Pollination Stress & Kernel Set in Corn

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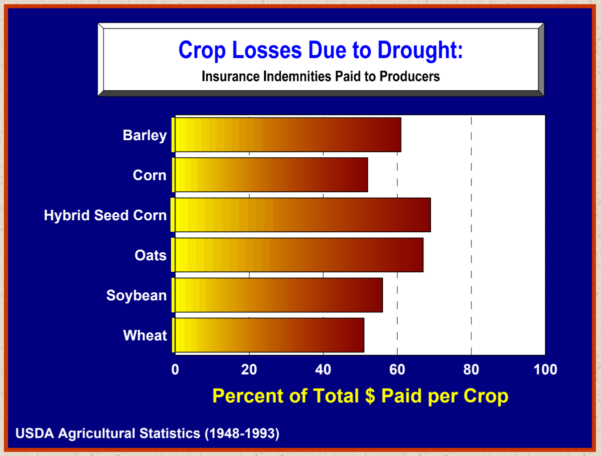
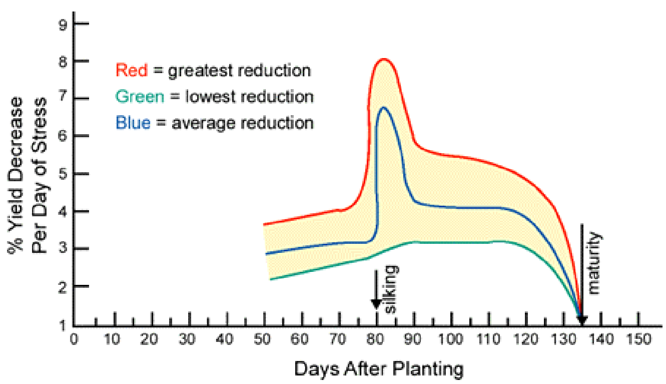
Despite decades of selection, today's corn hybrids remain quite vulnerable to severe drought.



In 2002, more than 50% of the $4.1 billion in crop insurance indemnity payments was for drought-related causes.

In 2003, indemnities were approximately $3.2 billion, about 54% attributable to drought-related losses.

Yield loss due to moisture stress varies with plant development



The Flowering Process in Corn

- multiple points of vulnerability

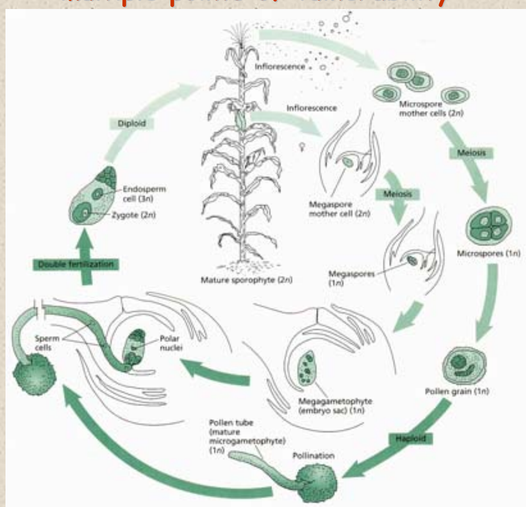
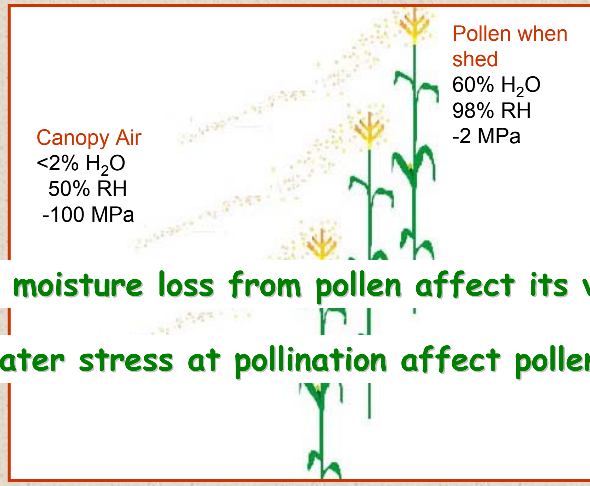


Fig 1.2 Taiz & Zeiger

Most important drought stress – induced problems to overcome for maize:

- Loss of pollen function
- Inhibition of ear development/silk emergence
- Failure of newly-formed kernels to develop

1. Loss of pollen function

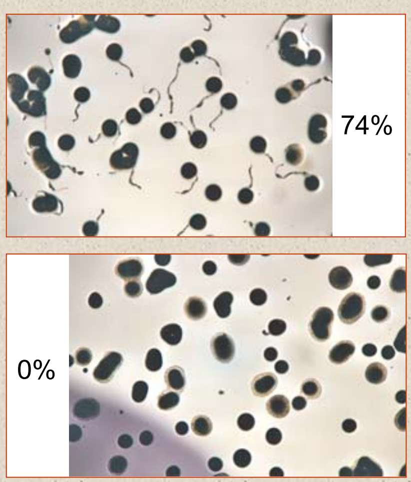


How does moisture loss from pollen affect its viability?

How does water stress at pollination affect pollen viability?

Pollen must travel through dry air to reach the silks

Measuring pollen viability

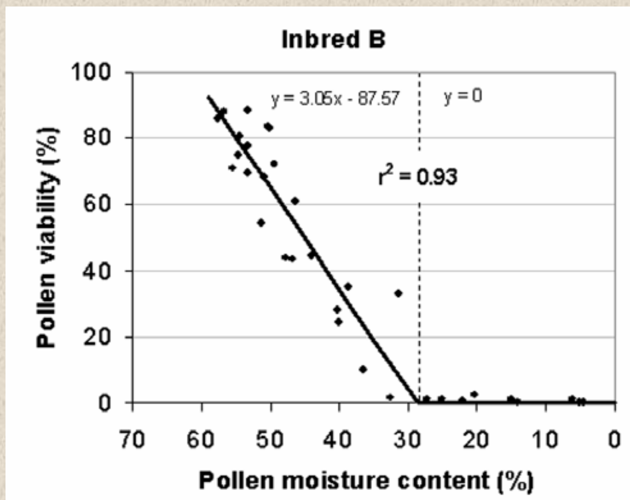


Pollen is collected from tassels and exposed to various combinations of temperature and relative humidity in micro-environment chambers.

