BI 111
Plant Growth and Development

Brassica Oleracea (cabbage)

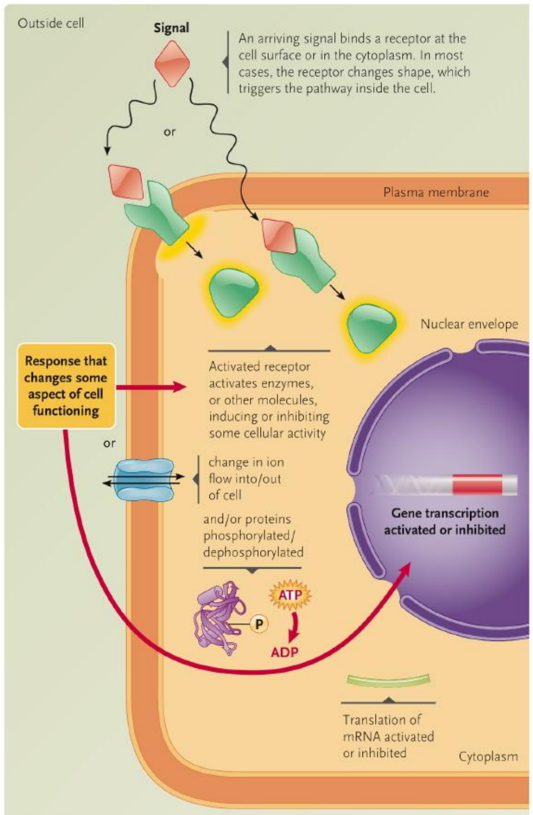
- Natural selection important plant
- Cultivars → variation of domesticators, different variations of a species
    - Modification of different parts of the body of the plant

Plant growth and development

- To understand diversity of plant structures and life histories, need to understand role that signal response pathways play in their growth and development
- ❖ Contain hormones → changes in shape, size, metabolic activity, turning on/off stimulus
- ❖ Plant hormones are really important, but we don't need them in large quantities
    - Hormones activate other enzymes in a cell

Signal Response Pathways

- Hormones and environmental stimuli alter behaviour of target cells
    - Signal molecules bind to receptors in target cells
    - Elicit cellular response (different response in different tissue)
- By means of a response pathway, signal can:
    - Induce changes in cell's shape or internal structure
    - Influence cell's metabolism
    - Alter gene activation and rate of protein synthesis
    - Set in motion events that modify existing cell proteins
- Some hormones and growth factors bind to receptors at target cell's plasma membrane, on ER, or in cytoplasm
- Binding triggers release of internal second messengers that diffuse through cytoplasm and provide main chemical signal that alters cell functioning
- Reaction sequence amplifies cell's response to signal
- ❖ Perfect control over the hormones is what lets it do specific enormous amounts of dramatic changes in plant's metabolic changes
- ❖ Enzymes within a cell → can cause big change in morphology
    - Small changes can have huge impacts
- ❖ Different tissues, different sensitivity in different hormones
- ❖ Control over growth and development



BI 111
Plant Growth and Development

Plant Hormones: 7 major classes

Auxins	Promote growth
Gibberellins	Stimulate growth, including the elongation of stems
Cytokinins	Enhance growth and retard aging
Ethylene	Regulates a range of responses, including senescence
Brassinosteroids	Regulate plant growth responses
Abscisic acid	Suppresses growth and influences responses to environmental stress
Jasmonate & oligosaccharins	Regulate growth and have roles in plant defence

