Topic 09

Plant Secondary Metabolites

Reading p. 184, 474-475

Bring pre-washed white t-shirt to lab next week!

I. Plant Secondary Metabolites

A. Definitions

1) Secondary Metabolism-

1a) Metabolite-

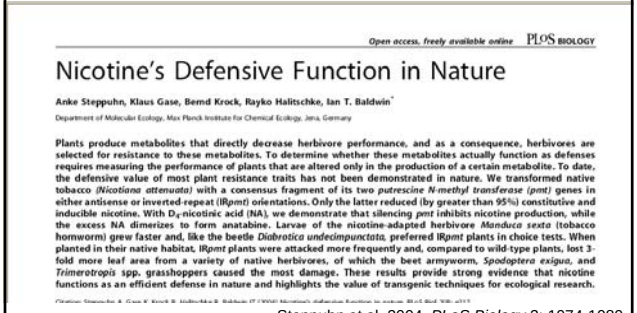
I. Plant Secondary Metabolites

B. Examples

Compound	Example Source	Human Use
ALKALOIDS		
Codeine	Opium poppy	Narcotic pain relief; cough suppressant
Nicotine	Tobacco	Narcotic; stimulant
Quinine	Quinine tree	Used to treat malaria; tonic
Cocaine	Coca	Narcotic, tea, anesthetic, stimulant
PHENOLICS		
Lignin	Woody plants	Hardwood furniture & baseball bats
Tannin	Leaves, bark, acorns	Leather tanning, astringents
Salicin	Willows	Aspirin precursor
Tetrahydrocannabinol	Cannabis	Treatment for glaucoma & nausea
TERPENOIDS		
Camphor	Camphor tree	Component of medicinal oils, disinfectants
Menthol	Mints & eucalyptus	Strong aroma; cough medicines

I. Plant Secondary Metabolites

C. Ecology



Open access, freely available online PLoS BIOLOGY

Nicotine's Defensive Function in Nature

Anke Steppuhn, Klaus Gase, Bernd Krock, Rayko Halitschke, Ian T. Baldwin*

Department of Molecular Ecology, Max Planck Institute For Chemical Ecology, Jena, Germany

Plants produce metabolites that directly decrease herbivore performance, and as a consequence, herbivores are selected for resistance to these metabolites. To determine whether these metabolites actually function as defenses requires measuring the performance of plants that are altered only in the production of a certain metabolite. To date, the defensive value of most plant resistance traits has not been demonstrated in nature. We transformed native tobacco (*Nicotiana attenuata*) with a consensus fragment of its two *putrescine N-methyl transferase* (*pmt*) genes in either antisense or inverted-repeat (IR*pmt*) orientations. Only the latter reduced (by greater than 95%) constitutive and inducible nicotine. With D_4-nicotinic acid (NA), we demonstrate that silencing *pmt* inhibits nicotine production, while the excess NA dimerizes to form anatabine. Larvae of the nicotine-adapted herbivore *Manduca sexta* (tobacco hornworm) grew faster and, like the beetle *Diabrotica undecimpunctata*, preferred IR*pmt* plants in choice tests. When planted in their native habitat, IR*pmt* plants were attacked more frequently and, compared to wild-type plants, lost 3-fold more leaf area from a variety of native herbivores, of which the beet armyworm, *Spodoptera exigua*, and *Trimerotropis* spp. grasshoppers caused the most damage. These results provide strong evidence that nicotine functions as an efficient defense in nature and highlights the value of transgenic techniques for ecological research.

Steppuhn et al. 2004. *PLoS Biology* 2: 1074-1080.

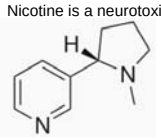
I. Plant Secondary Metabolites

C. Ecology

Nicotine negatively affects function of herbivores.

Tobacco (*Nicotiana tabacum*)

Nicotine is a neurotoxin.



Nicotine is made in roots and transported to shoots via xylem.

Tobacco (*Nicotiana tabacum*)

Most potential herbivores cannot deal with nicotine.

The tobacco hornworm (a moth larva) can sequester and secrete nicotine, with some energetic cost.

