Plants … Insects …
and the Changing Environment

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McGill

Plants … Insects …
and the Changing Environment

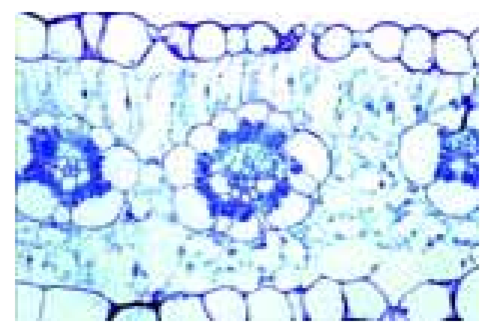
Plants

Insects

Climate Change

C3
Helicotropium tenellum

C4
H. polyphyllum



Muhaidat *et al* (2007) Am J Bot 94: 362

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Monocots Dicots

Plants

Insects

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Insects

Deciduous Gymnosperms

Climate Change

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Insects

Herbivores

Pollinators

Climate Change

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Phloem feeders
- aphids
- whiteflys

Chewers
- caterpillars
- beetles

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Plants

Insects

Specialists Generalists

Climate Change

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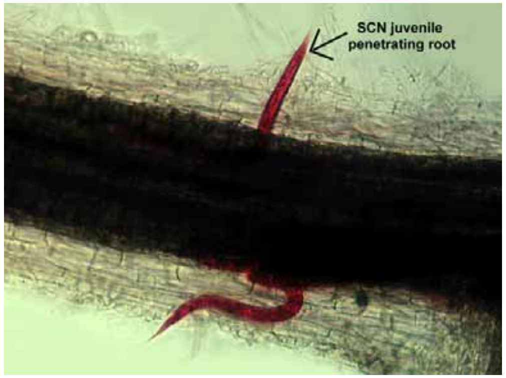
Insects

Figure 4. Mature *Disholcaspis* larva within spherical gall in November. Brown mantle color indicates gall growth has stopped.



Gall-feeders Leaf miners Nematodes

Climate Change

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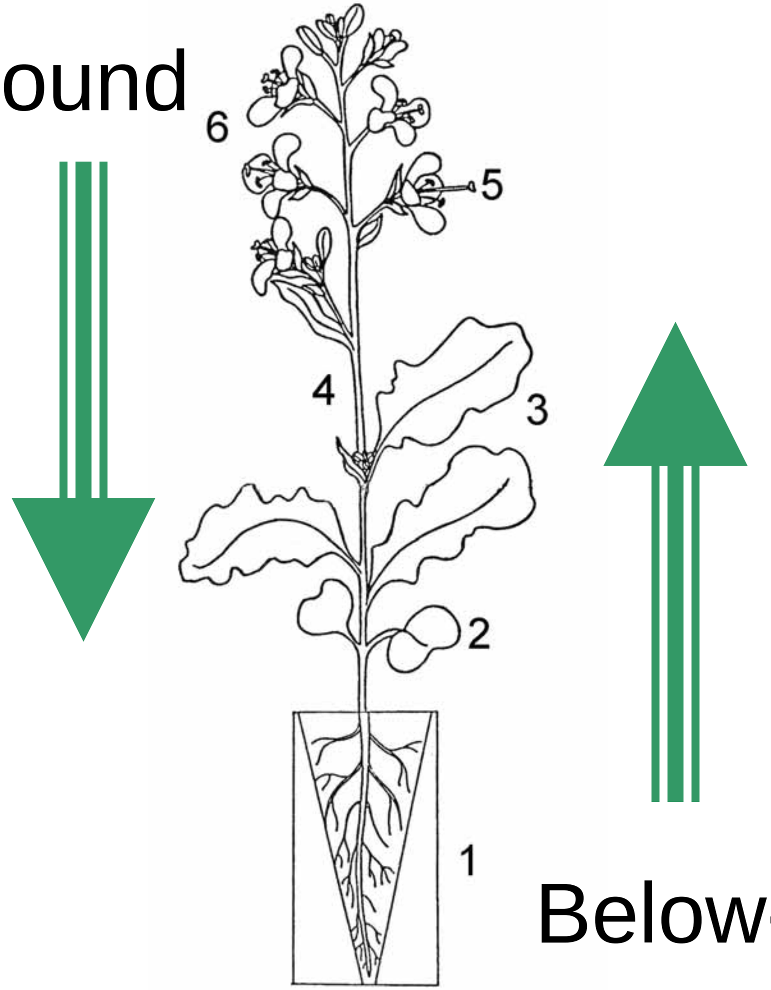
Plants

