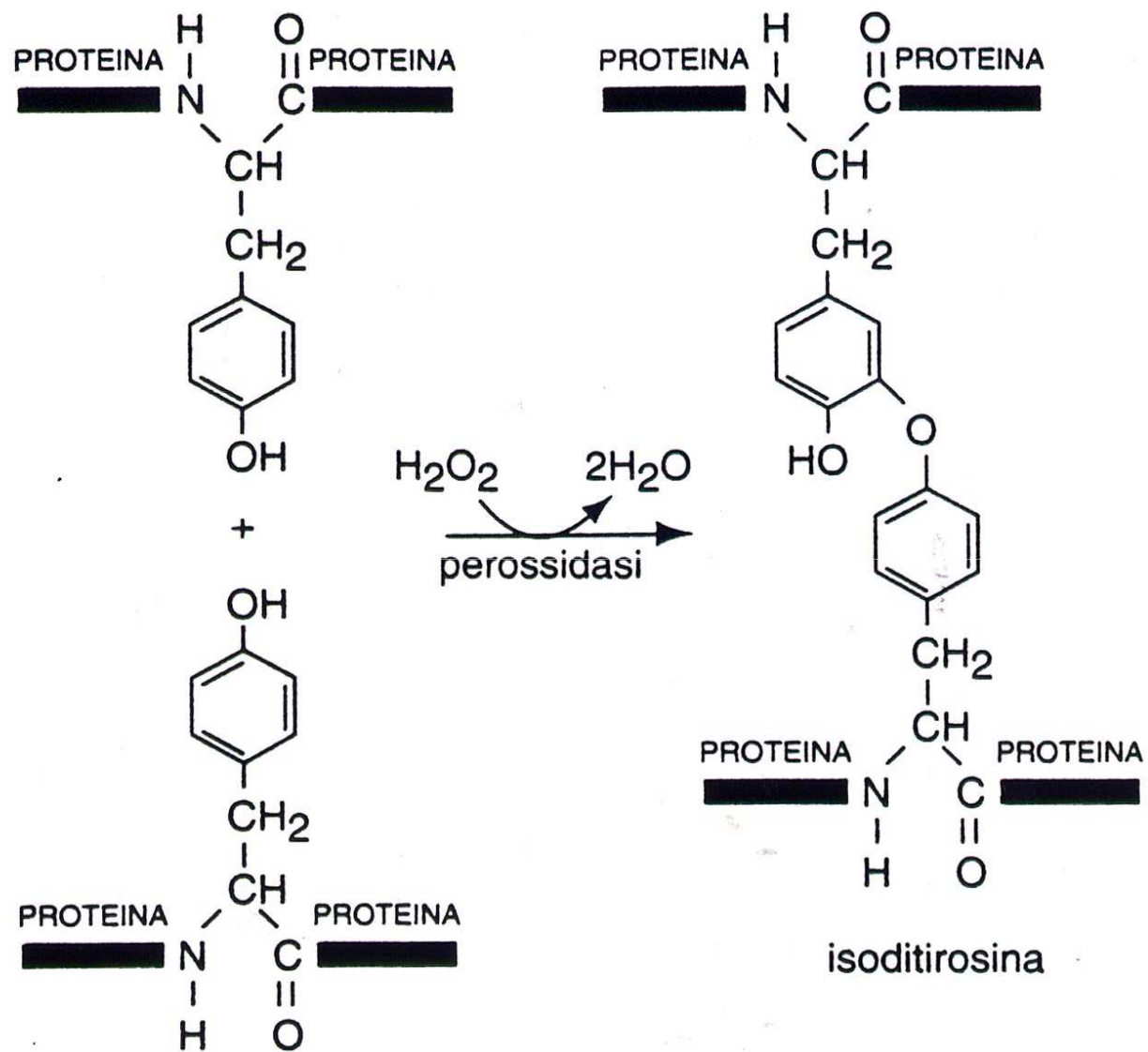


Figure 2.27 Cell-wall model illustrating the hydrogen-bond interactions of hemicellulosic polysaccharides ($-\triangle-\triangle-$; $-\bigcirc-\bigcirc-$; $-\square-\square-$; $-\bigcirc-\square-\bigcirc-$) with each other and with cellulose microfibrils. This produces a complex network of polysaccharides which contributes to maintaining the integrity of the cell wall.



residui di tirosina

isoditirosina

Le estensine possono intrappolare le microfibrille di cellulosa formando dimeri di tirosina intermolecolari

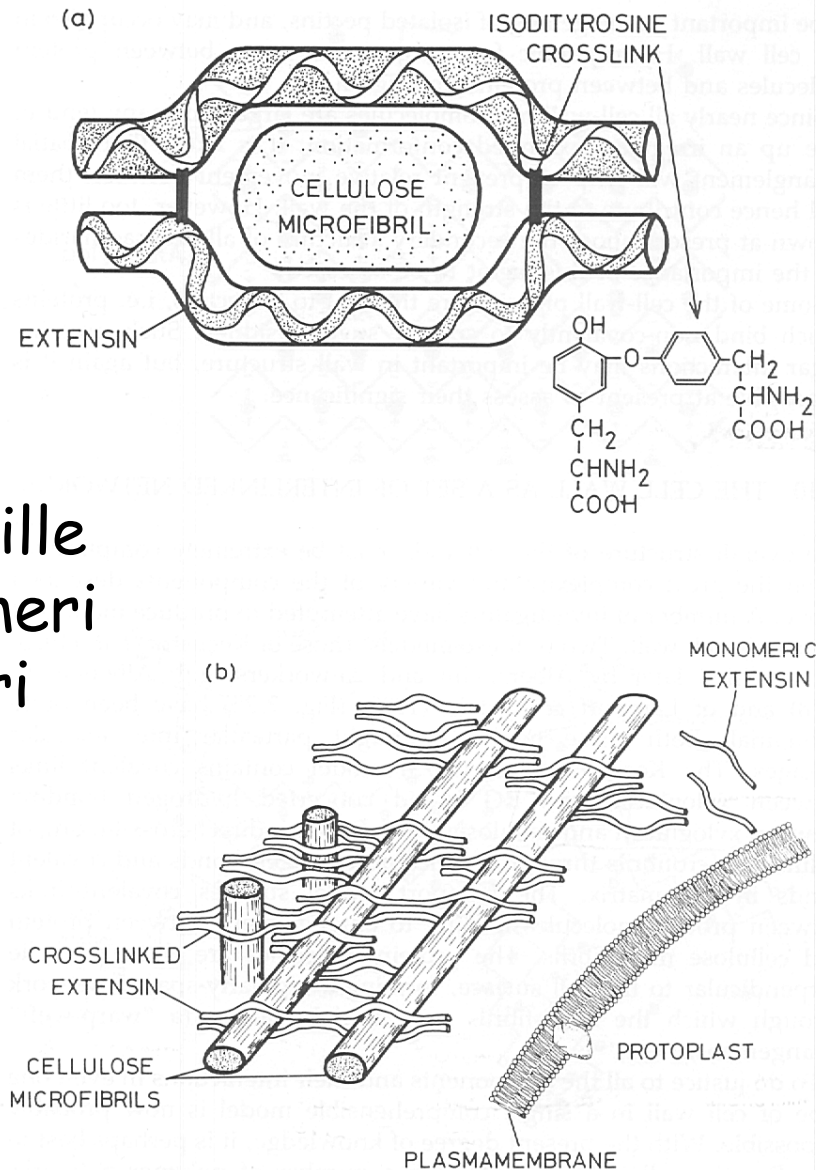
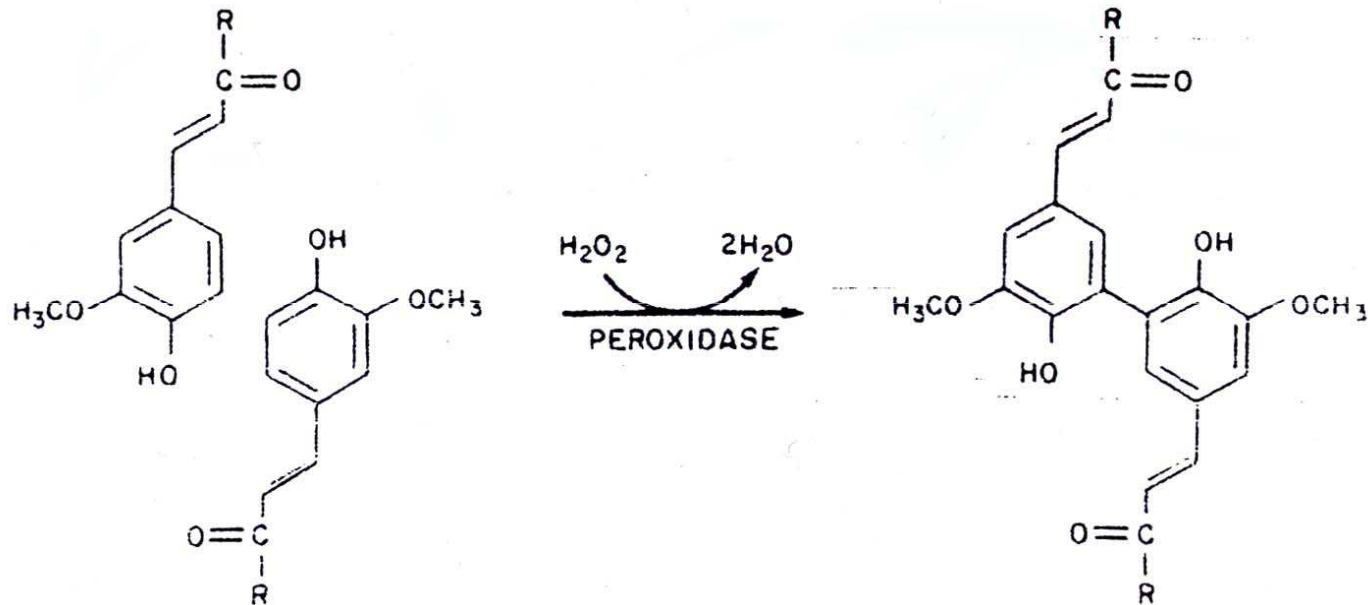
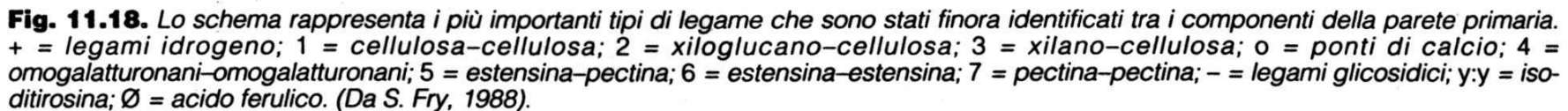


