Plant hormone
and
growth and development

Definition

Plant hormones are small organic compounds that influence physiological responses to environmental stimuli at very low concentrations (generally less than 10^{-7} M). Hormones are not directly involved in metabolic or developmental processes but they act at low concentrations to modify those processes.

What can they do?

Hormones regulate or influence a range of cellular and physiological processes, including

- Cell Division
- Cell Enlargement
- Cell Differentiation
- Flowering
- Fruit Ripening
- Movement (tropisms)

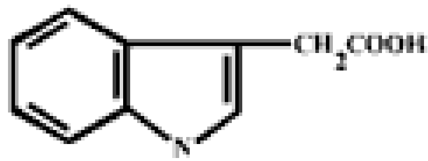
Not all researchers agree that the term "hormone" should be applied to plants.

Plants do not have a circulatory system and therefore hormone action in plants is fundamentally different from hormone action in animals. Many plant biologists use the term "plant growth regulator" instead of "hormone" to indicate this fact. The table below summarizes some of the differences between plant and animal hormones.

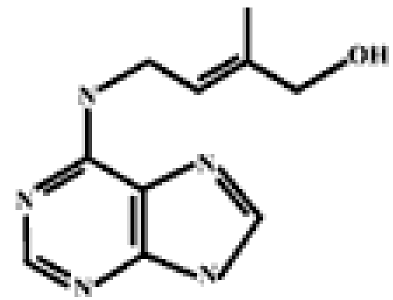
Plant Hormones	**Animal Hormones**
1.Small molecules only	1.Peptides/proteins and/or small molecules
2. Produced throughout the plant	2. Produced in specialized "glands"
3. Mainly local targets (nearby cells and tissues)	3. Distant targets ("action at a distance")
4. Effects vary depending on interaction with other hormones	4. Specific effects
5."Decentralized" regulation	5. Regulation by central nervous system

$CH_2=CH_2$

Ethylene

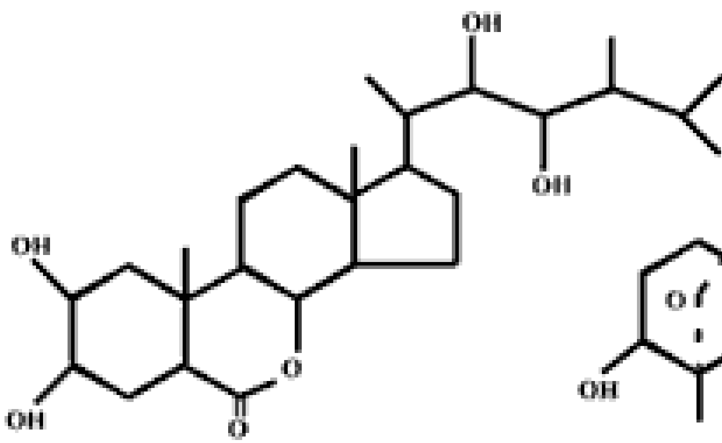


Auxin

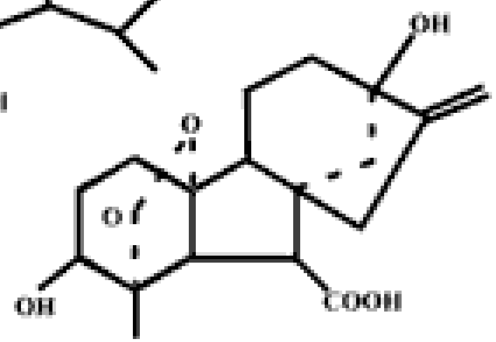


Cytokinins

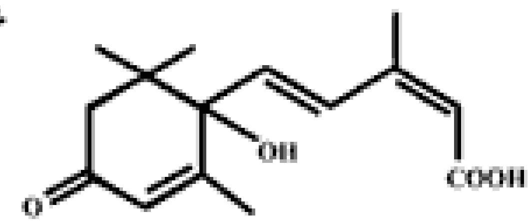
Jasmonic Acid



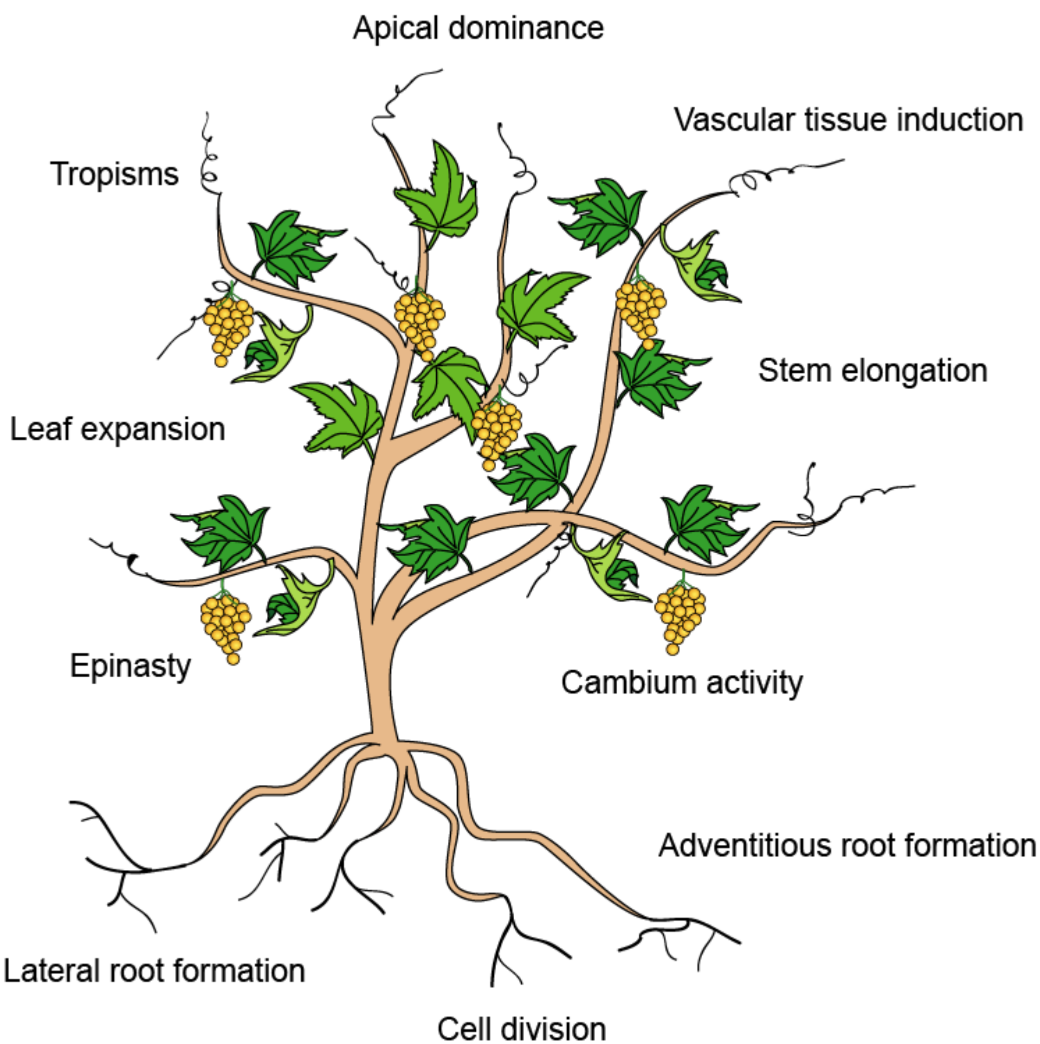
Brassinosteroids

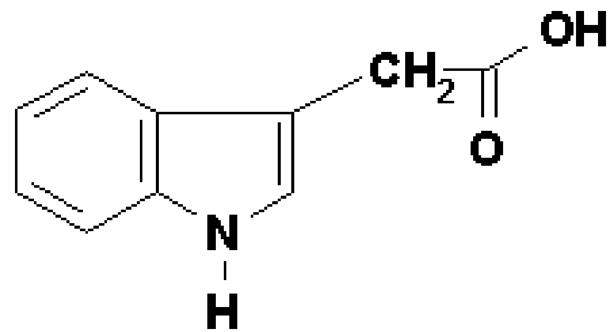


Gibberellins



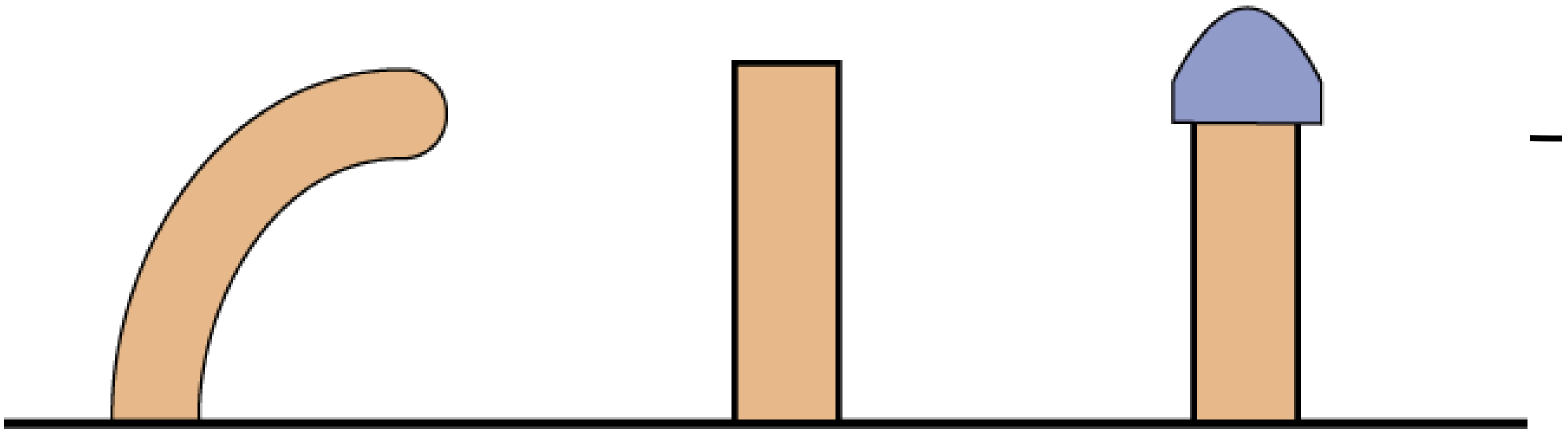
Abscisic Acid





Indole-3-acetic acid (IAA)

Discovery of auxin

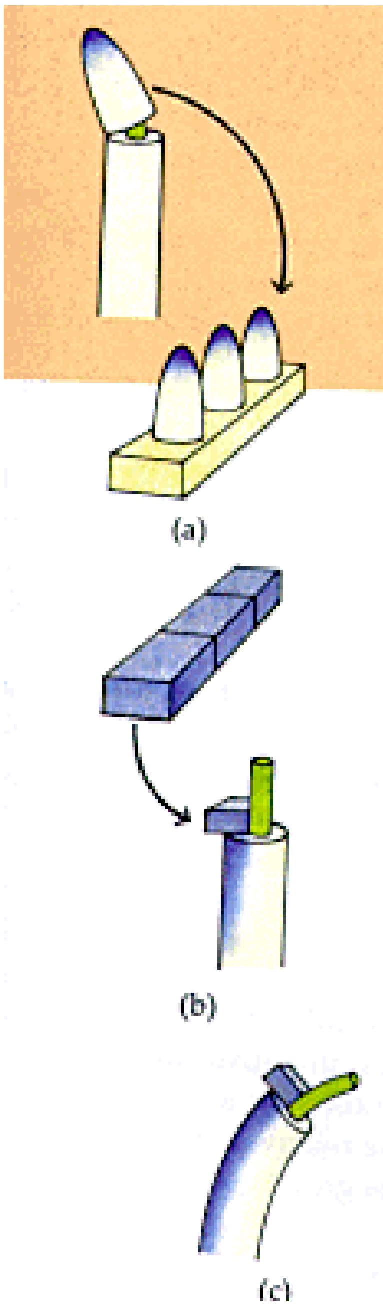


Intact seedlings
Curvature

Tip of coleoptile excised
no curvature

Opaque cap on tip
no curvature

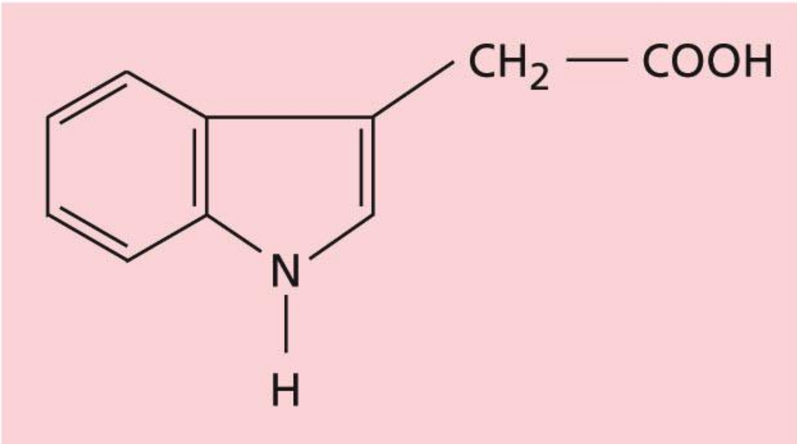
From experiments on coleoptile phototropism, Darwin concluded in 1880 that some sort of signal is produced in the tip, travels to the growth zone and causes the shaded side to grow faster than the illuminated side.



