Effect of Silicon fertilization on two major insect pests of tomato under greenhouse conditions

Aqeel Alyousuf (aqeel.alyousuf@okstate.edu)
University of Basrah https://orcid.org/0000-0002-7352-0168
Dawood Hamid
University of Basrah
Mohsen A. Desher
University of Basrah
Amin Nikpay
sugarcane and by products Development Company
Henk-Marten Laane
Rexil Agro BV

Original Research

Keywords: Silicon, Foliar application, Soil drench, Tomato, Fertilization

Posted Date: February 10th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-205218/v1

Version of Record: A version of this preprint was published at Silicon on April 6th, 2021. See the published version at https://doi.org/10.1007/s12633-021-01091-7.

Abstract

Tomato (*Solanum lycopersicum* L) is an important vegetable crop in Iraq. This horticultural crop is attacked by several insect pest species. Among them, the whitefly *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) and the tomato leaf miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) are the major threat of greenhouse tomatoes in Basrah province in south Iraq. The management of these pests is heavily based on application of chemical pesticides. Vast application of pesticides caused harmful damage to the environment, human health and may increasing the risk of pest resistance on insect populations. One of the promising strategies which are compatible with organic farming is application of silicon for enhancing plant vigor and resistance to pest damage on various agricultural crops. Due to these facts, the experiments have been carried out at Basrah University to evaluate the effects of silicon (Si) fertilization on tomato plants for reducing damage of these two major pests. Treatments comprised two type of Si applications (Soil drench treatment and foliar spraying) with four Si concentrations (0, 0.5, 1 and 2%) of AB Yellow ® silicic acid formulation. The population density of *B. tabaci* and *T. absoluta* were studied weekly during the growth season. The results clearly demonstrated that Silicon applications significantly decreased the population of immature of both whiteflies and tomato leaf miner on tomato crop in the greenhouse; Si-Foliar spraying was more effective in reducing the population density of these key pests compared to Si- soil drench application.

Introduction

Tomato (*Lycopersicum lycopersicum* Mill) is one of the most economic important crop of commercial plantations in Basrah Province, Iraq. The total area planted with this crop reached 2206 hectare, with a production rate of 239.8 thousand tons (almost half of the total production in Iraq, 467.6 thousand tons) in the growing season of 2018/2019 [1]. Annually, the crop is infested by many pests, but the whitefly *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) is the most destructive insect pest infesting the crop; It causes economic losses reaching 100% in the case of severe injury [2, 3]. The economic loss is due to the serious feeding on the phloem of the infested plants, as well as the transferring of the pathogenic viruses to the healthy plants [4, 5]. The tomato leaf miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) is a serious invasive pest, which was first recorded infesting tomato crop of Basrah in 2011 [6]. This pest can easily infest both fresh and processed tomatoes under greenhouse or field cultivated conditions. The tomato leaf miner may scatter rapidly and attack all stages of tomato and without appropriate management; heavy infestation of the pest usually destroys the unprotected tomato fields. Moreover, this pest can infest potatoes, sweet peppers, eggplants and several species of solanaceous crops [7–9]. The tomato leaf miner feeds on the leaves of tomato across all growth stages and on the fruits during productive growth stages [10, 11].

For effective management of *T. absoluta*, various control strategies such as cultural and biological control are applied; however, chemical control is extensively used against the pests globally and are especially disseminative in agricultural systems [12]. Due to the negative effects of chemical insecticides, scientific efforts have been focused on the successful alternatives enhancing the plant resistance against insects in the fields. These ways enable the plant to perform as an undesirable resistant plant to the pests or/and prevent herbivores from feeding and laying eggs [13–16]. One proposed action has been development application of silicon-based formulations as nutritional amendment as a part of proper integrated pest management scenario [17–20].

Silicon (Si) is one of the most abundant elements in the soil components that is mainly present in the inert state and is rarely found in the soluble state [21]. Si is absorbed by plant in the phase of silicic acid ($Si(OH)_4$) [22]. Although Si is not considered a major nutrient in plant growth, it functions in the development and production of some plant species; currently the element is recognized as an important factor increasing the tolerance of the plant to the biotic (insect and mite pests and plant diseases) and abiotic stresses (such as drought, metal toxicity, cold, lodging, high temperatures) [20, 23]; Si enhances the plant`s resistance to arthropod pests due to the ability of Biosilica to accumulate in the plants cellular walls that prevents pest feeding, and decreases the digestibility of the leaves and the biological performance of the pests [24–26]. Moreover, Si stimulates the chemical plant defense by increasing the synthesis of phenolic compounds and lignin [27–29, 13, 30].

Commercially, silicon-based fertilizer has been found as potassium silicate (K_2SiO_3) [31], which used against sugarcane yellow mite *Oligonychus sacchari* on sugarcane [32]. Si formulation can be supplied also as Calcium silicate (CaSiO3), which decreased the population and damage of some sucking-mouthpart pests *Frankliniella schultzei* Trybon (Thysanoptera: Thripidae) infesting tomato plants [33]. Application of silicon fertilizers has been successful used to enhance the resistance against pest infesting different crops such as sugarcane [34, 35, 19, 36, 37], rice [38], cucumber [39], cabbage [40] and soybean [41]. Generally, calcium silicate formulations contain Si in the inert forms, which is difficult to be absorbed by the plant. The soluble state, Orthosilicic acid (H_4SiO_4), has been stabilized as commercial formulations such as Silixol Granules, which used to decrease the infestation rate of Rice Stem borer *Scirpophaga incertulas* (Walker) and leaf folder *Cnaphalocrocis medinalis* on rice [42–44]. Several studies have indicated the vital role of silicon-based treatments improving resistance of tomato against different pests including herbivores insect *T. absoluta* by using calcium silicate treatments [45], and phloem feeder two-spotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae) by applying Soil and foliar application of rock dust including more than 60% SiO_2 [46]. One recently new silicon formulation has been developed by Rexil-Agro (Netherlands) and ranked as bio stimulants which recommended for different agricultural and horticultural crops under field and greenhouse conditions [47]. The objective of the study was to evaluate the response of tomato crop to the soluble state of Si formulation that could enhance anti-herbivore resistance against whitefly *B. tabaci* and tomato leaf miner *T. absoluta*.

