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FULL-LENGTH RESEARCH ARTICLE

Yield, Quality and Nutrient Content of Tomato in Response to Soil Drenching of Silicic Acid

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Abstract Although the role of silicon (Si) in enhancing crop performance has been proven in many field crops including rice, wheat, sugarcane and soybean, its influence on Si non-accumulator crops like tomato is very much limited. In order to evaluate the effect of silicic acid on tomato, a field experiment was conducted during summer 2018. The experiment consisted of with and without silicic acid treatments to test the efficacy of silicic acid soil drenching on yield, quality and nutrient content of tomato. The results revealed that soil drenching of silicic acid @ 4 ml L^{-1} at 15, 30 and 45 days after planting significantly increased the yield attributes, viz. number of fruits per plant (41.42 ± 2.77), fruit yield per plant (2.34 ± 0.05 kg) and fruit yield per hectare (86.66 ± 1.74 t) over control. Silicic acid soil drenching significantly enhanced the quality parameters in tomato. The total soluble solids (TSS) and lycopene content of tomato significantly improved with drenching of silicic acid @ 4 ml L^{-1} over control from 3.55 ± 0.23 to 4.23 ± 0.21 Brix and 4.65 ± 0.66 to 6.34 ± 0.22 mg 100 g^{-1} fruit, respectively, but significantly decreased the titratable acidity (0.45 ± 0.08 per cent) of tomato over control (0.63 ± 0.03 per cent) and enhanced major and micronutrients contents apart from Si. Thus, soil drenching of silicic acid @ 4 ml L^{-1} has found to be a novel way to enhance yield, quality and nutrient content of tomato.

Keywords Tomato · Silicic acid · Soil drenching · Yield · Quality · Nutrient content

Introduction

Tomato (*Solanum esculentum*) is one of the most important vegetable crops in the world. The crop is having significant role in human nutrition as it is a good source of essential amino acids, vitamins, minerals and antioxidants [55]. India is the second largest producer of tomato in the world and is estimated to cultivate in an area of 0.77 million hectares with an annual production of 19.39 million tonnes. However, the productivity is quite low (25.18 t ha^{-1}) due to deficiencies of nutrients, observed primarily due to intensive cropping and imbalanced fertilization [4]. Tomato being a heavy feeder and exhaustive crop removes substantial amount of nutrients from soil and responds well to the applied nutrients [44]. Consequently, it is essential to explore the possibilities of enhancing the production and productivity of the crop with alternative approaches. To maintain sustainability in the production and nutritive value, inclusion of beneficial elements like Si along with recommended dose of fertilizers helps in augmenting the production and productivity of tomato crop.

The effect of Si has been proven well in many agricultural crops [2, 37, 41, 46, 58] as foliar and soil application through different sources, viz. calcium silicate, diatomaceous earth, rice husk biochar, potassium silicate and silicic acid [31, 35, 51, 52]. Studies have revealed that application of soil and foliar Si has promising influence on nutrition, yield, quality, biotic and abiotic resistance in crops like rice [2, 30], finger millet [52], wheat [1, 15, 23], barley [28], soybean [11, 48, 54], onion [17], etc. The ability of Si accumulation in tissues varies among species,

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which are classified as accumulators (>4% Si; rice, sugarcane), intermediate (2–4% Si; soybean, cucumber) and non-accumulators of Si (<2% Si; tomato) [36]. In spite of proven benefits arising from the application of Si in the accumulator species, such as the grasses (poaceae) in terms of increase in the productive yield, promoting various desirable physiological and biochemical processes for plants [20], very limited research studies have been reported in Si excluding plants, such as tomato (*Solanum lycopersicum* L). Tomato being a high value crop, it is essential to enhance crop yields and to improve quality traits of fruits. Though attempts have been made to study the effects of Si on tomato [3, 10, 44, 61], its potential remained largely unexplored, and however, application of Si through soil drenching is very scarce. The soil drenching is a specific technique, that applies a chemical mixed with water to the soil around the base of the plant rather than the entire field, where the nutrients are most accessible to the plants, so that its roots can absorb the chemical (pesticide, herbicide, fungicide or fertilizer). Thus, soil drenching provides a nutritious banquet for crops. Hence, the present investigation aims to evaluate the effect of application of silicic acid as soil drench on yield, quality and nutrient content of tomato under field condition.

Material and Methods

Site Description

Field experiment was conducted during summer 2018 at Tarikere, Chikkamagaluru district, situated in Southern Transition Zone in state of Karnataka, India, at 13.72° N latitude 75.82° E longitude with an altitude of 698 m above mean sea level and an average annual rainfall of 797 mm.