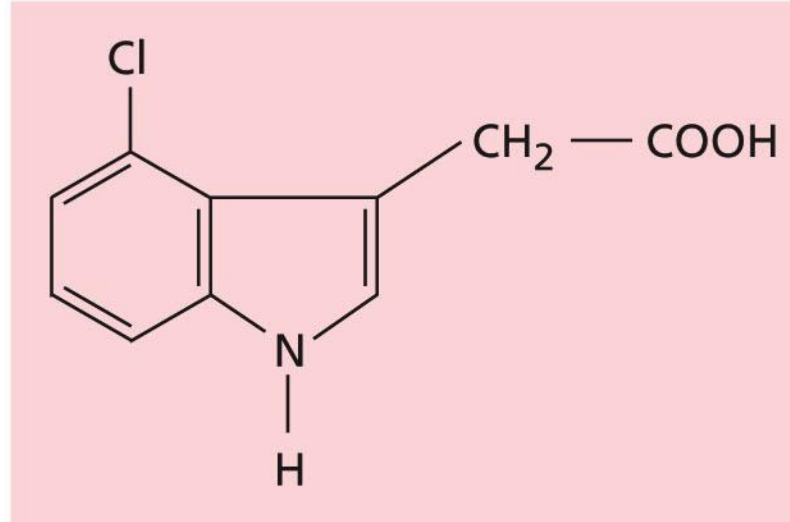
In 1926, Went showed that the active growth substance can diffuse into gelatin block and can cause the bending of coleoptile in absence of a unilateral light source

Because the substance promoted the elongation of the coleoptile sections it was eventually named **auxin** from the Greek *auxein*, meaning "to increase" or "to grow"

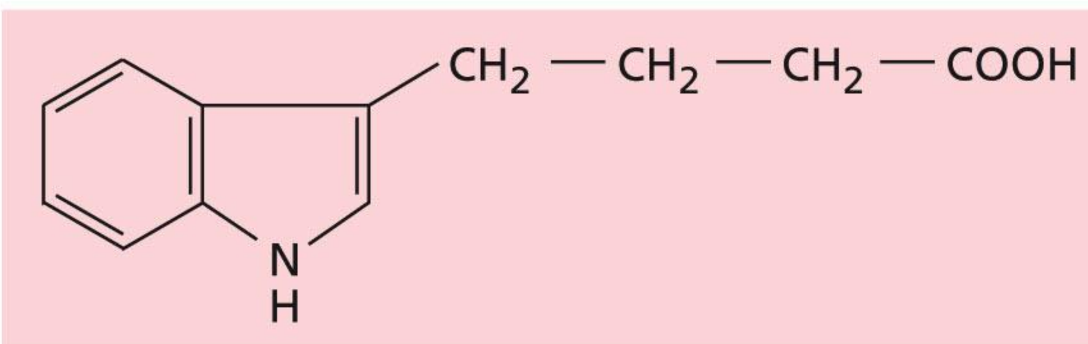
In mid 1930's Kogl and Haagen-Smit isolated several active substances from human urine and the most potent one Indole-3-acetic acid turned out to be the one synthesized and used by the plants



Indole-3-acetic acid (IAA)

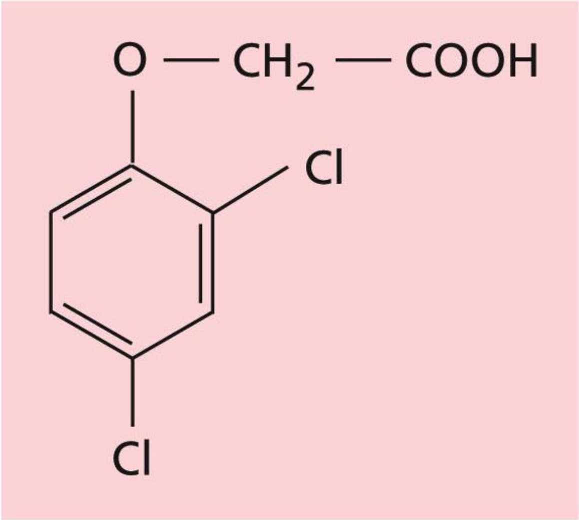


4-Chloroindole-3-acetic acid (4-Cl-IAA)

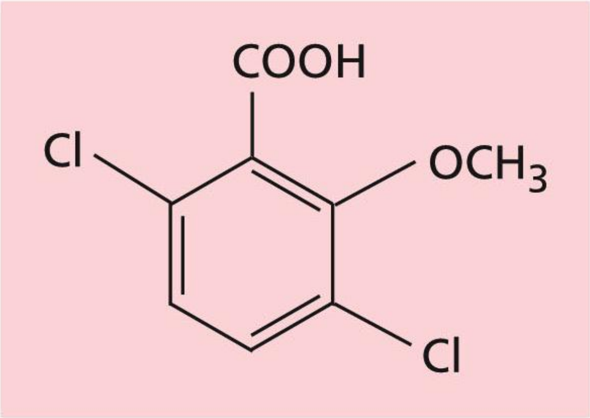


Indole-3-butyric acid (IBA)

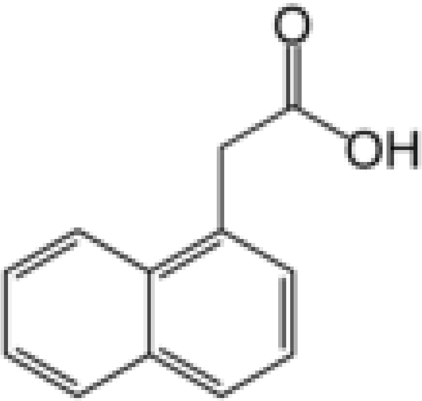
Synthetic auxin



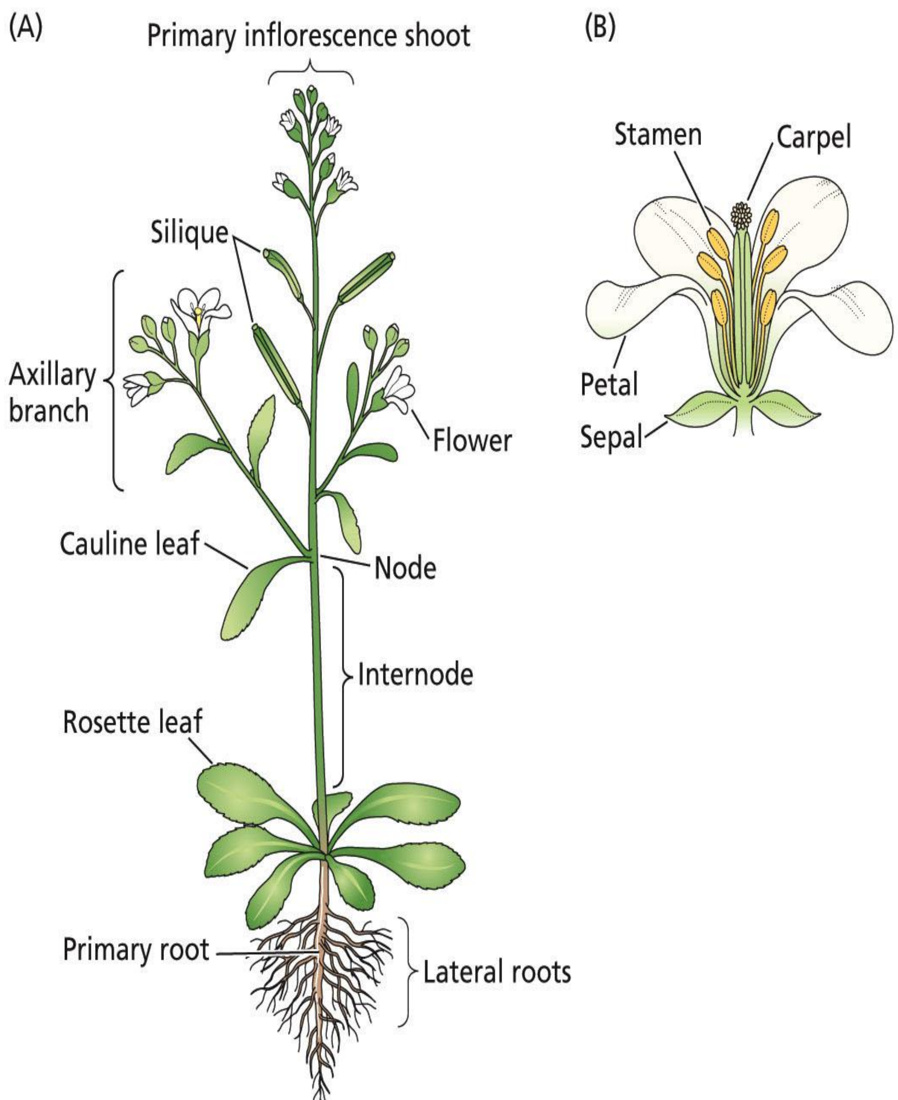
2,4-Dichlorophenoxyacetic acid (2,4-D)



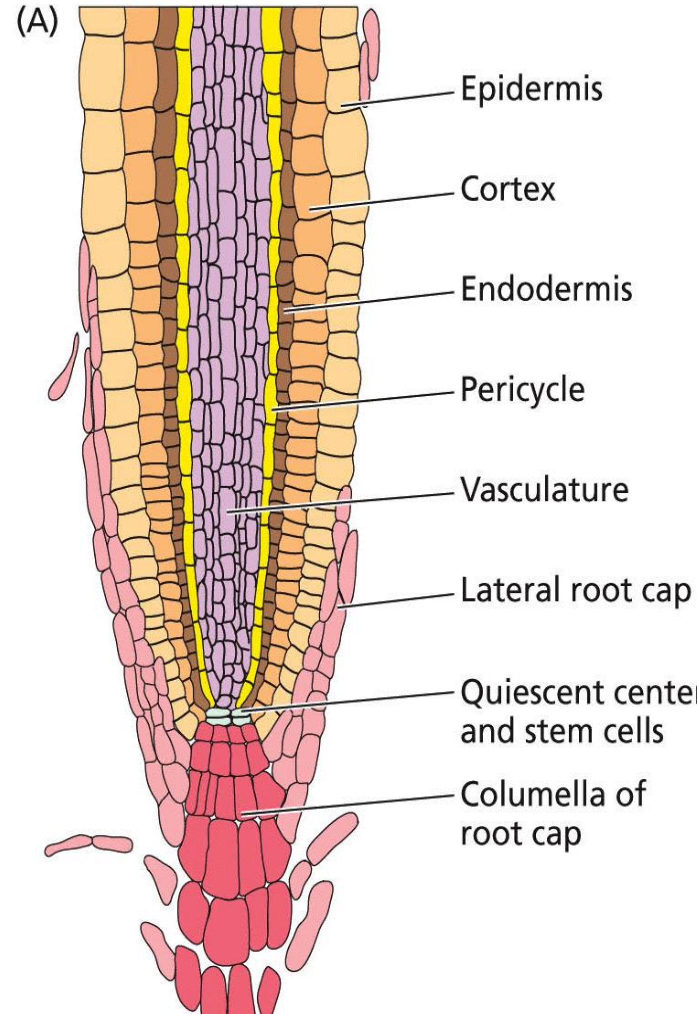
2-Methoxy-3, 6-dichlorobenzoic acid (dicamba)



