Silicon (Si): A Plant Beneficial Nutrient for Horticultural Crops

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Today's talk……

- Introduction
- Silicon (Si) uptake and transportation root to leaf
- Interesting facts
- Si sources, application methods / rate
- Si related research at UF/IFAS NFREC
- Take-home message

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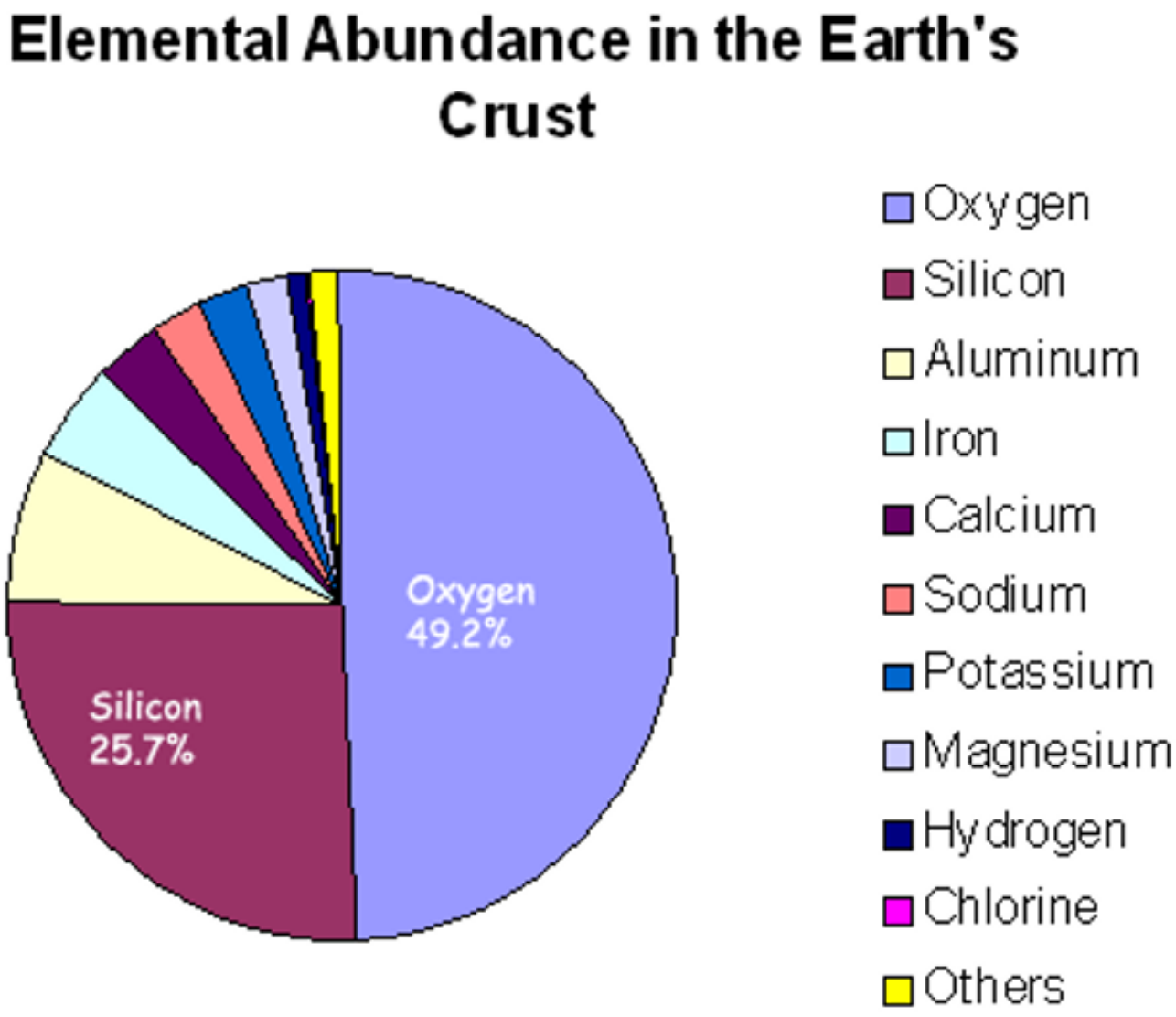
Introduction



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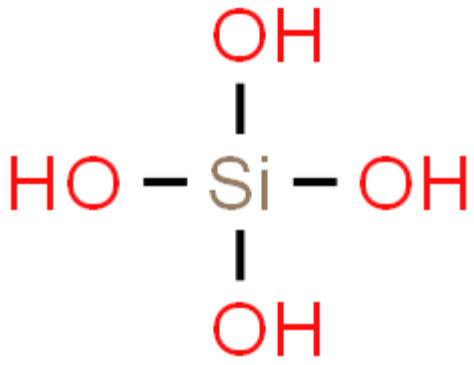
Silicon not Silicone

- **Silicon:**
- Orthosilicic acid: H_4SiO_4
  - Form absorbed by plants
- Silica, SiO_2, Quartz amorphous glass
  - Form deposited into plant tissues



- **Silicone:**
- Polymer of Si, C, H, and O
- Rubber-like consistency
- Commonly used in cookware, sealant, adhesive, lubricant

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Si concentration in plants

- Si concentration ranges 0.1 to 10% (dry weight basis)
- Monocots present higher level than dicots
- Si level increased in the following pattern

  Legumes < fruits < vegetables < grasses < grain crops

- Concentration of Si in a plant varies from organ to organ, with higher amount in mature leaves

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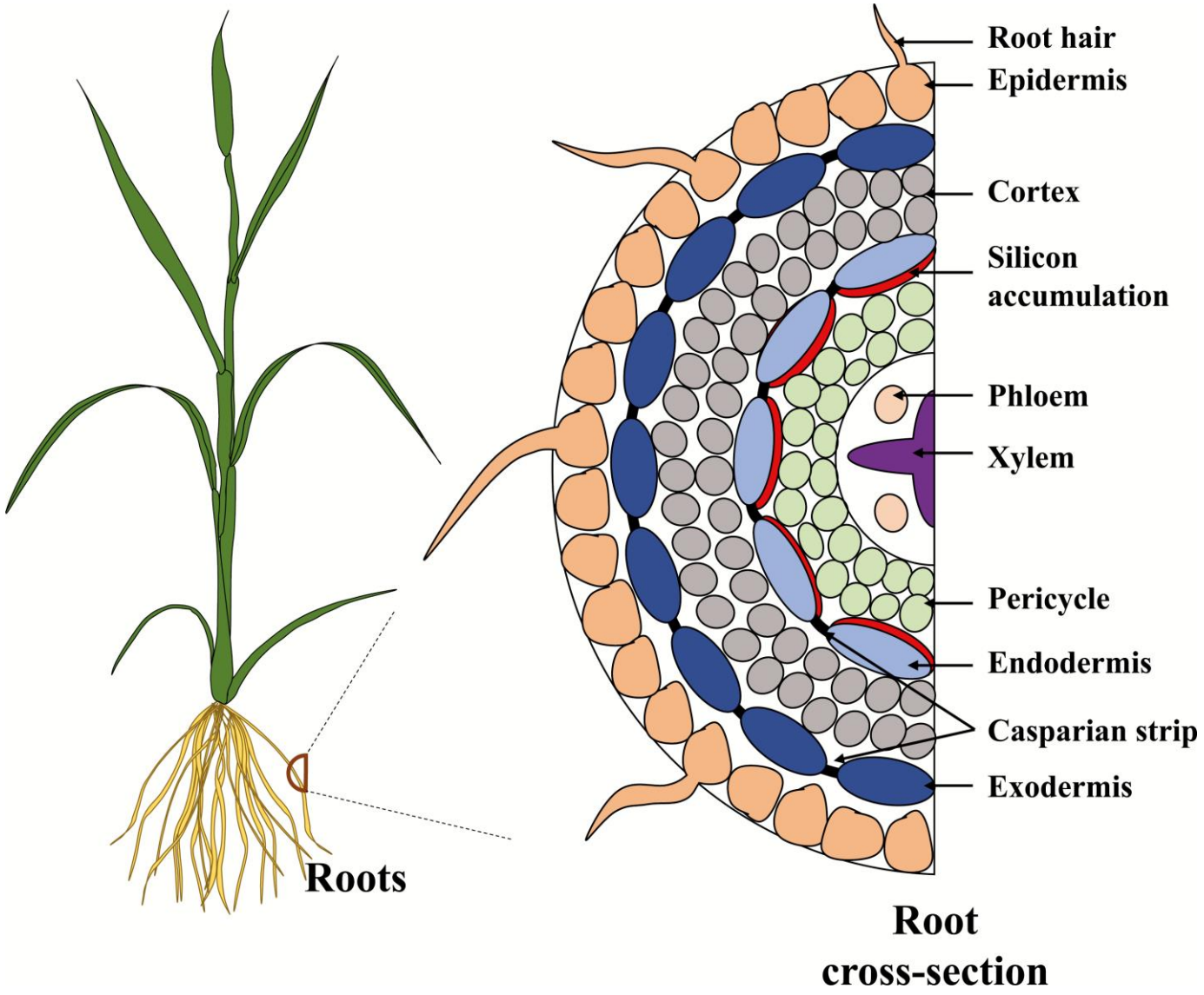
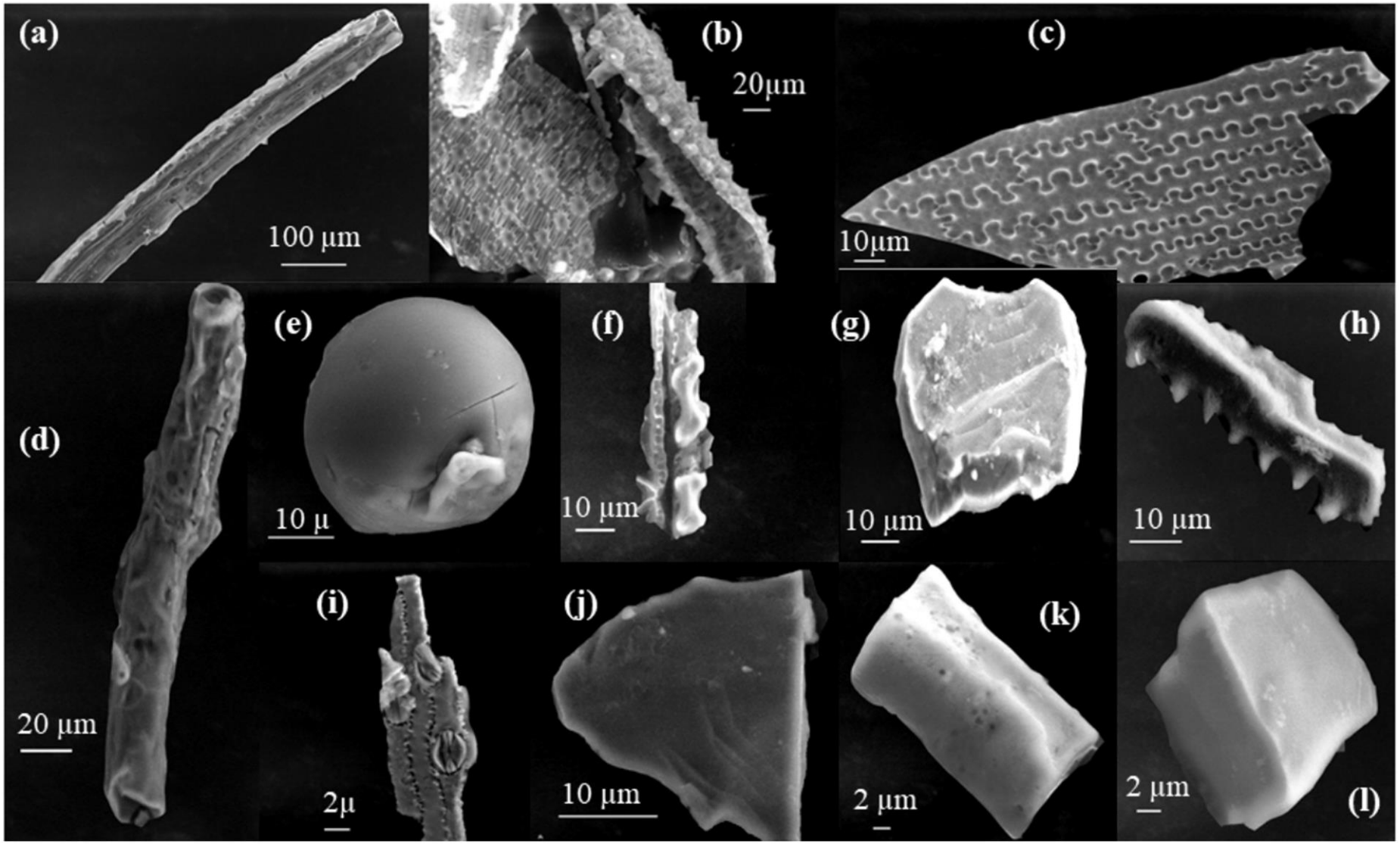
Silicification: Silicon deposition in leaf and root



Mandlik et al., 2020 & Lux et al, 2019

Silicon Deposition as Phytoliths of different Shapes



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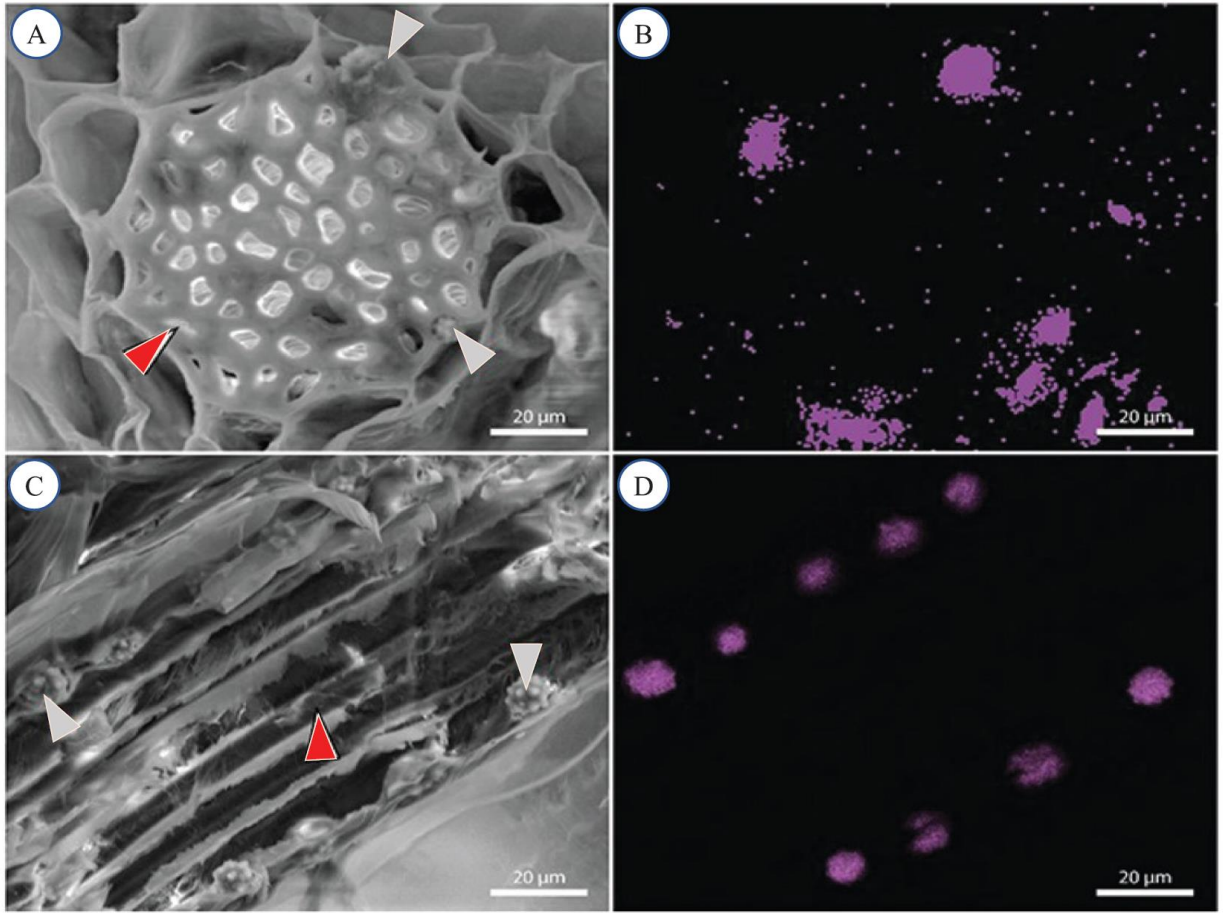
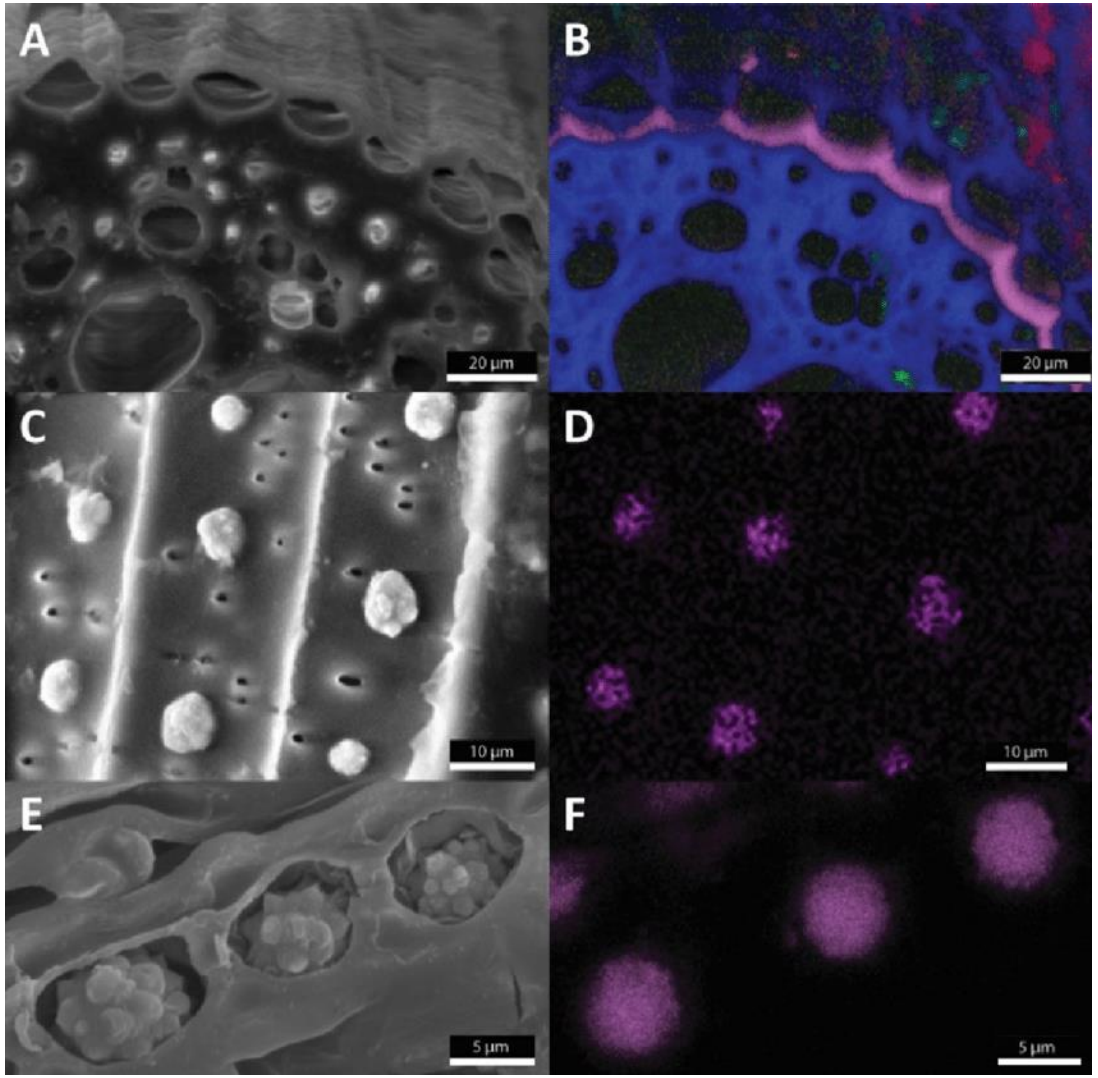
Rashid et al., 2019

Silicon deposition in date palm & wheat root





Mandlik et al., 2020

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Is Si beneficial or Essential???