Major Plant Hormones and Signalling Chemicals

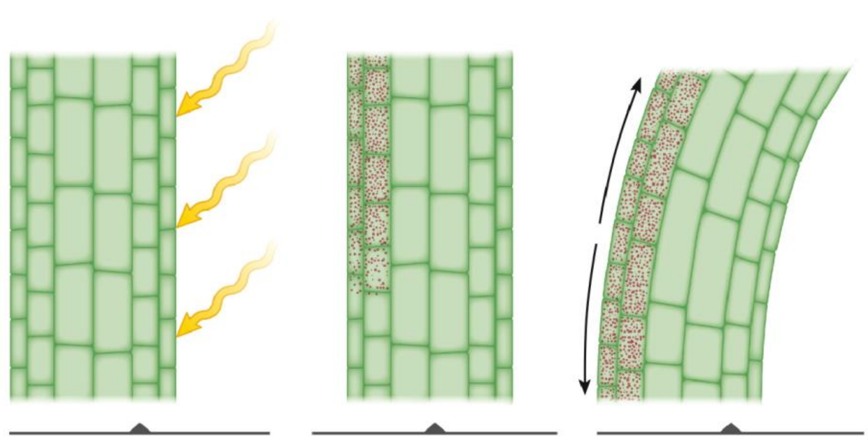
Hormone/Signalling Compound	Where Synthesized	Tissues Affected	Effects
Auxins	Apical meristems, developing leaves and embryos	Growing tissues, buds, roots, leaves, fruits, vascular tissues	Promote growth and elongation of stems; promote formation of lateral roots and dormancy in lateral buds; promote fruit development; inhibit leaf abscission; orient plants with respect to light, gravity
Gibberellins	Root and shoot tips, young leaves, developing embryos	Stems, developing seeds	Promote cell divisions and growth and elongation of stems; promote seed germination
Cytokinins	Mainly in root tips	Shoot apical meristems, leaves, buds	Promote cell division; inhibit senescence of leaves; coordinate growth of roots and shoots (with auxin)
Ethylene	Shoot tips, roots, leaf nodes, flowers, fruits	Seeds, buds, seedlings, mature leaves, flowers, fruits	Regulates elongation and division of cells in seedling stems, roots; in mature plants, regulates senescence and abscission of leaves, flowers, and fruits
Brassinosteroids	Young seeds; shoots and leaves	Mainly shoot tips, developing embryos	Stimulate cell division and elongation, differentiation of vascular tissue
Abscisic acid	Leaves	Buds, seeds, stomata	Promotes responses to environmental stress, including inhibiting growth/promoting dormancy; stimulates stomata to close in water-stressed plants
Jasmonates	Roots, seeds, probably other tissues	Various tissues, including damaged ones	In defence responses, promote transcription of genes encoding protease inhibitors; possible role in plant responses to nutrient deficiencies
Oligosaccharins	Cell walls	Damaged tissues; possibly active in most plant cells	Promote synthesis of phytoalexins in injured plants; may also have a role in regulating growth
Systemin	Damaged tissues	Damaged tissues	To date, known only in tomato and closely related species; roles in defence, including triggering jasmonate-induced chemical defences
Salicylic acid	Damaged tissues	Many plant parts	Triggers synthesis of pathogenesis-related (PR) proteins, other general defences

Auxins

- Mainly idoleacetic acid (IAA)
- Synthesized primarily in shoot apical meristem and young stems and leaves
- Promotes elongation of cells
- Governs growth responses to light and gravity
- ❖ Very important hormone
- ❖ Many different forms idoleactiv acid (IAA)
- ❖ Auxins → hormones that trigger elongation UPWARDS
  - o Plants direct its growth towards light and against gravity
  - o Tips of the stem
  - o Apical meristems axial direction
- ❖ Tip of the plant → auxins is found at high concentration
  - o conc. gradient decreases in the direction towards roots
  - o concentration gradient directs overall morphology
- ❖ continued auxin (upward) growth → prevention of lateral growth
  - o upwards axial growth suppression for lateral growth
- ❖ also important for
  - o positive phototactic behaviour in plants
    - ➔ grow towards light **phototropism**