1- naphthaleneacetic acid (NAA)



PLANT PHYSIOLOGY, Fourth Edition, Figure 16.1 (Part 1) © 2006 Sinauer A



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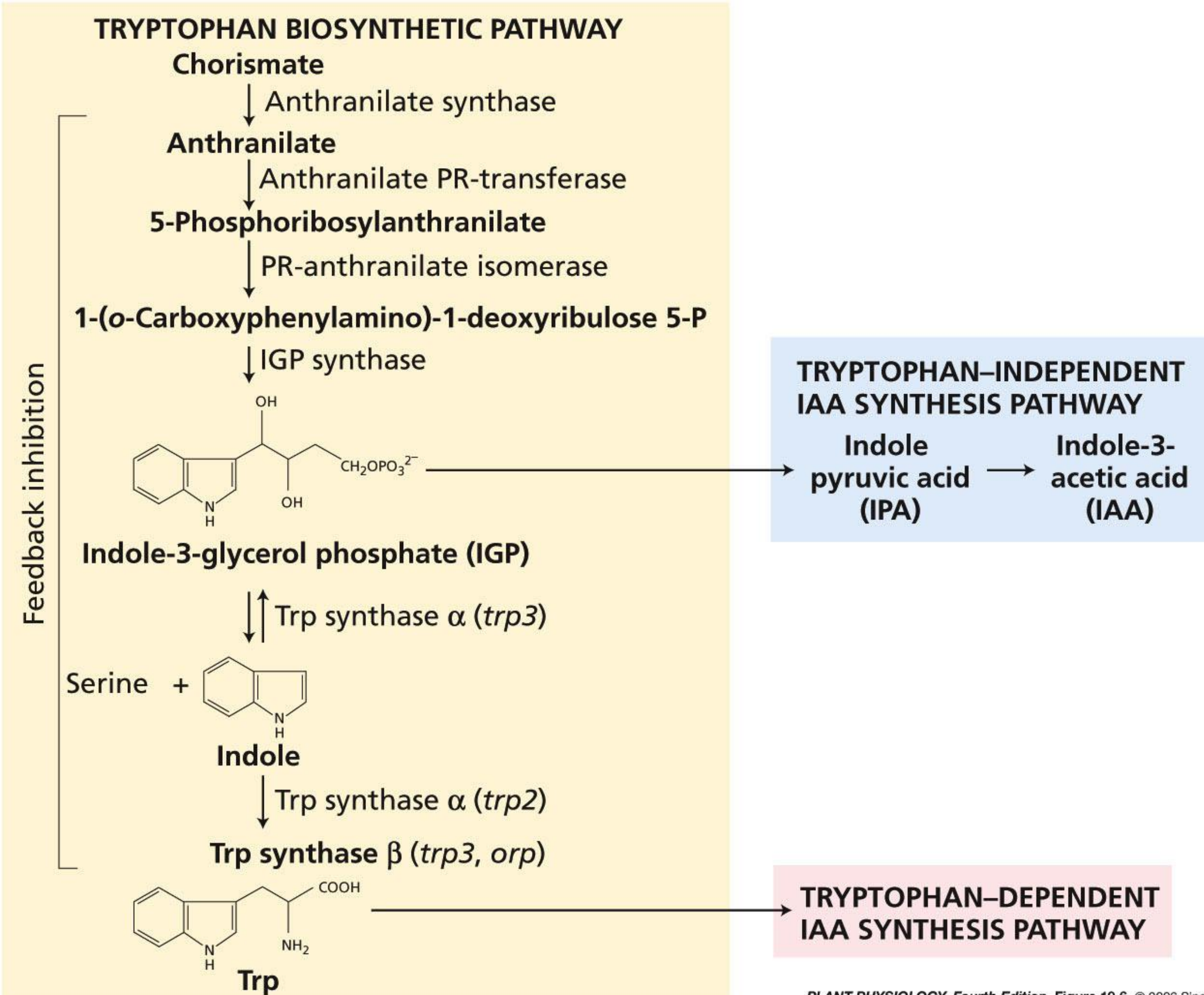
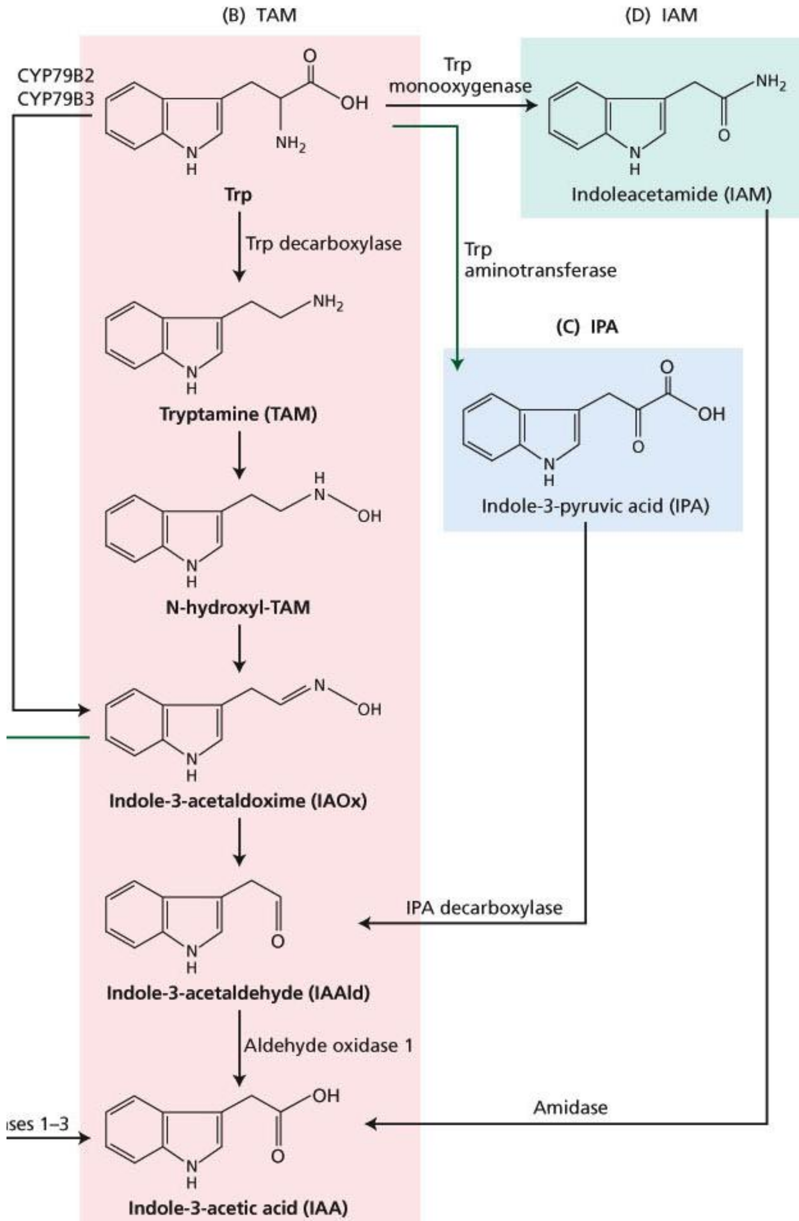
Auxin Biosynthesis

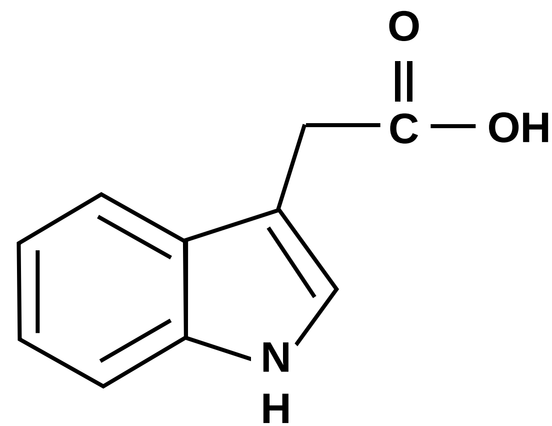


PLANT PHYSIOLOGY, Fourth Edition, Figure 19.6



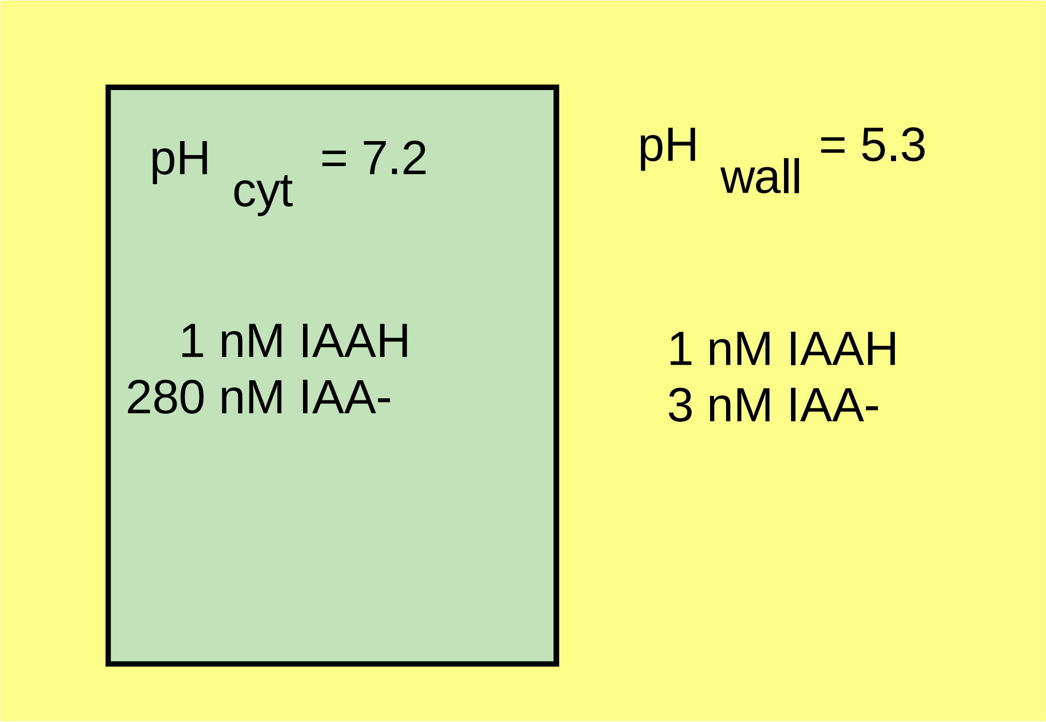
***PLANT PHYSIOLOGY*, *Fourth Edition*, Figure 1**

Indole-3-acetic acid (IAA)



- Mol wt 175
- A weak acid (pK_a = 4.8)
- IAAH is “membrane permeable”, IAA^{-} impermeable.
- Transported through shoots and roots towards root tips through parenchyma (also phloem?).