Essential Element	Beneficial Element
Plant must be unable to complete its life cycle in absence of mineral element	Not required to complete the life cycle
The function of the element must not be replaceable by another mineral element	Compensate toxic effects of other elements or replace mineral nutrients in some other less specific functions
The element must be directly involved in plant metabolism	Don’t directly involved in plant metabolism
N, P, K,C, H, O, Mg, S	Si, Se, Co

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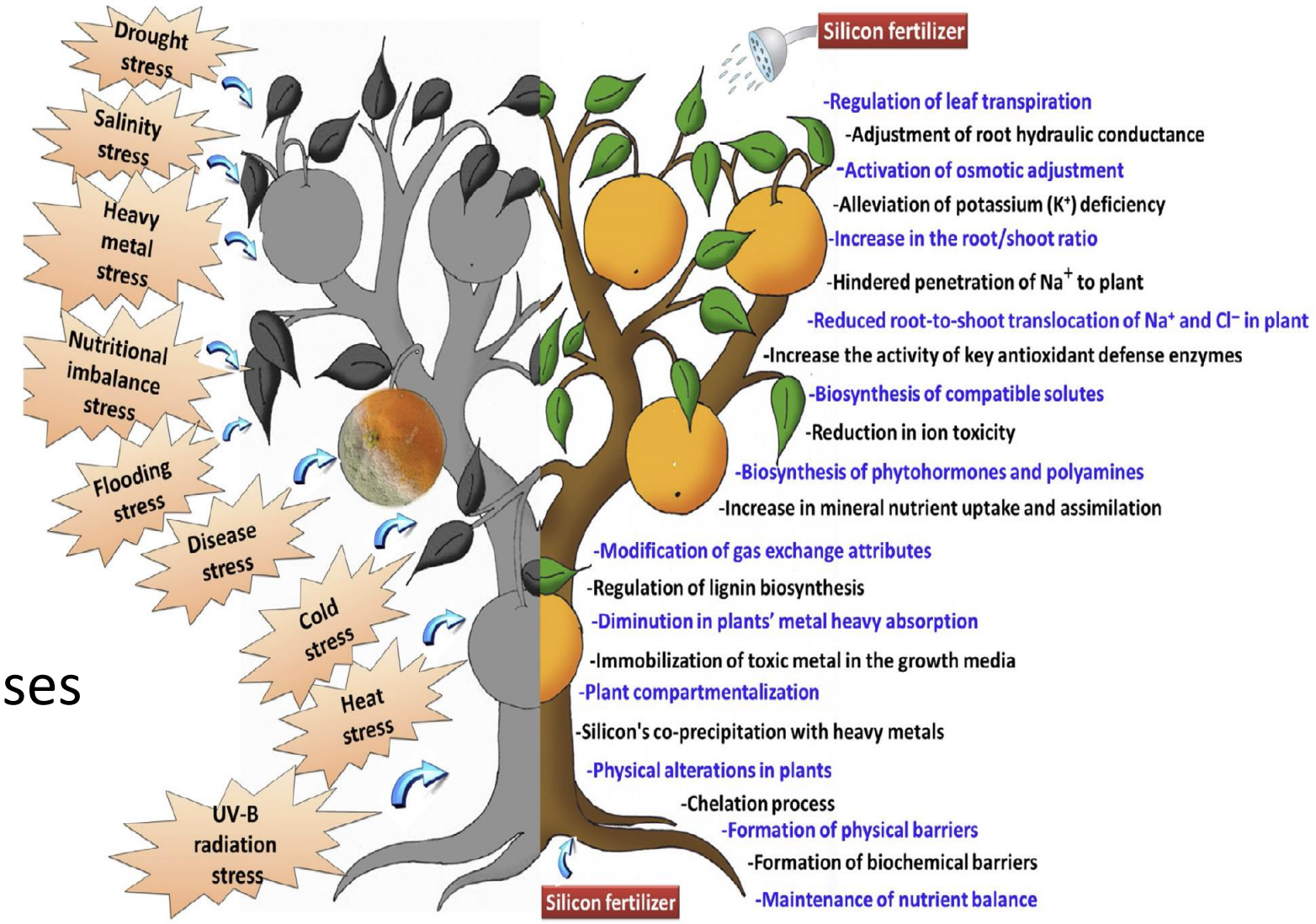
Arnon and Stout, 1939

Is Si beneficial or essential???

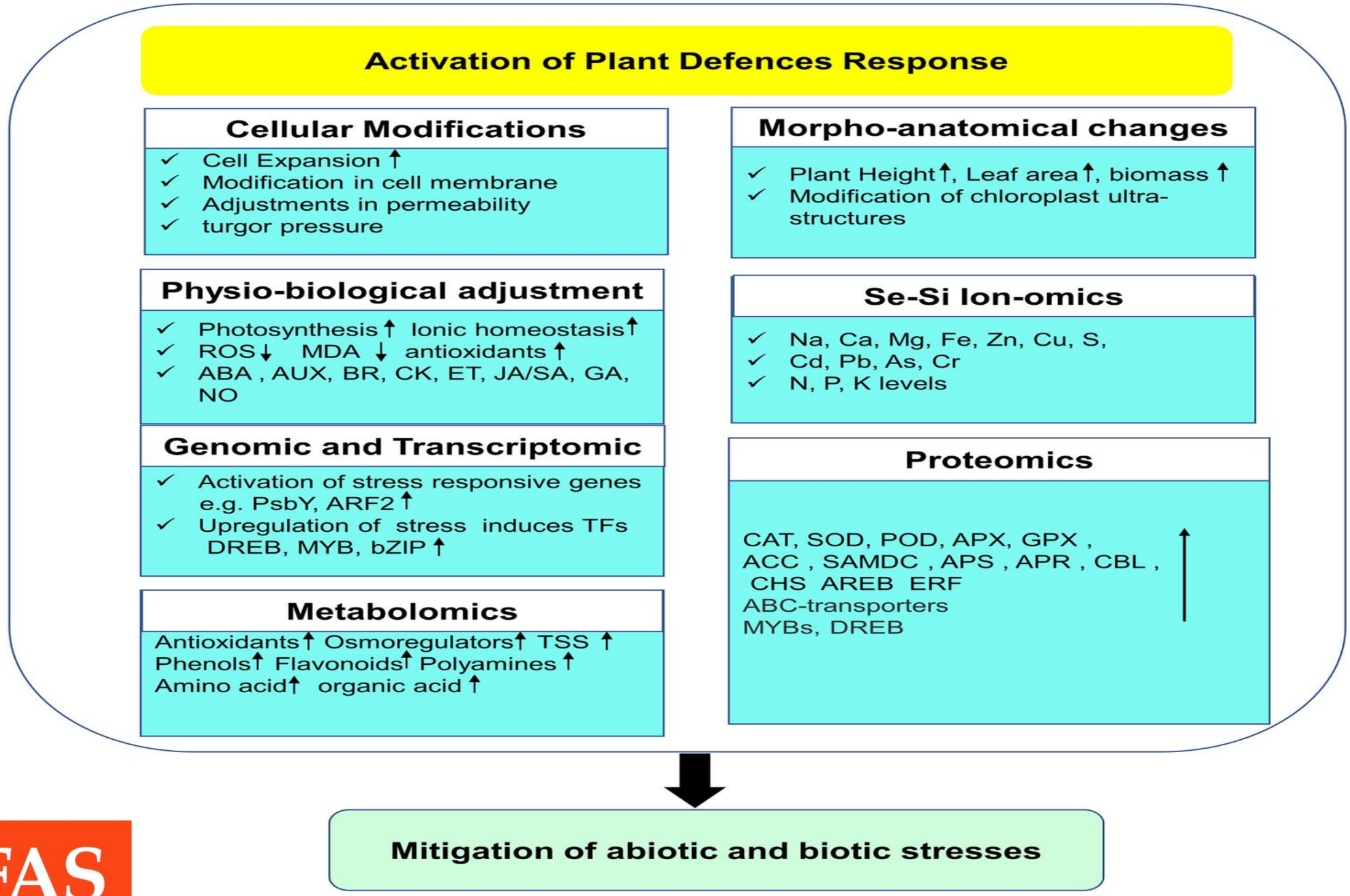
- In 2012, Si was categorized as a plant “beneficial substance” by ***Association of American Plant Food Control Officials (AAPFCO)***
- Prior to AAPFCO approval, all Si products were listed on fertilizer labels as “non-plant food ingredient”
- Now, manufacturers can identify qualifying formulations of Si as “plant beneficial substance”
- Si products are also approved by Organic Materials Review Institute (OMRI) for use in organic production

Why You Should Supplement Your Plants With Silicon???

- Improvement in
  - Yield
  - Germination
  - Rooting
  - Fruit size and number
  - Postharvest life
  - Resistance to plant pathogens
  - Tolerance to abiotic stresses

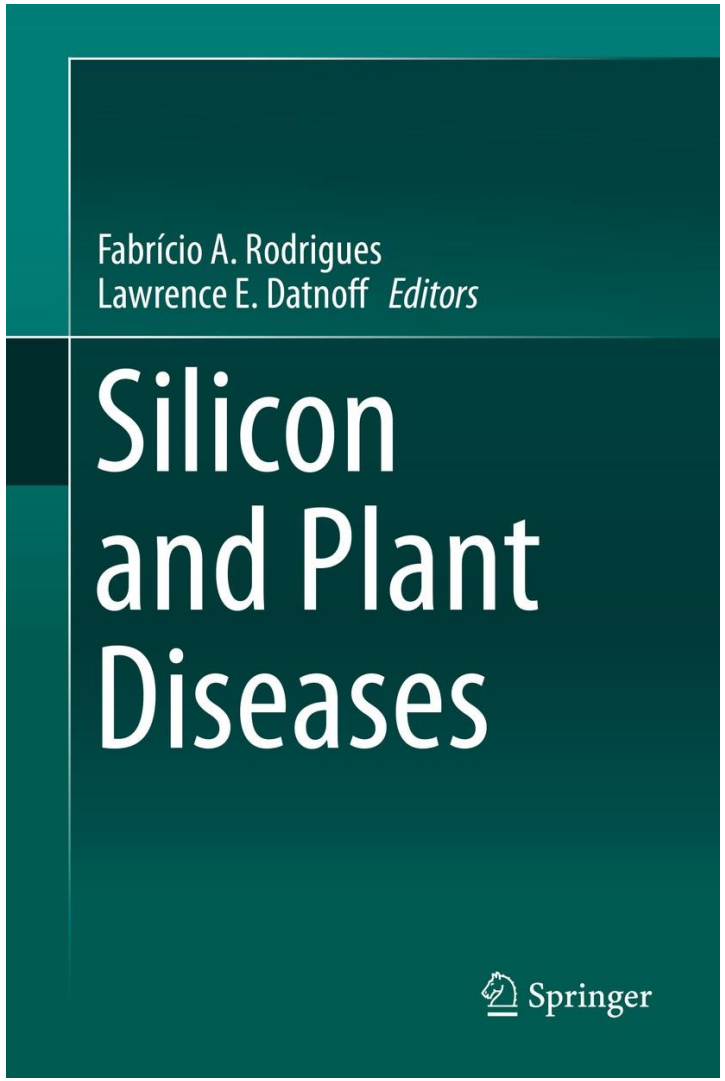


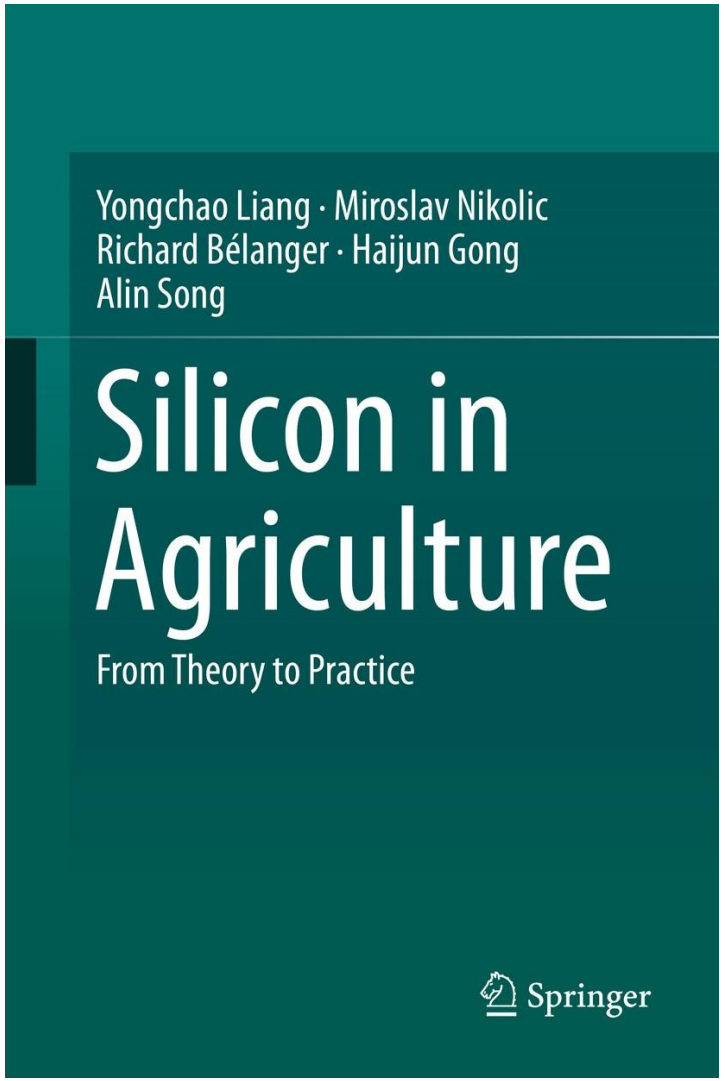
Etesami and Jeong 2018



Mandlik et al., 2020

Silicon in Plant Disease/Pest Management





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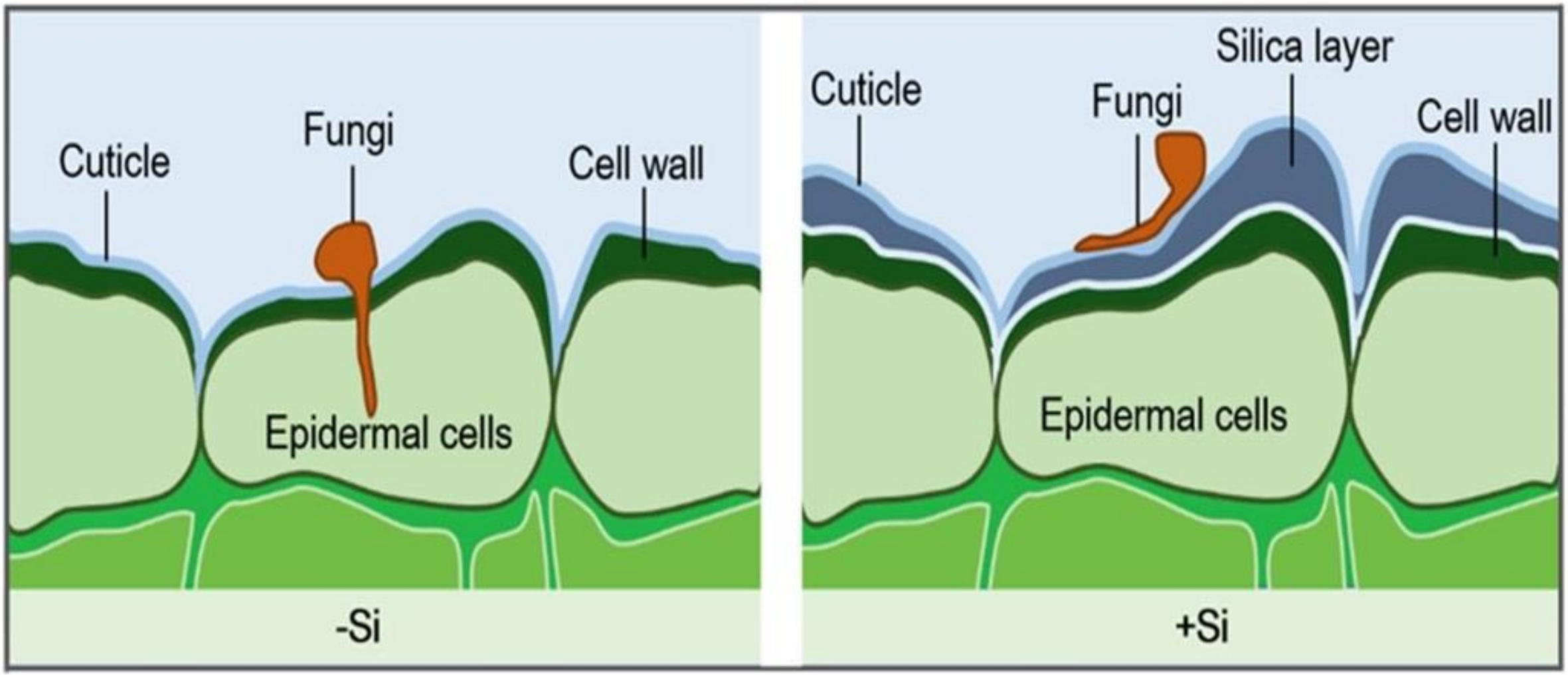
Mode of Action of Si



