Plants under Salt Stress: Is Energy a Limiting Factor?

Sven Schubert

Institute of Plant Nutrition (iFZ)

Heinrich-Buff-Ring 26-32

35392 Giessen

E-Mail: Sven.Schubert@ernaehrung.uni-giessen.de

Osmotic adjustment and energy limitations to plant growth in saline soil

(Munns, Passioura, Colmer, and Byrt: New Phytol. 1-5, 2019)

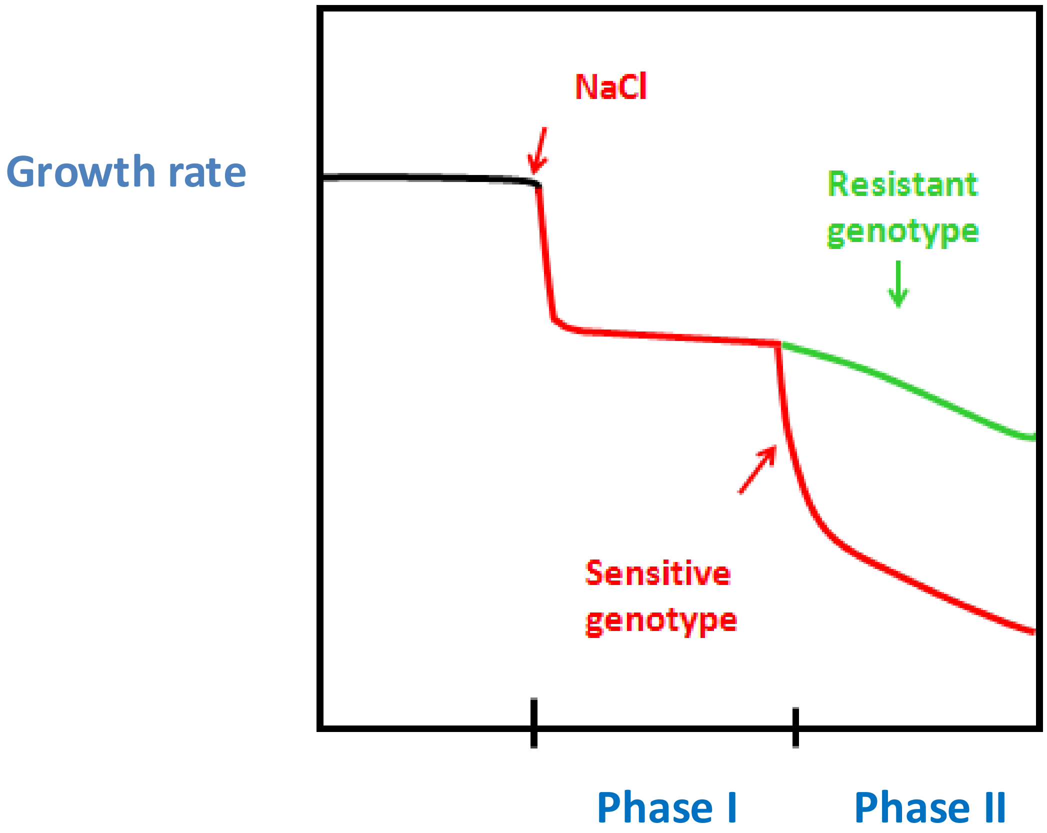
The authors calculated the costs of osmotic adjustment and ion exclusion. They suggested to explore energy-saving traits for the development of salt-resistant crops.

However:

Is energy a limiting factor for plants grown in saline soils?

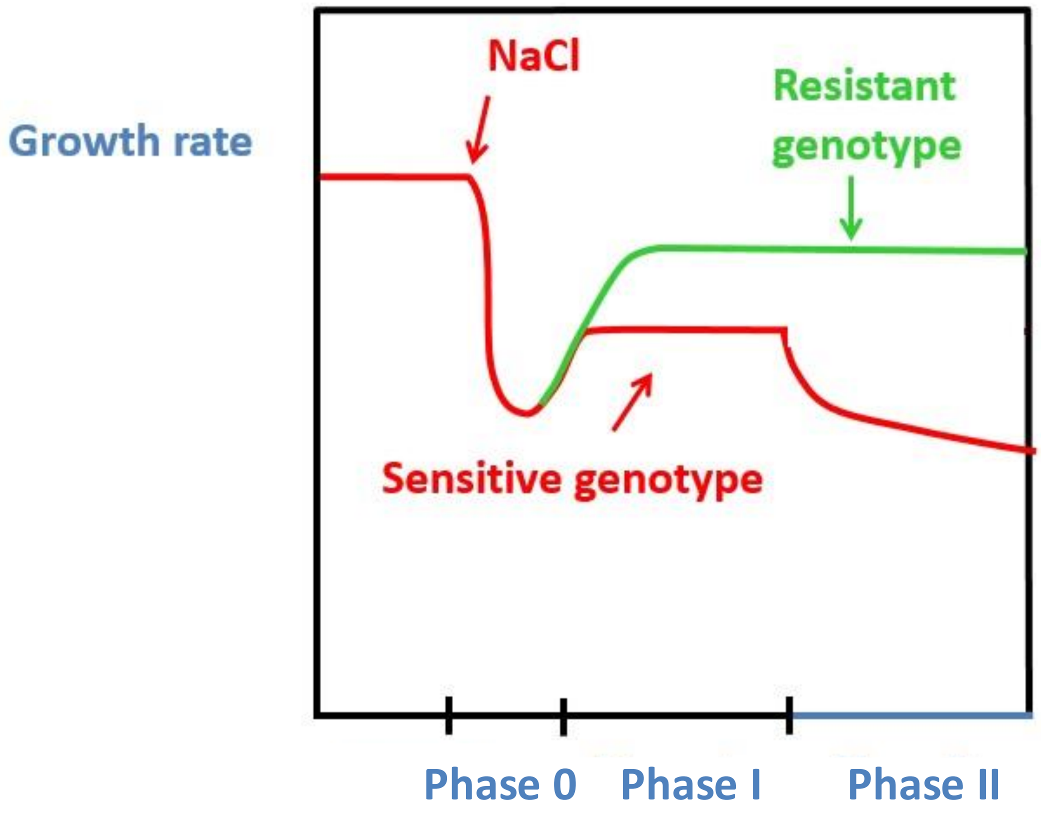
Growth responses to salt stress

(Munns 1993. Plant Cell Environ. 16, 15–24, 1993)