Above-ground



Insects

Climate Change

Below-ground

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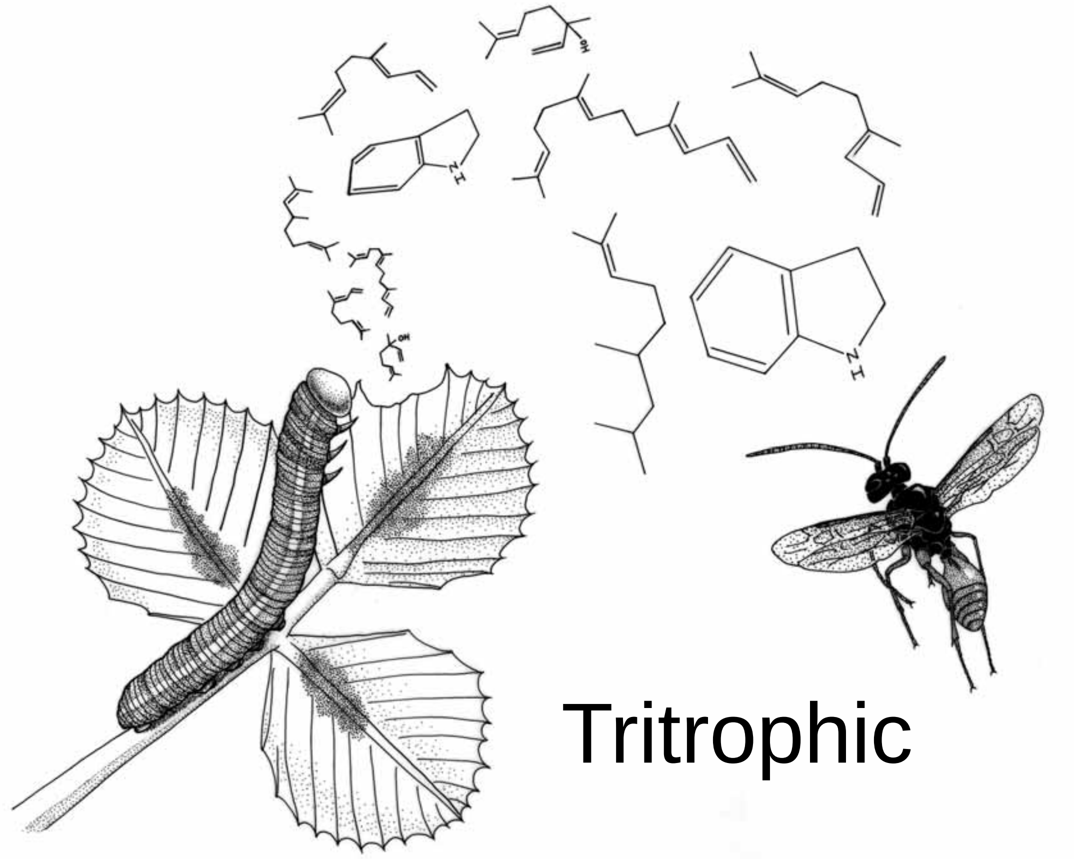
Insects

Climate Change



Tritrophic

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Plants

Insects

CO_2

Water use efficiency

Climate Change

Nitrogen use efficiency

Climate, RH, weather patterns

Plants … Insects … and the Changing Environment

- Plant (agricultural crop, C3)
- Caterpillar herbivory
- Elevated CO_2 levels

How do you think elevated CO_2 levels will impact plant defenses ?

