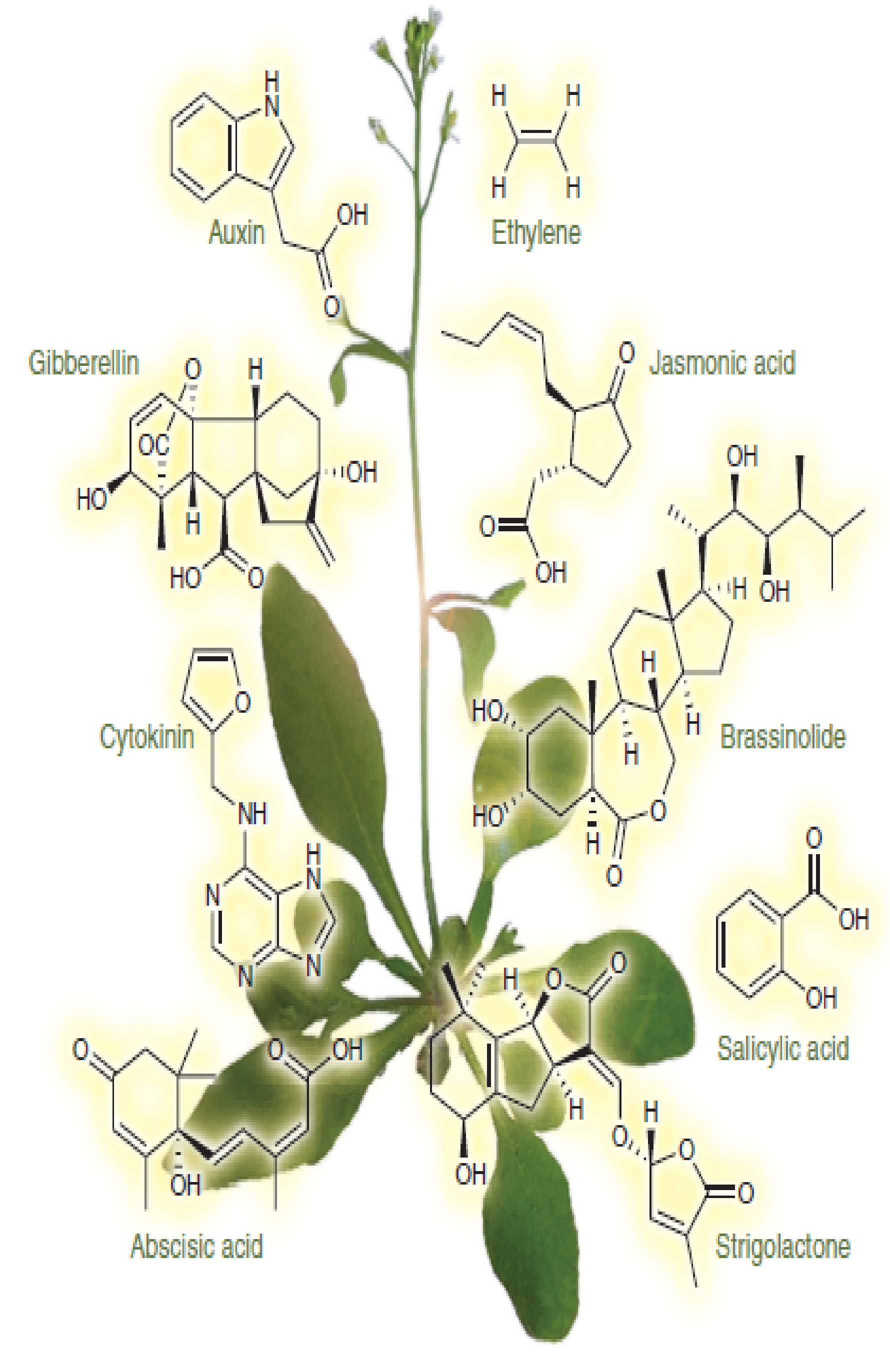
Introduction to Phytohormones



Kirti Vardhan
ASPEE COLLEGE of HORT. & Forestry, NAU

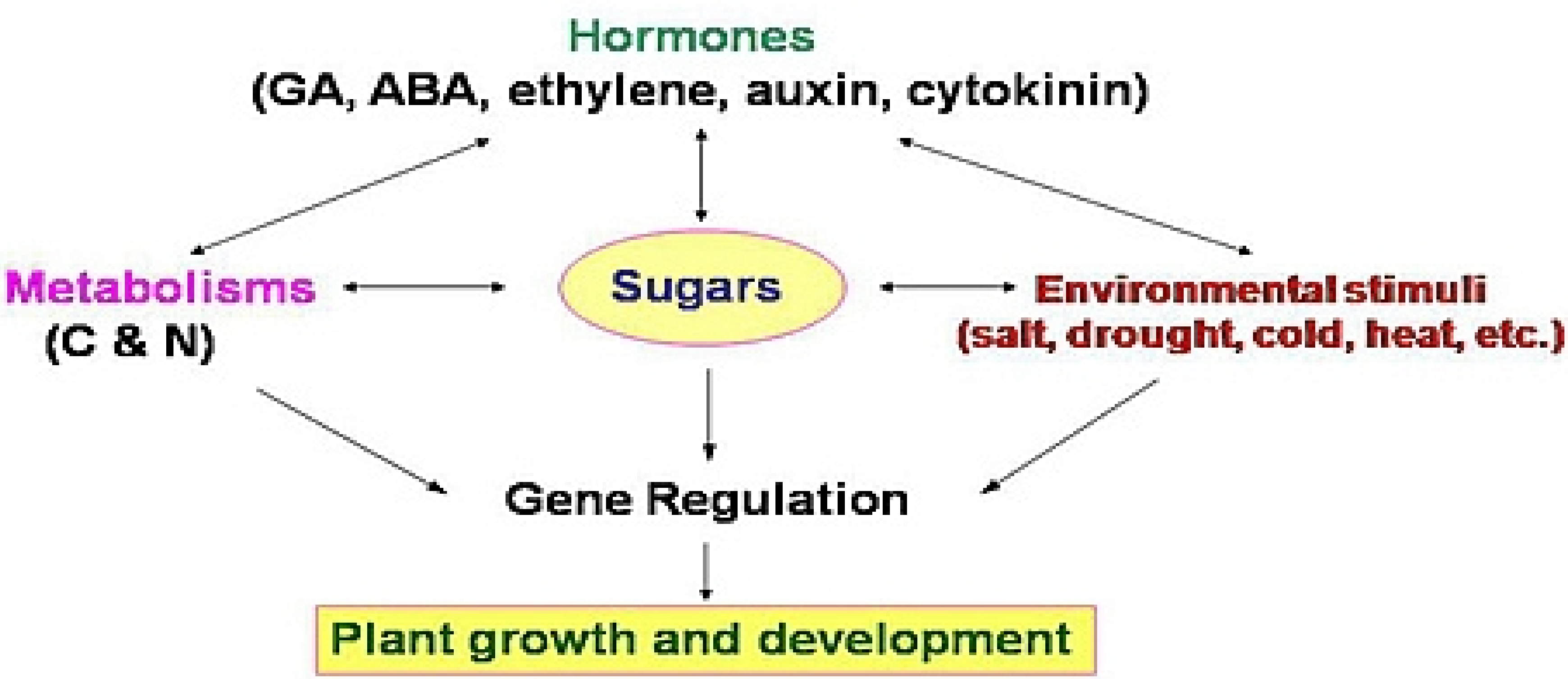
- The form and function of multicellular organism would not be possible without efficient communication among cells, tissues, and organs.

- In higher plants, regulation and coordination of metabolism, growth, and morphogenesis often depend on chemical signals from one part of the plant to another.

- This idea originated in the nineteenth century with the German botanist Julius von Sachs (1832–1897)

- Sachs proposed that chemical messengers are responsible for the formation and growth of different plant organs

Sugar signals interact with other signaling pathways for control of plant growth

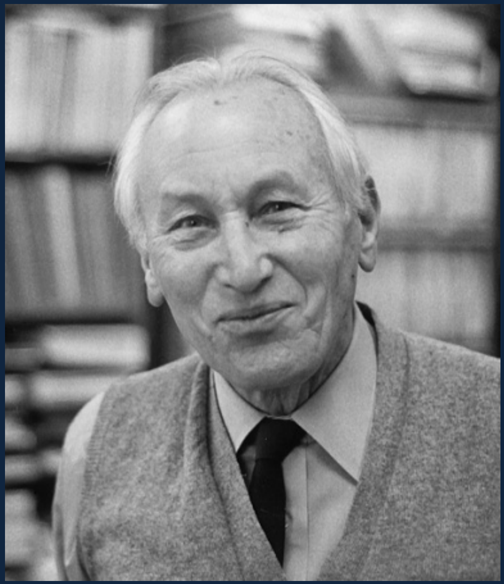


What are phytohormones?

Frits Went, 1903-1990

"........characterized by the property of serving as chemical messengers, by which the activity of certain organs is coordinated with that of others".

-*Frits Went and Kenneth Thimann, 1937*



Kenneth Thimann, 1904-1997

What they are?

- organic compounds;
- synthesized by the plant;
- active in low concentration ($<10^{-6}$);
- promote or inhibit growth and developmental responses;
- often show a separation of the site of production and the site of action

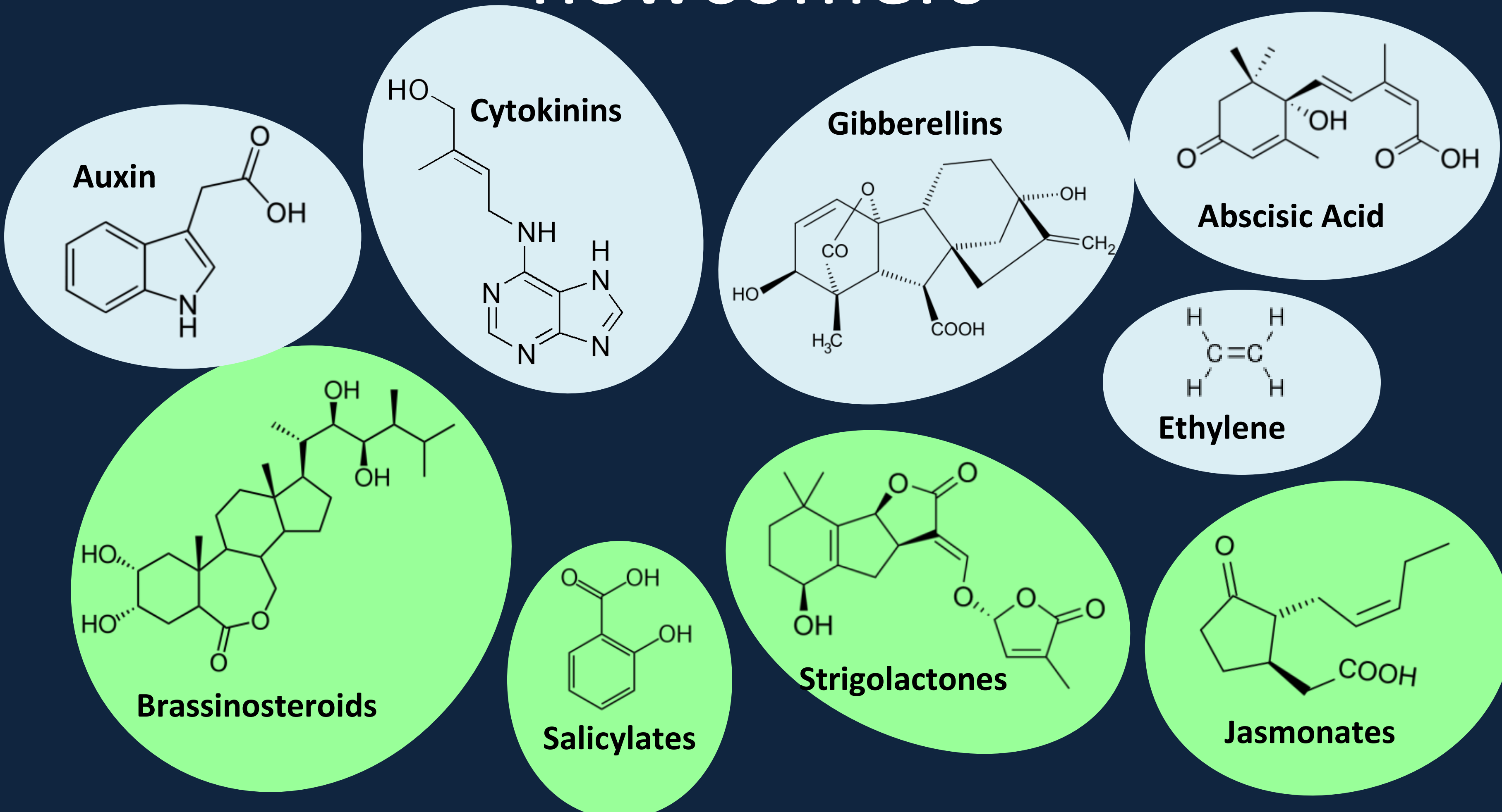
Plant hormones differ from animal hormones in that:

- No evidence that the fundamental actions of plant and animal hormones are the same.

- Unlike animal hormones, plant hormones are not made in tissues specialized for hormone production. (e.g., sex hormones made in the gonads, human growth hormone - pituitary gland)

- Unlike animal hormones, plant hormones do not have definite target areas (e.g., auxins can stimulate adventitious root development in a cut shoot, or shoot elongation or apical dominance, or differentiation of vascular tissue, etc.).

Phytohormones – old timers and newcomers

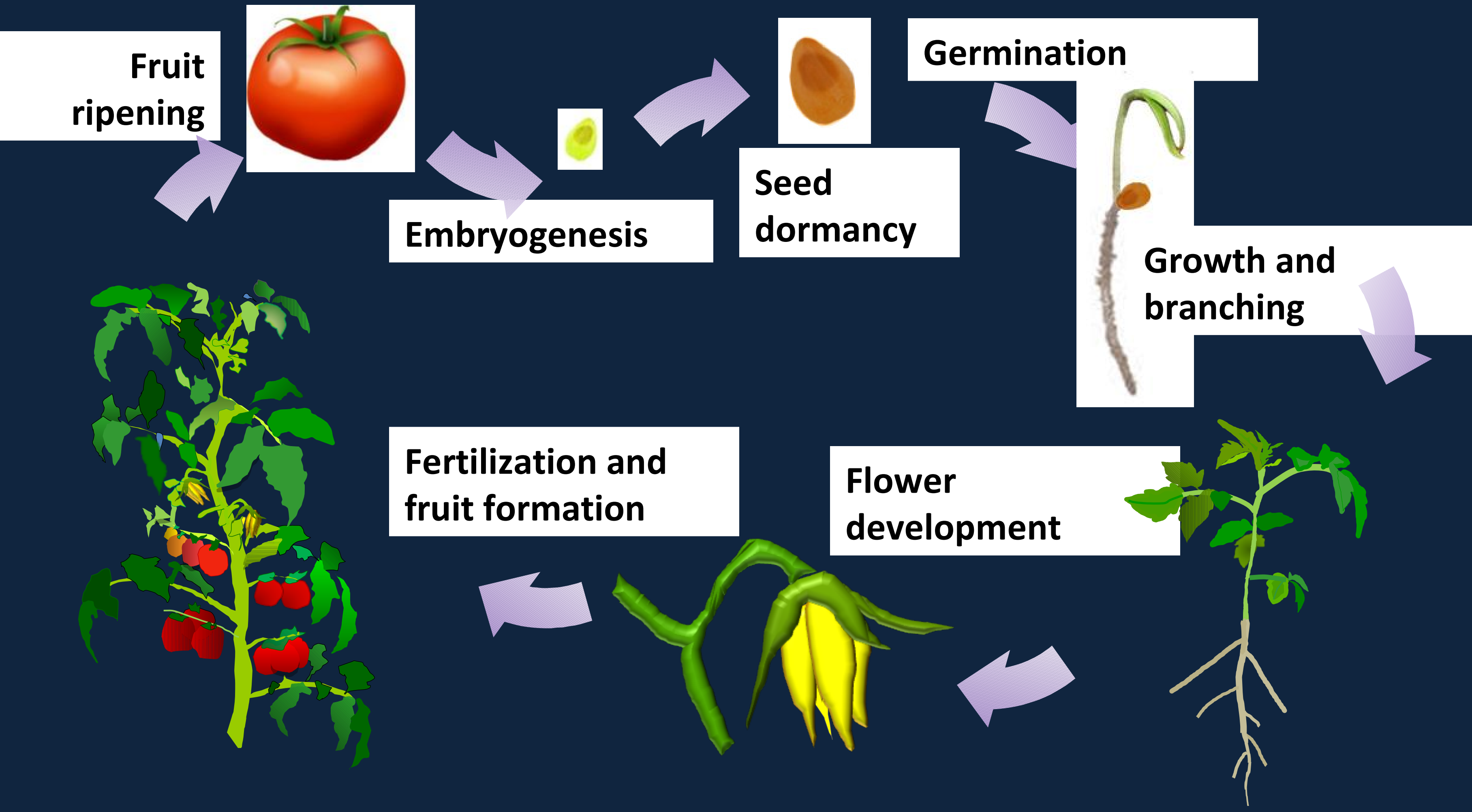


Phytohormones regulate cellular activities (division, elongation and differentiation), pattern formation, organogenesis, reproduction, sex determination, and responses to abiotic and biotic stress.