Figure 2.25 Cell-wall model of Lamport & Epstein (1983). (a) Proposed mechanism by which extensin might entrap cellulose microfibrils through isodityrosine cross-links. (b) Diagrammatic representation of this concatenation in wall architecture.

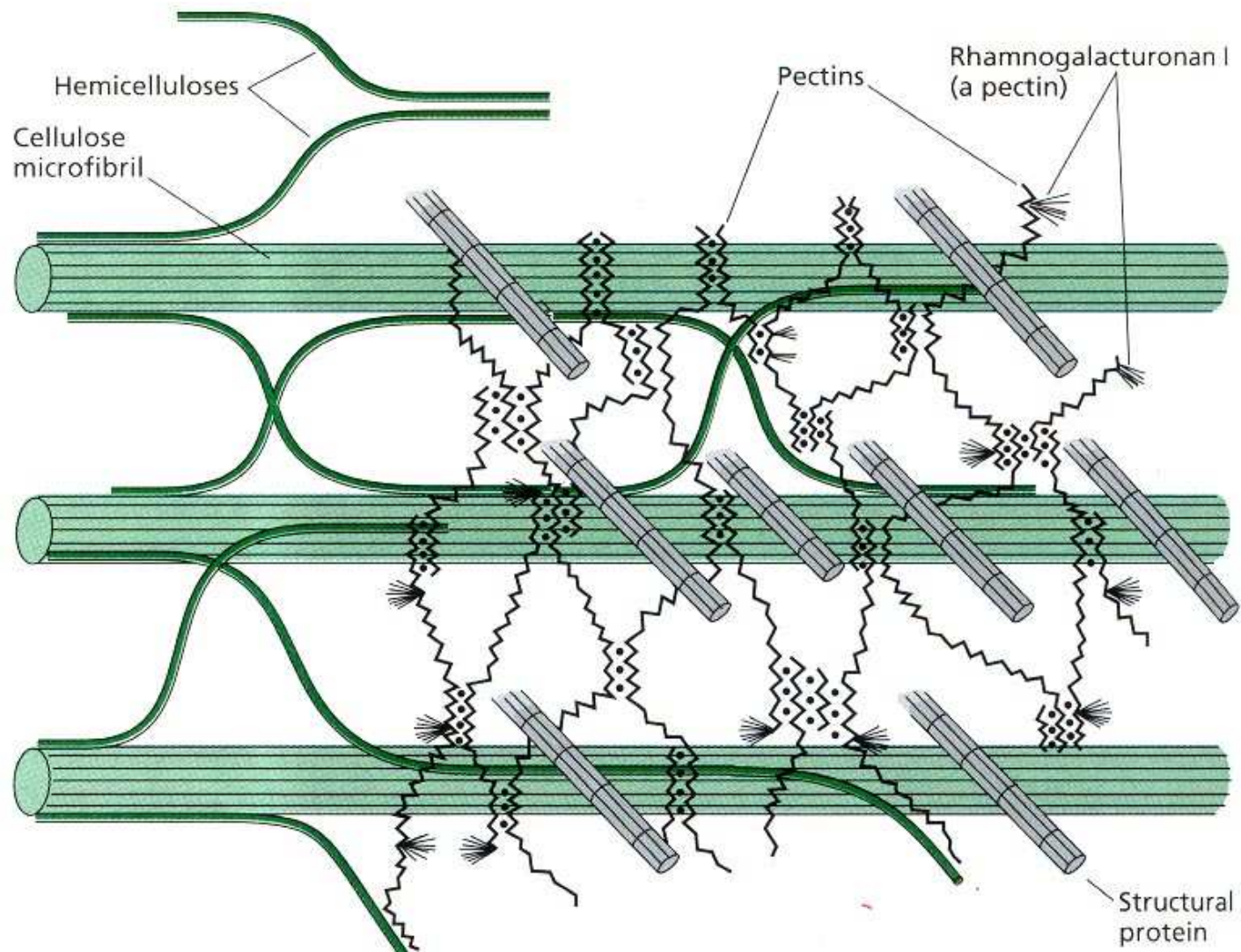
Le emicellulose e le pectine possono legare
molecole di **acido idrossiferulico**