Loss of viability is assessed *in vitro* and confirmed *in vivo*

Pollen viability decreases linearly with moisture content.

'On average' maize pollen loses viability completely
at about 30% moisture

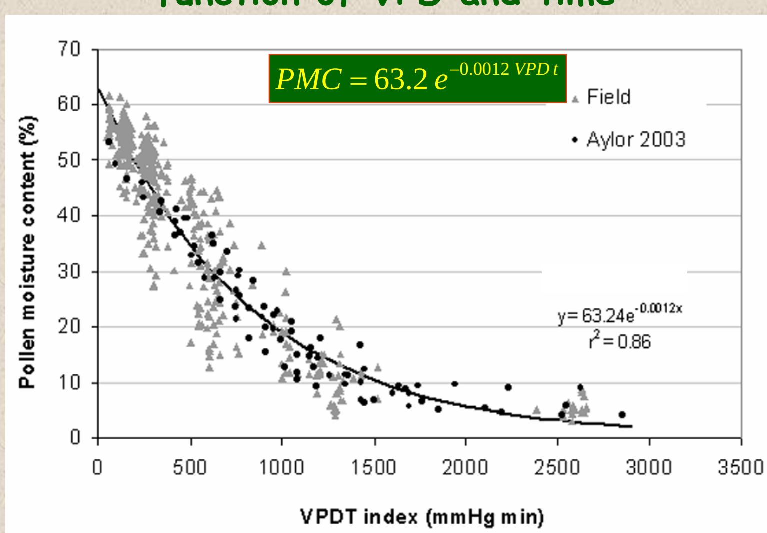


Average values for
11 genotypes

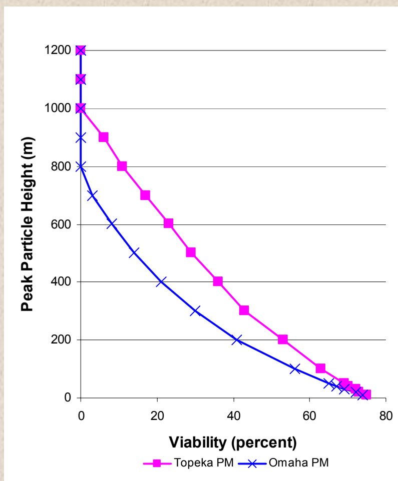
Initial viability 80%
PMC at 0% 30%

Pollen/tassel 3.1E[6]

Loss of pollen moisture is an exponential function of VPD and time

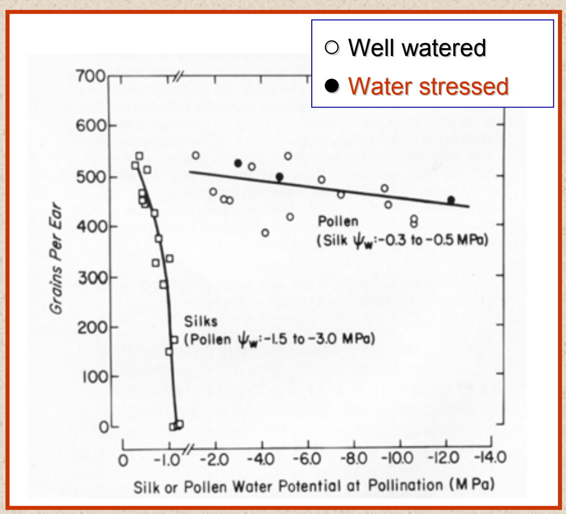


Modeling "terminal viability" of maize pollen lofted into the air



- Pollen lofted at 3 m/s through the atmosphere above Topeka, KS and Omaha, NE and allowed to fall to earth at 20 cm/s.
- Viability adjusted in response to VPD through the profile until the pollen grain returned to the ground
- Pollen lifted in an updraft would remain viable longer over Topeka *(about 88 min if it reached 1000m).*

Lack of soil moisture during anthesis has little impact on pollen's capacity to fertilize female flowers



Westgate and Boyer 1986

Direct effects of temperature:

Maize pollen can lose viability within the anthers if tassels are exposed to high temperature for an extended period of time (38°C for 24 hours)

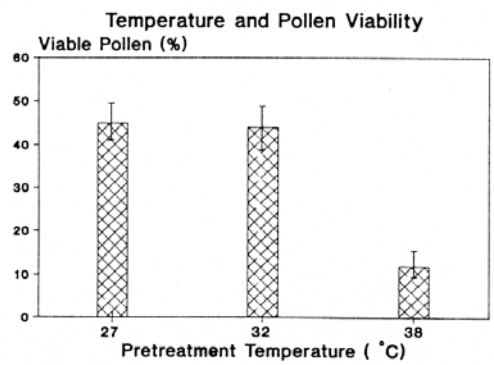


Figure 8. Effect of temperature pretreatment on pollen viability. Viability was measured as percent germination on an agar medium in the laboratory. Tassels were excised from field plants and incubated at the indicated temperature for 24 hr prior to testing. Data represent the mean ± SE for 15 genotypes (Adapted from ref. 5).

Herrero and Johnson 1981

Would minimizing loss of pollen viability have a large impact on kernel set during drought?