Materials And Methods

Silicon formulation

The Silicic Acid Agro Technology (SAAT) is the suitable form of stabilized silicic acid. AB Yellow® is a new silicic acid patent which is synthesized by Rexil-Agro Company (The Netherlands). It is stabilized silicic acid in which polymerization of silicon is halted. AB Yellow® is containing 2.5% plant-available silicic acid (0.8% Si) in combination with 0.3% boron, 1.5% zinc, 0.15% copper and 0.1% molybdenum [47].

Trial site, Experimental design, Silicon treatments and sampling methodology

The study was conducted in a greenhouse at the agricultural research station, College of Agriculture, University of Basrah (Basrah, Iraq) during the growing season 2019–2020. Tomato seeds (variety: REDFLORA F; Company: Apollo Seeds, USA) were cultivated on August (2019). After one month, the seedlings have been transplanted to a greenhouse where the treatments were laid out in a Randomized Complete Block Design (RCBD) with three blocks 25 meters length, 40 cm width and a distance of 100 cm between each block and all experimental field area was divided into 8 experimental plots. Each plot size was 3 m length, and unit-to-unit was 50 cm. The treatments comprised two types of Si applications (Soil drench treatment and Foliar spraying) with three Si concentrations (0.5, 1 and 2%) of AB Yellow ® silicic acid formulation. Untreated plots were considered as control check which received no silicon amendment. For the foliar spraying, tomato plants were sprayed from the bottom to the top, with 50 ml of the concentrations. All foliar sprays were applied by a 16 liter volume knapsack sprayer (Hardi International, England). In the soil treatments, each plant was drenched also with 50 ml of the solution. Two applications of the treatments were carried out at 20 days intervals. The first application was investigated at 30 days after the seedling transplantation. Irrigation, organic fertilization and other cultural practices were conducted as the common recommended protocol.

The population density of *B. tabaci* and *T. absoluta* were studied weekly during the grown season, starting from the second week of December (11/12/2019) until the second week of March (11/3/2020) (All pests infestations occurred naturally during growing season). Three fully expanded leaves (basal, middle and upper parts) were randomly collected from three plants per an experimental unit. Then, the sampled leaves were put in plastic bags and brought to the lab for counting the number of whiteflies and the *T. absoluta* larvae by using an accurate optical microscopy. *Tuta absoluta* larvae were calculated in each leaves, whereas, whitefly nymphs were counted from a one inch^2 area in each of the three leaves.

Data analysis

All data were analyzed for normality and homogeneity of variance (Bartlett's test), and appropriate transformations [arcsin, or log $(x + 1)$] were done where these conditions were not encountered, before analysis of variance was carried out. Data of the average numbers of immatures (nymphs or larvae) per leaf/ inch^2 of leaf were analyzed by two-way ANOVA; followed by a Least Significant Difference (LSD) test ($P \leq 0.05$) using the statistical software R [48].

Results

The results of Table 1 indicated that whitefly nymph population was 0.125 nymph/ unit area of leaf ($inch^2$) at the 1st week, and the highest population of 3.04 nymph/ leaf ($inch^2$) was recorded at 12th week ($F = 273.725$, $P < 0.00$). There was a negative response between Si concentrations and the whitefly nymph population density; at the highest concentration of Si (2%), average nymph numbers were reduced 50% compared to the control, with average of 0.76 and 1.55 nymph/unit area of leaf ($inch^2$), respectively ($F = 79.488$, $P < 0.00$; Fig. 1). The results of foliar-applied versus drench-applied Si (Fig. 2) showed a significant difference in nymph population between Si applications; the density of whitefly nymphs was lower on the foliar application, with average of 1.11 and 1.33 nymph / leaf ($inch^2$), respectively ($F = 28.119$, $P < 0.00$). The populations of the nymph in the plots with foliar application of Silicon were the lowest throughout the growing season ($F = 3.278$, $P < 0.00$; Fig. 3).

Table 1
The population density of whiteflies infesting tomato during the reproductive stage, 2019–2020.

Week	No. of nymphs/ leaf ($inch^2$)	
	Mean	SE
1	0.125^{e}	0.039
2	0.181^{de}	0.046
3	0.167^{de}	0.044
4	0.306^{de}	0.058
5	0.361^{de}	0.069
6	0.417^{de}	0.078
7	0.514^{d}	0.088
8	1.375^{c}	0.158
9	1.778^{b}	0.186
10	2.070^{b}	0.209
11	2.792^{a}	0.258
12	3.042^{a}	0.305
13	2.764^{a}	0.278

Means followed by the same letter are not significantly different using LSD test at $P \leq 0.05$; SE = Standard Error.

The results of response of tomato crop treated with different concentrations and application of Si to the infestation of *T. absoluta* (Table 2) showed the population was 0.11 larvae/ leaf at 1st week, and increased to reach the highest density of 1.86 larvae/ leaf at 11th week ($F = 74.738$, $P < 0.00$). In general, the highest Si concentration of 2% significantly ($F = 31.631$, $P < 0.00$) recorded the minimum number of the larvae (0.53 larvae/ leaf) on the treated plants compared to control treatment which did not differ significantly than the lowest concentration of 0.05% Si, with average densities of 0.98 and 0.94 larvae/ leaf, respectively (Fig. 4). Moreover, the foliar Si application showed significantly lower population of larvae compared to drench application, with average of 0.73 and 0.83 larvae/ leaf, respectively ($F = 13.320$, $P < 0.00$, Fig. 5). Over all the growing season, there was no significant differences between the populations of tomato leaf miners on foliar-applied and drench-applied plots ($F = 0.238$, $P < 0.997520$; Fig. 6)

Table 2
The population density of tomato leaf miner infesting tomato during the reproductive stage, 2019–2020.

week	No. of larvae/ leaf	
	Mean	SE
1	0.111^{h}	0.037
2	0.097^{h}	0.035
3	0.181^{h}	0.046
4	0.139^{h}	0.041
5	0.333^{gh}	0.059
6	0.556^{fg}	0.086
7	0.652^{efg}	0.084
8	0.819^{ef}	0.098
9	1.236 ^{cd}	0.126
10	1.306^{bc}	0.121
11	1.681^{a}	0.115
12	1.583^{ab}	0.122
13	1.556^{abc}	0.116
14	0.931^{de}	0.010

Means followed by the same letter are not significantly different using LSD test at $P \leq 0.05$; SE = Standard Error