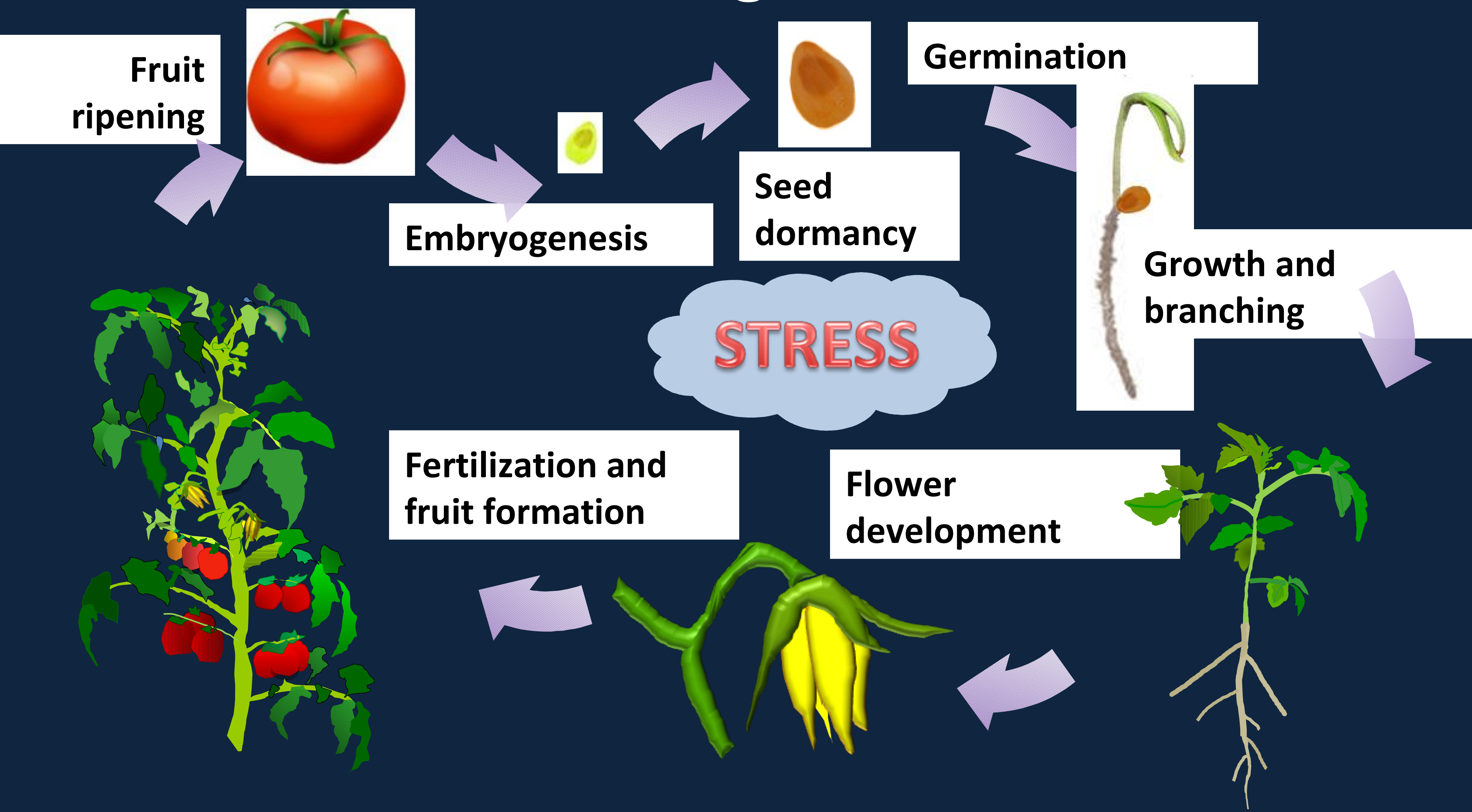




Phytohormones regulate all stages of the plant life cycle



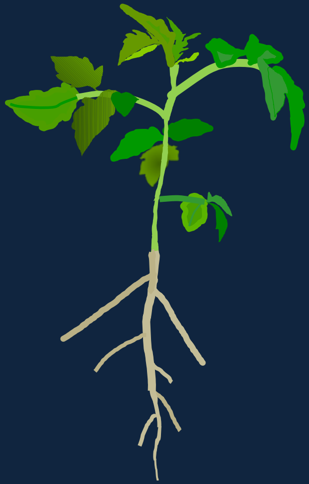
Hormones also help plants cope with stress throughout their life



Most hormones affect most stages of the plant life cycle

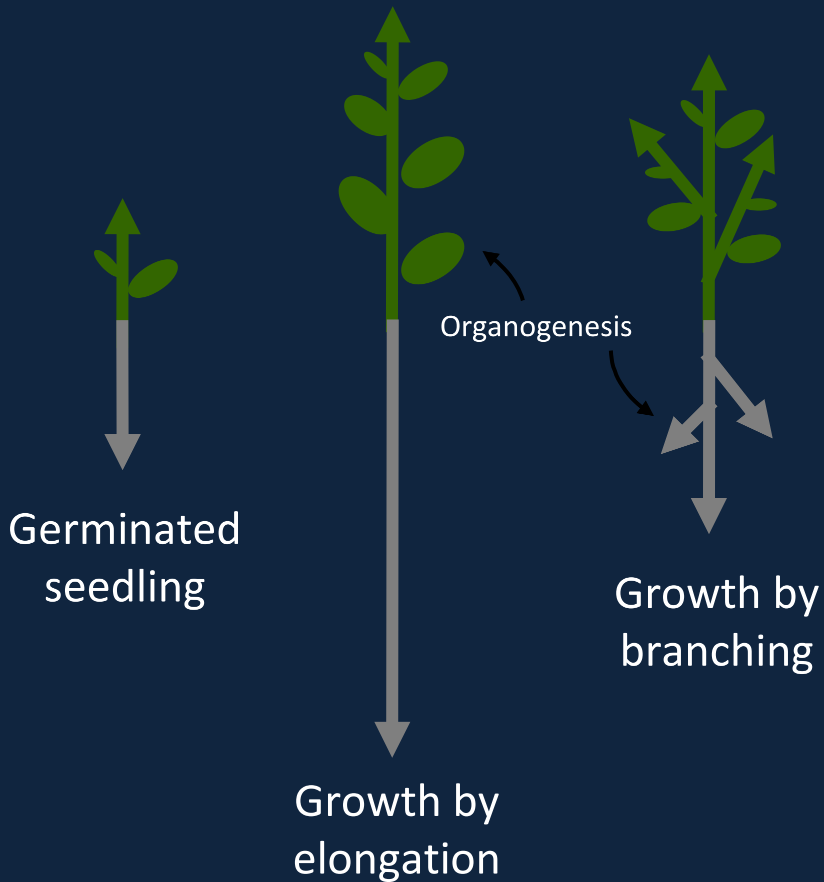
We will examine each hormones within the context of one of its roles.

Remember that these are merely examples; most hormones affect most processes in one way or another.

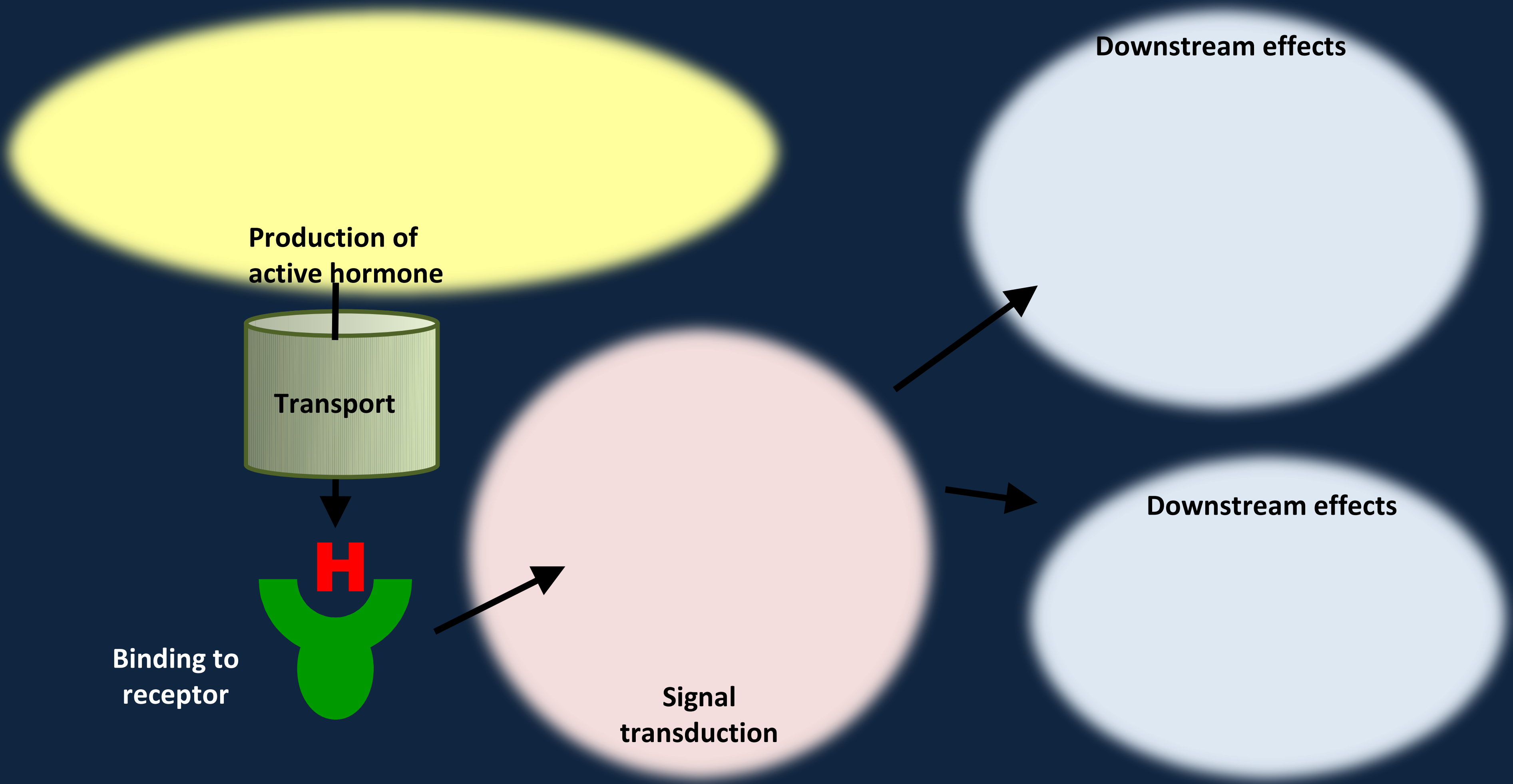


Hormones affect vegetative growth: elongation, branching and organogenesis

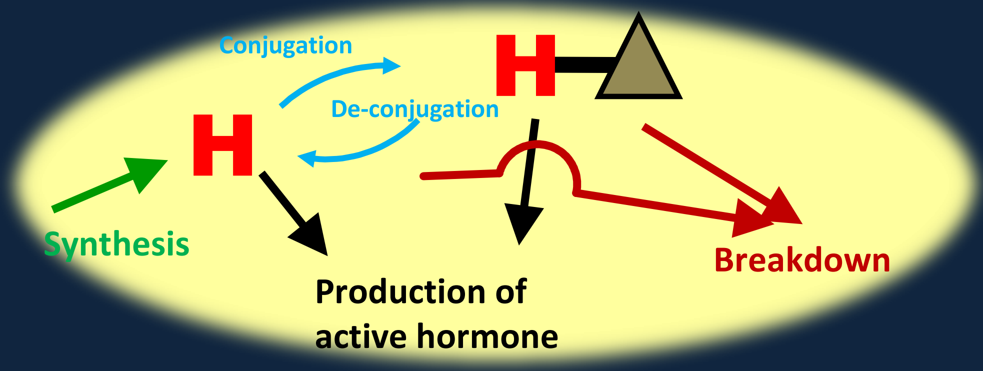
Elongation in the shoot and root of a germinating soybean



Hormones: Synthesis, transport, perception, signaling and responses



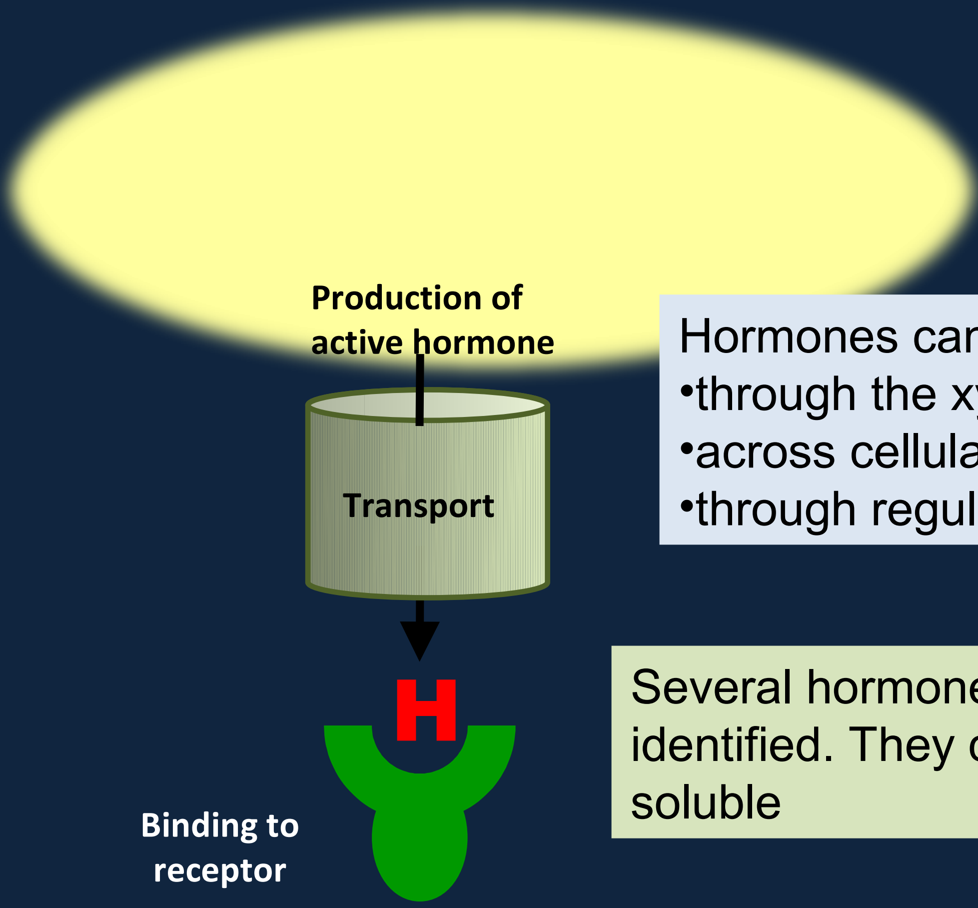
Synthesis



Many tightly regulated biochemical pathways contribute to active hormone accumulation. Conjugation can temporarily store a hormone in an inert form, lead to catabolic breakdown, or be the means for producing the active hormone.

Jasmonic acid is activated upon conjugation to isoleucine (JA-Ile). Usually though when hormones are conjugated they are inactivated.

Transport and perception

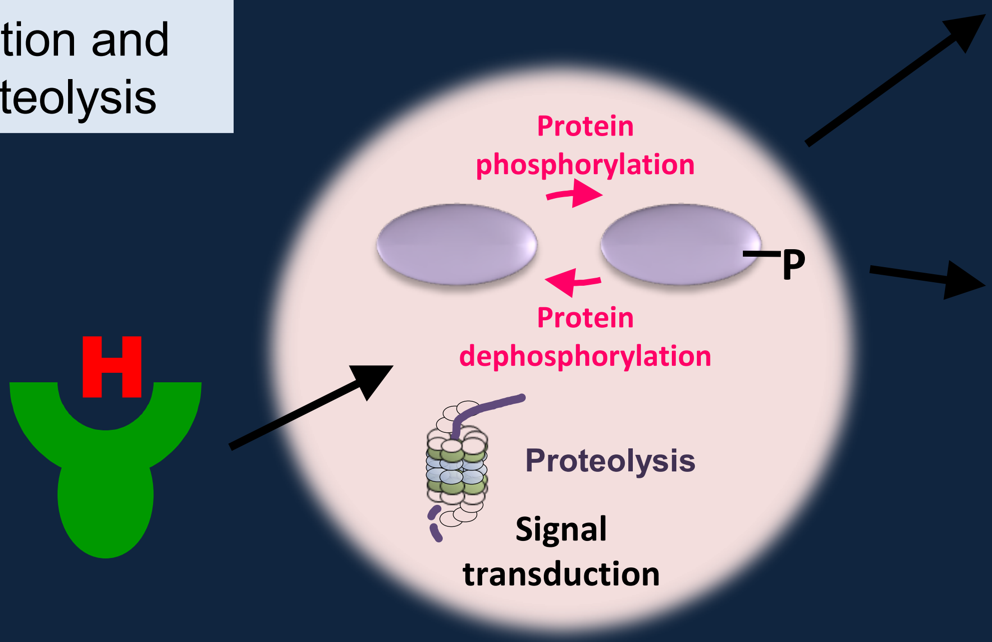


Hormones can move:
- through the xylem or phloem
- across cellular membranes
- through regulated transport proteins

Several hormone receptors have recently been identified. They can be membrane bound or soluble

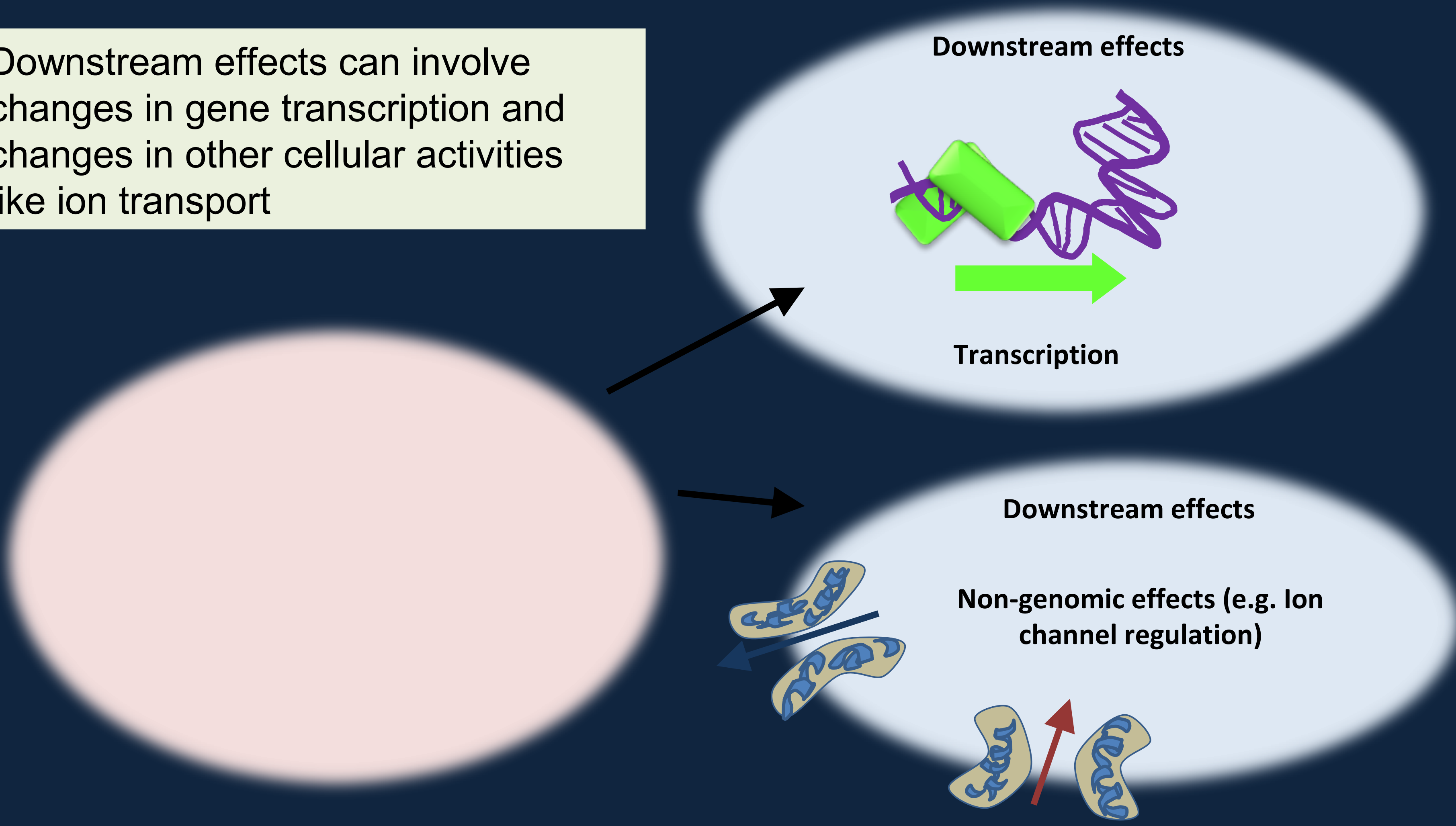
Signal transduction

Hormonal signals are transduced in diverse ways. Common methods are reversible protein phosphorylation and targeted proteolysis