Probably not…

Sustained temperatures of 38°C are very rare

Even if air temp exceeds 38°C during the day, pollen would remain viable long enough to reach the silks

Typical hybrids shed 3 - 5 times more pollen than needed to ensure 100% kernel set

2. Inhibition of ear development and silk emergence

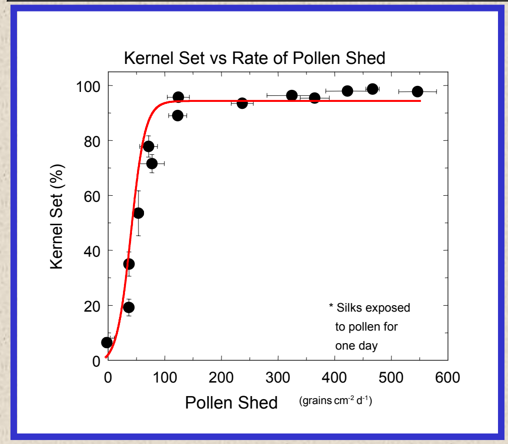
- ear and silk growth are very sensitive indicators of plant stress, particularly water stress.
- Inhibition of ear and silk growth results in asynchrony between pollen shed and silk emergence

Successful pollination (kernel set) depends on the dynamics of pollen shed as well as timely exsertion of receptive silks.

The percentage of silks that are pollinated each day depends on the daily pollen shed intensity

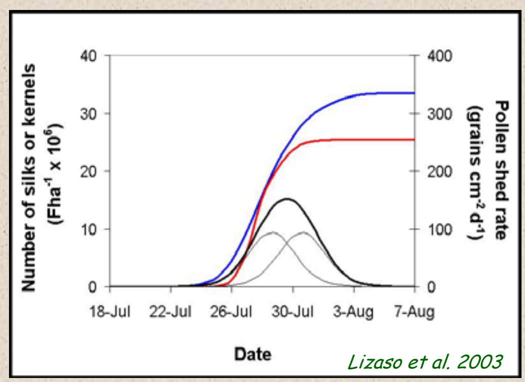
- Pollen shed density <100 grains·cm^{-2}·d^{-1} limits kernel set
- Response includes effect of pollen viability
- And the effect of asynchronous pollination within ear

Pollen shed density < 100 gr/cm^2 d limits daily kernel set



Bassetti and Westgate, 1994

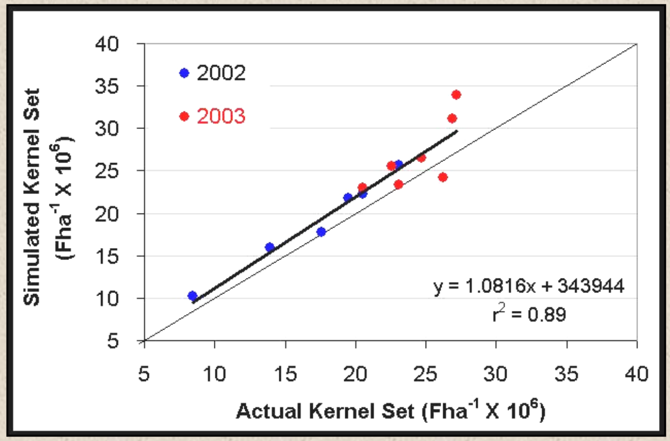
"Nick Manager" converts daily estimates of pollen shed and silk emergence into kernel set



Lizaso et al. 2003

Temporal profile of silk exsertion (blue), temporal profile of pollen shed (black), and simulated daily values of kernel set (red).

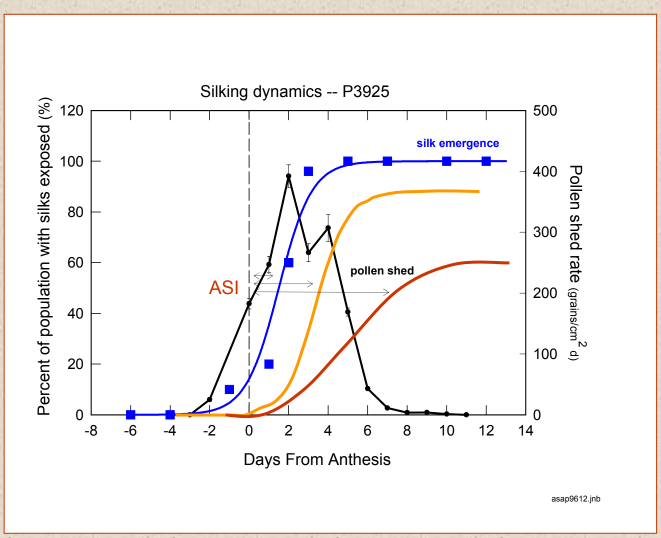
Kernel set is predictable from simple measures of pollen shed and silk emergence



Fonseca et al. (unpublished)

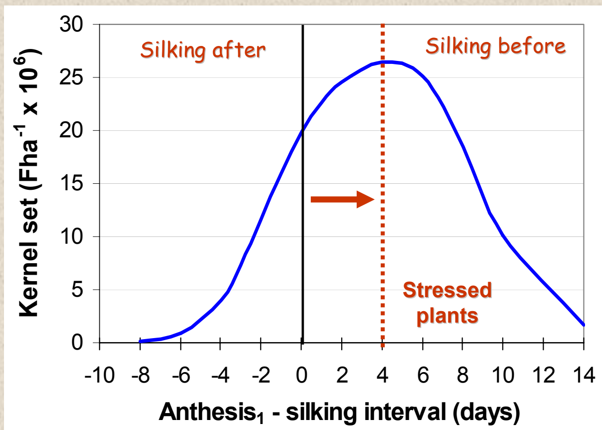
Loss of pollen viability and pollen trapping by leaves not taken into account

In stressed plants, more silks emerge as pollen shed declines or after shed has ended.