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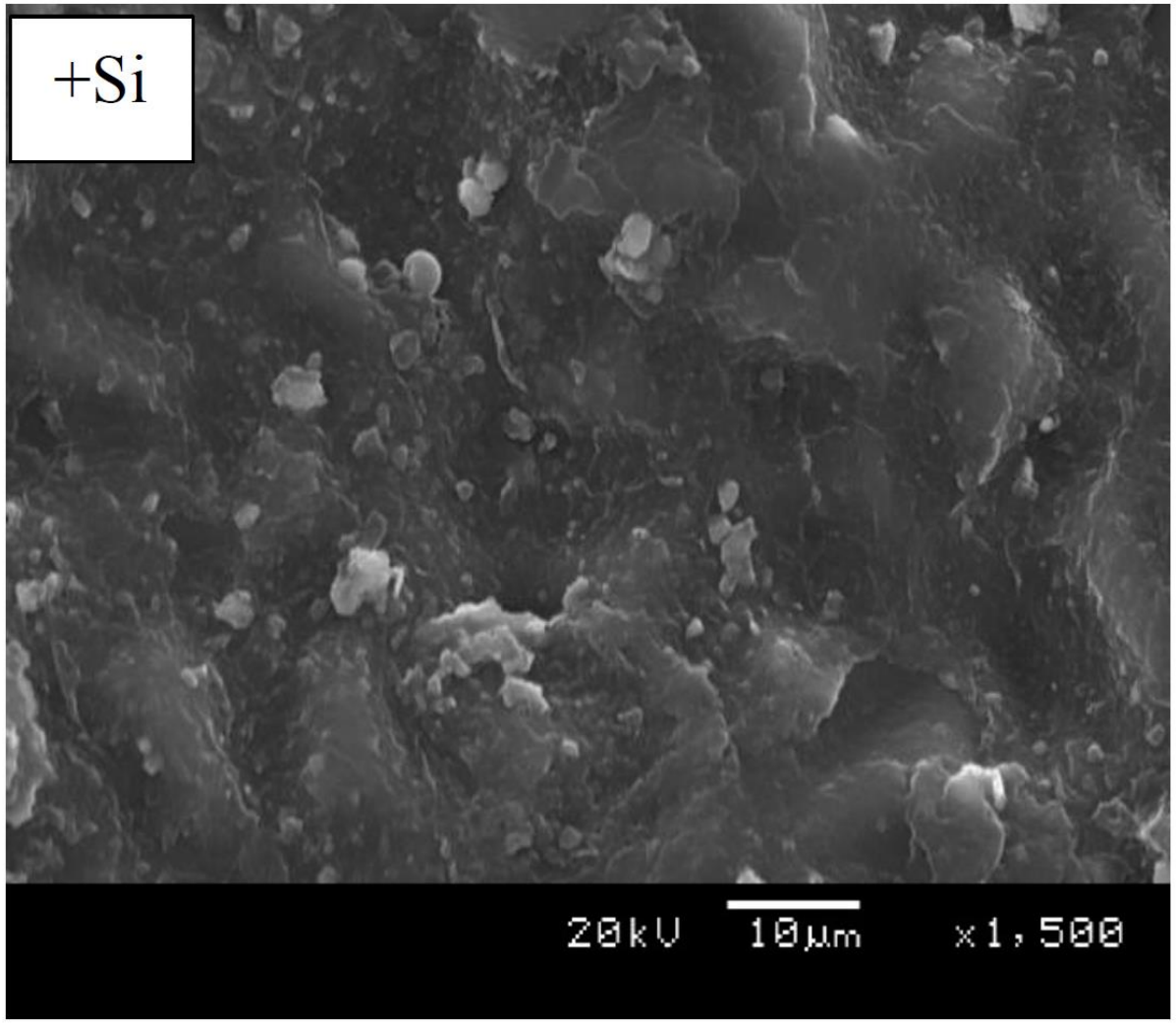
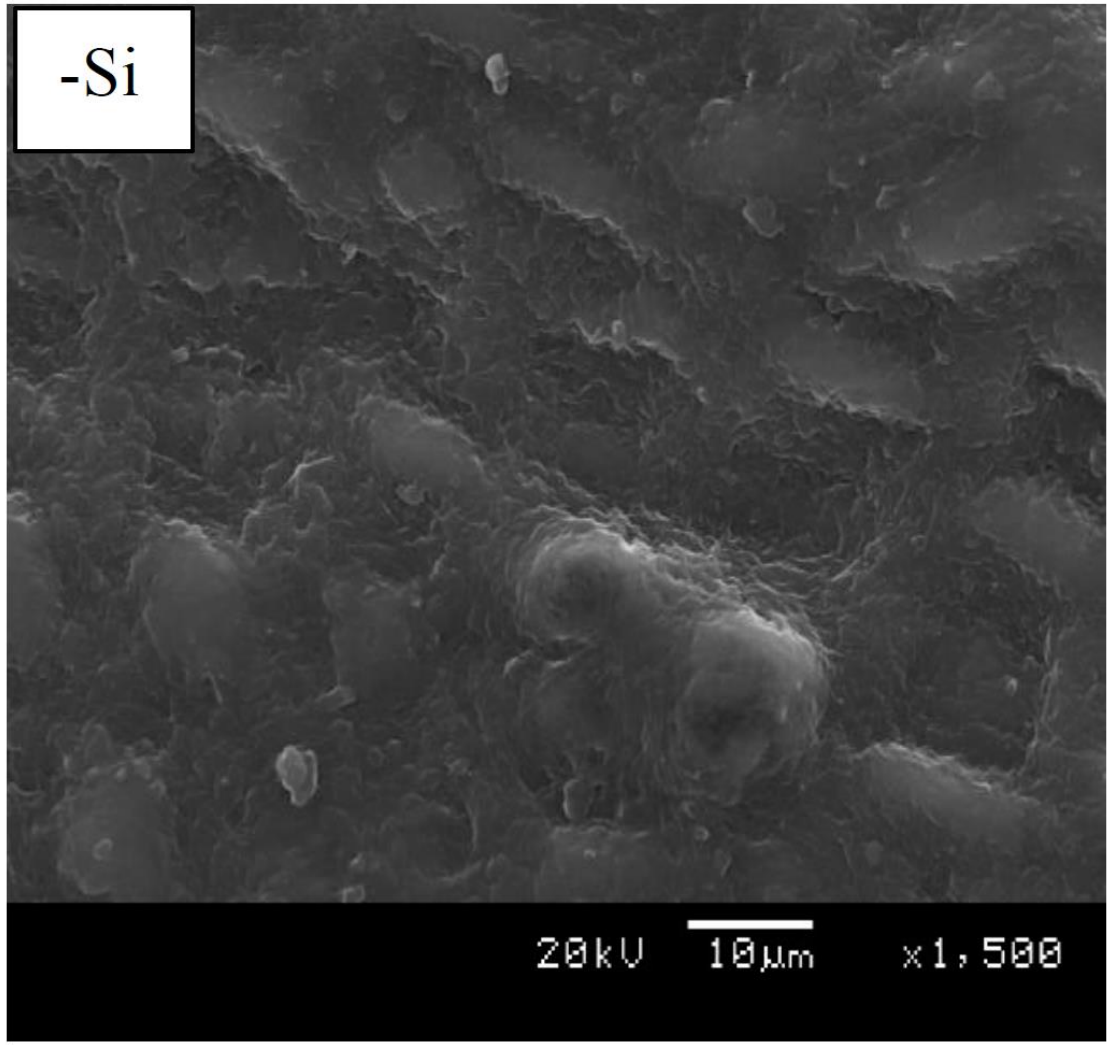
Wang et al., 2017

Upper Epidermal Surface of Si-treated Citrus





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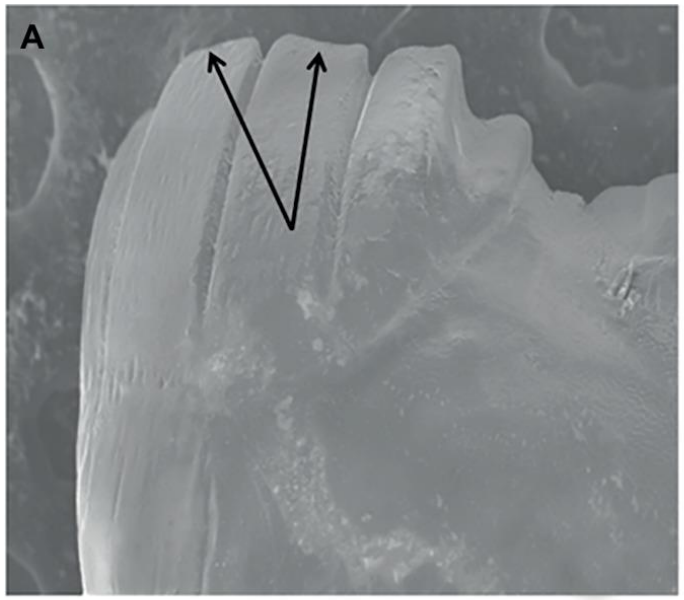
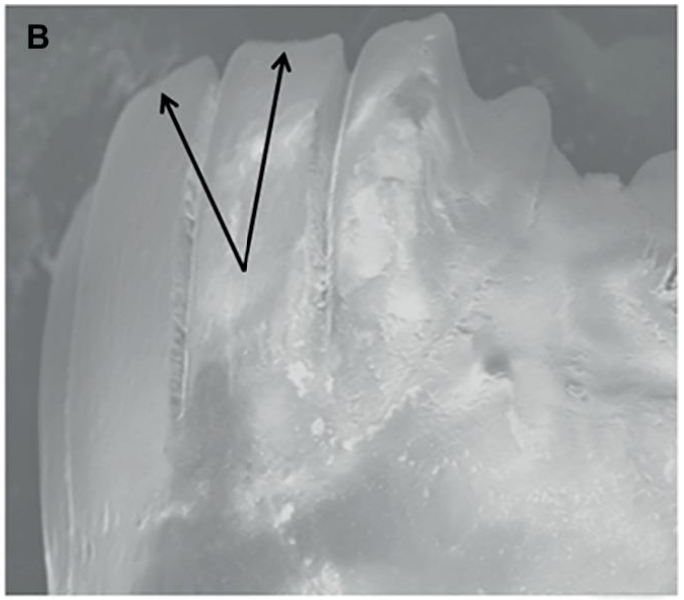
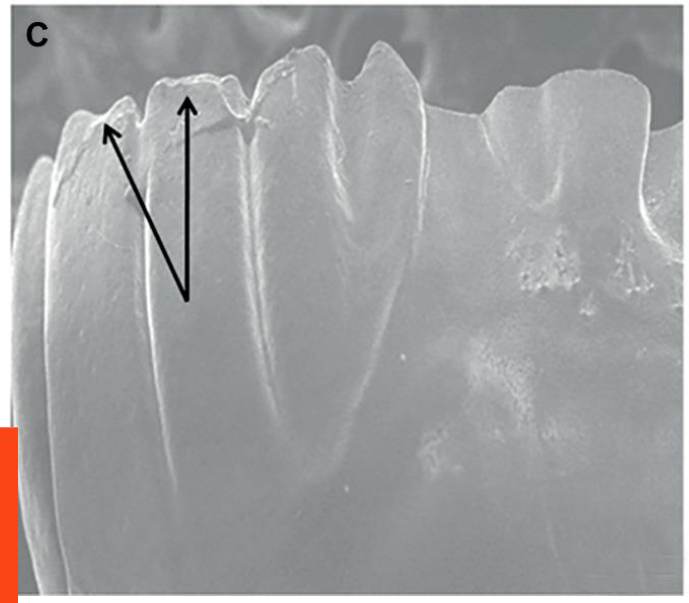
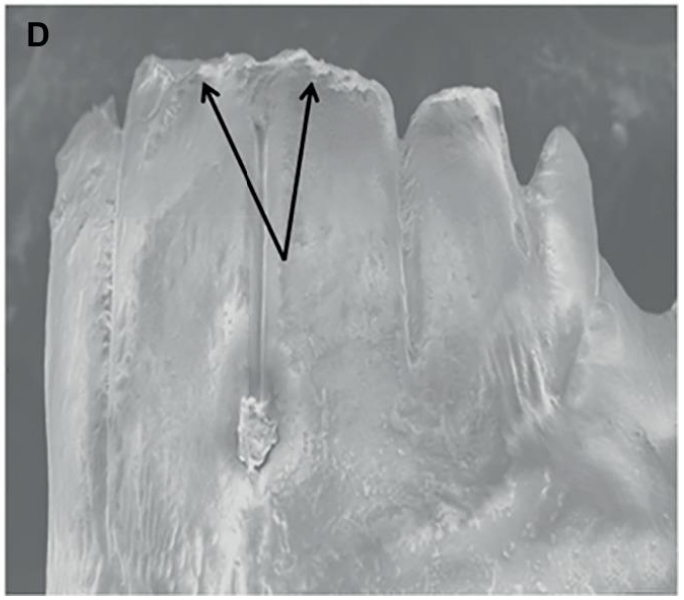
Mvondo-She and Marais, 2019

Silicon as a natural plant guard against insect-pests









Mir et al. 2019

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Si to reduced leaf minor attack

Si (0 ppm)

Si (100ppm)

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Silicon for Disease Control in Fruit Crops

Disease	Fruit Crop	Pathogen	Reference
Brown Spot	Citrus	*Alternaria alternata*	Asanzi et al. (2015)
Green mold	Citrus	*Penicillium digitatum*	Liu et al. (2010)
Green mold	Lemon	*P. digitatum*	Mkhize et al.(2012)
Root rot disease	Banana	*Cylindrocladium spathiphylli*	Vermeire et al.(2011)
Fusarium wilt	Banana	*Fusarium oxysporum f. sp. cubense*	Fortunato et al. 2012
Powdery mildew	Grapevine	*Uncinula necator*	Bowen et al. (1992)

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Silicon for Disease Control in Fruit Crops

Disease	Fruit Crop	Pathogen	Reference
Anthracnose	Avocado	*Colletotrichum gloeosporioides*	Anderson et al. (2005)
Black root rot	Avocado	*Calonectria ilicicola*	Dann and Le (2017)
Phytophthora root rot	Avocado	*Phytophthora cinnamomi*	Mkhize et al.(2012)
Powdery mildew	Strawberry	*Sphaerotheca aphanis*	Kanto et al. (2006)
Fruit decay	Cherry	*Penicillium expansum*	Qin and Tian (2005)

Silicon for Disease Control in Vegetable Crops

Disease	Fruit Crop	Pathogen	Reference
Root root	Tomato	*Pythium aphanidermatum*	Heine et al. (2011)
Powdery mildew	Pumpkin	*Podosphaera xanthii*	Lepolu Torlon et al (2016)
Powdery mildew	Zucchini	*Podosphaera xanthii*	Menzies et al.(1992)
Downy mildew	Lettuce	*Bremia lactucae*	Garibaldi et al. (2011)
Crown and root root	Cucumber	*Pythium ultimum*	Cherif et al. (1994)

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Si Sources, Application Methods, Rate

Sources of Si fertilizer

- **Wollastonite**: Naturally occurring wollastonite (Calcium silicate, $CaSiO_3$) contains higher amounts of soluble Si
- **Tuff:** Volcanic rock having soluble silicon
- **Byproducts** from industrial procedures such as smelting of wollastonite, iron, magnesium ore are also used Si fertilizers
- **Silicates** of potassium and sodium: commonly used for greenhouse applications
- **Biochar:** Rice husk, bamboo stick, miscanthus
- **Compost**: Cattle, poultry, swine manures
- **Silica nanoparticles**
- **Diatomaceous earth**

Factors affecting Si uptake/availability

- Soil type
  - Sandy and muck soils contain least amount of Si
  - Soilless substrate
  - Peat-based substrates contain very little Si
- Plant type
- Si form
- Application method

Si application methods/approaches

- Silicon fertilizers can be applied to….
  - **Soil**
    - Incorporated directly like wollastonite or steel slag
    - Dissolved in water to make solution and then apply to soil
      - Sprinkler, drip or overhead irrigation
  - **Soilless mixes**
    - Pre-mix with substrate
    - Fertigation
    - Foliar
  - **Seed Priming**
    - Dusting
    - Soaking in solution
  - **Cutting treatment**
    - Misting
    - Dipping/Soaking
    - Fertigation

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Si application rate

- Depends upon product type, application method and plant type (Si accumulator or non-accumulator)
- Run small test
- **Foliar spray** 50-100 ppm
- **Fertigation**, 50 ppm for regular fertigation or 100 ppm once in a week
- **Misting:** 25-50 ppm for cuttings
- **Soil Amendment,** 1-6 ton/ac wollastonite or slags
- **Soilless substrate**: It should have minimum 25-35ppm Si

