Journal of the Indian Society of Soil Science, Vol. 66, No. 4, pp 406-414 (2018)
DOI: 10.5958/0974-0228.2018.00051.8

Effect of Foliar Application of Silicic Acid on Soybean Yield and Seed Quality under Field Conditions

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A field experiment was conducted with two soybean varieties (MAUS-2 and KBS-23) and seven treatments in a randomized complete block design with three replications to investigate the effect of foliar application of silicic acid on soybean yield and seed quality under field condition. Significant increase in haulm, pod and seed yield was observed with the foliar application of silicic acid at 2 mL L^{-1} for three times and 4 mL L^{-1} for two times in MAUS-2 and KBS-23 variety, respectively. Foliar applied silicic acid significantly improved protein yield of KBS-23 variety and oil yield of MAUS-2 variety. Greater variation in silicon (Si) content among the various plant parts of soybean were recorded with the application of silicic acid and boric acid. The highest silicon content was in haulm followed by husk and seed. Among the two varieties, KBS-23 responded better for foliar application of silicic acid than MAUS-2 variety. Application of boric acid also enhanced the growth and yield of soybean over control. Foliar application of silicic acid at two different doses (2 and 4 mL L^{-1}) for two or three times significantly enhanced the yield, quality and Si content of soybean. Application of silicic acid at 2 mL L^{-1} thrice and 4 mL L^{-1} twice along with recommended dose of fertilizer was effective in MAUS-2 and KBS-23 variety, respectively.

Key words: Foliar application, silicic acid, boric acid, yield, quality, silicon content, soybean

Silicon (Si) is a ubiquitous element and the second most abundant after oxygen in soil, comprising approximately 28% of the Earth's crust. Despite this, most sources of Si in soil are present as crystalline aluminosilicates, which are insoluble and not directly available for plants (Richmond and Sussman 2003). To be taken up by plants, Si must be in the form of monosilicic acid (H_4SiO_4); but the natural release of H_4SiO_4 from SiO_2 is a very slow process (Raven 1983). Soil solution Si normally ranging from 0.1 to 0.6 mM (Gunnarsson and Arnorsson 2000). However, Si is present in varying amounts in all terrestrial plants, ranging from 0.1 to 10% of shoot dry weight. Different sources of foliar and soil applied Si such as calcium silicate, diatomaceous earth, rice husk biochar, potassium silicate, *etc*. are being widely used for different crops. For the prophylactic effect to manifest, Si needs to be absorbed in the form of silicic acid, where along with water, it follows the transpiration stream to finally deposit as silica (Canny 1990; Sangster *et al*. 2001). Foliar application of Si has been shown to (1) influence plant growth, yield and Si content of different crops such as rice (Prakash *et al*. 2011; Ahmad *et al*. 2013; Syu *et al*. 2016: Nagula *et al*. 2016), finger millet (Sandhya *et al*. 2010), maize (Venkataraju 2013) and banana (Hanumanthaiah *et al*. 2015), (2) control of disease in rice (Buck *et al*. 2008; Rezende *et al*. 2009), soybean (Rodrigues *et al.* 2009; Pereira *et al*. 2009; Cruz *et al*. 2013), grape (Bowen *et al*. 1992), coffee (Lopes *et al*. 2013), cucumber (Liang *et al*. 2005) and (3) induce resistance to abiotic stress in crops like rice (Wang *et al*. 2015; Liu *et al*. 2009), wheat (Gong *et al*. 2005; Maghsoudi *et al*. 2015) and soybean (Lee *et al*. 2010). However, information on effect of silicic acid on different oilseed crops is very limited. Most of the work with foliar Si in soybean is focused to its role in plant protection. Information regarding Si accumulation or its performance on growth and yield of soybean is very limited. With this in view, present investigation was carried out to evaluate the effect of soluble silicic acid along with boric acid as foliar spray on growth, yield and soybean seed quality.