ASI : anthesis – silking interval

Simulations with 'Nick Manager' indicate kernel set is very sensitive to ASI

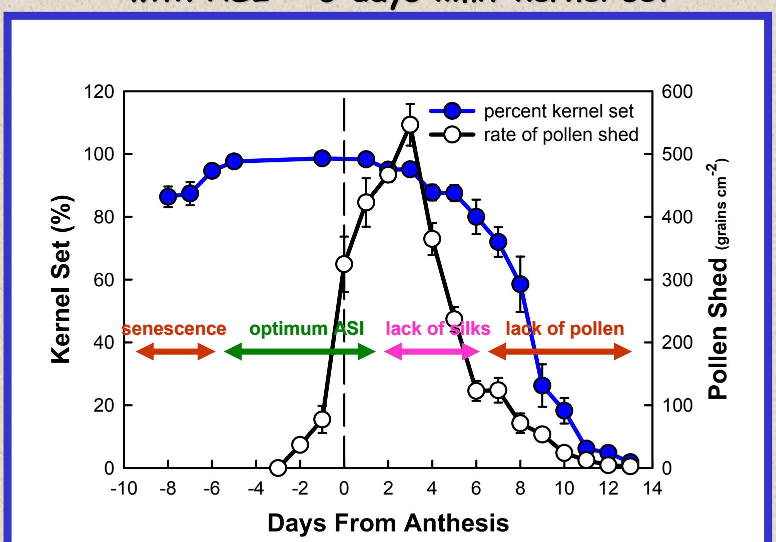


Fonseca et al., 2004.

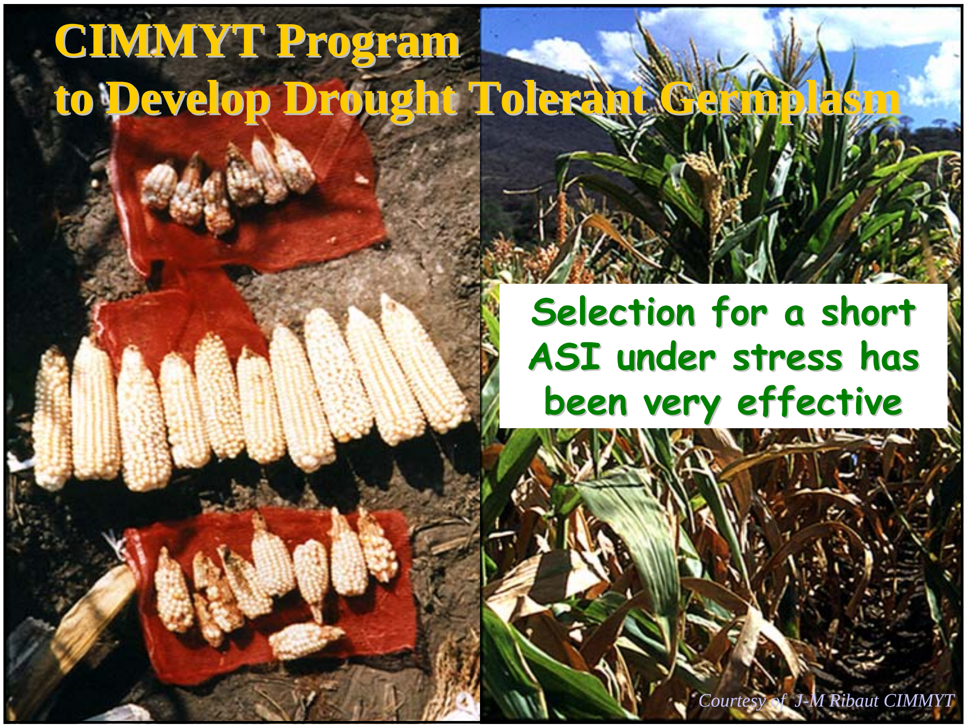
Maximum kernel set occurs when silk emergence begins 4 to 5 days before pollen shed.

Advantage under stress: silk emergence is delayed <u>into</u> peak pollen shed.

Field studies confirm low pollen density with ASI > 6 days limit kernel set



Bassetti and Westgate, 1994



Selection for a short Anthesis-Silking Interval during drought resulted in an earlier transition to rapid ear growth

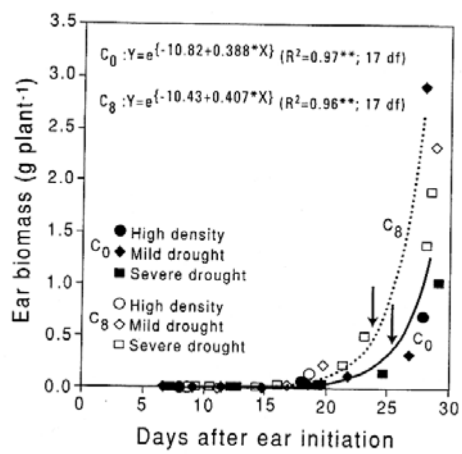
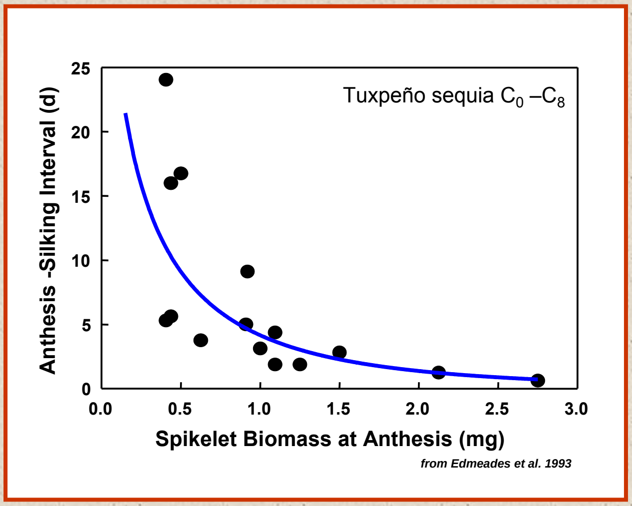


Fig. 4–4. Ear biomass vs. days after ear initiation for Tuxpeño Sequía C_0 (solid line) and Tuxpeño Sequía C_8 (dotted line) grown under stresses due to drought and high plant density, Tlaltizapán, México, 1989 -1990. Arrows indicate date of 50% anthesis (Edmeades et al., 1993, with permission).