The soil of experimental site was sandy clay loam in texture with neutral pH (7.48), normal EC (0.11 dS m^{-1}), low, high and low in available N (165.2 kg ha^{-1}), P_2O_5 (75.7 kg ha^{-1}) and K_2O (127.2 kg ha^{-1}), respectively. The plant available Si content as extracted by calcium chloride (91.5 mg kg^{-1}) and acetic acid (194.2 mg kg^{-1}) was high [42].

Extraction and Estimation of Plant Available Si in Soil by 0.01 M $CaCl_2$ Extractant

Two grams of soil was taken in a 50-ml centrifuge tube and added 20 ml of 0.01 M $CaCl_2$. After continuous end-to-end shaking in a mechanical shaker for sixteen hours, the solution was centrifuged at 2000 rpm for 10 min and then filtered [18].

Silicon in the extracting solution was determined by transferring 1 ml of filtrate into plastic centrifuge tube and then added 2.5 ml of 0.5 M sulphuric acid and 2.5 ml of ammonium molybdate solution (pH 7). After 5 min, 1.25 ml of tartaric acid solution was added. After allowing for additional two minutes, 0.25 ml reducing agent (ANSA) was added. After 30 min following addition of the reducing agent, absorbance was measured at 820 nm using UV–visible spectrophotometer (Shimadzu). Simultaneously Si standards (0, 0.5, 1, 2, 3, 4, 5 and 6 mg L^{-1}) prepared in the same matrix were also measured using UV–visible spectrophotometer by adopting the procedure of Narayanaswamy and Prakash [42].

Extraction and Estimation of Plant Available Si in Soils Using 0.5 M Acetic Acid Extractant

Available Si in soil was extracted using 0.5 M acetic acid with the soil to extractant ratio of 1:2.5. After shaking continuously for a period of one hour, solution was centrifuged at 3000 rpm for 3 min and then filtered [26]. The filtrate was then used for Si determination [42].

An aliquot of 0.25 ml filtrate was taken into a plastic centrifuge tube and then added with 10.5 ml of distilled water, 0.25 ml of 1:1 hydrochloric acid and 0.5 ml of 10 per cent ammonium molybdate solution. After allowing for 5 min, 0.5 ml of 20 per cent tartaric acid solution was added. After allowing for additional two minutes, 0.5 ml reducing agent (1-amino-2-napthol-4-sulfonic acid—ANSA) was added. After 5 min, but not later than 30 min following addition of the reducing agent, absorbance was measured at 630 nm using UV–visible spectrophotometer (SHIMADZU Pharma spec, UV-1700 series) with auto sample changer (ASC-5). Simultaneously Si standards (0.2, 0.4, 0.8, 1.2 and 1.6 mg L^{-1}) prepared in the same matrix were also measured using UV–visible spectrophotometer.

Experimental Details

Field experiment was conducted with two treatments consisting of with (+Si) and without (−Si, control) silicic acid soil drenching, replicated thrice with hybrid tomato (US-800) as test crop in plots of 4.5 m × 1.8 m area. For +Si treatment, silicic acid was applied @ 4 ml L^{-1} concentration through seedling treatment before planting and as soil drench at 15, 30 and 45 days after planting.

Nursery

The tomato seedlings were raised in plastic trays with coco peat as growing media and were allowed to grow for a period of 25 days under shade net.

Seedling Treatment

Vigorous and uniform-sized tomato seedlings of 25 days old were selected and were subjected to root dipping with silicic acid, only for +Si treatment but not for −Si treatment (control). The root portion of tomato seedlings was dipped in a container with 5 L of silicic acid solution @ 4 ml L^{-1} concentration for 30 min, then removed and left overnight before planting in the main field.

Land Preparation

The land was ploughed after application of recommended dose of farm yard manure (FYM) @ 12 t ha^{-1} with mouldboard plough, and cultivator was passed twice to get good tilth. Drip lines were laid in between the rows to facilitate irrigation. Recommended dose of fertilizer for tomato crop 115: 100: 60 kg N, P_2O_5, K_2O ha^{-1} was applied through urea, SSP and MOP, respectively, as basal dose.

Planting

The seedlings were transplanted to the main field with a spacing of 60 × 45 cm and at a depth of 2 to 2.5 cm. The seedlings were irrigated immediately after transplanting and later as and when needed.

Silicic Acid Drenching

Silicic acid solution of 4 ml L^{-1} concentration was prepared, and a volume of 250 ml per plant was drenched to the soil around the root zone of tomato plants at 15, 30 and 45 days after planting using concentrated soluble silicic acid (2.0% Si as H_4SiO_4) obtained from Rexil Agro BV. Chennai.