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Table 1. Characteristics of soybean varieties

Parameter	MAUS–2	KBS–23
Plant type	Erect, medium tall,Determinate	Erect, medium tall,Semi-determinate
Crop duration	105 – 115 days	85 - 90 days
Colour of flower	White	Purple
Parentage	Selection from SH-84-14	JS–335 × KHSb–2
Pubescence	Gray pubescence	Tawny pubescence
Hilum colour	Brown	Black
Average seed yield (t ha^{-1})	2.0 – 2.2	2.2 – 2.5

Material and Methods

Experimental site

Experiment was conducted at Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences, Bengaluru during *kharif*-2016, situated in the Eastern Dry Zone of Karnataka, India at 12°58′ N latitude 77°35′ E longitude with an altitude of 930 m above mean sea level (msl) and receives an average annual rainfall of 916.00 mm.

Soil

The soil of experimental site was sandy loam in texture with acidic pH (5.26), normal EC (0.08 dS m^{-1}) and low, high and medium in available N (156.8 kg ha^{-1}), P_2O_5 (463.6 kg ha^{-1}) and K_2O (185.4 kg ha^{-1}), respectively. The plant available Si content as extracted by acetic acid (AA) and calcium chloride (CC) was low (AA Si - 29.1 mg kg^{-1} and CC Si - 25.9 mg kg^{-1}).

Experimental details

The experiment was laid out in randomized complete block design (RCBD) having two soybean varieties (MAUS-2 and KBS-23; Table 1), seven treatments *viz*., T_1 : Recommended dose of fertilizer (RDF) + water spray (control); T_2 : RDF + Silicic acid @ 2 mL L^{-1} at 21 and 36 days after sowing (DAS); T_3 : RDF + Silicic acid @ 4 mL L^{-1} at 21 and 36 DAS; T_4 : RDF + Silicic acid @ 2 mL L^{-1} at 21, 36 and 51 DAS; T_5 : RDF + Silicic acid @ 4 mL L^{-1} at 21, 36 and 51 DAS; T_6 : RDF + 0.8% Boric acid @ 2 mL L^{-1} at 21, 36 and 51 DAS; T_7 : RDF + 0.8% Boric acid @ 4 mL L^{-1} at 21, 36 and 51 DAS with three replications. Since, soluble silicic acid also contains 0.8% of boron as boric acid, treatments with boric acid was considered in the present investigation to nullify the effect of boron present in the silicic acid. Hence, 0.8% of boron as boric acid foliar spray @ 2 mL L^{-1} and 4 mL L^{-1} were applied at an interval of 21, 36 and 51 DAS. The land was ploughed with mould board plough and cultivator was passed twice to get good tilth. Later, the land was converted into required sized plots and levelling was ensured within each plot. Channels were prepared to drain out excess water during heavy rains.

Recommended dose of fertilizer application at the rate of 25:60:25 kg of N: P_2O_5: K_2O ha^{-1} as urea, single superphosphate (SSP) and muriate of potash (MOP), respectively and zinc sulphate (12.5 kg ha^{-1}) were applied to the soil. Farmyard manure (6.25 t ha^{-1}) was applied 15 days prior to the land preparation.

MAUS-2 and KBS-23 seeds were used for sowing with recommended seed rate of 62.5 kg ha^{-1}. The small furrows were opened at a row spacing of 30 cm, and three seeds were placed at 10 cm distance within the rows to a depth of 5 cm and later soil was covered. To overcome the seedling disease, seeds were treated with fungicide SAAF (Mancozeb 63%+ Bavistin 12% Wettable Powder) at 6 g kg^{-1}. A week after the treatment with SAAF, the seeds were treated with *Rhizobium* at the rate of 500 g ha^{-1}.

Source of silicic acid and boric acid

Concentrated soluble silicic acid obtained from ReXil Agro BV, Chennai, was used for spraying. pH and composition of the formulation is given in the table 2. Chemical grade Boric acid Merck (Catalog No. 1.93409.0521) was used to prepare 0.8% boric acid.

Table 2. Composition and pH of foliar silicic acid material

Composition	Content (%)
Si as soluble H_4SiO_4	2.0
K as KCl	1.2
B as H_3BO_3	0.8
HCl	1.0
Demi water	47.0
$PEG*_{400}$	48.0
pH	
pH of raw material	0.88
pH of 2 mL L^{-1} solution	6.8
pH of 4 mL L^{-1} solution	6.0

*PEG – Poly ethylene glycol

Spraying of foliar silicic acid and boric acid

Foliar Si was given as silicic acid and B as boric acid @ 2 mL L^{-1} and 4 mL L^{-1} at an interval of 21, 36 and / or 51 DAS. Control plots received only water spray. For spraying, clean tap water of negligible Si content was used @ 250 L ha^{-1} for the first and second spraying and 500 L ha^{-1} for third spraying. Spraying was done with a backpack sprayer of 20 L capacity in the early morning during less wind to avoid drifting of spray droplet to adjoining plots.

