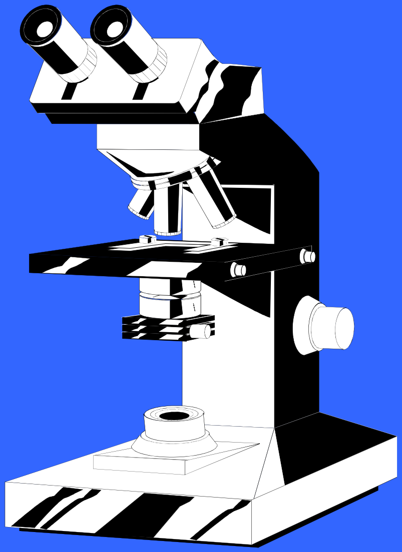
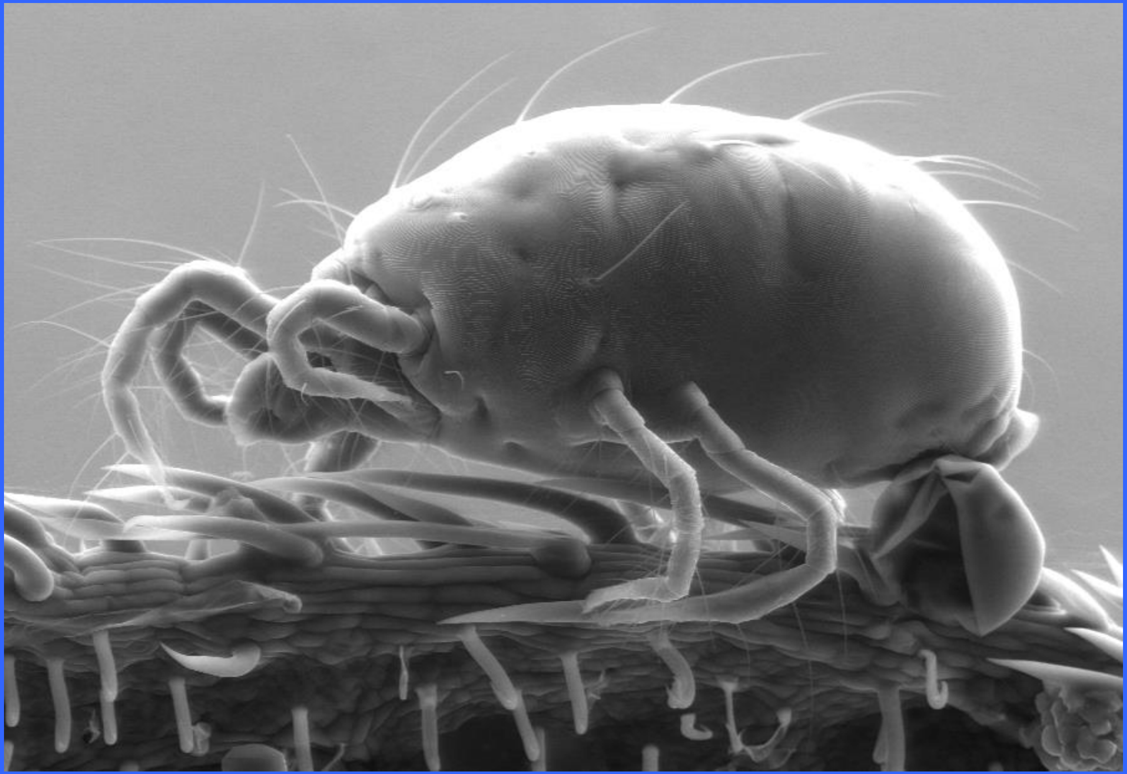
Spider Mites





Dr. Doug Walsh, Acarologist

Department of Entomology

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History

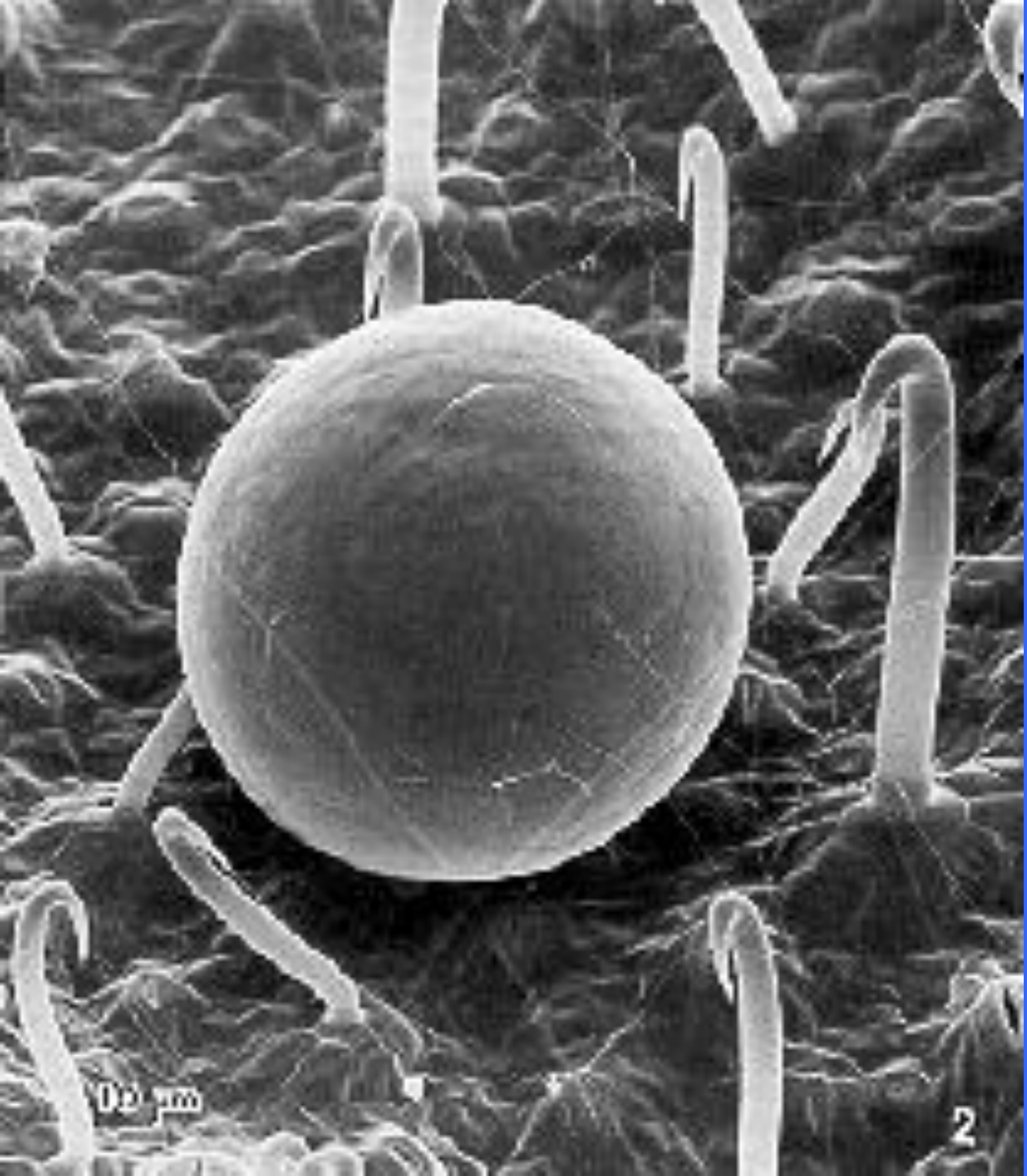
- Spider mite outbreaks were uncommon in situations where productivity was low.
- Mite populations stayed low due to natural regulation by predators, disease, and poor nutrition from low-quality host plants.

Modern factors that promote spider mite outbreaks

- **Biological disruption from use of fertilizers and pesticides.**

Good nutrition speeds the developmental rate, increases the fecundity, and lengthens the lifespan of mites.