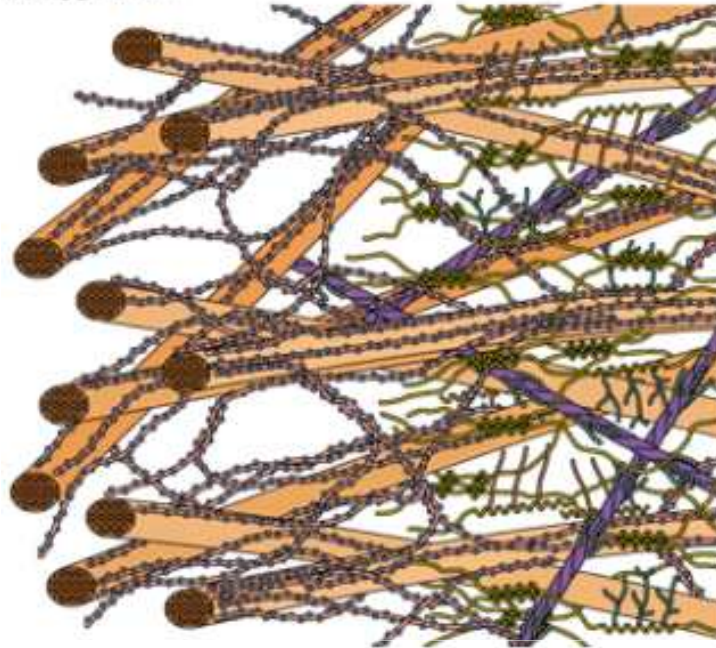
Cross-linking tra polisaccaridi



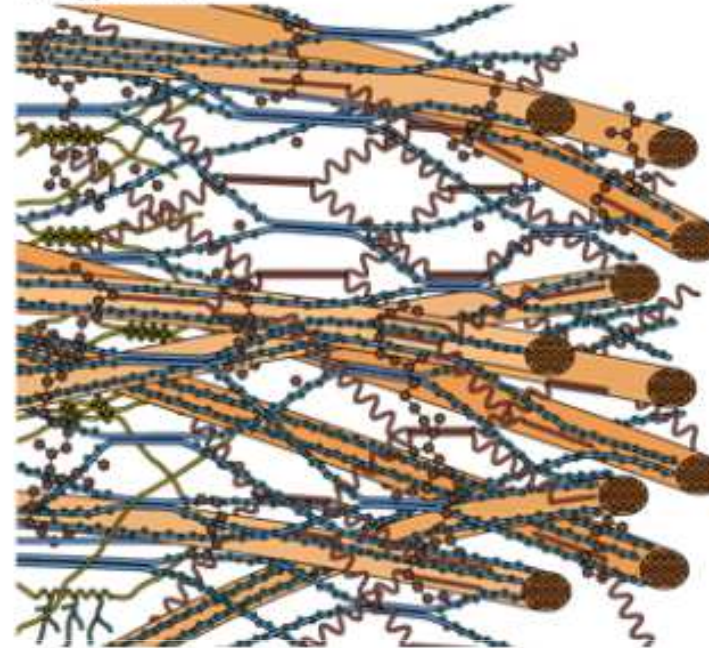
MODELLO TRAMA-ORDITO



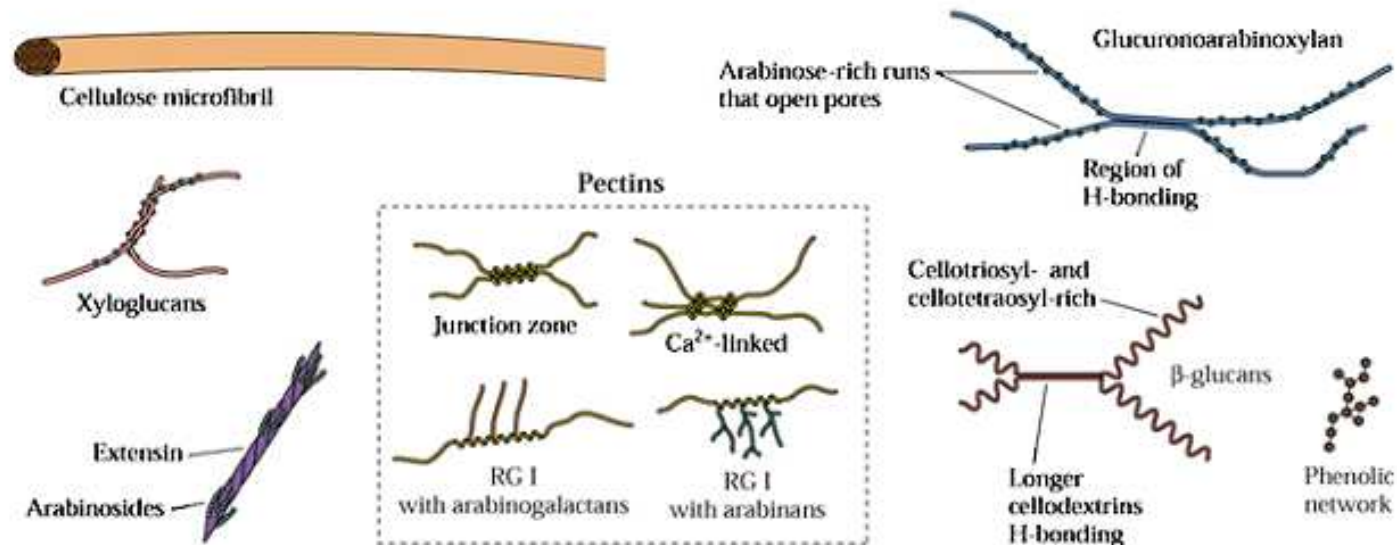
(A) Type I wall



(B) Type II wall



Key:



PROTEINE NON STRUTTURALI

Enzimi ossidativi: **PEROSSIDASI**

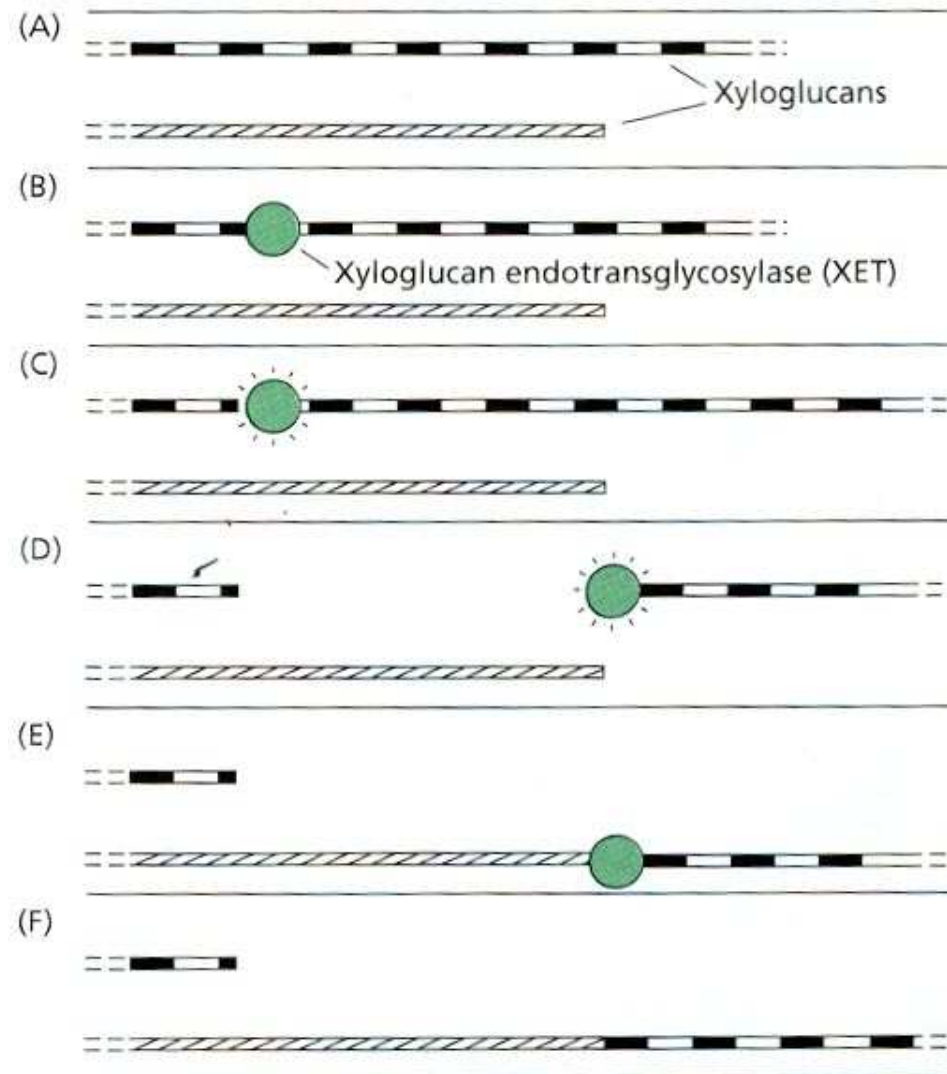
Enzimi idrolitici: **CELLULASI, PECTINASI, EMICELLULASI**

Enzimi per l'espansione cellulare: **TRANSGLICOSILASI**

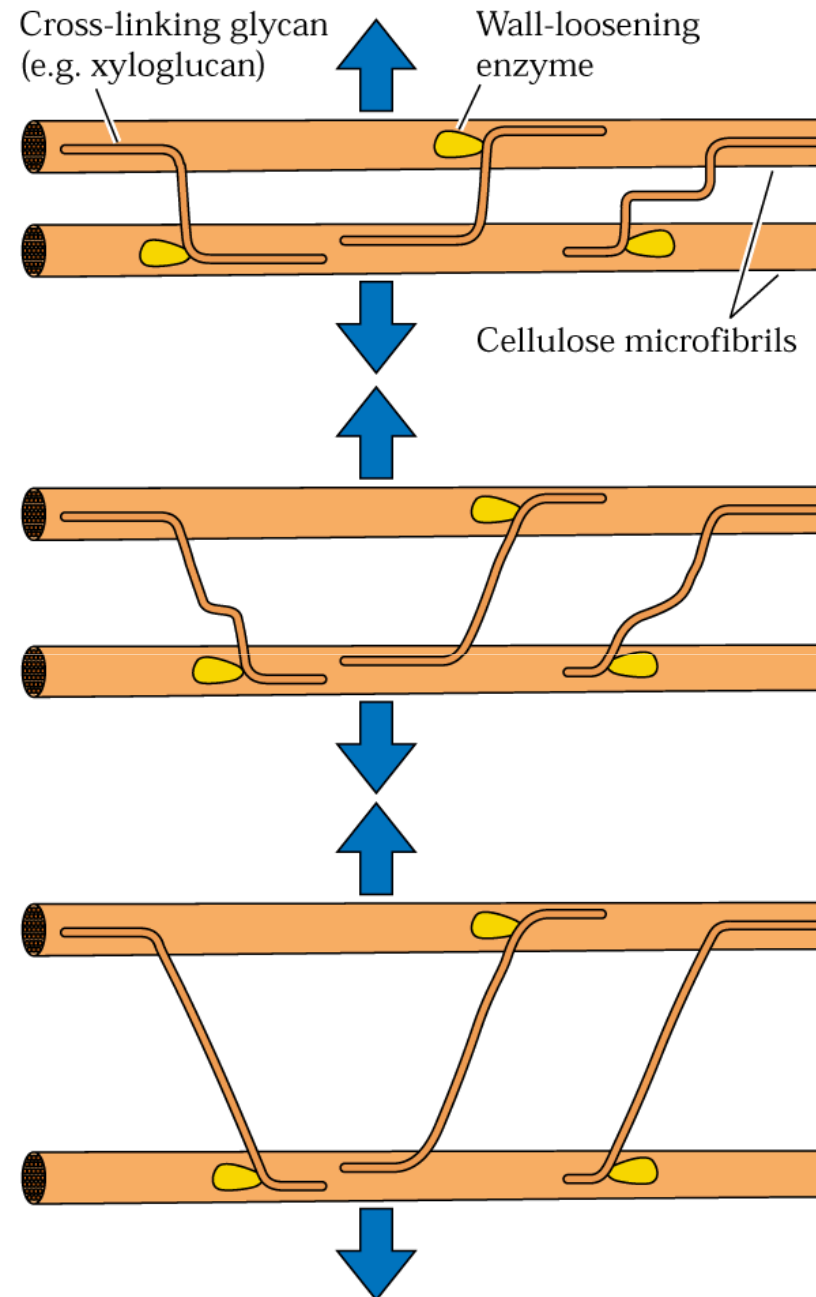
Altre proteine per l'espansione: **ESPANSINE**