Quality parameters of soybean

The protein content in the seeds was analyzed by estimating N content in seed by micro-Kjeldahl method (Piper 1966), then multiplied by a factor 6.25 and expressed in percentage. Protein yield was worked out on the basis of seed protein content and seed yield of soybean and expressed in kg ha^{-1}.

Protein yield (kg ha^{-1}) =

$$\frac{\text{Seed protein content (\%)}}{100} \times \text{Seed yield (kg ha}^{-1}\text{)}$$

The oil content of soybean seeds was estimated by Soxhlet extraction method. Powdered seed sample (5 g) was taken in thimble and placed in previously weighed flask with stones (W_1). Later 100 mL of petroleum ether (boiling range of 40-60 °C) was added to these flasks and kept in soxtherm and run the instrument for one and half hour. After complete extraction, flasks were kept in hot air oven at 105 °C for 30 min and weight (W_2) of flask was recorded after cooling. Oil yield was worked out on the basis of seed oil content and seed yield of soybean.

Oil content (%) =

$$\frac{W_2 \text{ g (flask + stones + oil)} - W_1 \text{ g (flask + stones)}}{\text{Weight of seed sample (g)}} \times 100$$

Oil yield (kg ha^{-1}) =

$$\frac{\text{Oil content in seed (\%)}}{100} \times \text{Seed yield (kg ha}^{-1}\text{)}$$

Determination of Si in plant samples

Silicon content in haulm, husk and seed were calculated from the plants collected at R7 stage of the crop; when one normal pod on the main stem was mature in colour (Moreira *et al*. 2016). Samples collected were thoroughly washed with deionized water and oven dried at 60 °C to obtain constant weight. Later plants were separated into haulm, husk and seed, cut to pieces, powdered and used for analysis.

Powdered plant sample (0.1 g) was pre-digested with 7 mL HNO_3 (70%), 2 mL H_2O_2 (30%) and 1 mL HF (40%) in PTFE (Poly Tetra Fluoro Ethylene) tubes and later digested using a microwave digester (Milestone- START D) at 150 °C with following steps: 1200 w for 15 min with a ramping rate of 7 °C per min, 1200 w for 10 min and venting for 10 min. The digested sample was stored in clean plastic tubes of 50 mL capacity, after making up the volume using 4% boric acid solution (Ma and Takahashi 2002).

Silicon in the digested plant sample was determined by the colorimetric molybdenum blue method at 600 nm (Ma *et al*. 2002; Narayanaswamy and Prakash 2009). Aliquot (0.5 mL) was taken to a plastic centrifuge tube, added 3.75 mL of 0.2 *N* HCl, and 0.5 mL of 10% ammonium molybdate. After one min, 0.5 mL of 20% tartaric acid and 0.5 mL of reducing agent (amino naphtholsulphonic acid - ANSA) were added. The volume was made up to 12.5 mL with distilled water. After one hour, the absorbance was measured at 600 nm with a UV-visible spectrophotometer (SHIMADZU Pharma spec, UV-1700 series) with auto sample changer (ASC-5). Standards (0, 0.2, 0.4, 0.8 and 1.2 ppm Si) were prepared by following the same procedure.