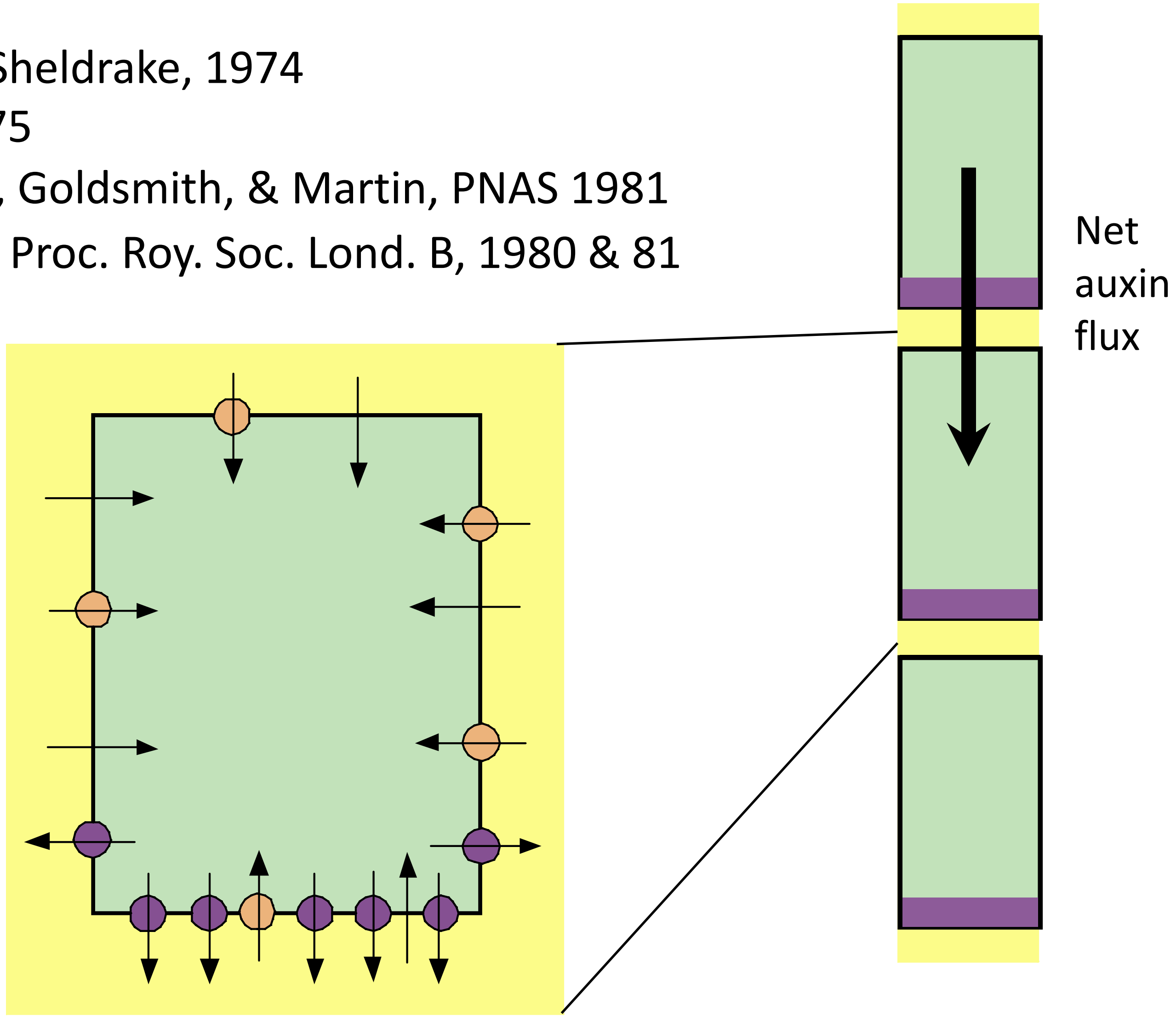
“Acid trapping”

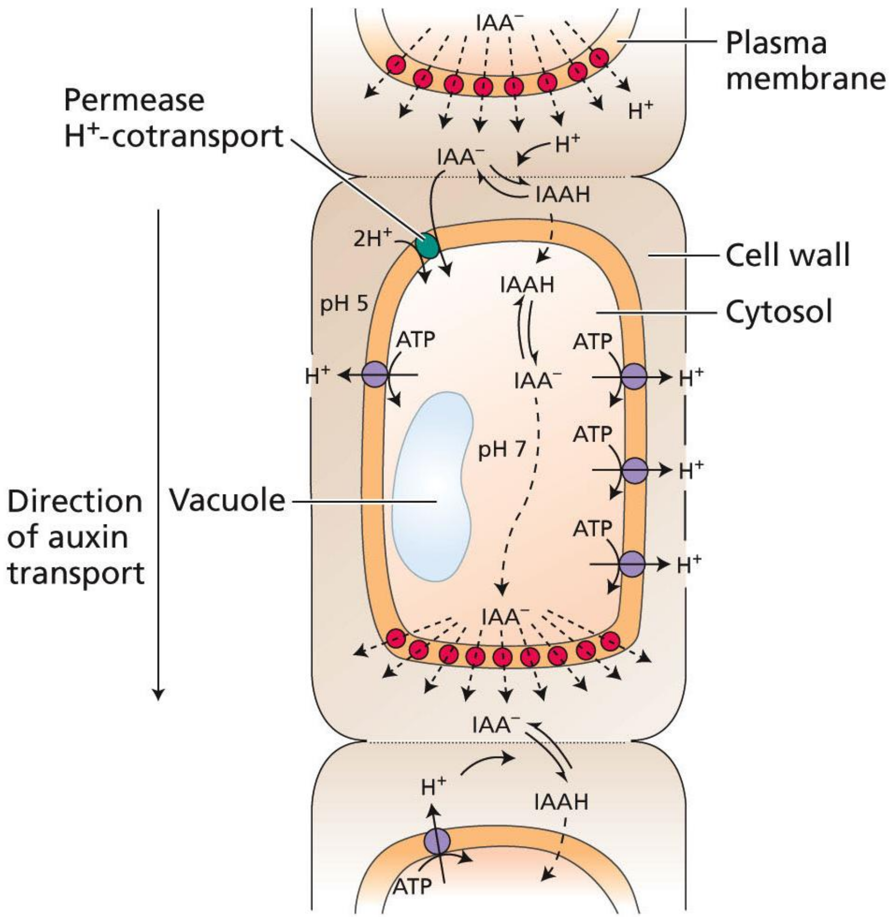


If the IAAH concentration is in equilibrium, the cytoplasmic auxin concentration is 70x higher than the cell wall.

Chemiosmotic theory

Rubery & Sheldrake, 1974
Raven, 1975
Goldsmith, Goldsmith, & Martin, PNAS 1981
Mitchison, Proc. Roy. Soc. Lond. B, 1980 & 81





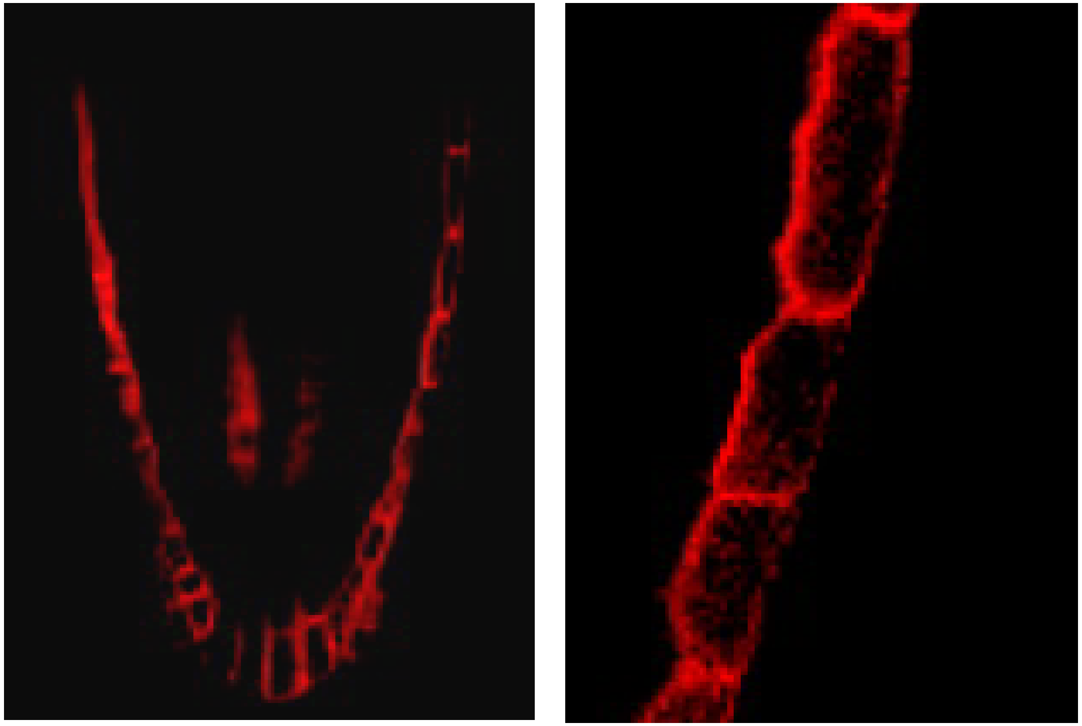
PLANT PHYSIOLOGY, Fourth Edition, Figu

Auxin influx carrier protein

Auxin efflux carrier proteins

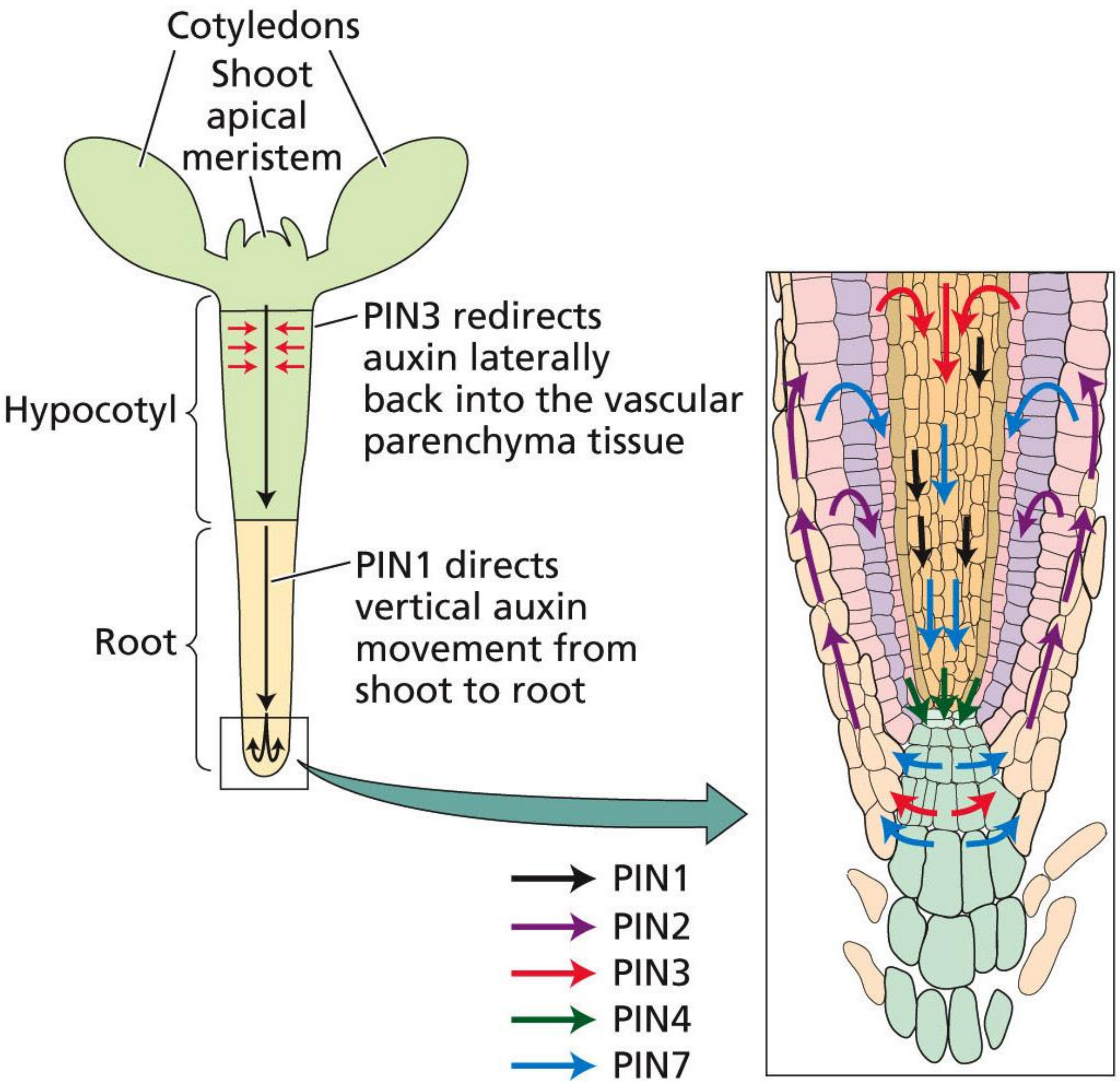
Our current understanding of the transport system originated from the analyses of several mutants