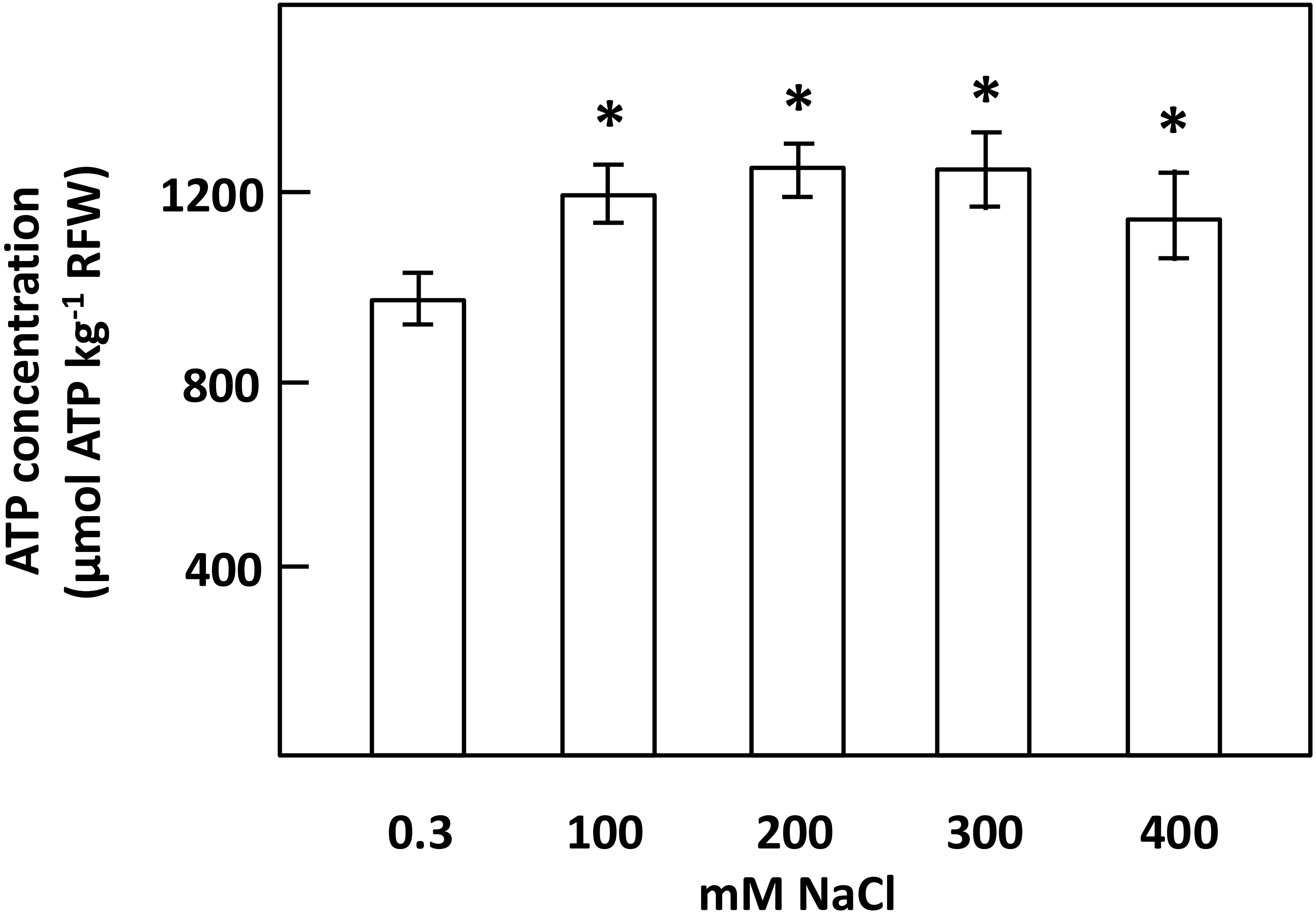
Growth responses to salt stress

(Schubert, *In:* The Molecular Basis of Nutrient Use Efficiency in Crops (M. Hawkesford and P. Barraclough, Hrsg.) Wiley Blackwell, Ames, USA, pp. 443-455 (2011)



Effect of NaCl on ATP concentrations of maize roots (cv. Pioneer 3905) after an incubation period of 30 min

(Schubert, unpublished)



Effect of a 5 d local nutrient supply on adenosine nucleotide concentrations (µmol kg^{-1}) and energy charge (EC) in maize roots (cv. Blizzard)

(Schubert and Yan: J. Plant Nutr. Soil Sci. 162, 577-582, 1999)

Parameter	NS	Ca	SRNS	SRCa
ATP	1102 (±207)	633 (±60)	1165 (±139)	601(±36)
ADP	118 (±15)	80 (±2)	83 (±10)	87 (±10)
AMP	255 (±8)	153 (±14)	259 (±8)	111 (±6)
EC	0.78 (±0.03)	0.78 (±0.01)	0.80 (±0.02)	0.81 (±0.02)

The increase in ATP concentration is related to an increase in respiration, but not in alternative respiration or relative abundance of transcripts of uncoupling proteins (Heinrich, Faust, and Schubert, unpublished)

There are many mechanisms to increase ATP concentrations:

1. Increase of respiration
2. Increase of photosynthesis
3. Decrease of alternative respiration in favor of conventional respiration
4. Reduction of metabolic energy dissipation by uncoupling proteins
5. Decrease of root exudation and volatilization of organic compounds

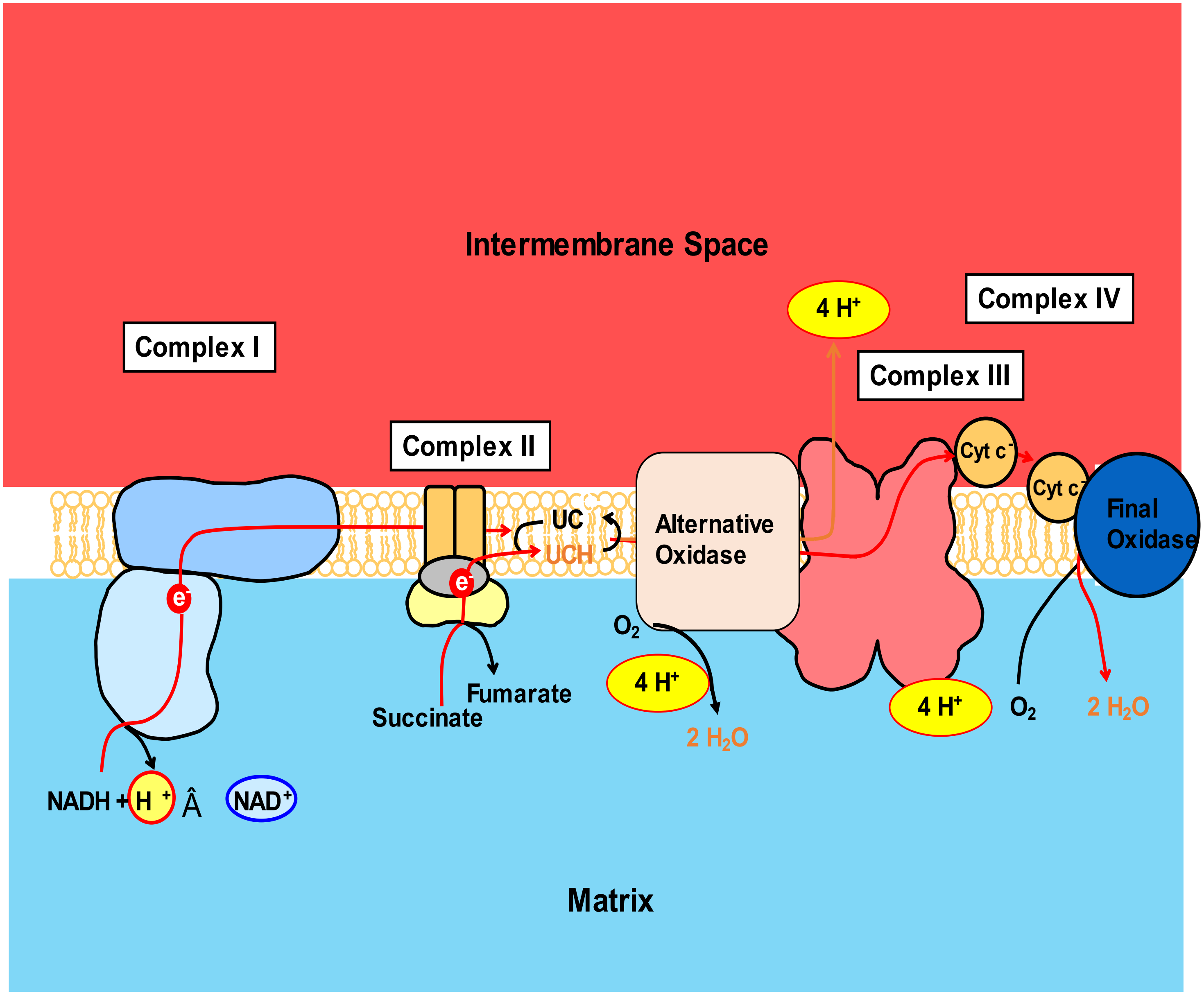
There are many mechanisms to increase ATP concentrations:

1. Increase of respiration
2. Increase of photosynthesis
3. Decrease of alternative respiration in favor of conventional respiration
4. Reduction of metabolic energy dissipation by uncoupling proteins
5. Decrease of root exudation and volatilization of organic compounds

There are many mechanisms to increase ATP concentrations:

1. Increase of respiration
2. Increase of photosynthesis
3. Decrease of alternative respiration in favor of conventional respiration
4. Reduction of metabolic energy dissipation by uncoupling proteins
5. Decrease of root exudation and volatilization of organic compounds

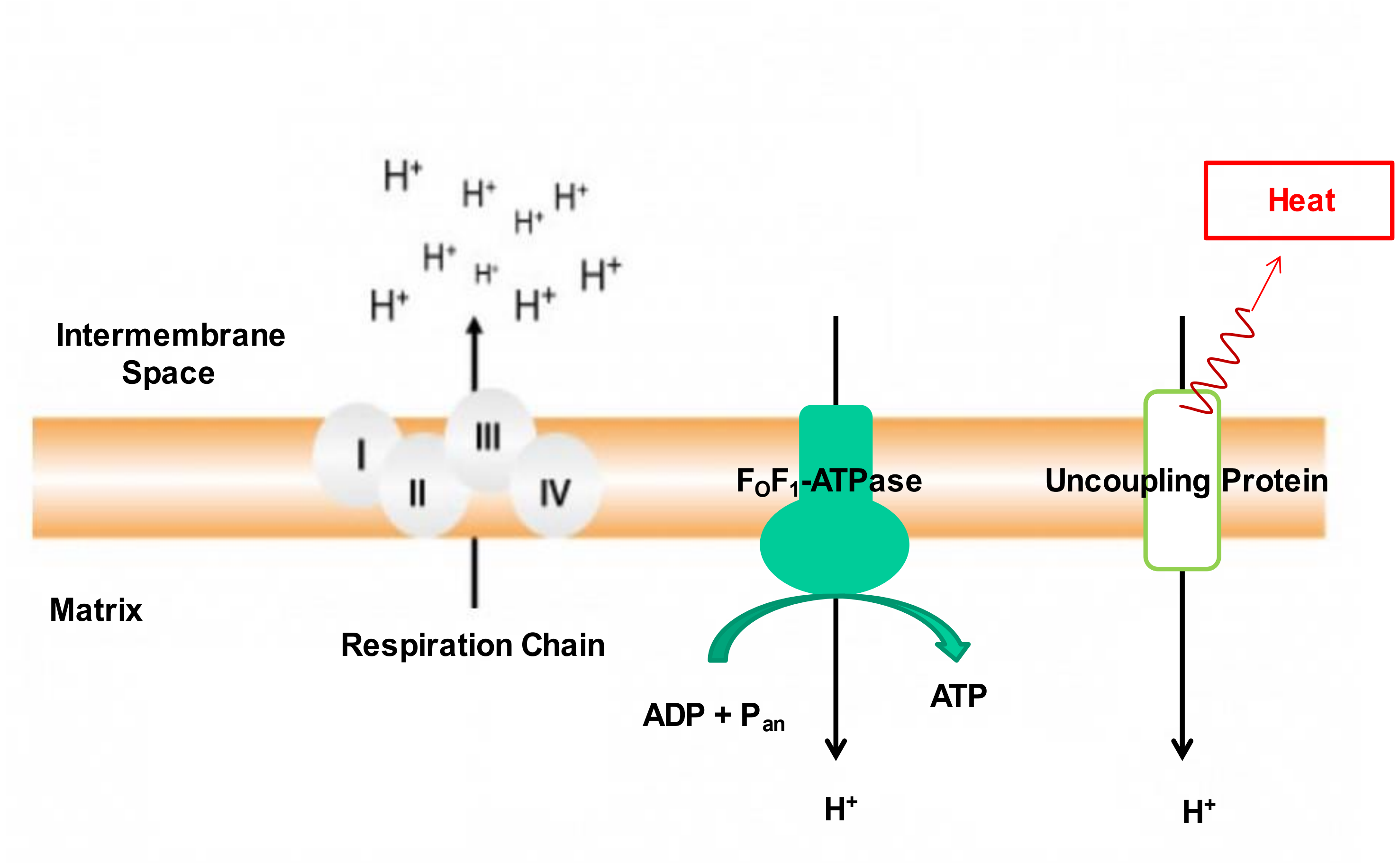
The respiration chain in the inner mitochondrial membrane of plants with the final oxidase and the alternative oxidase



There are many mechanisms to increase ATP concentrations:

1. Increase of respiration
2. Increase of photosynthesis
3. Decrease of alternative respiration in favor of conventional respiration
4. Reduction of metabolic energy dissipation by uncoupling proteins
5. Decrease of root exudation and volatilization of organic compounds

Inducible uncoupling proteins in the inner mitochondrial membrane decrease ATP production by the F_oF_1-ATPase