XET

xiloglucano endotransglicosilasi

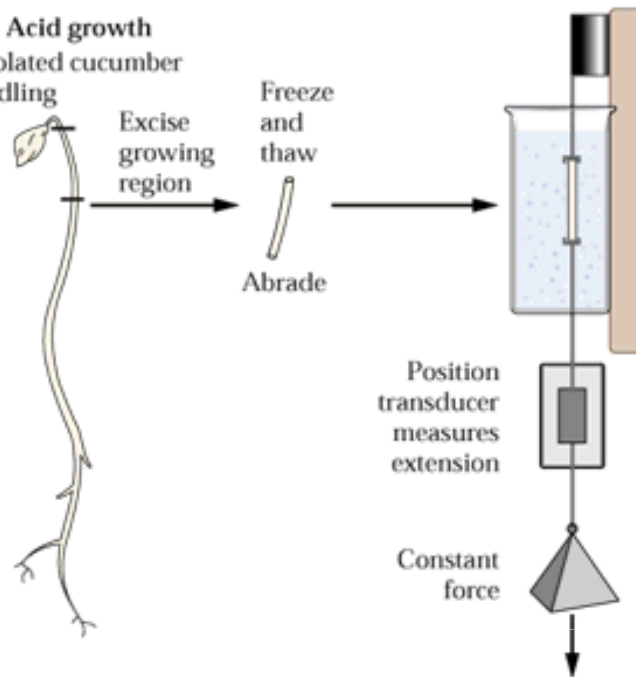


Rilassamento per stiramento



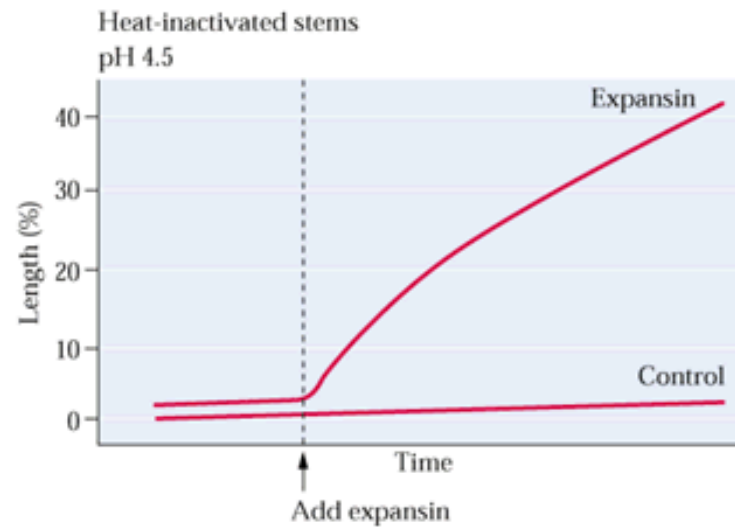
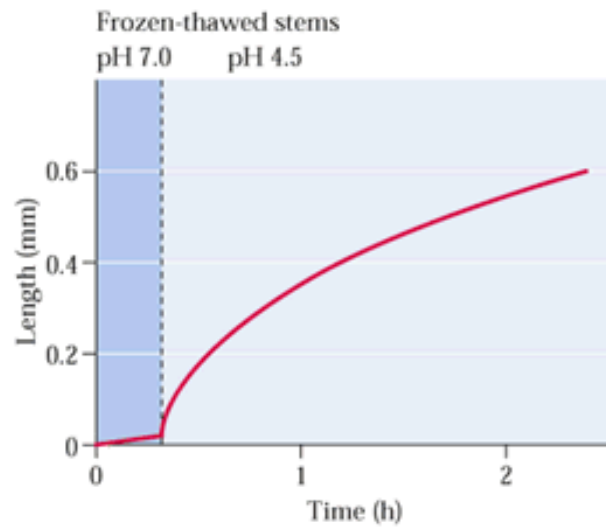
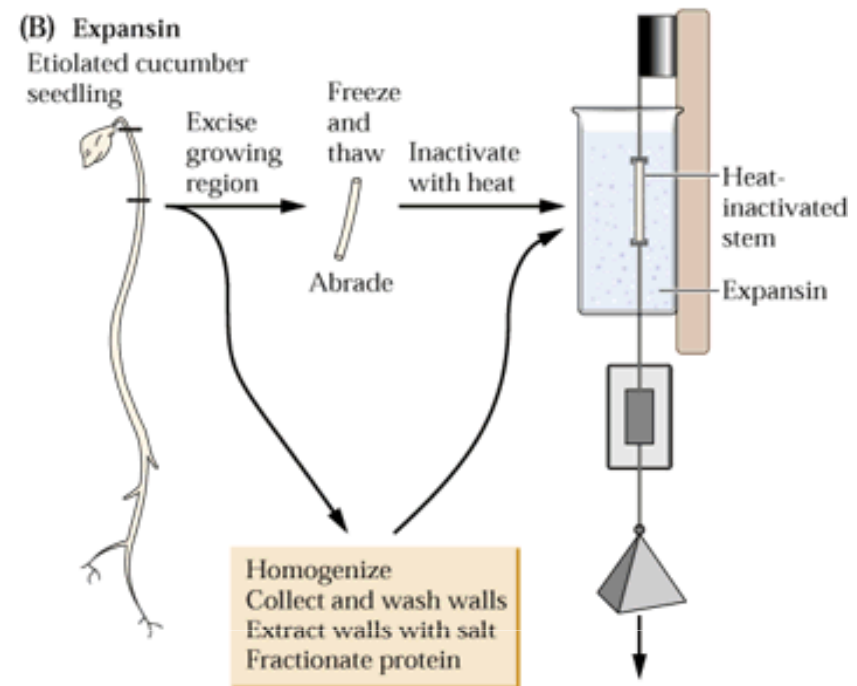
(A) Acid growth