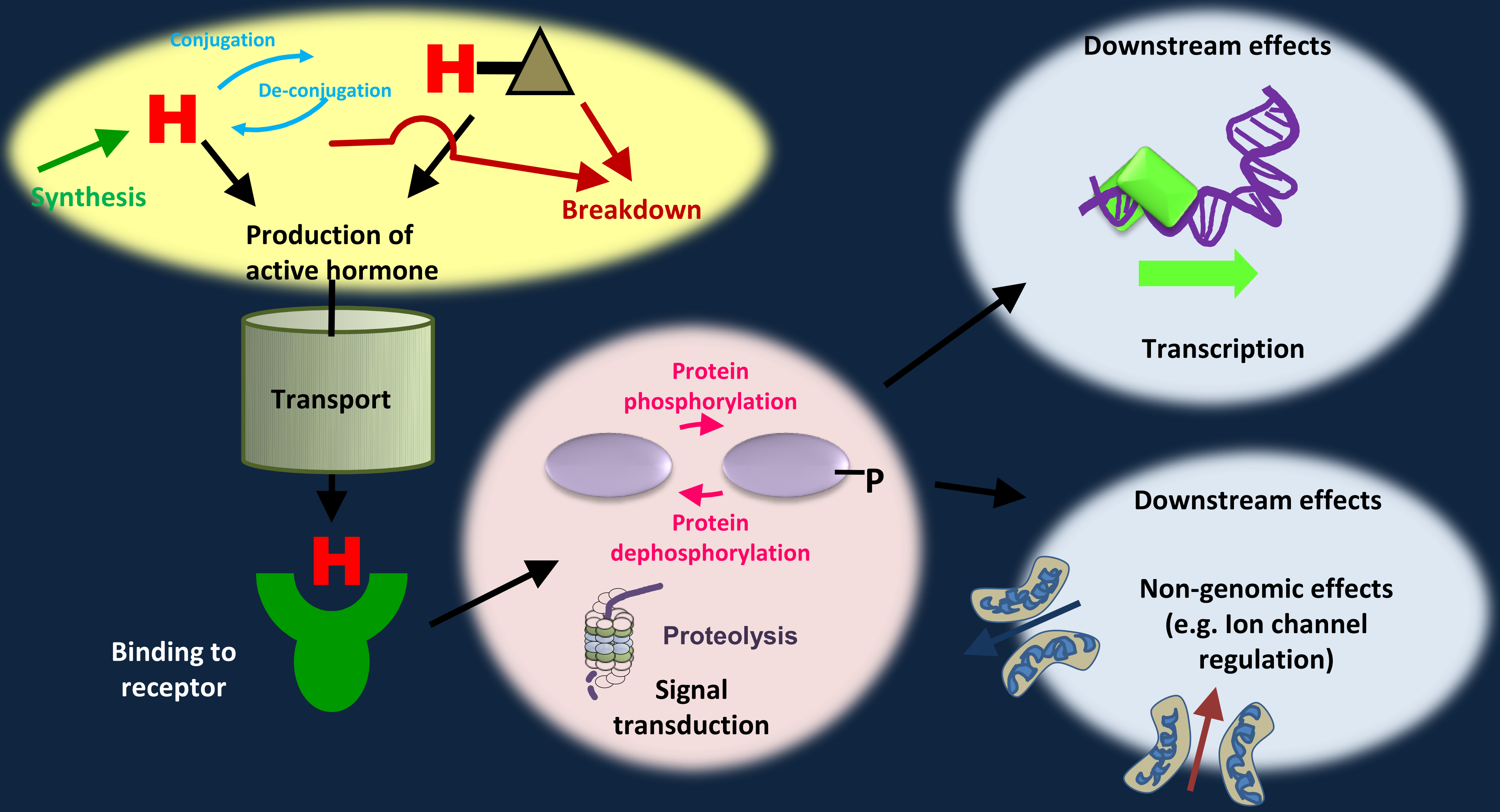


Responses

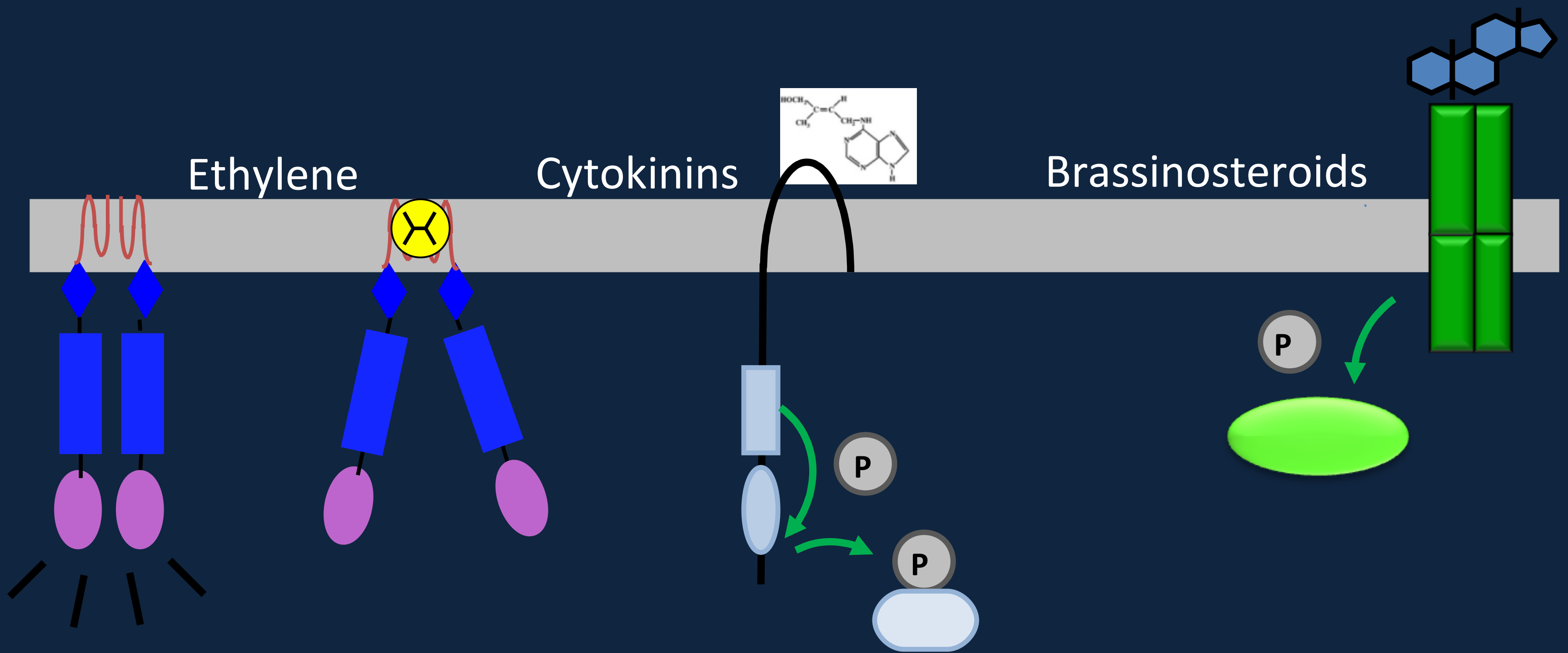
Downstream effects can involve changes in gene transcription and changes in other cellular activities like ion transport



Hormones: Synthesis, transport, perception, signaling and responses



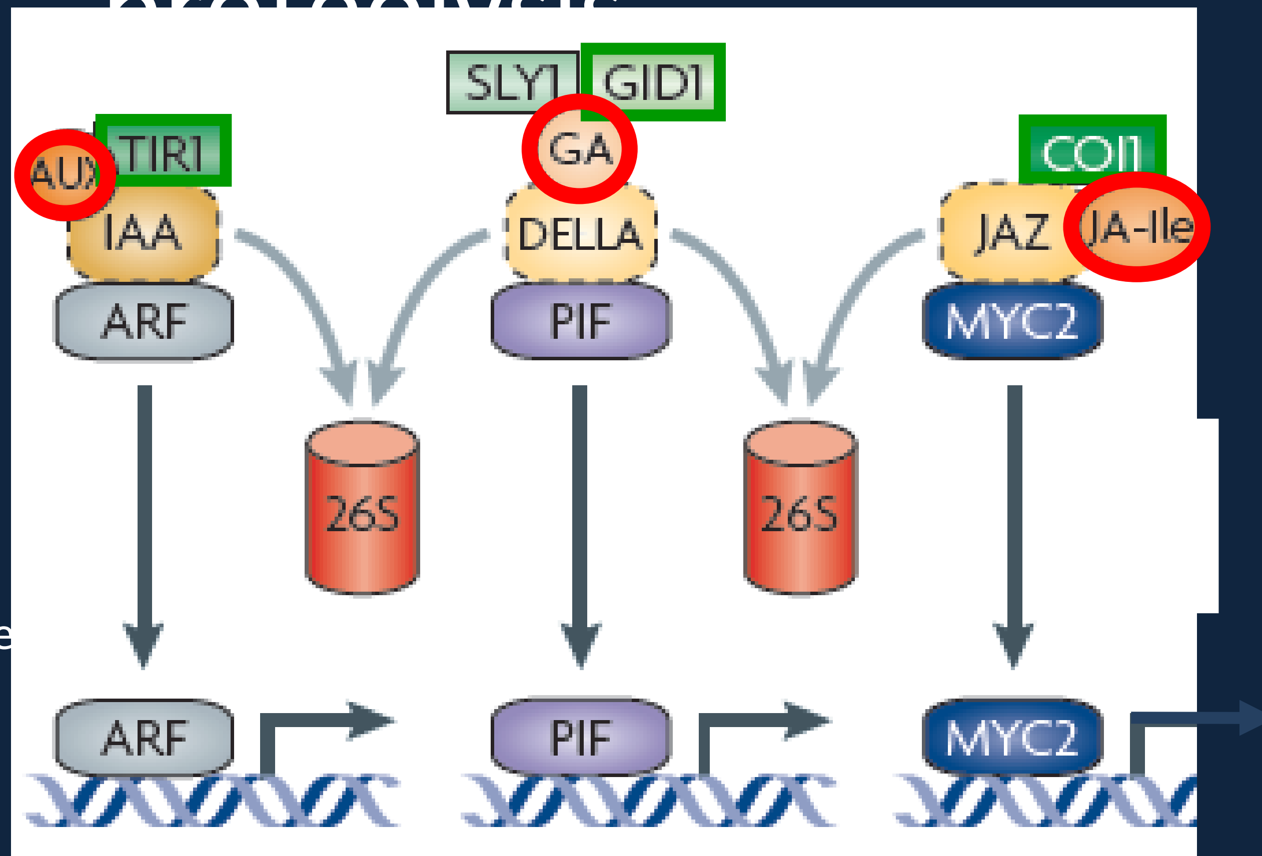
Receptors can be membrane-bound



Hormone binding initiates an information relay

Some receptors initiate protein proteolysis

The hormones (red) bind to receptors (green), initiating proteolysis of repressors (yellow) to activate a transcriptional regulator (blue



Auxin **Gibberellin** **Jasmonate**

Thus, for a response to occur:

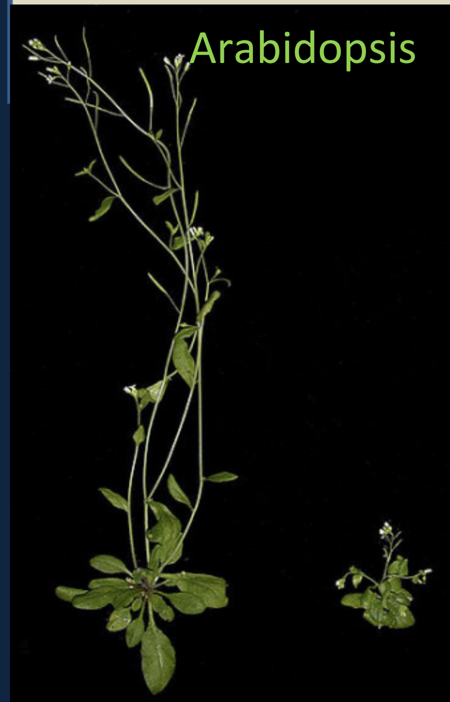
- **The hormone must be present in sufficient quantity;**
- **The target tissue must be sensitive (sensitized) to the hormone;**
- **The target tissue recognizes the hormone (i.e., there must be a receptor to which the hormone can bind);**
- **The binding of the hormone/receptor should initiate a change in the receptor (amplification).**
- **The activated receptor initiates a physiological response**

Disrupting hormone synthesis or response interferes with elongation

GA

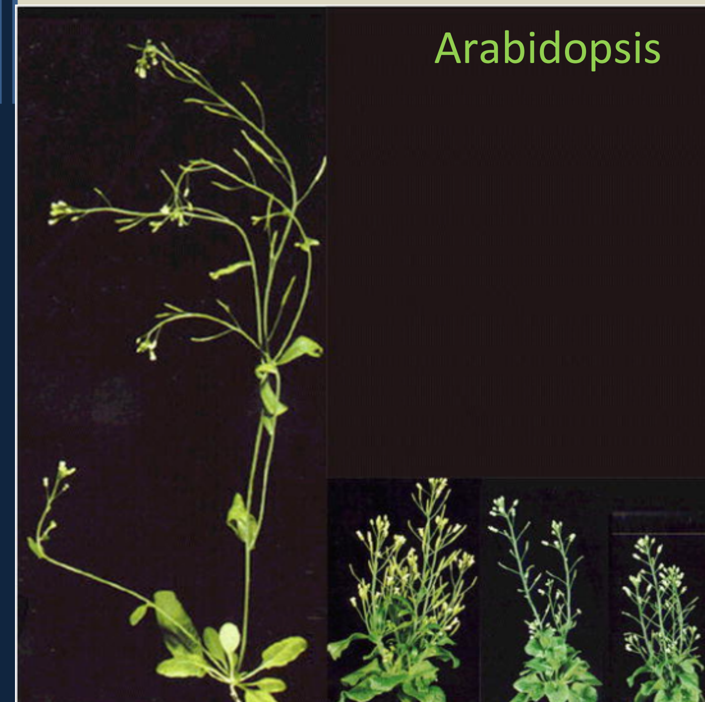
Wild type | Gibberellin biosynthesis mutant

Auxin



Wild type | Auxin response mutant

Brassinosteroid



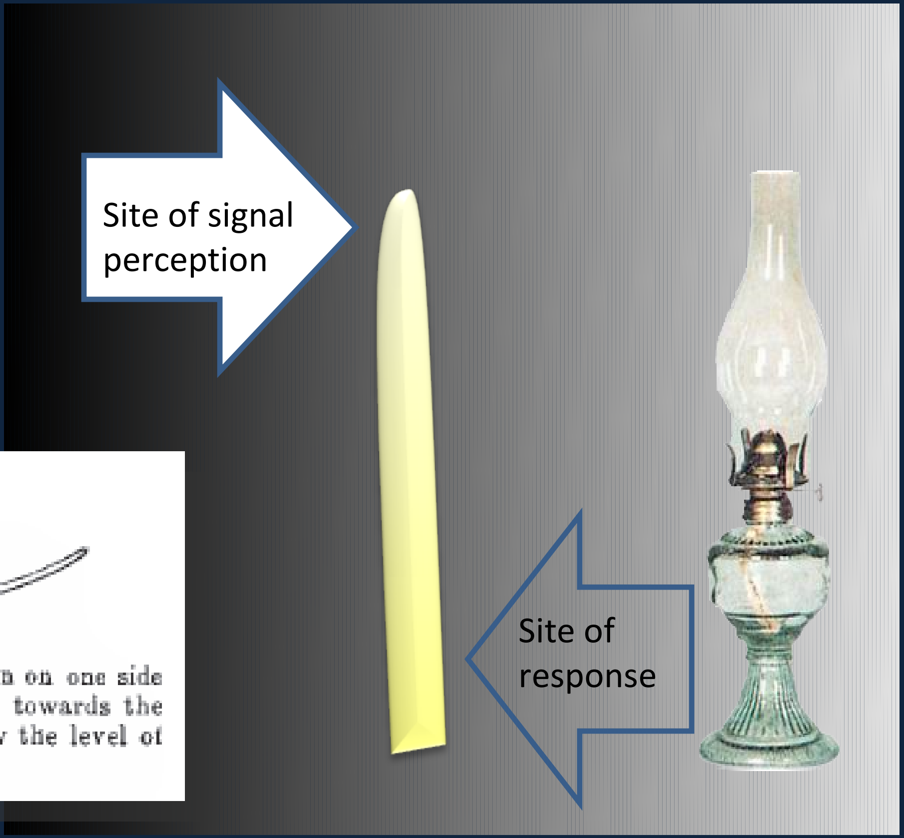
Wild type | Brassinosteroid biosynthesis mutants

Auxin controls growth

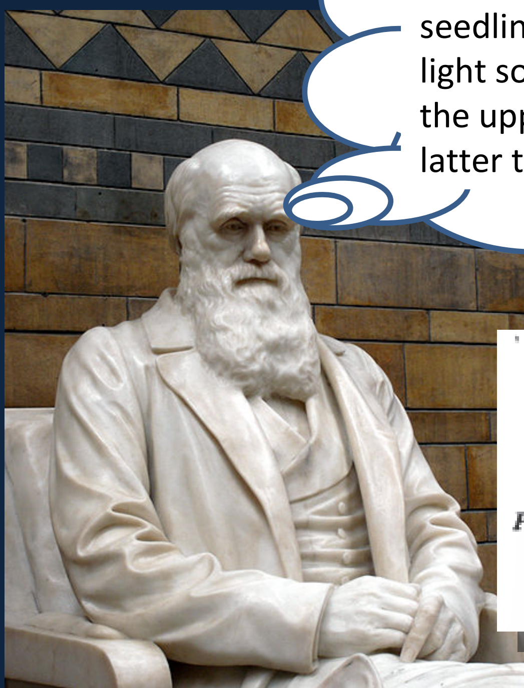
Charles Darwin studied the way seedlings bend towards light, a direct effect of auxin action

Fig. 181.