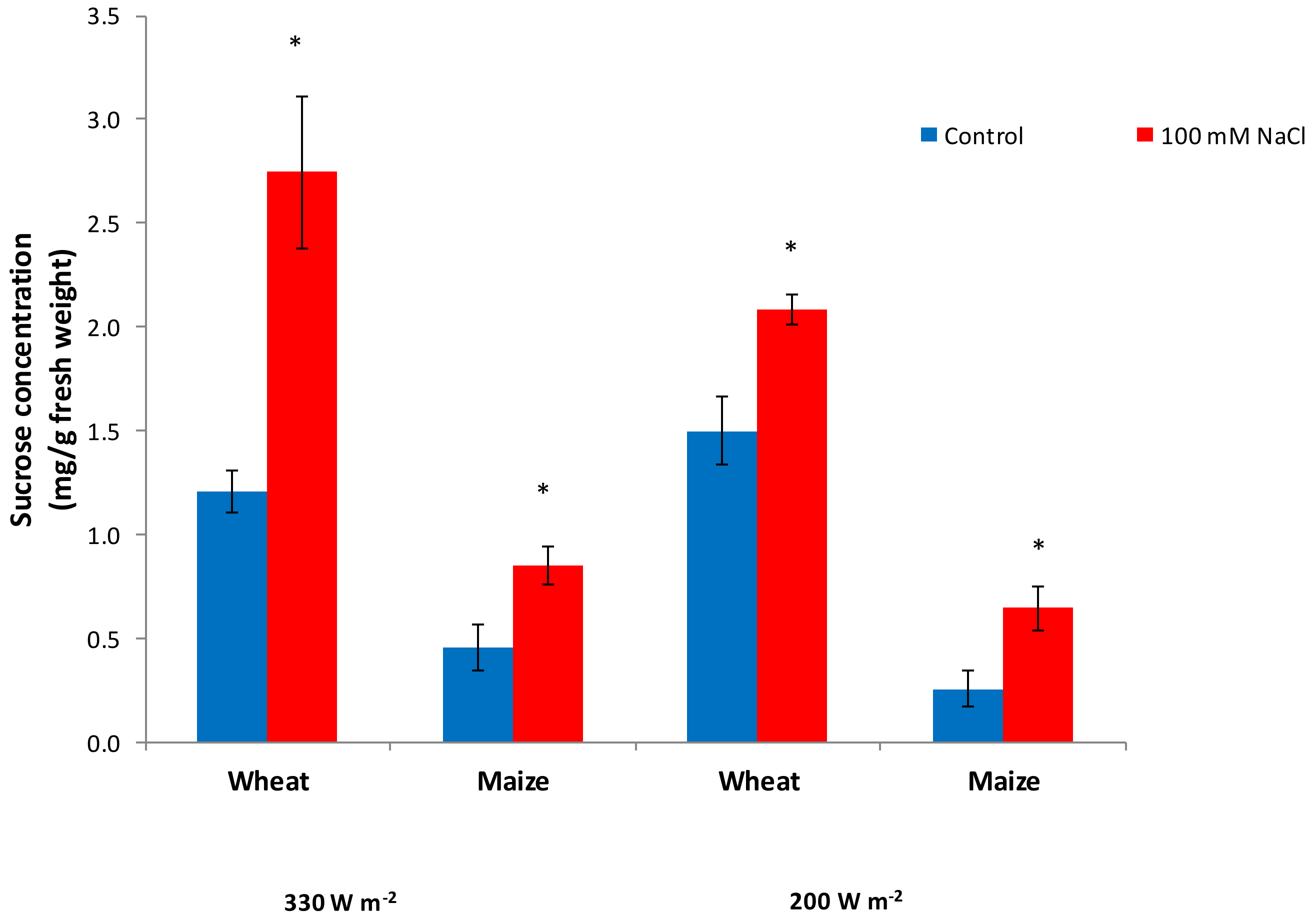


There are many mechanisms to increase ATP concentrations:

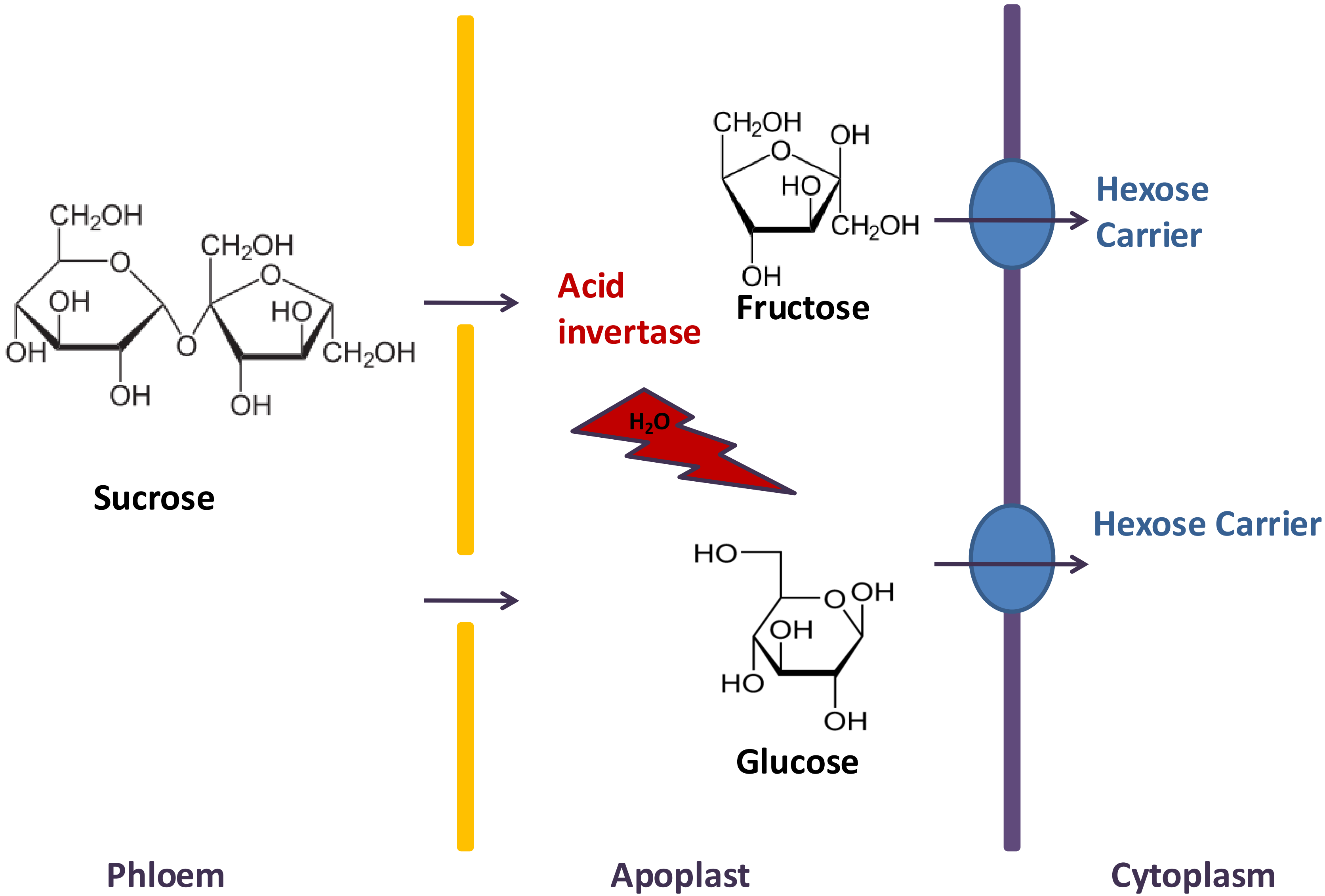
1. Increase of respiration
2. Increase of photosynthesis
3. Decrease of alternative respiration in favor of conventional respiration
4. Reduction of metabolic energy dissipation by uncoupling proteins
5. Decrease of root exudation and volatilization of organic compounds