Structural defenses

Structural defenses

- Waxes
- Trichomes
- Toughness (fiber, silica)

Toughness

- Comparison of C_3 and C_4 grasses
- Fiber (cellulose, hemicellulose, lignin)
- Toughness: mass needed to punch a hole in the leaf
- Leaf toughness strongly correlated to fiber content
- Ambient CO_2 (340 ppm): C_4 > C_3 grasses
- Elevated CO_2 (740 ppm):

  C_4 grasses: no effect

  C_3 grasses: toughness and fiber increase

  however, average C_4 plant levels still higher

Barbehenn et al (2005) GCB 10: 1565

Toughness

- Herbivores: *Spodoptera frugiperda* (generalist) and *Pseudaletia unipuncta* (specialist)
- C4 grasses (ambient and elevated CO_2) poor diets compared to C3 grasses
- caterpillars did not eat less on ambient vs elevated CO_2 grown plants; however, plants grown at elevated CO_2 levels were less digestible to *S. frugiperda* caterpillars.

Barbehenn et al (2004) Oecologia 140: 86-9

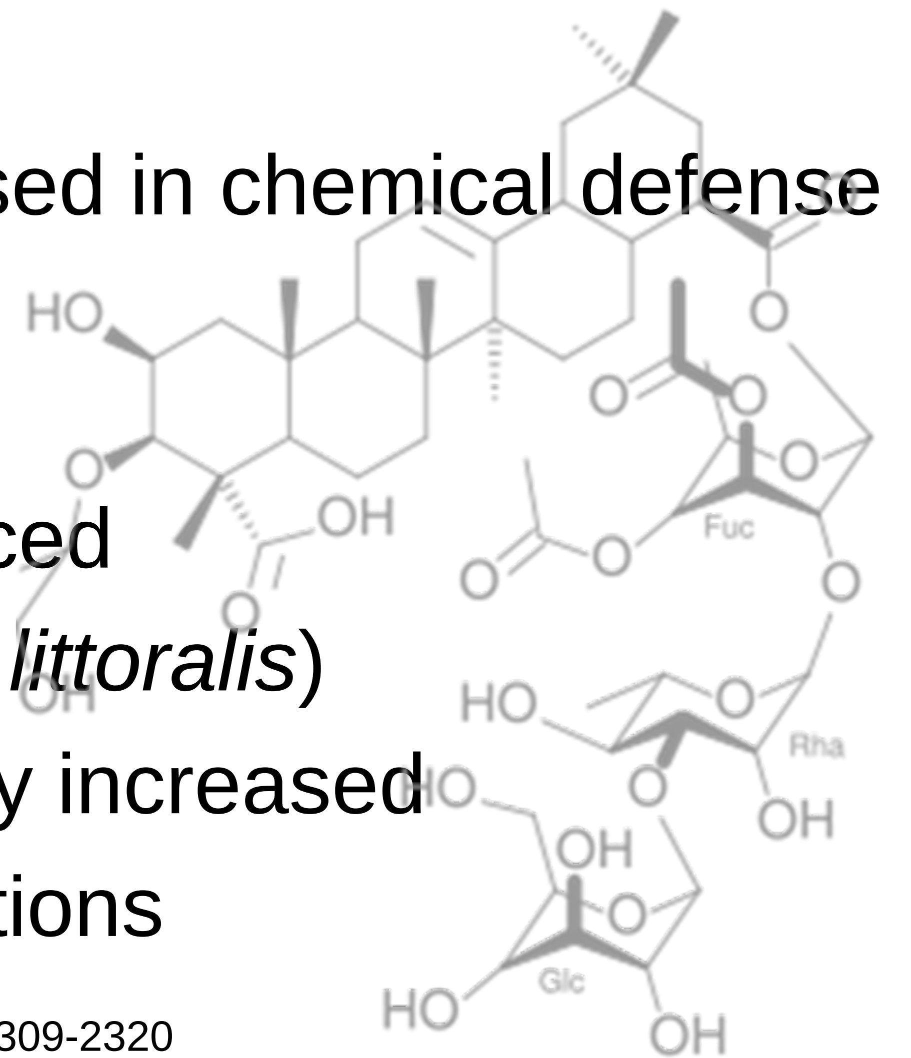
Chemical defenses

Chemical defenses

- Phenolics (C, H, O)
- Terpenoids (C, H, O)
- Alkaloids (C, H, O, N)
- Glucosinolates (C, H, O, S)
- Cyanogenic glycosides (C, H, O)
- etc.