aux1 *(1996)*: The roots are agravitropic and resistant to IAA and 2,4-D but sensitive to NAA. AUX1 encodes a permease-like regulator of root gravitropism. The uptake assay confirmed that this mutant has a reduced uptake capacity compared with wild-type. AUX1 is expressed in the LRC and epidermal cells in the root meristem and in the phloem of root vascular tissue. In the phloem AUX1 is polarly localized whereas in LRC and epidermal cell files it is axially localized.



AUX1 cellular localization in Arabidopsis root

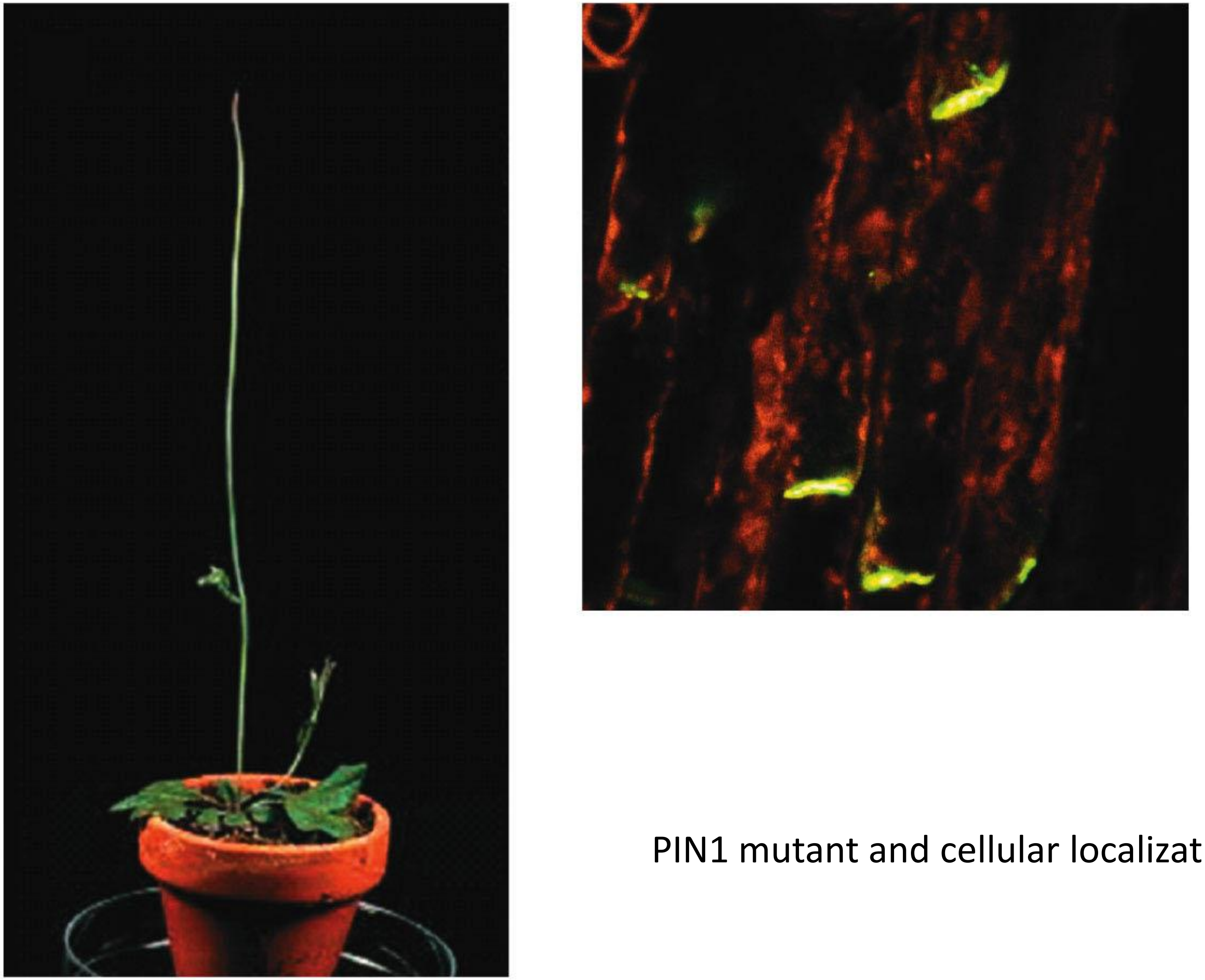
Auxin efflux carrier proteins
PIN family proteins



PLANT PHYSIOLOGY, Fourth Edition, Figure 19.15 (Part 2)

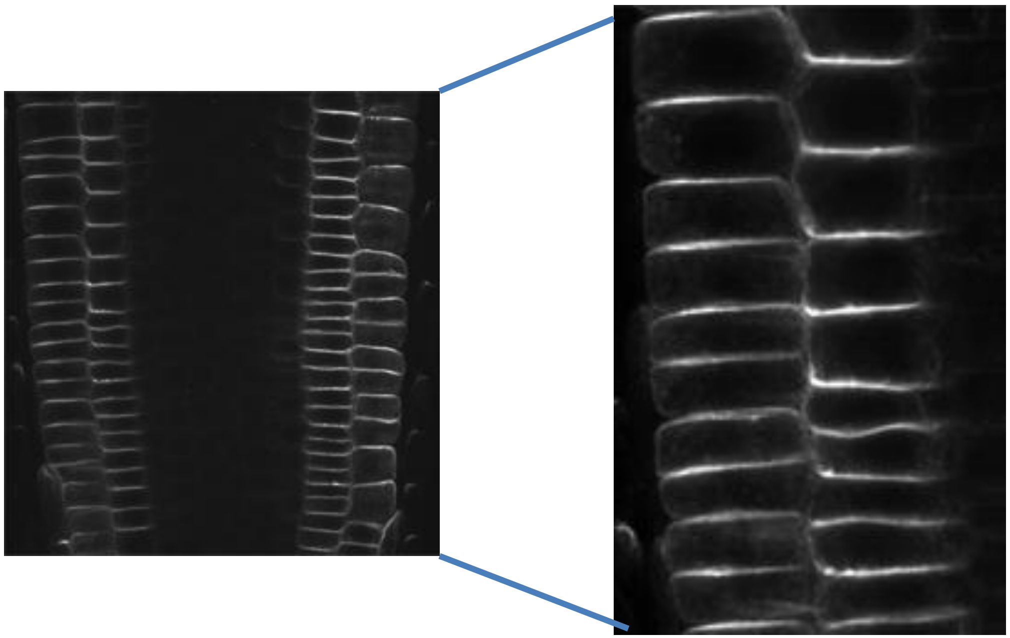
Some ABC transporters also
Play a role in auxin influx and
efflux

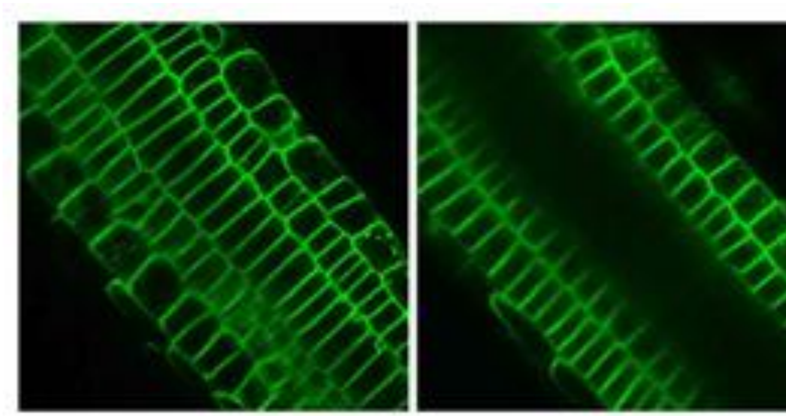
(A) (B)



PIN1 mutant and cellular localization

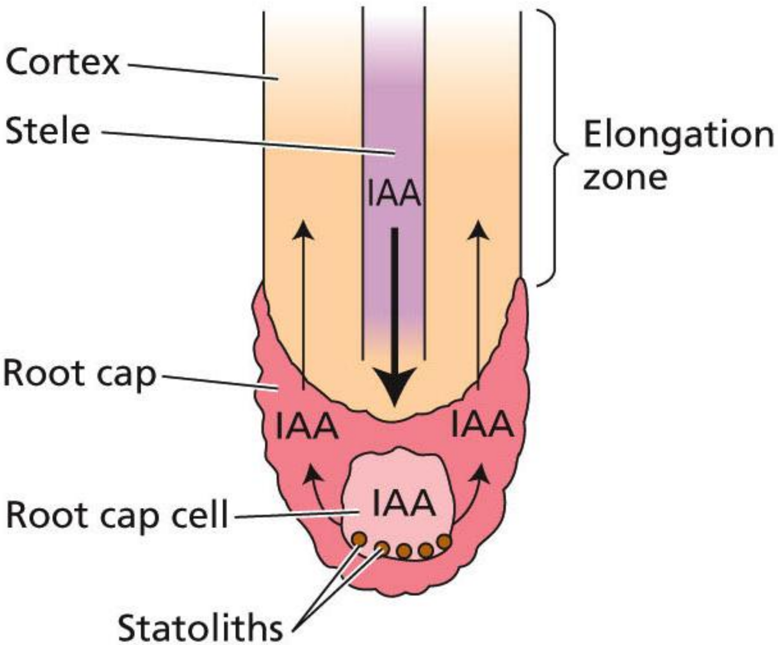
eir1/agr1/pin2 *(1998)*: roots are agravitropic but has a normal sensitivity to exo-genous auxins. EIR1 gene of Arabidopsis is a member of family of plant genes with similarities to bacterial membrane transporters. The basipetal transport of auxin in this mutant was found to be less compared to wild-type. PIN2 is localized in the epidermal and cortical cell file of roots with a reverse polarity