The shorter ASI reflects a rapid rate of ovary growth at anthesis



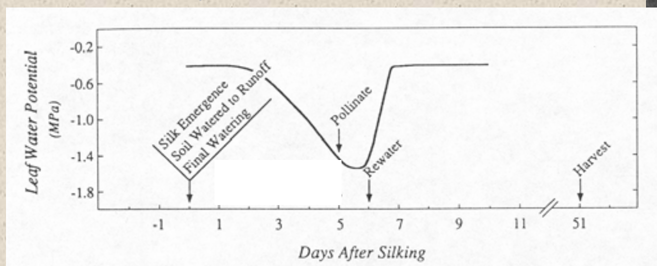
Phenotypic traits accompanying selection for greater tolerance to stressful (high population) environments -- indicate higher priority for ear development

"What is Yield" Duvick (1997)

Trait	slope	r^2
Tassel weight	0.05 g/year	-0.70
Silk delay	6 GDU/year	-0.61
Ears/100 plants	0.2/year	0.74
Kernels/ear	1.1 kernels/year	-0.11
Not root lodged	0.9%/year	0.68

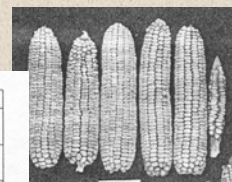
3. Failure of newly-formed kernels to develop

Stress during pollination causes more fertilized ovaries to abort



Zinselmeier et al. 1995

Control | K#



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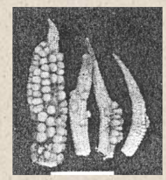
Stressed



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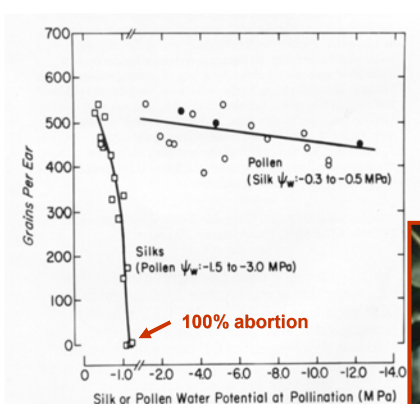
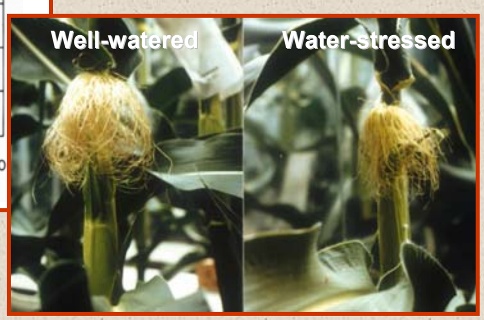
Success of kernel set when pollen is available depends on conditions within the pistillate flowers…



Westgate and Boyer 1986



High temperature is not a problem for the ovary

-- Exposure to 40°C for 4 h does not affect female flower function

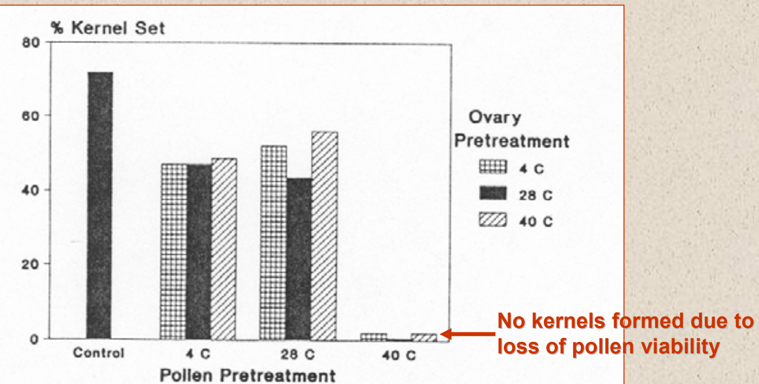
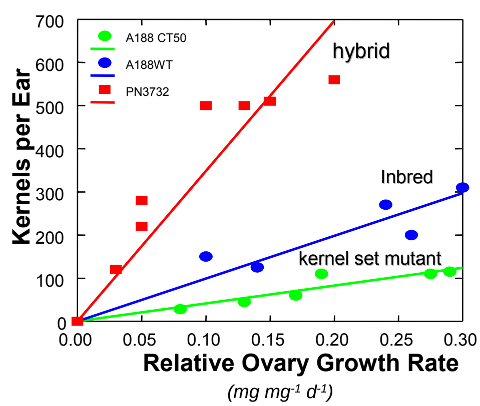


Figure 9. Effect of temperature on the success on *in vitro* pollination of maize ovaries. Pollen and/or isolated ovaries were pre-treated at the indicated temperature for 4 h prior to pollination. All treatments and pollinations were conducted in a humid chamber (from ref. 4), with permission of American Society of Plant Physiologists).