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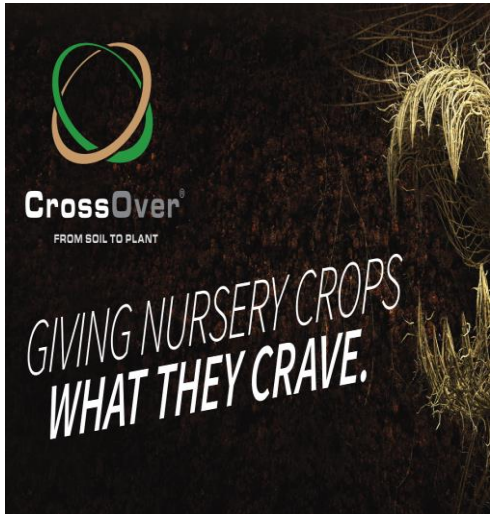
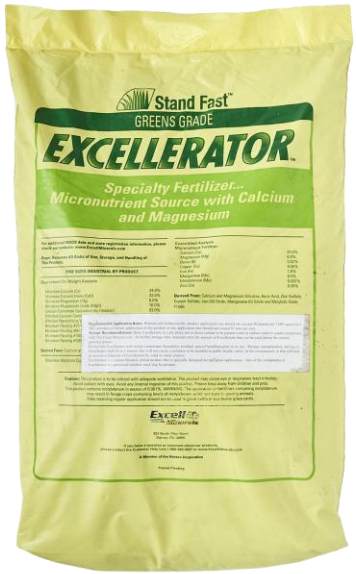
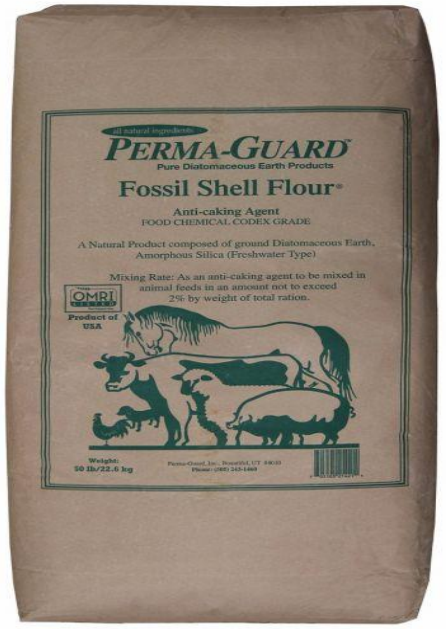
Commercially available Si products

AgrowSil®







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Commercially available Si products

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Si Related Research

- Leafy vegetable production
- Ornamentals
- Blueberry
- Grapes
- Citrus
- Peaches

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Si in hydroponic lettuce production

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Si improved head size lettuce

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Si mitigated tip burn/necrosis in lettuce

Contol (wihout Silicon)

Silicon

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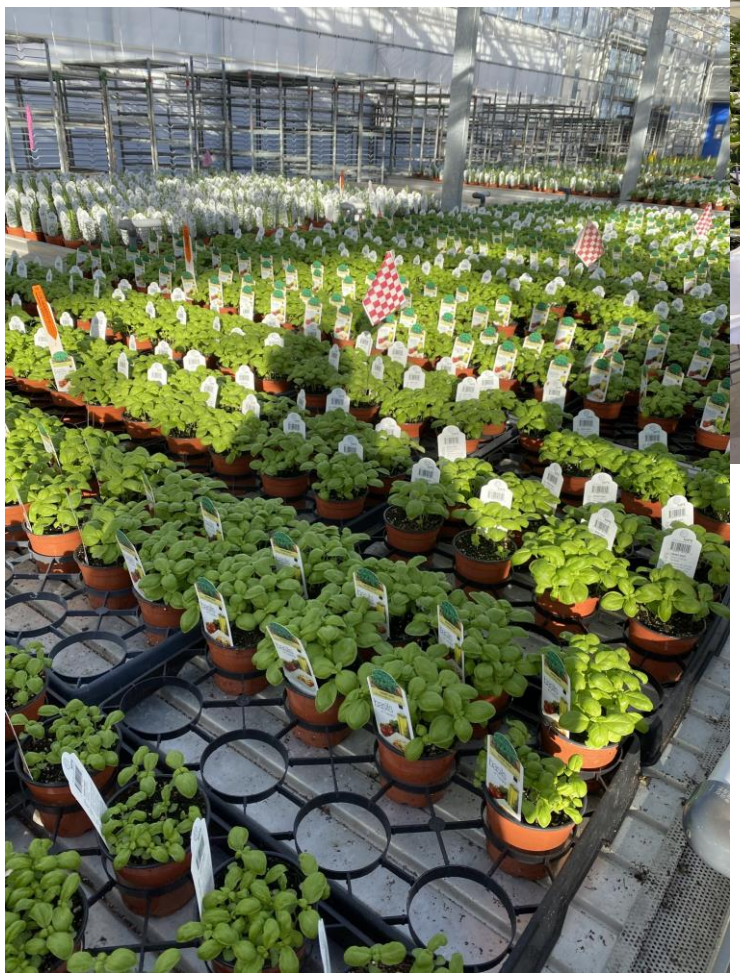
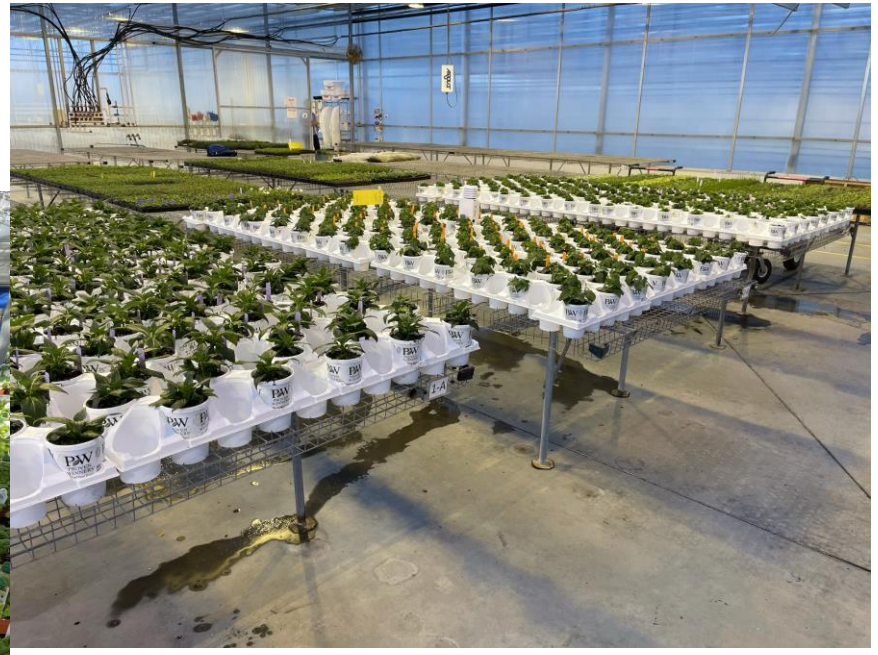
Si improved drought tolerance and resistance to lodging in ornamentals





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New Guinea Impatiens Infinity White

3.5 days after drought stress (no watering)

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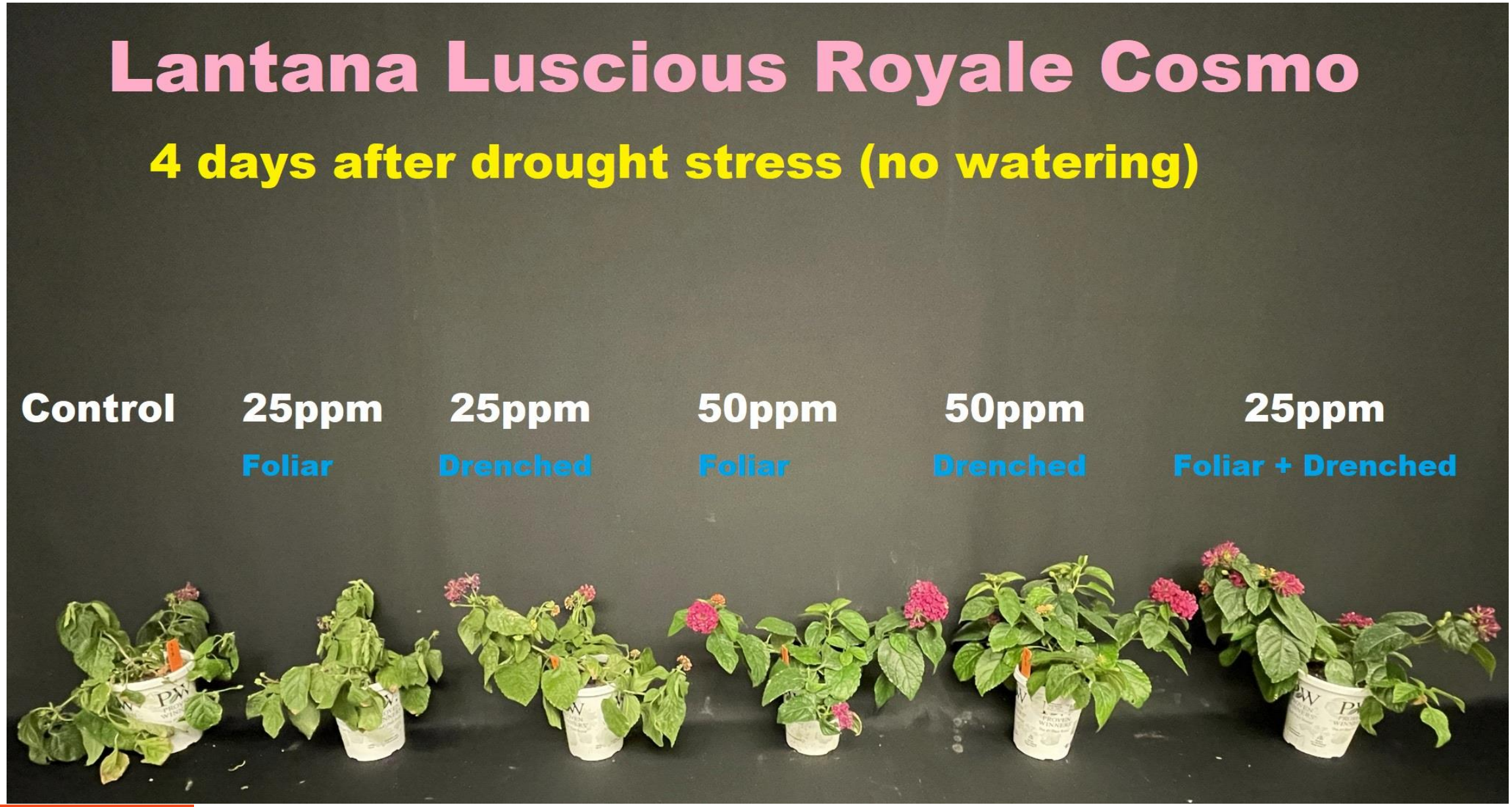
Lantana Luscious Royale Cosmo

4 days after drought stress (no watering)



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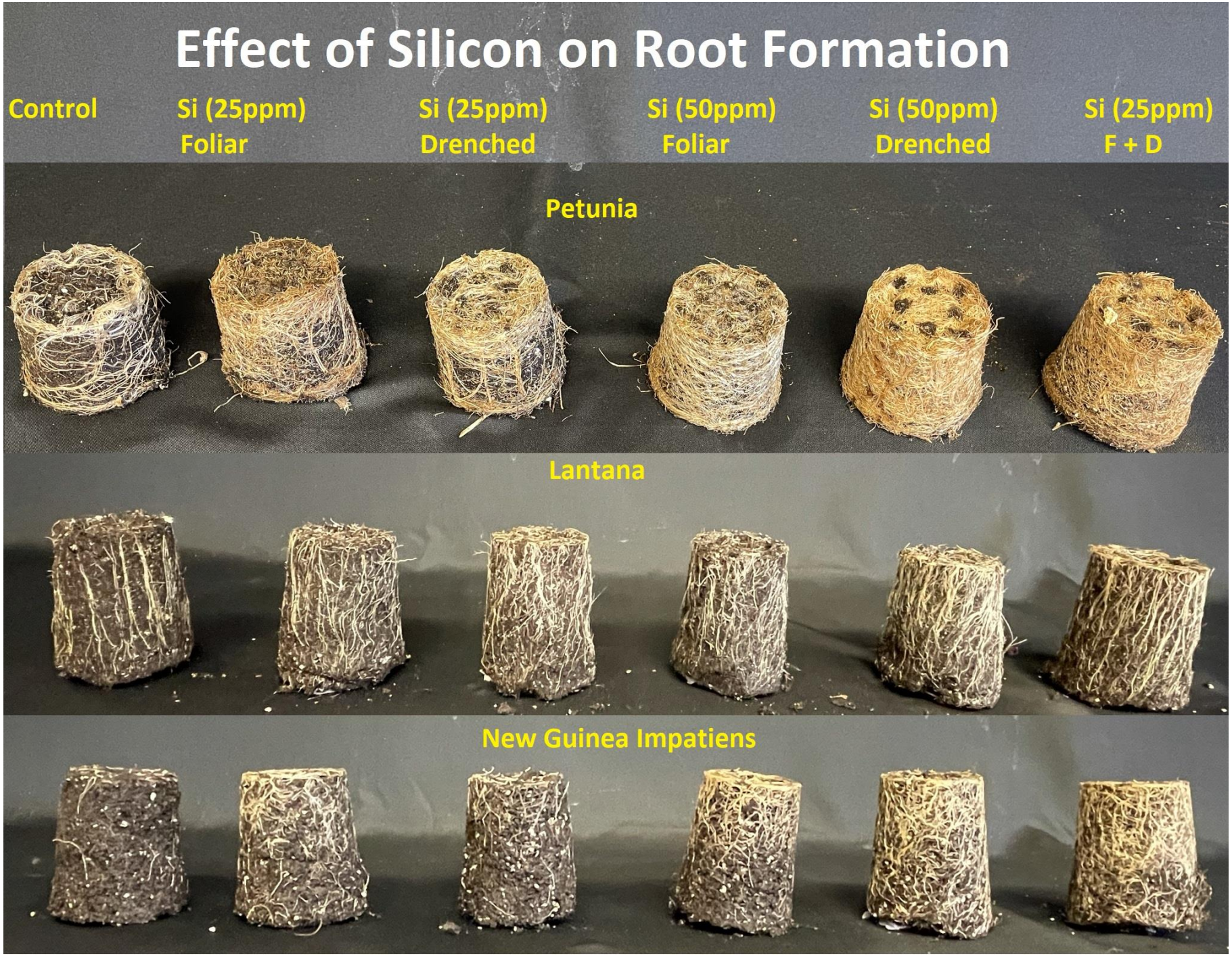
Effect of Silicon on Root Formation



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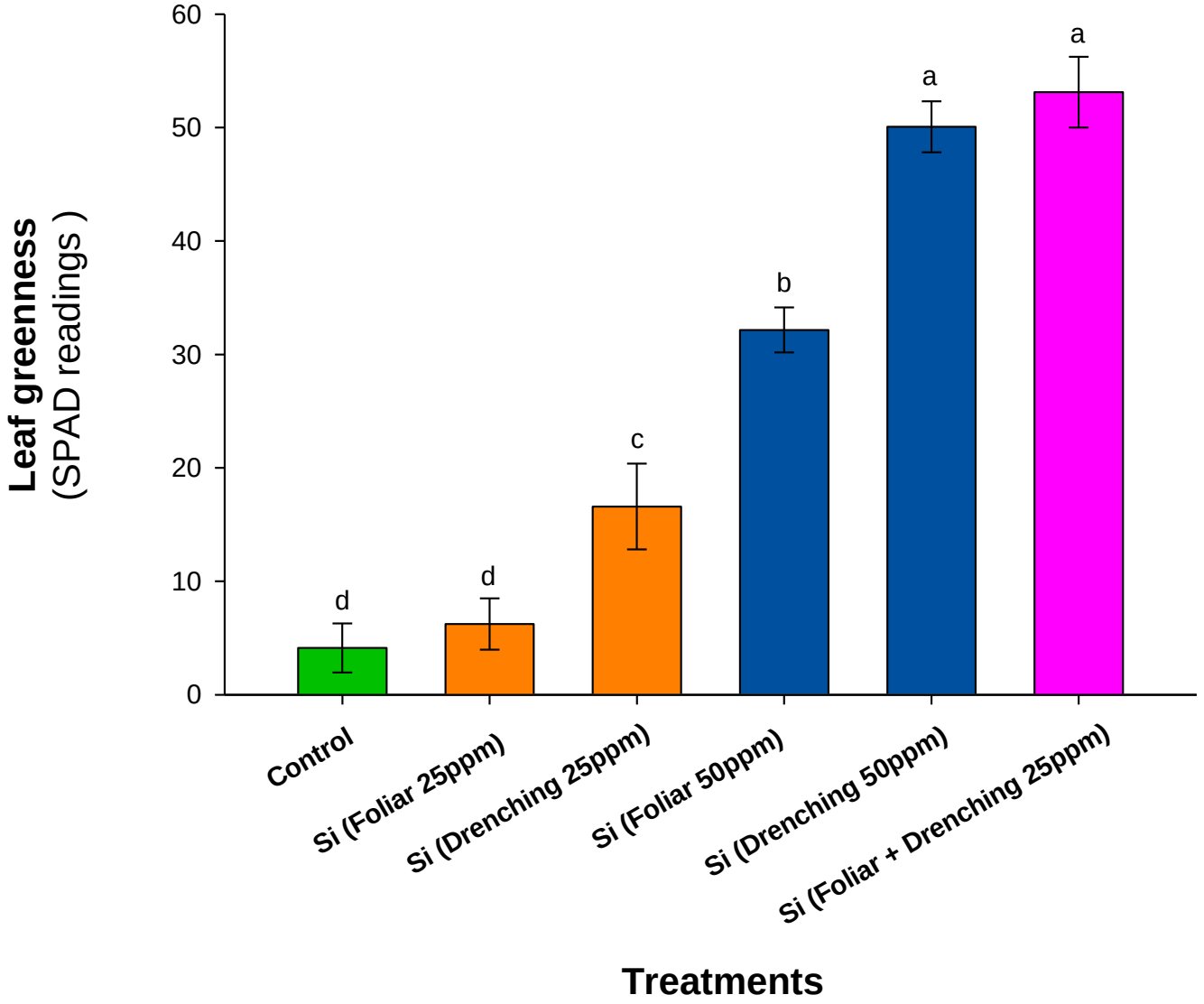
Silicon improved leaf greenness in droughted Lantana plants (4 days after drought)