Phalaris Canariensis: cotyledons after exposure in a box open on one side in front of a south-west window during 8 h. Curvature towards the light accurately traced. The short horizontal lines show the level of the ground.



Darwin concluded that a signal moves through the plant controlling growth



"We must therefore conclude that when seedlings are freely exposed to a lateral light some influence is transmitted from the upper to the lower part, causing the latter to bend."

THE

POWER OF MOVEMENT

IN PLANTS

BY

CHARLES DARWIN, LL. D., F. R. S.

ASSISTED BY

FRANCIS DARWIN

WITH ILLUSTRATIONS

NEW YORK

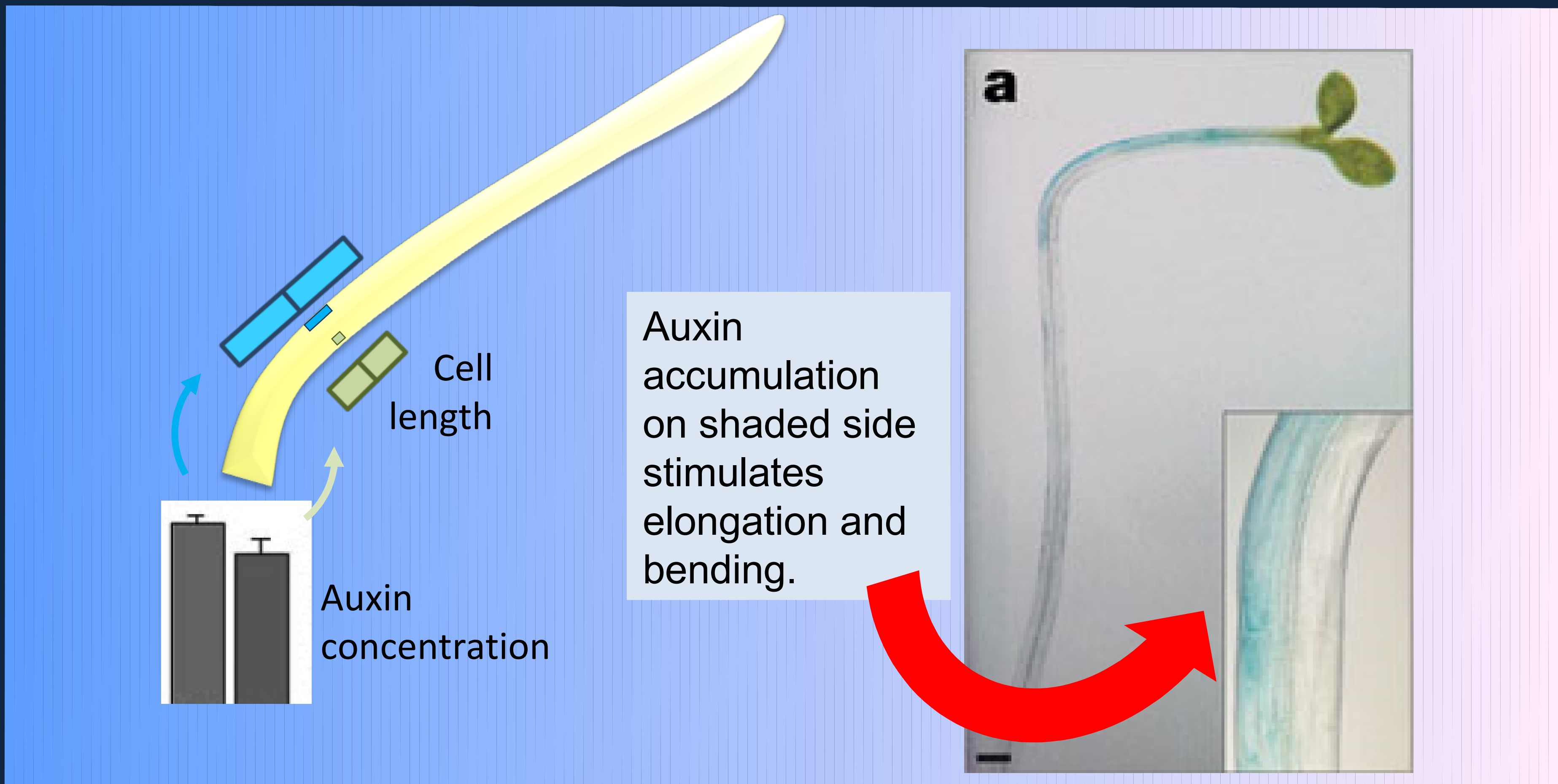
D. APPLETON AND COMPANY

1898

Fig. 181.

Phalaris Canariensis: cotyledons after exposure in a box open on one side in front of a south-west window during 8 h. Curvature towards the light accurately traced. The short horizontal lines show the level of the ground.

Differential cell growth is a result of auxin movement to the shaded side

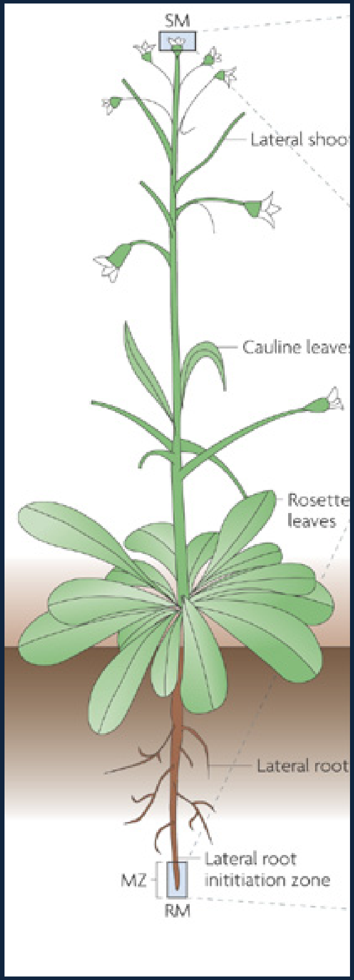


The plant on the right shows GUS expression from an auxin-inducible promoter. The blue color indicates the presence of auxin (through auxin-induced transcription

Auxin regulates plant development

Lateral organ initiation at the shoot apical meristem

Inhibit branching in the shoot

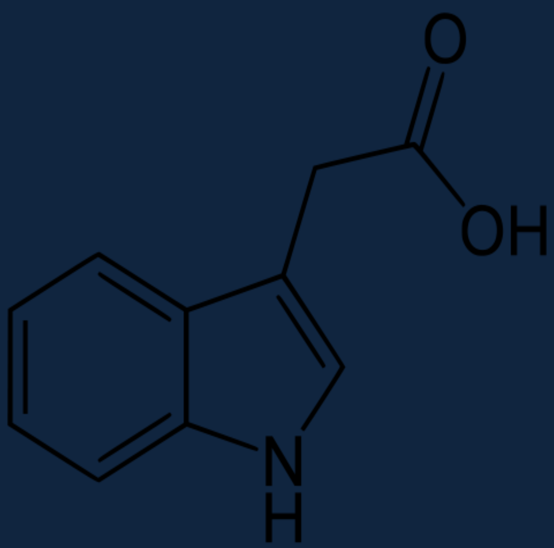


Patterning and vascular development

Maintain stem cell fate at the root apical meristem

Promote branching in the root

Many of auxin's effects are mediated by changes in gene expression



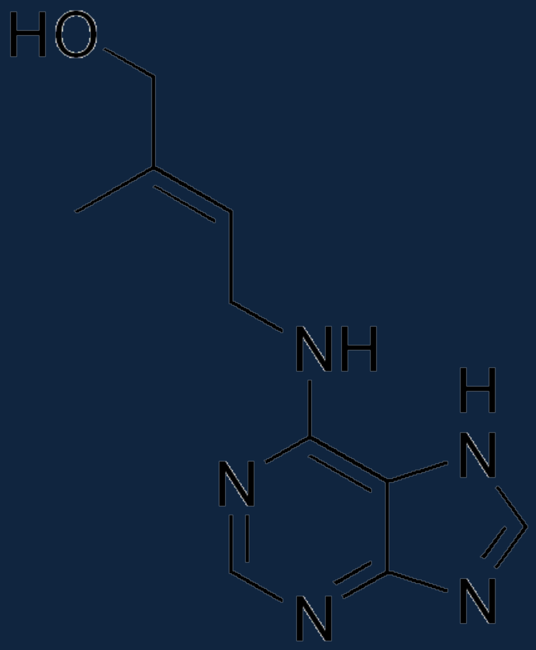
Genes controlling cell growth

Genes involved in signaling

Genes coordinating other hormone response pathways

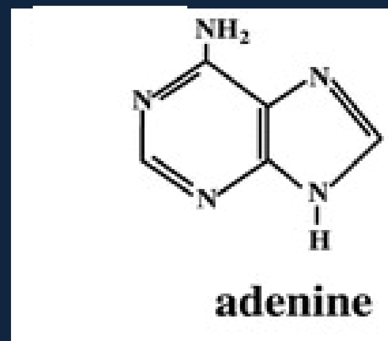
Cytokinins

- Cell division
- Control of leaf senescence
- Control of nutrient allocation
- Root nodule development
- Stem cell maintenance
- Regulate auxin action

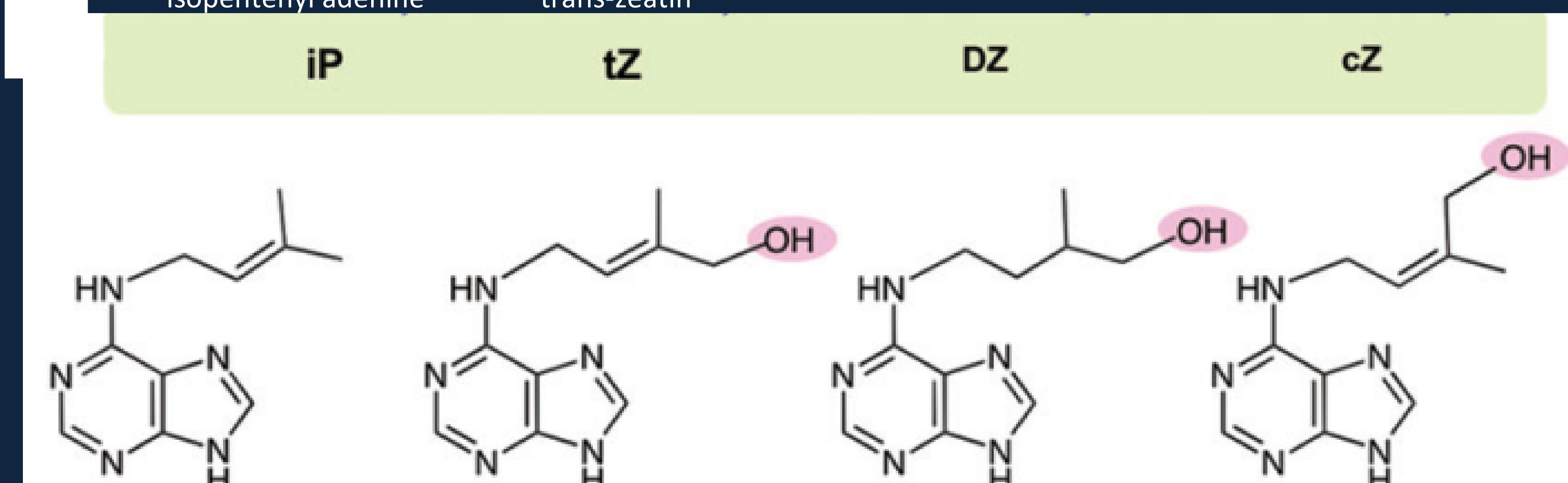


trans-zeatin, a cytokinin

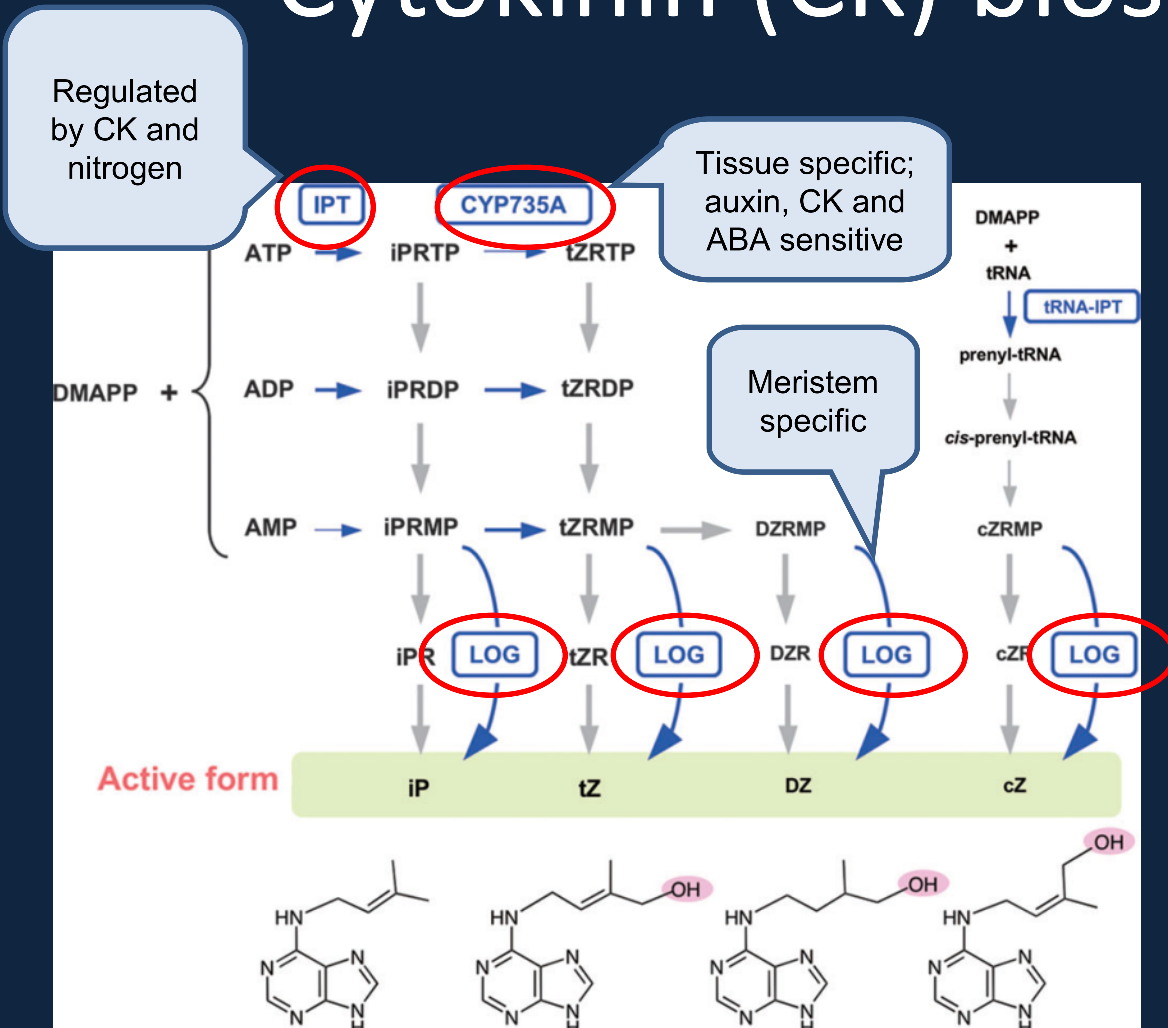
Cytokinins are a family of related adenine-like compounds



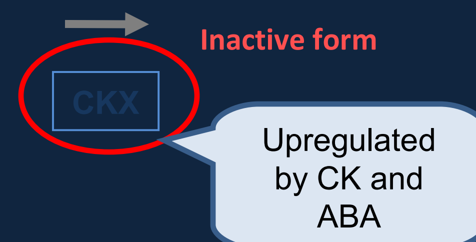
Isopentenyl adenine trans-zeatin dihydrozeatin cis-zeatin



Cytokinin (CK) biosynthesis



CK biosynthesis and inactivation are strongly regulated by CK, other hormones and exogenous factors.



Hirose, N., Takei, K., Kuroha, T., Kamada-Nobusada, T., Hayashi, H., and Sakakibara, H. (2008). Regulation of cytokinin biosynthesis, compartmentalization and translocation. J. Exp. Bot. 59: 75-83.

Cytokinins act antagonistically to auxins

CK

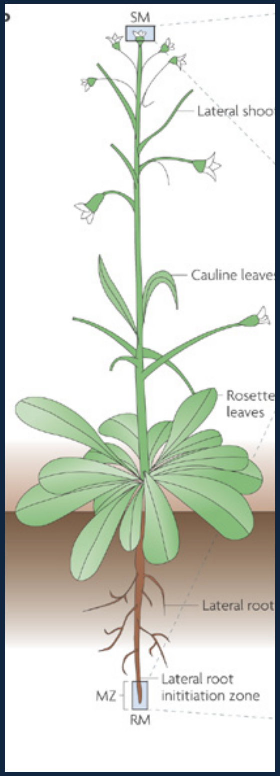
Promote stem cell fate at the shoot apical meristem

Auxin

Promote lateral organ initiation at the shoot apical meristem

Promote differentiation at the root apical meristem

Maintain stem cell fate at the root apical meristem



Promote branching in the shoot

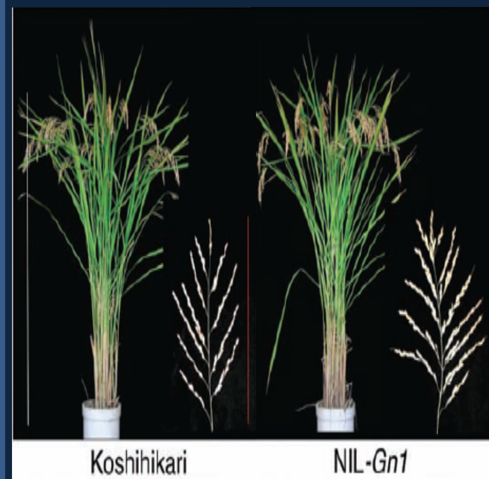
Inhibit branching in the shoot

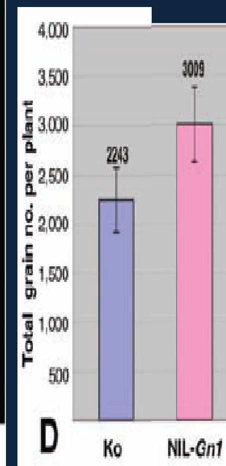
Inhibit branching in the shoot

Promote branching in the root

Cytokinins affect grain production and drought tolerance

The NIL plants are a near-inbred line that incorporates a quantitative trait locus (QTL) for increased grain production. The increased grain production locus encodes a cytokinin oxidase that degrades cytokinin. The enhanced grain production is caused by reduced levels of cytokinin oxidase and so higher levels of CK. The tobacco plants were droughted by withholding water for two weeks. These pictures were taken one week after rewatering – the plants overexpressing an IPT gene produce more CK and survived the drought stress.