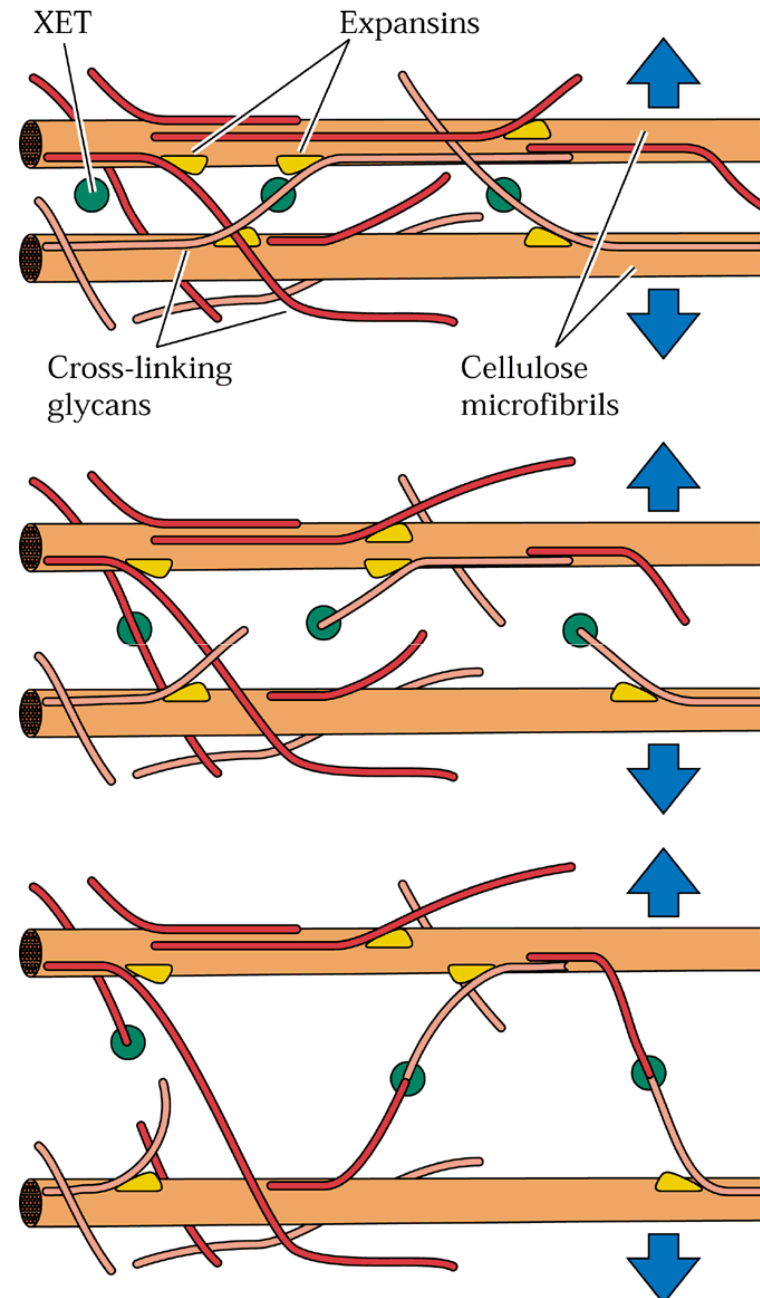
Etiolated cucumber seedling



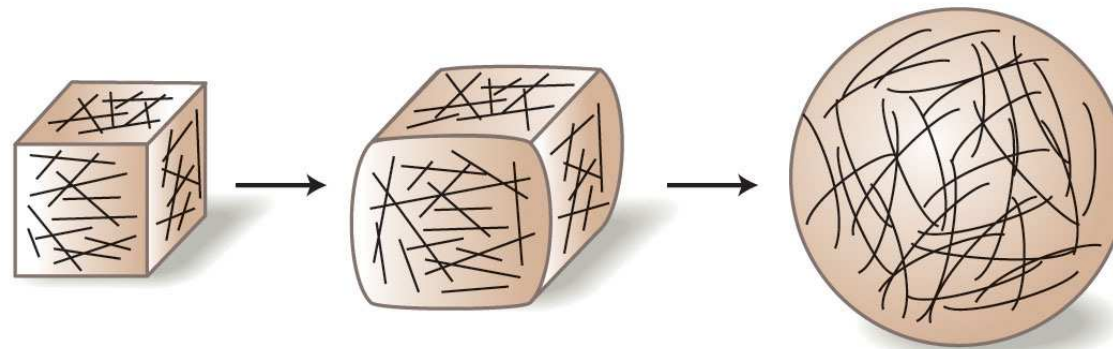
(B) Expansin

Etiolated cucumber seedling

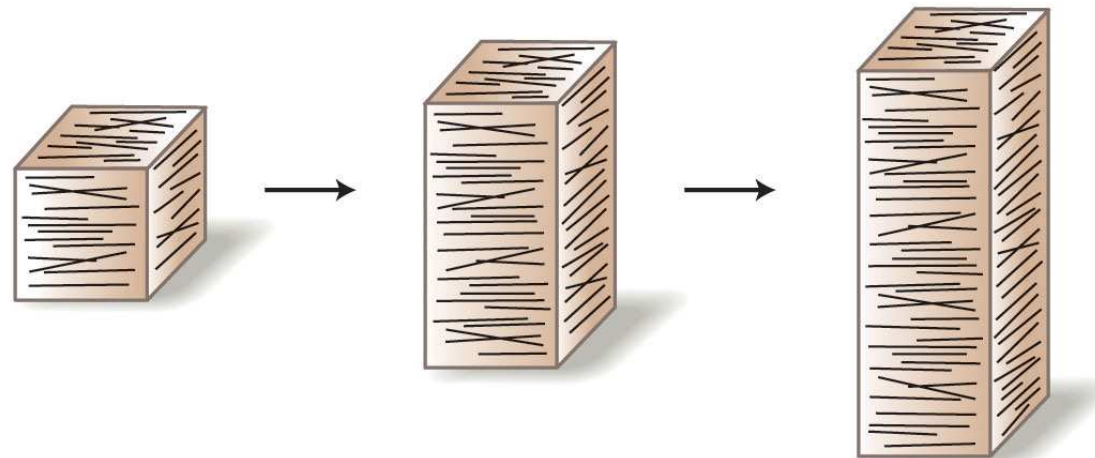




(A) Randomly oriented cellulose microfibrils



(B) Transverse cellulose microfibrils



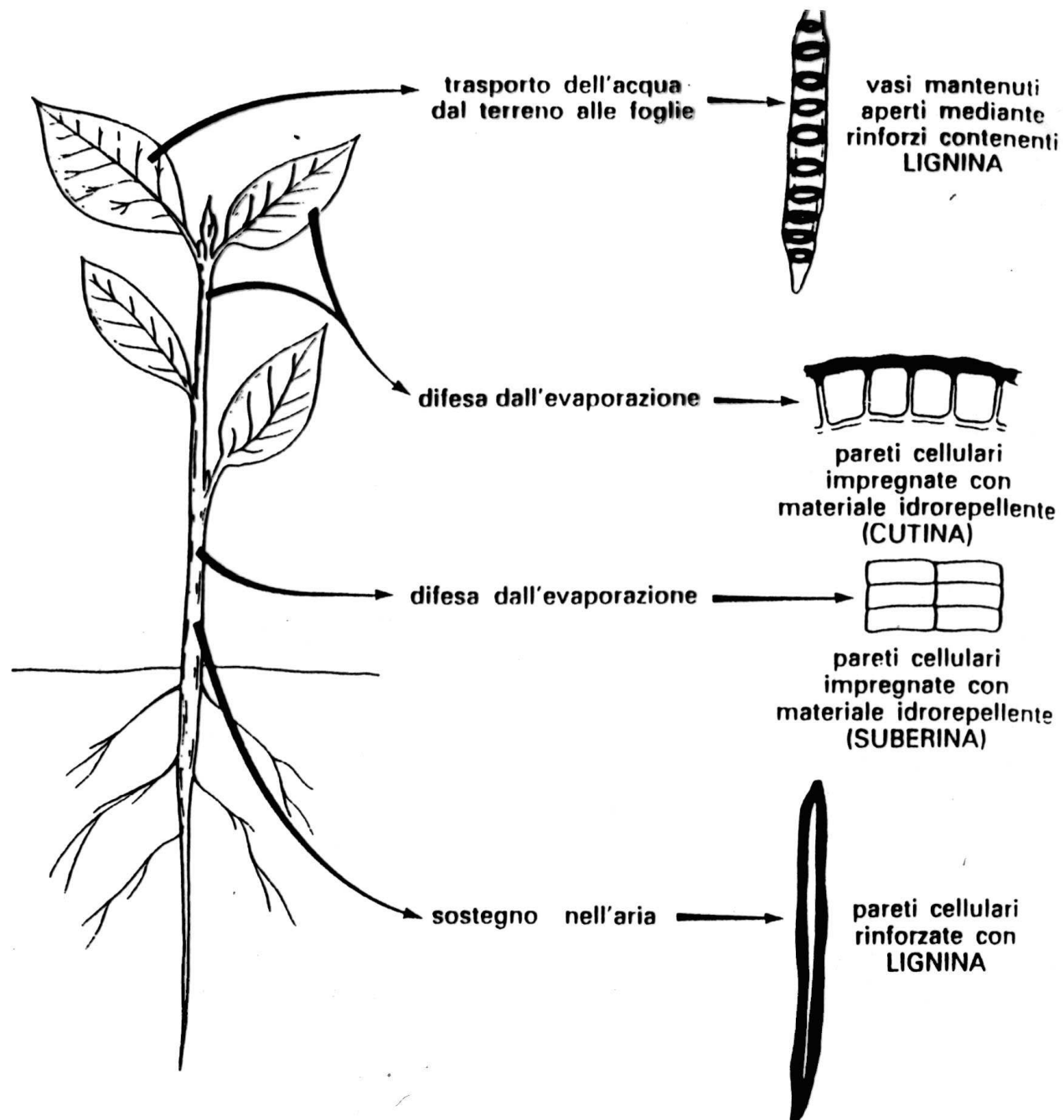
PARETE SECONDARIA

cessazione crescita → ispessimento della parete primaria per stratificazione di materiale