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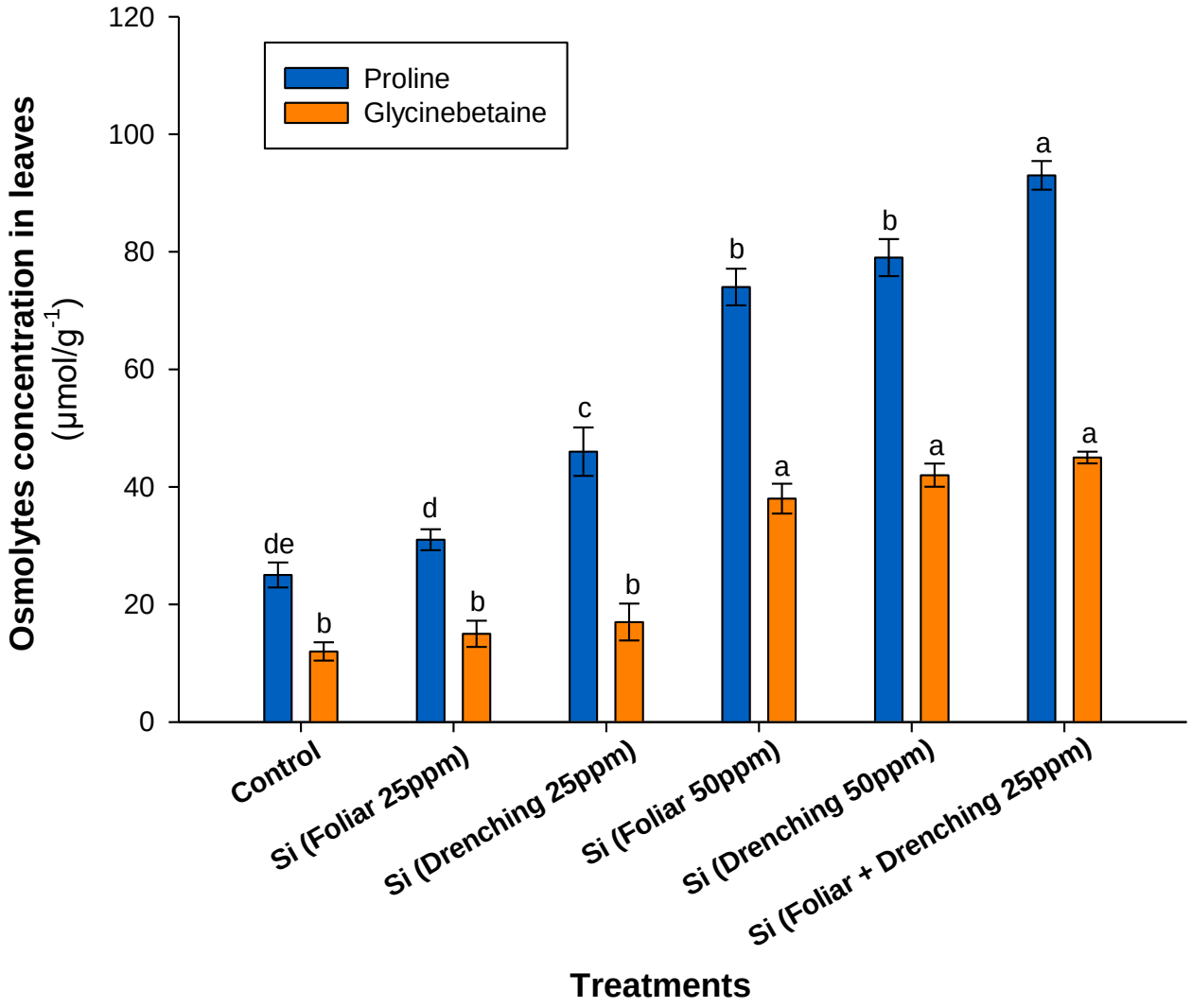
Silicon-induced drought tolerance is associated with higher osmolytes accumulation



Lodging in cut flowers

Si reduced lodging in snapdragon

Control (distilled water)

50ppm Si (foliar weekly)

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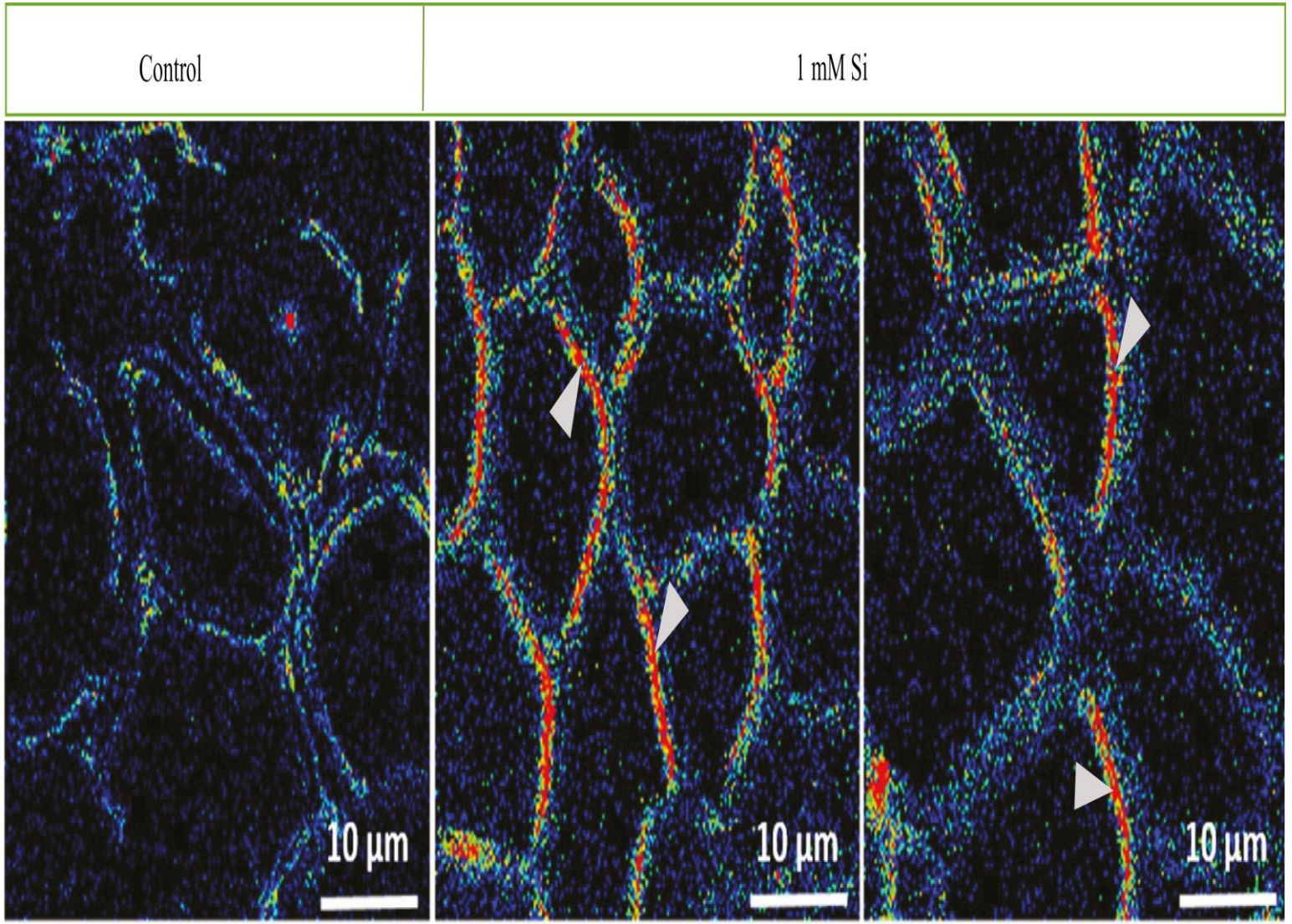
Silicon deposition in xylem cell walls leads to reduced lodging



Mandlik et al., 2020

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Si improved number of florets

Control

50ppm Si

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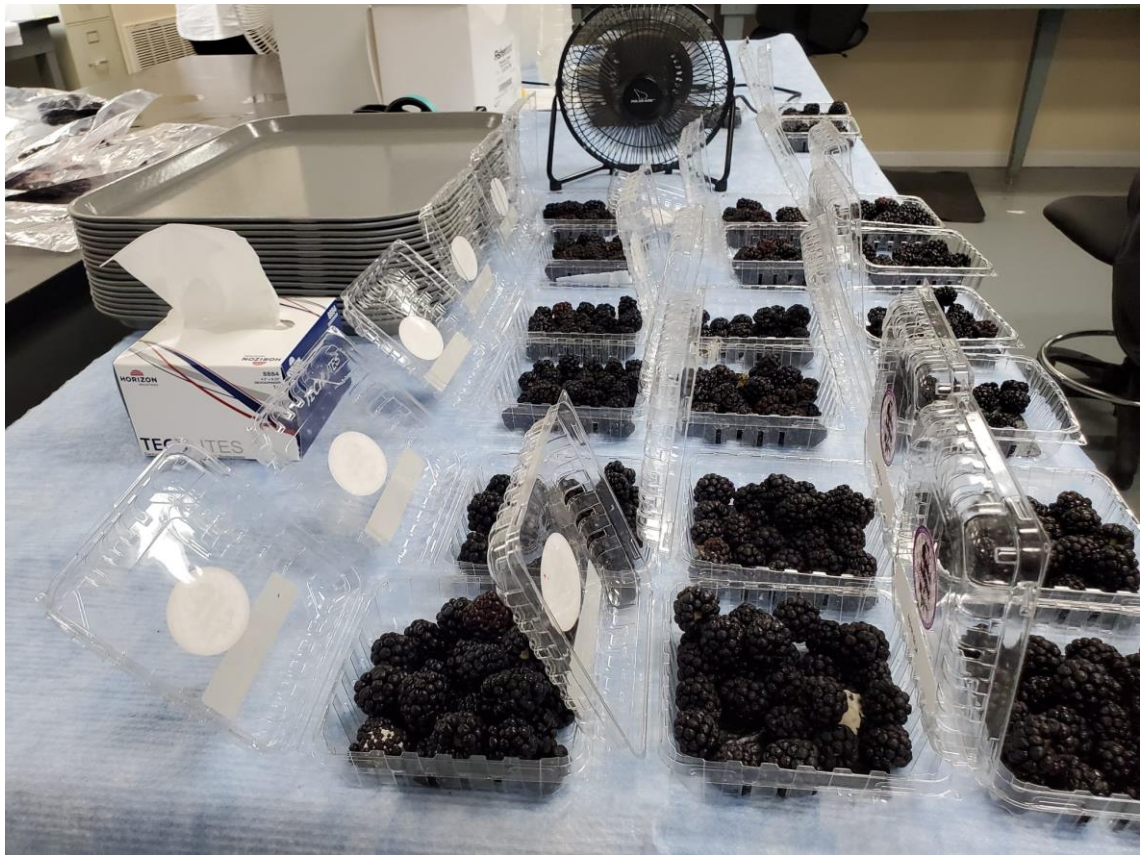
Key points

- Silicon is effective in improving drought tolerance and resistance to lodging in selected ornamental plant species
- Overall low level of silicon applied as foliar followed by drenching found to be more effective
- Improved drought tolerance is associated with high relative water content, chlorophyll content, improved accumulation of osmolytes, higher antioxidant activities and suppression of reactive oxygen species (ROS).

Si improved postharvest life in blackberry



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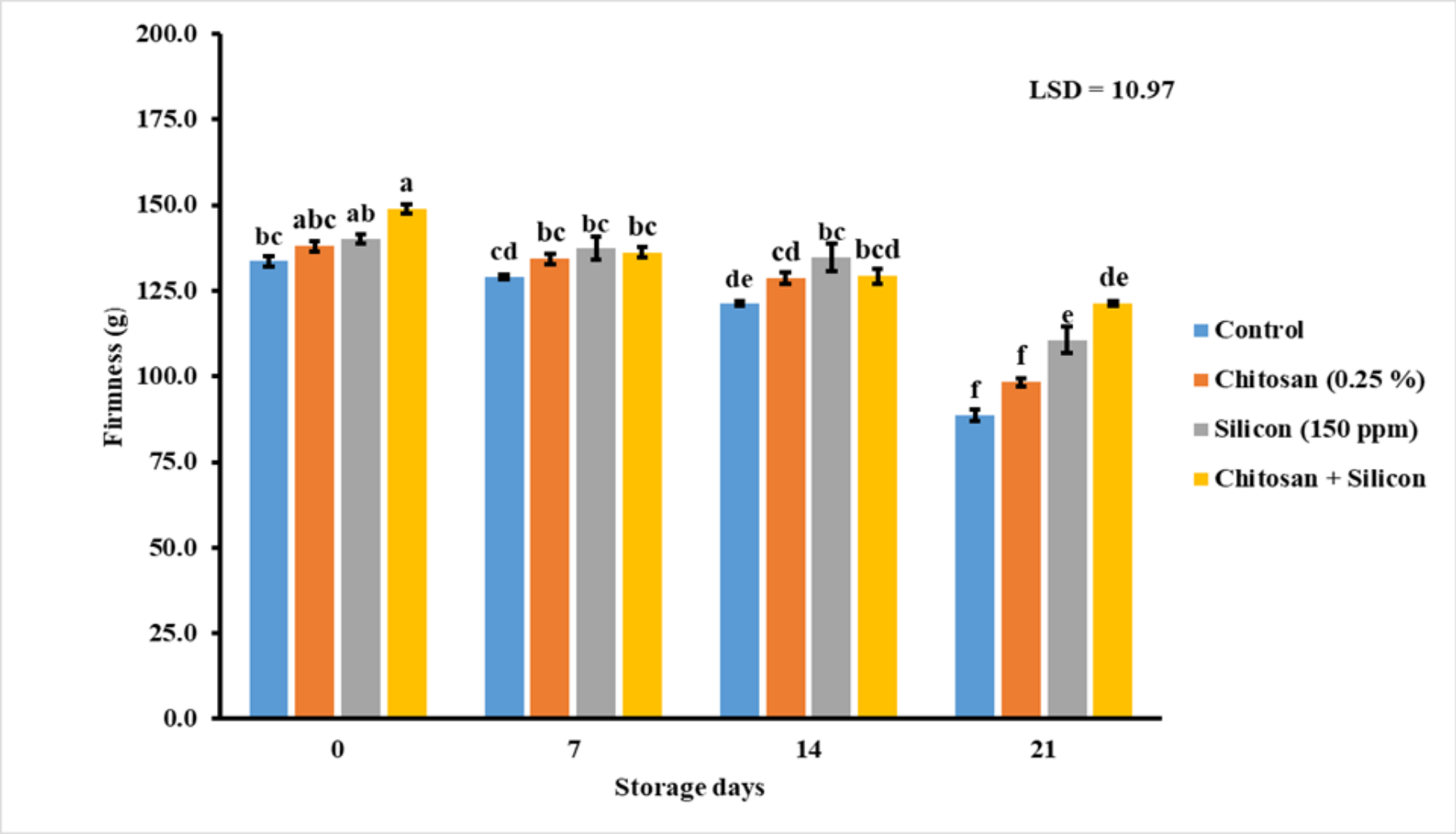
Si improved fruit firmness under storage



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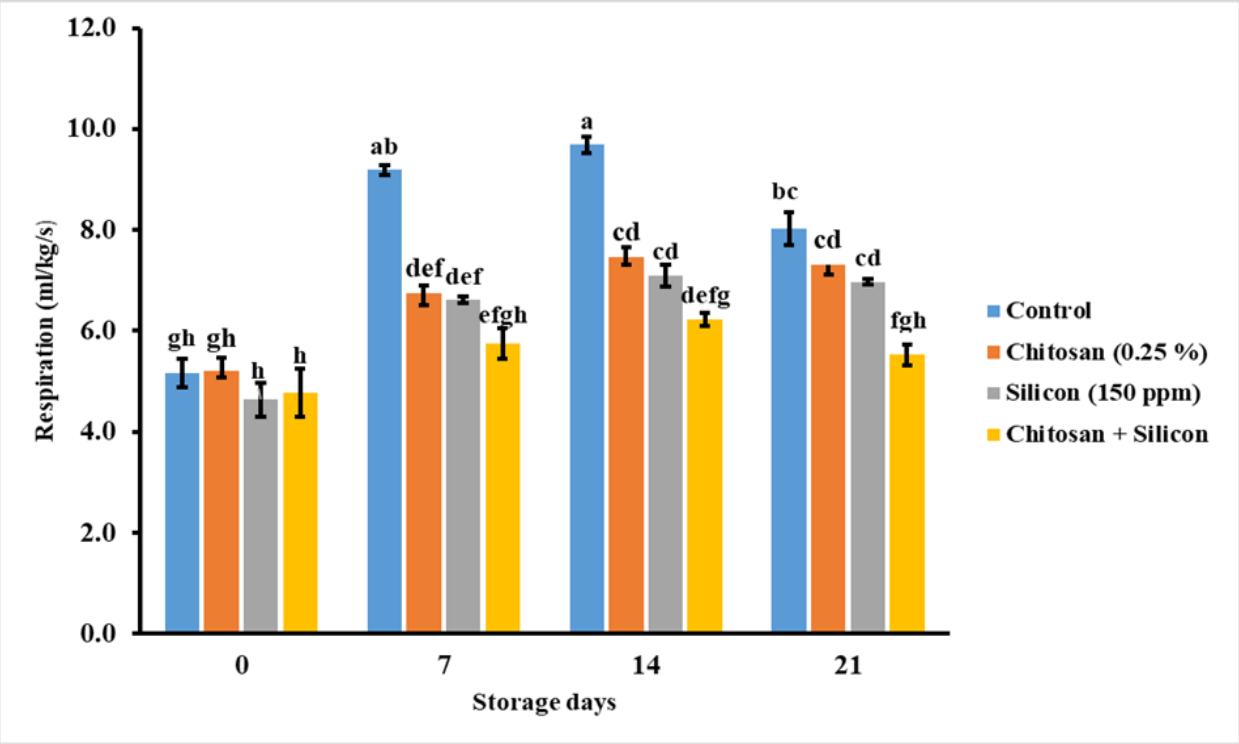
Si reduced fruit respiration under storage