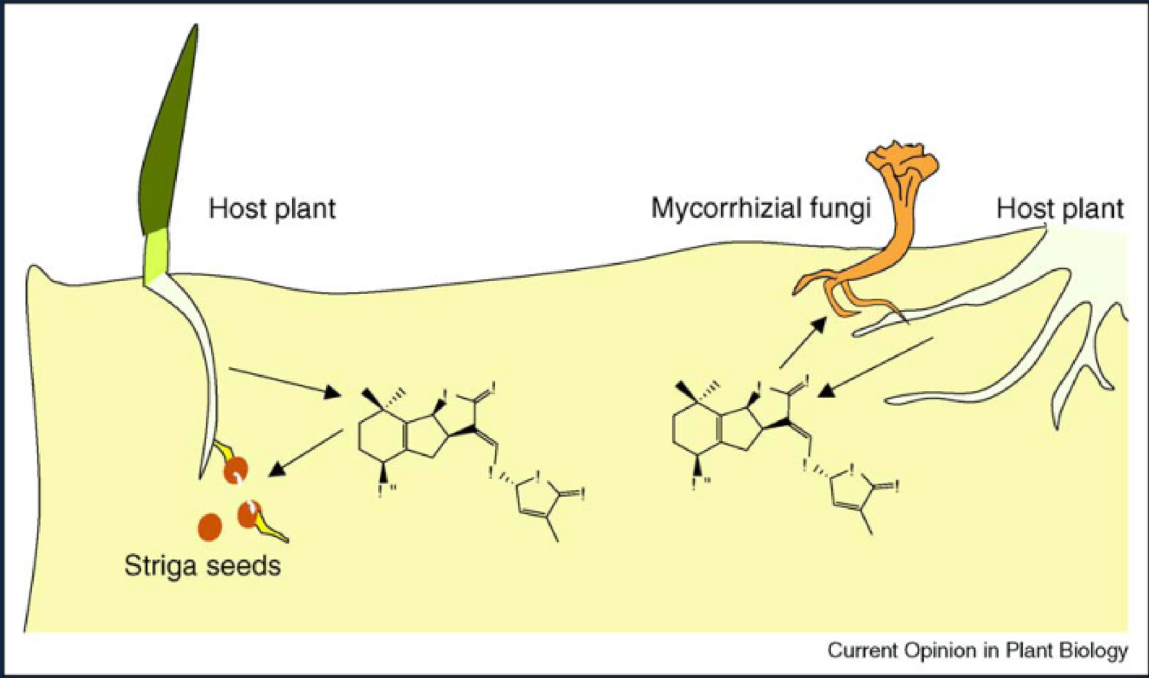


Rice plants that accumulate more CK can produce more grain per plant because of changes in inflorescence architecture.

Wild-type

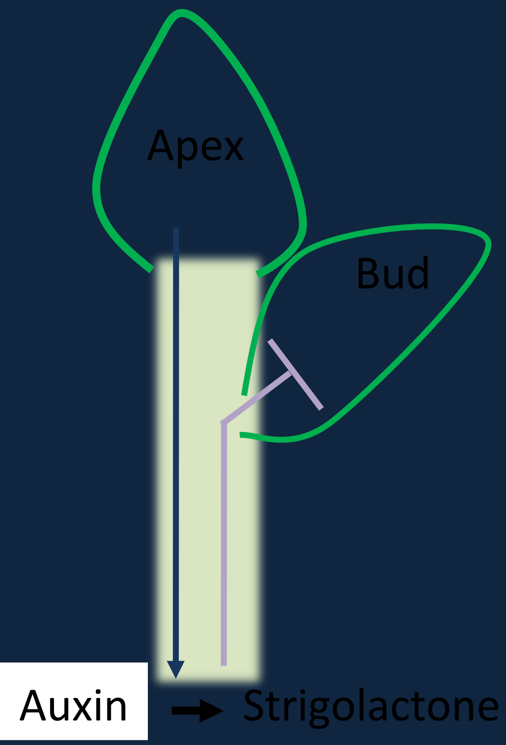
Tobacco plants that produce more CK are more drought tolerant because of the delay in leaf senescence conferred by CK.

Strigolactones



Strigolactones, synthesized from carotenoids, are produced in plant roots. They attract mycorrhizal fungi and promote the germination of parasitic plants of the genus *Striga*.

Strigolactones inhibit branch outgrowth

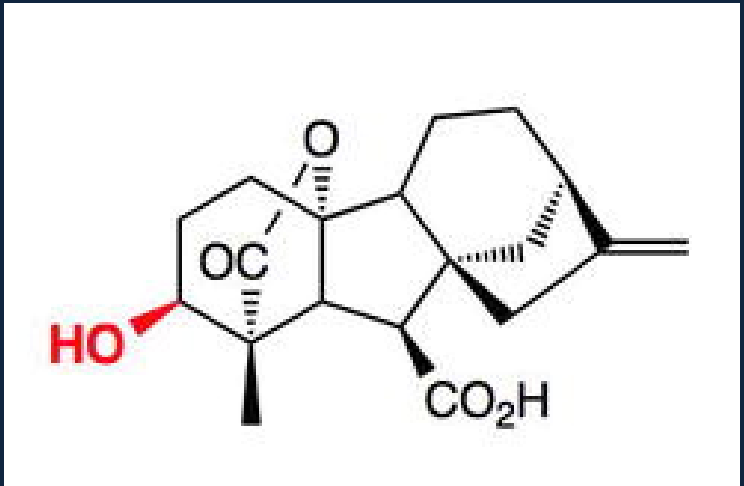


Auxin transported from the shoot to the root induces strigolactone synthesis, which indirectly inhibits bud outgrowth.

In a rice mutant that does not produce strigolactones, tillers (lateral branches) grow out as shown.

Gibberellins

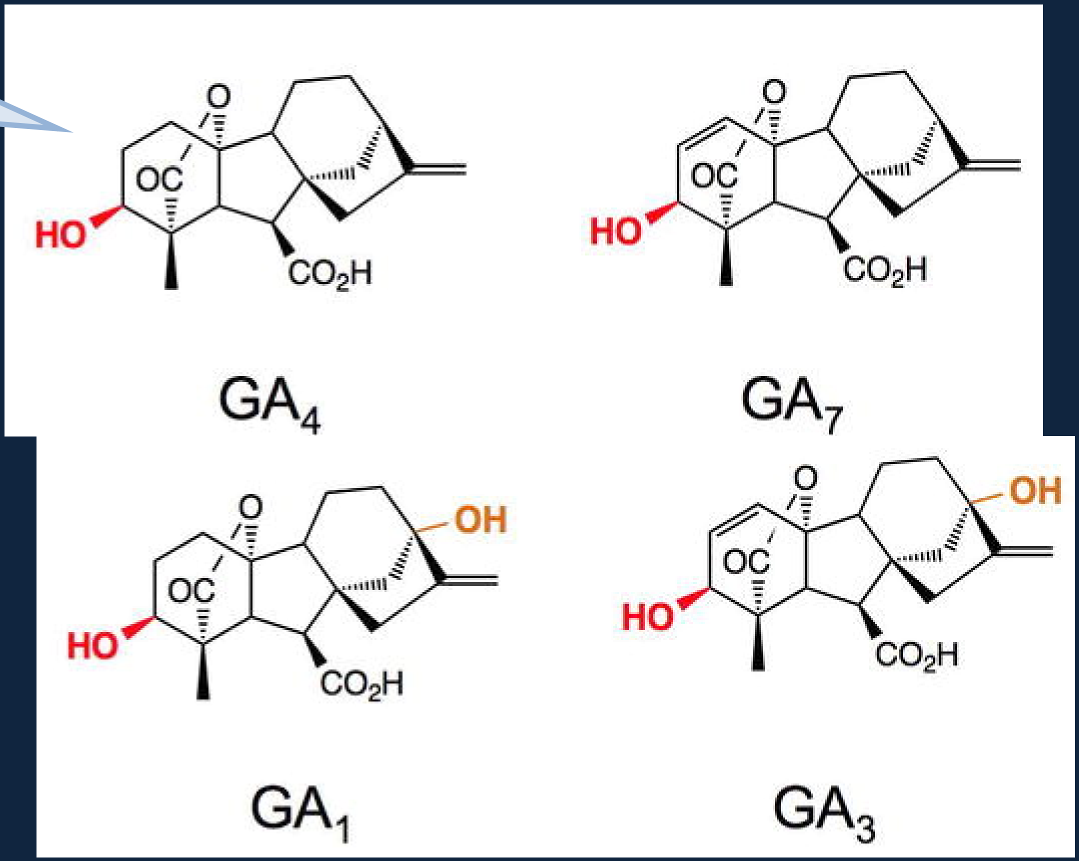
- Growth
- Seed germination
- Promote flowering
- Promote sex determination in some species
- Promote fruit growth



A Gibberellin (GA_4)

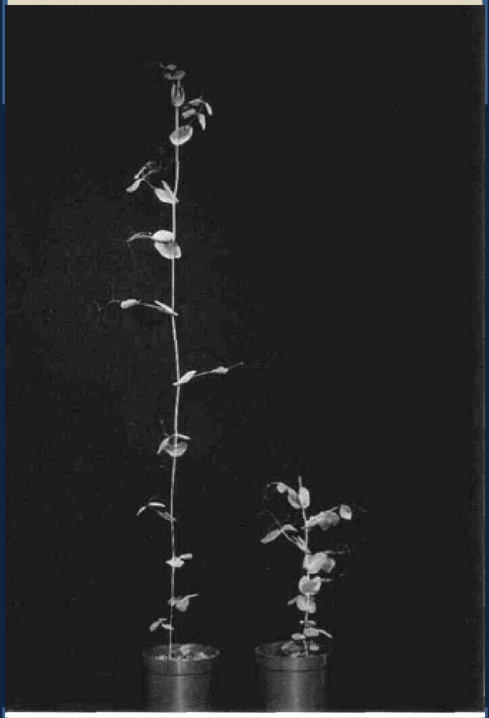
Gibberellins are a family of compounds

GA_4 is the major active GA in Arabidopsis



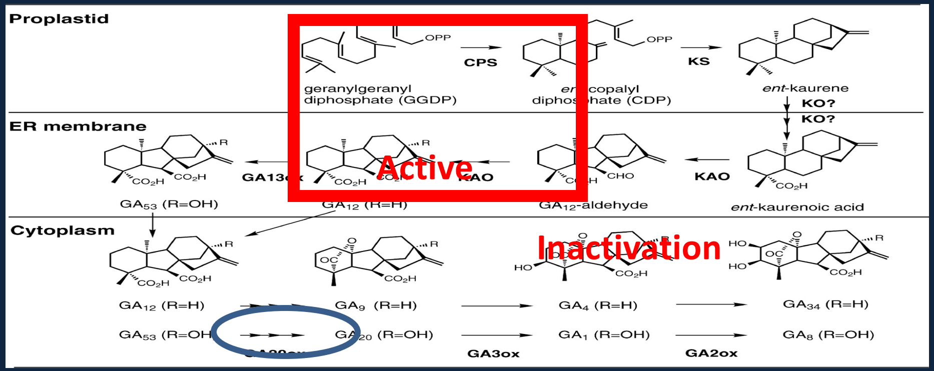
Only some GAs are biologically active. The major bioactive gibberellins are shown here.

Gibberellins regulate growth



Wild type | Gibberellin biosynthesis mutant *le*

The pea mutant *le*, studied by Mendel, encodes GA_3 oxidase, which produces active GA. Loss of function of *le* reduces active GA levels and makes plants dwarfed.



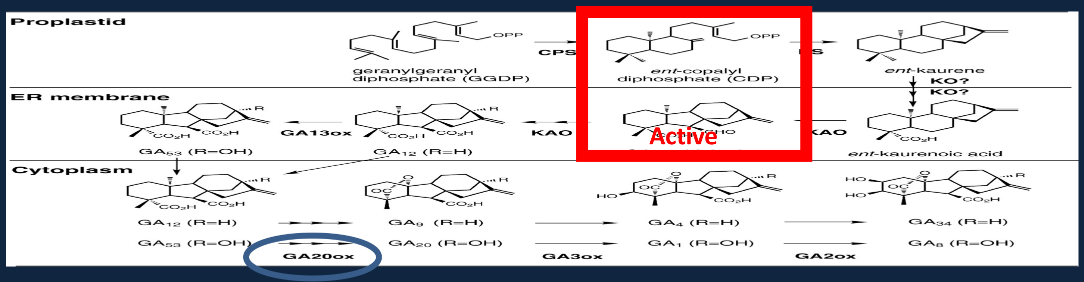
Genes controlling GA synthesis are important "green revolution" genes

Distinguished plant breeder and Nobel Laureate
Norman Borlaug **1914-2009**

Tremendous increases in crop yields (the Green Revolution) during the 20th century occurred because of increased use of fertilizer and the introduction of semidwarf varieties of grains.

The semidwarf varieties put more energy into seed production than stem growth, and are sturdier and less likely to fall over.

Several of the green revolution genes affect GA biosynthesis

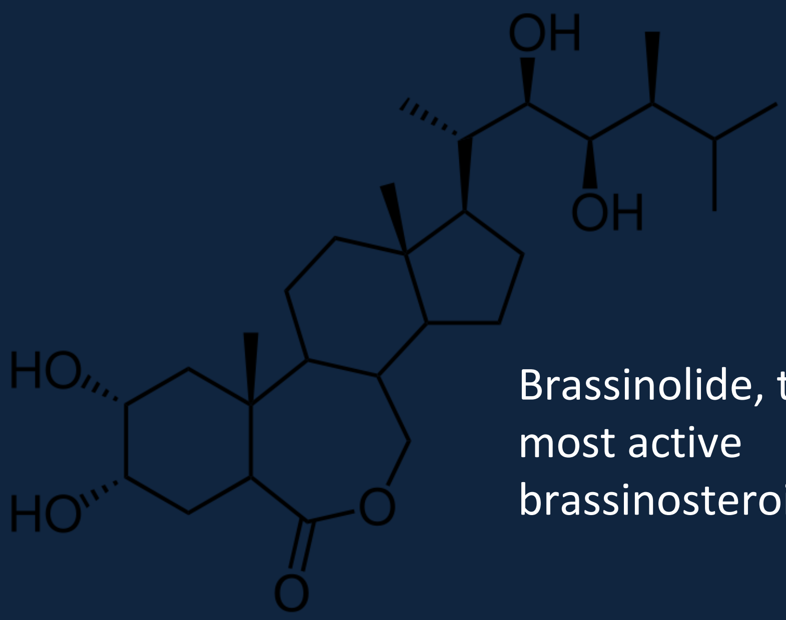


Semidwarf rice varieties underproduce GA because of a mutation in a the GA20 oxidase biosynthetic gene.

Wild-type Semidwarf

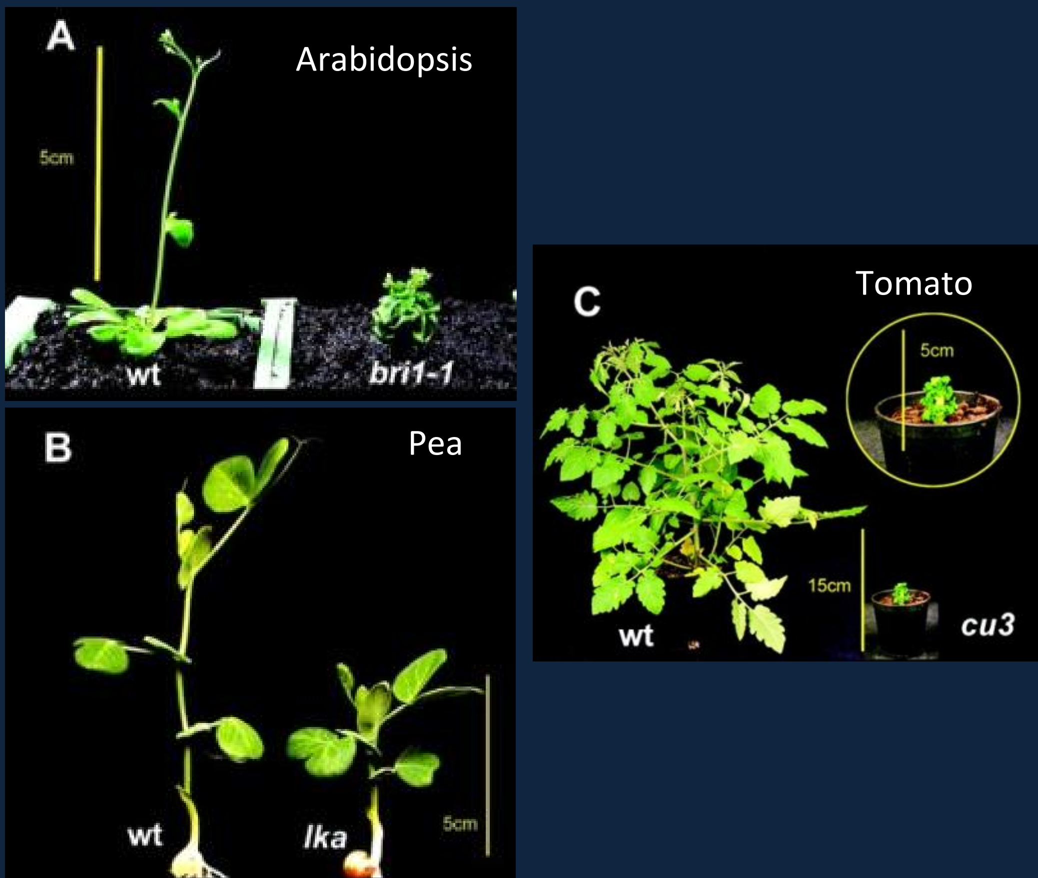
Brassinosteroids

- Cell elongation
- Pollen tube growth
- Seed germination
- Differentiation of vascular tissues and root hairs
- Stress tolerance

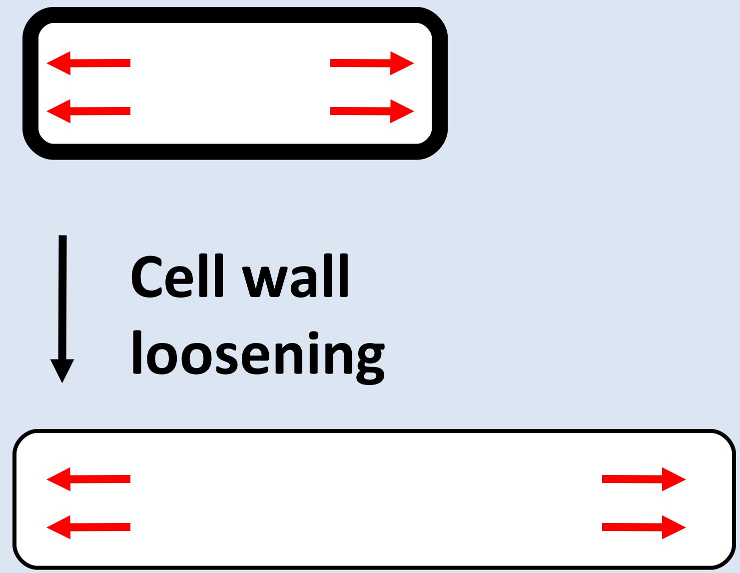


Brassinolide, the most active brassinosteroid

Brassinosteroid (BR) mutants are dwarfed



BRs promote cell elongation in part by loosening cell walls



Lowered resistance to internal turgor pressure; cell expansion

Summary – hormonal control of vegetative growth

Plant hormones have diverse effects on plant growth.