Staking

The tomato plants were specially supported with the help of string in order to keep plant and fruits off the ground. This reduces losses from fruit rots when fruits expose to soil and water.

Harvesting

The tomato fruits were harvested at weekly interval from 65 days after planting from randomly selected five plants in each replication of treatment. The fruits were harvested at breaker stage/pink stage wherein dim pink colour observed on ¼th part of the fruit or change from green colour to the pinkish appeared. Seven pickings were taken up in the crop.

The fruits were harvested from each replication of treatments and recorded the fruit number per plant, per plot and yield per plant (kg), per plot (kg) and per hectare (t).

Analysis of Tomato Fruit Samples for Nutrient and Quality Parameters

Collection and Processing of Tomato Fruits

Tomato fruits of second picking were collected for nutrient analysis as maximum uptake potential for nutrients will be at initial fruit bearing stage, i.e. first to third picking. The fruits were thoroughly washed with deionized water after harvest, cut into small pieces and oven-dried at 60 °C to obtain constant weight and powdered with ball mill. The powdered samples were further analysed for nutrient content.

Estimation of Major and Micronutrient Content in Tomato Fruits

The powdered fruit samples were analysed for major and micronutrient contents using standard procedures. The N estimation was done by kjeldhal method [45], P using phosphovanado molybdate complex method [7], K by flame photometry [21], Ca and Mg using complexometric titration method [21], total S by following turbidometric method [9], total micronutrients using atomic absorption spectrophotometer [29].

Estimation of Si Content in Tomato Fruits

Fruit Sample Digestion

The powdered fruit samples were dried in an oven at 70 °C for 2–3 h prior to analysis. 0.1 g of fruit sample was digested in a mixture of 7 ml of HNO_3 (70%), 2 ml of H_2O_2 (30%) and 1 ml of HF (40%) using microwave digestion system (Milestone-start D) at 150 °C with following steps: 1200 W for 15 min with a ramping rate of 7 °C per minute and 1200 W for 10 min at holding temperature of 150 °C and venting for 10 min. The digested samples were diluted to 50 ml with 4 per cent boric acid [33].

Analysis of Si in Fruit Samples

The Si content of digested fruit samples was estimated by colorimetric molybdenum blue method [32, 42]. 0.5 ml of digested aliquot was transferred to a plastic centrifuge tube, to which 3.75 ml of 0.2 N HCl, 0.5 ml of 10 per cent ammonium molybdate ($(NH_4)_6Mo_7O_2$), 0.5 ml of 20 per cent tartaric acid and 0.5 ml of reducing agent (amino naphthol sulphonic acid—ANSA) were added, and 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 with standards of 0, 0.2, 0.4, 0.8 and 1.2 ppm concentrations [32, 43, 54].

Calculation of Nutrient Uptake by Tomato Fruits

The uptake of major and micronutrients and Si was obtained by multiplying the dry weight of fruits at 2nd picking of tomato with content of corresponding nutrients at 2nd picking of tomato.

$$\text{Nutrient uptake}\left(\text{kg ha}^{-1}\right) = \frac{\text{Nutrient concentration}(\%) \times \text{Dry matter yield}\left(\text{kg ha}^{-1}\right)}{100}$$

Determination of Quality Parameters of Tomato

The tomato fruits were analysed for quality parameters, viz. titratable acidity [5], total soluble solids (hand refractometer method) and lycopene content of fruits [47].

Statistical Analysis

The data obtained from field experiment and laboratory analysis were tested at 0.05 level of significance by adopting *t*-test to find out the significance of silicic acid treatment on the yield, quality and nutrient content and uptake by tomato, using IBM SPSS Statistics 20 software.

Results and Discussion

Effect of Silicic Acid Drenching on Fruit Yield of Tomato

Soil drenching of silicic acid significantly enhanced the fruit yield parameters like number of fruits per plant, number of fruits per plot, fruit yield per plant and fruit yield per hectare (Table 1).

The soil drenching of silicic acid @ 4 ml L^{-1} significantly increased the number of fruits and fruit yield during each picking over control. In general, there was a sustainable production of fruits up to three pickings and decreased there after till seventh picking in both treated and non-treated plants. However, the silicic acid addition recorded significantly higher number of fruits and fruit yield even at the later pickings when compared to control. The treatment receiving silicic acid as soil drench, exhibited higher cumulative yield (sum total of yield recorded at different intervals) of 2.34 ± 0.03 kg per plant over 1.56 ± 0.07 kg per plant in control. This clearly indicates potential role of Si in enhancing the yield parameters of tomato crop (Fig. 1a, b).