An Ecologically Motivated Analysis of Plant-Herbivore Interactions in Native Tobacco[1]

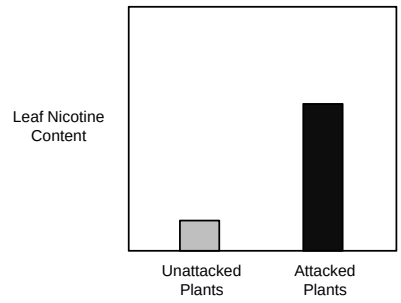
Ian T. Baldwin*

Department of Molecular Ecology, Max Planck Institute for Chemical Ecology, Carl Zeiss Promenade 10, D–07745 Jena, Germany

You can't always get what you want, but if you try some time, you just might find, you get what you need. . .
Mick Jagger

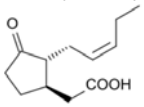
Unfortunately, a comprehensive understanding of internal processes is not sufficient to test the cost-benefit paradigm, because Darwinian fitness can also be influenced by processes external to the plant (Fig.

Baldwin, IT. 2001. *Plant Physiology* 127: 1449-1458.



Mechanism

1. Herbivory induces jasmonic acid (JA) production.



2. JA to roots, stimulates nicotine synthesis.

3. Nicotine to shoots

I. Plant Secondary Metabolites

C. Ecology

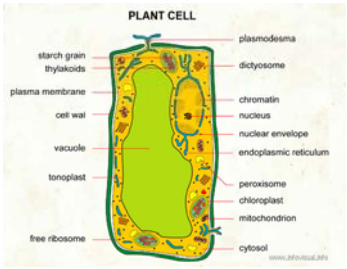
I. Plant Secondary Metabolites

C. Ecology

Jasminum

I. Plant Secondary Metabolites

D. Storage



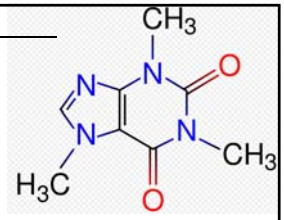
II. Caffeine case study

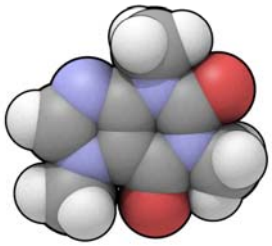
Caffeine

-*Coffea, Theobroma, Camelia, Cola,* etc.

-Psychoactive stimulant, diuretic

-Alkaloid





II. Caffeine case study

Caffeine

-syn. w/ guarinine

Species: *Paullinia cupana* (guarana' vine)
Family: Sapindaceae
Nativity: S. America

II. Caffeine case study

Caffeine

-syn. w/ theine

Species: *Camelia sinensis* (tea bush)
Family: Theaceae
Nativity: S. Asia

II. Caffeine case study

Caffeine

-syn. w/ mateine

Species: *Ilex paraguariensis* (yerba mate)
Family: Aquifoliaceae
Nativity: S. America.

II. Caffeine case study

Caffeine

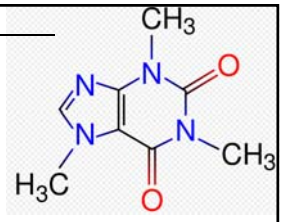
-known as caffeine (orig. *kaffein*, from German *kaffee*)

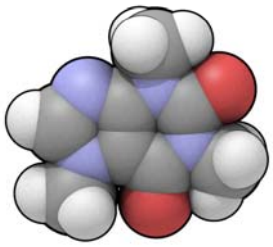
Species: *Coffea arabica* (arabica coffee)
Family: Rubiaceae.
Nativity: NE Africa.

II. Caffeine case study

Alkaloids in general

- Secondary metabolites
- Nitrogenous
- Psychoactive (act on CNS)

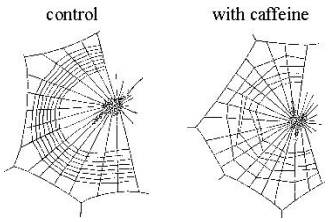




II. Caffeine case study

Ecological role of alkaloids

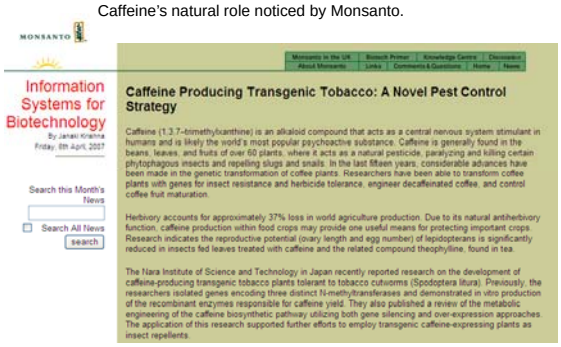
Spider web manufacture when influenced by caffeine.