Egg
Male two-spotted mite

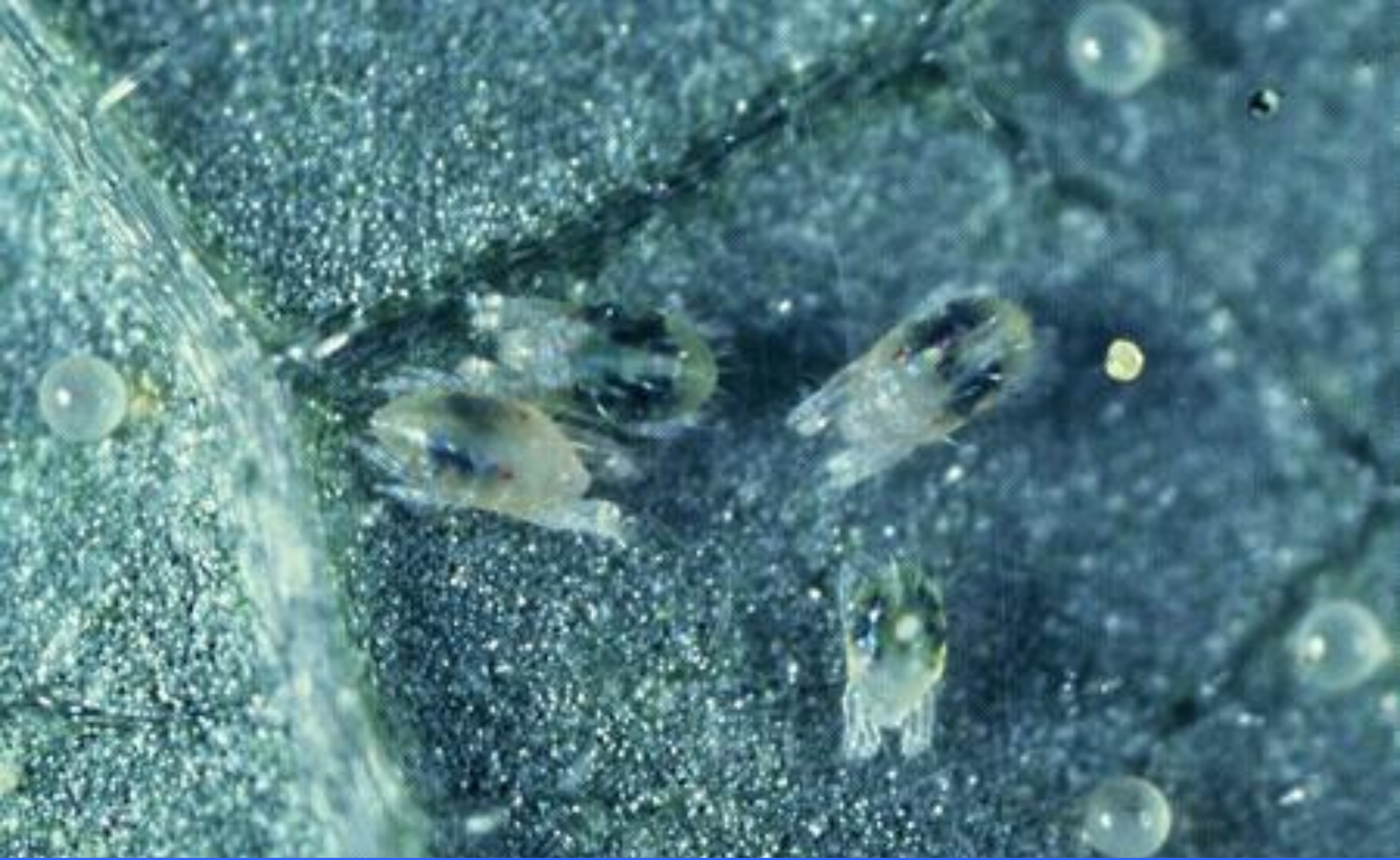


Spider mite Eggs

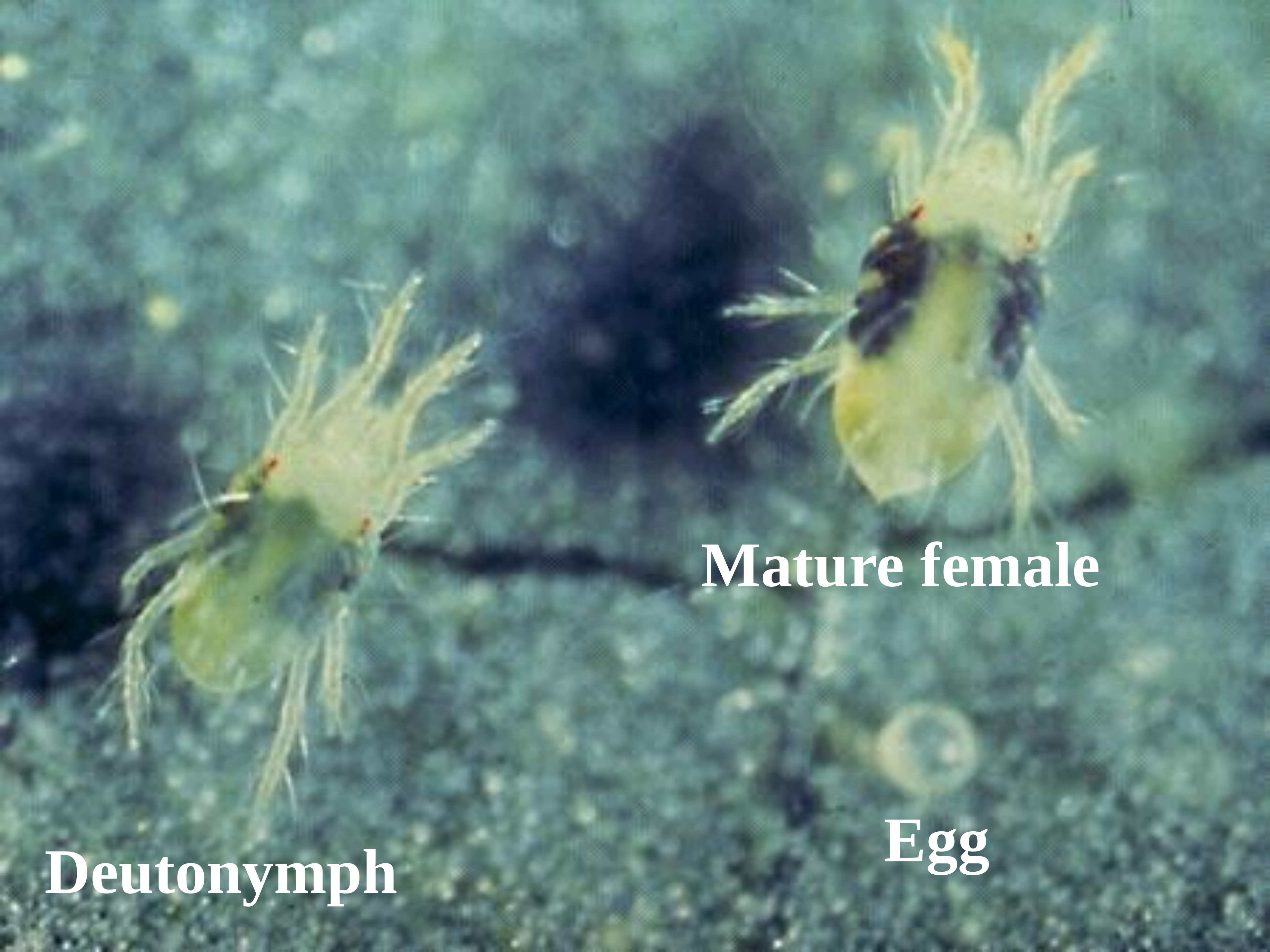
Spider mite eggs are about 0.006 inches in diameter.

Newly laid eggs are clear, but turn opaque and glassy as incubation progresses.

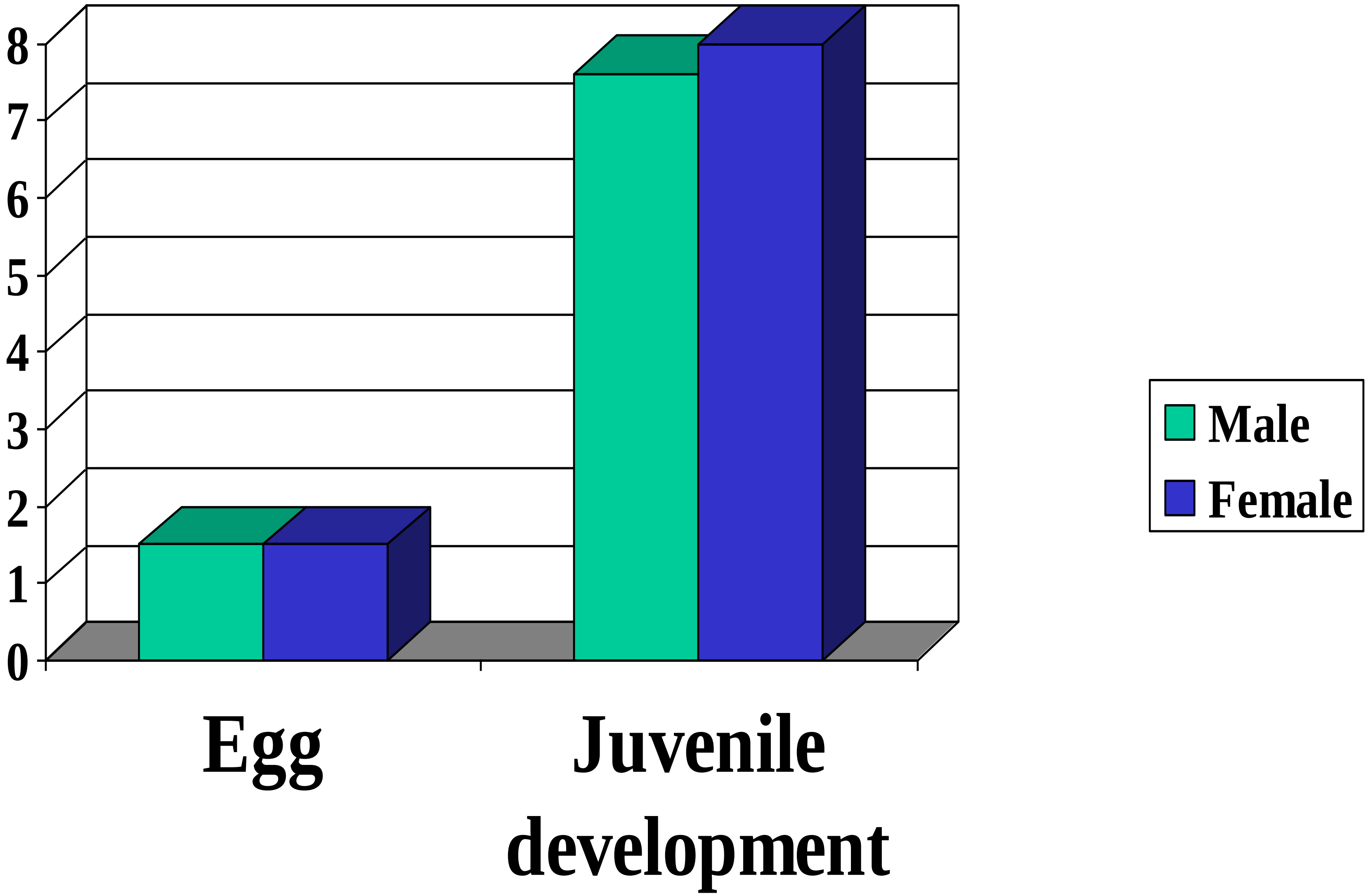

Predator mite egg
Spider mite egg
6 legged larva



quiescent protonymphs molt (shed skin) into deutonymphs


Mature female
Egg
Deutonymph

Developmental time in days @ 70º F



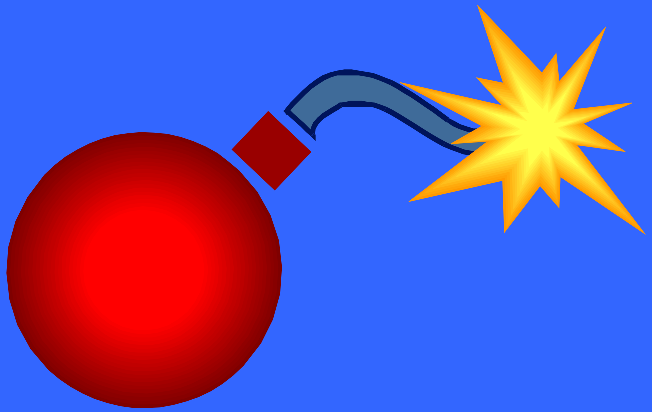

Male spider mite "guarding"
quiescent female deutonymph.

Eggs can exceed 1/3 of the diameter and 20% of the females body

A female will typically produce over 100 to 200 eggs in her lifetime.

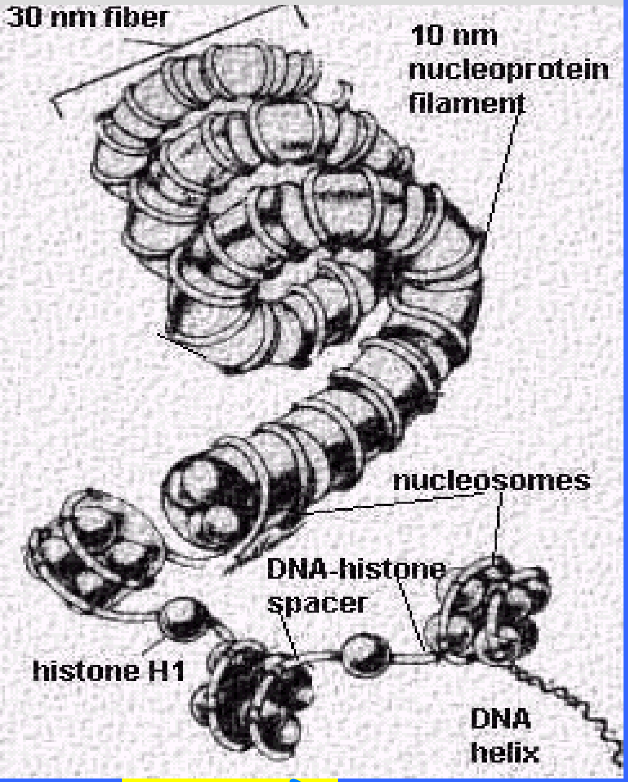
This can vary with temperature, host plant species, host plant quality, relative humidity, exposure to pesticides, etc.

Population Explosion

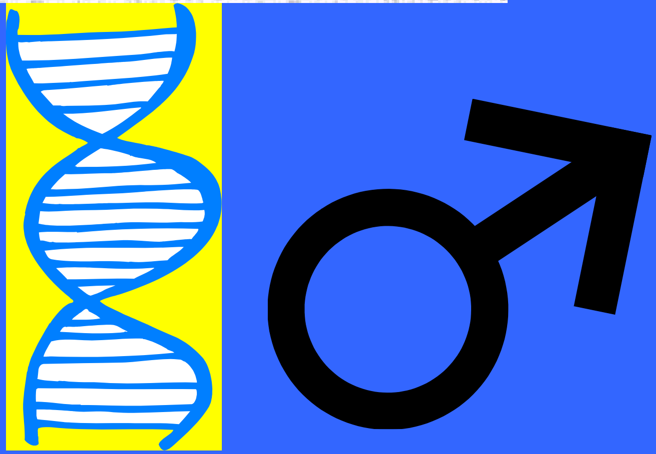


- 5 to 10 eggs are laid on average each day for about 10 days.
- After 10 days the number of eggs laid per day declines.
- Each female can lay between 100 & 200 eggs
- Morbidity sets in after ~25 days

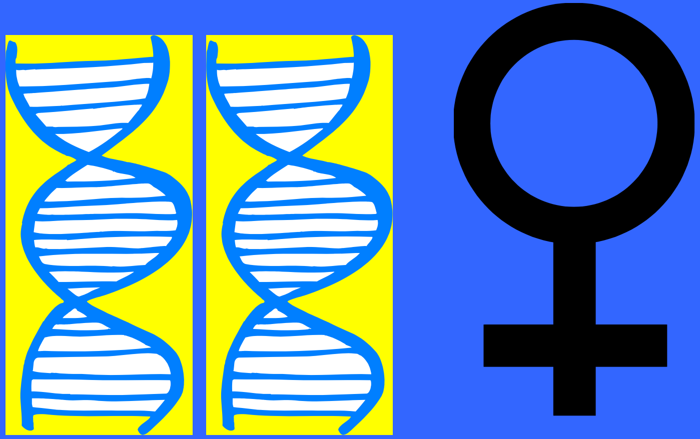
Chromosome



- Male eggs are produced parthenogenically (sex not required)
- males develop from unfertilized eggs
- females develop from fertilized eggs



Haploid becomes male



Diploid becomes female

Consequences of Haplo-Diploidy

Since most adult females only mate once all of a mite's daughters are "super sisters" and share ¾ of their DNA in common.

Producing haploid sons also speeds "local evolution"

e.g. pesticide resistance




Parthenogenic production of males

- Females can 'choose' the sex of their eggs!
- Virgin females can produce male eggs.
- A female can mate with her own son (this is important for a colonizing species)
- Populations are female biased--
- With optimum conditions up to 7/8 of the eggs laid by a female can be daughters.