Discussion

Silicon applications resulted in significantly decreased in population of immature of both whiteflies and tomato leaf miner on tomato crop in the greenhouse. The basic mechanism of Si applications on the pests is mechanical barriers (single or double-layer of silicon) which are connected directly under the cuticle. Silicon is accumulated and polymerized in the veins and leaf epidermal cells [49, 50] that preventing the feeding of phytophagous insect and reducing the host acceptance and suitability [25, 51, 26]. Moreover, Si applications enhance chemical plant resistance against pests by increasing the levels of vital biochemical such as phenols. Our results have been clearly showed that application of silicic acid formulation in the form of foliar or soil drench, may reduce significantly the population density of silver whitefly *B. tabaci* on tomato in comparison with control. Even though, by increasing the concentration of silicon, the reduction in population density was higher. In a research study in Brazil, Ferreira *et al.* [52] evaluated the efficacy of silicon application on two soybean cultivars under greenhouse conditions. The authors applied silicon treatment on the vegetative growth stage of soybean. The results of their study indicated that silicon fertilization significantly affected the pest and enhanced nymphs' mortality. On cucumber, Correa *et al.* [53] investigated effectiveness of silicon application for management of *B. tabaci*. The findings depicted that number of nymphs on treated plants was significantly lower than untreated cucumbers. In a similar experiment, Callis-Duehl *et al.* [39] assessed effects of silicon on *B. tabaci* on cucumber. The authors showed that application of potassium silicate solution, could reduce number of *B. tabaci* on cucumber leaves whereas the number of living whiteflies on untreated cucumber leaves was higher (44.5%). This finding revealed that *B. tabaci* populations has less preference to treated silicon plants. Silicon has negative effects on other sap-sucking insect pests on different plant crops. Ramirez-Godoy *et al.* [54] showed that the population density of Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) a major global threat for citrus industry, affected negatively by application of silicon. The authors concluded that application of silicon in the form of potassium silicate may significantly reduce the oviposition rate of *D. citri* up to 60% in Tahiti lime. In a recent study, Nikpay and Laane [37] assessed the effectiveness of silicic acid treatment on reduction damage of yellow mite on two sugarcane commercial varieties. The field trial data illustrated that foliar spraying of silicic acid at different rates can decrease the number of living mites on treated varieties. However, the effectiveness of silicon treatment may increase by increasing in the number of silicon application.

There is very few data on silicon application against tomato leaf miner *T. absoluta*. Our results clearly showed that the silicon treatment either by foliar spraying or soil drench treatment can significantly reduce leaf miner larvae populations on leaves under greenhouse conditions. The only published research by Dos Santos *et al.* [45] indicated that application of silicon on the form of liquid foliar treatment on tomato leaves affected the midgut of the treated larvae of *T. absoluta* due to the toxic effect of some biochemicals that simulated by the Si-foliar application.

Other species of lepidopteran pests have also been shown similar responding to Si application; Sidhu *et al.* [55] found that Si application contributed to the management of the sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) reducing the feeding injury by adversing the suitable host plant acceptance by the borers. Hall *et al*. [50] indicated that Si acted as a direct defensive mechanism against chewing mouthpart herbivores through enhancing the mechanical plant resistances. Moreover, Melo *et al.* [56] revealed that foliar application of 1% silicic acid solution ($SiO_2 .xH_2O$) reduced the numbers of whitefly eggs and nymphs in chrysanthemum plants.

Conclusion

Applying of Silicon formulation significantly decreased the population of key pests (whiteflies and tomato leaf miner) on tomato crop in the greenhouse. Using silicon products has been broadly accepted in organic farming and may be considered as an appropriate, effective and ecologically-sound strategy for alleviating of the biotic stressors such as arthropod pests under field and greenhouse conditions. This new potential concept should be chosen wisely in sustainable agriculture and production of agricultural and horticultural crops.

Declarations

Acknowledgements

The authors thank the staff of the agricultural research station, College of Agriculture, University of Basrah, for allowing us to conduct this study using the station’s greenhouse.

Funding statement: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors declare no conflict of interest.

Author contributions: All authors contributed to the study conception. Data collection and analysis were performed by Aqeel Alyousuf and Dawood Hamid. The first draft of the manuscript was written by Aqeel Alyousuf and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Availability of data and material: The data that support the findings of this study are available from the corresponding author, Aqeel Alyousuf, upon reasonable request.

Compliance with ethical standards: Not applicable

Consent to participate: We declare that we participated in the study and in the development of the manuscript titled (Effect of Silicon fertilization on two major insect pests of tomato under greenhouse conditions).

Consent for Publication: We hereby declare that we participated in the study and in the development of the manuscript titled (Effect of Silicon fertilization on two major insect pests of tomato under greenhouse conditions), and we give our consent for the article to de published in SILICON.

References

1. Central Statistical Organization (2020) Vegitable production of Iraqi provinces in 2018. from Central Statistical Organization, Iraq. http://cosit.gov.iq/documents/agriculture/agri_other/full%20reports.
2. Tan X-L, Wang S, Ridsdill-Smith J, Liu T-X (2014) Direct and indirect impacts of infestation of tomato plant by *Myzuspersicae* (Hemiptera: Aphididae) on Bemisia tabaci (Hemiptera: Aleyrodidae). Plos one 9 (4):e94310
3. Sani I, Ismail SI, Abdullah S, Jalinas J, Jamian S, Saad N (2020) A review of the biology and control of whitefly, *Bemisiatabaci* (Hemiptera: Aleyrodidae), with special reference to biological control using

