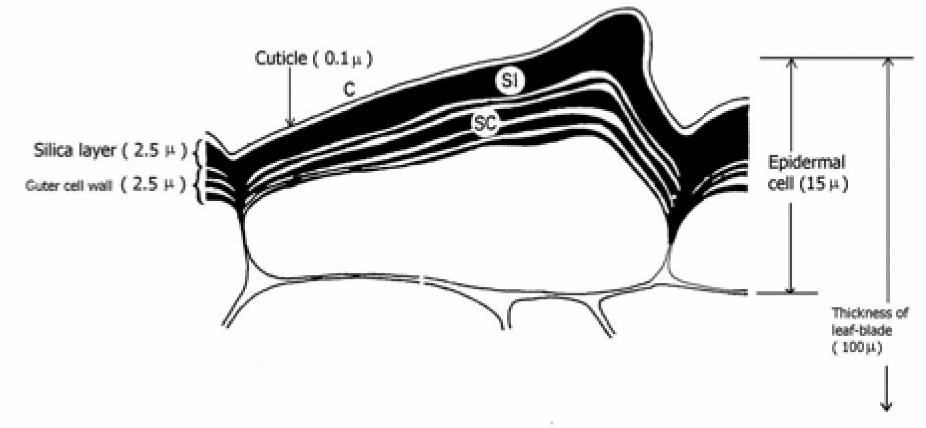
Plants and their defense system

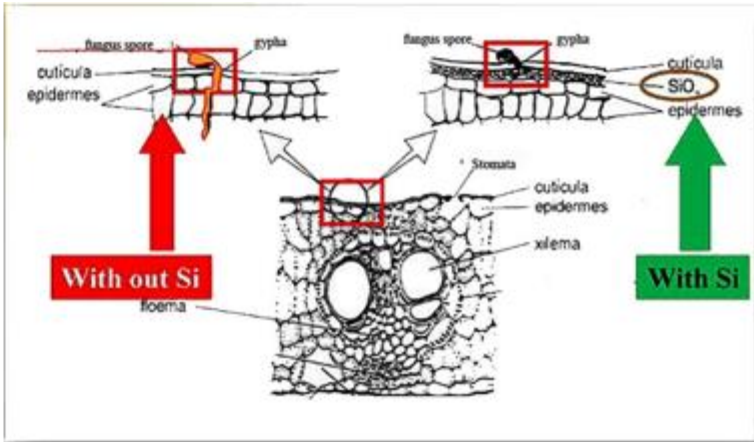
It is not a secret, that cultivated plants are only able to realize less than 20% of their natural plant protection possibilities, against stresses (insect, fungi, diseases, viruses' attacks, unfavorable climatic conditions, chemical pollution, nutrient deficiency et al.), and which are the functions of the plants genes. All plants have a lot of information in their DNA which can protect them against outside stresses, if the right mechanism can be triggered with the right conditions and at the appropriate time. Usually cultivated plants don't have enough time or proper conditions to develop this adequate response, against outside stress and as a result, a lot of dangerous and toxic agrochemicals are necessarily applied in order to protect the plants against stresses.

The most interesting and available solution is the optimization of the plant's natural protection potential, which is present in all living organisms, and especially in cultivated plants. These plant properties are the result of a natural selection process which began with wild plants, several thousand years ago. The best way to activate these natural plant protection mechanisms is to apply active Si to the plants. On this very subject, there are thousands upon thousands of scientific studies and literature citations available, which show that the optimization of plant Si nutrition protects plants against ANY STRESS, including fungi, insect attacks, diseases infection, unfavorable climatic conditions etc.
Our data and the literature showed that one of the most important functions of Si in the plant is providing reinforcements to the plant defense system. The following mechanisms of direct influence of active Si on plant defense system are suggested:
Mechanical

