SPECIAL TO THE ADVISER

Silicon undeniably supports plant health

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Silicon plays a critical role in plant health. Plants cultivated in limited silicon environment are more susceptible to biological pests and environmental stress. Silicon-fed plants are not just physically stronger, their internal immune response, or physiology, is enhanced. This allows them to respond and adjust to the adverse growing conditions more quickly, indicating the significance of this nutrient in the plant's defense response.

To begin, all plants absorb and accumulate silicon. Current descriptions give a misdirected view that most plants accumulate low concentrations of silicon. Essential nutrients are categorized as either macronutrient (containing greater than 1,000 ppm) or micronutrients (containing less than 1,000 ppm). Using these same parameters, silicon is a macronutrient for tomato, which is often referred to as a low-accumulator or silicon excluder. Even plants that accumulate silicon as a micronutrient, such as basil, tobacco, and onion, have enhanced stress tolerance when adequate silicon is supplied. At the other end of the spectrum are the hyperaccumulators, rice and sugarcane, that accumulate up to 10% Si in their leaves. This, however, seems to be the exception, not the norm. Most monocots and over 70% of reported dicots accumulate silicon in their leaves at macronutrient concentrations (Table 1). When plants are cultivated in silicon-limited environments, they become more susceptible to disease whether they accumulate silicon as a macro- or micronutrient.

Silicon's role in defense goes beyond the physical barrier theory and likely involves physiological changes in cellular contents of silicon treated plants. Tolerance to foliar pathogens with silicon treatment is the most dramatic and is easily visible to the naked eye (Fig. 1). Interestingly, scientist are finding out the reduction of fungal diseases is not due to failure of the pathogen to gain entry into the plant, but as a result of changes in the plants' internal environment, limiting adequate materials, such as sugars, amino acids and organic molecules, that would support development and spread of the infection. There are many reviews in the literature highlighting the protective role in plant-pathogen interactions for a wide range of fruits and vegetables (Table 2). Bacterial and viral infections are also managed more efficiently when plants are grown with adequate silicon.

Similar to findings for fungal and bacterial diseases, insect herbivory is also drastically reduced in silicon-treated plants. For some insect-host relationships, penetration events are not reduced, while feeding time and egg counts are lower. Damaged areas are also reduced in non-phloem feeding herbivores. This again suggests that silicon-fed plants have changes to their internal environment, reducing the viability of these insects.

Silicon protection does not just stop at biological agents, but also helps with environmental stress, such as salinity, drought, temperature extremes, and heavy metal stress. Most of these events lead to water and nutrient imbalances. When plants have adequate silicon, they can adjust their internal environment to negate water loss, while dealing with these adverse conditions. This is often observed with reduction in transpiration as well as reduced levels of malondialdehyde (MDA), a marker for lipid peroxidation that correlates to oxidative stress. Enzymes and hormones also change between control and silicon-treated plants, but their pattern of change is not always similar when studies are compared. Even with these contradictions in enzymatic and hormone concentrations, the end result is that plants return more quickly to an internal balance, or homeostasis, with silicon treatment.

Post-harvest protection in both fruits and vegetables is another benefit of silicon. In these cases, the fruit or vegetable is dipped in higher concentrations of silicon, usually in the form of liquid potassium- or

Table 1: Macronutrient and Micronutrient Silicon Accumulating Plants

Macro Si Accumulators:

Almonds	1,800
Apples	3,200
Asparagus	2,400
Avocados	2,300
Blueberry	
Broccoli	
Cauliflower	
Clementine	2,500
Cucumber	10,164
Grape	3,700
Lettuce	7,000
Mustard	30,000
Okra	2,041
Pumpkin	4,591
Spinach	2,500
Strawberry	3,000
Summer Squash	3,497
Sunflower	5,180
Tomato	2,000
Valencia	3,000
Walnuts	1,300
Watermelon	6,340
Winter Squash	2,031

Micro Si Accumulators:

Basil	678
Onion	500
Spinach	152
Swiss Chard	152
Tobacco	290

This is an abbreviated list of silicon accumulation in plants. Values are average concentrations reported in the literature. Data for blueberry, broccoli and cauliflower were not easily translated to ppm, but were determined to be in the macronutrient range.