Electron micrograph of spider mite spinneret

Consequences/ purposes of webbing

- Protect eggs from predators

- Regulate humidity and temperature for eggs

Consequences/ purposes of webbing

- Locomotion- movement in the plant canopy

Consequences/ purposes of webbing

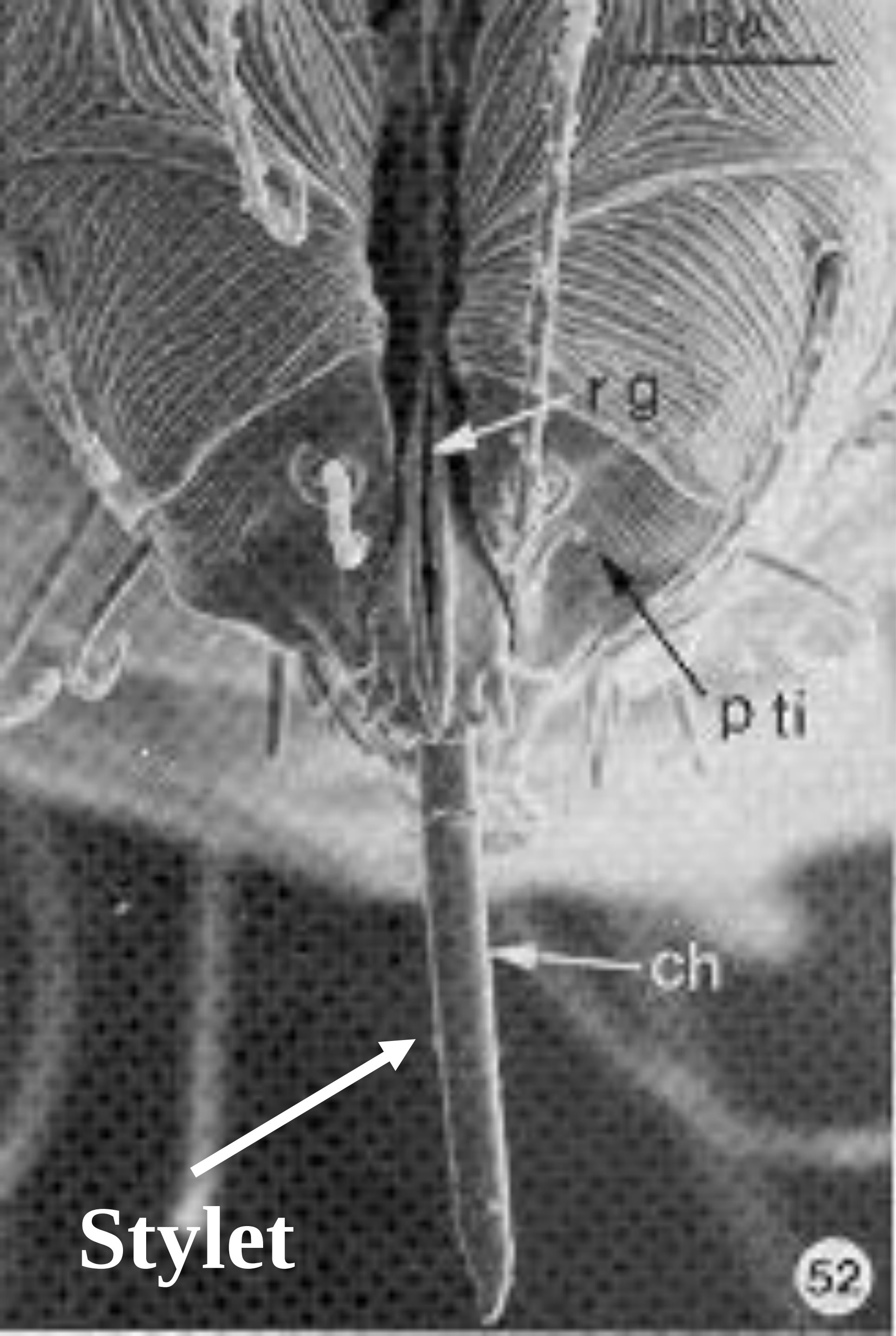
- Dispersal (known as parachuting)

Diapause- Overwintering

- **Is induced by environmental conditions (daylength, temperatures, host plant quality)**


Mated adult females replace as much of their body-water with fatty-carotenoid compounds as they can. This protects them from freezing
The carotenoid compounds cause the red coloration

- Diapause is broken by environmental cues and egg-laying commences. Typically the first few eggs laid are male

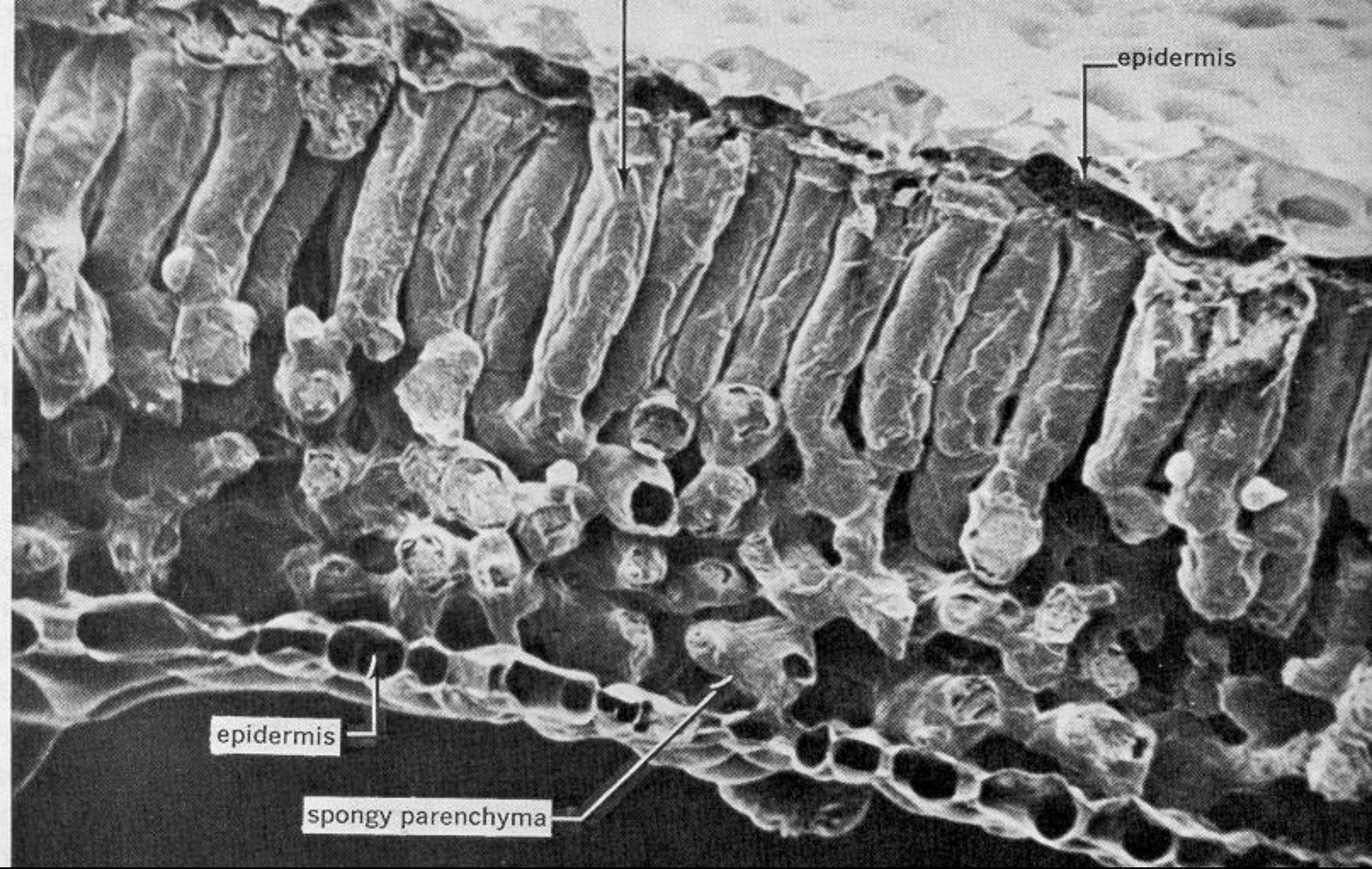


A Big Drain from the Feeding of Such Small Pests

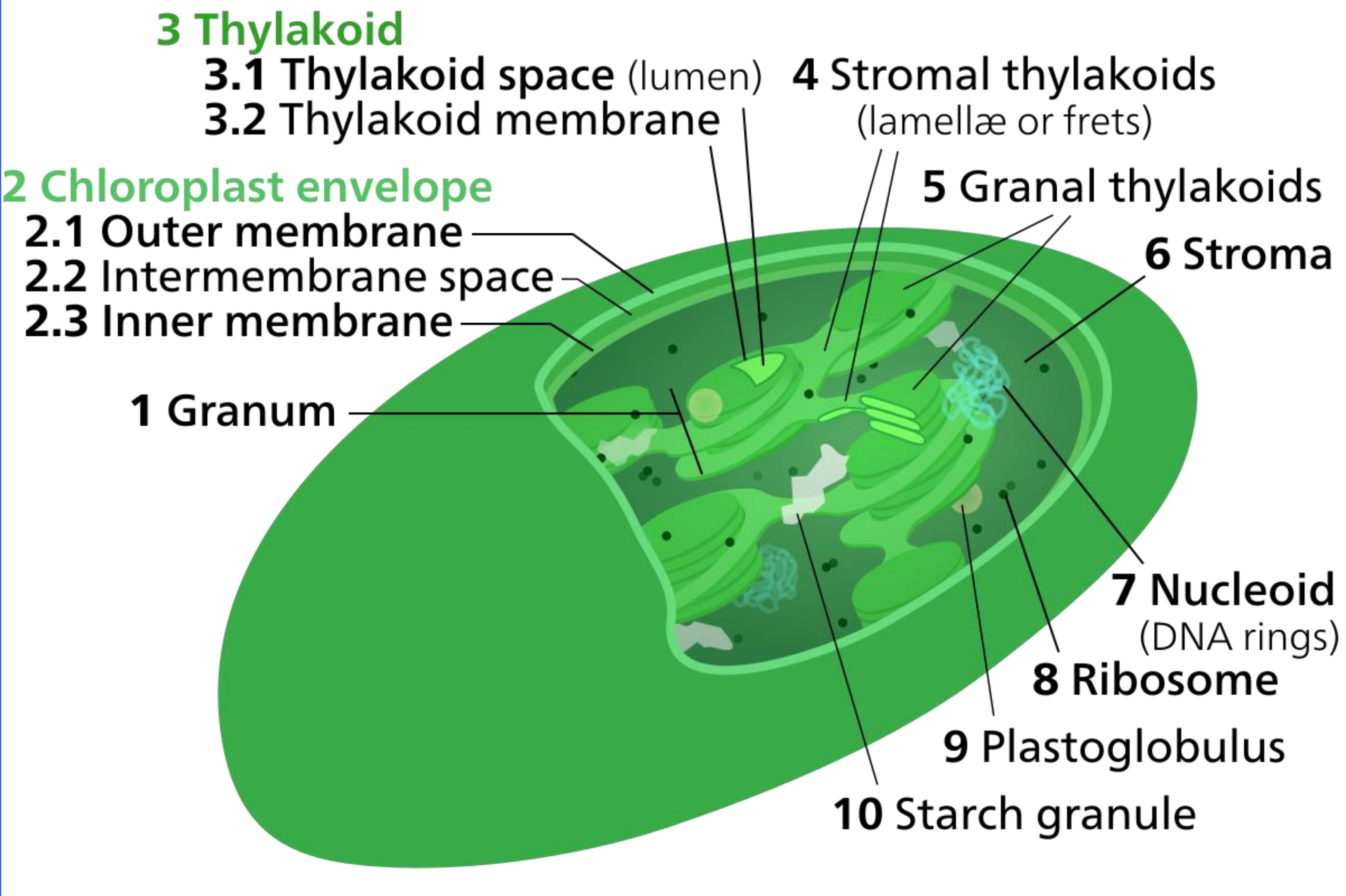
Adult female spider mites ingest 1.2×10^{-2} *ul* of plant juices pass per hour.

This equals 50% of the mass/ volume of a mite.