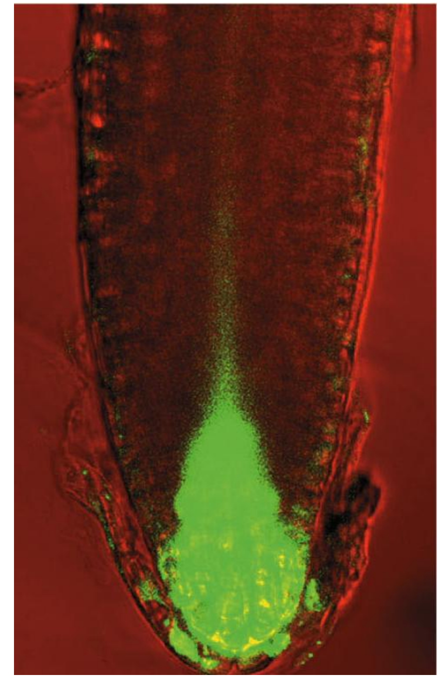




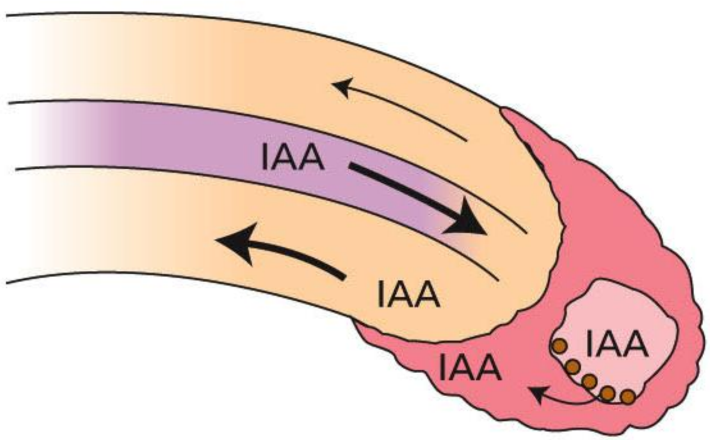
Cellular localization of PIN2

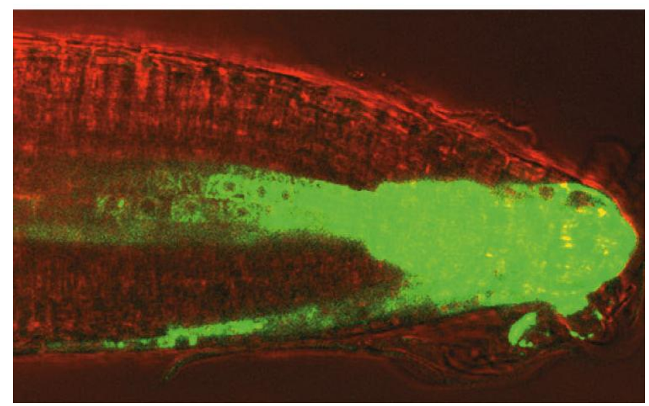
Vertical orientation





(B) Horizontal orientation





PLANT PHYSIOLOGY, Fourth Edition, Figure

Genes involved in downstream auxin signaling pathway

ARF: auxin-response factors

23 member family in Arabidopsis

has DNA binding domains

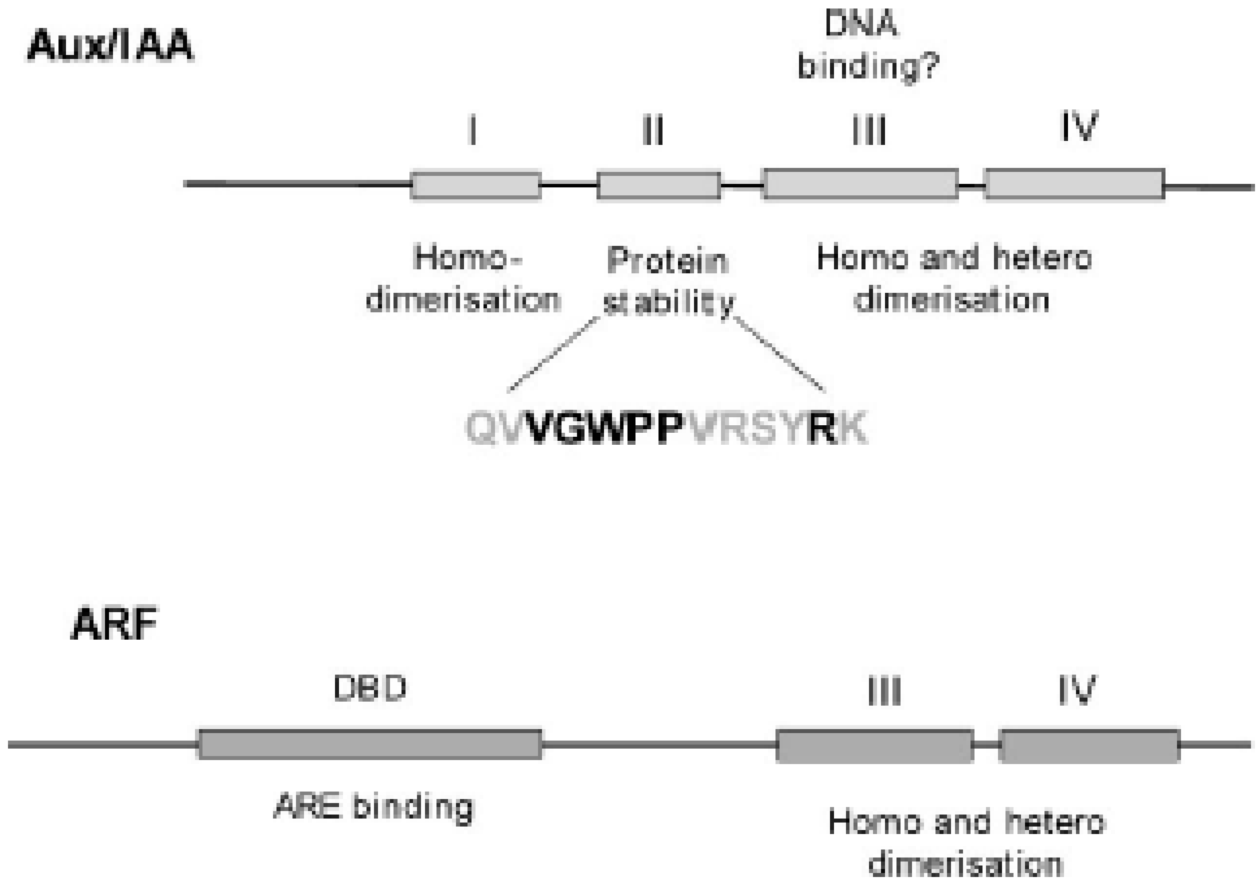
can be either activators or repressors

AUX/IAA: 29 member in Arabidopsis

Has protein binding domain

heterodimerize with ARFs

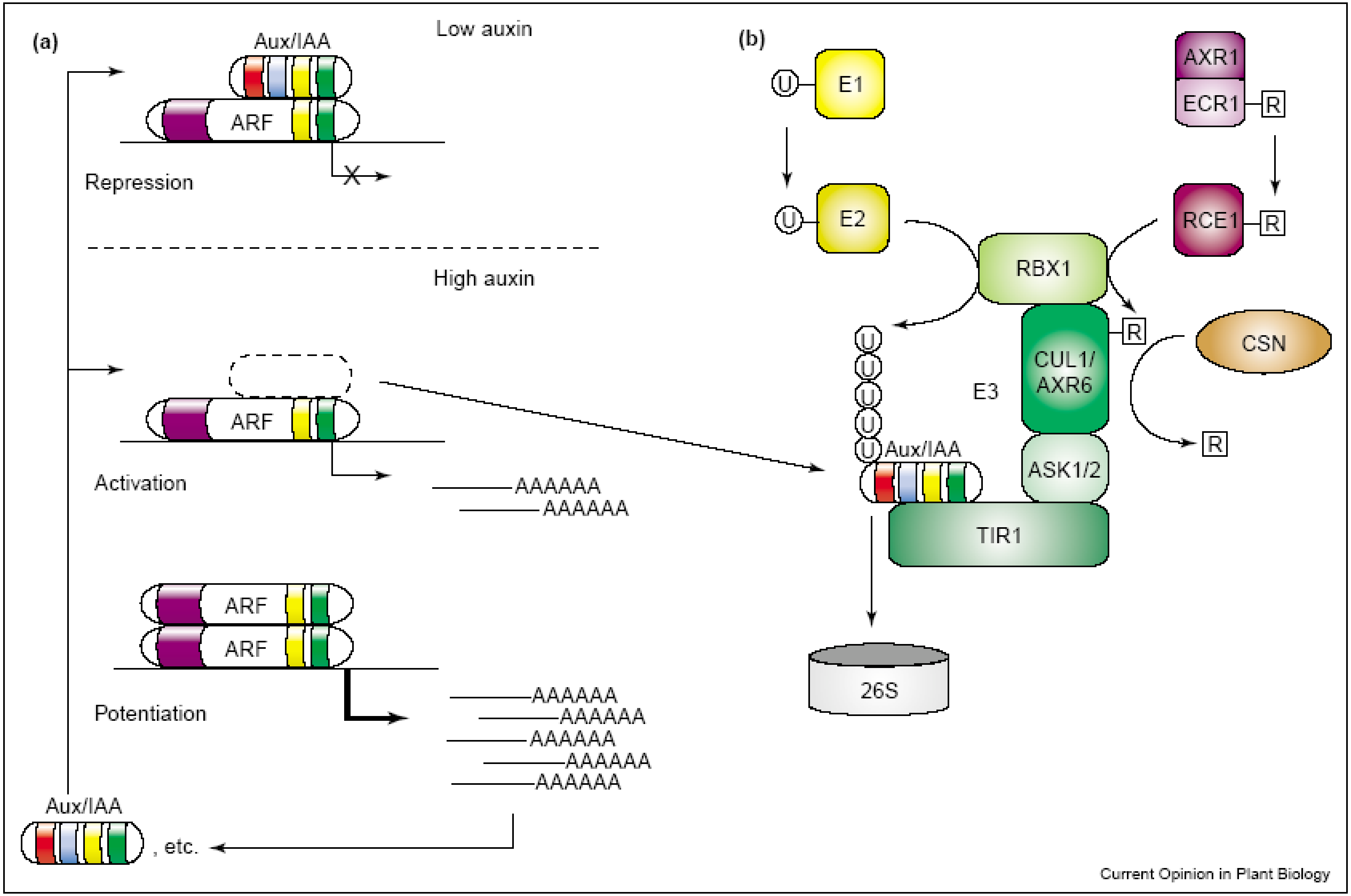
rapid auxin-dependent turn-over of AUX/IAA is dependent on ubiquitin-proteasome-pathway