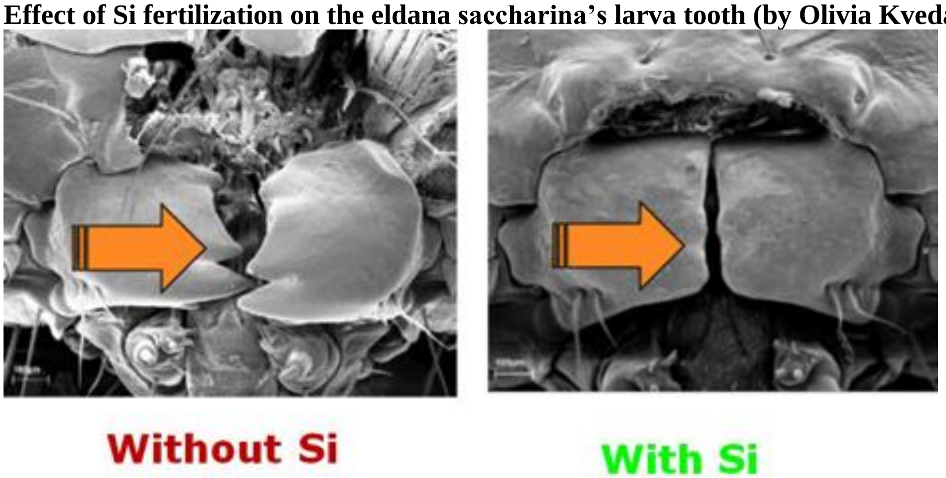


Most of the Si are adsorbed by plants is concentrated in epidermal tissue (Yoshida 1975). Accumulated Monosilicic acid transforms into polysilicic acid and amorphous silica that can associate with pectin and calcium ion (Waterkeyn et al. 1982). This means that a double cuticular layer forms protecting and mechanically strengthening plants. The effect of Si fertilizer on plant resistance to diseases, insect and fungi attacks is explained by this mechanism (Datnoff et al. 1997, Hodson & Sangster 1988) and today Si fertilization is recognized as an environmentally friendly alternative for pesticides and fungicides (Datnoff et al. 1997).

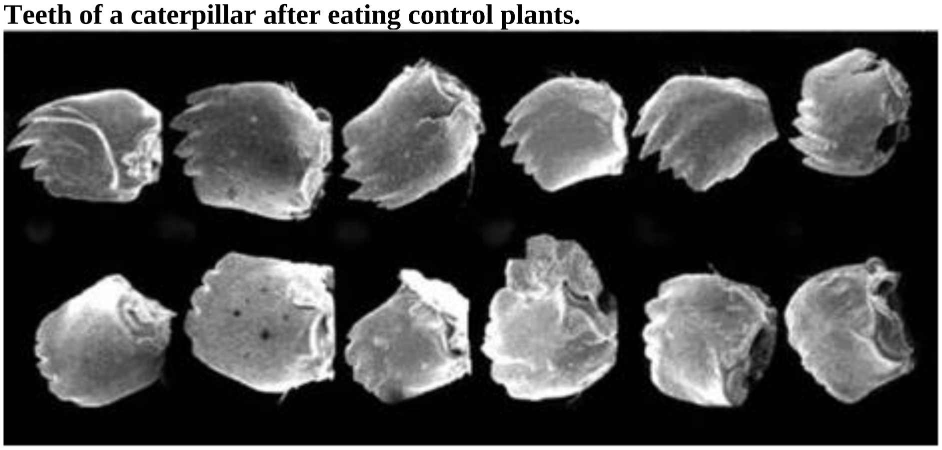
Effects of Si on fungi attacks (Bidwell, 1974)



Effect of Si fertilization on the eldana saccharina's larva tooth (by Olivia Kvedaras, 2005)



Teeth of a caterpillar after eating control plants.



Teeth of a caterpillar after eating plants treated by plant-available Si.

Physiological

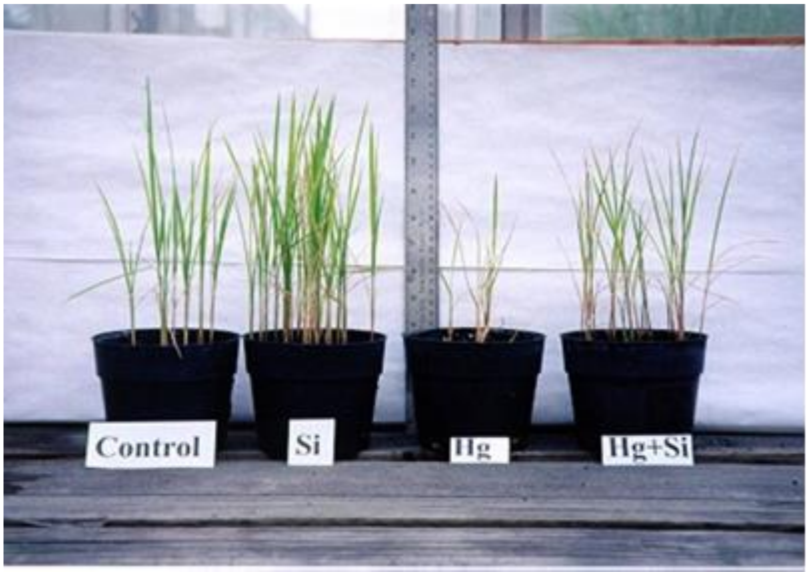
Physiological mechanism of direct influence of Active Si on plant defense systems are realized by direct improvement of plant viability with optimization of plant Si nutrition.