entomopathogenic fungi. Insects 11 (9):619

4. Moriones E, Navas-Castillo J (2000) Tomato yellow leaf curl virus, an emerging virus complex causing epidemics worldwide. Virus research 71:123-134. doi:10.1016/S0168-1702(00)00193-3
5. Matsuura S, Hoshino S (2009) Effect of tomato yellow leaf curl disease on reproduction of *Bemisiatabaci* Q biotype (Hemiptera: Aleyrodidae) on tomato plants. Applied entomology and zoology 44 (1):143-148
6. Abdlrazak AS, Abd –Alraheem, H. Y., Hassan, S. A., Mustafa, A. F., Mahmud, A. A., Abas, Sh. A., Mohammed, A. K. (2017) Geographical distribution of *Tutaabsoluta* (Meyrick 1917) (Lepidoptera: Gelechiidae) in Iraq. Iraqi J Agric Res 22 (1):137-146
7. Abdul Razzak AS, Al-Yasiri, I. I., Fadhil, H. Q. (2010) First record of tomato borer (tomato moth) *Tutaabsoluta* (Meyrick) (Lepidoptera: Gelechiidae) on tomato crop in Iraq, 2010. Arab and Near East Plant Protection Newsletter no 51, p 31
8. Mohamed E, Mahmoud M, Elhaj M, Mohamed S, Ekesi S (2015) Host plants record for tomato leaf miner *Tuta absoluta* (Meyrick) in Sudan. EPPO Bulletin 45. doi:10.1111/epp.12178
9. Bajracharya A, Mainali RP, Bhat B, Bista S, Shashank PR, Meshram N (2016) The first record of South American tomato leaf miner, *Tuta absoluta* (Meyrick 1917) (Lepidoptera: Gelechiidae) in Nepal. Journal of Entomology and Zoology Studies 4:1359-1363
10. van der Straten M, Potting RP, van der Linden A (2011) Introduction of the tomato leafminer *Tuta absoluta* into Europe. In: Proceedings of the Netherlands Entomological Society Meeting. pp 23-30
11. Baetan R, Oltean I, Addante R, Porcelli F (2015) *Tutaabsoluta* (meyrick, 1917) (Lepidoptera: Gelechiidae) adult feeding on tomato leaves. Notes on the behaviour and the morphology of the parts related. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca Agriculture 72. doi:10.15835/buasvmcn-agr:10619
12. Illakwahhi DT, Srivastava BBL (2017) Control and management of tomato leafminer-*Tutaabsoluta* (Meyrick)(Lepidotera, Gelechiidae). A review. IOSR Journal of Applied Chemistry (IOSR-JAC) 10 (6):14-22
13. Alhousari F, Greger M (2018) Silicon and mechanisms of plant resistance to insect pests. Plants 7 (2):33
14. Davis JA, Radcliffe EB, Ragsdale DW (2007) Resistance to green peach aphid, *Myzuspersicae* (Sulzer), and potato aphid, Macrosiphum euphorbiae (Thomas), in potato cultivars. American Journal of Potato Research 84 (3):259-269
15. Smith CM (2005) Plant resistance to arthropods: molecular and conventional approaches. Springer Science & Business Media,
16. Alyousuf AA (2011) Integrated control of *Tetranychusurticae* Koch on Cucumder *Cucumissativus* L. by using acaricides, plant cultivars and potash fertilizer. Al-Mustansiryah J of Science 22 (3):31-46
17. Bent E (2014) Silicon Solutions: Helping Plants to Help Themselves: an Holistic Review. Sestante, Bergamo, Italy

18. Tubaña BS, Heckman JR (2015) Silicon in soils and plants. In: Silicon and plant diseases. Springer, pp 7-51
19. Nikpay A, Goebel F-R The role of silicon in plant defence against insect pests with special reference to sugarcane pests: Challenges, opportunities and future directions in sugarcane IPM. In: XI Pathology and IX Entomology Workshops, Guayaquil, Ecuador, 2015. FIADE, p 44
20. Reynolds OL, Padula MP, Zeng R, Gurr GM (2016) Silicon: potential to promote direct and indirect effects on plant defense against arthropod pests in agriculture. Frontiers in Plant Science 7:744
21. Savant NK, Korndörfer GH, Datnoff LE, Snyder GH (1999) Silicon nutrition and sugarcane production: a review. Journal of plant nutrition 22 (12):1853-1903
22. Belton DJ, Deschaume O, Perry CC (2012) An overview of the fundamentals of the chemistry of silica with relevance to biosilicification and technological advances. FEBS J 279 (10):1710-1720. doi:10.1111/j.1742-4658.2012.08531.x
23. Balakhnina T, Borkowska A (2013) Effects of silicon on plant resistance to environmental stresses. International Agrophysics 27 (2)
24. Costa RR, Moraes JC (2006) Effects of silicon acid and of acibenzolar-S-methyl on *Schizaphisgraminum* (Rondani)(Hemiptera: Aphididae) in wheat plants. Neotropical entomology 35 (6):834-839
25. Massey F, Hartley S (2008) Physical defences wear you down: Progressive and irreversible impacts of silica on insect herbivores. The Journal of animal ecology 78:281-291. doi:10.1111/j.1365-2656.2008.01472.x
26. Keeping MG, Miles N, Sewpersad C (2014) Silicon reduces impact of plant nitrogen in promoting stalk borer (*Eldanasaccharina*) but not sugarcane thrips (*Fulmekiolaserrata*) infestations in sugarcane. Frontiers in Plant Science 5 (289). doi:10.3389/fpls.2014.00289
27. Vega I, Nikolic M, Pontigo S, Godoy K, Mora ML, Cartes P (2019) Silicon Improves the Production of High Antioxidant or Structural Phenolic Compounds in Barley Cultivars under Aluminum Stress. Agronomy 9:388. doi:10.3390/agronomy9070388
28. Chérif M, Benhamou N, Menzies JG, Bélanger R (1992) Silicon induced resistance in cucumber plants against *Pythiumultimum*. Physiological and Molecular Plant Pathology 41 (6):411-425
29. Keeping MG, Kvedaras OL (2008) Silicon as a plant defence against insect herbivory: response to Massey, Ennos and Hartley. Journal of Animal Ecology 77 (3):631-633
30. Zhang N, Li Z, Xiao Y, Pan Z, Jia P, Feng G, Bao C, Zhou Y, Hua L (2020) Lignin-based phenolic resin modified with whisker silicon and its application. Journal of Bioresources and Bioproducts 5 (1):67-77. DOI: 10.1016/j.jobab.2020.03.008
31. Hogendorp BK, Cloyd RA, Swiader JM (2009) Effect of silicon-based fertilizer applications on the reproduction and development of the citrus mealybug (Hemiptera: Pseudococcidae) feeding on green coleus. Journal of economic entomology 102 (6):2198-2208
32. Nikpay A, Soleyman Nejadian E (2014) Field Applications of Silicon-Based Fertilizers Against Sugarcane Yellow Mite *Oligonychussacchari*. Sugar Tech 16 (3):319-324. doi:10.1007/s12355-013-