Effect of salt stress on sucrose concentration in the young shoots of wheat and maize under high and low light intensity

(Hatzig, Kumar, Neubert, and Schubert: J. Agron. Crop Sci. 196, 185-192, 2010)

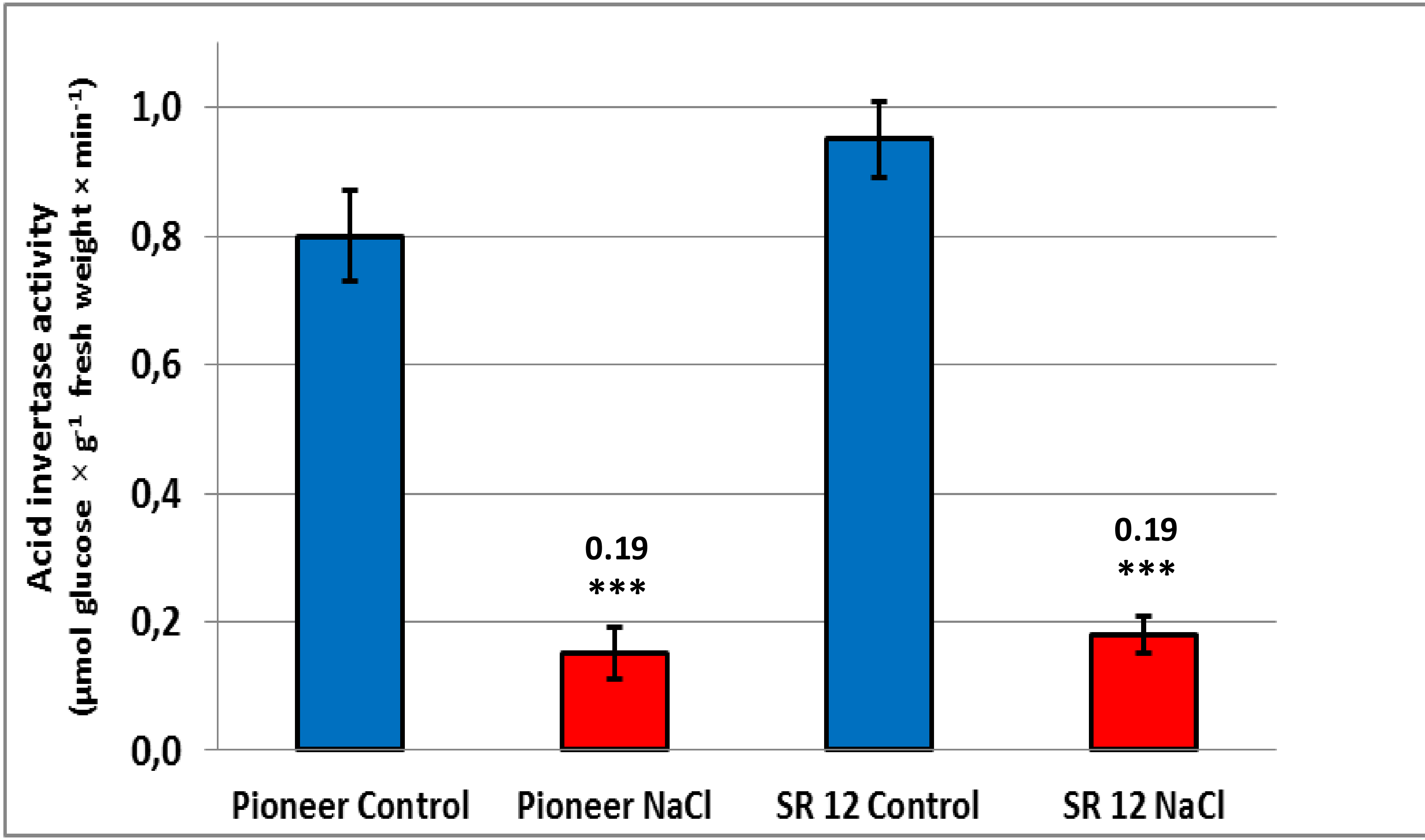


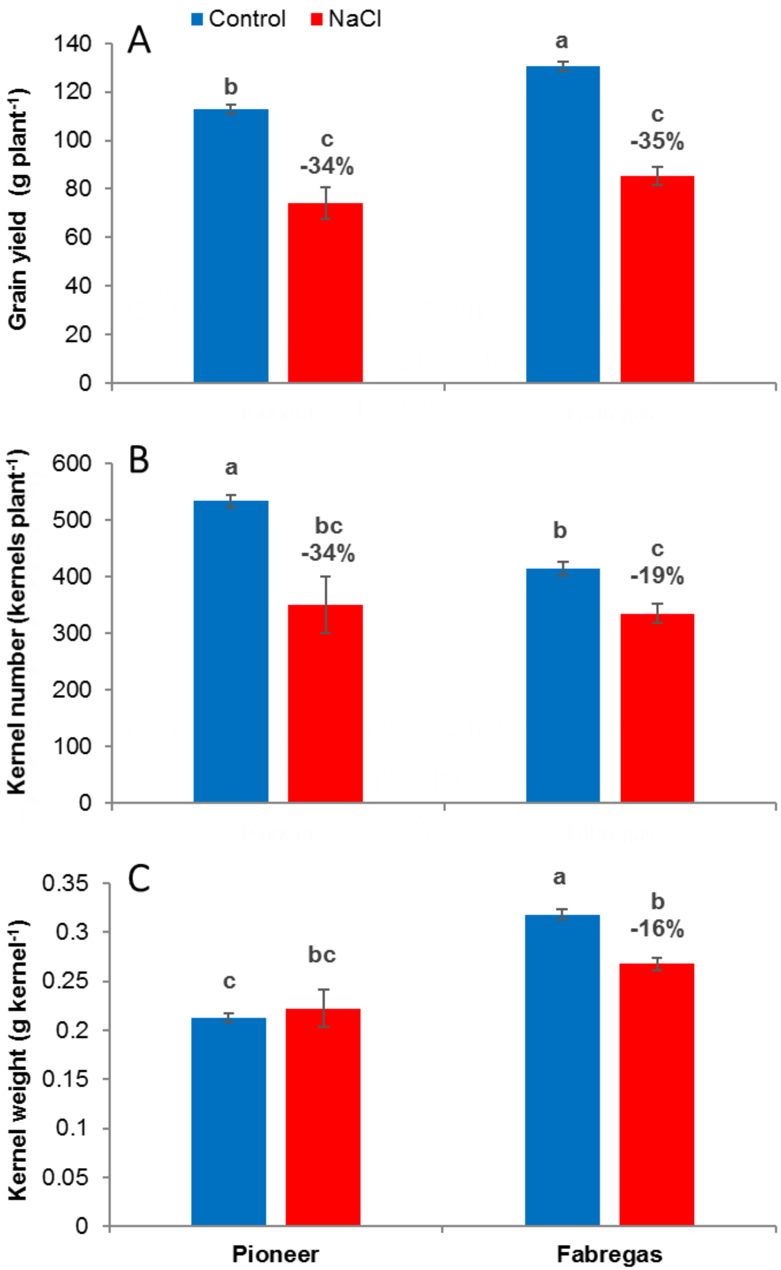
Acid invertase determines sink activity:



Effect of salt stress (100 mM) on the acid invertase activity in developing kernels of various maize hybrids

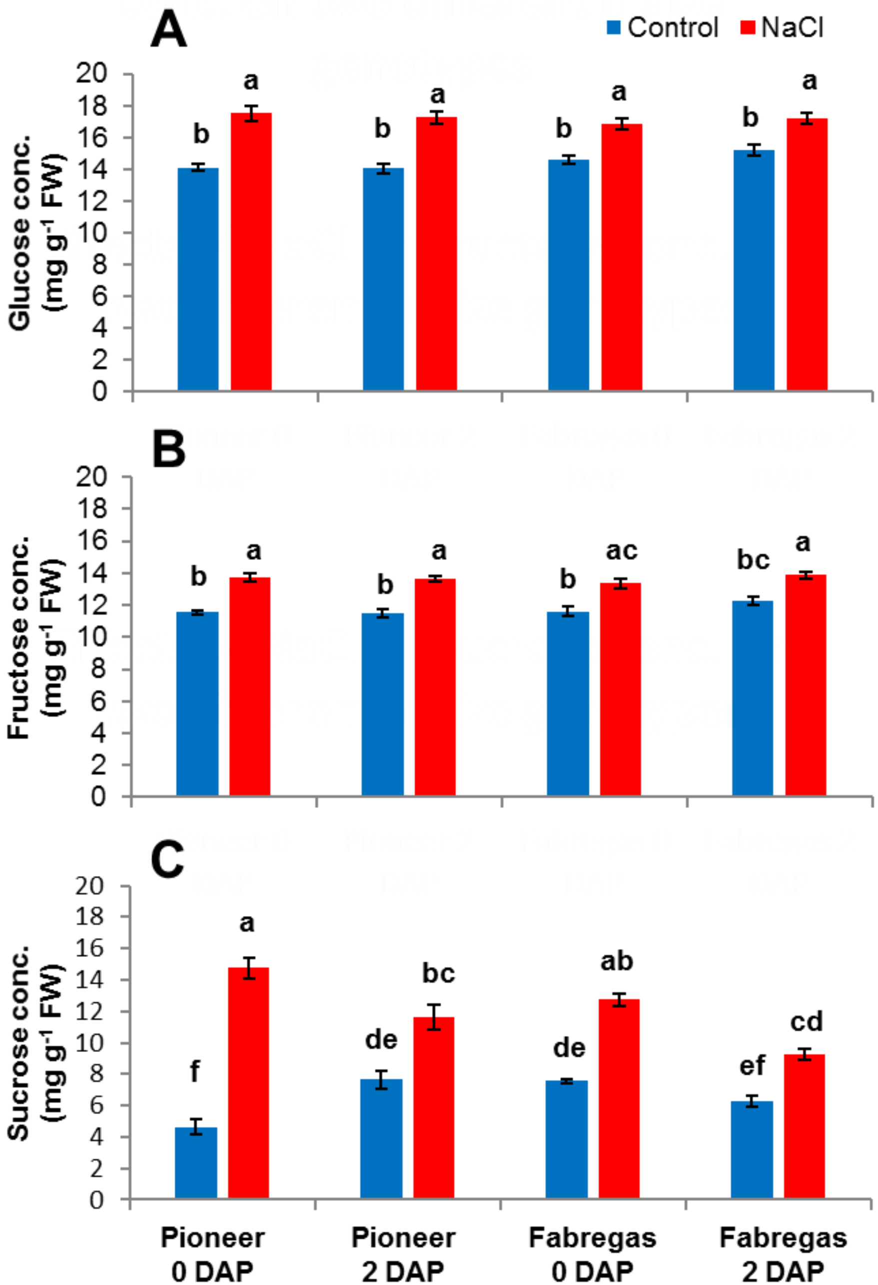
(Hütsch, Saqib, Osthushenrich and Schubert, J. Plant Nutr. Soil Sci. 177, 278-286, 2014)





Effect of salt stress on: grain yield (A), kernel number (B), and kernel weight (C) at kernel maturity of two maize cultivars

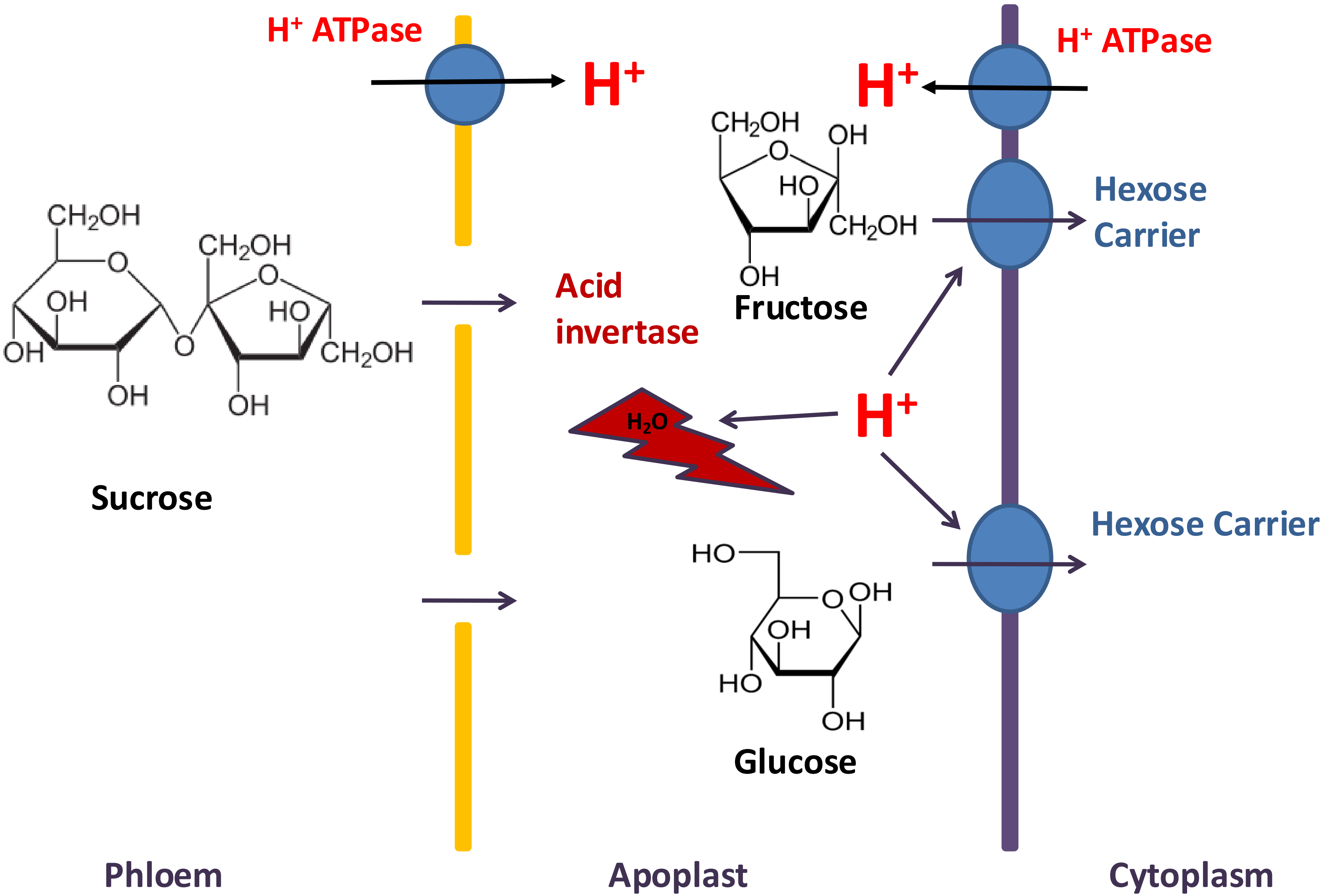
(Jung, Hütsch, and Schubert:
Plant Physiol. Biochem. 113, 198-207, 2017)