There is a great deal of data available, which shows that optimization of Si plant nutrition accelerates plant growth.

Bananas

Untreated Treated

Chemical



Chemical mechanisms of straight influence of Active Si on plant defense systems, is realized by the direct chemical reactions between soluble Si and substances (stress factors) inside plant tissue.

The detoxification of heavy metals by soluble Si is an example of such mechanisms. Another example of chemical mechanism is the reduction of plant's salt toxicity.

Considering that plant sap contains very high concentration of soluble Si, the application of active Si protects plants against heavy metals toxicity.

The mechanisms by which Si increases plant defense against salt toxicity remains unclear. Wang and Hang (2007) hypothesize that Si alters the distributions of Na and some trophic ions in alfalfa plants to improve the salt tolerance in salt-stressed environments.

Authors conclude that Si may alleviate salt stress in alfalfa by inhibiting Na uptake by roots and affecting in the shoots. Liang et al. (1996) demonstrated that added silicon increased salinity tolerance of barley grown hydroponically.

Added silicon enhanced the growth of salt-stressed barley which was found to have improved photosynthetic activity and the ultrastructure of leaf cell organelles (Liang, 1998) and reduced electrolytic leakage of the leaves (Liang et al., 1996).

Further studies indicated that silicon enhances K: Na selectivity ratio (S*k;Na*) that mitigated against the toxic effects of sodium (Liang et. al., 1996). As well known, selective uptake of mineral ions is associated with the activity of HC-ATPase (Marschner, 1995).

One possible mechanism of stimulating the effects of Si on K uptake by plants under salt stress is, therefore, assumed to be the activation of HC-ATPase in the membranes.

Application of Si to salt-treated barley reduced lipid peroxidation and SOD activity in leaves, HC-ATPase activity in roots, and sodium, potassium and calcium accumulation in the shoots and roots. (Liang et al., 1996; Liang, 1998).

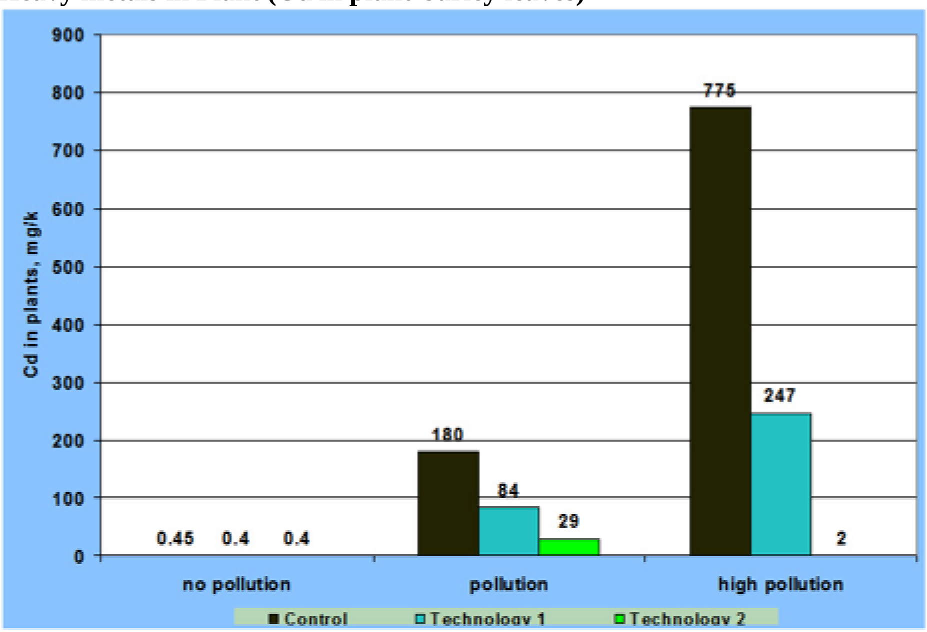
Our previous data demonstrated that increasing Si in plant tissue under stress is in direct proportion to intensity of stress (Biel et al., 2008; Matichenkov, 2008). Our data has shown enhancing silicon uptake