0276-z

33. Almeida GD, Pratissoli D, Zanuncio JC, Vicentini VB, Holtz AM, Serrão JE (2009) Calcium silicate and organic mineral fertilizer increase the resistance of tomato plants to *Frankliniellaschultzei*. Phytoparasitica 37 (3):225-230. doi:10.1007/s12600-009-0034-7
34. Goebel F-R, Nikpay A (2017) Integrated pest management in sugarcane cropping systems. Integrated pest management in tropical regions Ed by C Rapisarda & G E Massimino-Cocuzza, CAB International:113-133
35. Keeping MG, Kvedaras OL, Bruton AG (2009) Epidermal silicon in sugarcane: cultivar differences and role in resistance to sugarcane borer *Eldanasaccharina*. Environmental and Experimental Botany 66 (1):54-60
36. Nikpay A, Nejadian ES, Goldasteh S, Farazmand H (2017) Efficacy of silicon formulations on sugarcane stalk borers, quality characteristics and parasitism rate on five commercial varieties. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences 87 (2):289-297
37. Nikpay A, Laane H-M (2020) Foliar amendment of silicic acid on population of yellow mite, *Oligonychussacchari* (Acari: Tetranychidae) and its predatory beetle, Stethorus gilvifrons (Col.: Coccinellidae) on two sugarcane commercial varieties. Persian Journal of Acarology 9 (1)
38. HAN Y-q, WEN J-h, PENG Z-p, ZHANG D-y, HOU M-l (2018) Effects of silicon amendment on the occurrence of rice insect pests and diseases in a field test. Journal of Integrative Agriculture 17 (10):2172-2181
39. Callis-Duehl KL, McAUSLANE HJ, Duehl AJ, Levey DJ (2017) The effects of silica fertilizer as an anti-herbivore defense in cucumber. Journal of Horticultural Research 25 (1):89-98
40. Teixeira NC, Valim JOS, Oliveira MGA, Campos WG (2020) Combined effects of soil silicon and drought stress on host plant chemical and ultrastructural quality for leaf-chewing and sap-sucking insects. Journal of Agronomy and Crop Science 206 (2):187-201
41. Johnson SN, Rowe RC, Hall CR (2020) Silicon is an inducible and effective herbivore defence against *Helicoverpapunctigera* (Lepidoptera: Noctuidae) in soybean. Bulletin of entomological research 110 (3):417-422
42. Jawahar S, Jain N, Suseendran K, Kalaiyarasan C, Kanagarajan R (2015) Effect of silixol granules on silicon uptake, stem borer and leaf folder incidence in rice. Int J Curr Res Acad Rev 3:168-174
43. Jawahar S, Kalaiyarasan C, Ramesh S, Kumar SV, Suseendran K, Arivukkarasu K (2019) Effect of Orthosilicic Acid Formulations on Leaf Folder Incidence in Lowland Rice. Asian J Mult-Disciplinary Res 5 (1):1
44. Cuong TX, Ullah H, Datta A, Hanh TC (2017) Effects of silicon-based fertilizer on growth, yield and nutrient uptake of rice in tropical zone of Vietnam. Rice Science 24 (5):283-290
45. Dos Santos M, Junqueira MR, de Sá VM, Zanúncio J, Serrão J (2015) Effect of silicon on the morphology of the midgut and mandible of tomato leafminer *Tutaabsoluta* (Lepidoptera: Gelechiidae) larvae. Invertebrate Survival Journal 12 (1):158-165

46. Faraone N, Evans R, LeBlanc J, Hillier NK (2020) Soil and foliar application of rock dust as natural control agent for two-spotted spider mites on tomato plants. Scientific Reports 10 (1):1-9
47. Laane H-M (2017) The effects of the application of foliar sprays with stabilized silicic acid: An overview of the results from 2003-2014. Silicon 9 (6):803-807
48. R Development Core Team (2019) R: A Language and Environment for Statistical Computing 3.5.3 edn. R Foundation for Statistical Computing Vienna, Austri
49. Liang Y, Nikolic M, Bélanger R, Gong H, Song A (2015) Silicon in agriculture. Dordrecht: Springer doi 10:978-994
50. Hall CR, Dagg V, Waterman JM, Johnson SN (2020) Silicon Alters Leaf Surface Morphology and Suppresses Insect Herbivory in a Model Grass Species. Plants 9 (5):643
51. Massey F, Ennos R, Hartley S (2006) Silica in grasses as a defence against insect herbivores: Contrasting effects on folivores and a phloem feeder. The Journal of animal ecology 75:595-603. doi:10.1111/j.1365-2656.2006.01082.x
52. Ferreira R, Moraes J (2011) Silicon influence on resistance induction against *Bemisiatabaci* biotype B (Genn.)(Hemiptera: Aleyrodidae) and on vegetative development in two soybean cultivars. Neotropical entomology 40 (4):495-500
53. Correa RS, Moraes JC, Auad AM, Carvalho GA (2005) Silicon and acibenzolar-S-methyl as resistance inducers in cucumber, against the whitefly *Bemisiatabaci* (Gennadius)(Hemiptera: Aleyrodidae) biotype B. Neotropical Entomology 34 (3):429-433
54. Ramírez-Godoy A, del Pilar Vera-Hoyos M, Jiménez-Beltrán N, Restrepo-Díaz H (2018) Effect of Potassium Silicate Application on Populations of Asian Citrus Psyllid in Tahiti Lime. HortTechnology 28 (5):684-691
55. Sidhu J, Stout M, Blouin D, Datnoff L (2013) Effect of silicon soil amendment on performance of sugarcane borer, *Diatraeasaccharalis* (Lepidoptera: Crambidae) on rice. Bulletin of entomological research 103 (6):656-664
56. Melo BA, Moraes JC, Carvalho LM (2016) Resistance induction in chrysanthemum due to silicon application in the management of whitefly *Bemisiatabaci* Biotype B (Hemiptera: Aleyrodidae). Revista de Ciencias Agroambientais 13 (2)