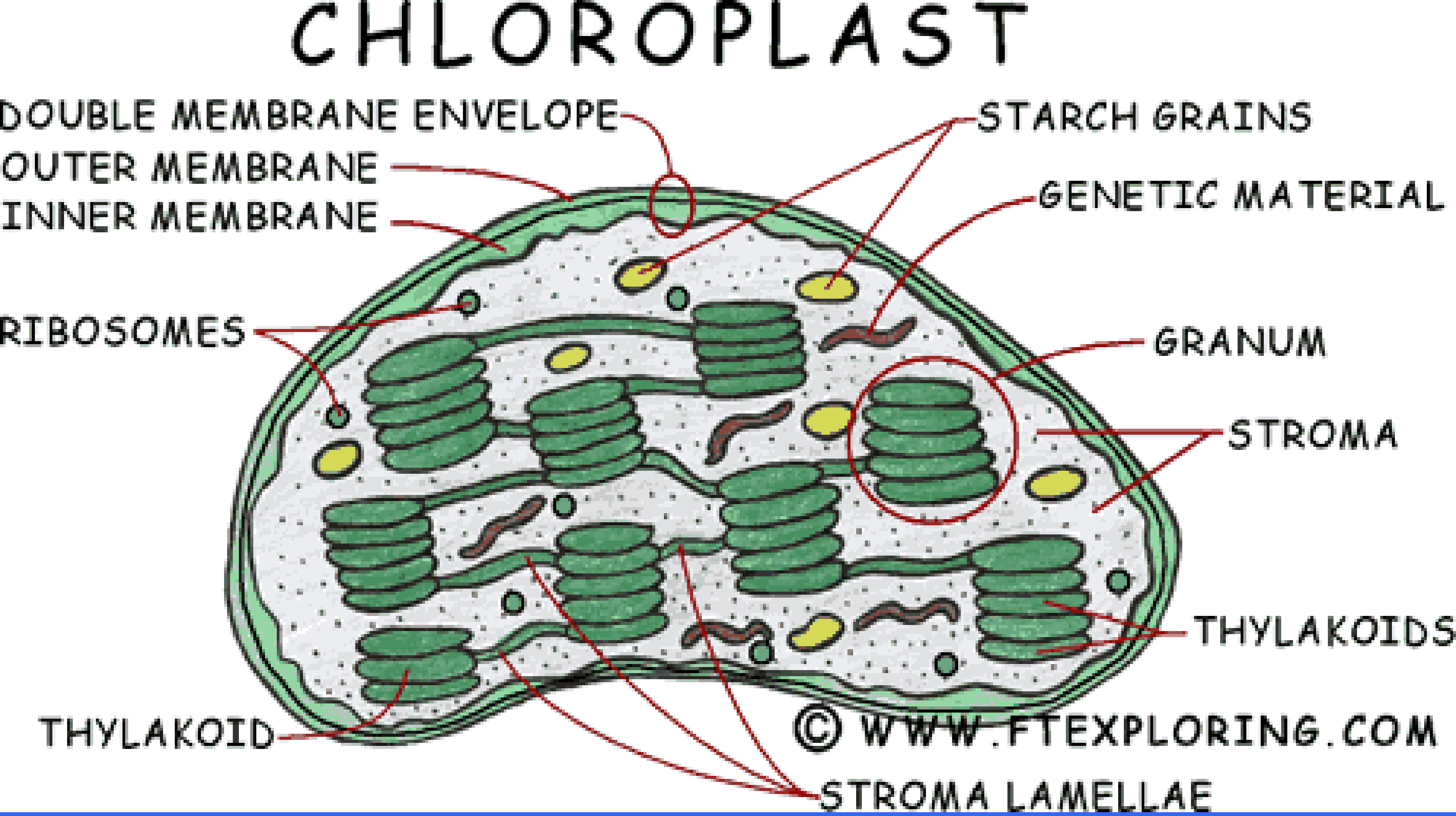
A feeding mite pierces and empties over 100 leaf cells per per minute.



Spider mites "filter feed" out the most nutritious parts of leaf cells

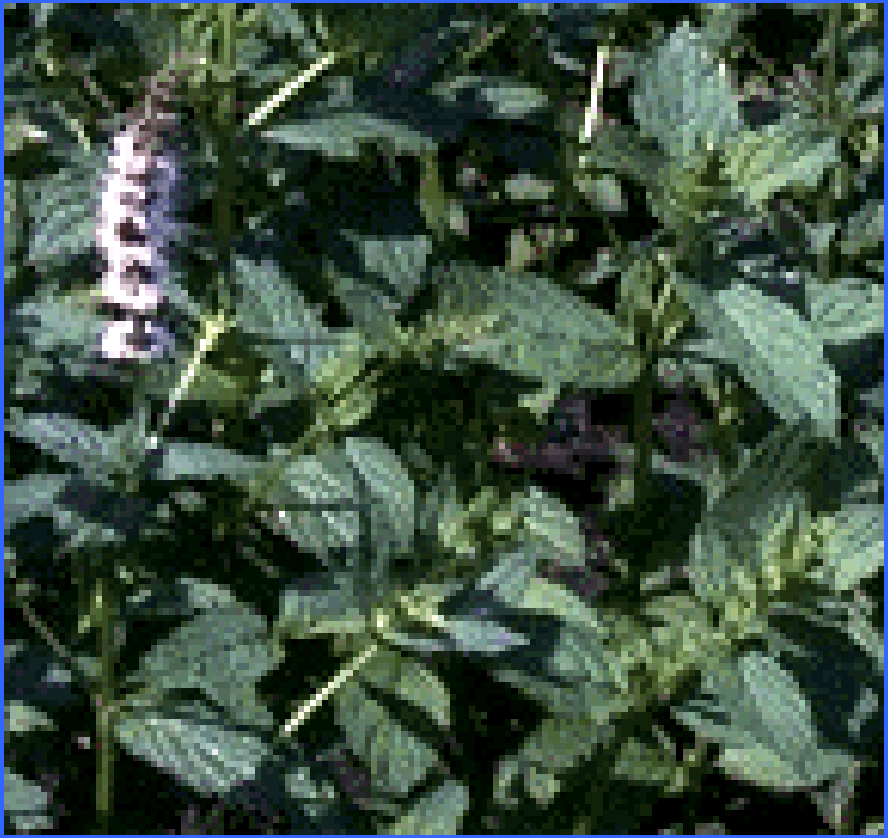


- **Thylakoid grana are a main component in *T. urticae* gut content studies.**



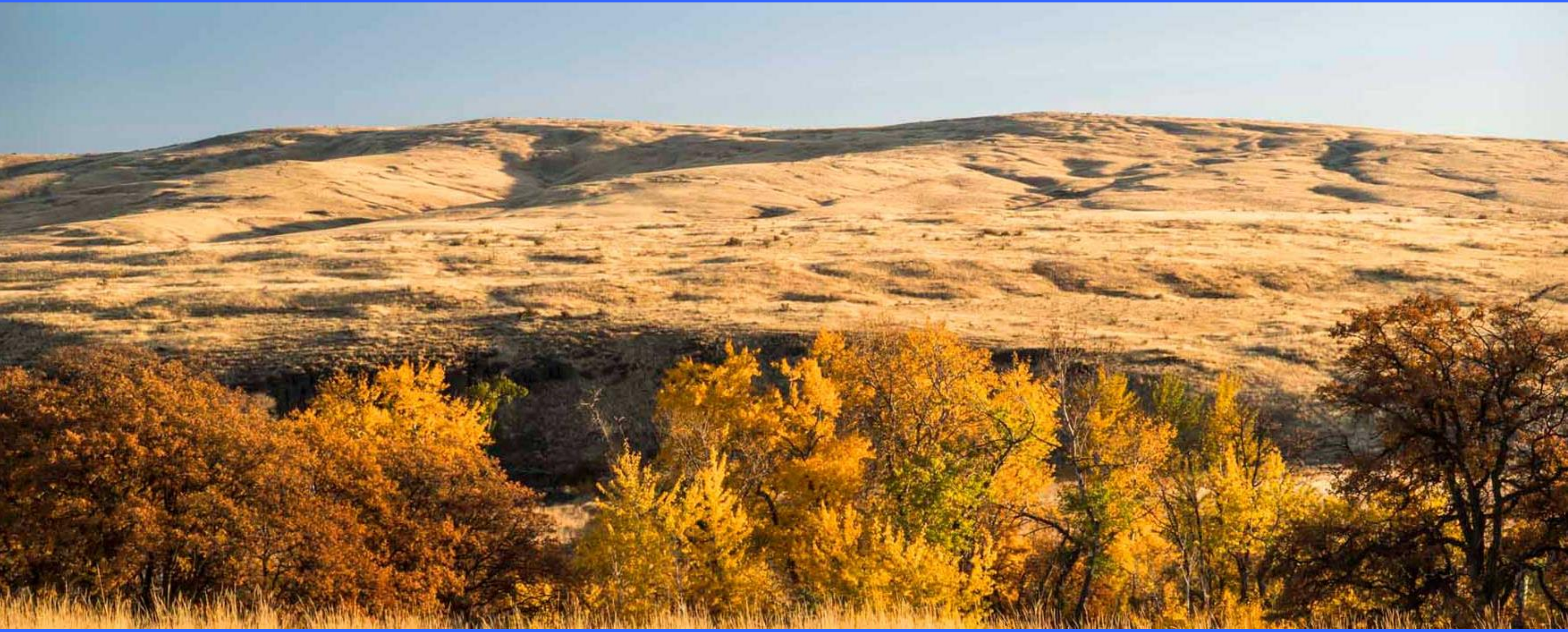
- Thylakoid grana are the photosynthetic engines of plant cells and consist of 45% protein, 50% lipid, and RNA and DNA. Mites excrete water and other low-density molecules.

Mite feeding causes bronzing, stippling, or scorching .



Mite feeding on mint causes a drop in photosynthesis.

Spider Mite Outbreaks are Promoted by Hot, Dry Weather



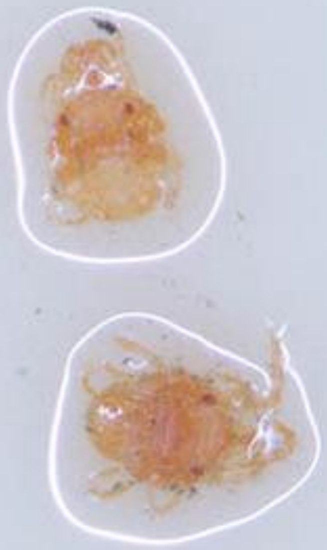
Water stress – Wind - Dust

- Monitoring and Thresholds
- Spider mite (and predatory mite) abundance can be monitored during the dormant season using a simple but effective method.
- In the hop yard, collect a small trowel of soil litter from the top inch around at least 25 dormant or semi-dormant hop crowns

- Place these samples all together, mixing them lightly, in the gallon bag.
- Indoors, fill 25 five-oz disposable cups approximately halfway with material.
- Place each cup upright on a 3- by 5-inch yellow insect sampling sticky card on a table or countertop at heated room temperatures of roughly 70˚ F for a week.

Whirlygig mite

Spider mites

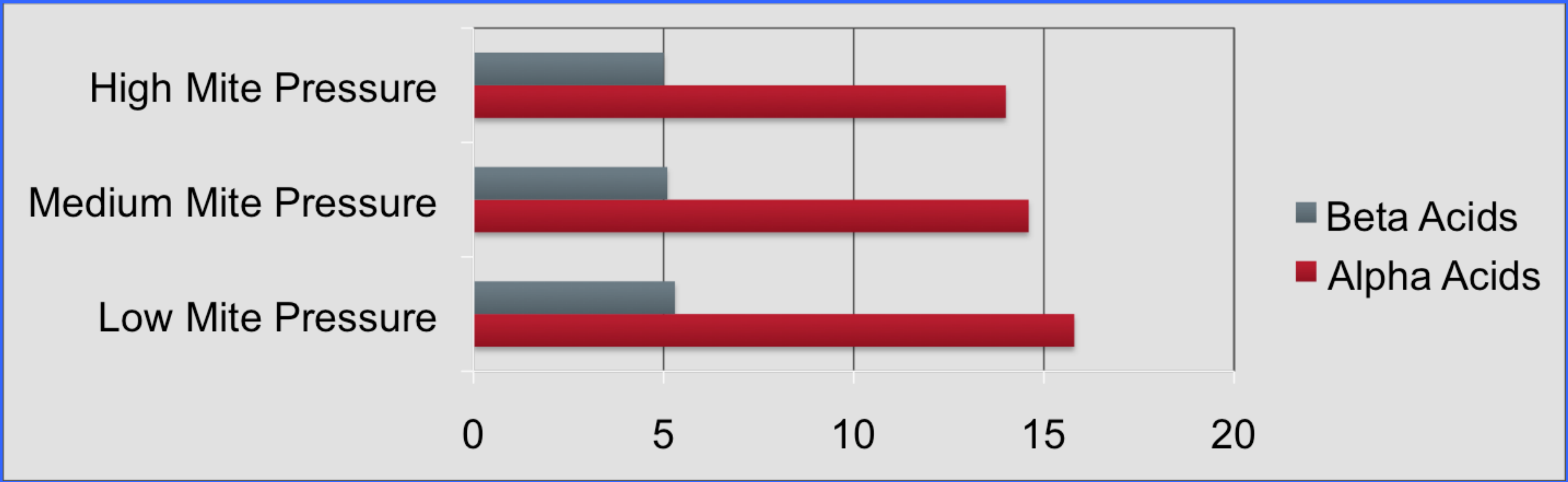


- At the end of this week, remove the cups and use a hand lens to count the pest and beneficial mites present on the sticky cards.
- Be aware that the adult female spider mites will be in their winter orange/red-colored diapausing morph and should not be confused with several species of predatory mites.
- This sampling technique is recommended in hop yards that had severe infestation the prior growing season.