Si reduced mycelium growth under storage

Control

Treated

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Si Improved hypoxia tolerance in highbush blueberry plants

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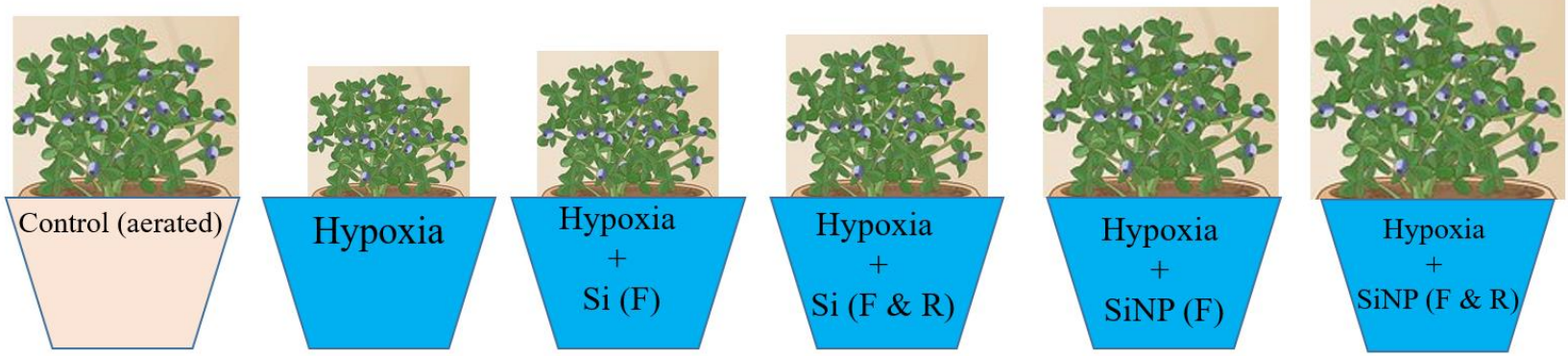
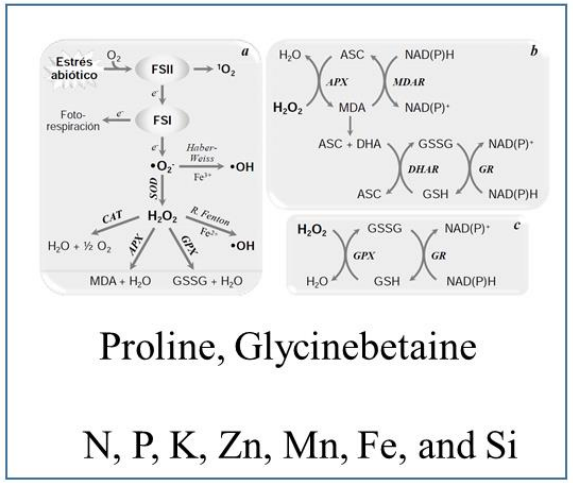
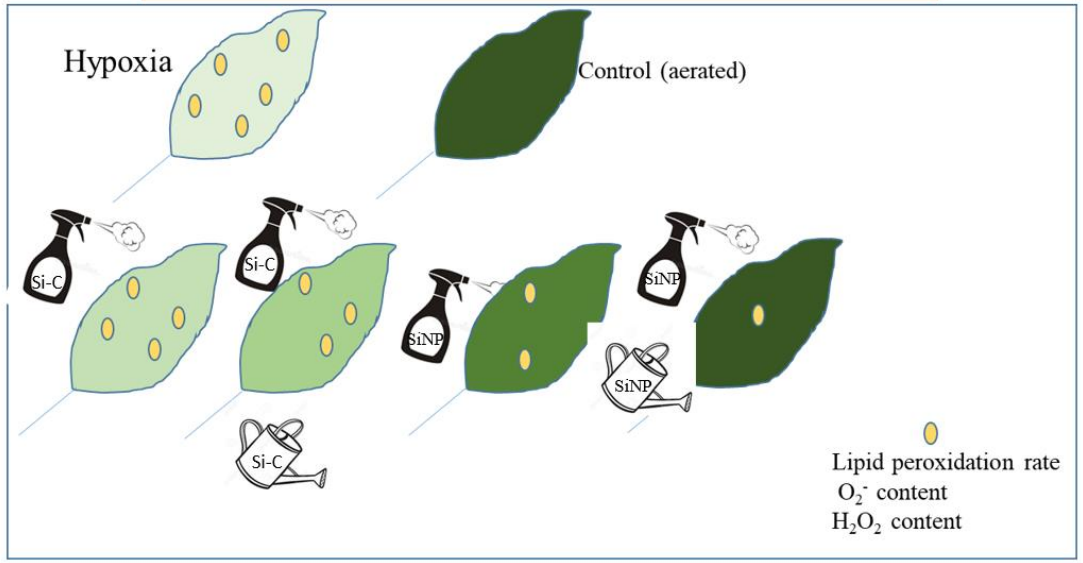


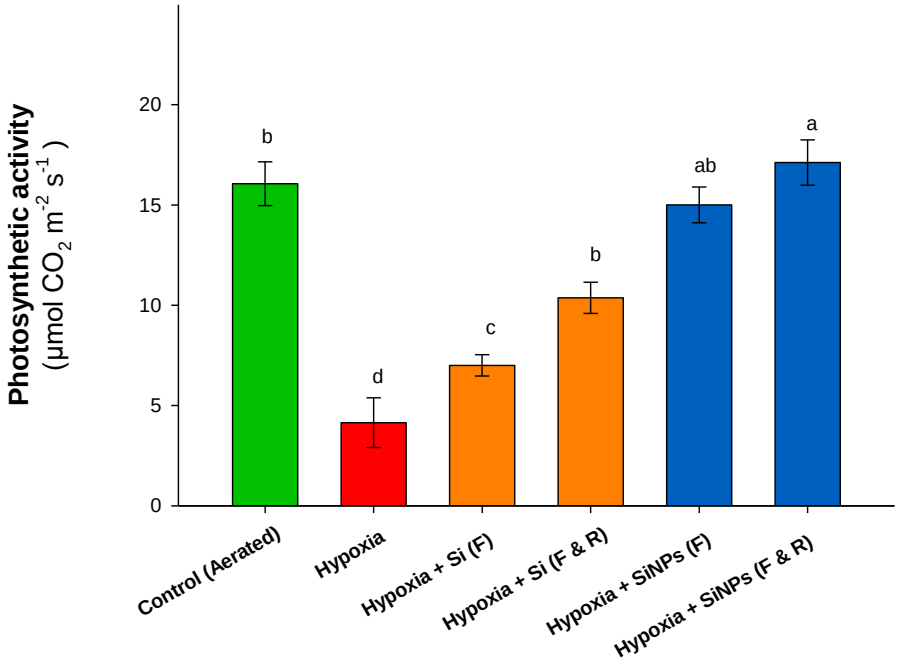
Si-C (conventional) and SiNP (nano) via foliar or foliar + root application increase antioxidative activities, organic solutes and mineral status in leaves and roots of blueberry plants suffering flooding

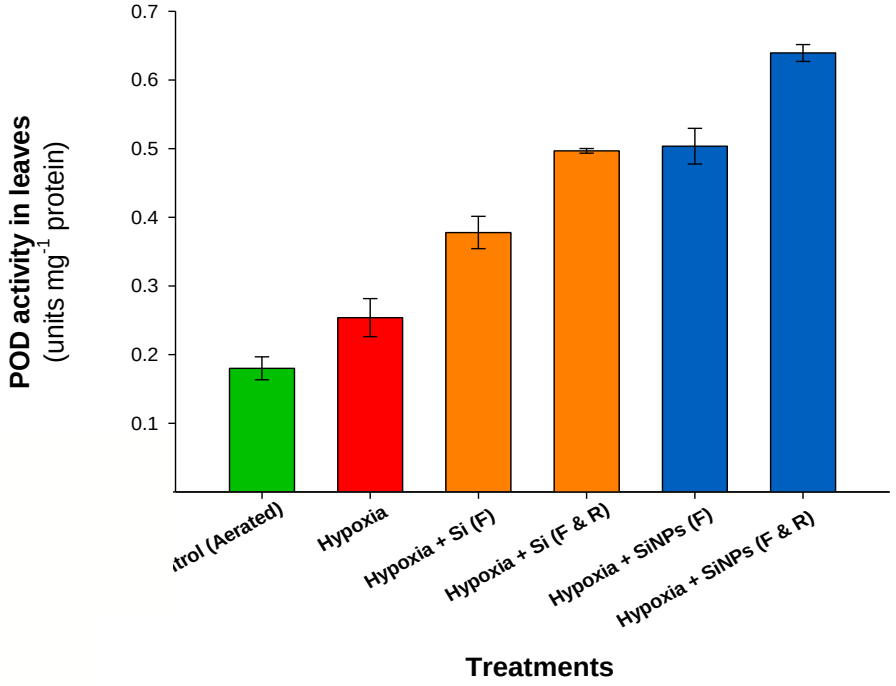


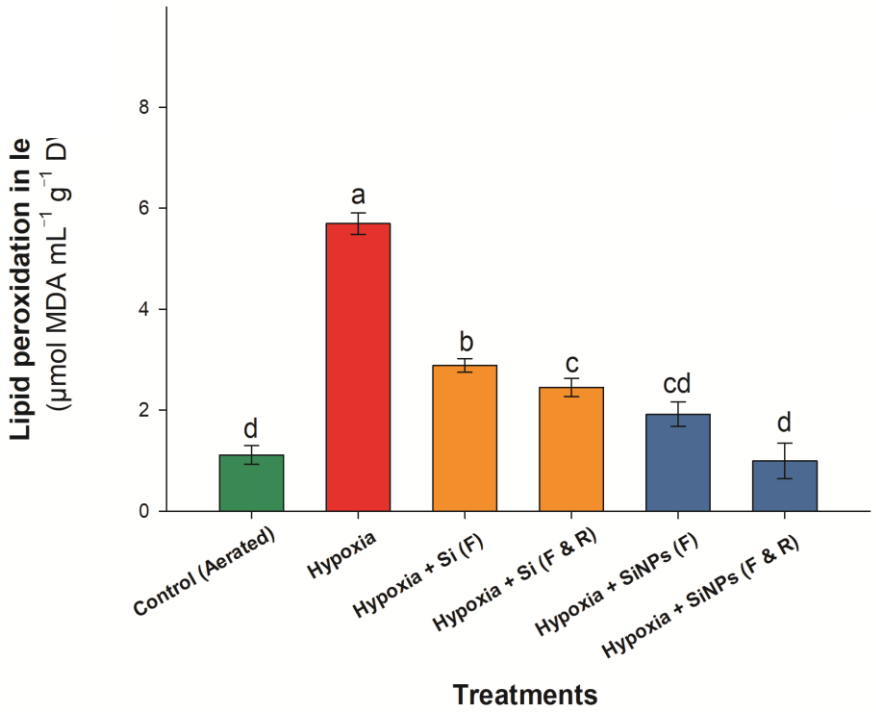
Plants with Si-C and SiNP applications decrease oxidative damage and increase chlorophyll concentration caused by flooding.



Si improved photosynthesis by limiting oxidative damage under hypoxia stress

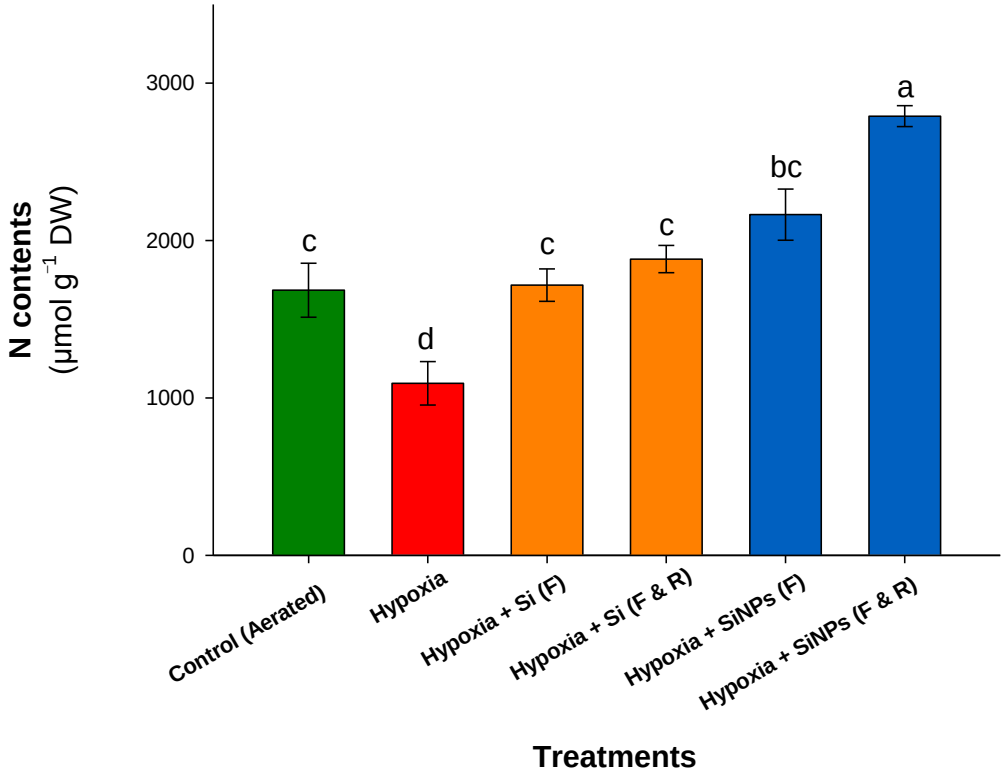


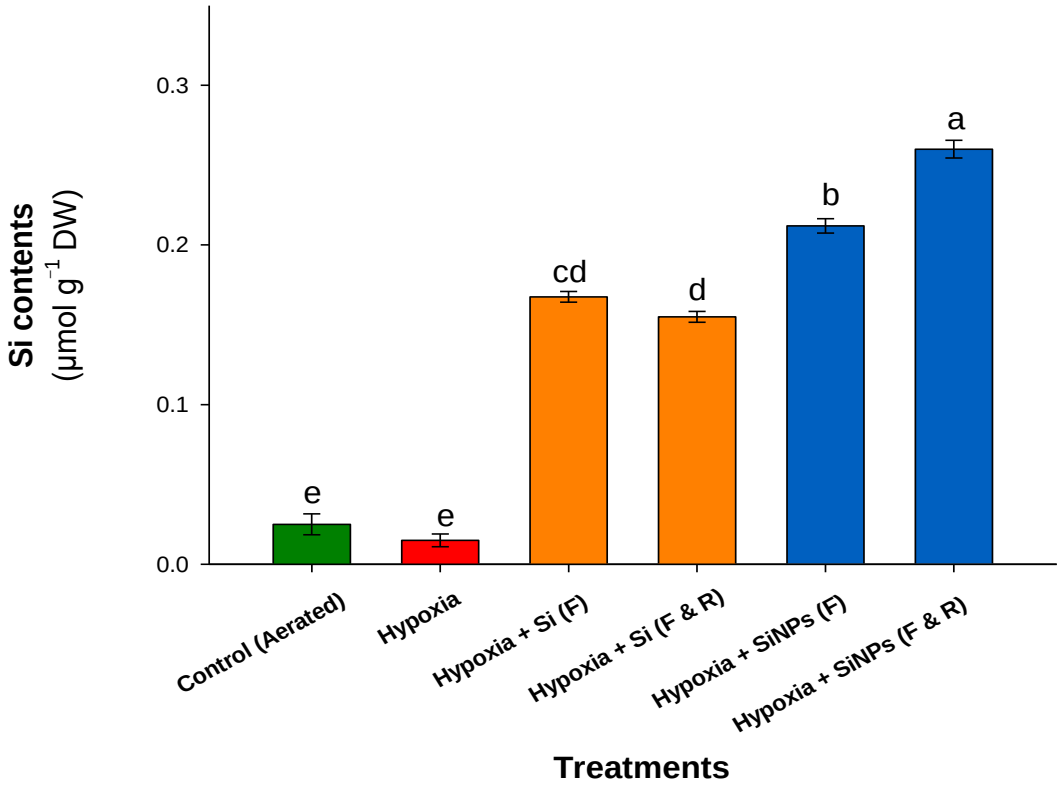




Zafar et al., 2021

Si regulated nutrient uptake





Zafar et al., 2021

SHB Bluberry Plants (7 days after drought stress)

Hypoxia Stress (no Si)

Hypoxia Stress (Conventional Si, 250-300nm)

Hypoxia Stress (Nano Si, 20-30nm)

Plants foliar treated with 50ppm of Si

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Key points

- Use of Si-C and SiNPs helps plant in mitigating hypoxia stress
- The application of SiNP through F & R has great potential to ameliorate the impact of flooding-induced hypoxia stress in blueberry plants
- The combined application of SiNP (F & R) triggered the antioxidant enzyme system in blueberries, which detoxified the harmful oxygen species and protected the leaf pigments from the lipid peroxidation caused by the excessive formation of ROS, and restored the leaf gas exchange traits, i.e., the Pn and gs
- Moreover, SiNP increased the accumulation of compatible solutes (proline and GB), which resulted in a greater osmotic adjustment potential of blueberry plants under hypoxia stress
- Elucidating the molecular mechanisms underlying these SiNP-mediated regulatory mechanisms requires further investigation and may be the subject of future studies

Silicon related research at UF/NFREC

- Evaluating beneficial effects of silicon in citrus production

Objective:

To investigate the effect of Si on….