Figures

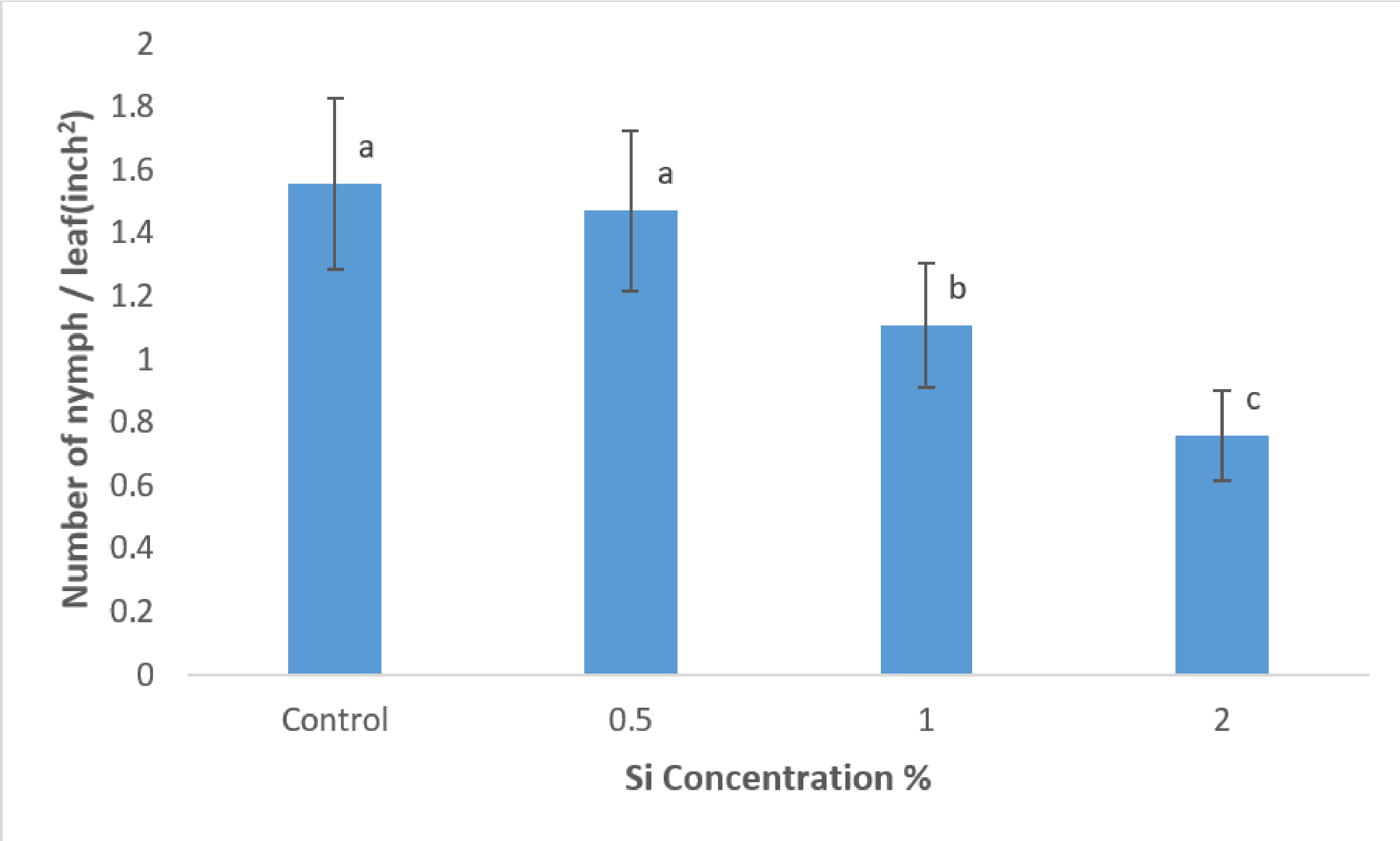

Figure 1

Effect of Silicon concentrations on the population density of whitefly infesting tomato during the reproductive stage; means followed by the same letter with each concentration are not significantly different using LSD test at $P \leq 0.05$.

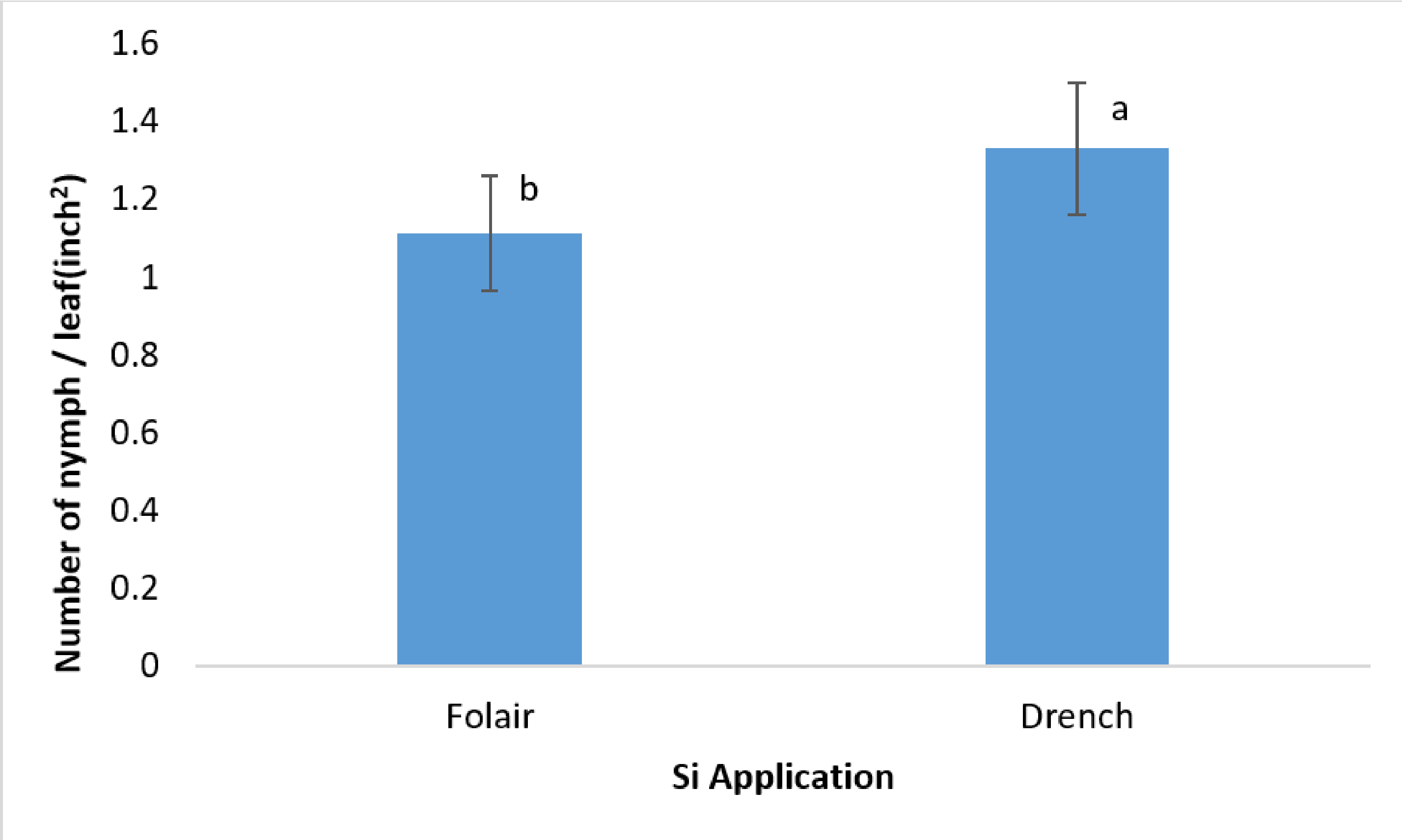

Figure 2

Effect of Silicon application on the population density of whitefly infesting tomato during the reproductive stage; means followed by the same letter within each application are not significantly different using LSD test at $P \leq 0.05$.