Statistical analysis

The data obtained from field observations and chemical analysis of soil and plant samples were subjected to statistical scrutiny to find out the influence of silicic acid treatments on the growth, yield, quality and Si content of soybean and the effects were tested at 5% level of significance (Sundarraj *et al*. 1972)

Result and Discussion

Influence of silicic acid on plant Si content

Greater variation in Si content among the various plant parts of soybean was observed with foliar application of silicic acid and boric acid. Among two varieties used in the investigation, MAUS-2 variety significantly recorded higher haulm Si content with the foliar application of silicic acid @ 4 mL L^{-1} for three times (0.920 ± 0.03%) over other treatments. In KBS-23 variety, control (water spray) treatment recorded significantly higher Si content in haulm (0.725 ± 0.05%) over silicic acid and boric acid application. Application of 4 mL L^{-1} silicic acid for two times in MAUS-2 variety, noticed significantly higher husk Si content (0.161 ± 0.006%) which was on par with silicic acid @ 2 mL L^{-1} for three times

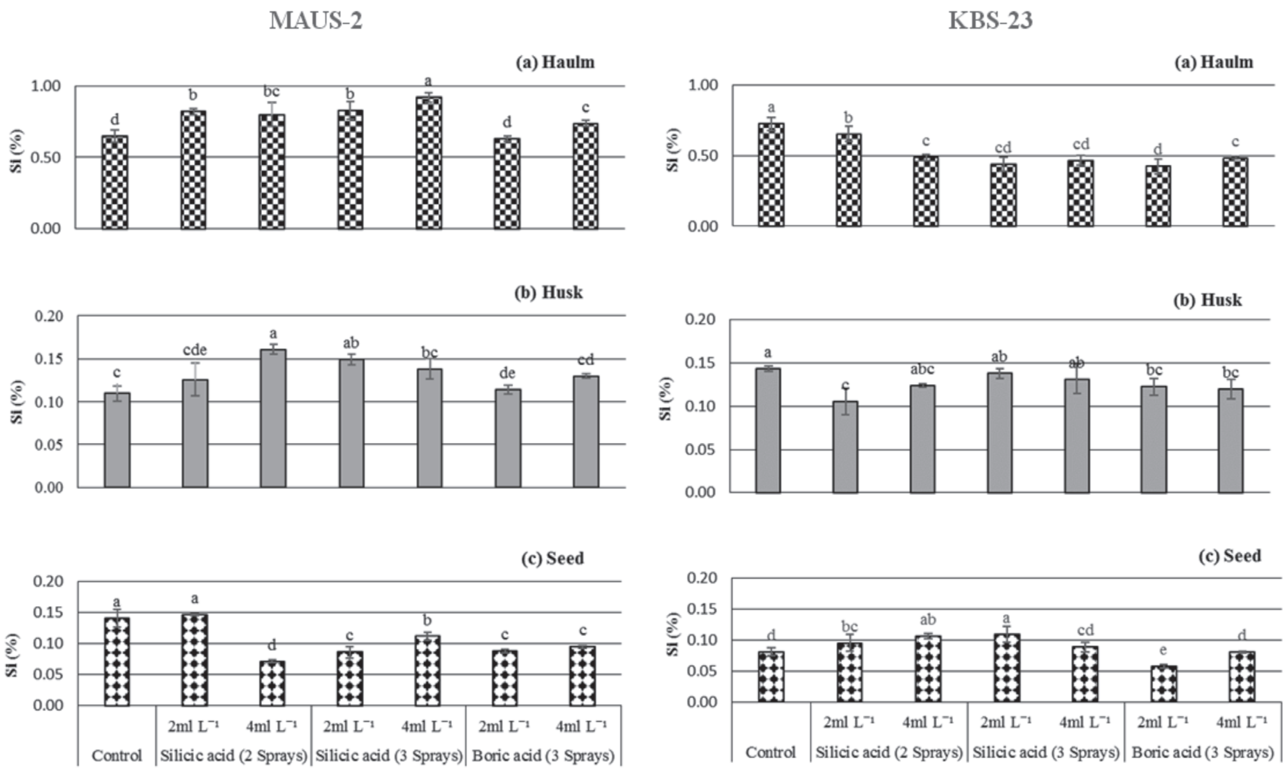

Fig. 1. Effect of foliar application of silicic acid and boric acid on (a) haulm, (b) husk and (c) seed Si content (%) of soybean

application. Treatment with control (water spray) in KBS-23 variety recorded significantly higher husk Si content (0.143 ± 0.003%) and on par with the silicic acid application at higher dosage. On the other hand, foliar application of silicic acid @ 2 mL L^{-1} for two times recorded significantly higher seed Si content (0.146 ± 0.001%) of MAUS-2 variety over silicic acid and boric acid application for two or three times, and on par with control (water spray) (0.141 ± 0.008%). In KBS-23 variety, higher seed Si content was recorded with the foliar application of silicic acid @ 2 mL L^{-1} for three times (0.109 ± 0.013%), which was on par with the silicic acid application @ 4 mL L^{-1} for two times (0.106 ± 0.004%).