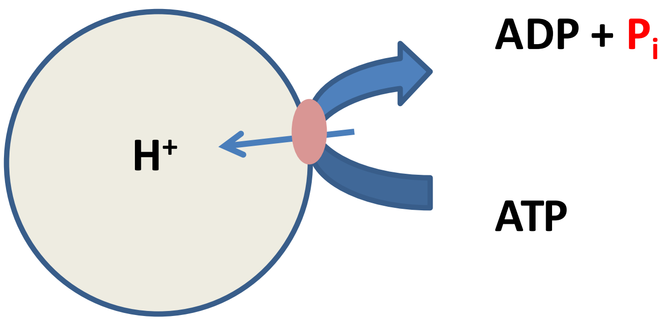
Effect of salt stress on: glucose concentration (A), fructose concentration (B), and sucrose concentration (C) 0 and 2 d after pollination (DAP) of two maize cultivars

(Jung, Hütsch, and Schubert:
Plant Physiol. Biochem. 113, 198-207, 2017)

Is H^+-ATPase a key enzyme that determines sink activity?



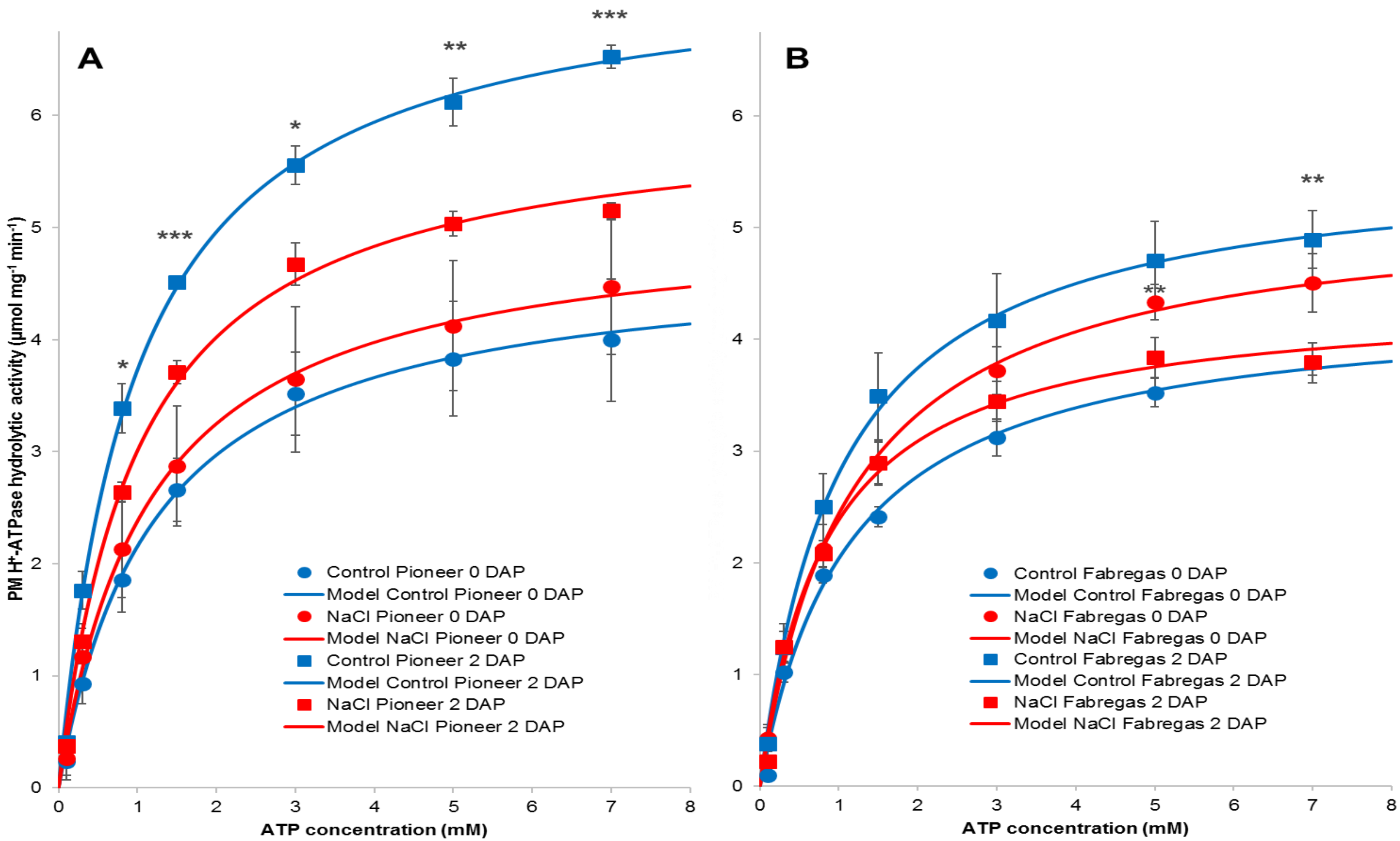
Determination of hydrolytic activity



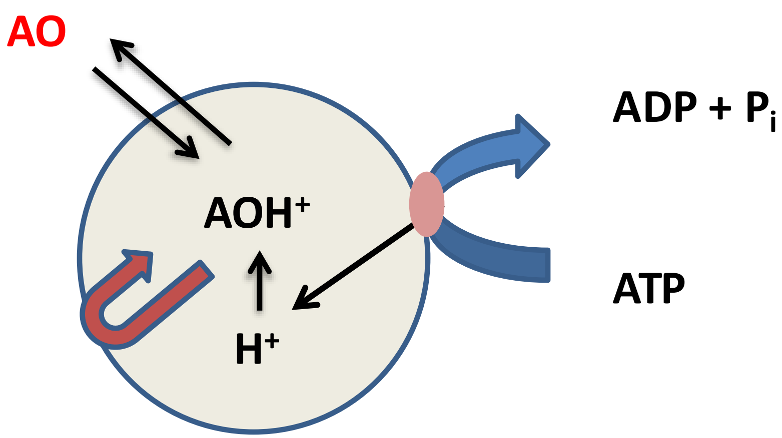
- liberation of inorganic phosphate
- photometer (820 nm):
  P_i + molybdate → complex
  complex is reduced by ascorbic acid → blue complex