In Season Foliar Samples

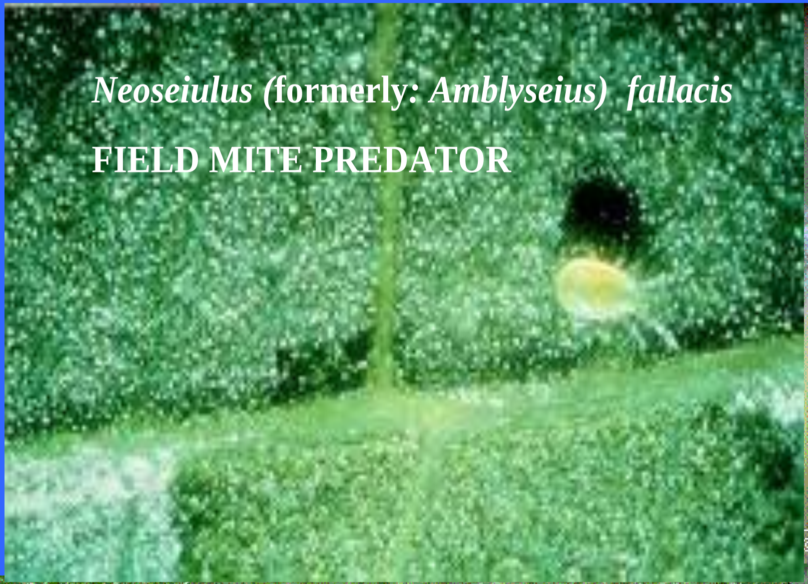
- Samples should be taken weekly beginning in mid- to late May by removing leaves and examining the undersides for the presence of spider mites, mite eggs, and webbing, as well as stippling and yellowing of leaves associated with spider mite feeding.
- After approximately mid-June, as the vines approach the trellis, samples should be taken from leaves higher in the canopy.
- Several leaves from each of 10 to 30 plants should be sampled depending on field size and the amount of time available.
- A 10X to 20X hand lens and a pole pruner are useful mite-sampling tools

Thresholds:
Mite Feeding Acid Results: Laboratory Study



- High >50, Medium 15 to 50, Low <15 mites per leaf
- Tomahawk hop variety
- Acids standardized to 8% moisture
- SE range ±0.1 to ±0.3
- Significantly lower alpha acids on medium and high mite pressure samples at $p<0.05$ than samples collected from low mite infestation plots

Biological controls



Primary method for control is still applying miticides

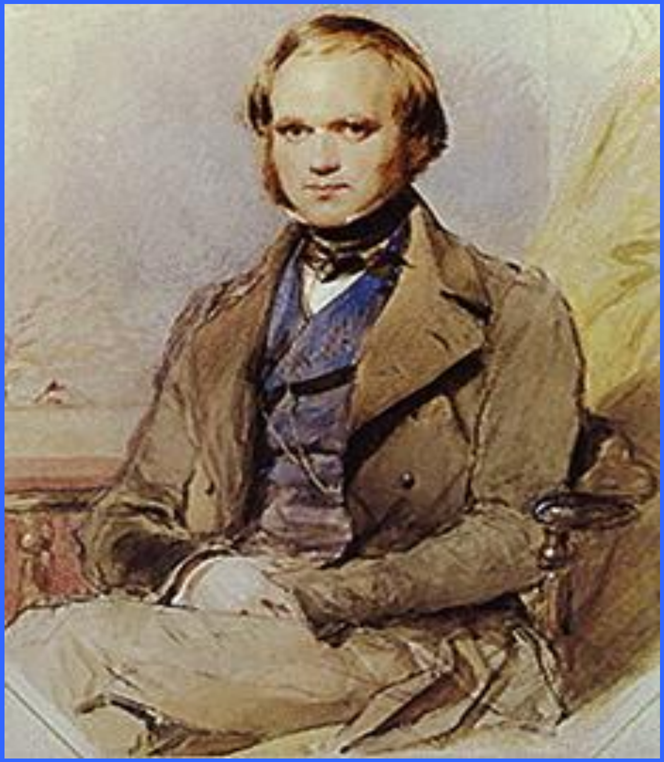
- Abamectin*
- Spirodiclofen
- Hexythiozox
- Etoxazole
- Fenpyroximate
- Spirotetramat
- Bifenazate*

*/ Well documented instances of field failures (e.g. Resistance) in Washington

Miticide Resistance

Doug Walsh
Acarologist

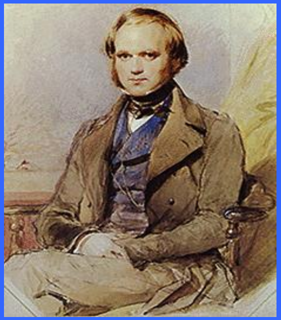
Classical Evolutionary Theory



Charles Darwin

- More individuals are born then will reproduce in a population.
- There is variation among individuals in a population.
- Specific traits can result in greater reproduction.
- Characteristics are heritable.
- Enormous spans of time are available for slow gradual change..

Natural Selection

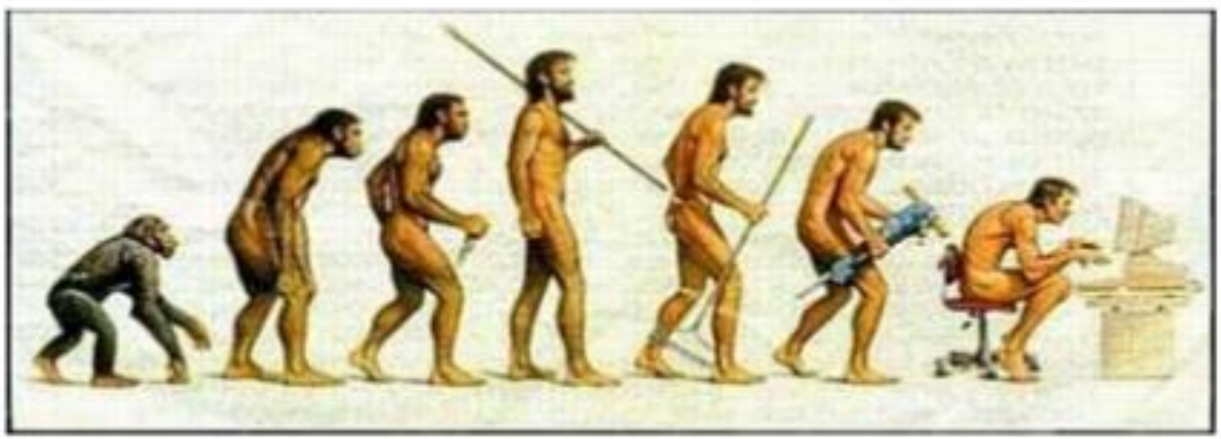


- 1. Acts on individuals, but its consequences occur in populations.
- 2. Acts on phenotypes; evolution results from changes in gene frequency.
- 3. Is backward, not forward looking.
- 4. Acts on existing traits.
- 5. Directed and purposeful, but not progressive

Classical Evolution

NATURAL SELECTION

- "Survival of the Fittest"
- Selection for traits that are most successful in current environment
- A constant process – environments change and therefore so do factors that determine success



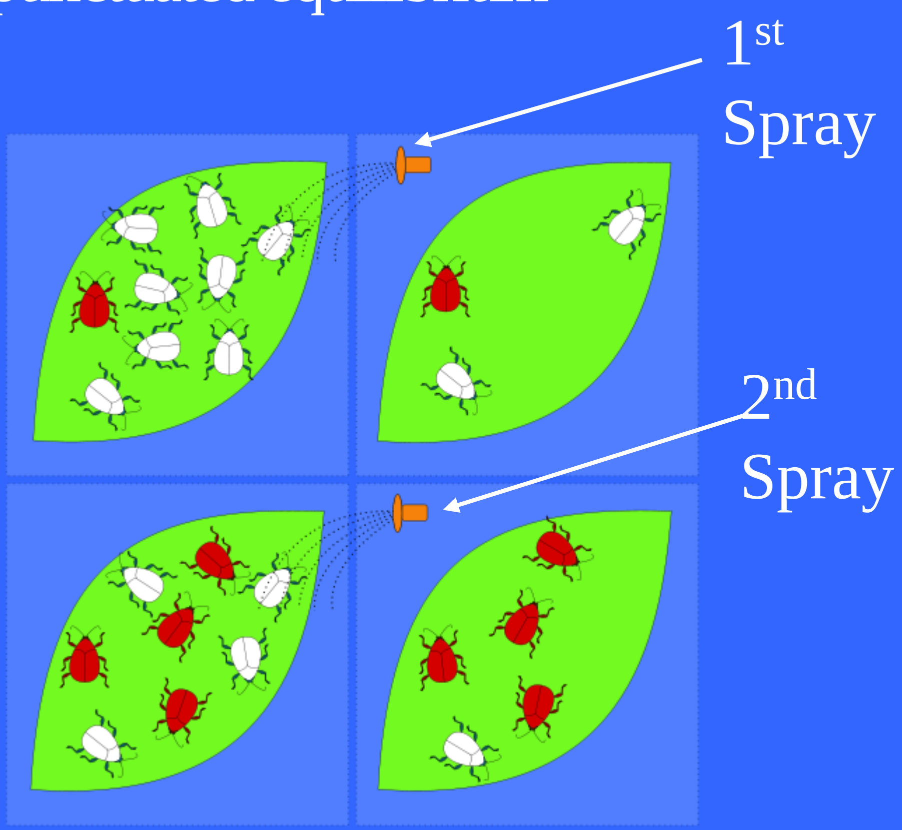
Punctuated Equilibrium

Eldridge and Gould (1972)

Short punctuated ecological phenomena drive the genetic makeup of populations.

Miticide resistance is evolution by punctuated equilibrium

- Theoretically there are always a few mites in a population that are naturally resistant to miticides



Red-resistant mite White-susceptible mite

Spraying a miticide selects for resistance to the miticide in a population

Genotype vs. Phenotype

- Genotype – Is the genetic makeup of the organism
- S = Susceptible
- r = resistant

- Phenotype – The way a mite responds to being sprayed.

Spray

SS → Dies

Sr → Dies

rr → Lives

Heritability

$$h^2 = V_G/V_P = V_G/(V_G + V_E)$$

$$h^2 = V_G/(V_G + V_E) + V_G/(V_G + V_E) + V_G/(V_G + V_E)$$

Multiple generations

V- Variation
G- Genotype
P- Phenotype
E- Environment

The *Phenotype* expressed is the product of the *Genotype's* response to the Environment

Selection Response (*Resistance*)

$$R = h^2 S$$

S is the “selection pressure”

S is the level of exposure of a mite population to miticides.

More exposure increases resistance!

Potency & Persistence

Resistance

"Cost" of the Resistance

- Mechanisms of miticide resistance can be categorized broadly into two categories.

- 1. Target site insensitivity conferred by conserved point mutations in specific target genes
- 2. Metabolic resistance mediated by detoxification enzymes

Mites Mode of Action
Classification by Target Site

Nerve & Muscle Targets

1. Acetylcholinesterase (AChE) inhibitors
1A Carbamates, 1B Organophosphates

2. GABA-gated chloride channel antagonists
2A Cyclodiene Organochlorines

3. Sodium channel modulators
3A Pyrethrins, Pyrethroids

6. Chloride channel activators
6 Avermectins, Milbemycins

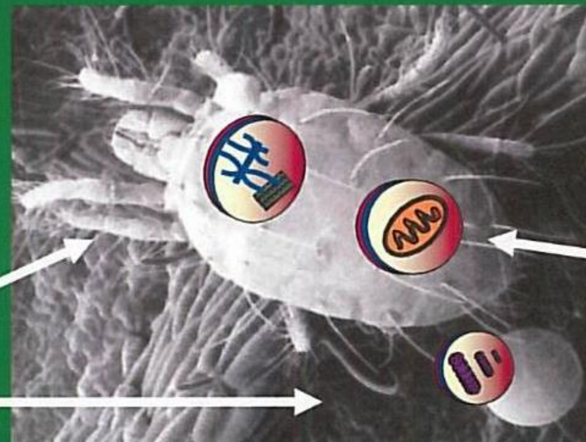
19. Octopamine receptor agonists
19 Amitraz

