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ROLE OF SILICA IN PLANTS

Absorption and Deposition of Silica by Four Varieties of Sorghum

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To study absorption and deposition of silica by four varieties of sorghum, plants were grown in an open field and gathered at regular 3-week intervals throughout the growing season. Silica content of leaf sheaths and leaves of all varieties continuously increased throughout the season. Stems and seeds remained low and constant in silica content. The silica content of roots decreased during the first 3 to 6 weeks; thereafter a slight increase was observed. Generally, roots had a higher silica content than had been expected. There was a considerable variation in rate and amount of silica absorbed by the four varieties. Spur feterita absorbed the most and Dwarf yellow milo the least. Plants resistant to insects or diseases had a higher silica content at most stages than corresponding susceptible varieties.

Early investigators thought silicon essential for plants, since it occurs in them in relatively large amounts. Later observations indicated that this element may be essential only to barley, sunflower, and beets (*10, 16*). There appears to be a relationship between silicon and phosphorus metabolism (*12*).

Wittenberger (*18*) and Cooper (*1*) showed that maximum absorption of soluble silica by certain plants was favored by neutrality (pH 7.1) and that grasses readily absorb silica at pH's between 4.74 and 7.64. Imaizumi and Yoshida (*4*) have shown that an available silica content of 13 mg. per 100 grams of soil, or above, is favorable for maximum absorption of silica by rice.

In general, the more water absorbed by a plant, the greater the amount of silica deposited; Laiseca (*8*) showed that the silica content (by weight) of the ash of beech leaves increased continuously from 1.2% in May to 24.4% of SiO_2 in November.

As early as 1913 Lundie (*11*) concluded that silicon would protect against fungal diseases. Palladin (*14*) recorded that wheat and rye grown in nutrient solutions deficient in silicic acid suffered severely from rusts. Since 1934, Japanese scientists have indicated that silicon is essential for normal growth of rice (*5, 13*).

The quantity of "dilute acid–soluble silicon" in soils was correlated by Imaizumi and Yoshida (*4*) with uptake of silica by the rice plant. The presence of free organic acids increases the availability of silicon. Field tests indicated that application of suitable silicon compounds to soil greatly diminished the appearance of blast and brown spot diseases. These results were confirmed by Ishibashi and Kawano (*6*).

Recently, Yoshida, Ohnishi, and Kitagishi (*19*) showed that silicon deficiency in rice increases susceptibility to diseases or insects. Ponnaiya (*15*) observed that irregularly shaped silica deposits in sorghum varieties resistant to *Antherigona indica M.* appeared in the leaf sheath epidermis at an earlier time than in nonresistant varieties. Palladin (*14*) reported that *Lithospermum arvense* grown without silica was badly attacked by plant lice.

The great economic losses in the United States due to attack on sorghum and corn by chinch bugs (*Blissus leucopterus*, Say) have long been known (*2*). The present work has been initiated to study absorption and deposition of silica by four different varieties of sorghum over the growing season as well as the possible relationship of silica to the susceptibility of sorghum to fungal diseases and chinch bugs.

Materials and Methods

The following four varieties of sorghum (*Sorghum subglabrascens*) were studied: Pink kafir, Spur feterita, Atlas, and Dwarf yellow milo. These varieties were chosen because of their resistance or lack of resistance to disease or insect pests (Table I). Sorghum was planted on June 9, 1959, in an open field in which the available silica content was approximately 20 mg. per 100 grams of soil. The pH of the soil was 5.2 at 1 to 1 dilution. Plants were collected during the growing season at 3-week intervals starting on June 29. Dwarf yellow milo showed typical chinch bug damage early in the season. No other insect damage or disease was observed.

Table I. Resistances of Sorghum Varieties Studied

	Resistance to Diseases and Insects		
Variety	Smut	Milo disease	Chinch bugs
Spur feterita	High		
Pink kafir	Very low	High	
Atlas			High
Dwarf yellow milo		Very low	Very low