Effect of salt stress on the hydrolytic H^+-ATPase activity of plasma membrane vesicles isolated from maize kernels of cultivars Pioneer 3906 and Fabregas 0 and 2 d after pollination (DAP)

(Jung, Hütsch, and Schubert: Plant Physiol. Biochem. 113, 198-207, 2017)

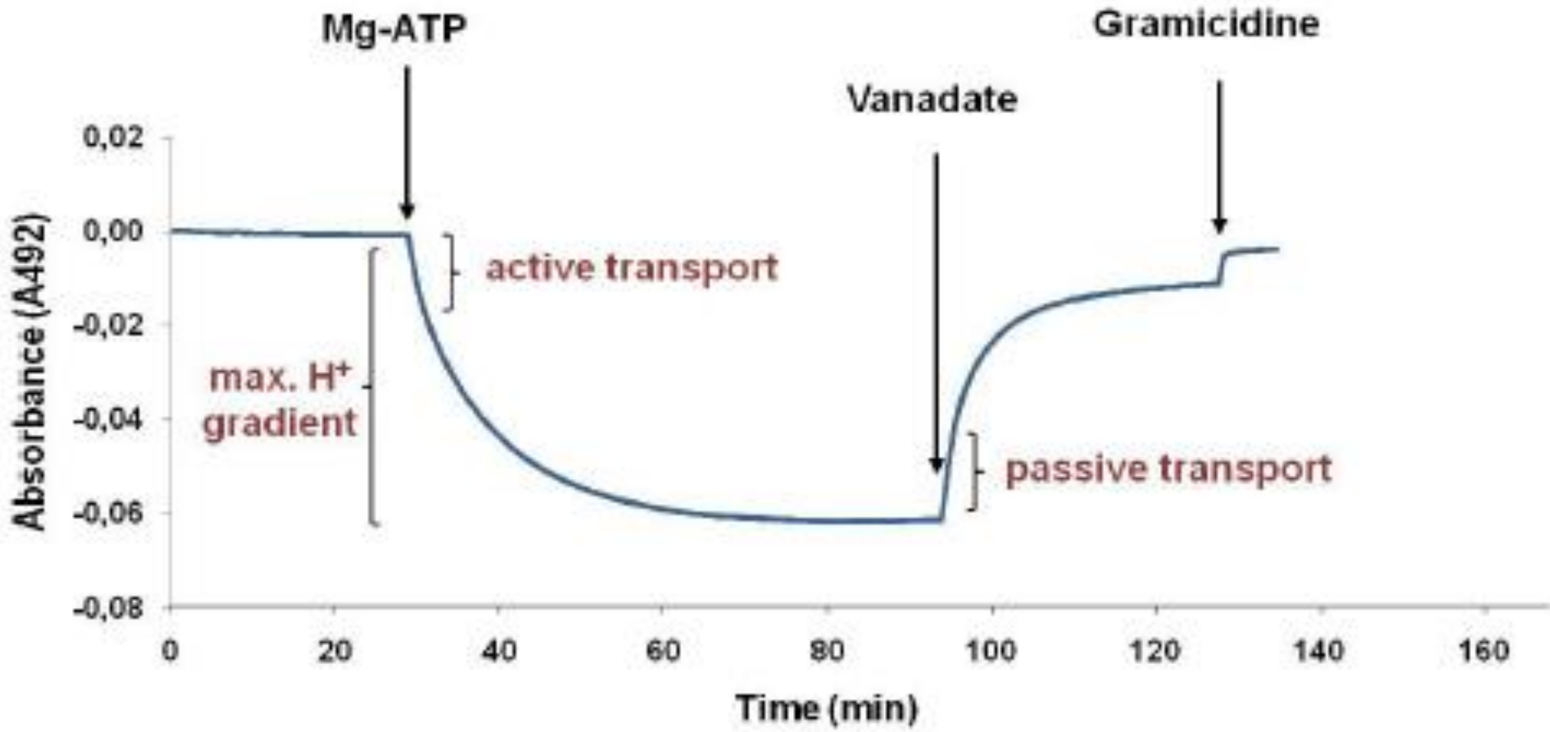


Determination of proton pumping activity



Decrease of absorbance (492 nm) by “capture“ of acridin orange (AO) inside of vesicles

Determination of proton pumping activity



Effect of salt stress on *in vitro* H^+ transport of plasma membrane vesicles isolated from maize kernels of cultivars Pioneer 3906 and Fabregas 0 and 2 d after pollination (DAP)

(Jung, Hütsch, and Schubert: Plant Physiol. Biochem. 113, 198-207, 2017)

		Pioneer 3906 0 DAP	Pioneer 3906 2 DAP	Fabregas 0 DAP	Fabregas 2 DAP
Active H^+ transport rate (influx) (ΔA_{492} µg $protein^{-1}$ min^{-1})	Control	0.21 ± 0.03	0.85 ± 0.06	0.12 ± 0.02	0.58 ± 0.02
	NaCl	0.23 ± 0.06	0.76 ± 0.02	0.14 ± 0.02	0.62 ± 0.04
Max. pH gradient (ΔA_{492})	Control	0.048 ± 0.005	**0.065 ± 0.002**	0.040 ± 0.002	0.051 ± 0.001
	NaCl	0.046 ± 0.001	**0.058* ± 0.001**	0.037 ± 0.002	0.048 ± 0.001
Passive H^+ transport rate (efflux) (ΔA_{492} µg $protein^{-1}$ min^{-1})	Control	0.28 ± 0.05	0.45 ± 0.04	0.34 ± 0.03	0.35 ± 0.04
	NaCl	0.35 ± 0.03	0.36 ± 0.03	0.30 ± 0.05	0.26 ± 0.04

Conclusions:

1. ATP concentrations can be flexibly adjusted according the plant‘s need and a shortage of ATP does not occur under salt stress.
2. There is no source limitation under salt stress (unless plant tissue is severely damaged by ion toxicity in Phase II).
3. Plant growth is limited by sink activity in vegetative and generative growth phases.
4. Energy-saving traits do not deserve priority in breeding programs.

Thank you for your attention!