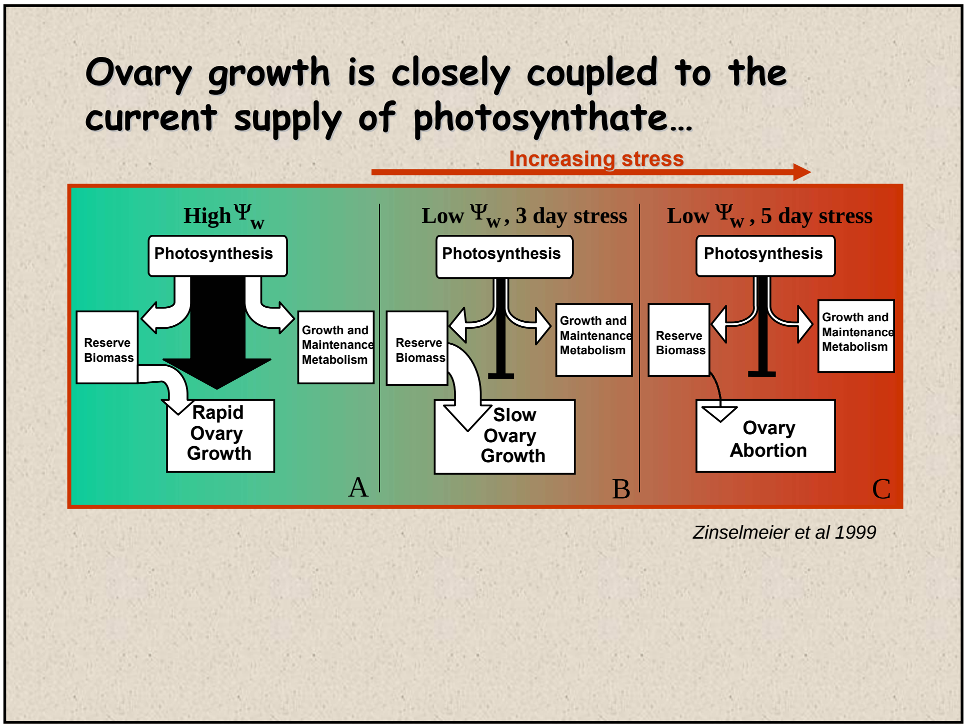
Dupuis and Dumas 1991

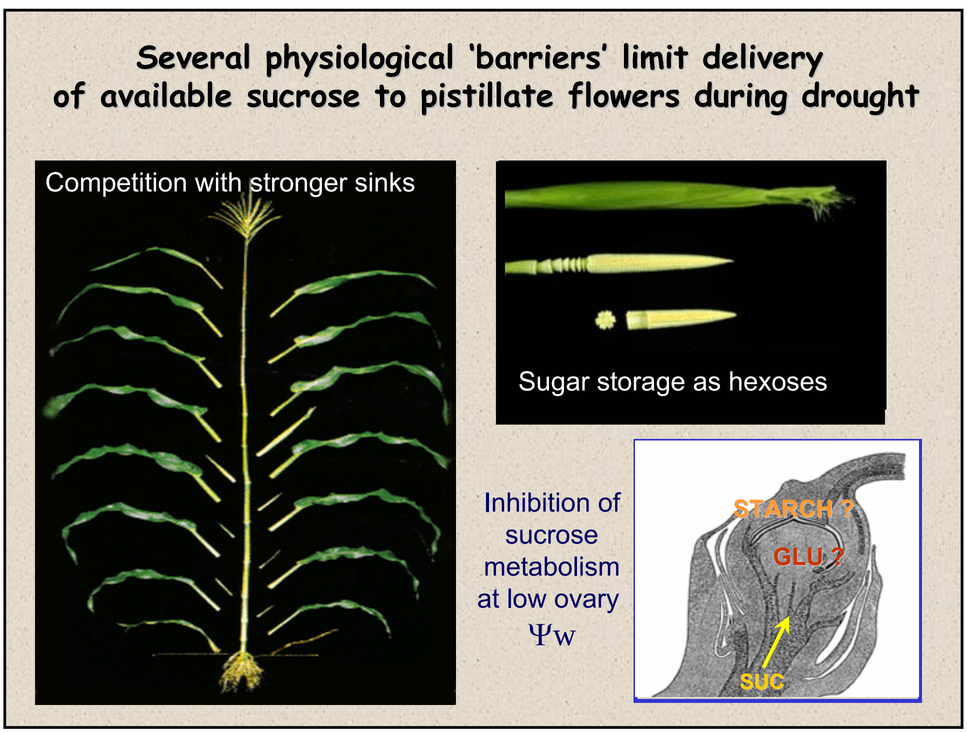
Kernel set in maize is closely correlated with ovary growth rate during anthesis

Plant stress caused drought, shading, density slow ovary growth rate, leading to abortion

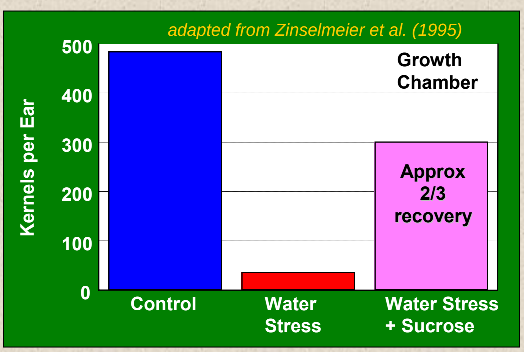


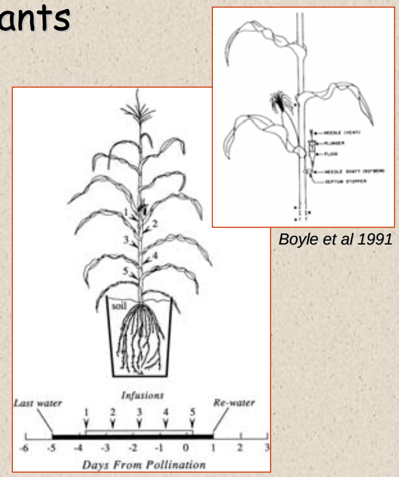
Schussler et al 1991
Zinselmeier et al 1995


Ovary growth is closely coupled to the current supply of photosynthate…
Increasing stress
High Ψw
Low Ψw, 3 day stress
Low Ψw, 5 day stress
Photosynthesis
Reserve Biomass
Growth and Maintenance Metabolism
Rapid Ovary Growth
Slow Ovary Growth
Ovary Abortion
A
B
C
Zinselmeier et al 1999