- forma cellulare
- sostegno meccanico della pianta
- difesa
- riduzione della traspirazione

componenti:

cellulosa (in strati sovrapposti)
lignina
cuticola (cutina e cere)
suberina



LIGNINA

polimero di natura fenolica
costituito principalmente da
fenilpropanoidi



alcool coniferilico
alcool sinapilico
alcool cumarilico

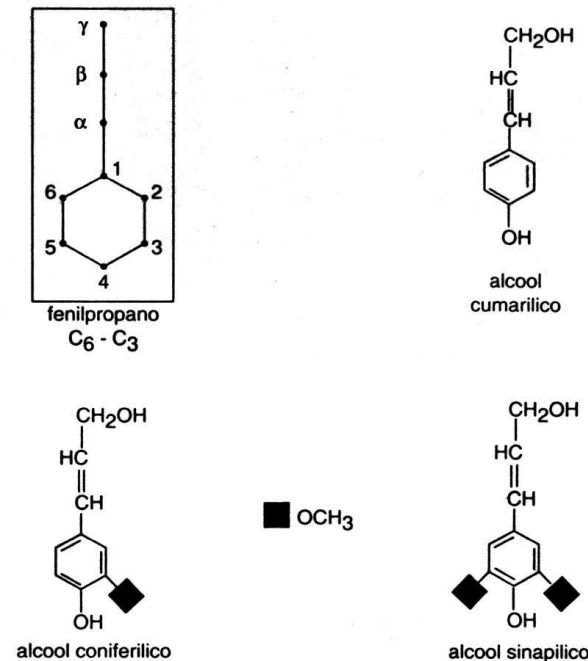


Fig. 11.22. Rappresentazione di una unità di fenilpropano e dei monomeri costitutivi della lignina. (Da D. Robert e J.C. Roland, 1989).

la via metabolica inizia dalla fenilalanina,
che si forma dalla via dell'acido scichimico

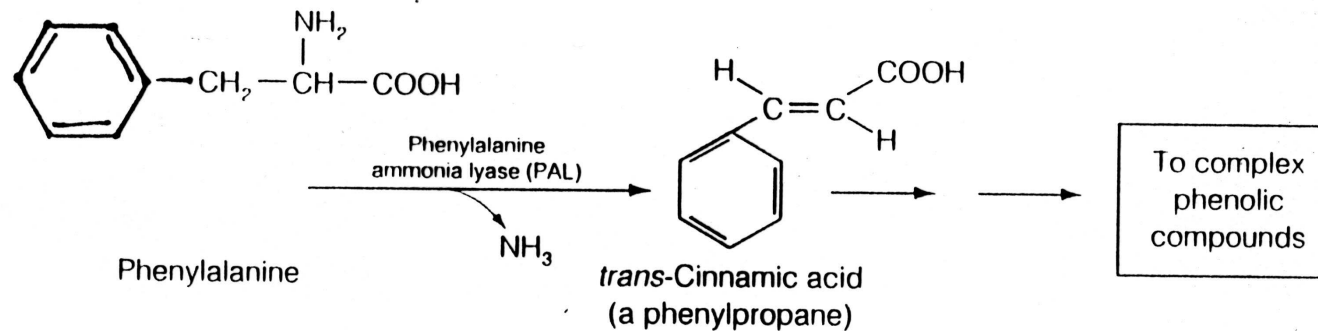


FIGURE 13.16. The deamination of phenylalanine to *trans*-cinnamic acid is an important step in phenolic biosynthesis in most species of plants. *trans*-Cinnamic acid, a phenylpropane, is an important building block of more complex phenolic compounds. This reaction is catalyzed by phenylalanine ammonia-lyase (PAL).

PAL= fenilalanina ammoniaca liasi

enzima regolatore del metabolismo secondario

sotto il controllo (enzima inducibile) di:

- luce
- ormoni
- ferite
- infezioni fungine

la polimerizzazione avviene mediante un meccanismo ossidativo che comporta la formazione di radicali liberi

PEROSSIDASI: emoproteina H_2O_2 -dipendente

LACCASI: ossidasi O_2 -dipendente

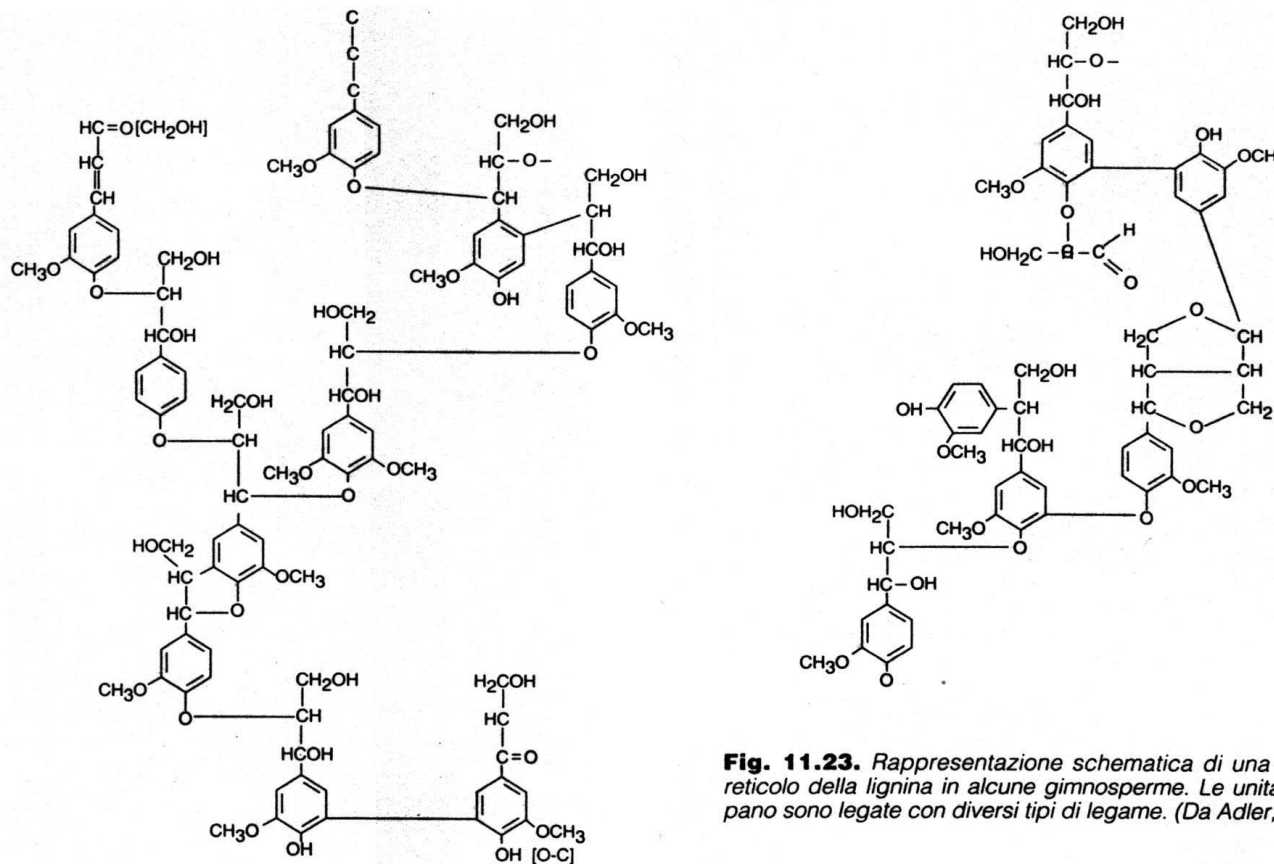
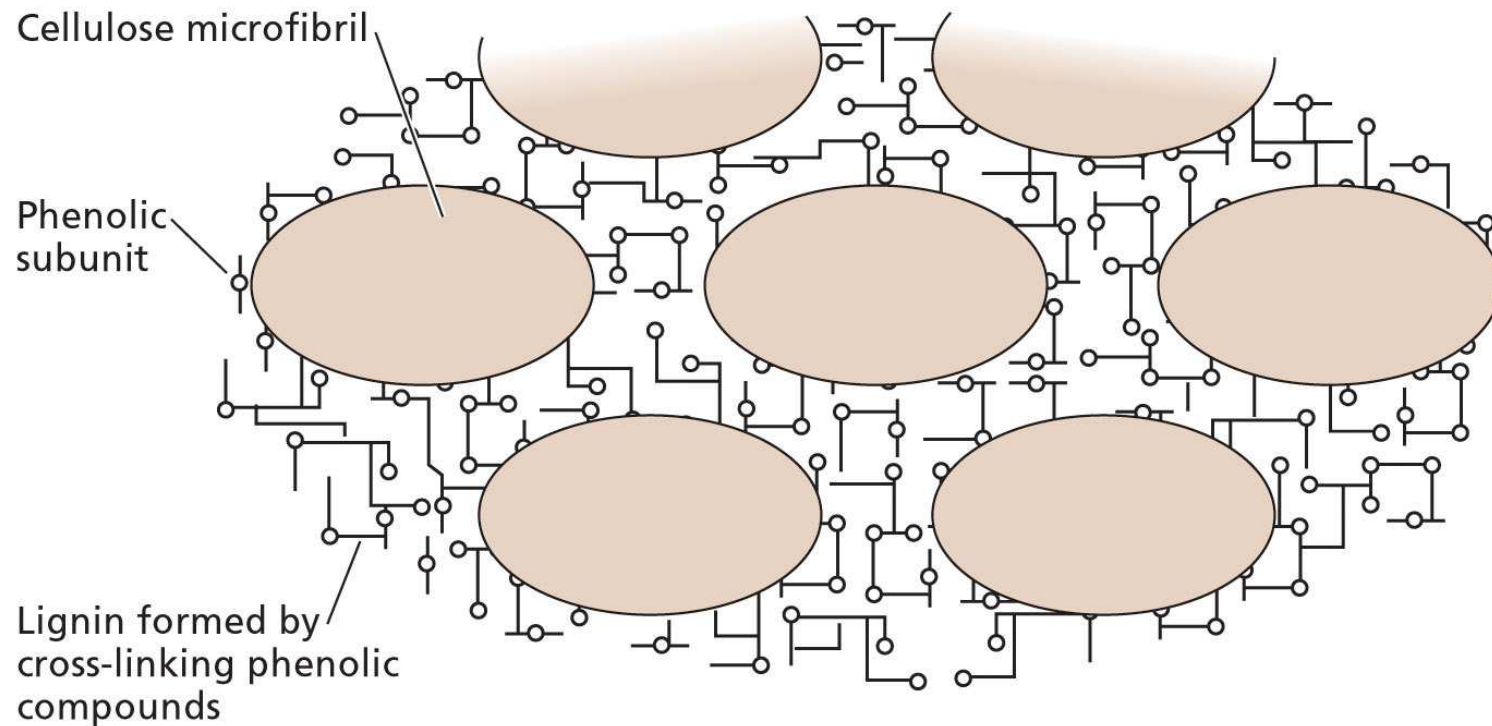