Phototropism in seedlings

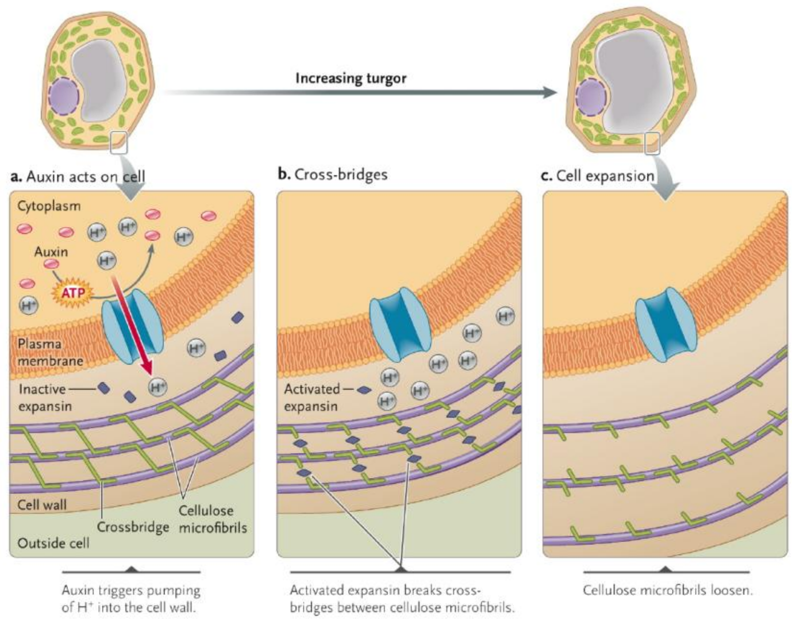
- from tip, move down the shaded side of the stem
- auxin is responsible for cell elongation
  - o increase their size by increasing the number of cells or elongation of cells
- shaded side with lots of auxin, will be elongating more rapidly and larger than on the sunny side
  - o difference in elongation will allow stem to "bend" towards light



b. Rays from the sun strike one side of a shoot tip.

c. Auxin (red) diffuses down from the shoot tip to cells on its shaded side.

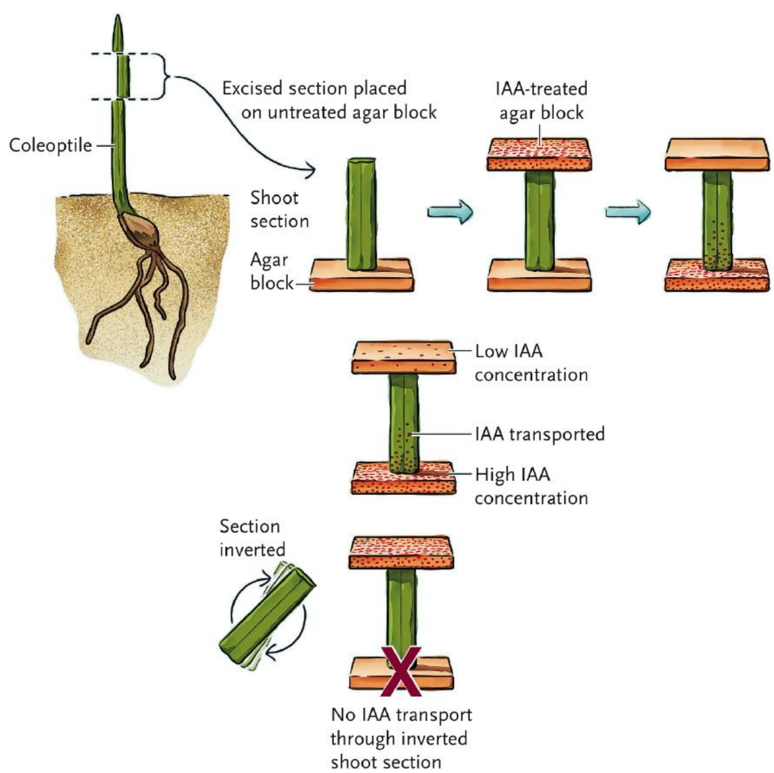
d. The auxin-stimulated cells elongate more quickly, causing the seedling to bend.