Several physiological 'barriers' limit delivery of available sucrose to pistillate flowers during drought
Competition with stronger sinks
Sugar storage as hexoses
Inhibition of sucrose metabolism at low ovary Ψw
STARCH ?
GLU ?
SUC

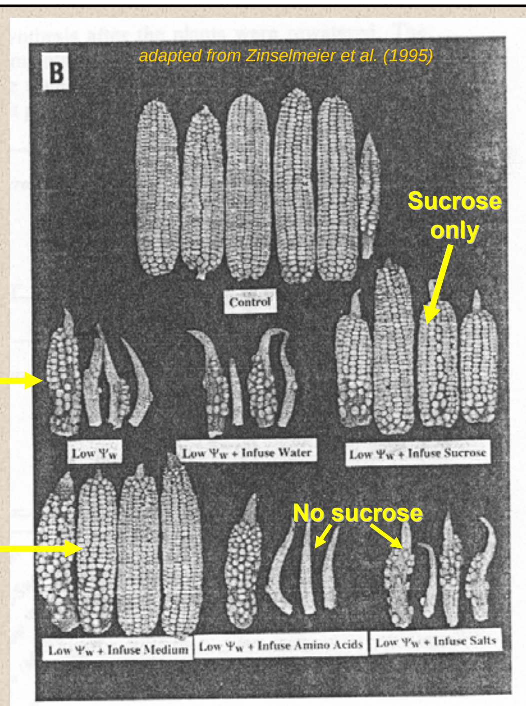
Artificially supplying extra photosynthate (sucrose) via stem infusion recovers about 70% of the kernels that would have aborted in water stressed plants

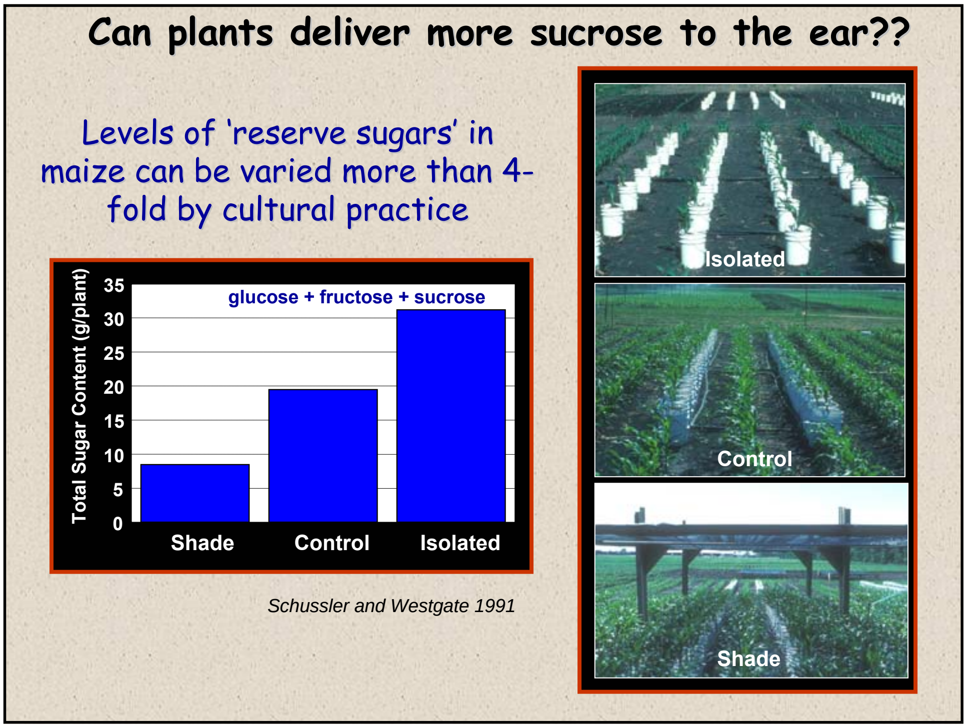


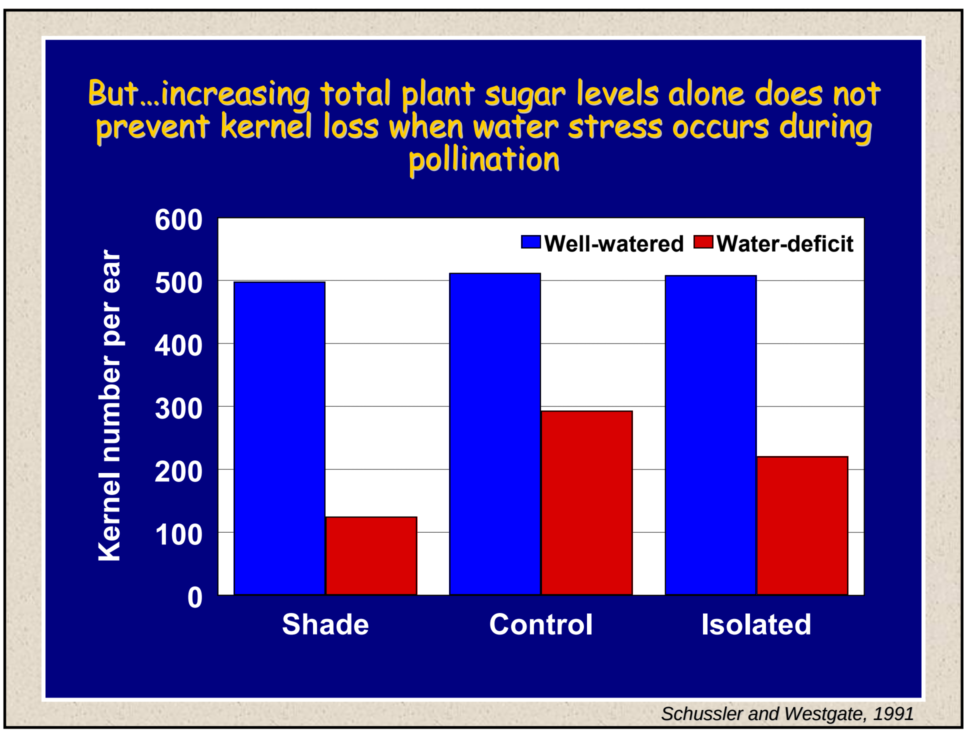


Boyle et al 1991

Additional sucrose overcomes kernel loss due to severe water deficit during pollination