The difference in Si accumulation of different plant species has been ascribed to the ability of the roots to take up Si (Mitani and Ma 2005). Ma *et al.* (2007) revealed that the genotypic difference in the Si accumulation results from the difference in abundance of Si transporters in rice roots. Difference in Si accumulation in plant part has been proven in many crops like rice (Prakash *et al.* 2011) and finger millet (Sandhya *et al*. 2010) with the foliar application of silicic acid.

In the present investigation, there was significant difference in accumulation of Si among haulm, husk and seed of two soybean varieties (Fig. 1). Highest Si accumulation was in haulm followed by husk and seed of soybean. Longer duration of MAUS-2, which responded better for absorption and accumulation of foliar applied Si than shorter duration variety (KBS-23) noticed higher accumulation of Si in haulm and husk. As noticed in rice (Snyder *et al*. 1986; Yogendra *et al.* 2017; Nagula *et al.* 2016) the dilution effect was also observed in the soybean, wherein higher seed Si content was recorded in control (water spray) and also with the application of foliar silicic acid spray @ 2 mL L^{-1} for two times in MAUS-2 variety.

Studies indicated that there is greater variation in the accumulation of Si in different organs of plants. Rice being a Si accumulator plant, its accumulation varies greatly among different organs of the plant (Alina 1984; Majumder *et al*. 1985; Winslow 1992; Winslow *et al*. 1997; Prakash *et al*. 2011). Silicon content in different organs of a rice plant generally ranged from high to low, in descending rank in the hull, leaf, leaf sheath, culm, and root. Sandhya *et al*. (2010), reported greater variation in Si accumulation in plant parts of finger millet with the foliar application of silicic acid and highest Si accumulation was observed in the glumes, followed by straw and least in grains. Silicon content on soybean leaves can reach high levels, indicating that Si is freely translocated to shoots in a nonrejective way (Ma *et al*. 2002; Mitani and Ma 2005). Nolla *et al*. (2006) found that application of calcium silicate up to 12 Mg ha^{-1} to a Si-deficient soil increased Si content in soybean leaf tissue from 0.34 to 0.55%. Rodrigues *et al*. (2009) while studying the effect of foliar application of potassium silicate (KSi) on soybean, found that the Si content in leaf tissue was on an average, 1.1 and 0.75% for field and greenhouse experiments, respectively. A great variation in Si content of soybean does exist and ranges from 0.42 to 0.92% in haulm, 0.11 to 0.16% in husk and 0.06 to 0.15% in seed with the foliar application of silicic acid and boric acid.

Effect of silicic acid on soybean yield

Foliar application of silicic acid significantly increased the haulm, pod and seed yield of soybean over control (water spray) and boric acid application (Table 3). Significantly higher haulm yield in MAUS-2 variety was observed with the foliar application of silicic acid @ 2 mL L^{-1} for three times (18.70 ± 1.02 q ha^{-1}), which was on par with foliar application of silicic acid @ 4 mL L^{-1} for three times (17.05 ± 1.35 q ha^{-1}) over control (water spray) and boric acid application. In KBS-23 variety, foliar application of silicic acid @ 4 mL L^{-1} for two times (19.77 ± 1.35 q ha^{-1}) significantly recorded higher haulm yield, which was on par with the foliar application of silicic acid @ 4 mL L^{-1} for three times (18.43 ± 0.20 q ha^{-1}). Significantly higher pod yield was observed in MAUS-2 variety with the foliar application of silicic acid @ 2 mL L^{-1} for three times (35.07 ± 1.69 q ha^{-1}) over other treatments. In KBS-23 variety, foliar application of silicic acid @ 4 mL L^{-1} for two times (34.59 ± 1.21 q ha^{-1}) recorded higher pod yield over other treatment. Silicic acid application @ 2 mL L^{-1} for three times in MAUS-2 variety (20.54 ± 1.66 q ha^{-1}) and silicic acid application @ 4 mL L^{-1} for two times in KBS-23 variety (21.76 ± 0.79 q ha^{-1}) significantly recorded higher seed yield over other treatments. Though separate treatments with boric acid sprays were given at different doses to nullify the effect of boric acid present in silicic acid, application of boric acid (@ 2 or 4 mL L^{-1} for three times enhanced the haulm, pod and seed yield of soybean over control (water spray). Similar effect on crop growth was noticed in rice (Nagula *et al*. 2016; Prakash *et al*. 2011), finger millet (Sandhya *et al*. 2010) and maize (Venkataraju 2013) through foliar applied silicon. In sunflower (Asad *et al*. 2003) foliar