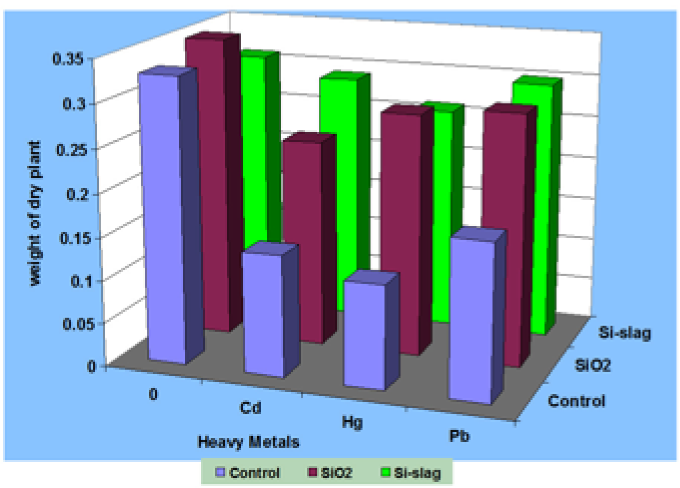
by plants exposed to stress. The redistribution of Si from leaves to problematic place was fixed on the results of total Si in plant tissue after the experiment.

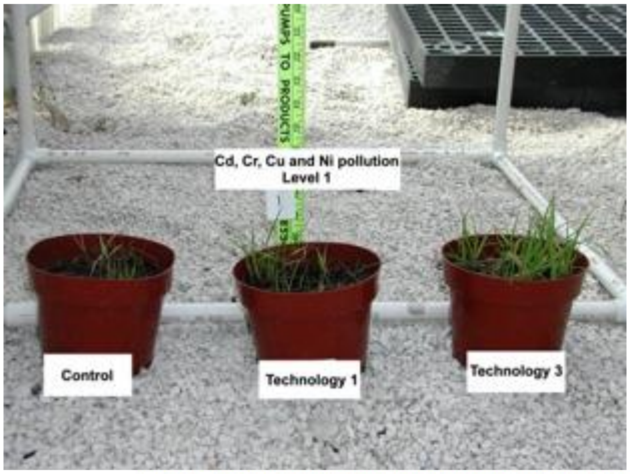
Using our methodology or testing of element concentration in apoplast and symplast of plant showed that Si significantly decreased Na uptake and root-to-shoot transport in barley plants exposed to salt stress.

Several mechanisms are available for prevention of sodium toxicity by soluble silicon compounds. The reduction or blockage of Na active transport in apoplast can be realized in roots, stems and leaves. Monosilicic acid also increases the resistance of chlorophyll molecules against their demolition by sodium. Soluble Si also can reduce the root adsorption of Na from solution. Probably all these mechanisms are at work simultaneously. Simplistic cells of roots and stems have the possibility to regulate Na penetration.

Heavy metals in Plant (Cd in plant-barley leaves)





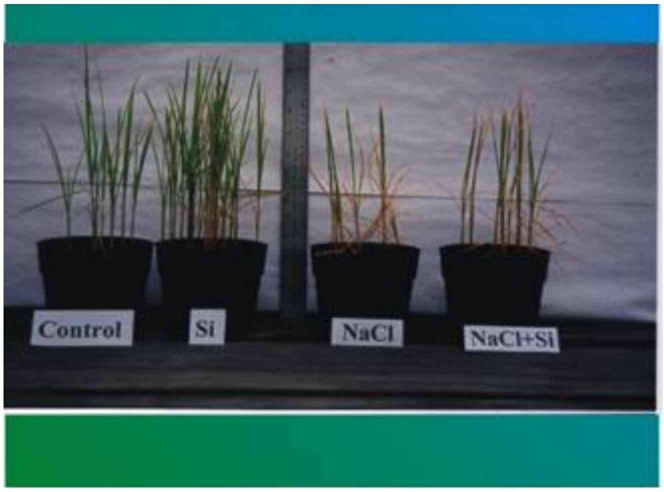


The effect of heavy metasl on the germination of the barley seeds.