Concordant to the present investigation, several studies have revealed the enhanced performance of tomato crop in response to Si nutrition. Wasti et al. [61] reported enhancement effects of Si on tomato yield and fruits quality traits. This enhancement effects of Si could be the sum of increasing the activity of many antioxidant enzymes, inhibiting H_2O_2 activity in addition to enhancement of chlorophyll content and photochemical efficiency and governing uptake and balance of K and Na [3, 28] due to enhanced water relations, membrane stabilization and altering the plant hormones such as auxin, cytokinin and abscisic acid (ABA) [16, 57]. Fertilization with Si positively influenced the crop, favouring the plant parameters and yield of tomato fruits. Similarly, Marodin et al. [38] reported significant gains in the yield of tomato crop with soil application of silicates, as a function of Si absorption by roots and translocation to the leaves. Fiori [13] also observed increased total number of fruits and enhanced productivity in tomato with the application of silicic acid. Photosynthesis is the physiological basis of biomass formation, which provides raw material and energy for the growth and development of plants [60]. The Si nutrition proved to help in expression of photosynthesis-related genes and regulation of the photochemical process, thus promoting photosynthesis of tomato seedlings in turn contributing to crop yields [64]. The beneficial effect of Si in tomato, a non-accumulator of Si suggests a possible involvement of Si in the physiological and/or biochemical

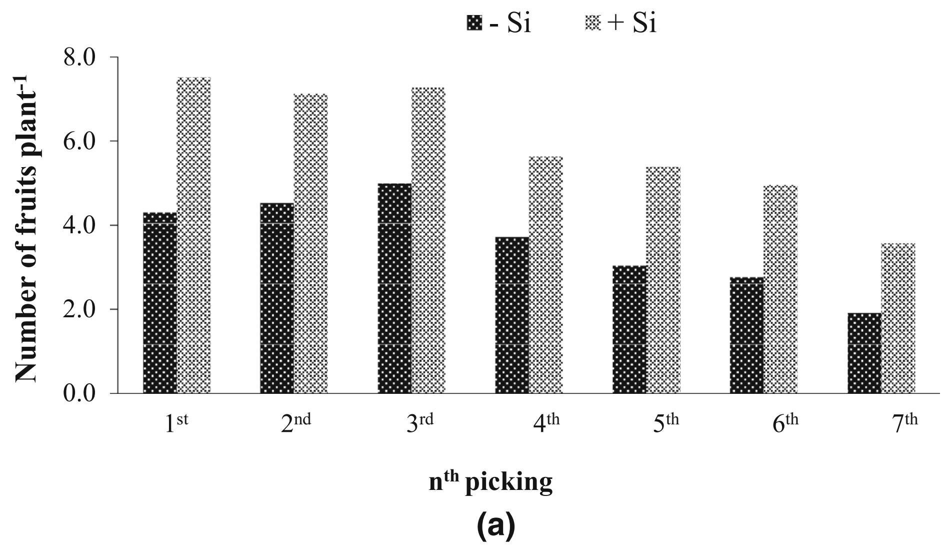
Table 1 Effect of soil drenching of silicic acid on number and yield of tomato fruits

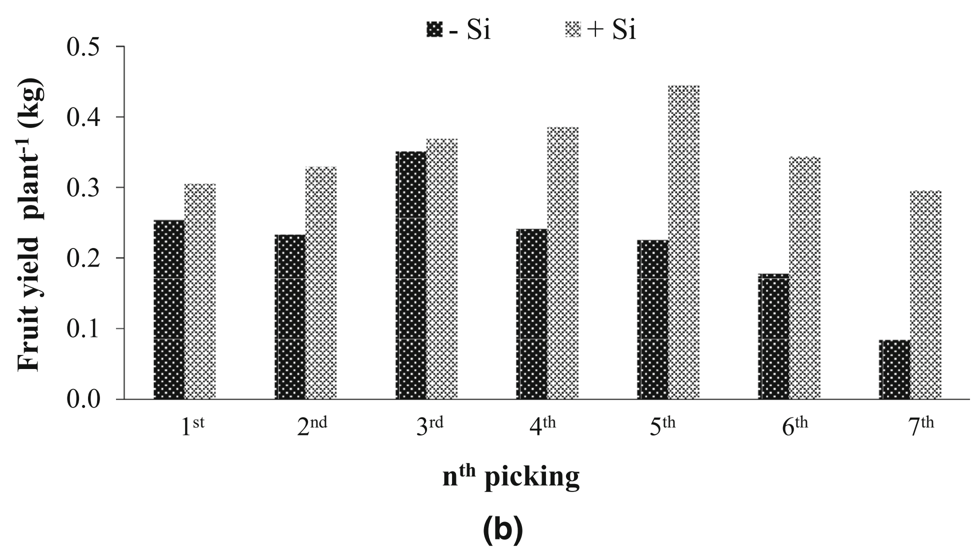
Treatments	Number of fruits		Fruit yield	
	Fruits plant^{-1}	Fruits plot^{-1}	kg plant^{-1}	t ha^{-1}
−Si	25.20 ± 1.93	756.14 ± 58.01	1.57 ± 0.20	57.99 ± 7.37
+Si	41.42 ± 2.77	1242.68 ± 83.10	2.34 ± 0.05	86.66 ± 1.73
t value	−8.311**	−8.315**	−6.560**	−6.562**