Fig. 11.23. Rappresentazione schematica di una porzione del reticolo della lignina in alcune gimnosperme. Le unità del fenilpropano sono legate con diversi tipi di legame. (Da Adler, 1977).

La sintesi di lignina **elimina acqua** dalla parete e forma una trama **idrofobica** che lega la cellulosa e **previene l'espansione cellulare**



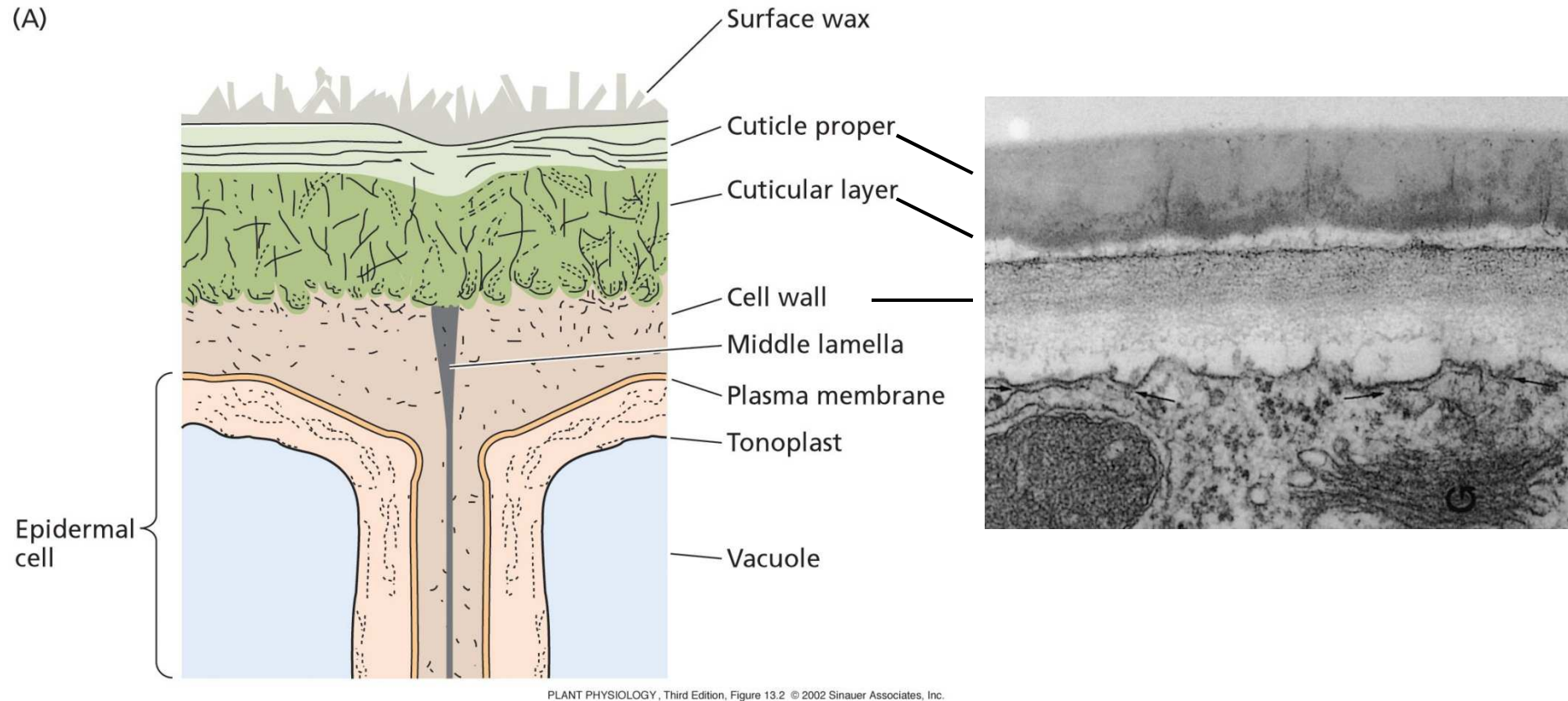
Le cellule epidermiche delle parti aeree sono coperte da un film di lipidi solubili e polimerizzati



CUTICOLA

Barriera alla perdita d'acqua

Resistenza a patogeni e insetti

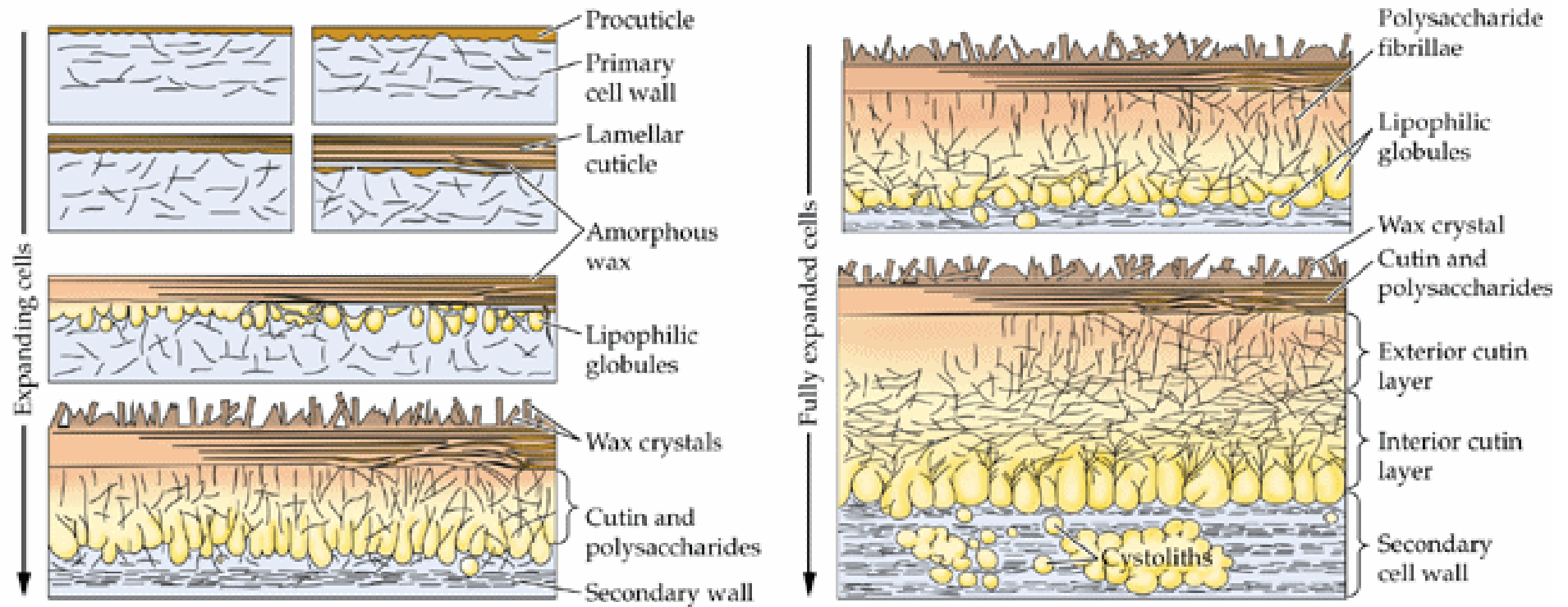


Strato superiore di cere

Strato mediano costituito da cutina inclusa in cere

Strato inferiore costituito da cutina e cere miscelate con componenti pectiche (strato cuticolare)