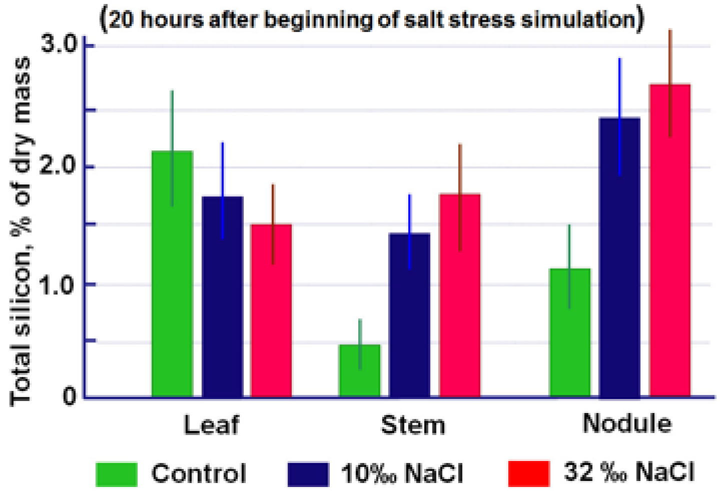
Treatmnet	% of germinated seeds
Control	85±3
SiO_2	90±3
Cd	32±3
Cd + SiO_2	55±3
Hg	75±3
Hg + SiO_2	85±3
Pb	40±3
Pb + SiO_2	75±3

Content of heavy metals in stems and roots of barley.

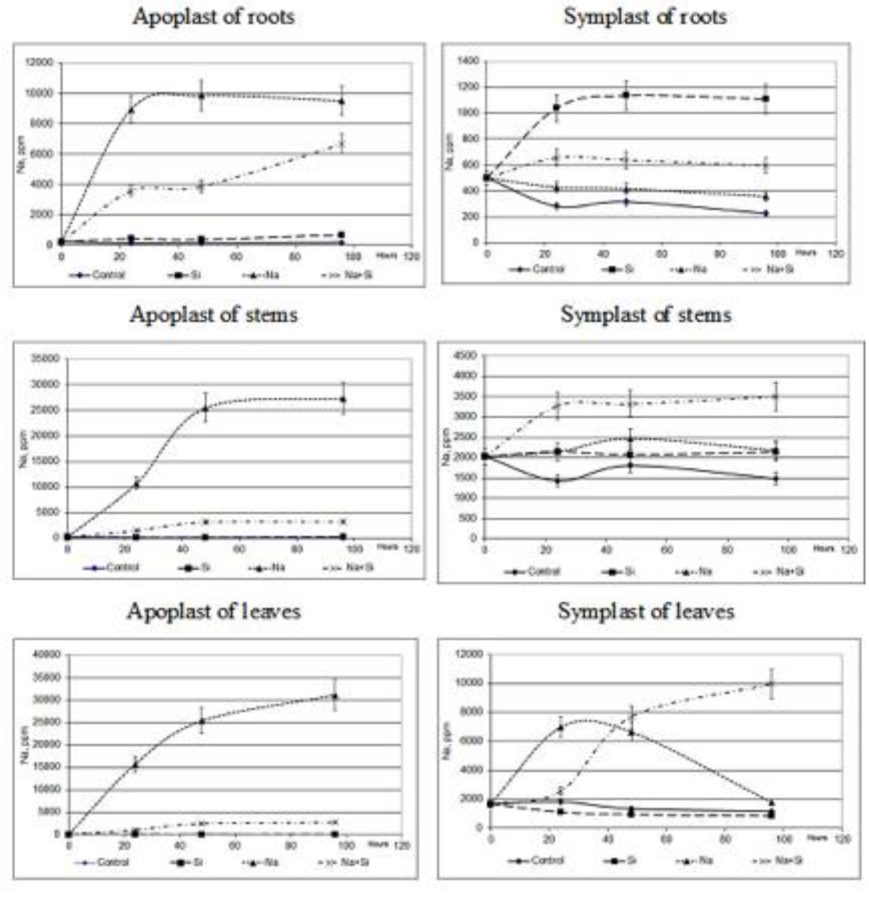
	No pollution					Low level of pollution					High level of pollution				
	Cd	Cr	Cu	Ni	Pb	Cd	Cr	Cu	Ni	Pb	Cd	Cr	Cu	Ni	Pb
Stems, mg/kg of dry mass															
Control	0,45	0,91	12,64	1,07	0,00	180,00	997,40	106,80	113,60	0,00	775	4048	211	564	0,0
SiO_2	0,24	0,71	11,19	1,07	0,00	170,60	1676,60	81,60	107,60	0,00	969	5126	205	506	0,0
Monosilicic acid	0,40	0,56	10,20	0,60	0,00	134,00	1815,20	79,00	103,00	0,00	626	3067	158	395	0,0
Roots, mg/kg of dry mass															
Control	0,88	5,88	7,94	0,29	0,60	318,20	1625,40	336,00	112,60	0,90	1040	2306	445	234	1,2
SiO_2	0,91	4,55	6,73	0,45	0,40	497,20	1968,60	198,00	156,00	0,60	1065	2639	730	281	0,2
Monosilicic acid	0,40	8,60	6,60	0,45	0,60	352,20	1417,20	270,20	111,20	0,80	1016	2046	497	263	1,0
LSD_{05}	0,05	0,1	0,2	0,1	0,04	1,2	15,3	5,2	4,6	0,05	20	25	10	15	0,1