- Plant growth and development (vegetative and reproductive)
- Fruit yield and quality
- Resistance to pest and disease attack
- Tolerance to different abiotic stresses
- Economics

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Christmas & Late Freeze Events

Before Freeze (December 15th, 2022)

After Freeze (January 7th, 2023)

Recovering from freeze (April 11th, 2023)

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Experiment layout

Sites:

- Florida Georgia Citrus, Monticello
- Bob & Valinda Root, Lake Byrd
- Rowell Citrus, Perry
- Gram's Legacy Grove, Perry
-

Treatments:

- T1: Distilled water
- T2: 50ppm silicon
- T3: 100ppm silicon.

Application time:

- Biweekly
- Monthly

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Silicon Therapy to Improve Cold Tolerance

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Silicon Therapy to Improve Cold Tolerance

Silicon Therapy to Improve Cold Tolerance

After 48 hours of freezing stress (-6 C)

No Si (distilled water)

100ppm Silicon

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Silicon Therapy to Improve Cold Tolerance

After 48 hours of freezing stress (-6 C)

100ppm Silicon

No Si (distilled water)

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Si to improve cold tolerance in citrus: large scale on farm project

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Si to improve heat and cold tolerance in citrus: large scale on farm Study

Application Time:

Two week
Four week

Silicon level:

50ppm
100ppm

Location: Perry FL

Cultivars:

Satsuma (Owari)
Red Navel

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Three weeks after freeze event

Without Si

100ppm (4 weekly)

Silicon improved freezing tolerance

Without Si

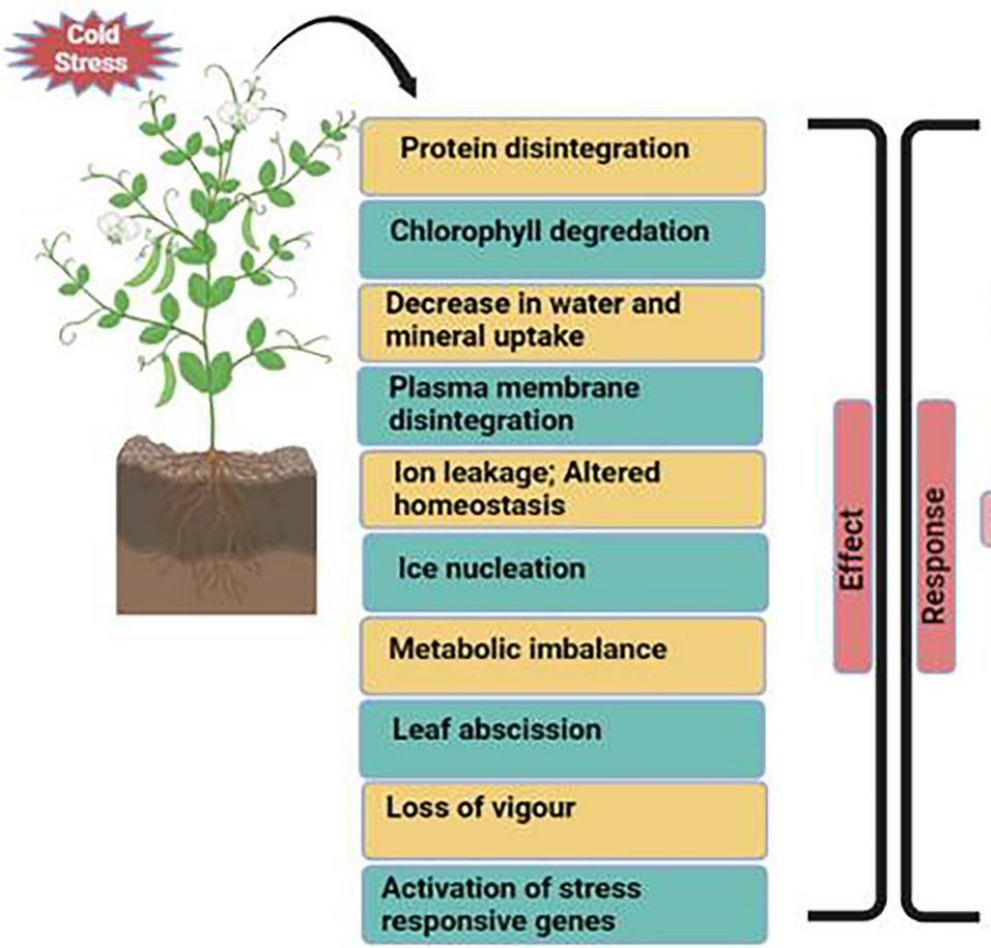
100ppm (4 weekly)

Silicon improved freezing tolerance

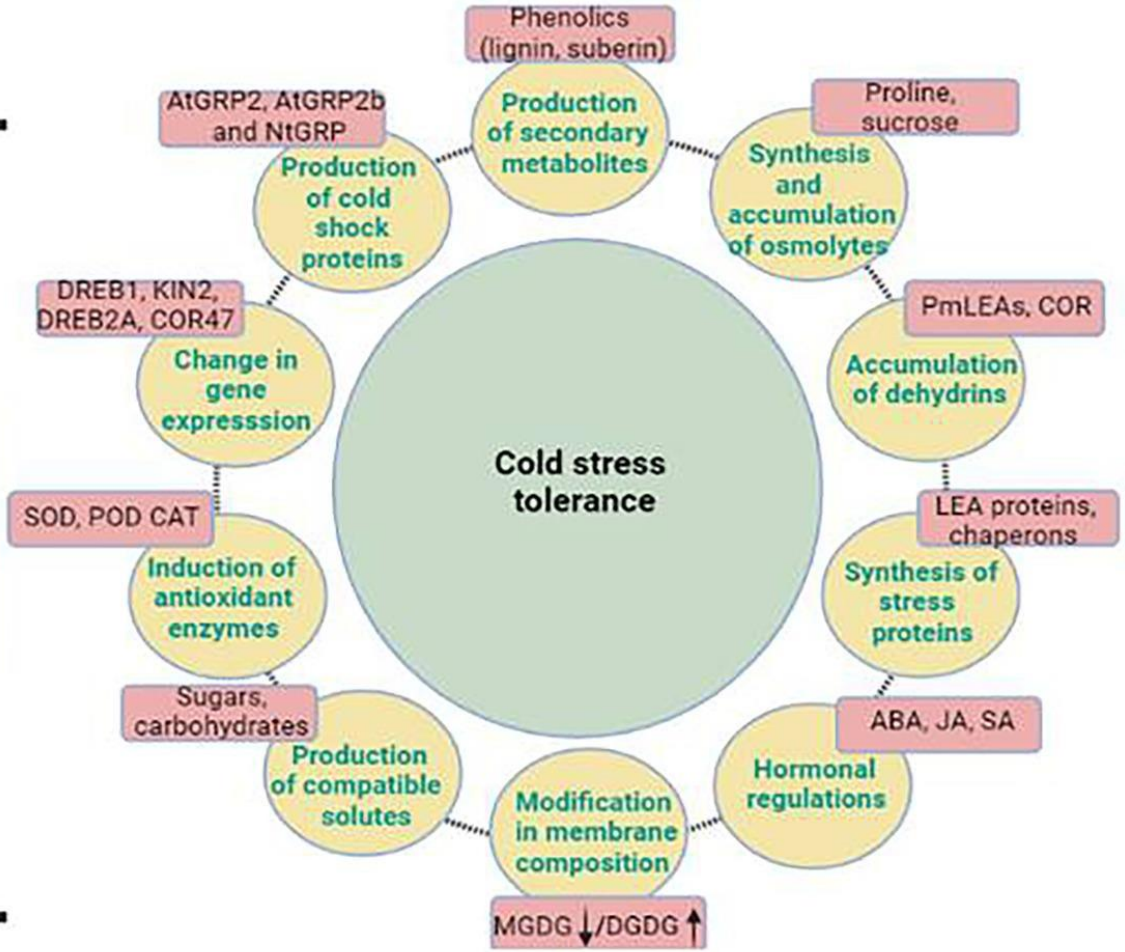
Without Si

100ppm (4 weekly)

What makes Si-treated plants freeze tolerant



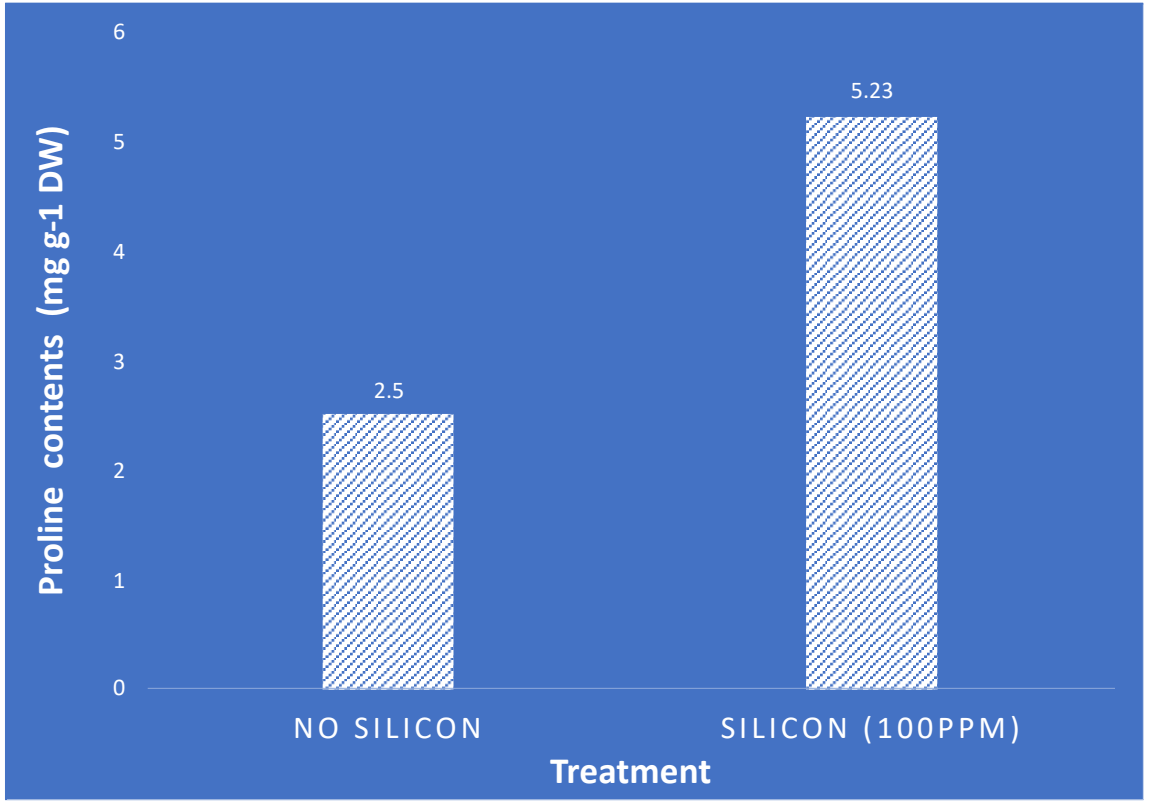
Major alterations due to cold stress in plants (physiological, biochemical, morphological and molecular)



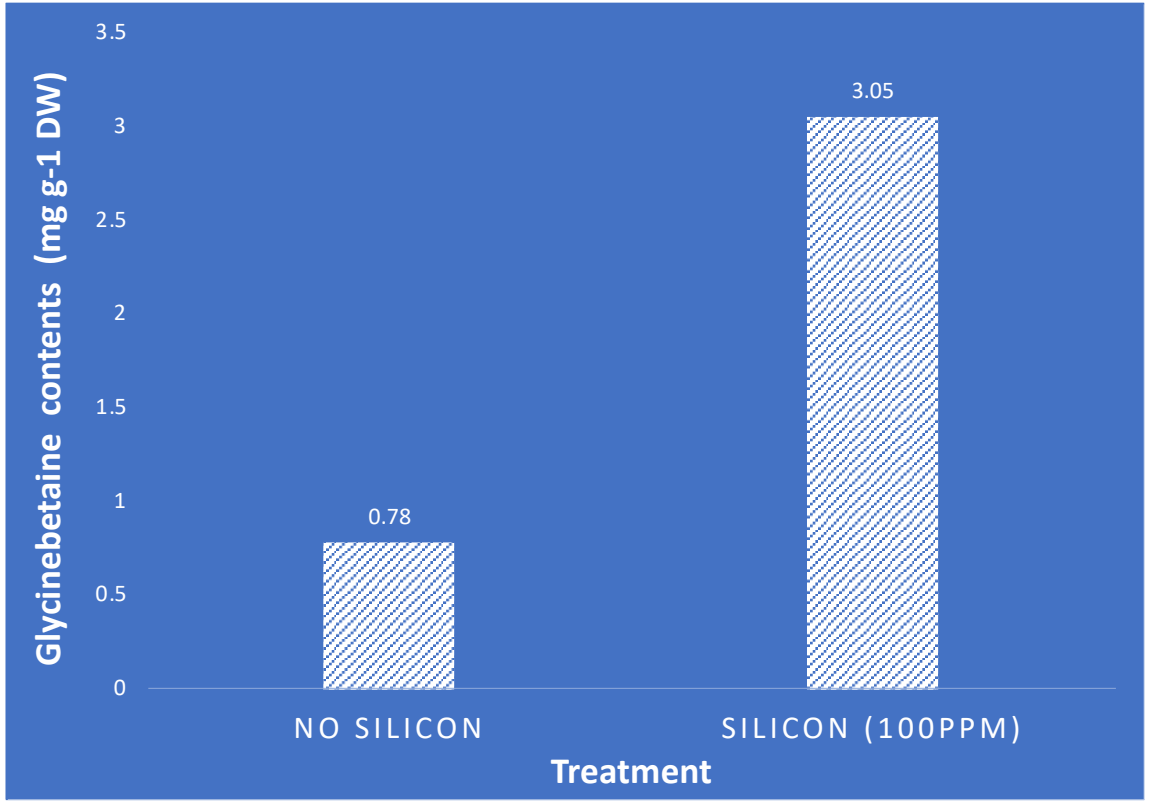
Fundamental mechanisms to cold stress tolerance by plants