Auxin, gibberellins and brassinosteroids contribute to elongation growth.

Auxin, cytokinins and strigolactones regulate branching patterns.

Growth and branching profoundly affect crop yields.

Hormonal control of reproductive development

In angiosperms:

- transition from vegetative to reproductive growth
- flower development,
- fruit development and ripening
- seed development, maturation and germination

Flower development

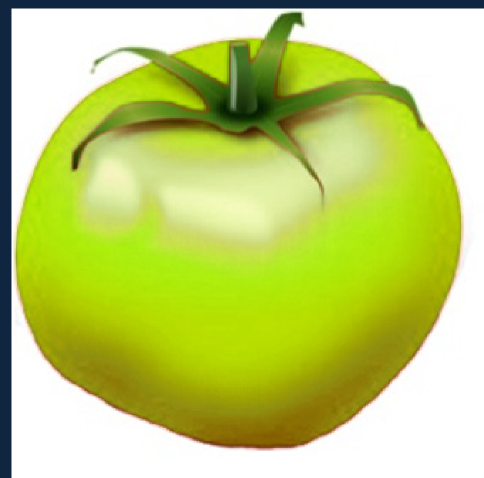
Hormones contribute to flower development in many ways:

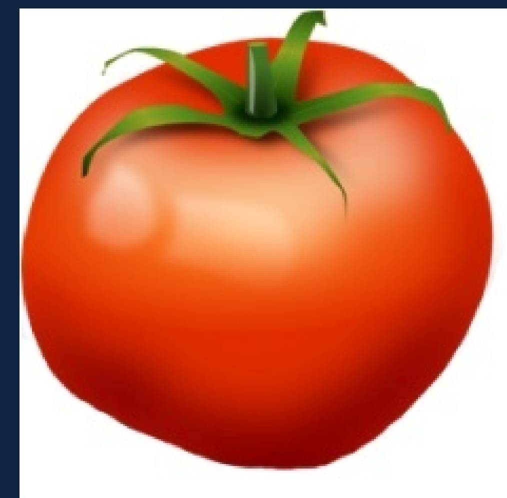
- Patterning of the floral meristem
- Outgrowth of organs
- Development of the male and female gametophytes
- Cell elongation

Ethylene and gibberellins are involved in sex determination

Hermaphrodite Male Female

Fruit development and ripening are under hormonal control

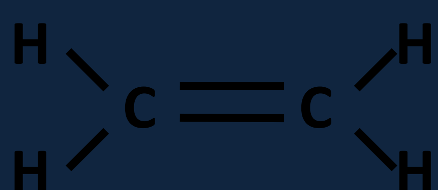


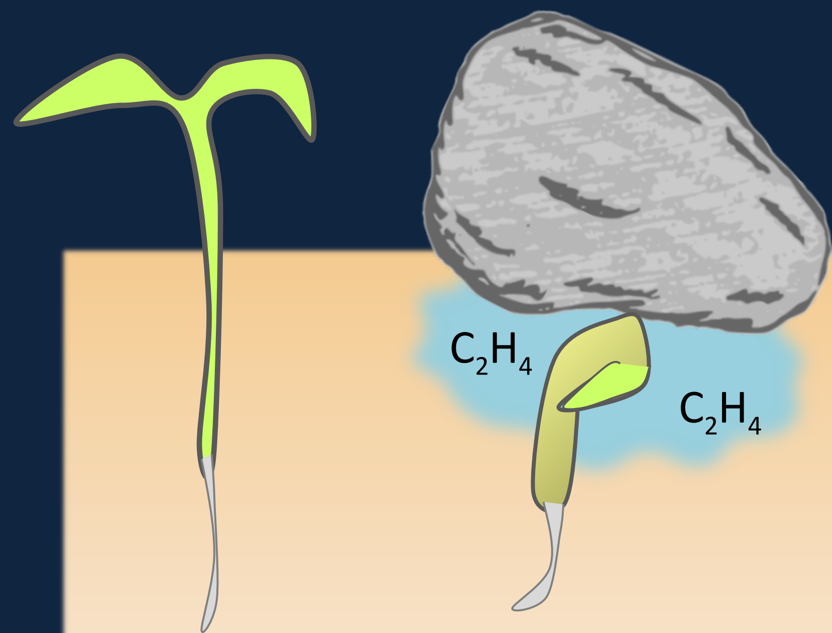


Pollination initiates petal senescence, cell division and expansion in the ovary to produce a fruit, and fruit ripening.

Ethylene

- Control of fruit ripening
- Control of leaf and petal senescence
- Control of cell division and cell elongation
- Sex determination in some plants
- Control of root growth
- Stress responses



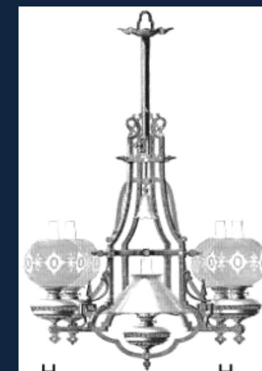


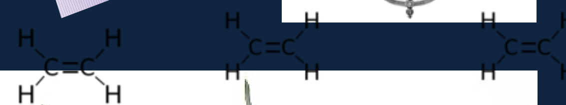
Ethylene induces the triple response:
- reduced elongation,
- hypocotyl swelling,
- apical hook exaggeration.

Ethylene promotes senescence of leaves and petals

Air (control) 7 days ethylene

Ethylene promotes leaf and petal senescence.





In gas-lit houses,
lants were harmed
by the ethylene
produced from
burning gas.
idistra is ethylene-
resistant and so
became popular
houseplant.

Ethylene shortens the longevity of cut flowers and fruits

Ethylene levels can be managed to maintain fruit freshness, commercially and at home.

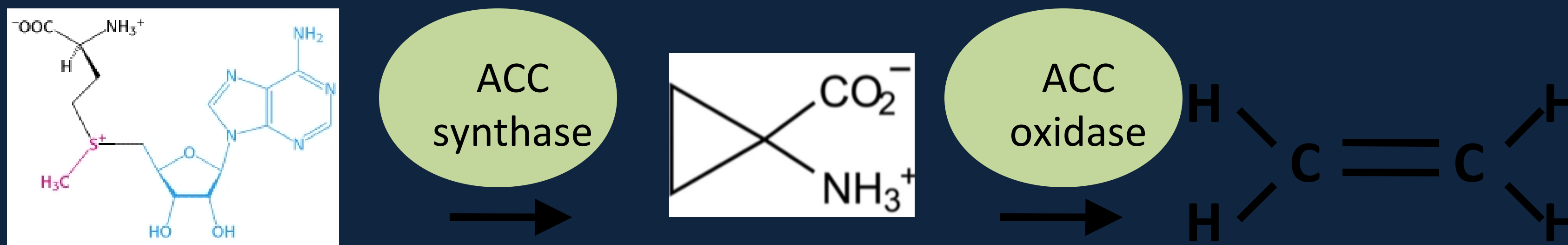
<u>Strategies to limit ethylene effects</u>

Limit production - high CO_2 or low O_2

Removal from the air -$KMnO_4$ reaction, zeolite absorption

Interfere with ethylene binding to receptor - sodium thiosulfate (STS), diazocyclopentadiene (DACP), others

Molecular genetic approaches can limit ethylene synthesis

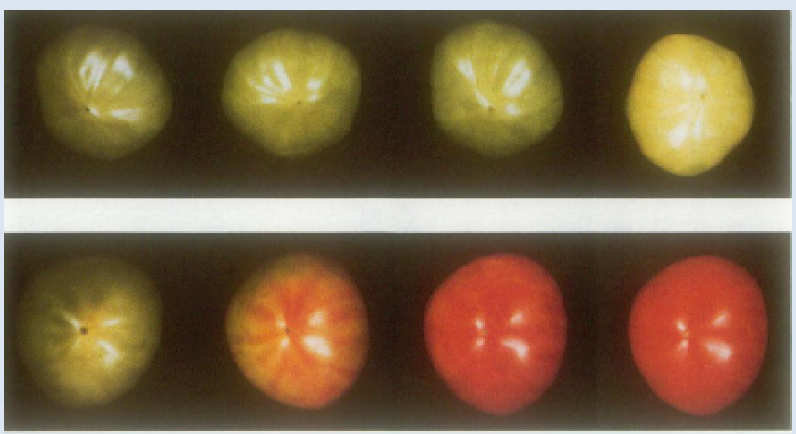


S-adenosyl methionine

ACC

(1-aminocyclopropane-1-carboxylic acid)

Ethylene



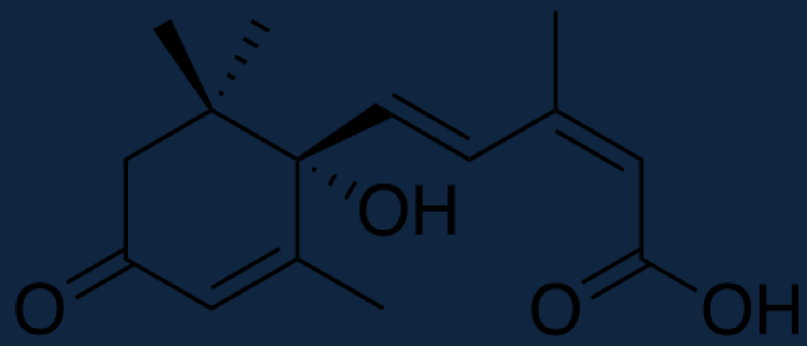
Antisense ACC synthase

Control

Introduction of antisense constructs to interfere with expression of biosynthesis enzymes is an effective way to control ethylene production.

Abscisic acid

- Seed maturation and dormancy
- Desiccation tolerance
- Stress response
- Control of stomatal aperture



ABA accumulates in maturing seeds

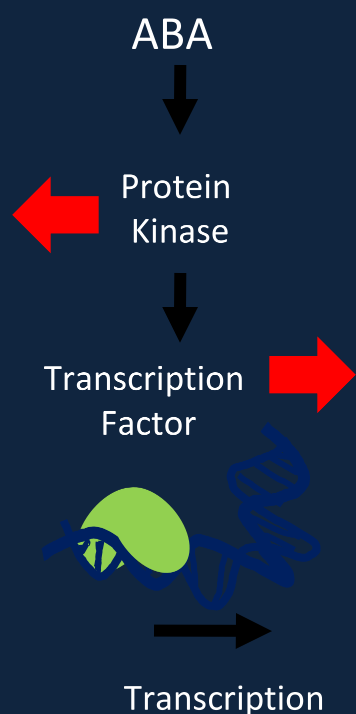
Embryonic patterning

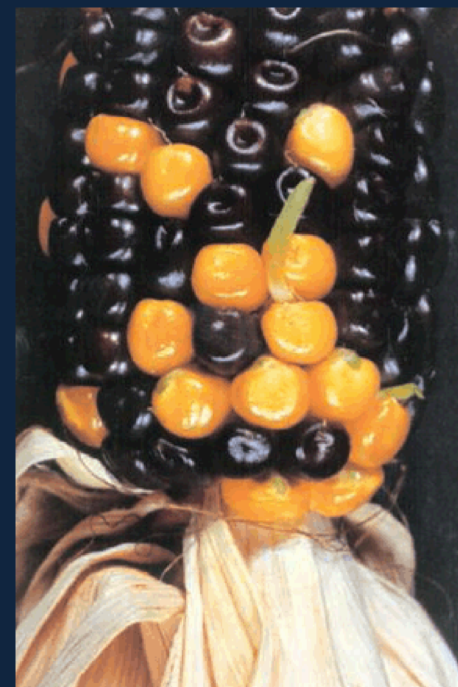
Reserve accumulation

Desiccation tolerance

Seed maturation requires ABA synthesis and accumulation of specific proteins to confer desiccation tolerance to the seed.

ABA synthesis and signaling is required for seed dormancy

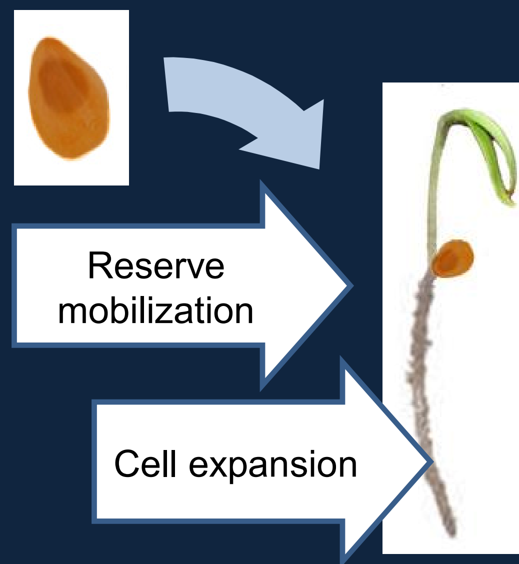


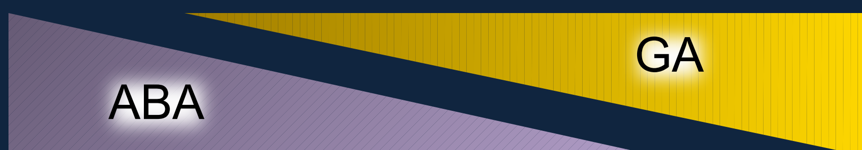


Loss of function of ABA signaling (protein kinase or transcription factor function) interferes with ABA-induced dormancy and causes precocious germination.

GA is required for seed germination

Seed germination requires elimination of ABA and production of GA to promote growth and breakdown of seed storage products.





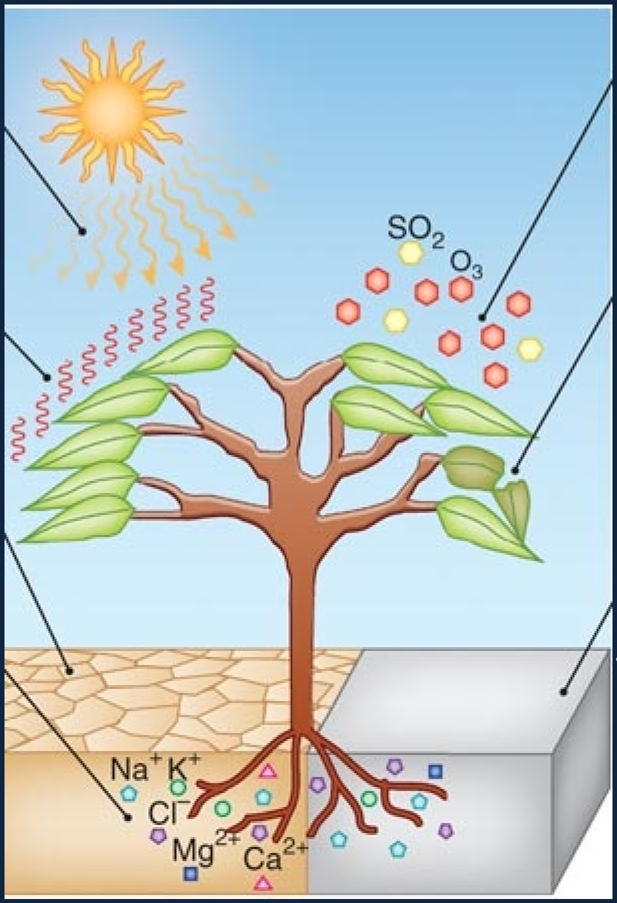
Hormonal responses to abiotic stress

Photooxidative stress

High temperature stress

Water deficit, drought

Soil salinity



Air pollution

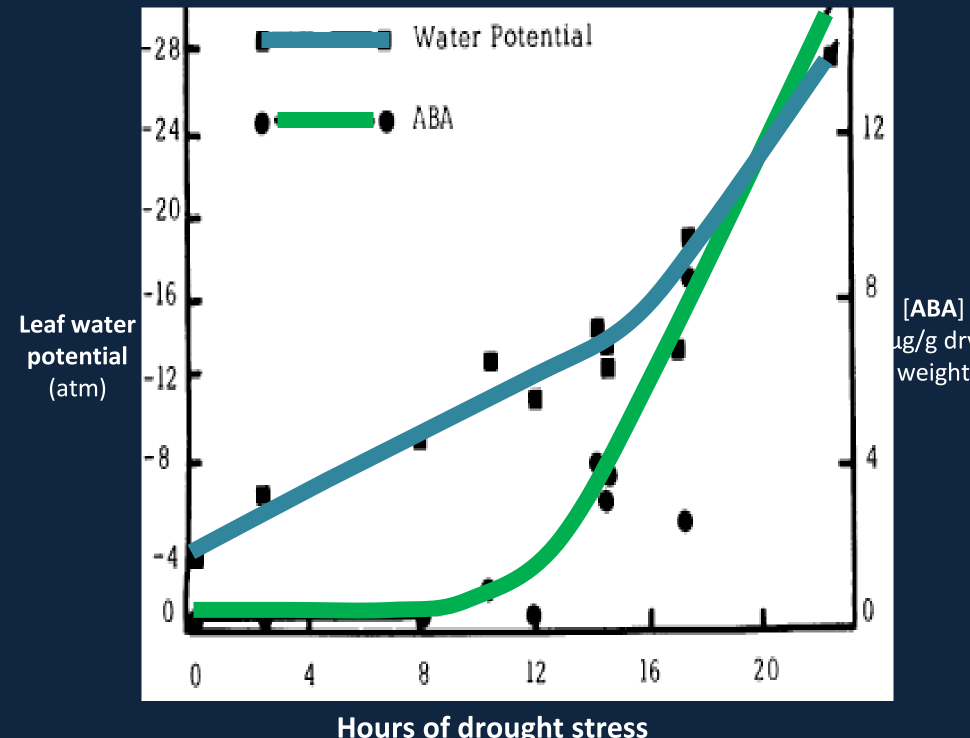
Wounding and mechanical damag

Cold and freezing stress

Plants' lives are very stressful.....