Si distribution in different organs
of *D.spicata* vs.
(20 hours after beginning of salt stress simulation)



Dynamic of Na in tissues of barley plants exposed to salt stress.



Biochemical:

It is a known fact that cultivated plants use only 10- 20% of their natural potential ability to self-protect against abiotic and biotic stresses (Tarchevsky 2002).

It is also well known that the mechanism of natural self-protection of plants against any stress is chemically based (Zaitlin & Palukaitis 2000).

Investigations showed that soluble Si or mixture of plant-available Si with specific substances can initiate natural self-defense mechanisms of plants via signal system that enhance the resistance of cultivated plants against biotic stresses.

The mixture used was called Activated Si or Immunized Si. Several modifications of this mixture were elaborated and have been certified for using in organic farming since they do not contain any synthetic substances.

Plants have a non-specific defense system that is manifested by synthesizing non-specific stress-ferments and a gene controlling defense system, which is realized by synthesizing specific and non-specific stress-proteins managed by genetic information (Tarchevsky 2001). The system of plant protection acts through the following process:

- **Stress effects plant cells either physically or chemically.**

- This effect activates the signal system (formation of special signal molecules) of the plant resulting in transforming the information of the stress to the plant nucleolus and to other plant organelles that control plant metabolism.

- Following the information of incoming stress, the processes of synthesizing non-specific stress ferments begin.

- If the nucleolus of the cell recognized a type of stress using the specific signal system, it selects the information in the DNA about the specific stress protein required and its synthesis.

- The information RNA transforms this information and sends new orders to organelles to start synthesizing determined stress proteins.

- Newly synthesized specific and non-specific stress-proteins move to a stress area and alleviate a negative impact of a stress (Tarchevsky 2001).

Many studies on the effects of soluble silicon compounds in relation to plant growth and development indicate the hypothesis of an inherent universal mechanism by which silicon improves plant stress-tolerance (Belanger 2005, Biel et al. 2008, Ma and Takahashi 2002, Matichenkov & Bocharnikova 2004, Savant et al. 1997, Snyder et al. 2006).

We suggest that except for mechanical, physiological and chemical mechanisms of the direct effect of active Si on the plant defense system, there is another universal biochemical mechanism available. This biochemical mechanism provides additional energy-free synthesis of part or whole of specific and non-specific anti-stress proteins on Si matrix (polysilicic acid). The mechanism of the beneficial effect the activated Si has on plants' immune system has been poorly investigated. This mechanism is realized according to the following's steps:

- ***Silicon uptake:*** **Molecules of Monosilicic acid from the soil (or foliar-applied on plants) penetrate across the root plasmalemmal (cell "sluice") or leaf epidermal tissue. Inside of plant, Monosilicic acid is partly condensed into polysilicic acids and distributed between plant organs.**

Silicon distribution**:**

Silicon compounds are partly accumulated in the epidermal layer, root caps, cell walls, and other organs and tissues for synthesis of phytoliths and other Si-containing structures. Some silicon compounds penetrate into the cells to form silica gel – a matrix for further low-temperature synthesis of organic compounds. Some absorbed silicon is preserved and stored "in reserve" as polysilicic acid or silica gel with non-active surface within the cells or in the intercellular space.