Cell Expansion: Acid-growth hypothesis

- active proton pump
- pH change
  - more acidic → activates expansion
    - by breaking cross bridges that links the cellulose microfibrils (makes up cell wall)
  - cellulose microfibrils → crystallized structure [tightly organized sugar molecules]
    - very inflexible
- connected by network of other molecules such as Hemicellulose
  - holds it together(cage) provides physical pressure that offsets water potential

Auxin Transport: Polar transport



- One way channel
- Helps maintain gradients
- Different concentration of auxins have different impact
- This slide shows that auxin, produced in the apical meristem at the tip of the shoots, travels down towards the root system. Furthermore, this transport is one-way: always away from the tip of the shoot. These images show how even if a section of stem is reversed, it will not transport IAA (an auxin) in the "wrong" direction.
  Polar transport is how plant establish and maintain an auxin gradient across their body

Auxin effects on stems

- Frequently promotes axial elongation of stems
- Maintains apical dominance
    - Inhibits growth of lateral meristems (branching)
- Promote fruit development → cell division
- Inhibit leaf abscission(단풍)
- ❖ Apical dominance (suppression of lateral growth) as well as elongation of the cells
- ❖ Auxin is extremely important when it comes to keeping plants young and stimulating new development
- ❖ Initiation of new flowers, new fruits, keeping the plant young by preventing senescence

Abscission Zone

- Structural decay at cell wall
- Abscission zone is located at the base of leaf where it joins the stem

Auxin Effect on Roots

- promote root initiation
- growth of pre-existing roots
- lateral branching of roots
- formation of adventitious roots
    - Except at very high concentrations
- ❖ Number of different plants
    - Initiation of new roots
    - Stimulates branching of lateral roots
    - Unexpected places on the stem
- ❖ Senesce and decay at high concentration
- ❖ Eudicots are far more sensitive to auxin than monocots
- ❖ Inhibit growth of eudicots but doesn't inhibit growth of monocots

Lateral Root Formation

- Root primordia in pericycle form lateral roots
- Start forming lateral roots

Clicker

1. The growth promoting substance that promotes stem elongation and bending towards light is produced primary in **shoot tip**
2. Environmental signals influence the distribution of an auxin in a plant by
    a. Causing auxin to migrate into the shaded portion of plant

Gibberellins

- GA_1 is most common
- Synthesized in shoot and root tips
- Increases cell division rate, and cell elongation
- ❖ Produced in the shoots; but also in the roots
- ❖ Involved in cell elongation
  - Unlike auxin, it also increases cell division rates
  - Increase in number and size of cells

Gibberellin effects

- Promote stem elongation
- "bolting"
  - Increases inter-node distance
- Fruit/Stem enlargement
- Helps seeds and buds break "dormancy"
- ❖ Large amounts of gibberellins → far more elongation between nodes (TALLER)
- ❖ Used extensively in agriculture to make foods more "delightful"
- ❖ Important when coming back from "dormant" season
- ❖ Gibberellins can mess with sex ratios sometimes

Broccoli and B. oleracea

- Suppression of flower development and selected against the trait made broccoli florets
- Q: Compared to ancestral, wild B. oleracea, I predict that it is likely that broccoli exhibits
  a. Less auxin production
  b. Less gibberellin production

Broccolini

- Hybrid of broccoli and kai-lan
- Easily hybridized
- Initially looks like broccoli… gets more elongated
  - Nodes are more separated from each other
  - More flower developed
- Q: how much auxin and gibberellin is expressed in broccolini
  - Less than b. oleracea and more than broccoli

Cabbage & b.o.

- Internode distance has been wildly shortened
- Q: compared to ancestral, b.o., I predict that it is likely that cabbage exhibit
  - Less gibberellin production

Brussel Sprouts & b.o.