−Si and +Si indicates treatments without and with soil drenching of silicic acid

*values are significant at 0.05 level, **values are significant at 0.01 level

Fig. 1 **a, b** Effect of soil drenching of silicic on number of fruits and fruit yield per plant (kg) at different pickings in tomato





process that in turn aids in positive influence on yield parameters of the crop [63]. Supplementing recommended dose of fertilizer (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 [54]. Foliar spray of silicic acid sprayed at the rate of 2 or 4 ml L^{-1} for 3 to 4 times during the growing period significantly enhanced the rice yields [46].

Effect of Silicic Acid Drenching on Quality Parameters of Tomato

Total soluble solids (TSS-B), titratable acidity (TA %) and lycopene content (mg 100 g^{-1} fruit) of the fruits are important quality parameters as they enhance the marketability and processing efficiency of tomato. Soil drenching of silicic acid significantly enhanced these quality parameters (Fig. 2a–d).

The TSS content of tomato significantly increased with application of silicic acid @ 4 ml L^{-1} as soil drench (4.27 ± 0.40°B) over control (3.55 ± 0.23°B). The titratable acidity (TA) per cent found to decrease significantly with the silicic acid application over control (0.43 ± 0.07%). Significantly higher TA was recorded in control (0.63 ± 0.03%). The application of silicic acid @ 4 ml L^{-1} as soil drench significantly enhanced lycopene content of fruits from 4.65 ± 0.66 mg 100 g^{-1} in control to 6.94 ± 0.14 mg 100 g^{-1} in treated plants. The ripening index of tomato fruits (ratio of TSS to TA), an indicator of degree of maturity of the raw material and its