II. Caffeine case study

Ecological role of alkaloids

Caffeine's natural role noticed by Monsanto.



www.monsanto.co.uk

II. Caffeine case study

Ecological role of alkaloids

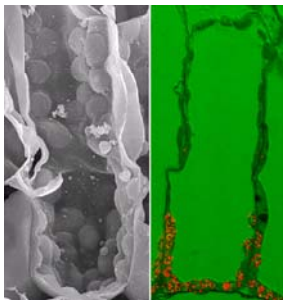
Nitrogen availability is a major limiting factor in plant growth.

II. Caffeine case study

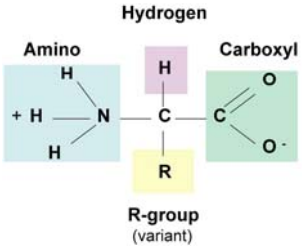
Ecological role of alkaloids

Proteins (which drive biological reactions) require large amounts of N.

*Proteins drive life processes (e.g., RuBisCO) and are important structural elements.



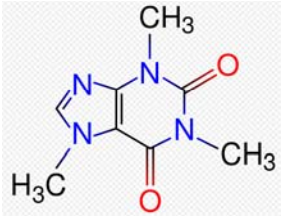
*Amino acid structure



II. Caffeine case study

Ecological role of alkaloids

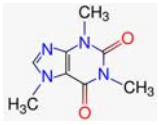
*Classic alkaloid composition exemplified by caffeine



Caffeine 's effects on CNS

•Caffeine from coffee in blood w/in 5 min
•Stimulates heart
•Increases stomach acidity
•Increases urine output
•10% rise in metabolic rate

•Mimics feelings assoc. w/ adrenaline



caffeine

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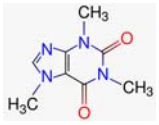

caffeine

•Excess (1 g; 10 cups) can cause anxiety, headache, dizziness, insomnia, heart palpitations, delirium, 4% lower birth weights.

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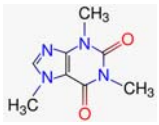


caffeine

•Excess (1 g; 10 cups) can cause anxiety, headache, dizziness, insomnia, heart palpitations, delirium, 4% lower birth weights.

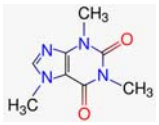
•Ranks as most widely used psychoactive drug worldwide (coffee, tea, additives to soft drinks)

Caffeine 's effects on CNS

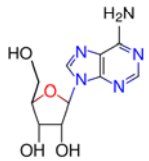
How?

Antagonist of adenosine.

Adenosine:
- Attaches to brain cell receptors.
- Neurotransmitter inhibitor.
- Promotes sleep
  (accumulates in brain each waking hour).
- Suppresses arousal.



caffeine



adenosine

Caffeine and Parkinson's prevention?

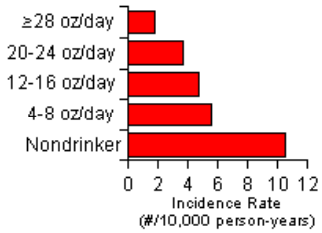
What is Parkinson's Disease?
Journal of the American Medical Association, March 24, 2000

•afflicts ca. 1-1.5 million people in the U.S., mostly 60 years +
•no known cause and no cure, just treatments
•symptoms of trembling arms and legs, trouble speaking, and difficulty coordinating movement

•neuron degeneration in spec. part of brain
•many of these neurons contained the neurotransmitter dopamine
•dopamine levels fall, and the balance between dopamine and other neurotransmitters disrupted, affecting muscular control

Caffeine and Parkinson's prevention?

Honolulu Heart Program study of 8,000+ men over 30?

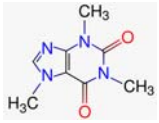


Mechanism: When adenosine receptors are blocked, dopamine levels increase.

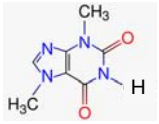
Caffeine and Theobromine are similar in structure and action

Table 1. Stimulant alkaloids in world's major stimulating beverages (Simpson 1986). Given in % weight. Amt. in particular beverage depends on how it is made.

Plant, part	Caffeine	Theobromine
Coffee, unroasted, dried seeds	1-1.5	--
tea, dried lvs.	2.5-4.5	--
Cacao, dried or fresh seeds	0.6-0.8	1.7-2.4
Kola, fresh seeds	2.0	--
Guarana, dried fruit	3.0-4.5	--



caffeine

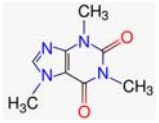


theobromine

Caffeine in some beverages

Table 2. Caffeine quantities in select beverages.