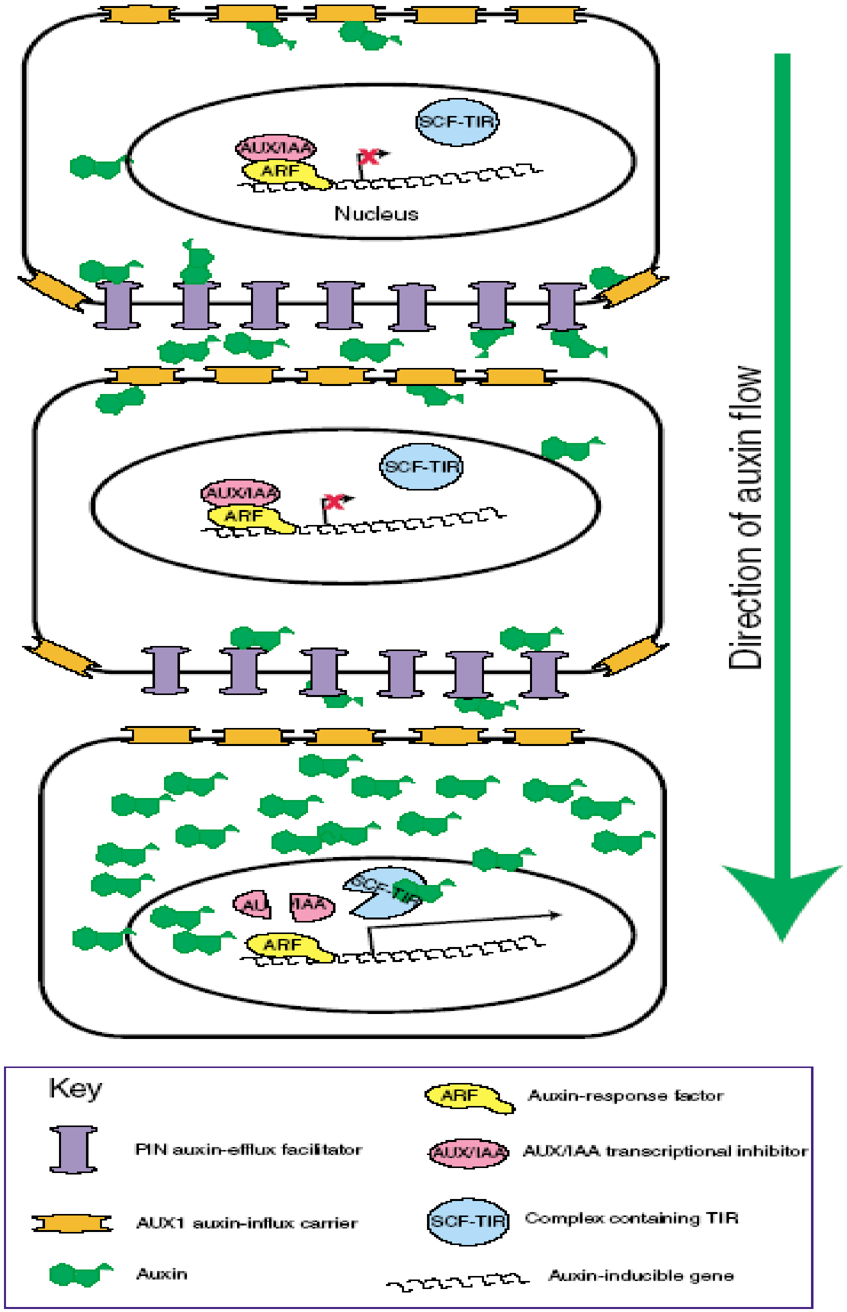

Aux/IAA
DNA binding?
I
II
III
IV
Homo-dimerisation
Protein stability
Homo and hetero dimerisation
QVVGWPPVRSYRK
ARF
DBD
III
IV
ARE binding
Homo and hetero dimerisation

Functionally characterized genes.

Gene name	Gene identifier
Auxin-response factors	
ARF3/ETT[a]	AT2G33860
ARF5/MP	AT1G19850
ARF7/NPH4/TIR5/MSG1	AT5G20730
***Aux/IAA* genes**	
IAA3/SHY2	AT1G04240
IAA6/SHY1	AT1G52830
IAA7/AXR2	AT3G23050
IAA12/BDL	AT1G04550
IAA14/SLR	AT4G14550
IAA17/AXR3	AT1G04250
IAA18	AT1G51950
IAA19/MSG2	AT3G15540
IAA28	AT5G25890

Auxin signaling pathway





SCF-TIR
AUX/IAA
ARF
Nucleus
SCF-TIR
AUX/IAA
ARF
AU
IAA
SCF-TIR
ARF
Direction of auxin flow
Key
PIN auxin-efflux facilitator
AUX1 auxin-influx carrier
Auxin
ARF
Auxin-response factor
AUX/IAA
AUX/IAA transcriptional inhibitor
SCF-TIR
Complex containing TIR
Auxin-inducible gene

Auxin Inhibitors

Auxin influx inhibitors

Chromosaponin I
1-Napthoxyacetic acid (1-NOA)

Auxin efflux inhibitors

Flavonoids
Triiodobenzoic acid (TIBA)
Naphthylpthalamic acid (NPA)

Auxin action inhibitor

p-chlorophenoxyisobutyric acid (PCIB)

Ethylene

- Ethylene is a gaseous molecule produced in all parts of the plant

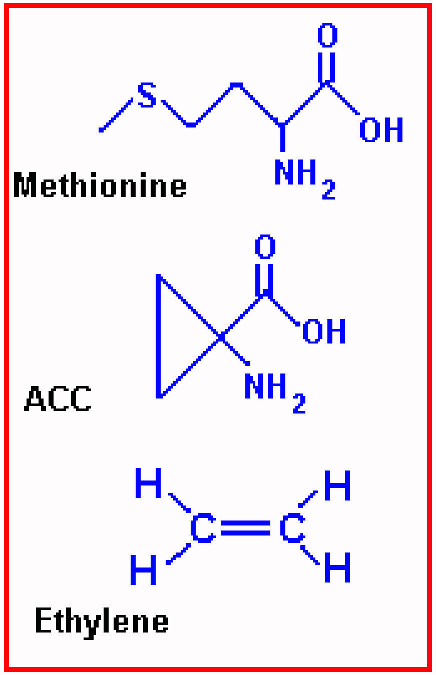
- made by most plants including angiosperms, gymnosperms, ferns, mosses and also synthesized by fungi and bacteria

- meristematic regions (shoot apex) and senescing tissues are rich sources

- ethylene production is stimulated by physiological stresses including wounding, anaerobic conditions, flooding, chilling, disease and drought

- in 1901, D. Neljubow realized that his dark-grown pea seedlings were short, fat and negatively gravitropic (**the triple response**) because of a component in "laboratory air" which he subsequently identified as ethylene

- Cousins (1910) first reported that ethylene occurred in plants.



Developmental processes regulated by ethylene

Promotion of seed germination

Inhibition or promotion of root growth

Inhibition of shoot growth

Promoting the elongation growth of submerged aquatic species

Inhibition/promotion of cell division and cell elongation

Induction of lateral cell expansion

Bud dormancy release

Initiation of adventitious roots and root hairs

Altering gravitropism in roots and stems

Promoting leaf epinasty

Inhibition/promotion of flowering

Abscission of leaves, flowers, fruits

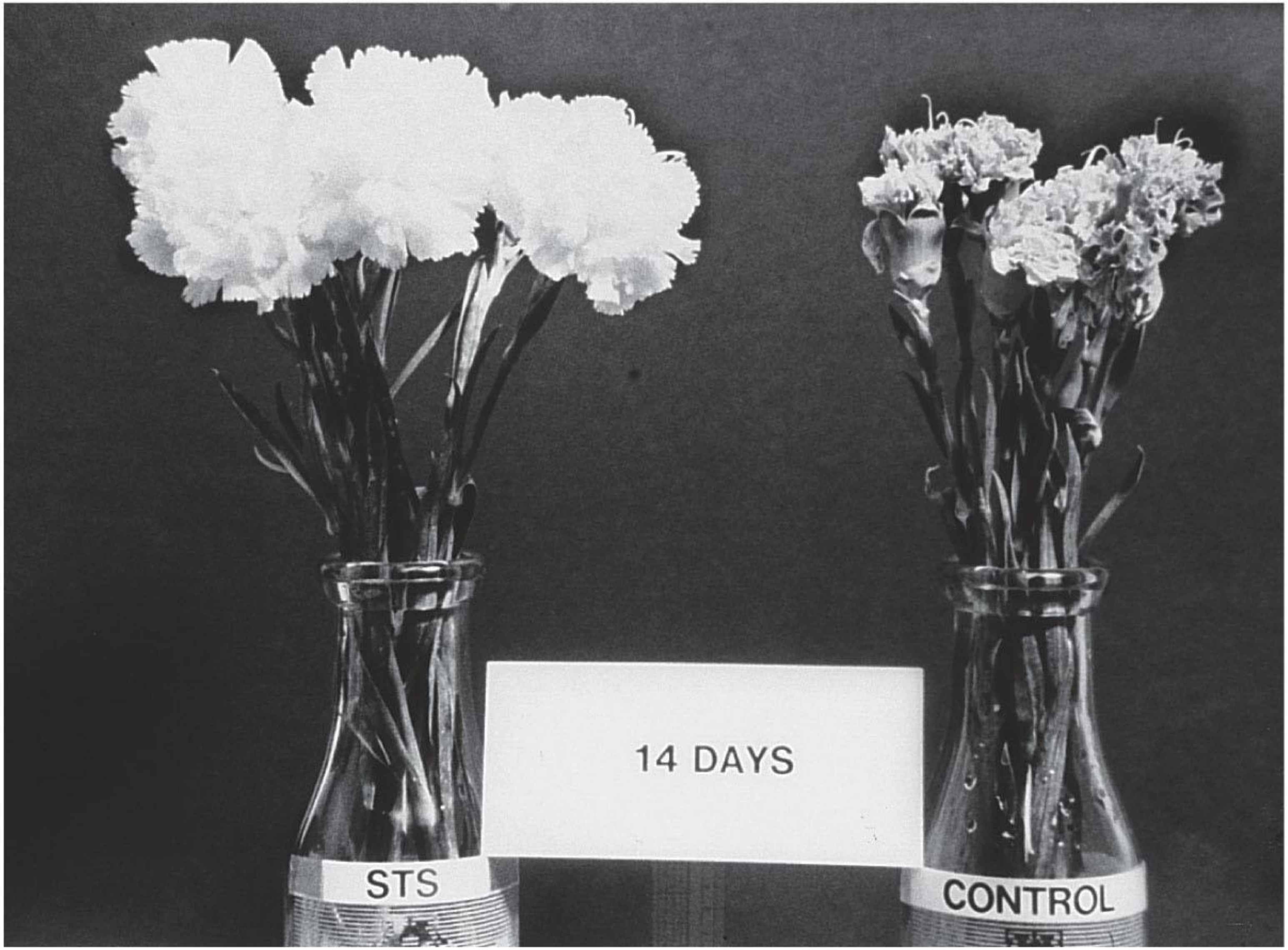
Promoting senescence of leaves, flowers

Involved in defense response pathway

Induction of phytoalexins and other disease resistance factors

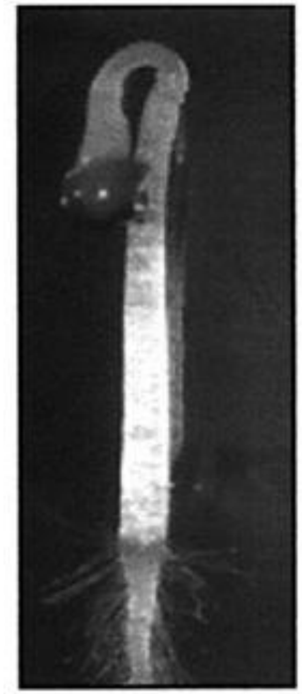
Fruit ripening

(C) Flower senescense

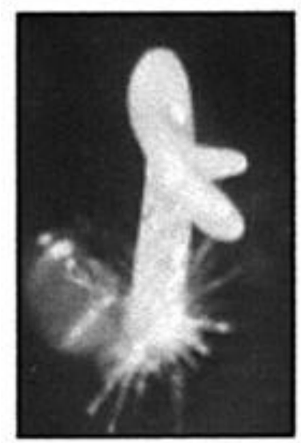


Triple response phenotypes

- ★ Reduced elongation of hypocotyl and root
- ★ Thickening of hypocotyl
- ★ Exaggeration of the apical hook curvature