Synthesis of organic compounds on the polysilicon matrix at non-stressed conditions: **Silicon compounds are located inside the cells as polysilicic acid gel. At certain moments, former-molecules (protein, simple or complicated protective compounds, and so on) are delivered to activated gel and silicon replica-matrixes are formed by means of former-molecules (Figure). After printing and moving out replicating substances, modified polysilicic acid gel-plate becomes able to catalytic synthesis of the copies of former-molecules by using simpler structural elements and components located in cytoplasm.**

Silicon-dependent synthesis of protective compounds at stressful conditions:

External irritant activating cell signal system switches on identification mechanism to identify stress inductor and to locate its primary target.

Simultaneously, organism forwards demands for additional silicon uptake from the environment and transport of reserved silicon compounds to tissues subjected to stress.

Cell nucleus received information about stress finds adequate response, i.e. induction of the chain of reactions provided synthesis of the protective compounds such as stress-proteins, antioxidant enzymes, antioxidants and others (Figure).

Then, the molecules synthesized in response to stress are transported to damaged targets. However, at strong stress, the rate of synthesis and quantity of synthesizing material may be insufficient owing to a necessity to solve other problems vitally important for the organism.

As a result of escalating energy deficiency and informational resources, the process of synthesis of "routine" compounds essential for cell functioning slows down or even stops.

We suppose that some of protective compounds are transported within living cell to the activated matrix of polysilicic acid gel where these compounds are printed as former-molecules.

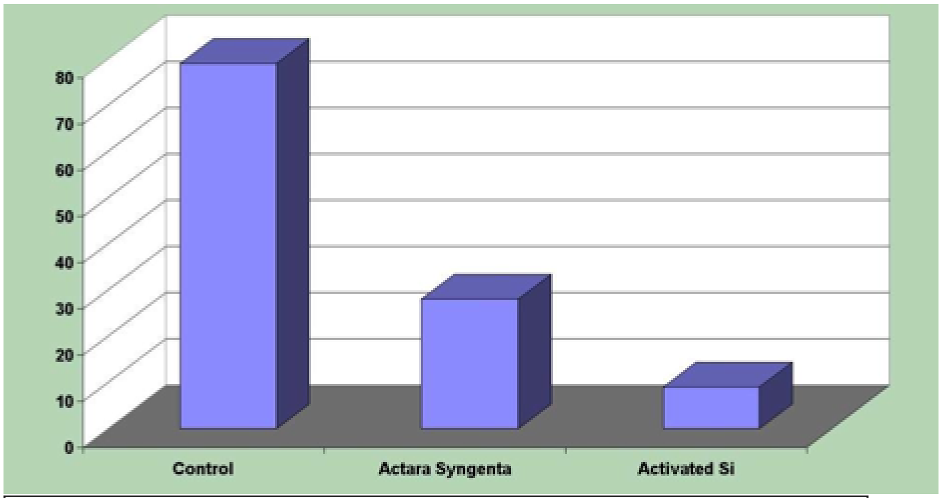
Then, former-molecules are transported to stress-zone leaving their prints on the gel surface, while the silica gel matrix begins to clone the same molecules from the improvised material localized in cytoplasm.