C-based chemical defenses: saponins

- Elevated CO_2:
  - – Extra C that can be used in chemical defense



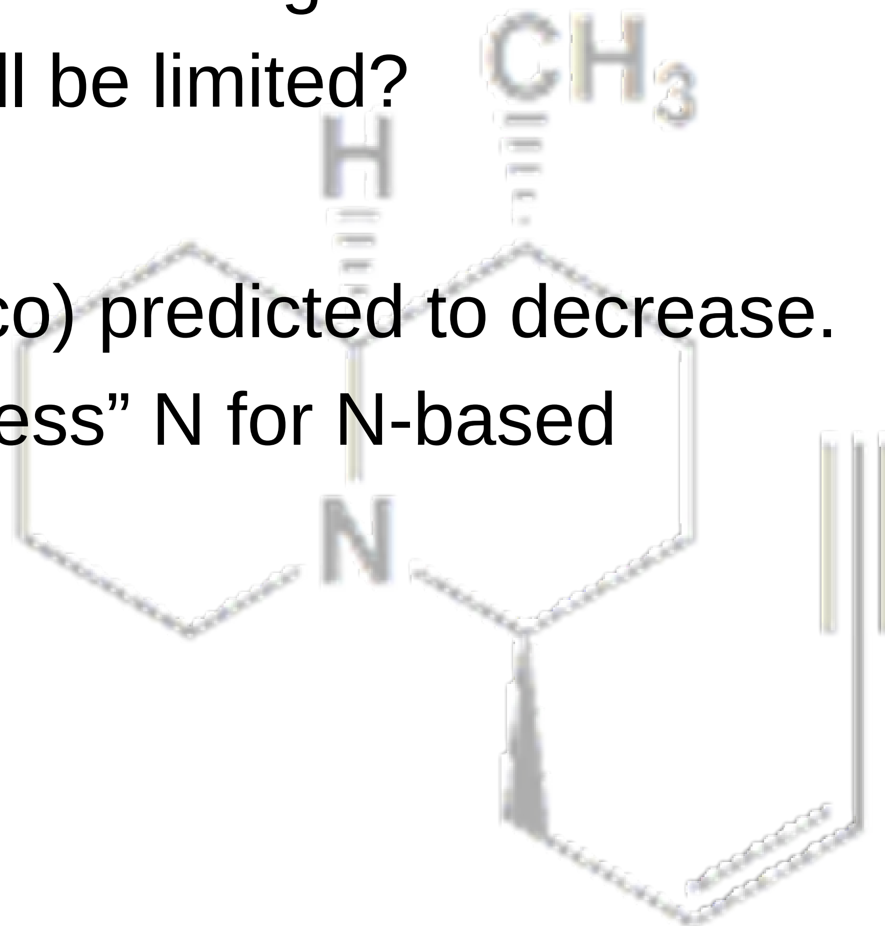
- Alfalfa saponin levels:

both constitutive and induced
by caterpillar (*Spodoptera littoralis*)
herbivory were significantly increased
under elevated CO_2 conditions

Agrell et al (2004) Journal of Chemical Ecology 30:2309-2320

N-based chemical defenses: Alkaloids

- Elevated CO_2:
  - Often results in an increased growth rate.
  - Does this mean N will be limited?
- Acclimation:
  - Plant N levels (rubisco) predicted to decrease.
  - Does this mean “excess” N for N-based defenses ?