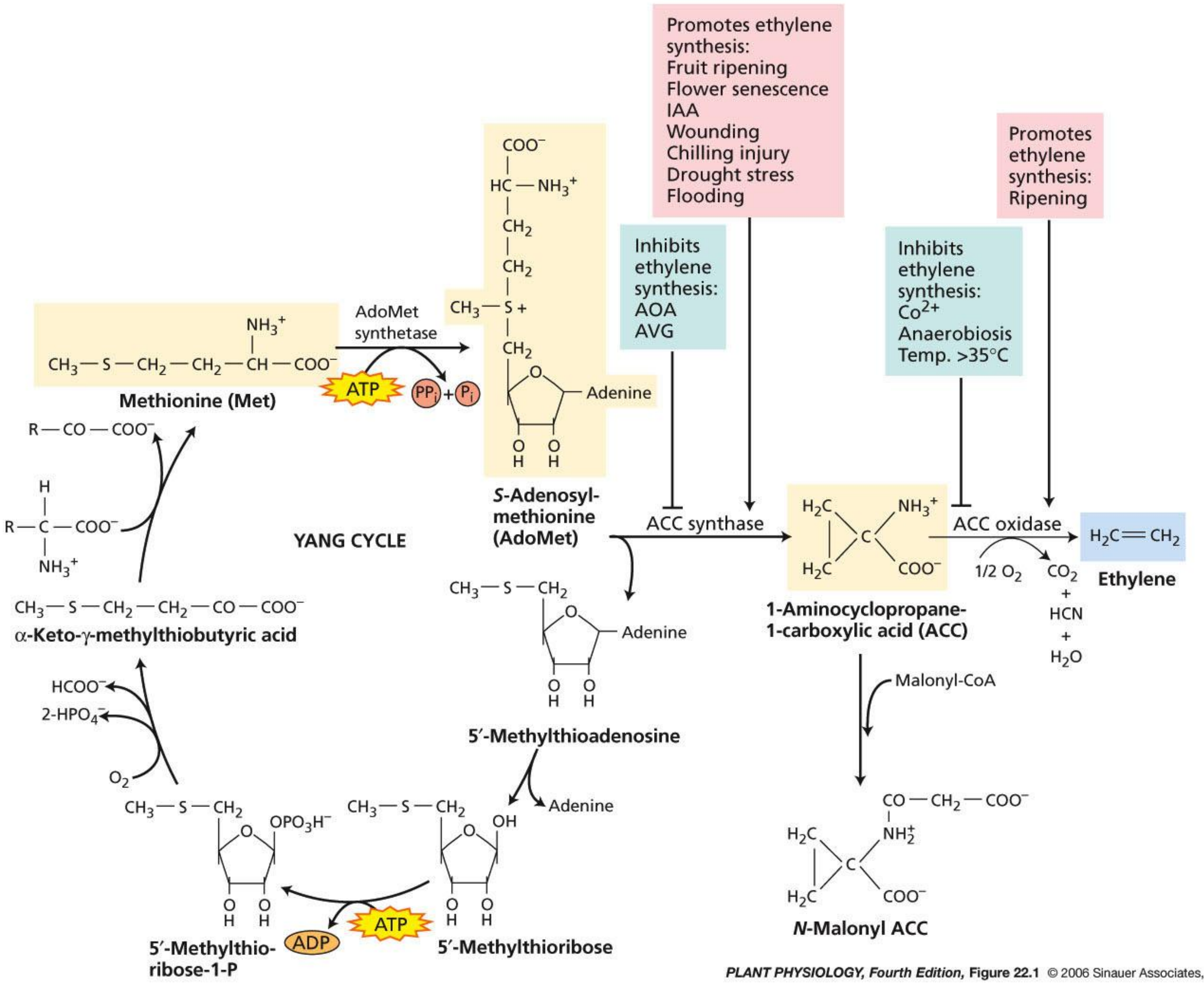
-Ethylene



+Ethylene

In 1988, on the basis of triple response screening, the first ethylene mutant was isolated and reported

Ethylene Biosynthesis



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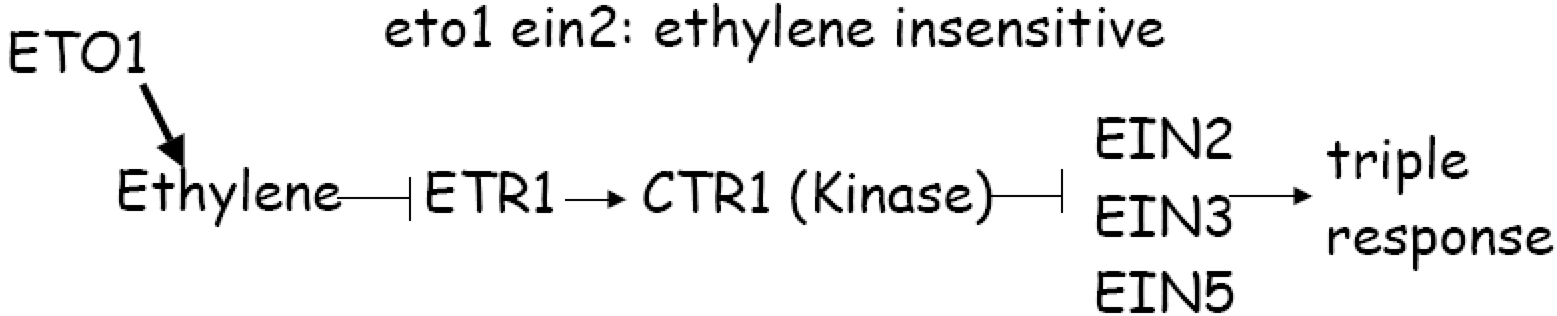
Tab. 1. Ethylene-related mutants.

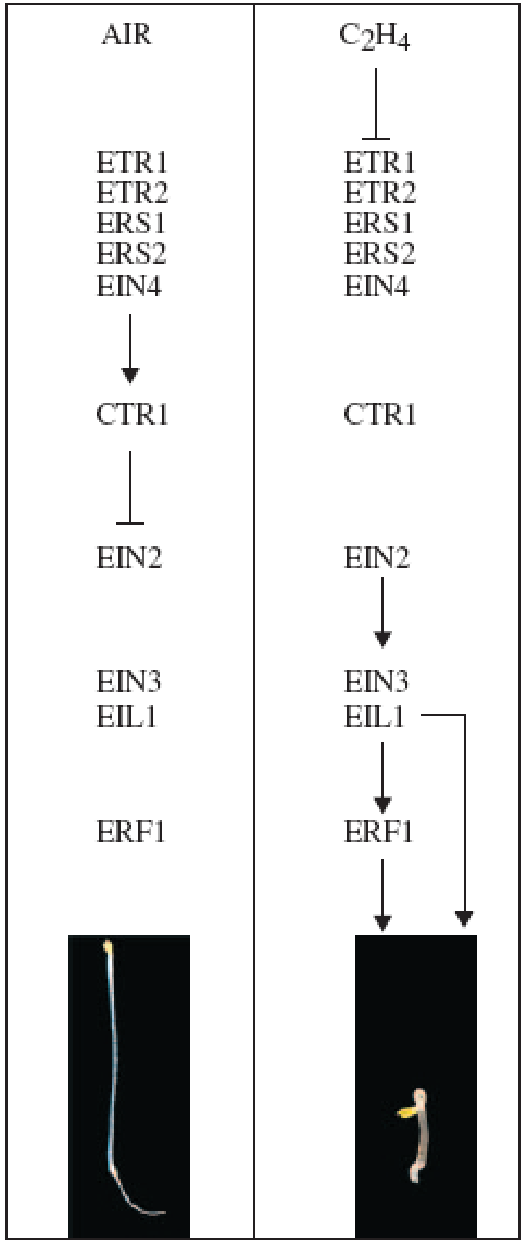
Locus	Name	Phenotype and comments	References
Arabidopsis thaliana			
etr1	Ethylene resistant	Ethylene insensitive; delay in bolting time; increase in rosette size; *ETR1* is homologous to two-component regulators	Bleecker et al. 1988, Chang et al. 1993
ers	Ethylene response sensor	Ethylene insensitive; *ERS* is homologous to *ETR1*; mutation was induced with reverse genetics	Hua et al. 1995
ein2	Ethylene insensitive	Ethylene insensitive; delay in bolting time; increase in rosette size	Guzmán and Ecker 1990
ein3	Ethylene insensitive	Ethylene insensitive	Kieber et al. 1993
ein4	Ethylene insensitive	Ethylene insensitive	Roman et al. 1995
ein6	Ethylene insensitive	Ethylene insensitive	Roman et al. 1995
ein7	Ethylene insensitive	Ethylene insensitive	Roman et al. 1995
ain1	ACC insensitive	Ethylene insensitive; increase in rosette size	Van Der Straeten et al. 1993
eti	Ethylene insensitive	Ethylene insensitive	Harpham et al. 1991
eto1	Ethylene overproducer	Constitutive ethylene response in etiolated seedlings, due to higher ethylene biosynthesis level	Guzmán and Ecker 1990
eto2	Ethylene overproducer	Constitutive ethylene response in etiolated seedlings, due to higher ethylene biosynthesis level	Kieber et al. 1993
eto3	Ethylene overproducer	Constitutive ethylene response in etiolated seedlings, due to higher ethylene biosynthesis level	Kieber et al. 1993
ctr1	Constitutive triple response	Constitutive ethylene responses at all developmental stages tested, not due to higher ethylene biosynthesis; phenocopied by ethylene treatment; *CTR1* is homologous to Raf kinases	Kieber et al. 1993
hls1	Hookless	No differential growth in apical hook of etiolated seedlings; phenocopied by treatments with auxins or auxin transport inhibitors; *HLS1* is homologous to *N*-acetyltransferases	Guzmán and Ecker 1990, Lehman et al. 1996
eir1	Ethylene-insensitive root	Root is ethylene insensitive and agravitropic	Roman et al. 1995
aux1	Auxin insensitive	Root is agravitropic and insensitive to ethylene and auxin; apical hook slightly ethylene insensitive; *AUX1* is homologous to amino acid permeases	Maher and Martindale 1980, Pickett et al. 1990, Roman et al. 1995, Bennett et al. 1996
axr1	Auxin resistant	Root is agravitropic and insensitive to ethylene, auxin and cytokinin; the shoot is short and bushy; etiolated seedlings have a short hypocotyl and are defective in apical hook formation; *AXR1* is homologous to ubiquitin-activating enzyme E1	Estelle and Somerville 1987, Lincoln et al. 1990, Leyser et al. 1993

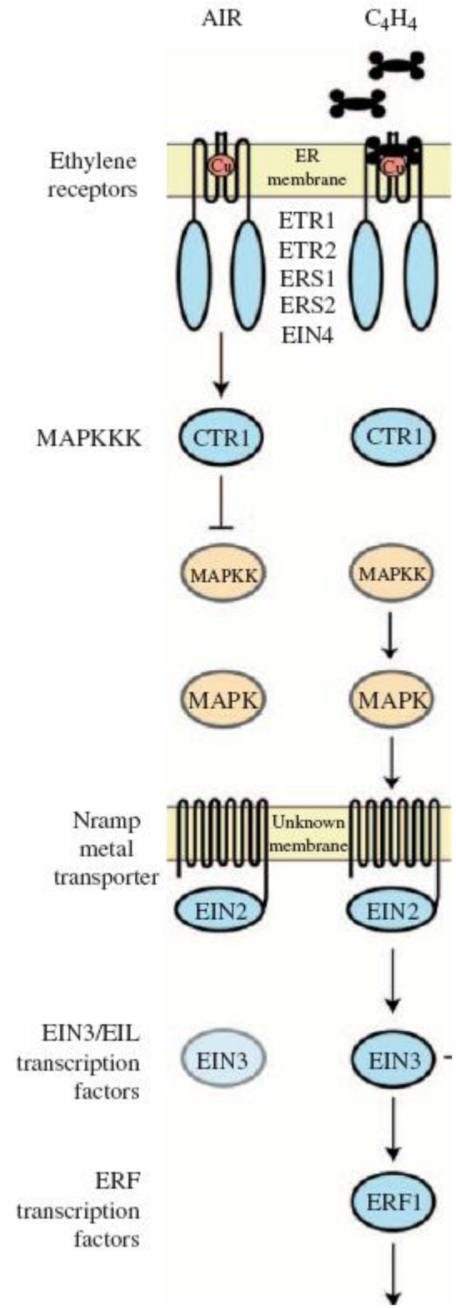
Epistasis pathway established by double mutant analysis

ctr1: constitutive responses
eto1: constitutive responses:
etr1: ethylene insensitive
ein2: ethylene insensitive

etr1 ctr1: constitutive response
ein2 ctr1: ethylene insensitive
eto1 etr1: ethylene insensitive
eto1 ein2: ethylene insensitive







Ethylene response