Control   Silicon-Treated

Figure 1: *Peanuts grown without calcium silicate (control) developed more symptoms throughout their leaves compared to silicon-treated plants.*

calcium silicates. This leads to a longer shelf life with reduction in many of the diseases that afflict produce during storage. Apples, avocados, carrots, lemons, and strawberries have all shown postharvest protection. Reduction in ethylene and CO_2 and increases in cytokinins are likely involved in the response.

Silicic acid and silica nanoparticles are two known forms of plant-available silicon. They can be supplied through a number of products that include both liquid and solid fertilizers, depending on the production styles. Since plants need available silicon at the time of stress, ensuring a continual supply in the growing media or through foliar applications provides protection to the previously listed situations. While the mode of action for silicon protection is still unclear, its positive benefits to plant health is undeniable. ■

Is Silicon Supplementation Needed for your Production?

Some final questions to consider on whether silicon supplementation is needed for crop production.

- Are you growing in silicon-limited soils or media?
  - What media are the plants growing in?
    - mineral-rich soils tend to have more plant-available silicon than heavily cultivated soils, with soil-less medias, including hydroponics, containing the least
- Are you irrigating with silicon-limited water?
  - surface or ground water have higher plant-available silicon than rainwater
- Are you cultivating plants that accumulate macronutrient concentrations of silicon?
- Is there a good chance for disease from environmental or biological factors?
  - Salinity, heat/drought, high UV, heavy metals
  - Mildews, root rots, bacterial blights, viral infections
  - Aphids, thrips, nematodes, mites

If you answer yes to any of these, then silicon fertilization may help give that additional protection, allowing for the plants not just to strive, but to thrive when growth conditions become challenging.

Table 2: A condensed list of Silicon-induced tolerance to economically important diseases.

Hosts	Diseases	Pathogens
Arugula	Black spot disease	*Alternaria japonica*
Asparagus	Stem blight	*Phomopsis asparagi*
Avocado, Soybean, Bell Pepper	Phytophthora root rot	*Phytophthora cinnamomi, P. sojae, P. capsici*
Bean	Angular leaf spot	*Pseudocercospora griseola*
Bean, Cucumber, Strawberry	Anthracnose	*Colletotrichum lindemuthianum; C. orbiculare, C. acutatum*
Bitter gourd, Tomato	Pythium root rot	*Pythium aphanidermatum*
Cucumber	Black rot	*Didymella bryoniae*
	Crown and root rot	*Pythium ultimum and P. aphanidermatum*
	Gray mold rot	*Botrytis cinerea*
Cucumber, Grape*, Melon, Muskmelon, Pumpkin, Strawberry, Tomato*, Zucchini Squash	Powdery mildew	*Podosphaera xanthii, Uncinula necator, Sphaerotheca xanthii, S. macularis, Oidiopsis sicula, Oidium necolycopersici*
Cucumber, Lettuce, Melon, Tomato*	Fusarium wilt	*Fusarium oxysporum* spp., *F. semitectum*
Lettuce	Down mildew	*Bremia lactucae*
Melon	Alternaria	*Alternaria alternata*
Melon, Muskmelon	Pink rot	*Trichothecium roseum*
Muskmelon	Bacterial fruit blotch	*Acidovorax citrulli*
Onion	White rot disease	*Sclerotium cepivorum*
Pea	Leaf spot	*Mycosphaerella pinodes*
Peach	Brown spot	*Monilinia fructicola*
Strawberry	Pestalotia leaf spot	*Pestalotia longisetula*
Tobacco	Tobacco Ringspot Virus	*Tobacco ringspot virus*
Tomato	Bacterial speck	*Pseudomonas syringae pv. Tomato*
	Bacterial wilt	*Ralstonia solanacearum*
Watermelon	Gummy stem blight	*Didymella bryoniae*
Yellow Passion fruit	Bacterial Spot	*Xanthomonas axonopodis pv. Passiflorae*

**Indicates different studies have shown contrasting results with silicon treatment.*