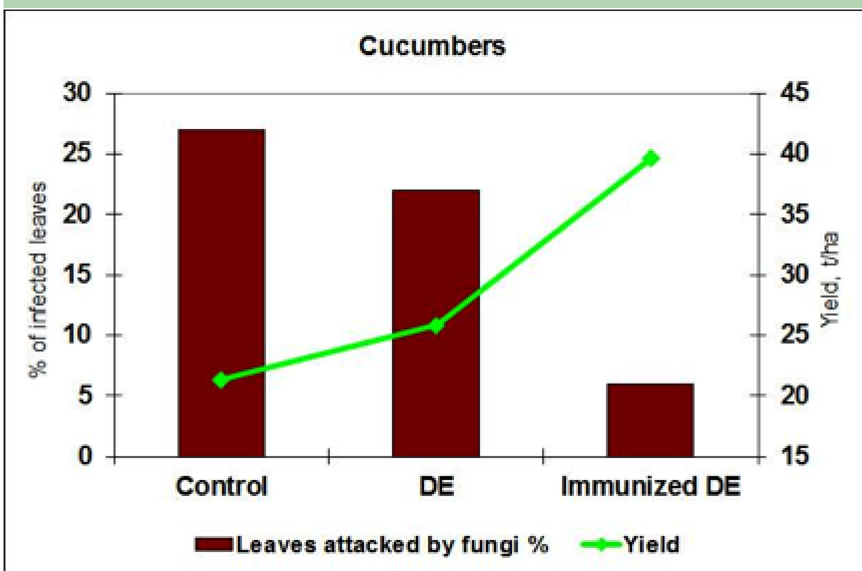
At such cooperation, silica gel matrixes give organisms the possibility, without respect to stress, to release informational-commanding resources and part of energy for cell functioning in former "before-stress" regime.

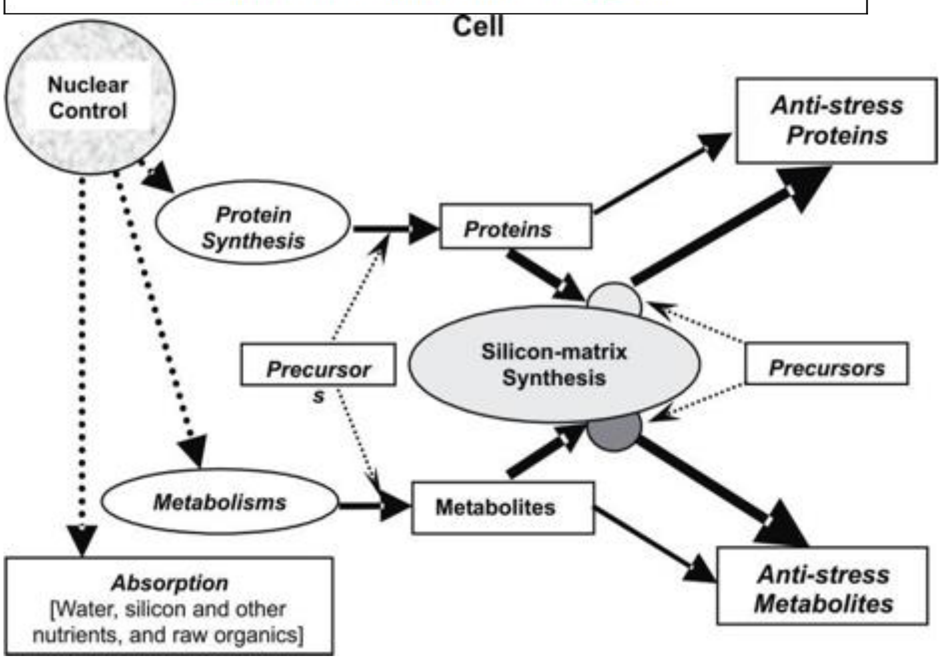
Thus, additional synthesis of protective compounds on polysilicic acid gel matrixes is carried out without direct participation of the genetic apparatus.

It is important to note that the activation of the silica gel for synthesis of specific and non-specific antioxidants and stress-ferments could be induced by artificial simulation of stress caused by the application of special molecules that are able to activate the plant signal system. As a result, it is possible to immunize cultivated plants against biotic stresses BEFORE stress comes in.

Effect of activated Si fertilizer and Syngenta's insecticide on the % of cauliflower leaves infected by louse-plant


80
70
60
50
40
30
20
10
0
Control
Actara Syngenta
Activated Si


Cucumbers
% of infected leaves
Yield, t/ha
30
25
20
15
10
5
0
45
40
35
30
25
20
15
Control
DE
Immunized DE
Leaves attacked by fungi %
Yield


Cell
Nuclear Control
Protein Synthesis
Proteins
Anti-stress Proteins
Precursor s
Silicon-matrix Synthesis
Precursors
Metabolisms
Metabolites
Anti-stress Metabolites
Absorption
[Water, silicon and other nutrients, and raw organics]