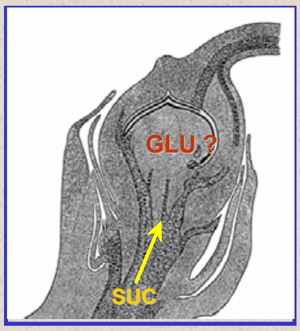



Can plants deliver more sucrose to the ear??
Levels of 'reserve sugars' in maize can be varied more than 4-fold by cultural practice
Total Sugar Content (g/plant)
35
30
25
20
15
10
5
0
glucose + fructose + sucrose
Shade
Control
Isolated
Schussler and Westgate 1991
Isolated
Control
Shade


But…increasing total plant sugar levels alone does not prevent kernel loss when water stress occurs during pollination
Kernel number per ear
600
500
400
300
200
100
0
Well-watered
Water-deficit
Shade
Control
Isolated
Schussler and Westgate, 1991

Severe water stress affects the capacity of the ovaries to utilize sucrose supplied by the plant

-- production of enzymes that metabolize sucrose is inhibited



Zinselmeier et al 1999

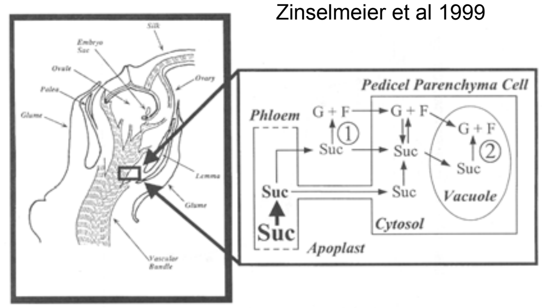
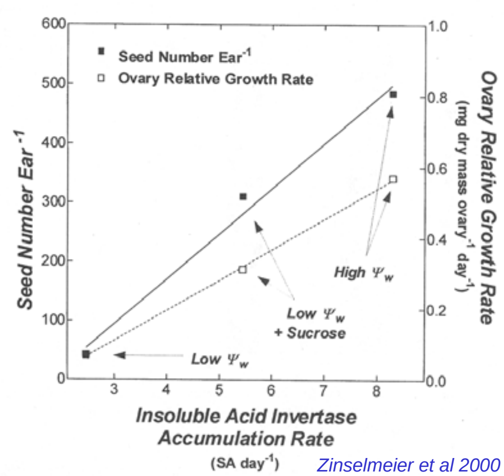


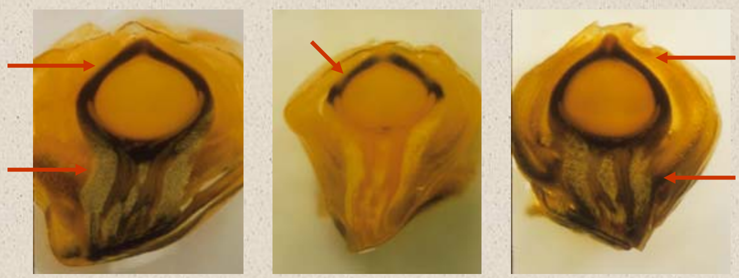
Fig. 1–1. Model depicting the possible fates of sucrose after phloem unloading in a hypothetical pedicel parenchyma cell in a developing maize ovary. 1 = insoluble acid invertase. 2 = soluble acid invertase. Longitudinal section is redrawn from Miller (1919).

The relative inhibition of insoluble invertase activity is correlated with the inhibition of ovary growth rate and subsequent kernel set



Zinselmeier et al 2000

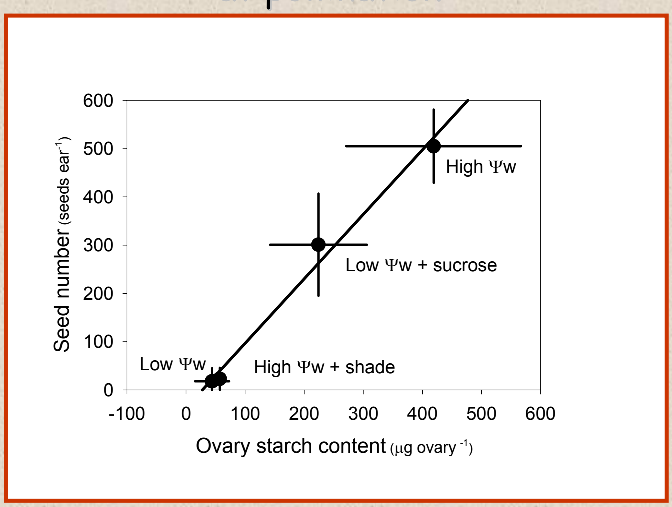
Ovaries deplete starch 'reserves' during drought. Supplemental sucrose increases ovary starch content during drought



Control **-H_2O** **-H_2O + sucrose**

Arrows indicate areas of starch deposition

Kernel set is correlated with ovary starch content at pollination



from Zinselmeier et al 2000

General conclusions: "Plant Stress" during corn pollination…

- Has little impact on pollen function (except at extremely high temperatures)
- Inhibits development of the female flowers resulting in asynchrony between pollen shed and silk emergence
- Accentuates the poor capacity of the female flowers to compete for assimilates produced by the plant

Improving kernel set in stressful environments requires…

- Adopting management practices that promote ear development and expansion
- Aggressive selection for rapid ear growth rate
- Greater understanding of mechanisms coupling sucrose metabolism and kernel formation

Crop Production and Physiology

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