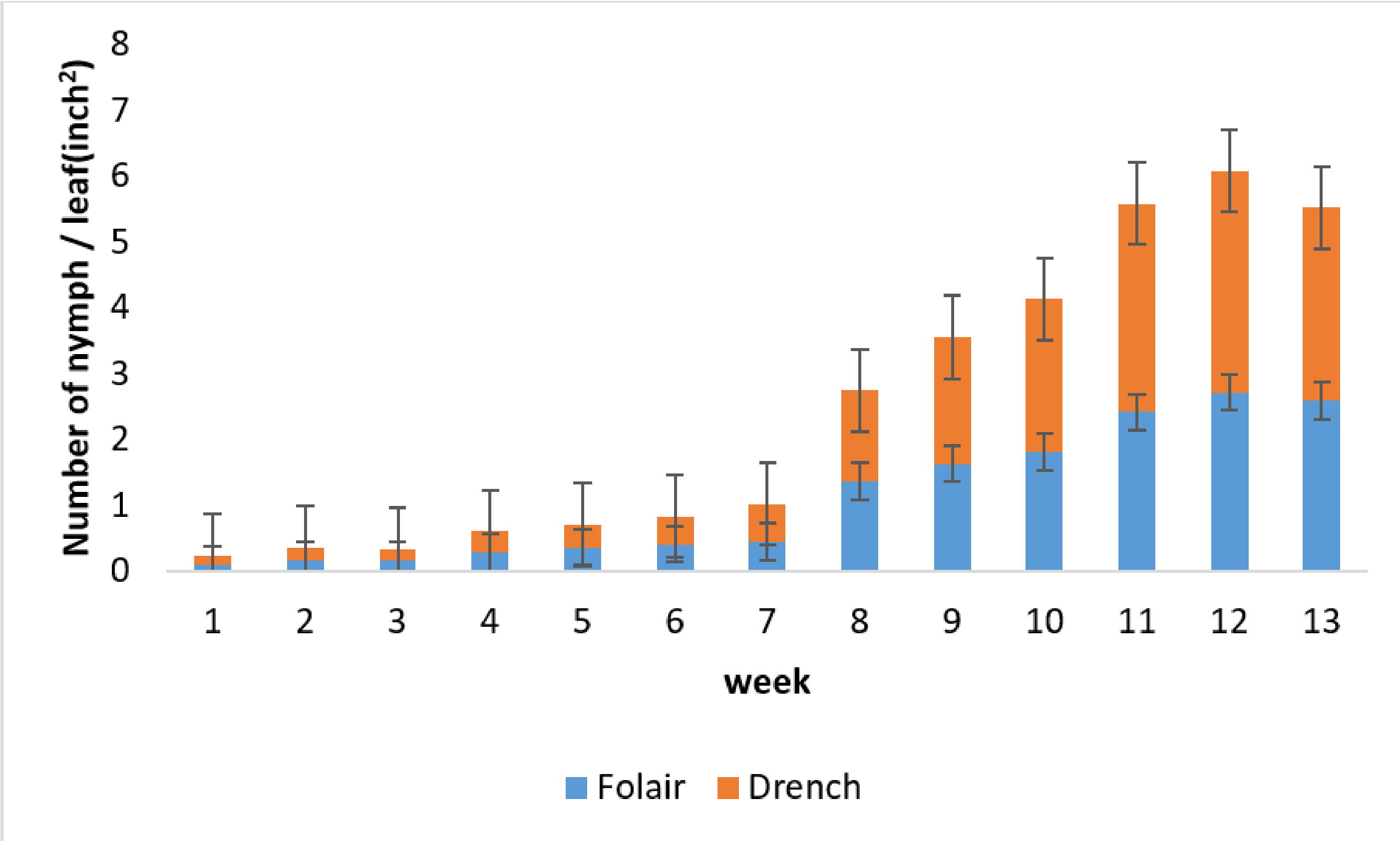

Figure 3

Effect of Silicon application on the population density of whitefly during the growing season of 2019/2020, (LSD ($P \leq 0.05$) = 0.291)