Table 3. Effect of foliar application of silicic acid and boric acid on yield of soybean

Treatments	Haulm yield (q ha^{-1})		Pod yield (q ha^{-1})		Seed yield (q ha^{-1})	
	MAUS-2	KBS-23	MAUS-2	KBS-23	MAUS-2	KBS-23
T1 : RDF + Water spray (control)	10.08 ^{c} ± 0.65	14.34 ^{c} ± 0.46	19.49 ^{d} ± 2.76	22.74 ^{d} ± 0.97	10.83 ^{d} ± 1.97	12.86 ^{d} ± 0.19
T2 : RDF + SA @ 2 mL L^{-1} at 21 and 36 DAS	10.78 ^{c} ± 0.87	14.15 ^{c} ± 0.03	20.75 ^{d} ± 2.05	24.58 ^{cd} ± 2.02	11.53 ^{cd} ± 1.99	16.15 ^{c} ± 1.11
T3 : RDF + SA @ 4 mL L^{-1} at 21 and 36 DAS	11.70 ^{c} ± 0.95	19.77 ^{a} ± 1.35	26.51 ^{bc} ± 1.84	34.59 ^{a} ± 1.21	12.57 ^{cd} ± 1.17	21.76 ^{a} ± 0.79
T4 : RDF + SA @ 2 mL L^{-1} at 21, 36 and 51 DAS	18.70 ^{a} ± 1.02	14.12 ^{c} ± 0.89	35.07 ^{a} ± 1.69	30.84 ^{b} ± 1.96	20.54 ^{a} ± 1.66	19.55 ^{b} ± 0.35
T5 : RDF + SA @ 4 mL L^{-1} at 21, 36 and 51 DAS	17.05 ^{a} ± 1.35	18.43 ^{a} ± 0.20	28.92 ^{b} ± 1.13	32.79 ^{ab} ± 1.67	16.86 ^{b} ± 1.48	19.97 ^{b} ± 0.75
T6 : RDF + 0.8% BA @ 2 mL L^{-1} at 21, 36 and 51 DAS	14.74 ^{b} ± 1.13	12.03 ^{d} ± 0.86	25.23 ^{c} ± 1.24	22.09 ^{d} ± 1.05	13.72 ^{c} ± 2.07	13.42 ^{d} ± 0.17
T7 : RDF + 0.8% BA @ 4 mL L^{-1} at 21, 36 and 51 DAS	10.87 ^{c} ± 1.38	16.74 ^{b} ± 0.26	21.26 ^{d} ± 0.24	27.15 ^{c} ± 2.03	11.59 ^{cd} ± 0.77	16.71 ^{c} ± 1.22

Means within a column followed by the same letter are not significantly different at 5% level of significance.

application of 28-1200 mM B (soluble sodium tetraborate - 20.8% B) increased the total dry mass of the most B-deficient plants. Tahir *et al*. (2012) reported significant effect of foliar applied B on number of grains panicle^{-1}, number of filled grains and final grain yield of maize.

There was no severe incidence of plant diseases or pests during the cropping season. One of the most important role of Si is to stimulate the plants defense abilities against abiotic and biotic stresses. Silicon deposited on the leaf tissue surface has been proposed to be responsible for the protective effect of Si against biotic stress. The effect of foliar potassium silicate in reducing diseases unquestionably contributes to increased yield (Rodrigues *et al.* 2009). Similarly, beneficial effect of Si on soybean yield have been reported by Cruz *et al.* (2013), Lee *et al.* (2010) and in some of leguminous crops like cowpea (Nelwamondo and Dakora 1999) through metasilicic acid application to hydroponically grown plants. Duration, vegetative and reproductive stages of the crop play an important role for the absorption and utilization of applied nutrients, as two (21 and 36 DAS) or three (21, 36 and 51 DAS) times application of silicic acid coincide with vegetative and reproductive stages of soybean crop.