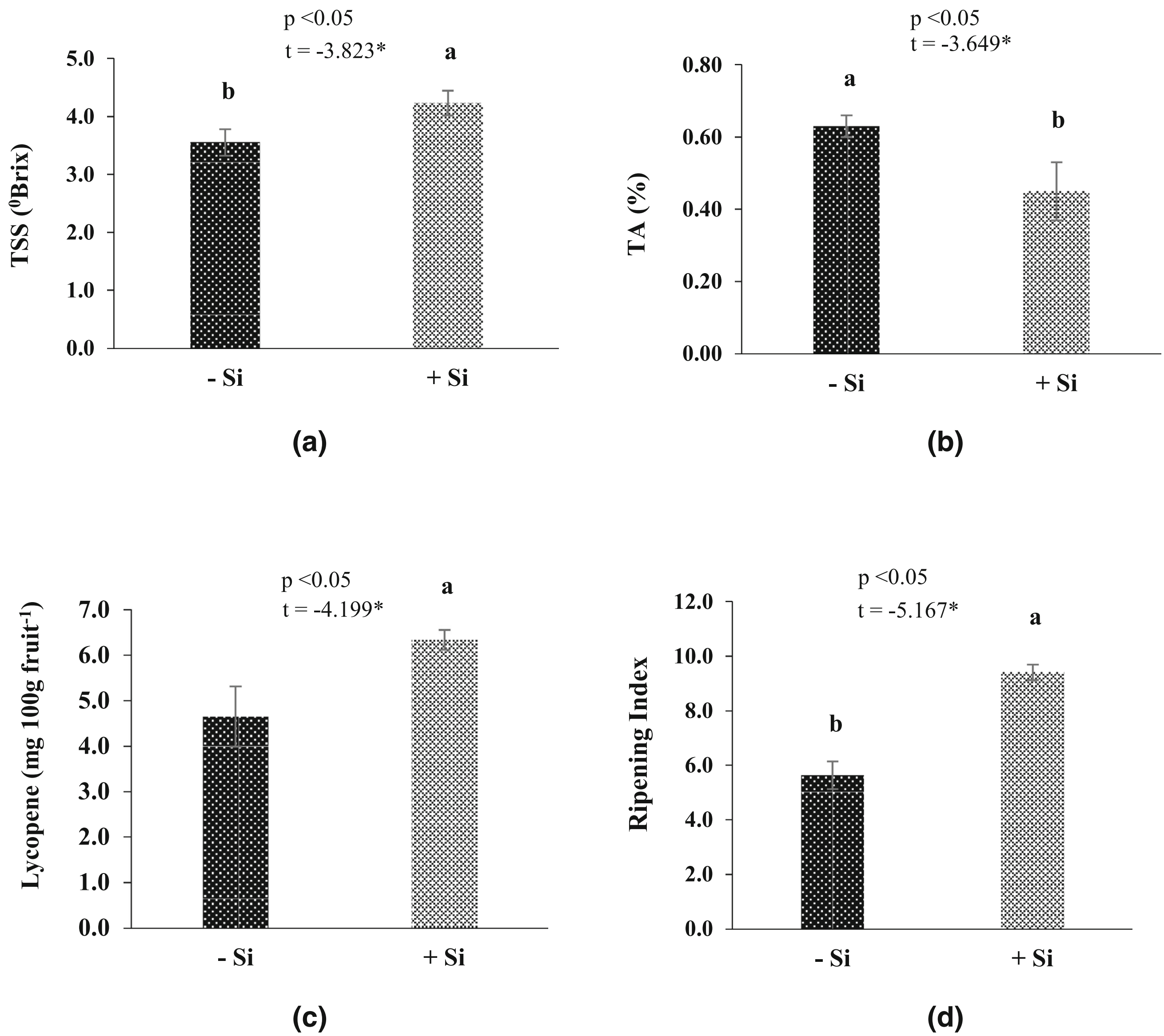


Fig. 2 a–d Effect of soil drenching of silicic acid on quality parameters. 2(a) Total soluble sugars (TSS- ^{o}B); 2(b) titratable acidity (%); 2(c) lycopene content (mg 100 g fruit^{-1}) and 2(d) ripening index of tomato

palatability, significantly improved from 5.63 in control to 9.40 with soil drenching of silicic acid @ 4 ml L^{-1}.

It is well known that the application of Si improves keeping quality, texture, appearance and nutritional value by aiding in reduction of transpiration. Further, it avoids water loss from fruits and prevents deterioration of fruit tissue and hence improves keeping quality [8]. These results corroborate those of Cliff et al. [10] for the variables °Brix and TA %, in a study with tomatoes, where the application of Si in tomato positively contributed to these traits. Silicic acid application was found efficient in promoting benefits possibly because of the reduction in fruit transpiration and improving water relations and significantly contributing to fruits quality in terms of total soluble solids and lycopene content. Figeuiredo et al. [12] also reported increase in the contents of total sugars and glucose, corroborating the present study. The decreased titratable acidity noticed with silicic acid drenching in fruit juice might be due to their rapid metabolic transformation of organic acids into sugars in citrate fruits [25]. Sabir et al. [50] also noticed higher ripening index with increased trend of TSS/TA. The application of Si has profound effect on quality improvement of crops. Similarly, enhanced quality attributes were recorded with the foliar application of silicic acid in terms of protein content/yield and oil content /yield in soybean [54]. Savant et al. [53] reported that Si promoted the number of spikelets per panicle, grain filling, grain yield and quality of rice. Addition of different levels of Si under salt stress interacted with Na^+ reduced its uptake and transport to shoots with a resultant improvement in cane yield and juice quality of sugarcane genotypes [6].

This is mainly due to the lack of functional Si efflux transporter LSI2 which is very important for transport of Si from root to shoot and responsible for Si accumulation in the shoots [40].

Effect of Silicic Acid Drenching on Si Content and Uptake of Tomato Fruits

The Si content and uptake by fruits were significantly enhanced with soil drenching of silicic acid @ 4 ml L^{-1} over control (Fig. 3a, b). Although tomato crop is considered as a Si non-accumulator species, considerably higher content of Si (0.30 to 0.43%) and its uptake (1.28 ± 0.21 to 2.60 ± 0.14 kg ha^{-1}) by tomato were observed in the present study.

The results were parallel to those recorded by Romero-Aranda et al. [49] who reported Si content of 0.4 to 0.5 per cent in tomato crop. Jarosz [22] revealed that fertilization with Si influences the Si content of fruits and observed Si content ranging from 0.08 to 0.10 per cent in tomato. Similar results were evidenced in other crops with silicic acid application. 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 enhancing Si content and its uptake by MAUS-2 and KBS-23 varieties of soybean, respectively [54]. Prakash et al. [46] revealed that foliar spray of soluble silicic acid @ 2 and 4 ml L^{-1} increased the Si content and its uptake in both straw as well as grain in both hilly and coastal zones of Karnataka.