Chemical defenses: Alkaloids

- Ambient (378 ppm) vs elevated (690 ppm) CO_2

	Tobacco	Jimson weed
Biomass	↑ ↑ ↑	↑
Alkaloid (mg/g DW)	nicotine ↓	Atropine: NC Scopolamine: ↑

Ziska (2005) Global Change Biology 11: 1798

Chemical defenses: Alkaloids

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- Unfortunately: did NOT challenge with caterpillars

Ziska (2005) Global Change Biology 11: 1798

N-based defenses: proteins

- Proteinase inhibitor:
  - Plant protein which interferes with the ability of insect digestive enzymes, such as trypsin, to breakdown proteins
  - Induced plant defense

Wound-induced pathways

Wounding/herbivory

↓

OGAs, electrical, hydraulic

↓

Octadecanoid-dependent responses (ie JA)

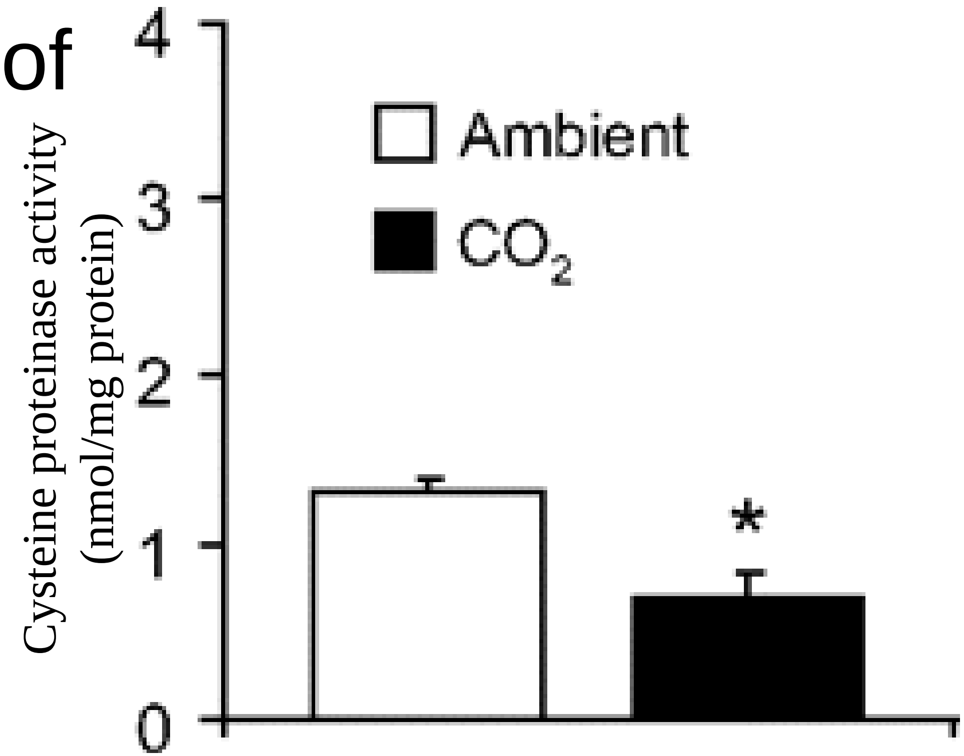
↓

Proteinase inhibitor, lipoxygenase,
1-aminocycloproane-1-carboxylate synthase

Induced resistance (IR) pathway

N-based defenses: induced proteinase inhibitor

- Beetle herbivory (Japanese beetle)
- Soybean grown in a FACE experiment
- 3d after initiation of herbivory



Zavala et al (2008) PNAS 105: 5129

Chemical defenses: octadecanoid pathway

- Typical octadecanoid-dependent genes related to defense signaling (lipoxygenase and 1-aminocyclopropane-1-carboxylate synthase (ACCS)) had lower induced levels when plants were grown at elevated CO_2.
- Implies that plants may be less able to mount defense responses when grown under conditions of elevated CO_2.