- Compared to ancestral, b.o., I predict that increase lateral growth on brussel sprout plants is likely due to **less auxin**

Abscisic Acid (ABA)

- Synthesized in all plant parts
    - E.g. roots, flowers, leaves and stems
- Produced in response to environmental stress
    - Heat, water, salt, soil compaction
- Synthesized in green fruits at the beginning of the winter period
- Synthesized in maturing seeds, establishing bud dormancy
- ❖ Primarily thought to associated with leaves to fall off (name stuck: misnomer)
- ❖ Produced in response to environmental stress
- ❖ Tends to shut down metabolic activity

Guard Cells and ABA

- Mobile within the leaf and can be rapidly translocated from the roots to the leaves by the transpiration stream in the xylem
- Abscisic acid is produced
    - ion in high concentration around turgid
- Temperature drops or rain fall
- Extensively when there is long term of stress (winter coming)
- Period of time in which the plants need to be metabolically inactive
- Central cell, egg, developing the seed
    - Period of time without any metabolic activity
    - Metabolic dormancy activated by ABA

Breaking dormancy

- Requires exposure to sufficient period of low temperatures
    - Gibberellin and abscisic acid signals
- Gibberellins important for new developmental growth (Spring)
- Gibberellin helps break dormancy
    - ABA helps to usher in dormancy
- Signals are disrupted
    - Do not get proper development of "flower" in spring time
    - Cold ushered in helps spike in gibberellin come spring

Ethylene

- Gas at normal pressure/temperature
- Present in fruits, flowers, seeds, leaves, roots
- Promotes fruit ripening, senescence and abscission
- ❖ Simple chemical structure compared to other hormones
- ❖ Can be found in gaseous form
- ❖ Found in many parts of the plant
- ❖ Help mature → ripen fruit and leaves
- ❖ Usher in the phenomenon of senescence
    - Biological aging process and abscission of leaves
- ❖ Senescence goes through at the end of plant's life
    - Controlled plant death

Senescence

- Aging of living organisms
- Removal of seed pods in soy bean delays senescence since ethylene is not produced
- ❖ Plants can think that it is old or not
- ❖ Trick the plant to thinking that it is young → by removing source of ethylene (pods)
- ❖ Dousing plant with auxin → fountain of youth for plants
- ❖ Ethylene and auxin has antagonistic effects

Abscission zones & dehiscence

- Dehiscence → shed ripened grains
- Indehiscence → hold on to ripened grains i.e. rice
- ancestral may be dehiscence → shed ripened grains
- spike in ethylene when plant aging
- mutation → signal responses resulting in less sensitivity to ethylene leads to indehiscence
    - dousing them with auxin perhaps

Ethylene production & dehiscence

- ethylene production associated with maturation
- after a month between the bloom and the spike of ethylene (pollination, seeds/fruits forming)
    - off the branch by weakening the stem it is on
    - stalk to weaken, fruit falls off the tree
- i.e. old lanterns (releases ethylene) → trees around lanterns lost leaves early

Ethylene Promotes Horizontal growth

- stimulates horizontal growth
- expansion in the girth

Kale & b.o.

- starts to grow much later in the growing season
- continues to grow until late in the season
- Q: compared to ancestral, wild b.o., I predict that it is likely that kale exhibits
    - Less ABA and ethylene

Cytokinins

- Zeatin is most abundant natural cytokinin
- Synthesized mostly in **root tips**
    - Stimulate cell division
    - Promote leaf expansion
    - Promotes auxiliary bud formation
    - Inhibits leaf aging
- Involves cellular division auxin → elongation; gibberellin→ elongation & cell division
- Inhibits leaf aging
- Causes cells to divide and divide (just division, not cell growth)

Kohlrabi & b.o.