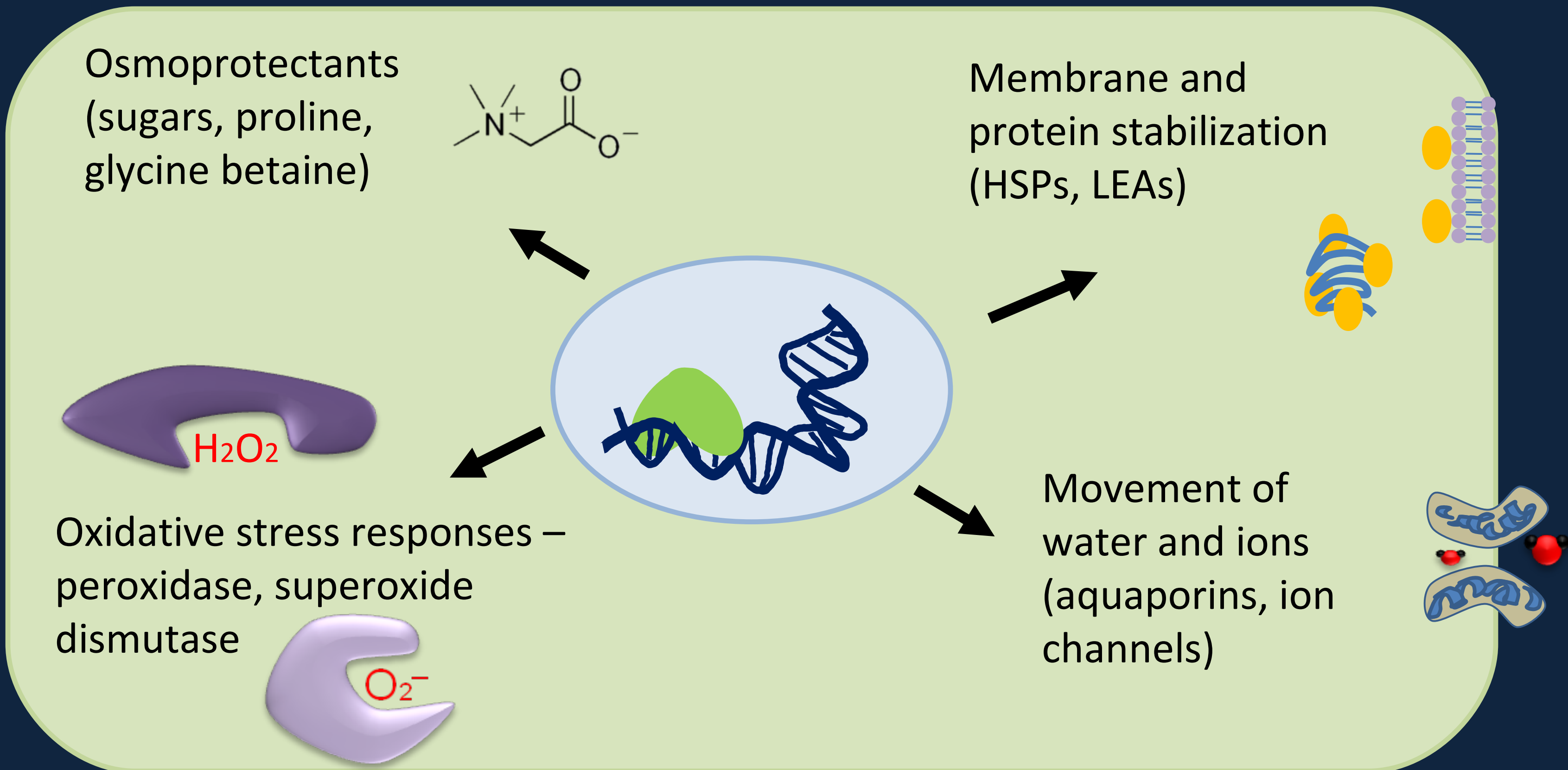
ABA and ethylene help plants respond to stress.

ABA synthesis is strongly induced in response to stress

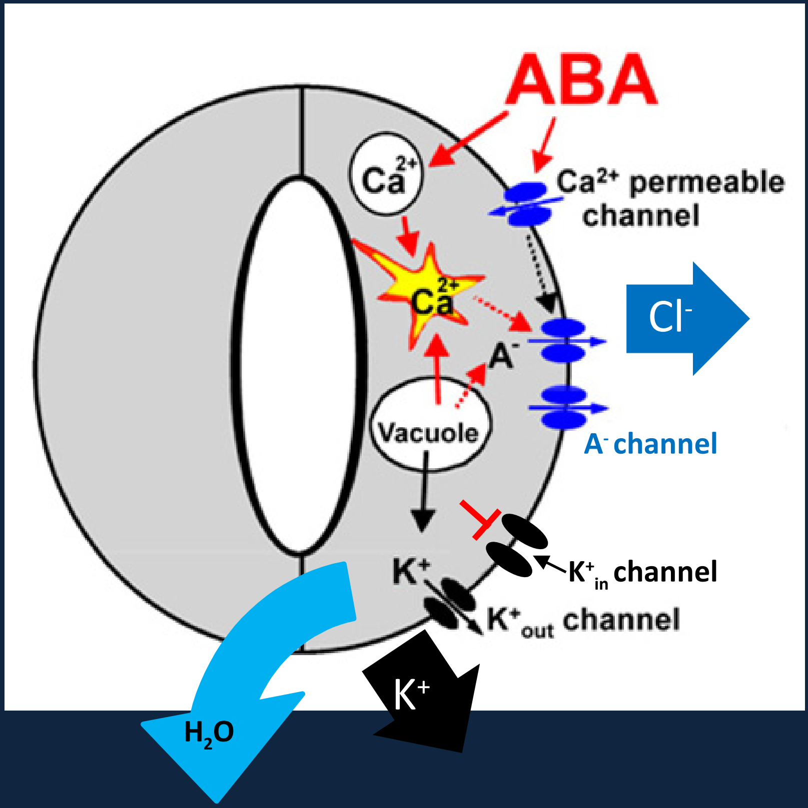


ABA levels rise during drought stress due in part to increased biosynthesis

ABA induces stress-responsive genes



ABA-induced stomatal closure is extremely rapid and involves changes in ion channel activities

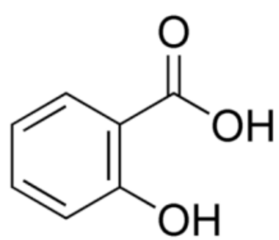


ABA triggers an increase in cytosolic calcium (Ca^{2+}), which activates anion channels (A^-) allowing Cl^- to leave the cell. ABA activates channels that move potassium out of the cell (K^+_{out}) and inhibits channels that move potassium into the cell (K^+_{in}). The net result is a large movement of ions out of the cell.

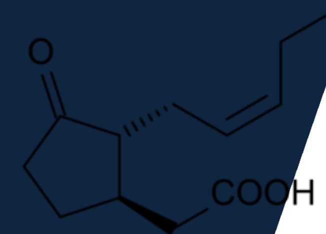
As ions leave the cell, so does water (by osmosis), causing the cells to lose volume and close over the pore.

Hormonal responses to biotic stress

Bacteria, fungi, viruses – Biotrophic organisms



Salicylic Acid

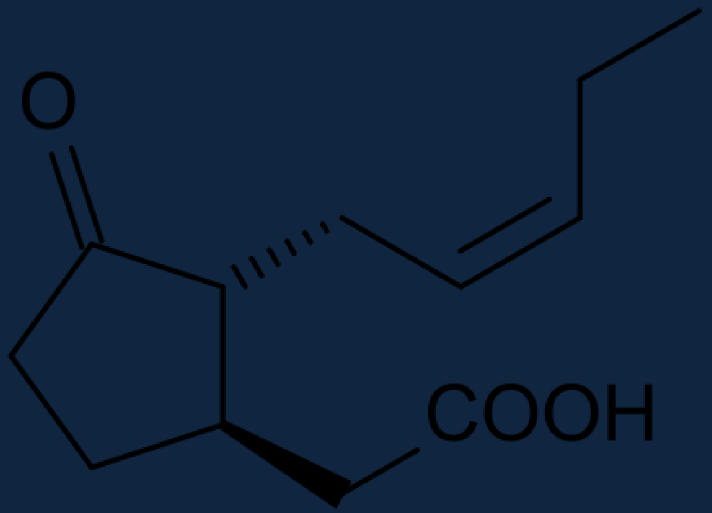


Jasmonates

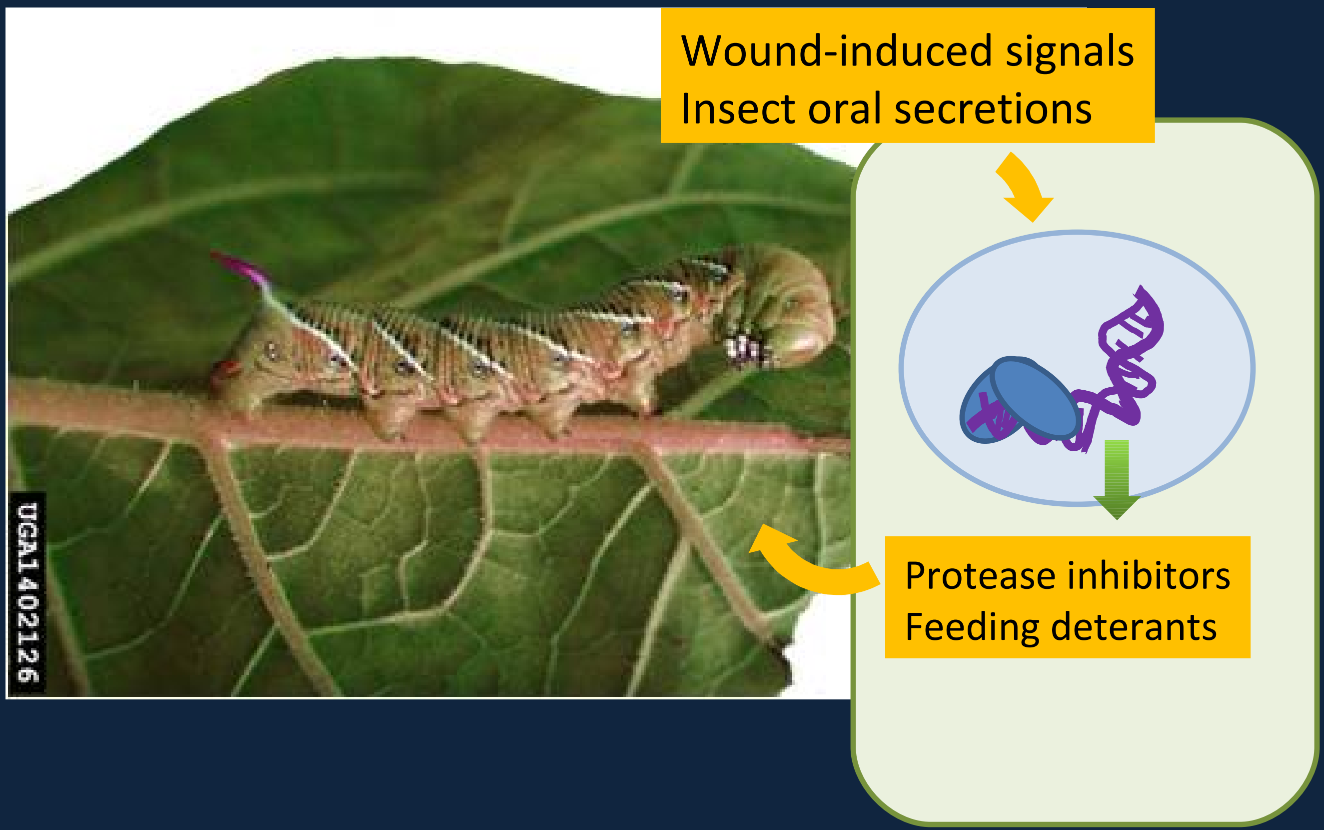
Herbivores – insects, other animals, fungi – Necrotrophic organisms

Jasmonates

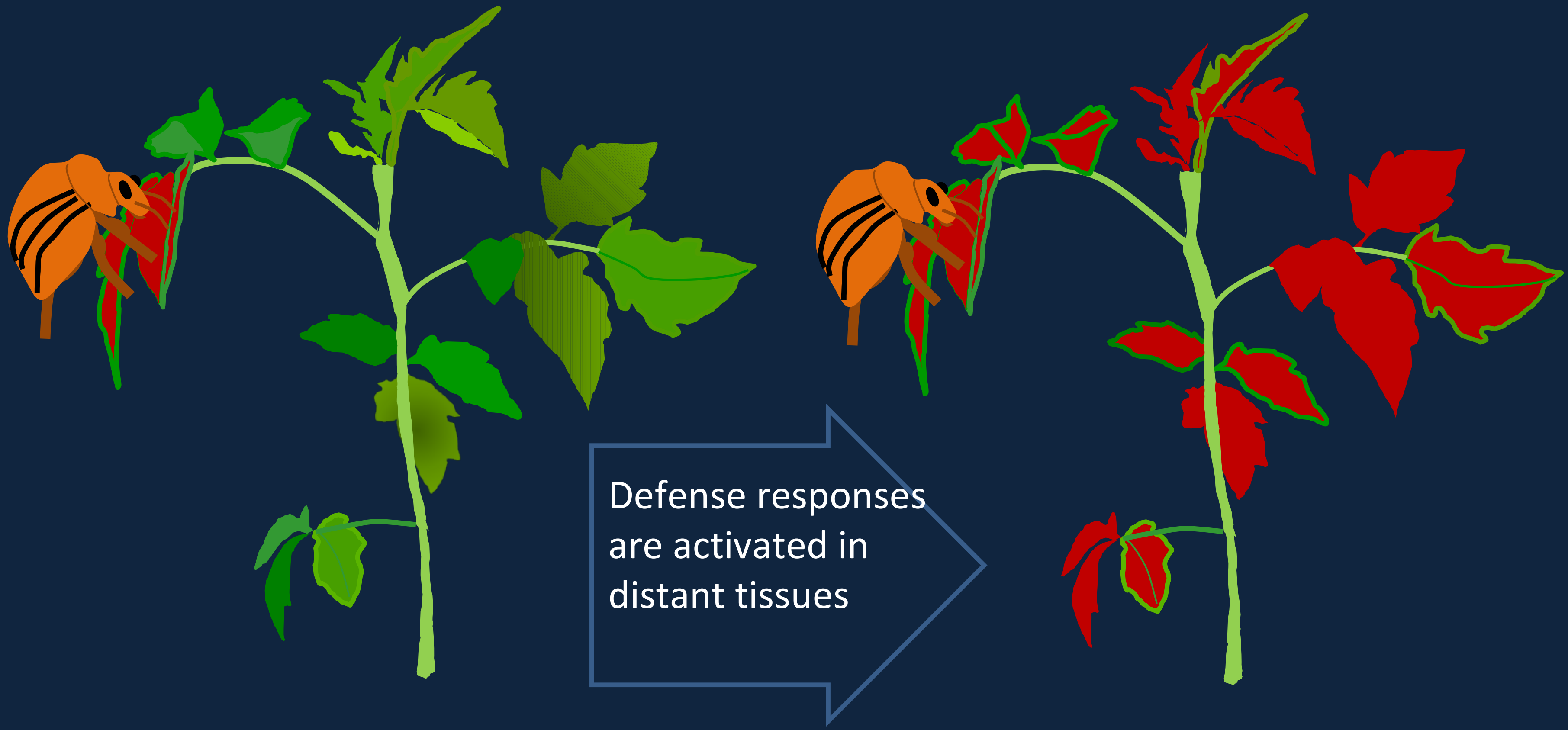
- •Response to necrotrophic pathogens
- •Induction of anti-herbivory responses
- •Production of herbivore-induced volatiles to prime other tissues and attract predatory insects



Jasmonates induce the expression of anti-herbivory chemicals

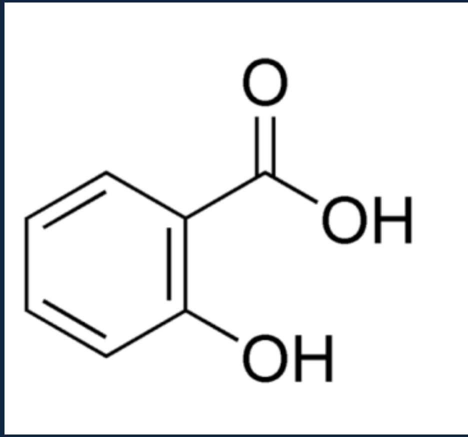


Jasmonates contribute to systemic defense responses



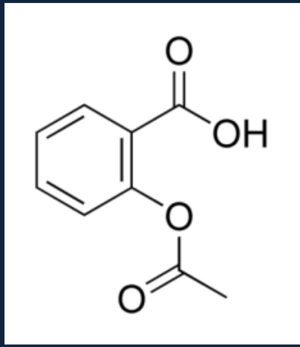
Salicylic Acid – plant hormone and painkiller

- Response to biotrophic pathogens
- Induced defense response
- Systemic acquired resistance



Salicylic Acid

Salicylic acid is named for the willow *Salix* whose analgesic properties were known long before the chemical was isolated.