Nutritional quality

Nutritional quality

Plant chemical defenses pose a formidable obstacle to insect herbivores in “evolutionary time” but once that defense is breeched, plant nutritional quality plays a critical role in “ecological time”

- Paul Feeny

Caterpillar herbivores

- Protein: growth and development
- Carbon: lipids for oviposition

Plants as a food ?

Protein-poor
Carbohydrate-rich

Plant strategies to interfere with protein intake

- Proteinase inhibitor interferes with the ability of insect digestive enzymes, such as trypsin, to breakdown proteins
- Arginase and threonine deaminase degrade essential amino acids to avoid absorption
- Laccase (polyphenol oxidases) catalyzes the conversion of plant phenolics to reactive quinones which bind to proteins in the caterpillar gut to prevent their absorption.

Elevated CO_2

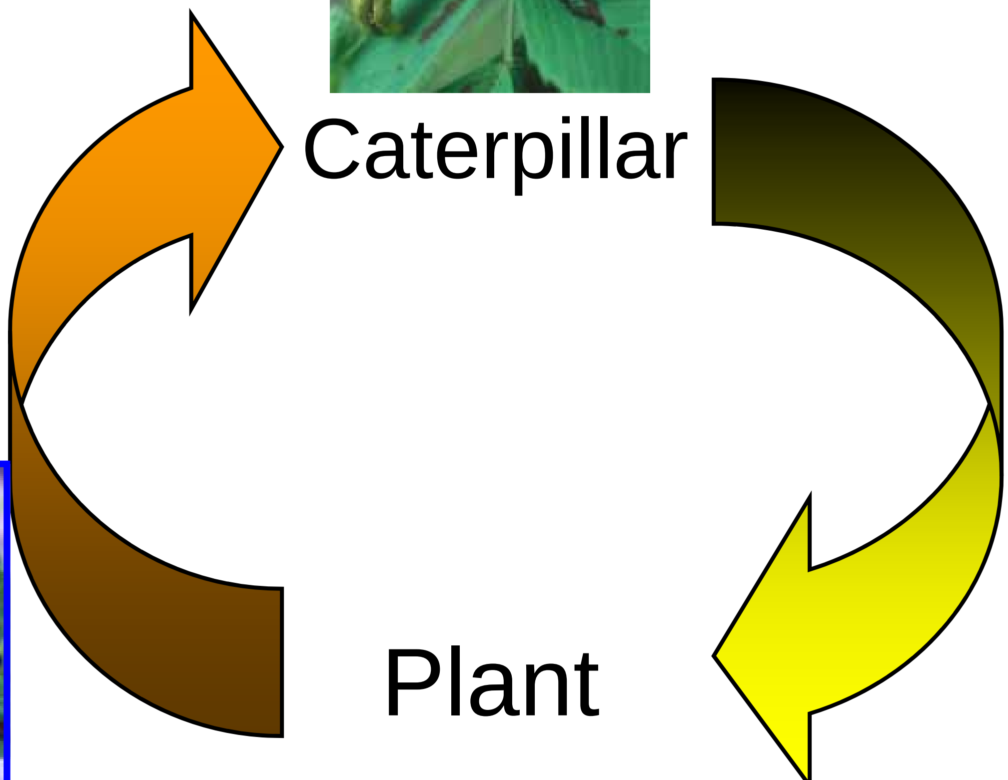
- Initially: increased growth rate
- Acclimation: decrease in rubisco levels
- Increase in the C:N ratio of plant tissues reducing nutritional quality

Some insect species eat more
to obtain sufficient N

Japanese beetles increase leaf damage to soybean plants grown under elevated CO_2 (FACE)