- Base of the plant is ingested
- Increase in density of tissue (not size of the cells)
- Very dense → usually needs to be cooked
- Q: compared to ancestral, wild b.o., I predict that it is likely that kohlrabi exhibit
    - **more cytokinins**

Auxin: Cytokinin variation growth of roots and shoots

- interaction between
- in combination they regulate overall patterns of both roots and shoots
    - two hormones off balance → inclusive growth in one way but not the other

	Cytokinin absent	Cytokinin present
Auxin present	Primarily ROOT GROWTH	Undifferentiated growth Callus → unorganized cell masses
Auxin absent	Control group	Primarily SHOOT GROWTH

Cauliflower & b.o.

- Cluster of flowers
- Dense underdeveloped flowers (florets)
- Q: compared to ancestral, wild b.o., I predict that it is likely that Cauliflower exhibit
    - More cytokinin but less auxin
    - Auxin stimulates flower development, therefore low level of auxin in cauliflower

Brassinosteroids

- Group of steroid hormones
- Highest concentrations in shoot tips and developing seeds and embryos
- Stimulate cell diision and elongation
    - Differentiation of vascular tissue
    - Inhibits root elongation
    - Necessary for pollen elongation for pollen tube formation
    - Acceleration of senescence

Jasmonates

- JA derived from fatty acids
- Signalling roles → with microorganisms
- Regulate growth → inhibits root growth
- Stimulate the germination of dormant seeds and inhibits germination of nondormant seeds
- Trigger of defence responses

Plants and Chemical Defences

- Plants have been constantly exposed to predation and pathogens
- Plants don't have immune systems like those evolved in animal, but selection over time has resulted in the production of chemical defences
    - Prevent or mediate damage to plant tissues from infectious bacteria, fungi, worms, or plant-eating insects

Hypersensitive Response

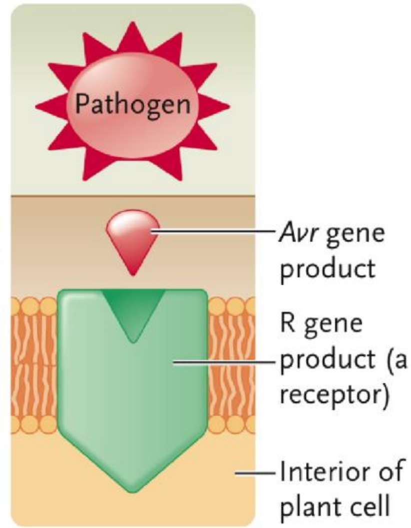
- Isolates an infection site by surrounding it with dead cells
- Salicylic acid (SA) induces synthesis of pathogenesis-related (PR) proteins