In the present study, the Si content recorded in tomato, being a Si non-accumulator found to be far more lesser than Si-responsive crops like rice, sugarcane and soybean, which is concordant to findings of Ma and Yamaji [36]. Physiological studies also proved that Si uptake by tomato is much lower compared to Si accumulators like rice [39].

Effect of Silicic Acid Drenching on Content and Uptake of Major and Micronutrients by Tomato

The application of silicic acid as soil drench significantly enhanced the nutrient content and uptake in tomato fruits (Tables 2, 3). The plants drenched with silicic acid @ 4 ml L^{-1} recorded increased N, P and K content in tomato fruits from 2.94 ± 0.12 to 3.38 ± 0.41 per cent, 0.30 ± 0.02 to 0.45 ± 0.02 per cent, 1.56 ± 0.03 to 1.67 ± 0.05 per cent, respectively, over control. The uptake of N, P, K by fruits also increased from 12.72 ± 2.19 to 20.48 ± 1.22 kg ha^{-1}, 1.30 ± 0.16 to 2.72 ± 0.09 kg ha^{-1} and 6.71 ± 0.81 to 10.17 ± 0.62 kg ha^{-1}, respectively. The soil drenching of silicic acid @ 4 ml L^{-1} also recorded higher contents of secondary nutrients, viz. Ca (0.74 ± 0.03%), Mg (0.25 ± 0.01%) and S (0.35 ± 0.02%) than control. The uptake of Ca, Mg and S was also higher viz. 4.50 ± 0.49, 1.53 ± 0.07, and 2.14 ± 0.04 kg ha^{-1}, respectively, with silicic acid soil drenching over control. The content and uptake of micronutrients also showed increased response with drenching of silicic acid @ 4 ml L^{-1} (Tables 2, 3). Significantly higher content of Fe (177.3 ± 5.20 mg kg^{-1}), Mn (49.67 ± 3.58 mg kg^{-1}), Zn (30.60 ± 4.88 mg kg^{-1}) and Cu (30.63 ± 4.56 mg kg^{-1}) as well as uptake of Fe (108.30 ± 12.23 g ha^{-1}), Mn (30.41 ± 4.84 g ha^{-1}), Zn (18.55 ± 2.23 g ha^{-1}) and Cu (18.79 ± 4.10 g ha^{-1}) by tomato was observed with soil drenching of silicic acid @ 4 ml L^{-1} over control.

The effect of Si on content and uptake of nutrients has been reported from many studies in different crops.

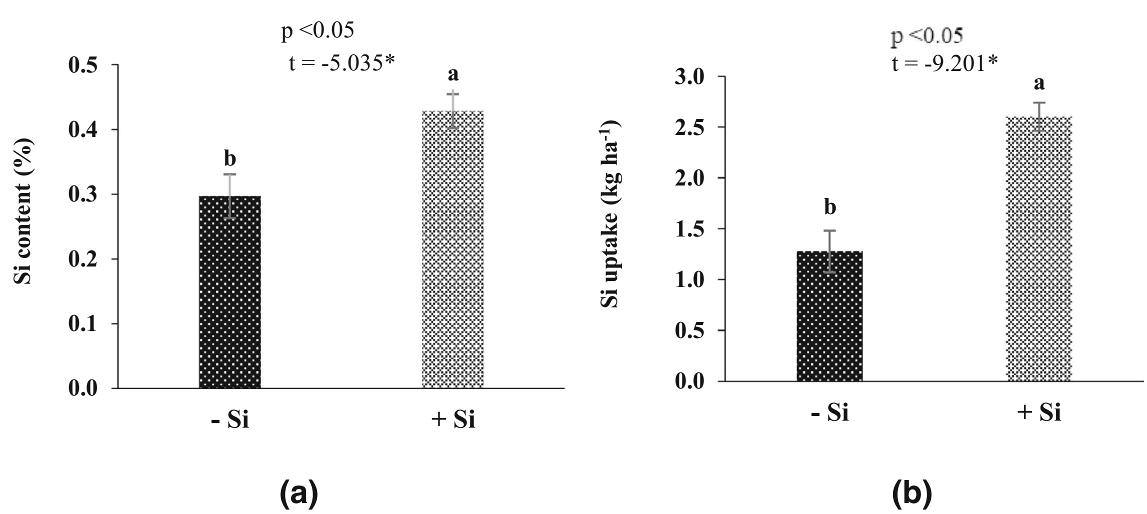


Fig. 3 **a, b** Effect of silicic acid on Si content (%) and its uptake (kg ha^{-1}) by tomato fruits at second picking