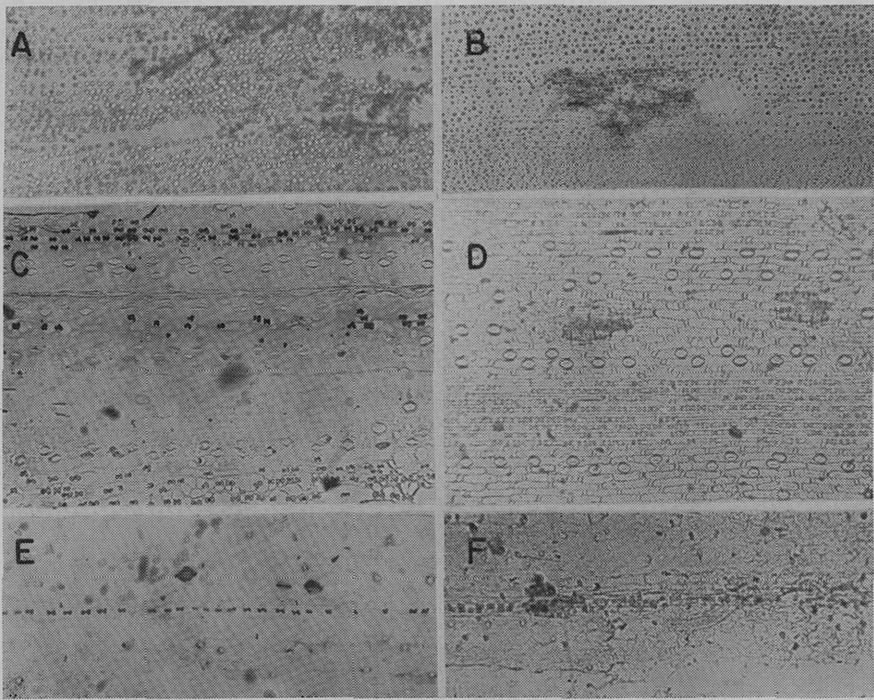

Figure 1. Spodograms of parts of Spur feterita plants at 80×

A. Root, 7/20/59
B. Root, 8/10/59
C. Leaf sheath epidermis, 7/20/59
D. Leaf sheath epidermis, 8/31/59
E. Leaf, 7/20/59
F. Leaf, 8/10/59

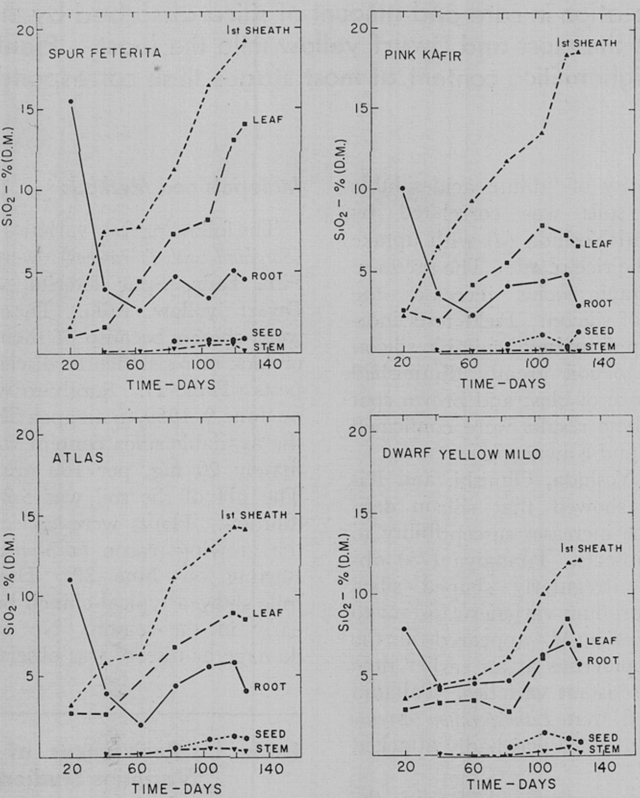

Figure 2. Uptake of silica by different varieties of sorghum

Spur feterita and Dwarf yellow milo plants were grown in a greenhouse by the water culture method described by Hoagland and Arnon (*3*). Sodium silicate was added to the nutrient solution to produce a silica concentration of 100 p.p.m.

The plants were separated into roots, sheaths, leaves, stems, and seeds. Sheaths were further divided into first, second, third, and younger ones (as a group). The plant parts were thoroughly washed to remove all dirt and then air-dried at 110° C. The roots had to be scraped to remove all dirt from them.

Available silica in soil was determined as acetate soluble silica according to the Imaizumi and Yoshida (*4*) modifications of Kahler's method (*7*). A 10-gram sample of soil was extracted by 100 ml. of $1N$ acetate buffer of pH 4.0 for 5 hours at 40° C. To a 10-ml. aliquot of extract, 5 ml. of $0.60N$ hydrochloric acid and 5 ml. of ammonium molybdate (102 grams per liter) were added. After standing for 3 minutes, 10 ml. of sodium sulfate (170 grams per liter) was added. This mixture was allowed to stand 10 minutes and then absorbance at 634 $m\mu$ was measured with a Beckman DU spectrophotometer.

For determination of soluble silica in juice of stems, the juice was pressed out by means of a hydraulic press. To a 5-ml. aliquot, 5 ml. of distilled water, 5 ml. of $0.25N$ hydrochloric acid, and 5 ml. of ammonium molybdate solution were added. Final steps were the same as described above.

Silica content of plant material was determined by classical gravimetric techniques. The material was ashed at about 600° C. and the ash treated repeatedly with $6N$ hydrochloric acid to remove other mineral impurities. The silica was filtered out and ignited. The silicon dioxide content was determined as difference of weights before and after treatment with hydrofluoric acid.

Spodograms were prepared by the Ponnaiya (*15*) modification of the Uber (*17*) method. The material to be examined was placed between microscope slides, and was then ashed in a muffle furnace at 450° to 500° C. The ash was prepared for microscopic examination and photography by removing the upper slide, adding Canada balsam directly to the mass, and covering with a cover glass. A petrographic microscope was used to study the nature of silica deposits.