Growth & Development Targets

10. Mite growth inhibitors
10A Clofentezine, Hexythiazox
10B Etoxazole

15. Inhibitors of chitin biosynthesis, Type 0
15 Benzoylureas

23. Inhibitors of lipid synthesis
23 Tetronic & Tetramic acid derivatives



Respiration Targets

12. Inhibitors of mitochondrial ATP synthase
12A Diafenthiuron
12B Organotin miticides
12C Propargite.

13. Uncouplers of oxidative phosphorylation via disruption of the proton gradient
13 Chlorfenapyr

20. Mitochondrial complex III electron transport inhibitors
20B Acequinocyl, 20C Fluacrypyrim

21. Mitochondrial complex I electron transport inhibitors
21A METI acaricides

25. Mitochondrial complex II electron transport inhibitors
25 Cyenopyrafen

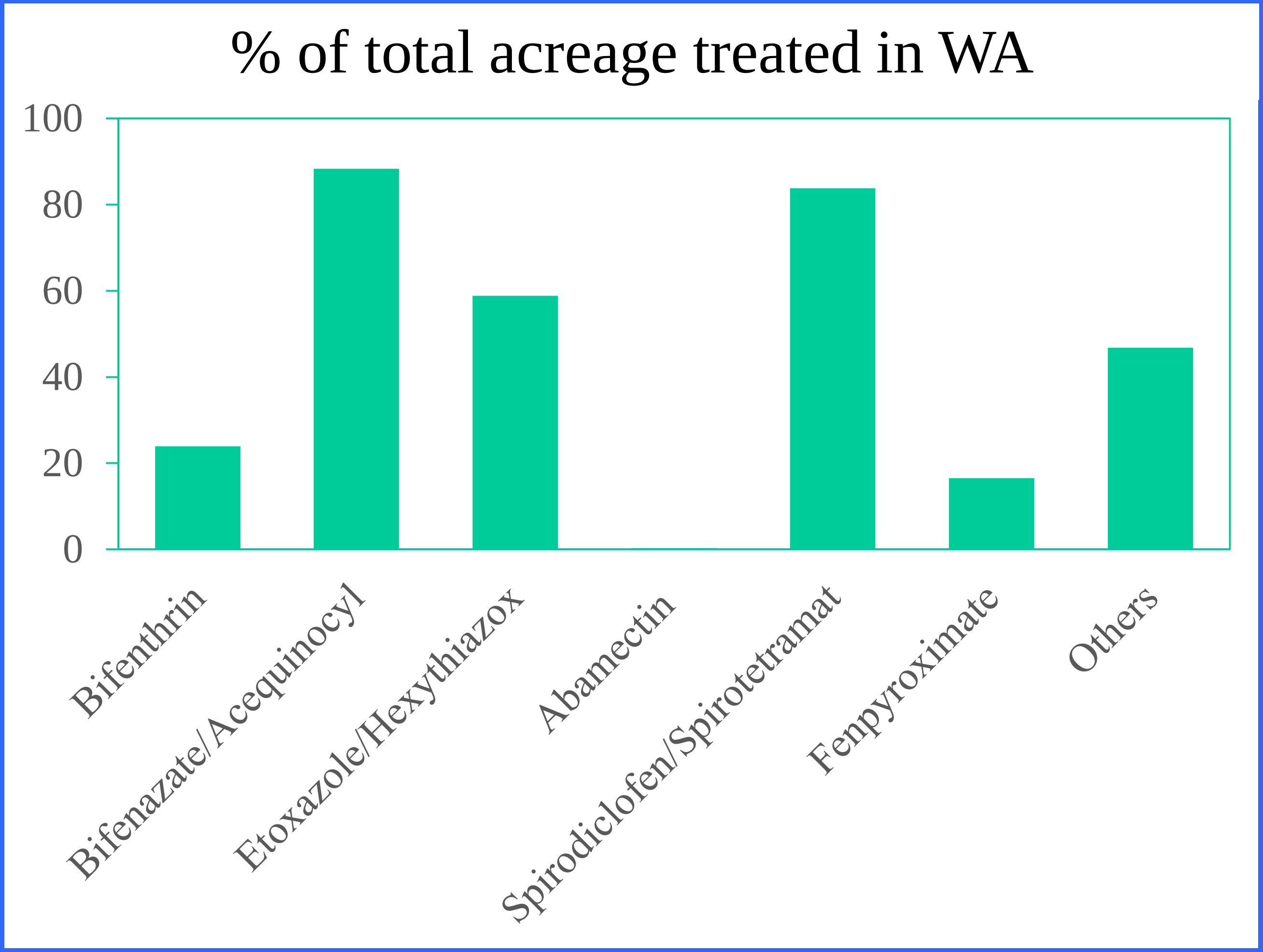
Unknown or uncertain MoA
Benzoximate, Bifenazate, Dicofol, Chinomethionat, Cyflumetofen,

IRAC- Insecticide Resistance Action Committee

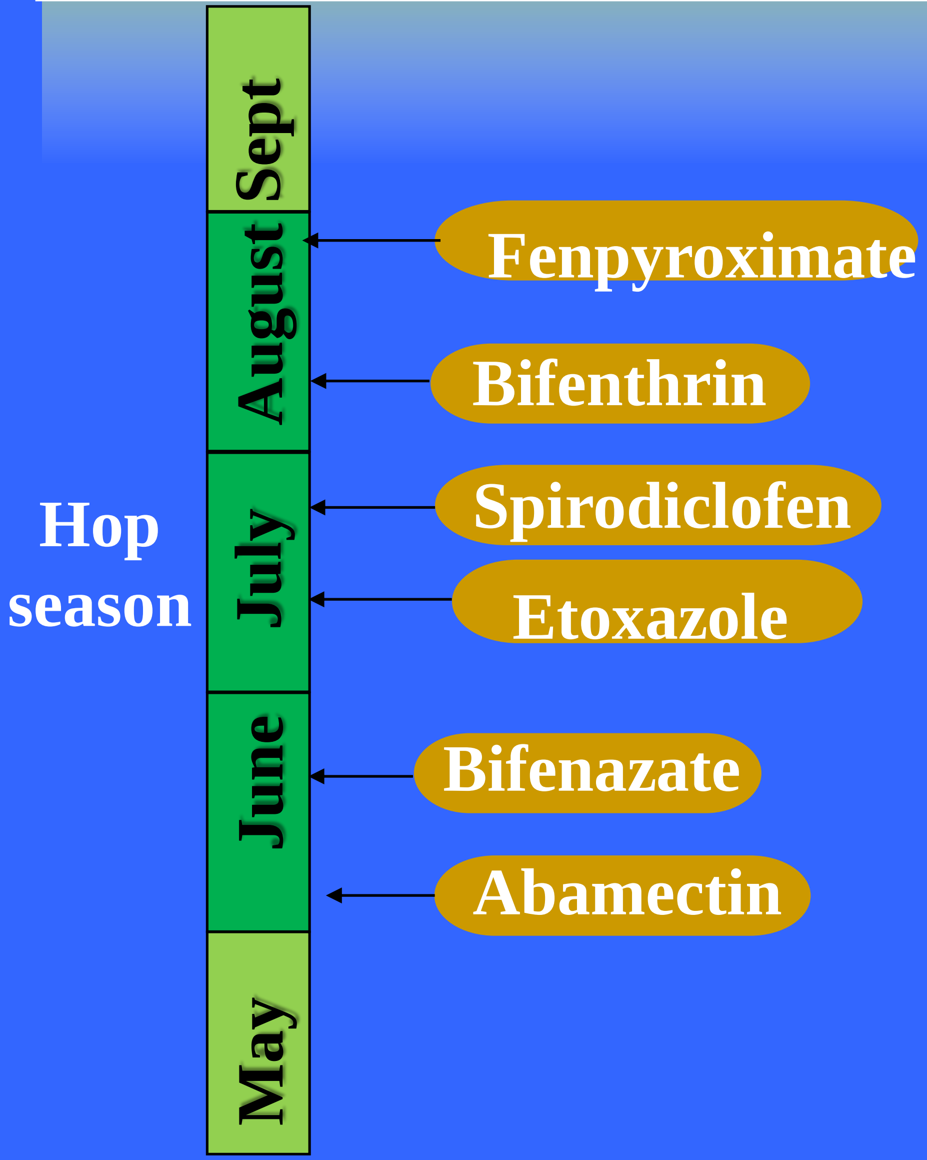
- Promotes the use of Mode of Action (MoA) classification of acaridies as a basis for effective and sustainable mite management.
- Rotating MoAs is an attempt to minimize the selection of resistance to any one acaricidal MoA.

Miticide spray records provided by a major hop merchant for 2016

Data collected from 37 farmers, 624 fields (spray >6 times/season)



Commercially important acaricides used in Washington



Mode of action classification by Insecticide Resistance Action Committee (IRAC)

21A (Mitochondrial complex I electron transport inhibitors)

3A (Sodium channel modulators)

23 (Inhibitors of acetyl CoA carboxylase)

10 (Mite growth inhibitors)

20D (Mitochondrial complex III electron transport inhibitors)

6 (Glutamate-gated chloride channel allosteric modulators)