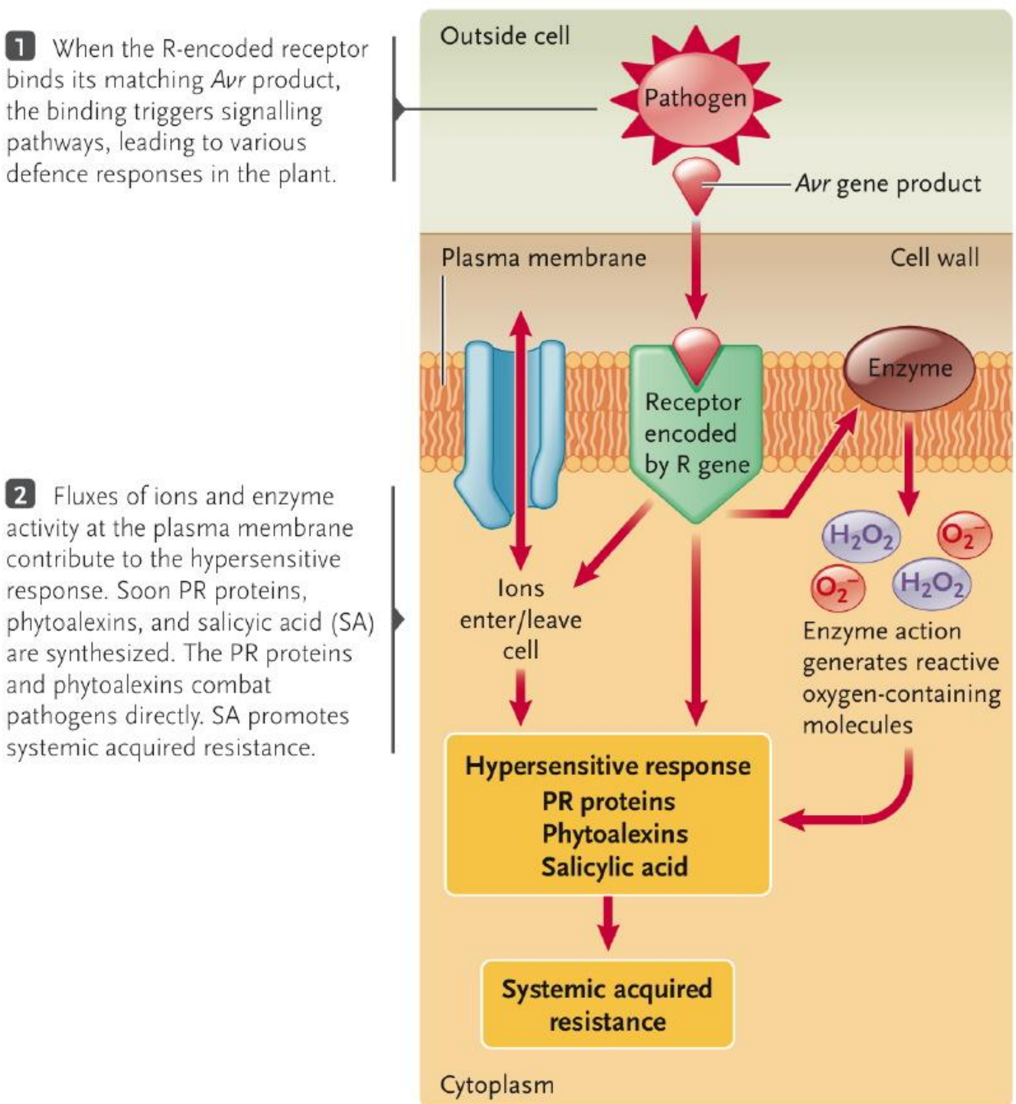
Secondary Metabolites

- Defend against pathogens and herbivores
- Plants counter bacteria and fungi by making phytoalexins
- Function as antibiotics
- Other examples of secondary metabolites:
    - Caffeine, cocaine, strychnine
    - Tannins
    - Terpenes → conifer resins, essential oils

Gene-for-gene recognition

- Enables plant to recognize pathogen chemically and mount defences against it
- Matchup between products of dominant alleles of two types of genes
    - Plant's **R gene**
    - Pathogen's **Avr gene**
- Required precondition
    - A plant has a dominant R gene encoding a receptor that can bind the product of a specific pathogen dominant Avr gene