Table 2 Effect of soil drenching of silicic acid on nutrient content of tomato fruits at second picking

Treatments	N (%)	P	K	Ca	Mg	S	Fe (mg kg^{-1})	Mn	Zn	Cu
−Si	2.94 ± 0.12	0.30 ± 0.02	1.56 ± 0.03	0.56 ± 0.02	0.19 ± 0.01	0.25 ± 0.03	136.5 ± 13.50	41.20 ± 1.66	19.83 ± 1.53	22.13 ± 0.93
+Si	3.38 ± 0.41	0.45 ± 0.02	1.67 ± 0.05	0.74 ± 0.03	0.25 ± 0.01	0.35 ± 0.02	177.3 ± 5.20	49.67 ± 3.58	30.60 ± 4.88	30.63 ± 4.56
t value	−1.764*	−8.855**	−3.601*	−11.260**	−8.500**	−4.685**	−4.887**	−2.417	−3.645*	−3.161*

−Si and +Si indicate treatments without and with soil drenching of silicic acid

*values are significant at 0.05 level, **values are significant at 0.01 level

Table 3 Effect of soil drenching of silicic acid on nutrient uptake by tomato fruits at second picking

Treatments	N (kg ha^{-1})	P	K	Ca	Mg	S	Fe (g ha^{-1})	Mn	Zn	Cu
− Si	12.72 ± 2.19	1.30 ± 0.16	6.71 ± 0.81	2.41 ± 0.33	0.83 ± 0.10	1.08 ± 0.08	59.31 ± 13.77	17.97 ± 4.56	8.60 ± 1.85	9.50 ± 0.93
+Si	20.48 ± 1.22	2.72 ± 0.09	10.17 ± 0.62	4.50 ± 0.49	1.53 ± 0.07	2.14 ± 0.04	108.30 ± 12.23	30.41 ± 4.84	18.55 ± 2.23	18.79 ± 4.10
t value	− 5.355**	− 13.204**	− 5.833**	− 6.165**	− 9.712**	− 19.822**	− 4.607*	− 3.241*	− 5.946**	− 3.827*

−Si and +Si indicate treatments without and with soil drenching of silicic acid

*values are significant at 0.05 level, **values are significant at 0.01 level

Positive interaction of Si on the uptake on N by rice straw was reported by Savant et al. [53]. Li et al. [27] also elucidated that Si application greatly increased the concentration of N and P in corn plants. Ma and Takahashi [34] conducted a pot experiment to measure the effect of Si on P uptake and growth of rice at different P levels. Further they opined that addition of Si raised the optimum P level in rice. Application of 9.6 Mg ha^{-1} of calcium silicate increased the K levels in wheat flag leaves by 29 per cent over control [56]. Zhang et al. [62] noticed increase in uptake of NPK by rice with the application of calcium silicate to soil. He and Wang [19] reported that application of Si fertilizer could enhance the contents of Ca and Mg besides N, P, K in wheat. Likewise, Venkataraju [59] reported that the application of foliar silicic acid enhanced the S uptake by maize. Application of 9.6 Mg ha^{-1} of calcium silicate increased the Ca concentrations in the wheat flag leaves 38 per cent over control [56].

The increased content and uptake of Fe, Mn, Zn and Cu attributed to the fact that the Si addition enhances the expression of Si transporters which in turn influence uptake and translocation of these nutrients [13]. Gonzalo et al. [14] reported that the addition of 0.5 mM of Si to the nutrient solution without iron maintained the Fe content in leaves. Foliar sprays of $NaSiO_3$ at a rate of 150 mg Si L^{-1} accumulated higher levels of nutrients such as N, K, S, Ca, Mg and micronutrients such as B, Cu, Fe and Mn in gerbera [24].

Conclusions

Despite tomato being a Si non-accumulator, it showed significant response to application of silicic acid as a soil drench @ 4 ml L^{-1} at 15, 30 and 45 days after planting along with recommended dose of fertilizers in terms of fruit number and yield besides quality parameters such as total soluble solids, titratable acidity, ripening index and lycopene content. Increase in content of Si, major and micronutrients and as well their uptake by tomato suggests soil drenching of silicic acid, a novel approach to boost the nutrition and yield of tomato which needs to be explored further.

Availability of data and material

Not applicable.

Funding Not applicable.

Availability of Data and Material Not applicable.

Code Availability Not applicable.

Compliance with Ethical Standards

Conflicts of interest The authors declare that they have no conflict of interest.

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