DeLucia et al (2008) PNAS 105: 1781-1782

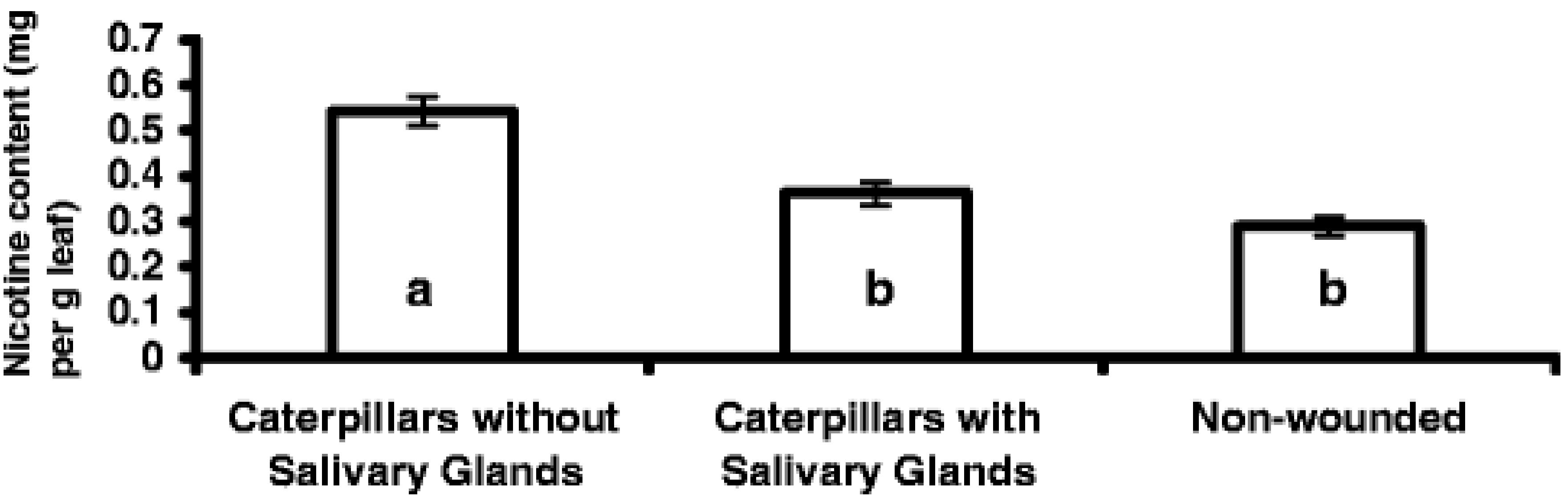
Model



- Atmospheric CO_2

Caterpillar labial saliva contains elicitors which prevent the plant from mounting defense responses

- Tobacco
- *Helicoverpa zea* caterpillars with or without salivary secretions



Musser et al (2006) J Chem Ecol 32: 981-992

Caterpillar salivary elicitors: glucose oxidase (GOX)

GOX catalyzes the conversion of glucose to gluconate and hydrogen peroxide (H_2O_2).

- Oxygen utilization: lowers reactivity of plant compounds (ie quinones) in the gut of the caterpillar
- H_2O_2: antimicrobial agent
- H_2O_2 (a signaling molecule) interferes with plant defense responses
- GOX is a mechanism for the caterpillar to pre-ingestively metabolize excess carbohydrates in it's diet

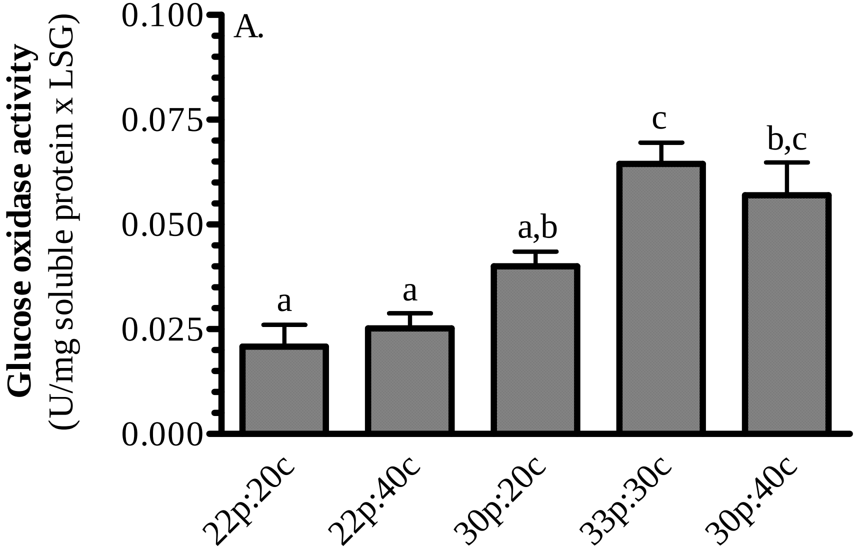
Eichenseer et al (1999) Arch Insect Biochem Physiol 42: 99-109
Musser et al (2002) Nature 416: 599-600
Lui et al (2004) J Chem Ecol 30: 2439-2457
Bede et al (2006) Peptides 28: 185-196