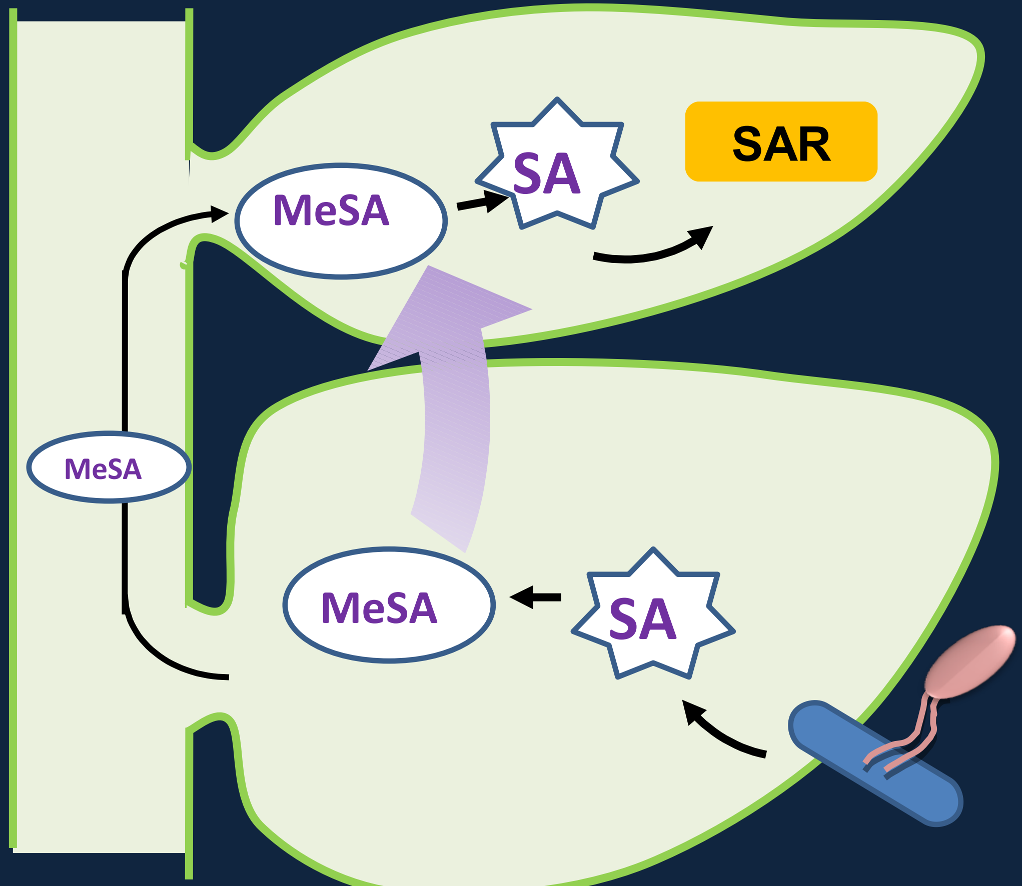


Acetylsalicylic Acid - aspirin

Salicylates contribute to systemic acquired resistance

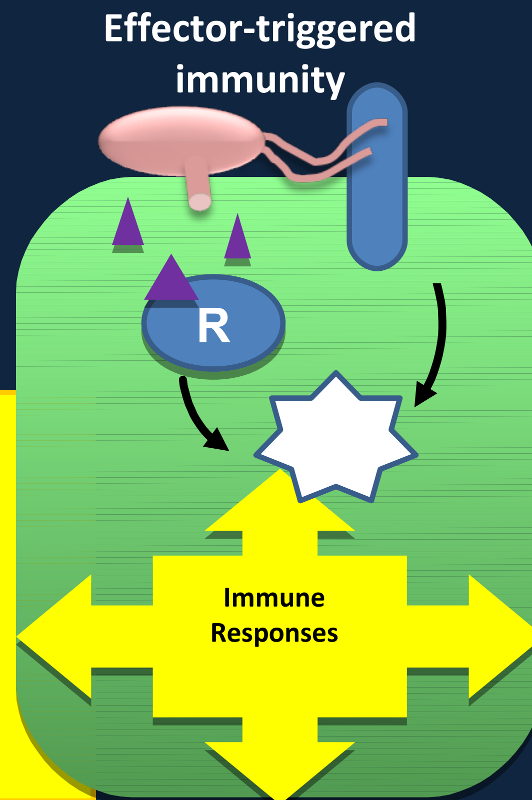
SA is necessary in systemic tissue for SAR, but the nature of the mobile signal(s) is still up in the air

It is likely that multiple signals contribute to SAR

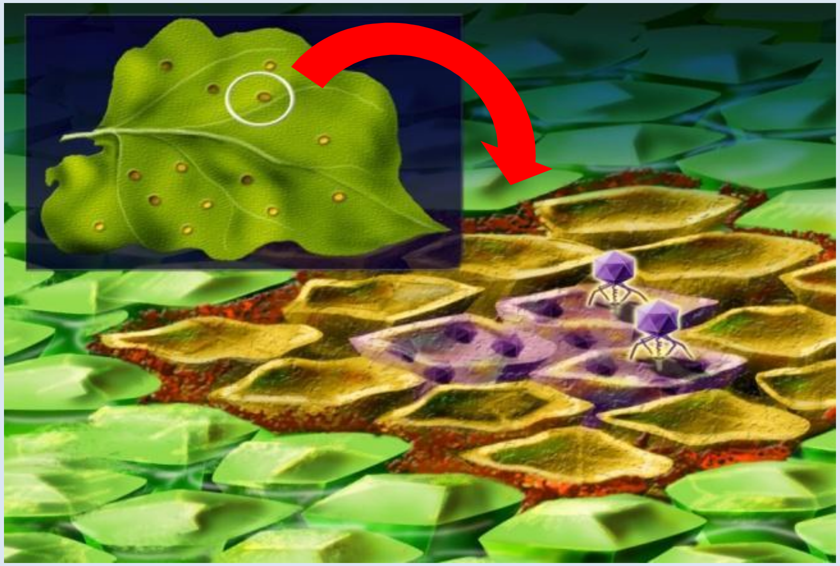


The hypersensitive response involves cell death

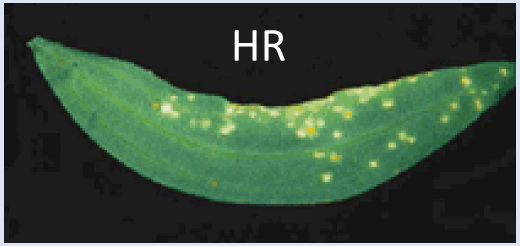
Pathogen Response (PR) genes
Antimicrobial compounds
Strengthening of plant cell walls
Programmed cell death
Hypersensitive response (HR)

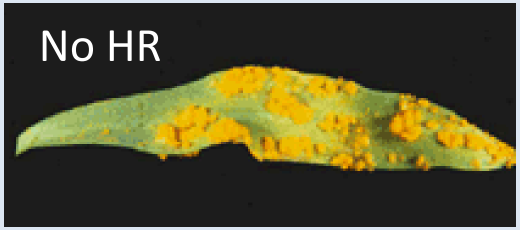


The hypersensitive response seals the pathogen in a tomb of dead cells



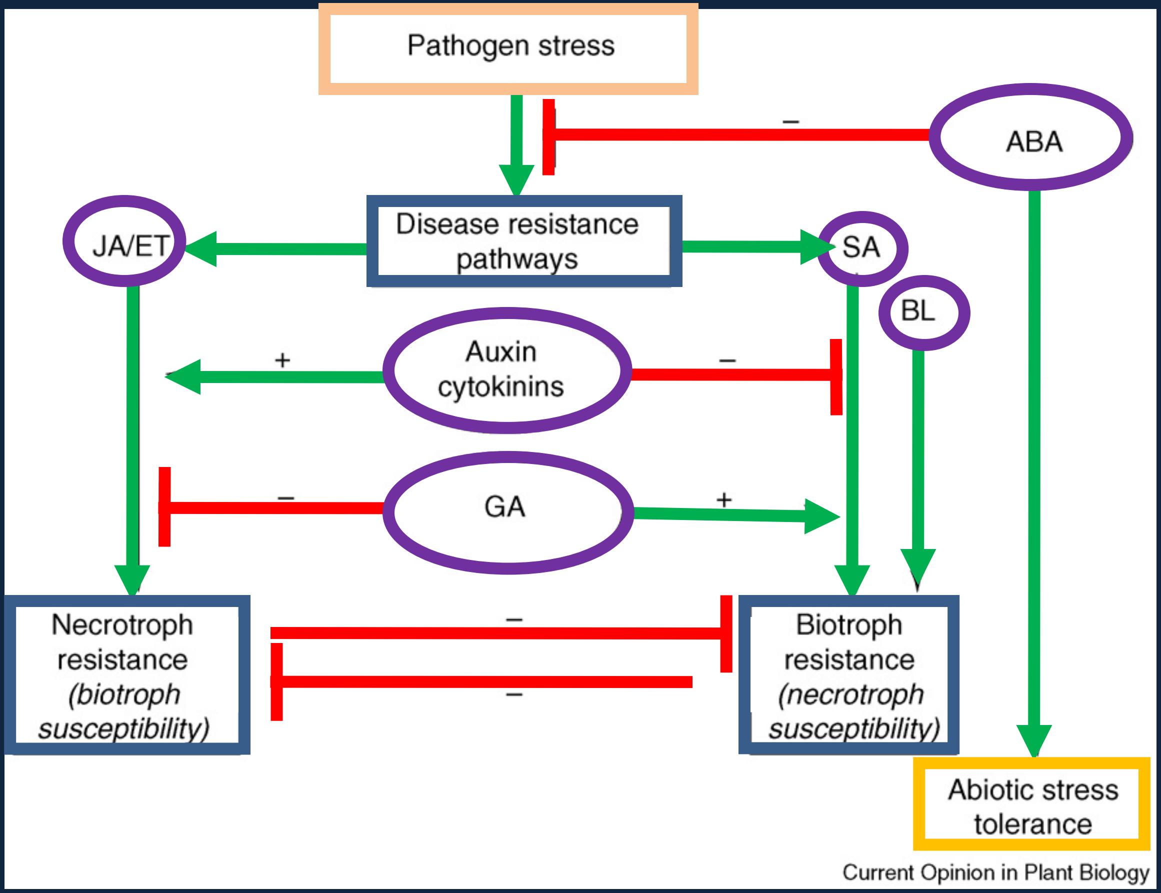
The HR kills the infected cells and cells surrounding them and prevents the pathogen from spreading.





Without a hypersensitive response, the pathogen can multiply.

Other hormones affect defense response signaling



As part of their immune responses, plants modulate synthesis and response to other hormones. Some pathogens exploit the connections between growth hormones and pathogen-response hormones to their own advantage, by producing "phytohormones" or interfering with hormone signaling.

Summary – stress responses

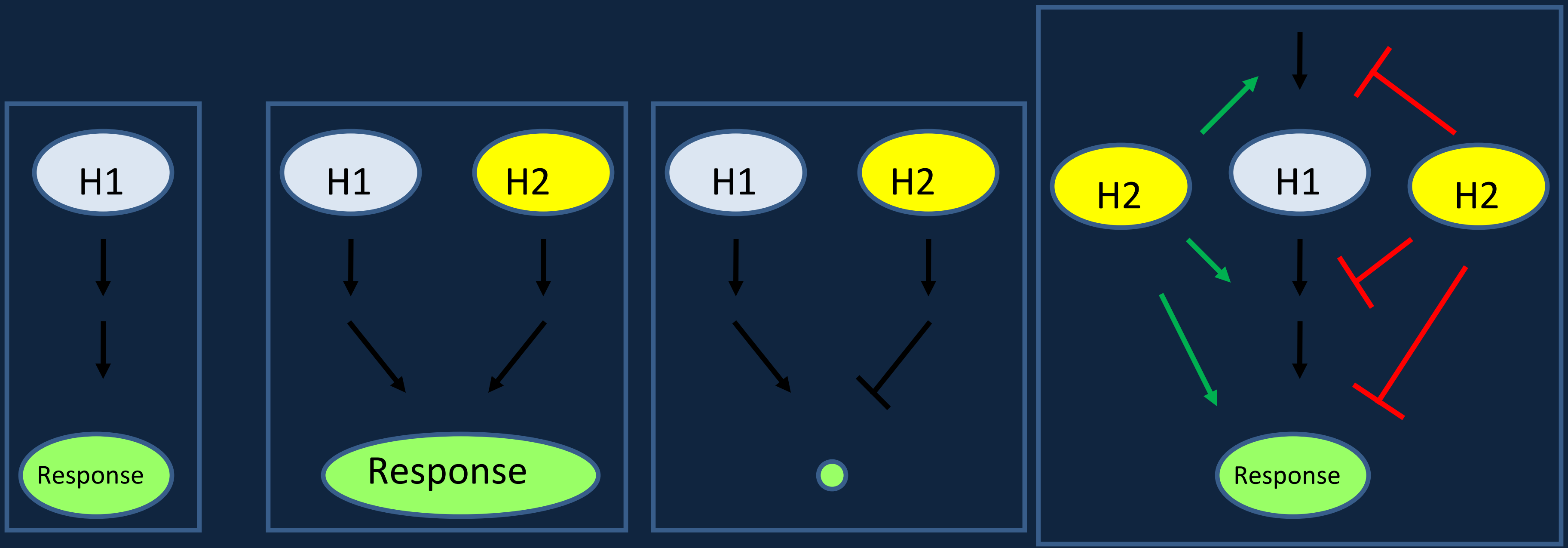
Hormonal signaling is critical for plant defenses against abiotic and biotic stresses.

ABA and ethylene are produced in stressed plants and critical for activating their defense pathways.

JA and SA contribute to local and systemic defenses against pathogens.

Understanding plant hormonal responses to stress is needed to improving agricultural yields. Abiotic and biotic stresses are major causes of crop losses and reduced yields and which must be minimized.

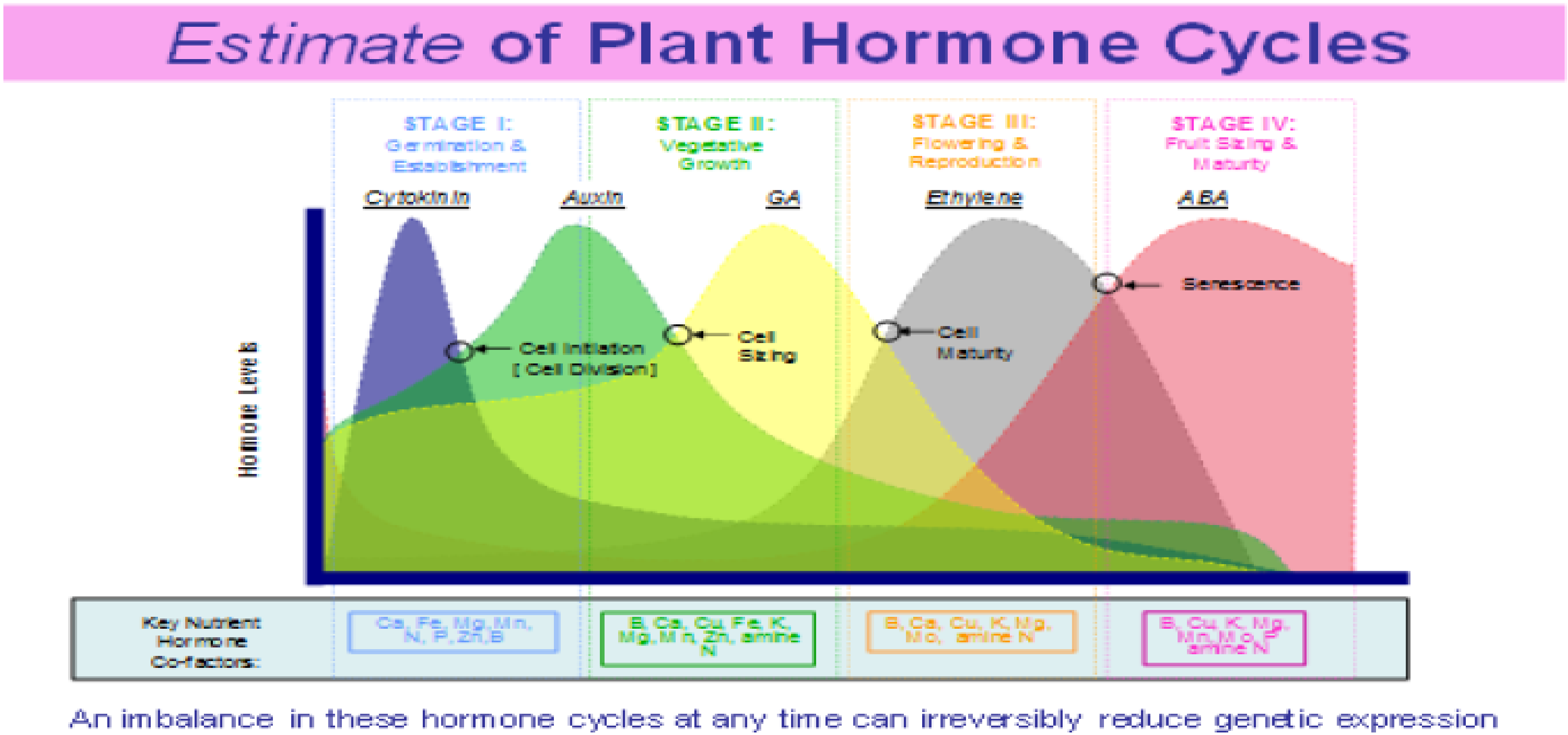
Crosstalk between hormone



Crosstalk (or cross-regulation) occurs when two pathways are not independent. It can be positive and additive or synergistic, or negative.

Crosstalk can affect the synthesis, transport or signaling pathway of another hormone.

PGR and Pest Disease management:



Onion Thrip Infestation One Treatment Of Auxin Containing Solution.

[063] TABLE VII

REDUCTION OF ONION INFESTATION BY (*THRIPS TABACI*) AFTER SINGLE TREATMENT WITH AUXIN-CONTAINING SOLUTION

	Test 1			Test 2		
	THRIPS (counted after 7 days)			THRIPS (counted after 8 days)		
	LARVAE	ADULT	TOTAL	LARVAE	ADULT	TOTAL
Control (untreated)	53.9 ± 4.3	7.1 ± 0.7	61.0 ± 4.7	87.7 ± 15.2	4.7 ± 0.8	92.4 ± 15.5
Treated with Auxin solution (12 oz / acre)	21.8 ± 2.4	3.4 ± 0.4	25.2 ± 2.6	40.1 ± 7.9	3.3 ± 0.9	43.4 ± 8.2
F	42.82	20.15	44.84	7.71	1.35	7.81
P	<0.0001	<0.0001	<0.0001	0.0124	0.2596	0.0120

Two-spotted Spider Mite Infestation of Melons: Single Treatment with Auxin Containing Solution.

TABLE VIII

REDUCTION IN INFESTATION OF MELONS BY TWO-SPOTTED SPIDER MITES (*TETRANYCHUS URTICAE*) AFTER SINGLE TREATMENT WITH AUXIN-CONTAINING SOLUTION

	No. Mites per 4 cm^2		
	No. Live Mites	No. Dead Mites	Percent Dead Mites
Prior to Treatment	3.14 ± 0.78	0.02 ± 0.02	0.04 ± 0.04
5 Days after Treatment	0.59 ± 0.26	0.24 ± 0.07	56.76 ± 10.51
5 Days later with NO Treatment	1.54 ± 0.27	1.22 ± 0.24	21.64 ± 6.39
F	3.42	3.21	9.20
P	0.0659	0.0749	0.0036

- **Auxins with other phytohormones support metabolic processes suppressive to**
  - Necrotrophic fungi (*Rhizoctonia solani*),
    - Pink Root of Onion (*Phoma terrestris)*
  - Insects
    - Aphid
    - Other Sucking insects
    - Citrus Leaf Miner (*Phyllocnistis citrella)*
    - Rice Stink Bug (Oebalus pugnax)
    - Onion Thrips (*Thrips tabaci)*
    - Bean Thrips (*Caliothrips fasciatus)*
    - Western Flower thrips (*Frankliniella occidentalis)*
  - Arachnids
    - Two spotted spider mites (*Tetranychus urticae)*
    - Broad Mite (*Polyphagotarsonemus latus)*
  - Nematodes (root knot in soil and roots) (*Meloidogyne* spp.)
- **Preferred applications**
  - Small amounts frequently; better than large single application
- **Mechanism (s) of suppression remains under investigation**

Ongoing research

- Hormones coordinate plant growth and defense
- Many aspects of hormone synthesis, homeostasis and signaling are still being discovered
- Knowledge of these processes provides tremendous opportunities for agricultural improvements including the development of stress-resistant and pathogen-resistant plants, plants with greater abilities to take up nutrients, foods that stay fresh longer, and increased crop yields