Target sites of important acaricides

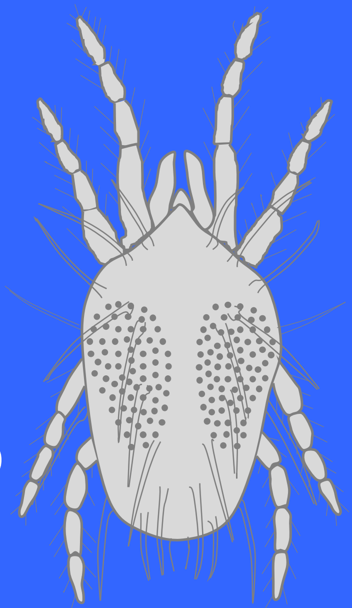
Nerve

Bifenthrin

Sodium channel

Abamectin

Glutamate-gated chloride channel



Respiration

Bifenazate

Cytochrome b

Fenpyroximate

NADH dehydrogenase 1

Growth and development

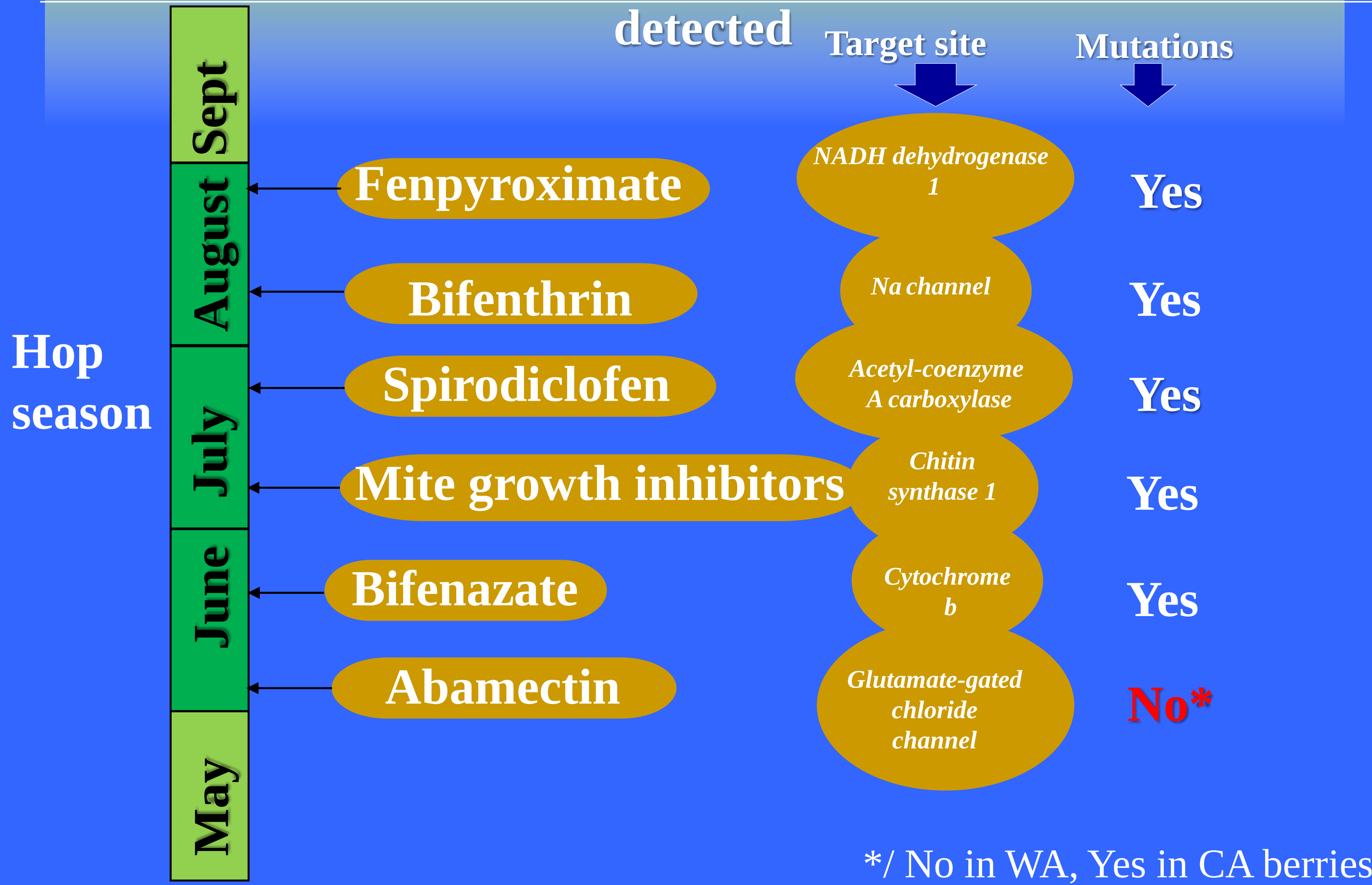
Mite growth inhibitors

Chitin synthase 1

Spirodiclofen

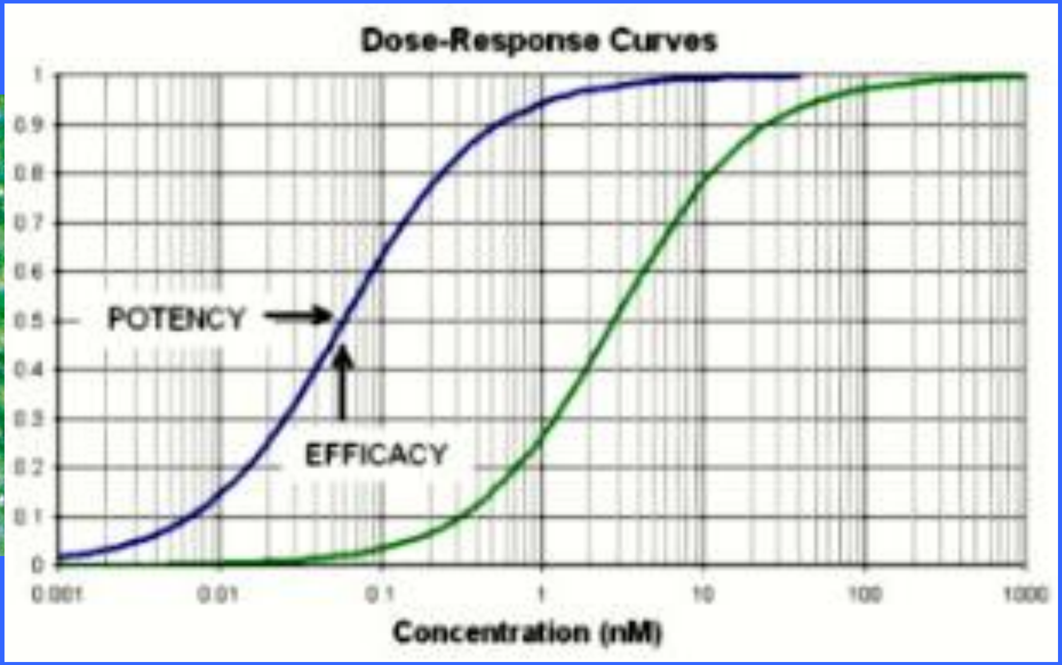
Acetyl-coenzyme A carboxylase

Point mutations associated with these acaricides have been detected



*/ No in WA, Yes in CA berries

We have developed baseline dose response curves of spider mite populations susceptible to abamectin, bifenazate, bifenthrin, hexythiozox, etoxazole, clofentazine, spirodiclofen, propargite acequinicyl and fenaziquin and fenpyroxamate.

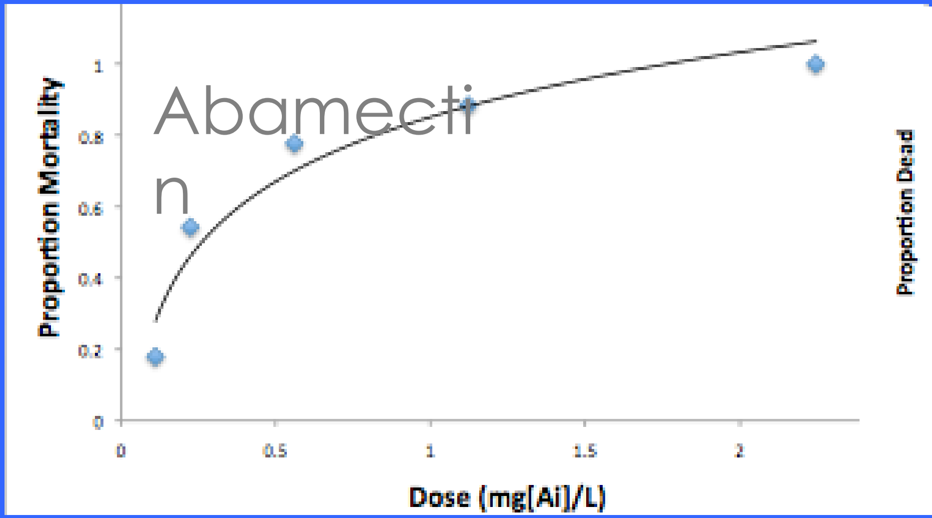


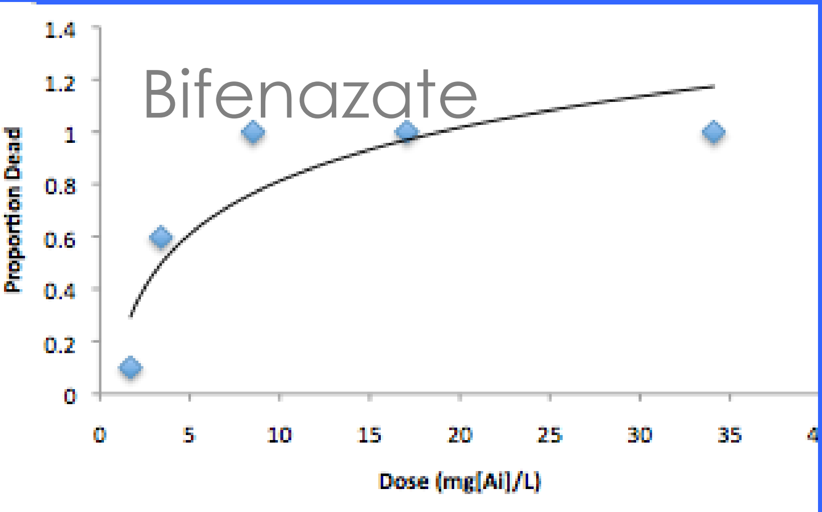
Leaf Disc Bioassay for Adulticidal acaricides

- Transferred ten adult female mites to leaf discs placed on top of soaked cotton
- Exposed to 2 mL of varying concentration of candidate acaricides.
- Mites are held at 24C for 24 hrs, and evaluated for mortality

Results:

Dose response curves of susceptible colony





Miticide	Slope ±SEM	LC_{50} (mg[Ai]/L)	LC_{90} (mg[Ai]/L)
Abamectin	2.1398±0.2707	**0.216** (0.4826-0.8937)	1.18 (0.8937-0.9194)
Bifenture	1.217±0.097	**91.2** (0.4735-0.542)	218.7 (0.35-0.867)
Bifenazate	4.723±0.240	**3.05** (0.478-0.539)	5.54 (0.863-0.918)

Bioassay methods to evaluate the efficacy of ovicidal miticides.



- <u>We have validated 3 methods for screening ovicides.</u>

1. Direct exposure of mite eggs to ovicidal miticides
2. Exposure of gravid females and then monitor the eggs she lays
3. Spray the leaf disk and then place the female on the disk and permit her to lay eggs.

Baseline dose response curves of spider mite populations susceptible to hexythiozox, etoxazole and clofentazine

Dose response of ~24 hr old *T. urticae* eggs from susceptible colony

Acaricide	**LC10 (ppm)**	**LC50 (ppm)**	**LC90 (ppm)**	**Slope ± Std error**
Zeal (etoxazole)	0.215	0.646	1.937	2.68±0.21
Savey (hexythiozox)	0.011	0.715	48.115	0.7±0.067
Apollo (clofentazine)	0.073	2.173	64.67	0.87±0.09

Every summer we go out and collect mite populations from crops including hops, peppermint, silage corn, and alfalfa grown for seed and run the same series of bioassays on them. We've done some populations from berry fields in California too.

For example: This is the phenotypic response to exposure to etoxazole (Zeal) by 9 populations of mites collected from, hop yards near Prosser in 2016.

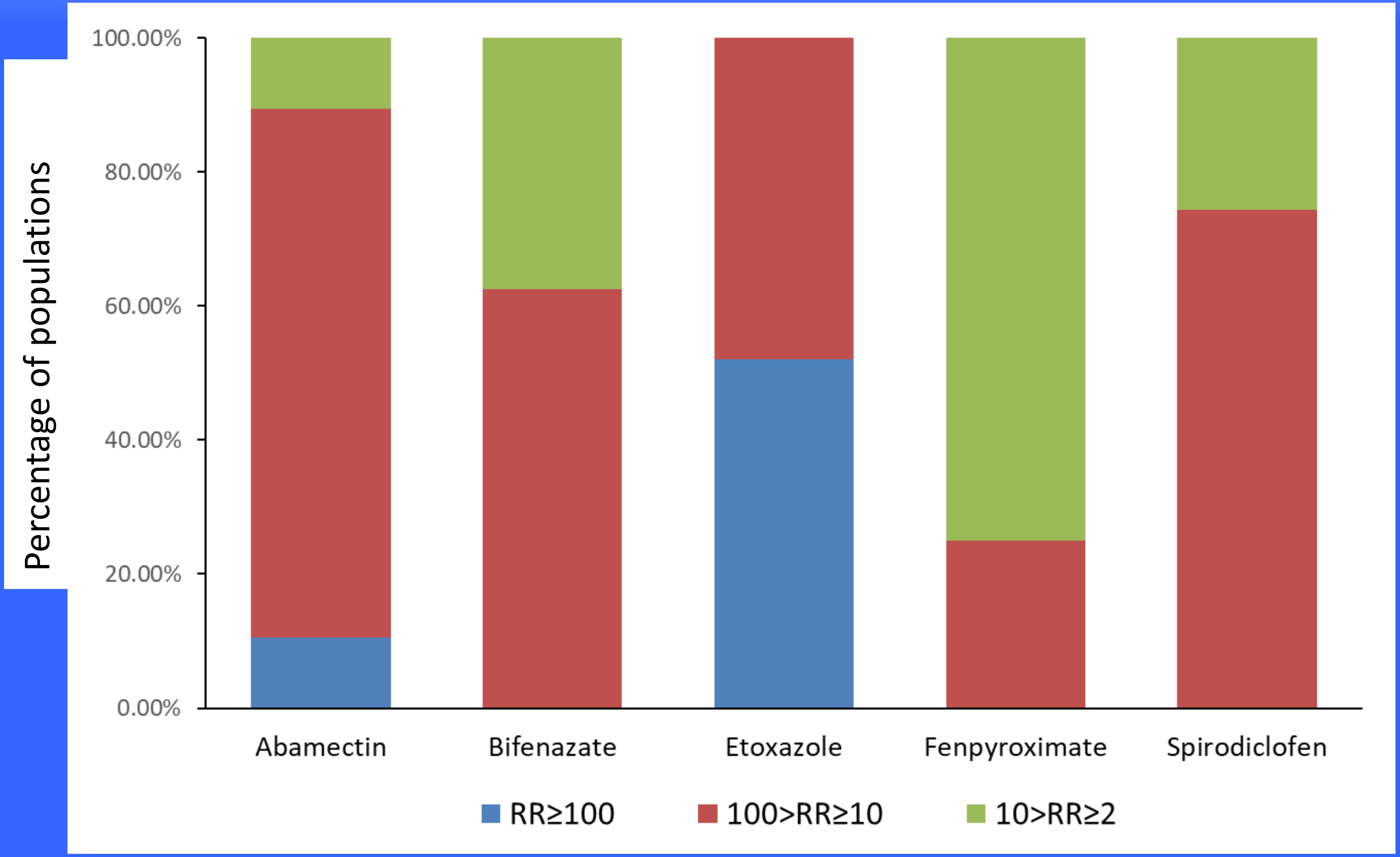
Name	% Mortality at field dose	LC_{50} (ppm a.i.)	RR
Susceptible	100	0.65	1.00
Prosser_1	63.2	217.4	336.6
Prosser_2	68.2	66.9	103.6
Prosser_3	84	60.5	93.6
Prosser_4	86.5	72.9	112.8
Prosser_6	76.4	30.1	46.6
Prosser_7	83.1	16	24.7
Prosser_8	74.2	21.7	33.6
Prosser_9	81.1	25.5	39.5

We calculate RR (resistance ratios by dividing the LC50 of the field population by the LC50 of the susceptible population.