Caterpillar salivary elicitors (ie GOX) can interfere with the plant’s ability to mount defense responses

Caterpillar salivary GOX depends on the nutritional quality of the diet the caterpillar is feeding on

- Merkx-Jacques et al (2005) Journal of Insect Science 5:48

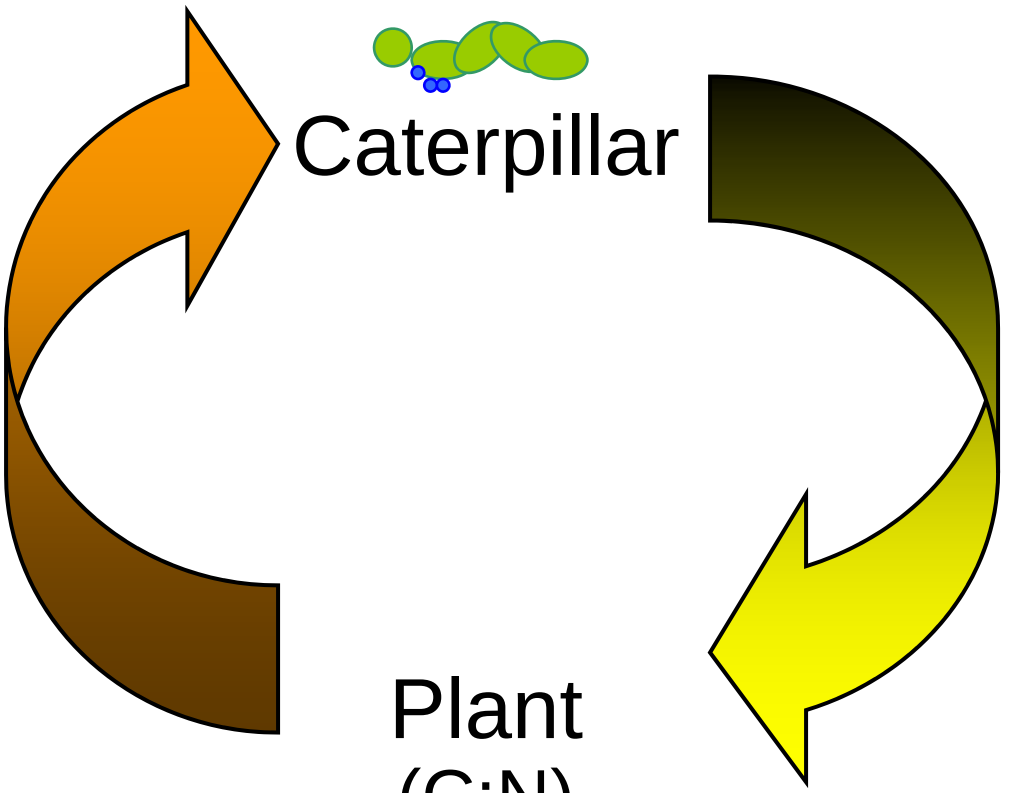
Caterpillar salivary elicitors are diet-dependent



Both P and C are important

- Need sufficient dietary P for growth and development
- As dietary C levels increase glucose oxidase increases

What does this mean for the plant?



- Atmospheric CO_2
- Fertilizer

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