Longer duration variety MAUS-2 (105 days) performed better in terms of soybean yield with foliar application of silicic acid @ 2 mL L^{-1} for three times and shorter duration variety KBS-23 (83 days) with silicic acid @ 4 mL L^{-1} for two times. A short duration crop would require less water per crop; would be less exposed to hazards. Water stress is more damaging to those varieties that have longer life cycle compared to early duration variety (Vergara *et al*. 1966; Akhter *et al*. 2017). Vegetative and reproductive stages of short duration variety (KBS-23) coincide with the foliar applied silicic acid than long duration variety (MAUS-2), which helped in efficient partitioning of photosynthates and better utilization of absorbed nutrients and in turn resulted in higher yield of KBS-23 variety than MAUS-2 variety.

Effect of silicic acid on soybean seed quality

The application of foliar silicic acid significantly enhanced the protein content, protein yield, oil content and oil yield of soybean (Table 4). No significant difference was observed for protein content of soybean in MAUS-2 variety. Significantly higher protein content (39.67 ± 3.07%) was observed in KBS-23 variety with the foliar application of silicic acid @ 2 mL L^{-1} for two times which was on par with

Table 4. Effect of foliar application of silicic acid and boric acid on seed quality of soybean

Treatments	Protein Content (%)		Protein yield (q ha^{-1})		Oil Content (%)		Oil yield (q ha^{-1})	
	MAUS-2	KBS-23	MAUS-2	KBS-23	MAUS-2	KBS-23	MAUS-2	KBS-23
T1 : RDF + Water spray (control)	32.08 ^{a} ± 2.20	30.04 ^{d} ± 1.82	3.48 ^{c} ± 0.74	3.86 ^{c} ± 0.23	18.69 ^{c} ± 0.25	17.84 ^{ab} ± 0.68	2.02 ^{e} ± 0.34	2.29 ^{b} ± 0.10
T2 : RDF + SA @ 2 mL L^{-1} at 21 and 36 DAS	29.46 ^{a} ± 1.82	39.67 ^{a} ± 3.07	3.41 ^{c} ± 0.71	6.39 ^{c} ± 0.47	19.06 ^{bc} ± 1.19	15.34 ^{e} ± 0.33	2.18 ^{de} ± 0.29	2.47 ^{b} ± 0.19
T3: RDF + SA @ 4 mL L^{-1} at 21 and 36 DAS	30.92 ^{a} ± 2.02	37.63 ^{ab} ± 2.63	3.88 ^{c} ± 0.36	7.89 ^{a} ± 0.33	20.95 ^{a} ± 0.73	15.52 ^{de} ± 0.45	2.63 ^{cd} ± 0.25	3.37 ^{a} ± 0.17
T4 : RDF + SA @ 2 mL L^{-1} at 21, 36 and 51 DAS	32.38 ^{a} ± 3.03	34.71 ^{bc} ± 2.67	6.66 ^{a} ± 0.94	6.78 ^{bc} ± 0.39	20.46 ^{a} ± 0.11	16.39 ^{cd} ± 0.57	4.20 ^{a} ± 0.36	3.20 ^{a} ± 0.13
T5 : RDF + SA @ 4 mL L^{-1} at 21, 36 and 51 DAS	32.96 ^{a} ± 1.82	37.33 ^{ab} ± 1.82	5.54 ^{b} ± 0.26	7.45 ^{ab} ± 0.19	20.17 ^{ab} ± 0.22	16.85 ^{bc} ± 0.37	3.40 ^{b}± 0.33	3.36 ^{a} ± 0.15
T6 : RDF + 0.8% BA @ 2 mL L^{-1} at 21, 36 and 51 DAS	29.17 ^{a} ± 1.34	32.96 ^{cd} ± 1.34	4.00 ^{c} ± 0.66	4.42 ^{c} ± 0.17	20.65 ^{a} ± 0.26	17.77 ^{ab} ± 0.49	2.83 ^{c} ± 0.46	2.38 ^{b} ± 0.04
T7 : RDF + 0.8% BA @ 4 mL L^{-1} at 21, 36 and 51 DAS	28.29 ^{a} ± 1.34	31.50 ^{cd} ± 1.75	3.28 ^{c} ± 0.27	5.27 ^{d} ± 0.67	19.25 ^{bc} ± 0.65	18.45 ^{a} ± 0.72	2.22 ^{de} ± 0.12	3.08 ^{a} ± 0.33