Bhat et al., 2022

What makes Si-treated plants freeze tolerant



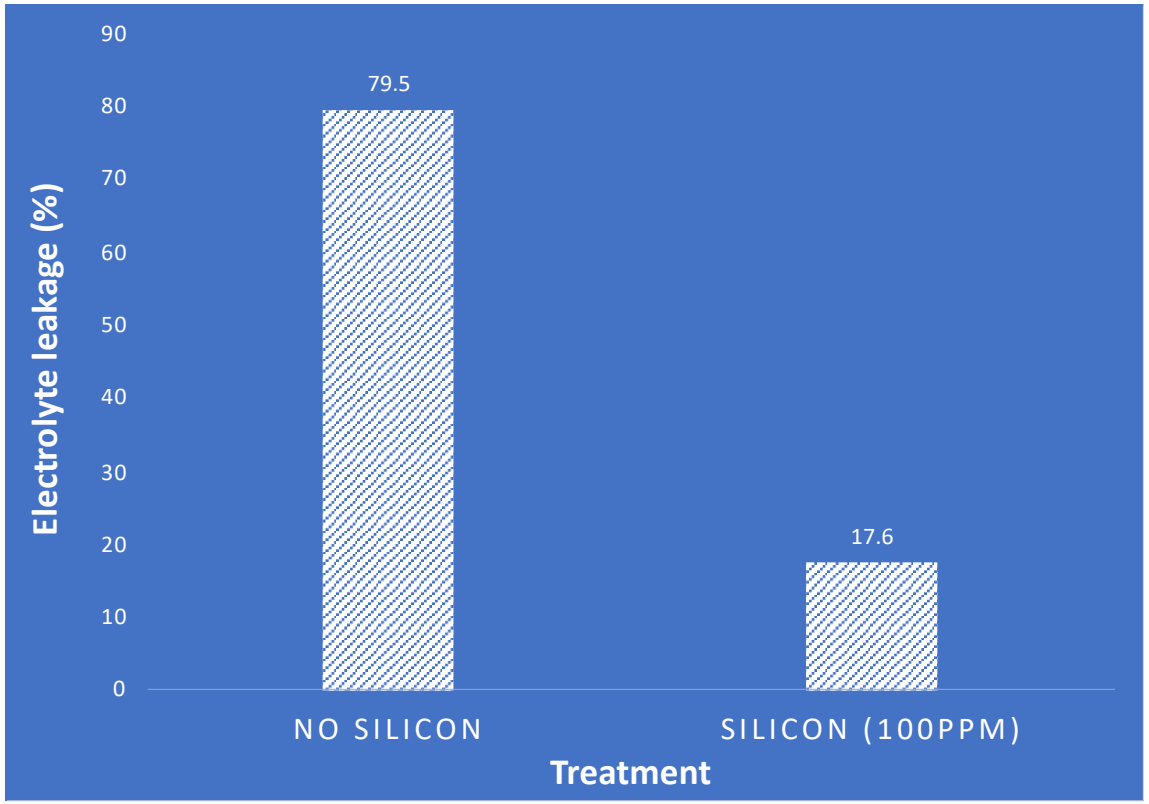
Proline

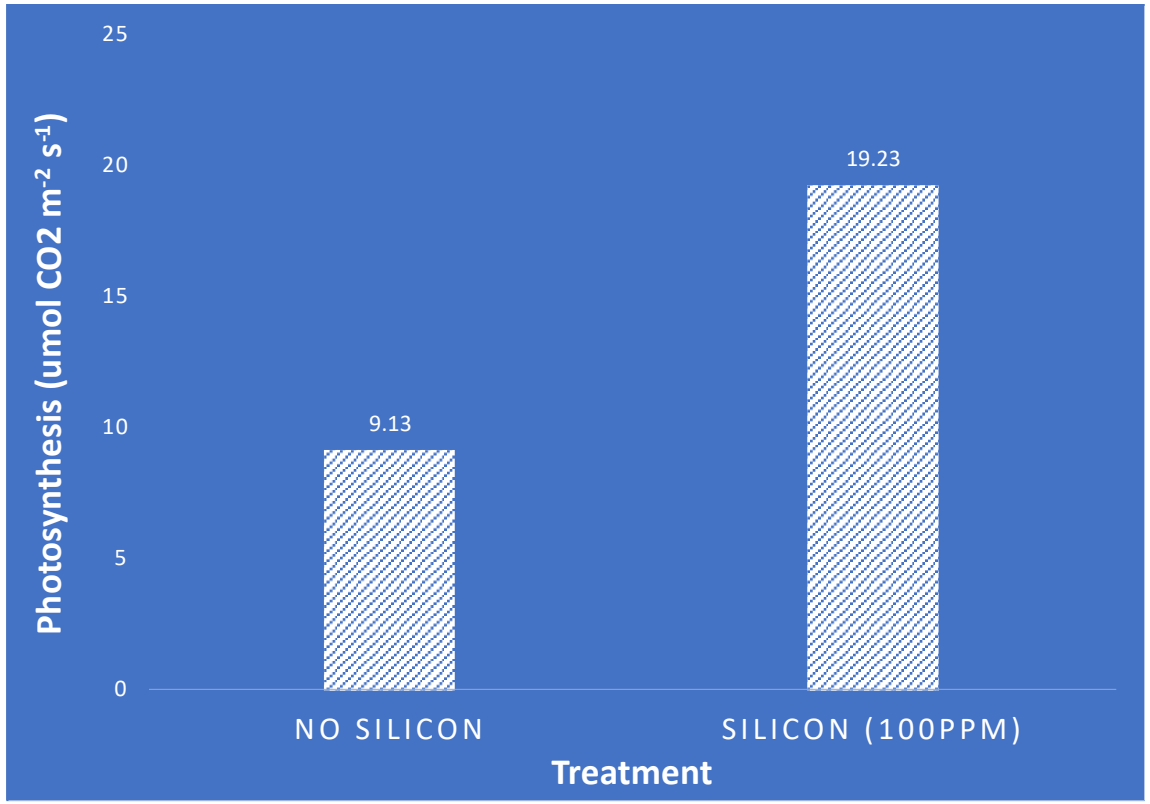


Glycinebetaine

Bhat et al., 2022

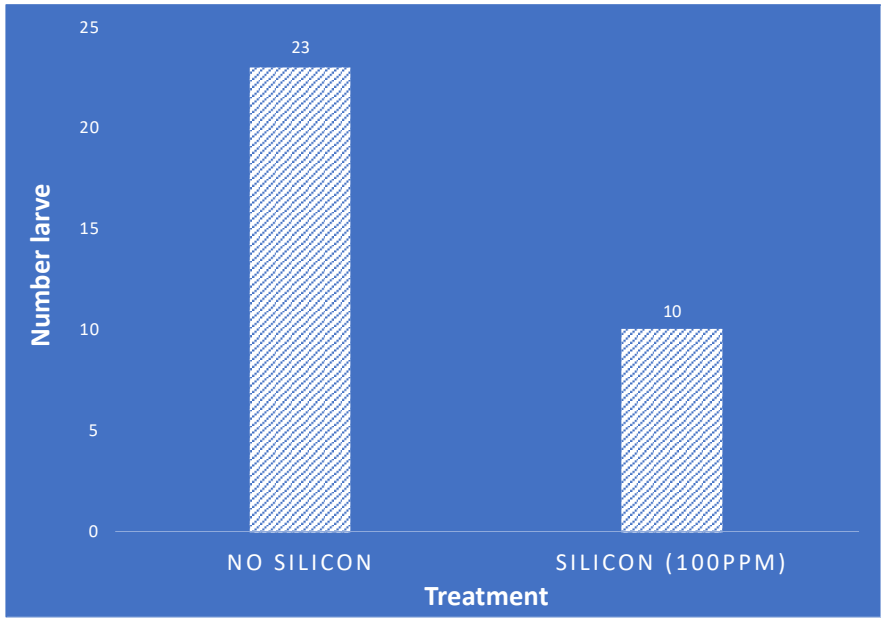
What makes Si-treated plants freeze tolerant

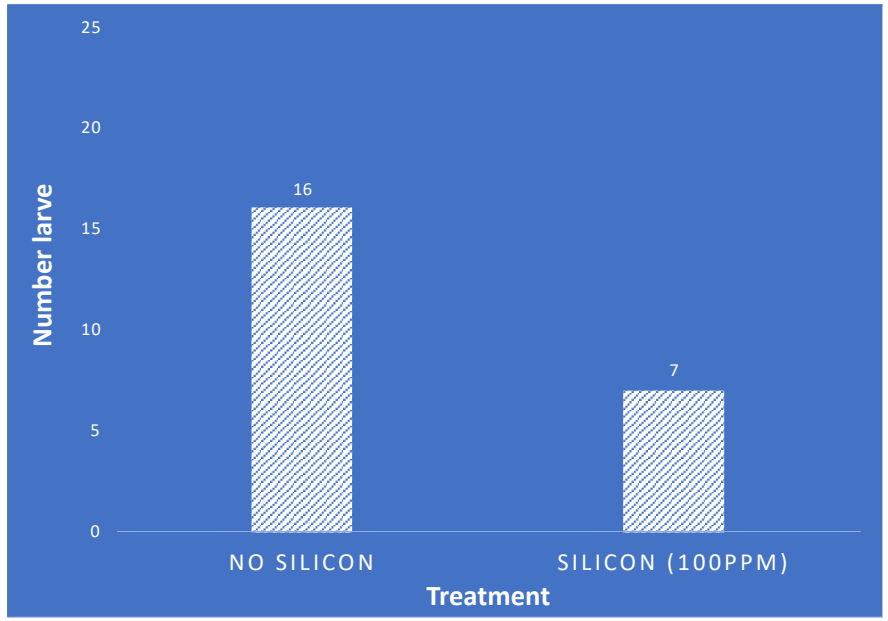


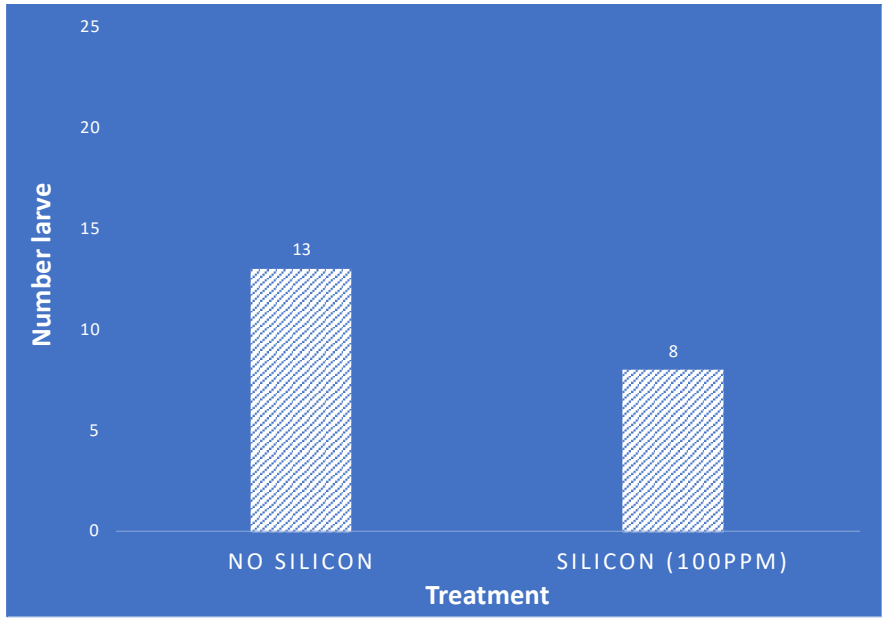


Bhat et al., 2022

Si reduced leaf minor attack







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Si improved fruit quality

Firmness

Shelf life

Fruit drop

Respiration

Fruit weight loss

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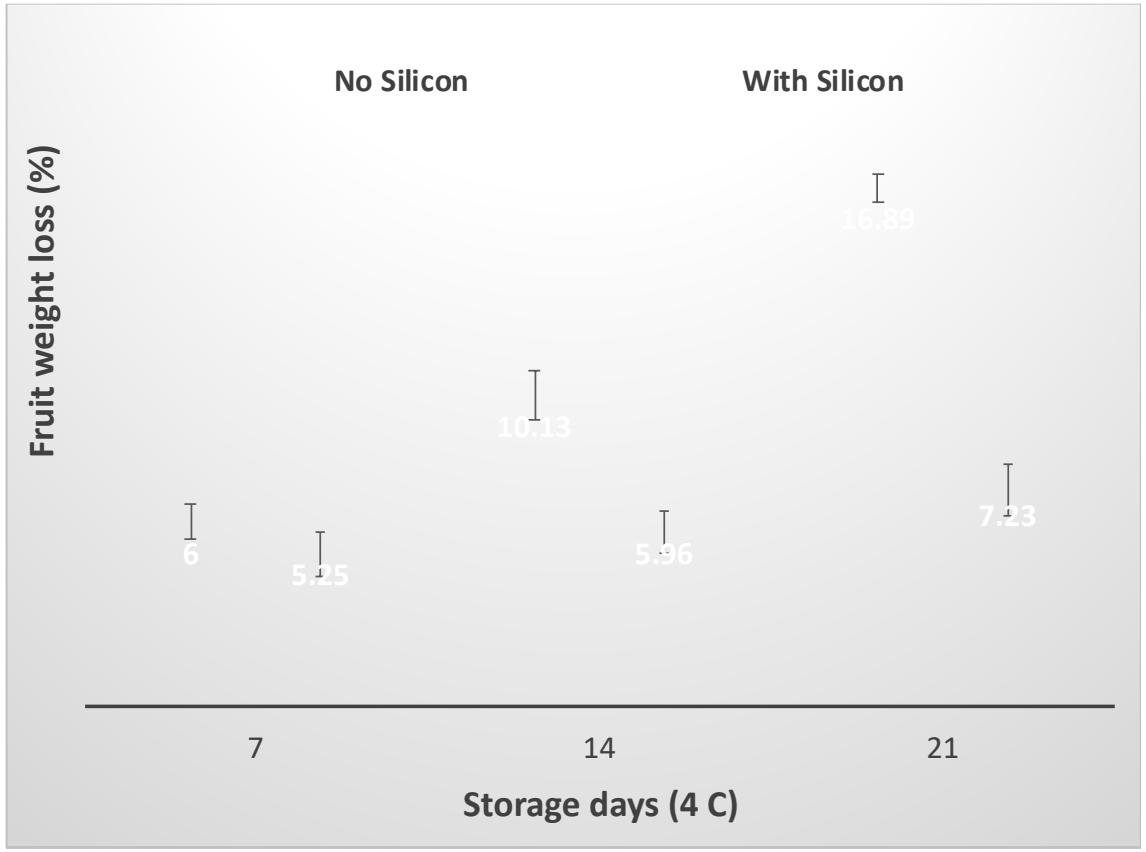
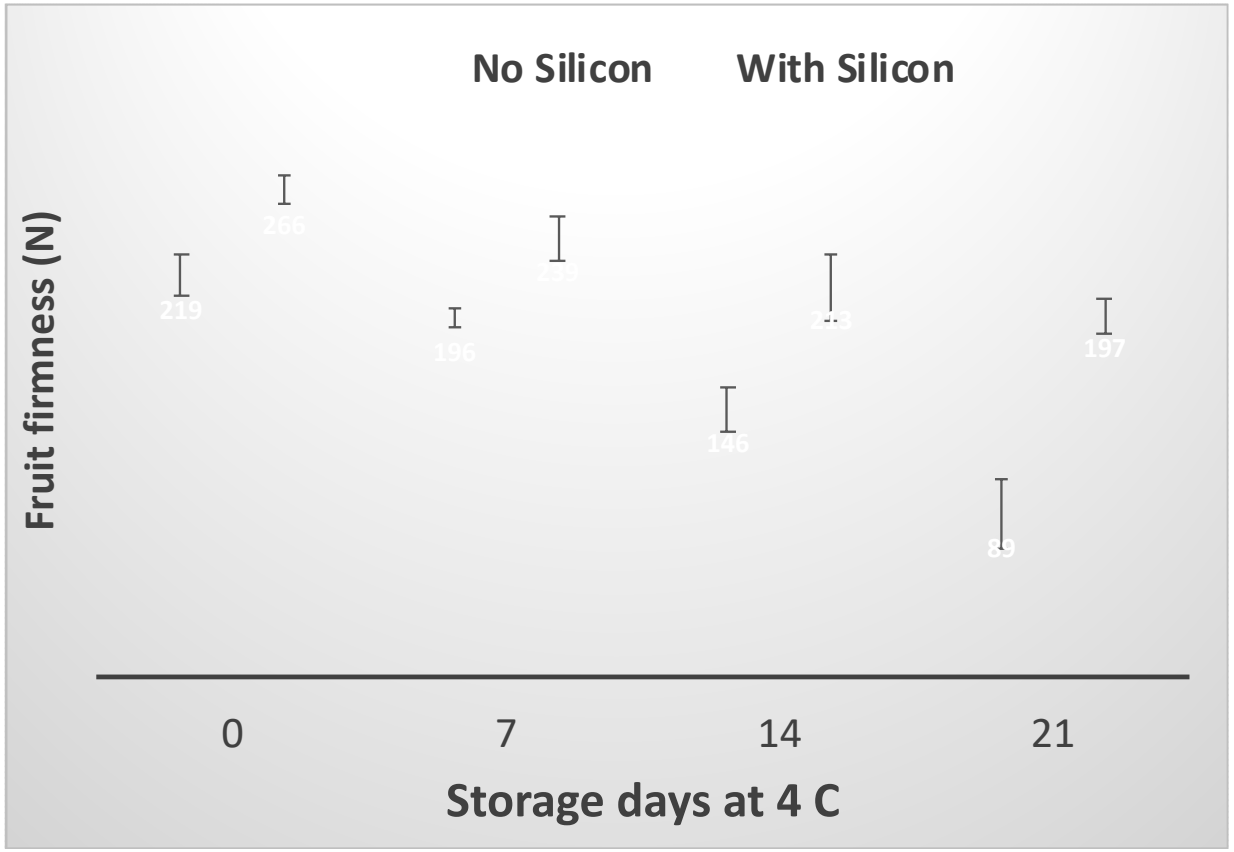
Si improved fruit quality





Take-home message

- Si is effective in improving plant growth and shelf life in variety of plant species including citrus
- Plants can only uptake Si in the form of Mono-silicic acid (water soluble Si)
- No phytotoxicity - conduct small test runs
- Application rate vary from crop to crop
- Continuous supply of silicon to plants is more effective than single time application
- Drenching found to be more effective than foliar application
- Always select product with maximum % of water soluble silicon
- Since, Si mitigates various environmental stresses and suppress pest and disease attack, so could be beneficial in plant nutrition program in citrus and other fruit crops
- ***More research on molecular physiology is needed to understand the stress tolerance mechanism in Si treated plants***

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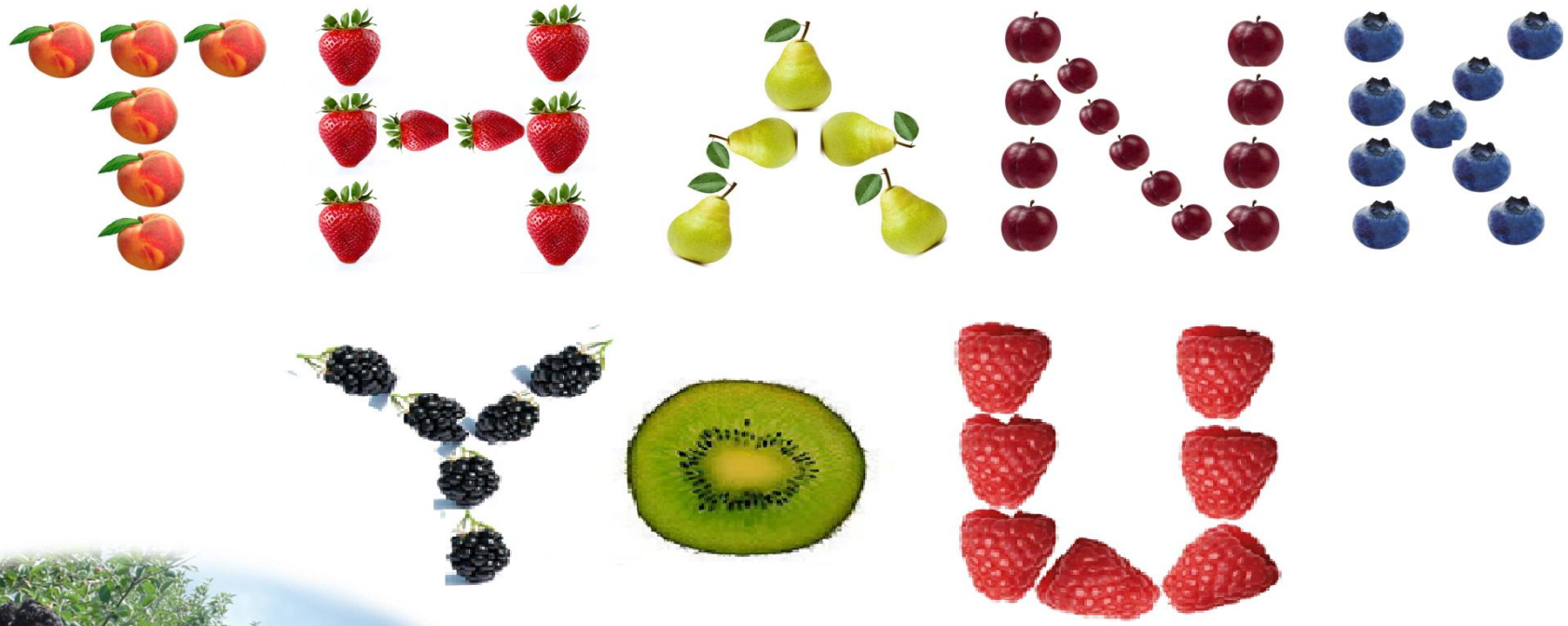

Questions

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