STADI DI SVILUPPO DELLA CUTICOLA



CUTINA

è il principale costituente della cuticola

ricopre le pareti esterne dell'epidermide delle parti aeree delle piante erbacee

**poliestere a maglie tridimensionali di
acidi grassi e idrossiacidi**

può legarsi alle pectine

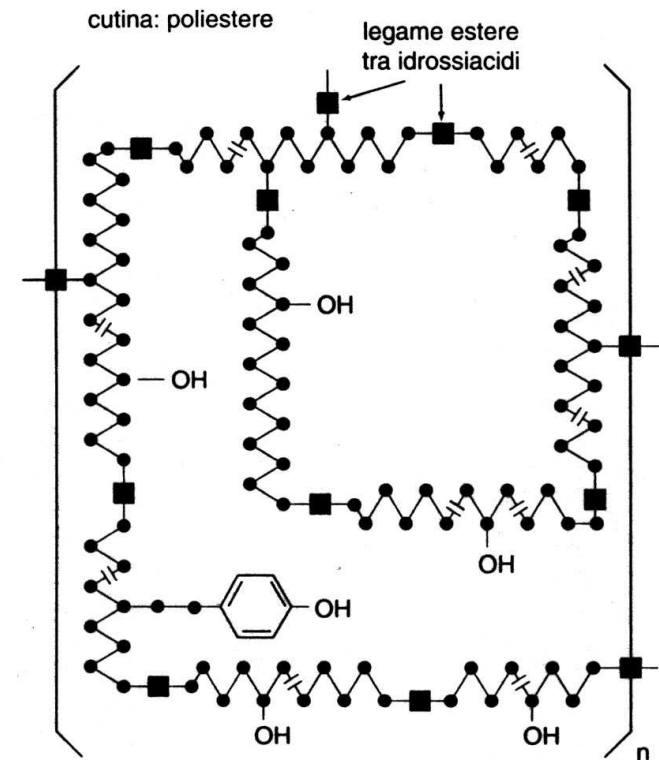


Fig. 11.28. Formazione dei poliesteri a reticolo tridimensionale nella cutina. (Da Robert e Roland, 1989).

CERE

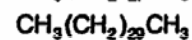
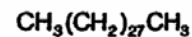
Miscele complesse di lipidi

alcani a catena lineare 25-35 C

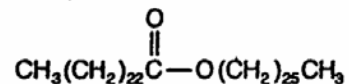
Presenti esteri tra acidi grassi e alcoli a lunga catena

Examples of common wax components:

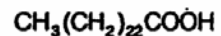
Straight-chain alkanes



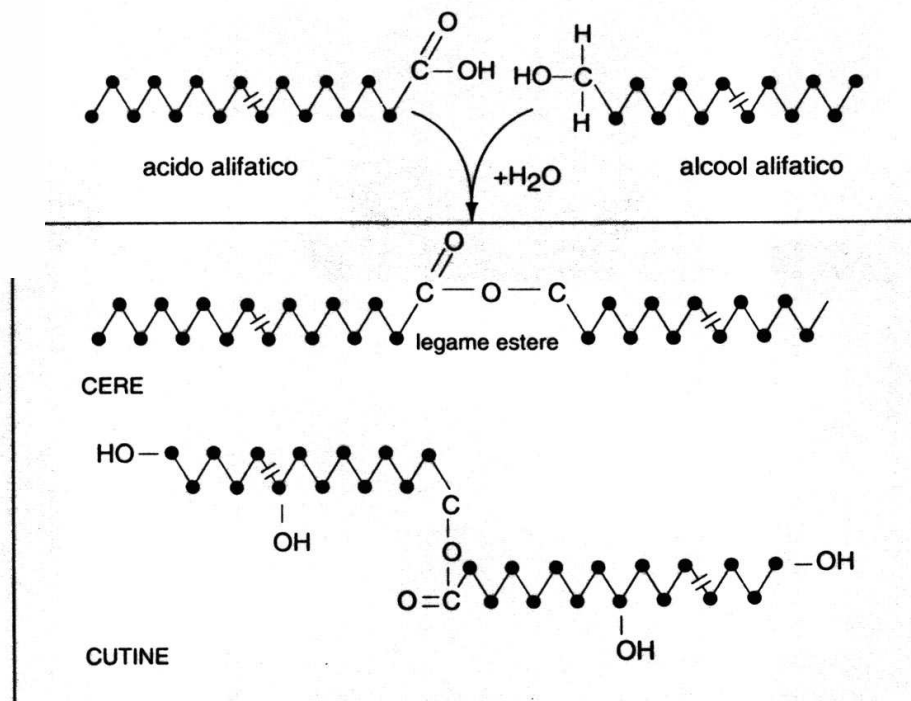
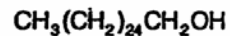
Fatty acid ester



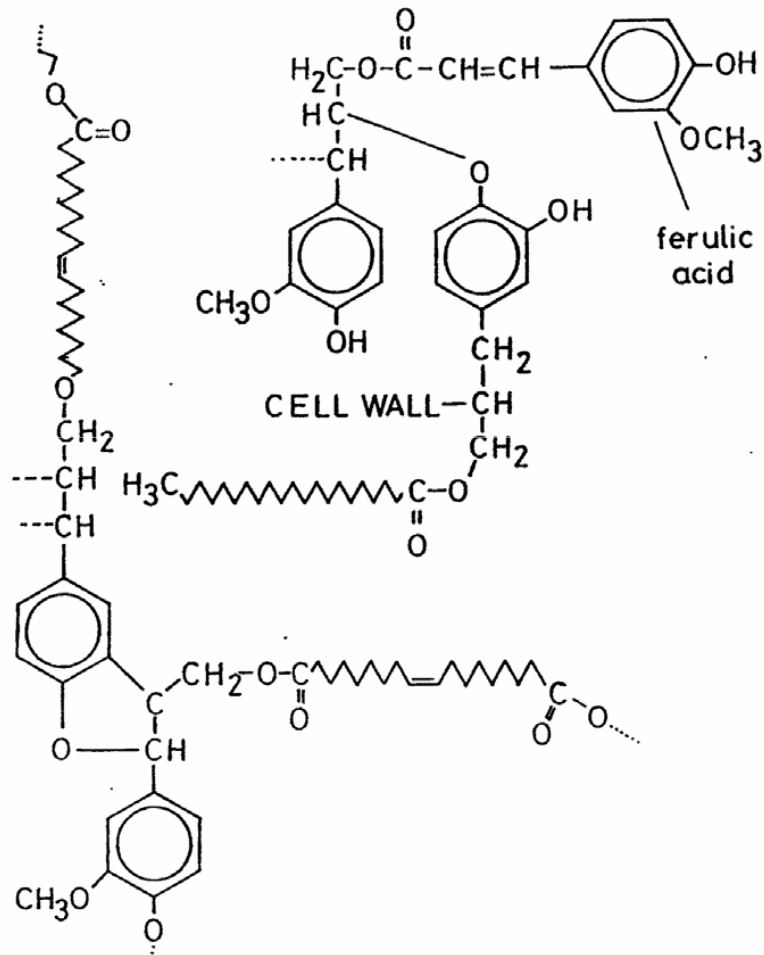
Long-chain fatty acid



Long-chain alcohol



SUBERINA



Simile alla cutina. Contiene acidi dicarbossilici, composti fenolici. Gli acidi grassi hanno catene più lunghe

Componente principale pareti esterne organi ipogei (ex. banda di Caspary)