Drink	Caffeine (mg)
Coffee	
5 oz Drip, percolator, instant, decaf	146, 110, 53, 2
1 oz espresso	**?**

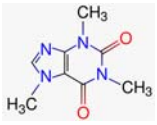


caffeine

Caffeine in some beverages

Table 2. Caffeine quantities in select beverages.

Drink	Caffeine (mg)
Coffee	
5 oz Drip, percolator, instant, decaf	146, 110, 53, 2
1 oz espresso	**50**



caffeine

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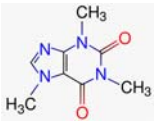
Drink	Caffeine (mg)
Coffee	
5 oz Drip, percolator, instant, decaf	146, 110, 53, 2
1 oz espresso	50
Tea (5 oz)	
Brewed 1 min, 3-5; 12 oz can	9-33, 20-50, 22-36
Cocoa and chocolate	
6 oz, from powder	10
1 oz milk choc	6
1 oz dark choc	20
1 oz baking choc	35
Soda (12 oz)	
Mt. Dew	52
Dr. Pepper	37-38
Pepsi	37
Coca cola	34



caffeine

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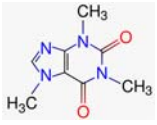


caffeine

III. *Coffea*

Coffee intro

Coffee is world's second most traded commodity.

Table 3. Production of top 3 stimulant beverages.

Top 3 continents	Total (MT)
Coffee	5,919
1. S Amer	
2. Africa	
3. N & C Amer	
Tea	2,473
1. Asia	
2. Africa	
3. S Amer	
Cocoa	2,329
1. Africa	
2. S Amer	
3. Asia	

Coffea arabica (arabica coffee)

III. *Coffea*

Coffee breeding

Coffee Biotech Group (Campinas, Brazil)

III. *Coffea*

Coffea berries and flowers

III. *Coffea*

Coffea berries and flowers

III. *Coffea*

Coffea seeds

III. *Coffea*

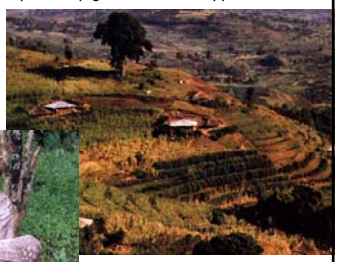
Coffea seeds

III. *Coffea*

Coffee origins

Coffea arabica, old world tropical/subtropical crop grown at mid to upper-middle elevations

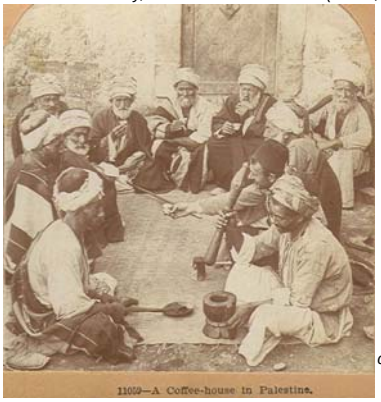
- Relatively few Africans drink it.
- Traditionally chewed leaves & fruits.
- Relief of fatigue, hunger on hunts.



Farmer in Ethiopia

Coffee (the drink) developed in Yemen

Arrival in Yemen 13-14 century, where it was first brewed (hence, Coffea arabica).



ca. 1900

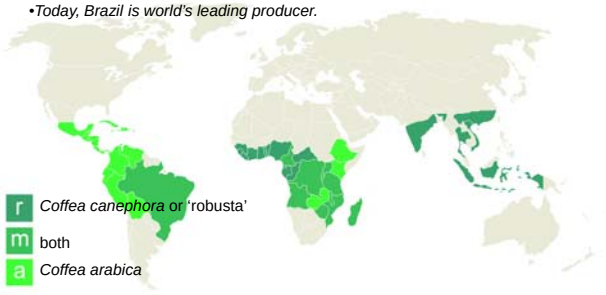
Coffee timeline

1. *First brewed in Yemen 13-14 century (hence, Coffea arabica).*
2. Arabia to Egypt by 1510.
3. To Italy & Europe by 1616.
4. Vienna priests threatened by "coffee culture", but Pope Clement VIII would not ban coffee.
5. To England by 1650 and coffee houses became important socio-politico institutions.
6. Europe looked to break Arabian monopoly on production.

   (*Arabians killed embryos in seeds before export*).

Spread of Coffee production

- *Dutch obtained live seeds from Mocha (Red Sea Coast, Yemen, 1706)*
- *Throughout Dutch colonies in Indonesia (e.g., Java) and to S America by 1717.*
- *Today, Brazil is world's leading producer.*



r *Coffea canephora* or 'robusta'

m both

a *Coffea arabica*