Results and Discussion

Petrographic microscope studies of silica from ash of the four varieties of sorghum studied showed it to be clear, colorless, and isotropic with an index of refraction of 1.45. These properties are typical of the mineral opal as was shown to be the case for Westland sorghum (*9*). The patterns of deposition in the leaves and sheaths (Figure 1) were similar to those found in Westland sorghum by Lanning, Ponnaiya, and Crumpton (*9*).

Results of silica analysis made on the sorghum plants are given in Figure 2. Silica content of roots was high at 20 days. A rapid drop occurred between the 20th and 41st days with a minimum value at 62 days for all, except Dwarf yellow milo, which had a minimum value at 41 days. Spodograms of Spur feterita roots (Figure 1, *A* and *B*) also

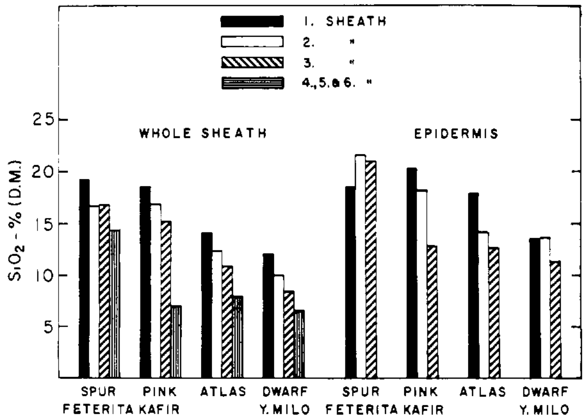

Figure 3. Silica content of sheaths after 126 days

show that silica particles in roots became smaller between 41 and 62 days of growth. After minimum values, a slow increase took place for the remainder of the growing season. From 41 days on, Dwarf yellow milo roots had a higher silica content than the roots of the other sorghums.

Spur feterita and Pink kafir sheaths both developed a high silica content early and achieved by far the highest silica content of the four varieties at the end of the season. Dwarf yellow milo had the lowest silica content. Spodograms (Figure 1, *C* and *D*) show the increase in silica deposition in Spur feterita leaf sheath epidermis between 7/20/59 and 8/31/59. Spodograms of other varieties showed the same trend. Figure 3 shows that the younger the sheath, the lower the silica content at any given time.

Spur feterita leaves had a much higher silica content throughout the growing season than any of the other varieties of sorghum. Dwarf yellow milo had the lowest silica content over the growing season. Figure 1 (*E* and *F*) shows the increase in silica deposition in Spur feterita leaves between 7/20/59 and 8/10/59. Spodograms of the other varieties show the same type of change.

The silica content of the stem was low and showed only slight change over the growing season. Much of this silica occurred as soluble silica in the juice. The silica in sorghum stem juice after 141 days of growth is tabulated as follows:

Variety	*Mg. SiO_2/5 Ml. Juice*
Atlas	0.300
Spur feterita	0.215
Pink kafir	0.182
Dwarf yellow milo	0.170

The silica content of juice was determined several times during the season with essentially the same results. Dwarf yellow milo was always low.

Silica content of seed was slightly higher than that of the stem, but the percentage of silica in dry matter remained nearly constant.

The silica content of plants grown in nutrient solutions in a greenhouse for 44 days is given in Table II. There were no chinch bugs. The silica content of Spur feterita sheath was 1.65 times that of the Dwarf yellow milo. For field grown plants the ratio was nearly the same, 1.78 to 1.00. The low silica content of Dwarf yellow milo sheath and leaves was a plant characteristic and not due to chinch bug damage.

Total ash content without SiO_2 was calculated for the sheath of all four varieties grown in the field. This showed that variations in total ash content were due to silica. The values varied only from 5.54% for Atlas to 6.12% for Spur feterita. Furthermore the values remained fairly constant throughout the season. Consequently, total ash content without SiO_2 did not correlate with disease and insect resistance.

These studies show that in the four varieties studied, absorption of silica in resistant varieties is more rapid than in nonresistant ones. Chinch bug damage did occur to Dwarf yellow milo, the plant that had the lowest silica content in the leaves and sheath. At 62 days, the first leaf sheath epidermis of Atlas, the most resistant variety, had 7.90% of SiO_2 while the corresponding sheath of Dwarf yellow milo had only 4.45% of SiO_2. Spur feterita which is resistant to smut had a much higher silica content in the leaves than Pink kafir, the susceptible variety. Pink kafir which is resistant to milo disease had a much higher silica content in the sheath and somewhat more in the leaves than Dwarf yellow milo, the susceptible variety. More work will be needed to determine the exact relationship between silica content and resistance to invading organisms.

Table II. Silica in Sorghum Plants Grown in Nutrient Solutions

Variety	*Part of Plant*	*Ash, %*	*SiO_2 D. M., %*
Dwarf yellow milo	Root	8.87	1.22
	Leaf	9.07	1.11
	Sheath	14.30	1.72
Spur feterita	Root	12.73	0.93
	Leaf	10.85	1.18
	Sheath	17.50	2.84

[a] D. M. = dry matter.

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