silicic acid @ 4 mL L^{-1} for two times (37.63 ± 2.63%) or 4 mL L^{-1} for three times (37.33 ± 1.82%). Protein yield was significantly higher with the foliar application of silicic acid application @ 2 mL L^{-1} for three times in MAUS-2 variety (6.66 ± 0.94 q ha^{-1}) over other treatments. In KBS-23 variety, higher protein yield was observed with silicic acid @ 4 mL L^{-1} for two times (7.89 ± 0.33 q ha^{-1}), which was on par with the foliar application of silicic acid @ 4 mL L^{-1} for three times (7.45 ± 0.19 q ha^{-1}). In that context, Schwarz (1973) reported that Si influences cell wall components, such as pectic acid and protein. Similarly, increase in protein content was also noticed in wheat (Gong *et al*. 2005) and in rice (Ahmad *et al*. 2013) with the application of sodium silicate and silicon aqueous solution, respectively. Application of silicic acid at higher concentration might have involved in the biosynthesis of cell wall components there by enhanced the protein content of soybean.

Higher oil content was observed with the foliar application of silicic aid @ 4 mL L^{-1} for two times (20.95 ± 0.73%) in MAUS-2 variety, which was on par with the silicic acid @ 2 mL L^{-1} (20.46 ± 0.11%) or 4 mL L^{-1} for three times (20.17 ± 0.22%) and boric acid @ 2 mL L^{-1} for three times (20.65 ± 0.26%). Irrespective of dosage and time of application, lesser oil content was recorded with silicic acid application when compared to control (water spray) and boric acid. Higher oil content was observed with the boric acid application @ 4 mL L^{-1} for three times in KBS-23 variety (18.45 ± 0.72%). In MAUS-2 variety, application of silicic acid @ 2 mL L^{-1} for three times (4.20 ± 0.36 q ha^{-1}) significantly increased the oil yield over other treatments. Application of silicic acid @ 4 mL L^{-1} for two times (3.37 ± 0.17 kg ha^{-1}) recorded significantly higher oil yield in KBS-23 variety, which was on par with silicic acid @ 2 mL L^{-1} (3.20 ± 0.13 t ha^{-1}) or 4 mL L^{-1} (3.36 ± 0.15 q ha^{-1}) for three times and boric acid @ 4 mL L^{-1} for three times (3.08 ± 0.33 q ha^{-1}). Application of 4 mL L^{-1} of boric acid significantly enhanced the protein and oil yield of soybean over control treatment. Foliar application of boric acid might have enhanced the nucleic acid metabolism in plants, which resulted in higher oil content in seeds. Gowthami *et al*. (2018) and Bellaloui *et al*. (2013) reported increased oil content of soybean with the foliar application of boric acid. Though, application of boric acid influenced the oil content in short duration variety (KBS-23), long duration variety (MAUS-2) responded well for the application of both silicic acid and boric acid sprays. This may be due to better utilization of both silicic acid and boric acid in longer duration variety. Although data pertaining to beneficial effects of foliar applied Si on quality of crop is limited, its mode of action is still unknown.

Conclusions

Supplementing RDF with foliar application of silicic acid at two different doses (2 and 4 mL L^{-1}) for two and/or three times significantly enhanced the crop yield, seed quality and Si content of soybean. In general, foliar silicic acid @ 2 mL L^{-1} for three times and 4 mL L^{-1} for two times along with recommended dose of fertilizer was found to be effective in MAUS-2 (long duration) and KBS-23 (short duration) variety, respectively.

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Received 3 August 2018; Accepted 18 December 2018