LC50<10= susceptible; 10>LC50<100= low to moderate resistance; LC50>100= resistant (and more resistant as the RR increases)

Resistance Status of T. urticae in Washington Hop Yards

2018 (46 populations)



Things could be worse….
Mites were collected on March 5, 2018

Watsonville & Salinas

One population from organic blackberries

Two populations from organic strawberries

Two populations from conventional strawberries

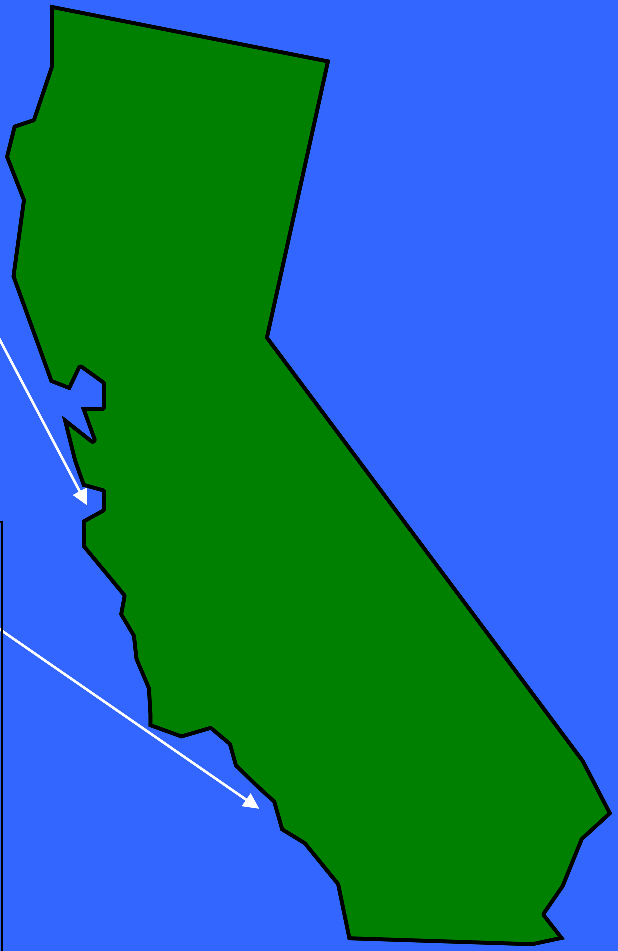
Oxnard

One population from organic raspberries

One population from conventional raspberries

One population from organic strawberries

One population from conventional strawberries



Bifenazate- Acramite

Toxicity of bifenazate to *T. urticae* populations collected from California berry plantations								
Population	Mortality[a]	N	Slope±SEM	LC50(95% CI)	RR50	LC90 (95% CI)	RR90	χ^2 (df)
Susceptible WA	100	2195	5.7±0.46	0.82(0.79-0.85)	1	5.9(3.8-9.6)	1	12(18)
Oxnard 1 Conv SB	56.3	202	1.4±0.4	493.8(340-870)	602.2	4000 (1581-25135)	678	6.6(10)
Oxnard 2 Organic SB	85.6	186	3.0±0.4	218(177-266)	265.9	576 (444-876)	97.6	5.6(10)
Oxnard 3 Organic RB	90.5	184	2.0±0.3	116.2(81-151)	141.5	518 (362-955)	87.8	2.2(10)
Oxnard 4 Conv RB	80	185	1.9±0.3	199(150-2630	242.7	929 (596-2107)	157.5	3.1(10)
Salinas 1 Conv SB	57.2	228	1.1±0.3	404(271-813)	492.7	5634 (1948-94645)	954.9	4.6(10)
Wat 1 Organic SB	66.6	240	1.2±0.2	298(225-443)	363.4	3167 (1465-17734)	536.8	1.6(10)
Wat 2 Organic BB					0		0	
Elkhorn 1 Organic SB	94.8	193	3.0±0.4	97(52-136))	118.3	557 (361-1392)	94.4	4.9(10)
Elkhorn 2 Conv SB	46	236	1.0±0.3	761(470-2283)	928.1	16262 (4163-29990)	2756.3	3.6(10)

[a]**: % Mortality** stands for the % mortality of mites at the maximum labelled rate of bifenazate
Conv= Conventional field; SB = strawberry; RB = raspberry; BB = blackberry

Bifenazate-Acramite

- Some of the RRs we calculated for bifenazate were substantially greater than any values we have calculated for populations of mites that we have collected and screened from multiple cropping systems including hops, peppermint, and silage corn in Washington State.

- The greatest RR for bifenazate we have calculated in Washington State was from a hopyard and the RR value was 96.

- The lowest RR were from organic raspberries in Oxnard with a RR of 87.8 and the greatest RR we calculated were from strawberries near Elkhorn Slough in Monterrey County south of Watsonville with a RR of 928.1.

- Basically all of the populations that were tested with bifenazate in California were moderately to highly resistant to bifenazate

Hexythiozox- Savey

Toxicity of Hexythiazox (Savey) to *T. urticae* populations collected from California Berry plantations								
Population	% Mort[a]	N	Slope±SE	LC50(95% CI)	RR_{50}	LC_{90}(95% CI)	RR_{90}	χ^2 (df)
Susceptible, WA	100	656	0.87±0.09	2.2(1.0-4.5)	1	64.7(24.5-395.7)	1	71.6(13)
Oxnard 1 Conv SB	48.7	315	0.5±0.1	1190(399.7-13465)	541	>>	>>	3.8(10)
Oxnard 2 Organic SB	82.8	283	0.5±0.1	43.1(15.9-127)	19.6	11257(2053-59791)	174	13.3(10)
Oxnard 3 Organic SB	83.4	301	0.9±0.12	64.8(37-111)	29.5	2029(856-8352)	31.4	8.4(10)
Oxnard 4 Conv RB	64.1	296	0.6±0.1	189.1(93-532)	86	42325(6884-173481)	654.2	7.4(10)
Salinas 1 Conv SB	77.6	236	0.7±0.13	829(425-1674)	376.8	4207(1308-38157)	65	3.4(10)
Wat 1 Organic SB								
Wat 2 Organic BB	84.9	250	0.7±0.1	43.7(22.6-84.7)	19.9	3335.8(1013.8-29929)	51.6	7.7(10)
Elkhorn 1 Organic SB	78.2	256	0.7±0.1	143.7(56.4-465)	65.3	9328(1756-854447)	144.2	10.8(10)
Elkhorn 2 Conv SB	75.1	314	1.1±0.2	204.8(119-343)	93.10909	3531(1439-25271)	54.6	5.7(10)

[a]**: % Mortality** stands for the % mortality of eggs at the maximum labelled rate of hexythiozox
Conv= Conventional field; SB = strawberry; RB = raspberry; BB = blackberry

Hexythiozox (Savey)

- There was substantial variation among the California mite populations tested in their response to exposure hexythiozox.
- From our past studies in Washington State the greatest RR we have calculated was from a hopyard in Mabton, WA. This population exhibited a RR of 25.
- The lowest RR we calculated among the screened California populations was 19.6 from an organic field near Oxnard.
- However, the greatest RR we calculated was 541 from a conventional field near Oxnard. This field had received multiple applications of hexythiozox in the prior several months.
- Among the 8 mite populations from California that we calculated RRs for we consider 2 to be highly resistant (RR>100) and the other 6 populations to be moderately resistant (10>RR<100).
- Obviously resistance to hexythiozox is widespread among the California berry growing districts.

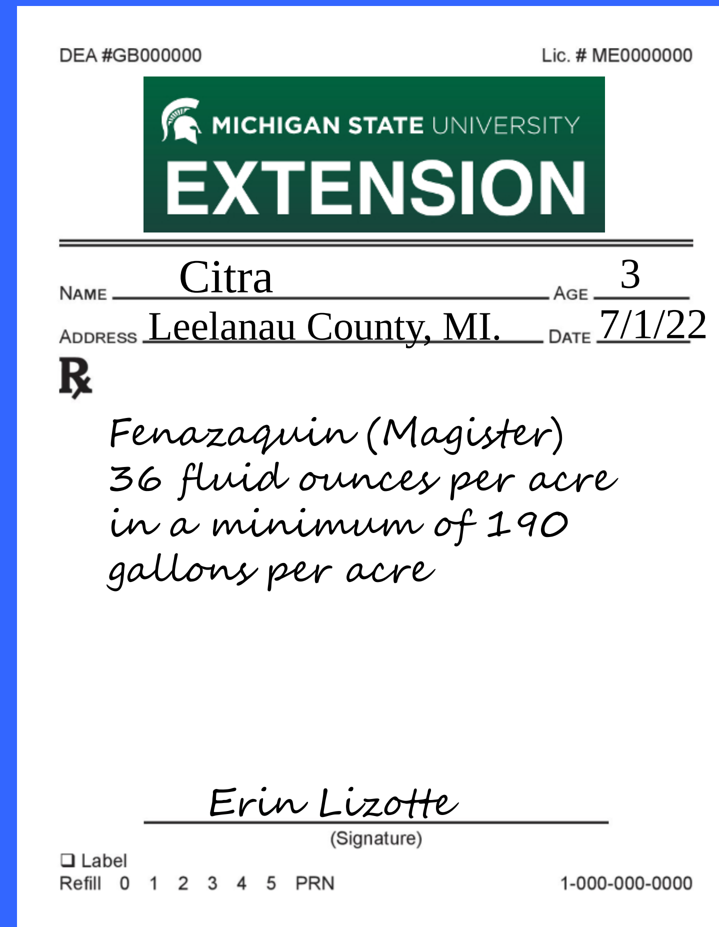
All is not lost!
There is hope in the PNW.

- Our levels of resistance (even in hops) are still low compared to California berries.
- Spray coverage– don’t cheat on water volume!
- Rotating modes of action among miticides is critical.
- Dust management through use of grass cover crops helps
- Avoid early season use of disruptive pesticides
  - Bifenthrin (Brigade), Myclobutanil (Rally)
- Get off the calendar
- Scout and monitor for mites throughout the season

My hope for the future is prescriptive miticide application based on the genetics of the mite population a grower wants to control.

We now have molecular markers associated with miticide resistance for all the miticides that are registered on hops (and other crops too). We’re workin on multiplex methods to test multiple miticides in combined tests.

Based on the genetics of the mites we now can predict how a mite population will respond to being sprayed by a miticide.


DEA #GB000000 Lic. # ME0000000

MICHIGAN STATE UNIVERSITY
EXTENSION

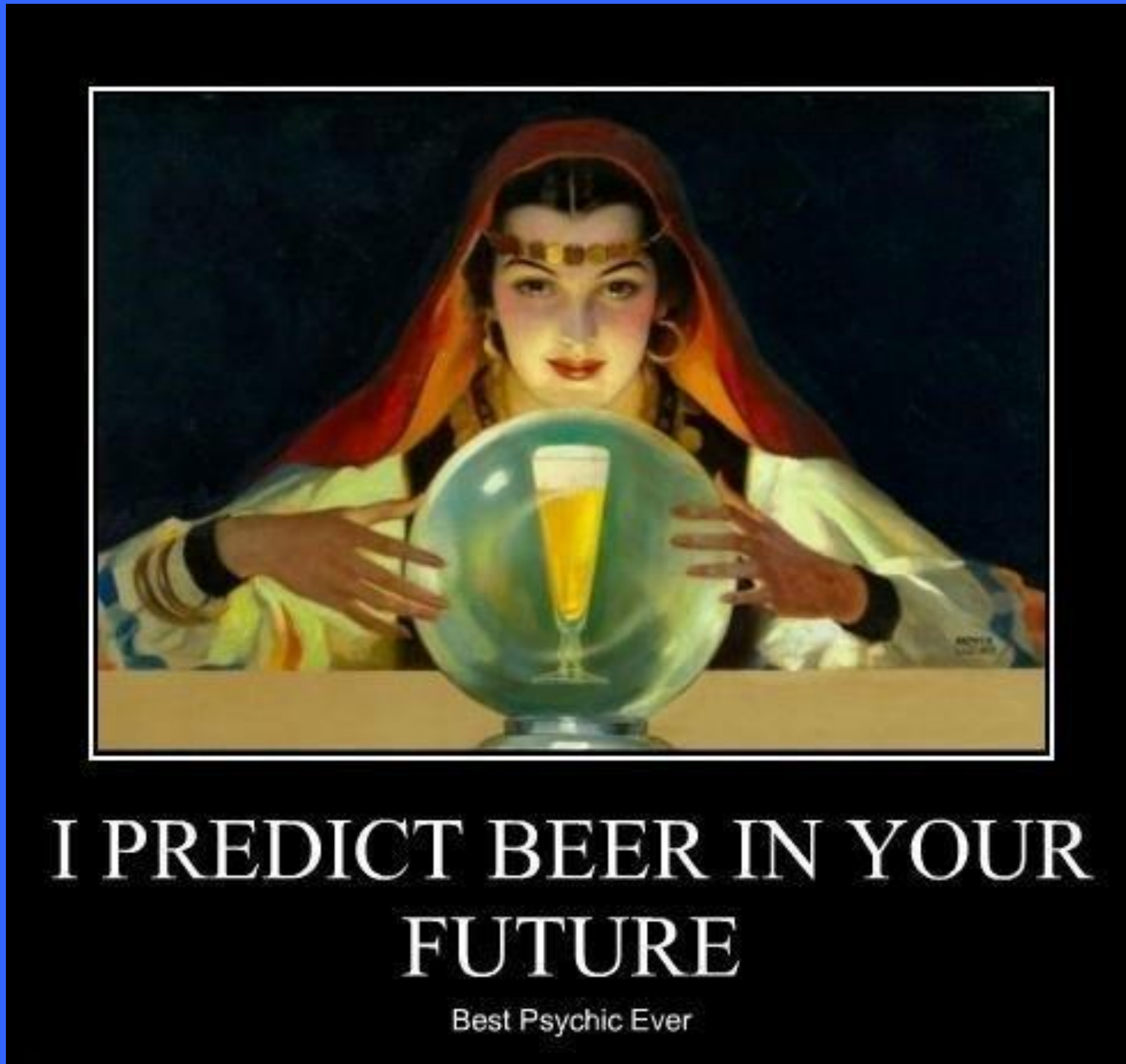
NAME Citra AGE 3
ADDRESS Leelanau County, MI. DATE 7/1/22

℞

Fenazaquin (Magister)
36 fluid ounces per acre
in a minimum of 190
gallons per acre

Erin Lizotte
(Signature)

❑ Label
Refill 0 1 2 3 4 5 PRN 1-000-000-0000


I PREDICT BEER IN YOUR FUTURE
Best Psychic Ever


Questions?