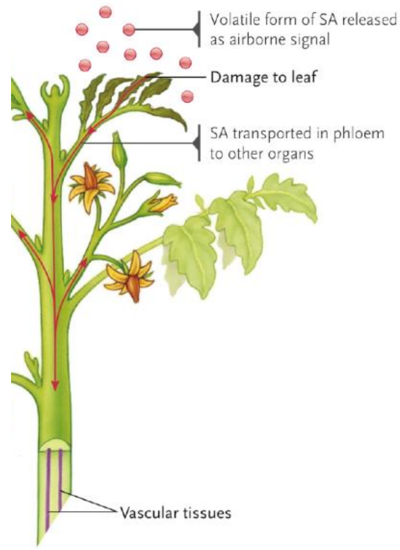




BI 111
Plant Growth and Development

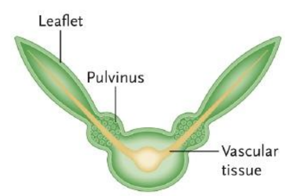
Systematic Acquired Resistance

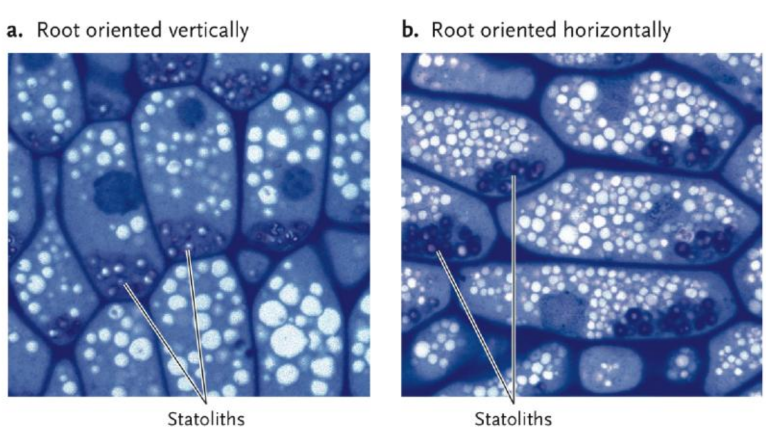
- Provides long-term protection against some pathogens
- Salicylic acid passes from infected organ to newly forming organs such as leaves, which hen synthesize PR proteins

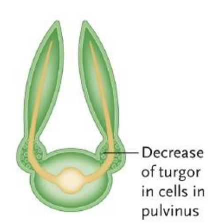


Plant responses to the Environment: Movements

- Phototropism
  - o responses to light
  - o growth responses to directional light source
  - o Blue light receptors trigger auxin transport
  - o Auxin triggers differential cell elongation
- Gravitropism
  - o orients plant parts to the pull of gravity
  - o Growth response to Earth's gravitational pull
    - ▪ Statoliths (modified plasmids) move in response to gravity
- Thigmotropism and thigmomorphogenesis
  - o responses to physical contact
  - o thigmotropism → growth in response to contact with a solid object
  - o thigmomorphogenesis
    - ▪ mechanical stress causes the stem to add girth
    - ▪ caused by frequent strong winds, rainstorms, grazing animals
- Nastic movements
  - o nondirectional
  - o Reversible responses to nondirectional stimuli
  - o Movement in leaves, leaflets, flowers
  - o Sensitive plant → *mimosa pudica*
  - o Mechanical stimulation triggers a membrane action potential
  - o Water then enters or exits cells of pulvinus, triggering leaf folding







Circadian Rhythms

- Biological clocks
  - Internal time-measuring mechanisms with a biochemical basis
  - Adapt organism to recurring environmental changes
- Circadian rhythms
  - 24 hours cycles, even when environmental conditions remain constant
  - Regulated by a biological clock and helps ensure that of single species do same thing
- Environmental cues can "reset" clocks
  - Enables seasonal adjustments in growth, development and reproduction

Photoperiodism

- Responses to change in relative length of daylight and darkness
- Also allows biological clock to be "reset" for seasonal adjustments to day length
- Controlled by phytochrome pigment

Phytochrome

- Blue-green pigment
- Converts to active form (P_{fr}) during daylight, when red wavelengths dominante
- Reverts to inactive form (P_r) at sunset, at night, or in shade, when far-red wavelengths predominante
- P_{fr} controls types of enzymes produced in particular cell
  - Seed germination
  - Stem slongation
  - Leaf expansion
  - Formation of flowers, fruits, seeds
- Phytochrome used to sense long nights of autumn in preparation for dormancy

Flowering Responses

- Long-day plants
  - Flower in spring or summer, when day length is long relative to night
- Short-day plants
  - Flower in late summer or autumn, when day length is relatively short
- Intermediate-day plants
  - In between long and short day plants
- Day-neutral plants
  - Flowering not affected by photoperiod