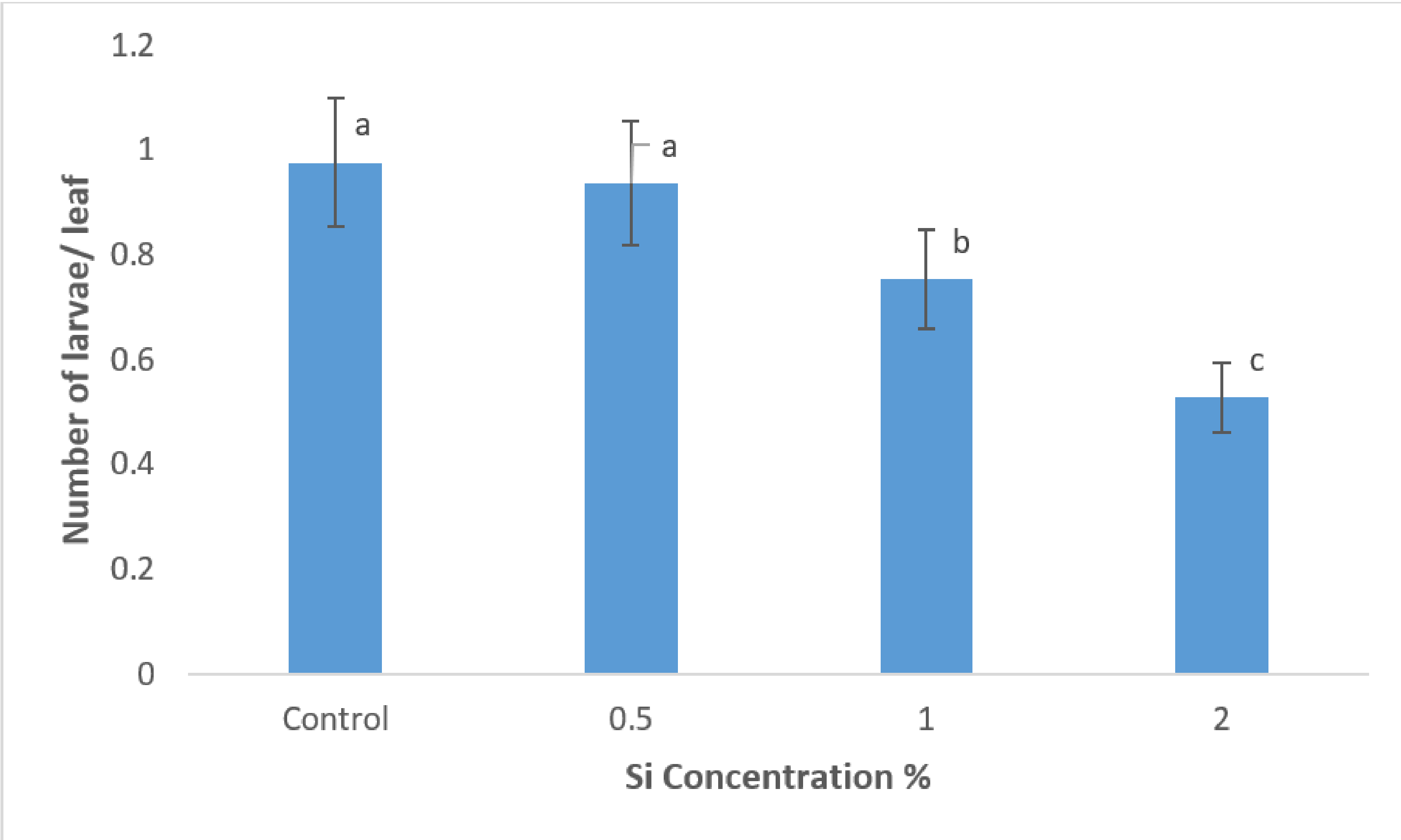

Figure 4

Effect of Silicon concentrations on the population density of tomato leaf miner infesting tomato during the reproductive stage; means followed by the same letter with each concentration are not significantly different using LSD test at P ≤ 0.05.

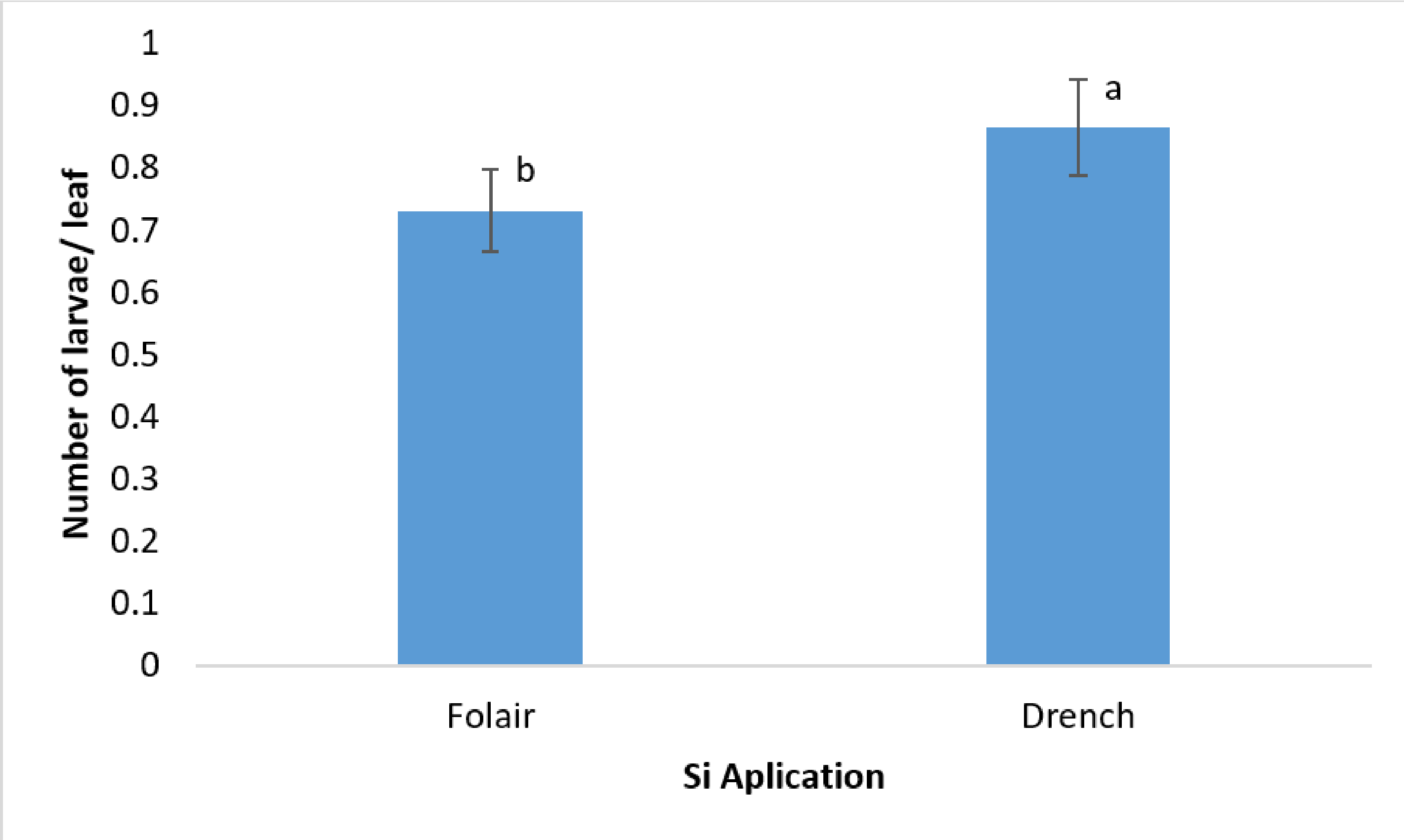

Figure 5

Effect of Silicon application on the population density of tomato leaf miner infesting tomato during the reproductive stage; means followed by the same letter within each application are not significantly different using LSD test at P ≤ 0.05.

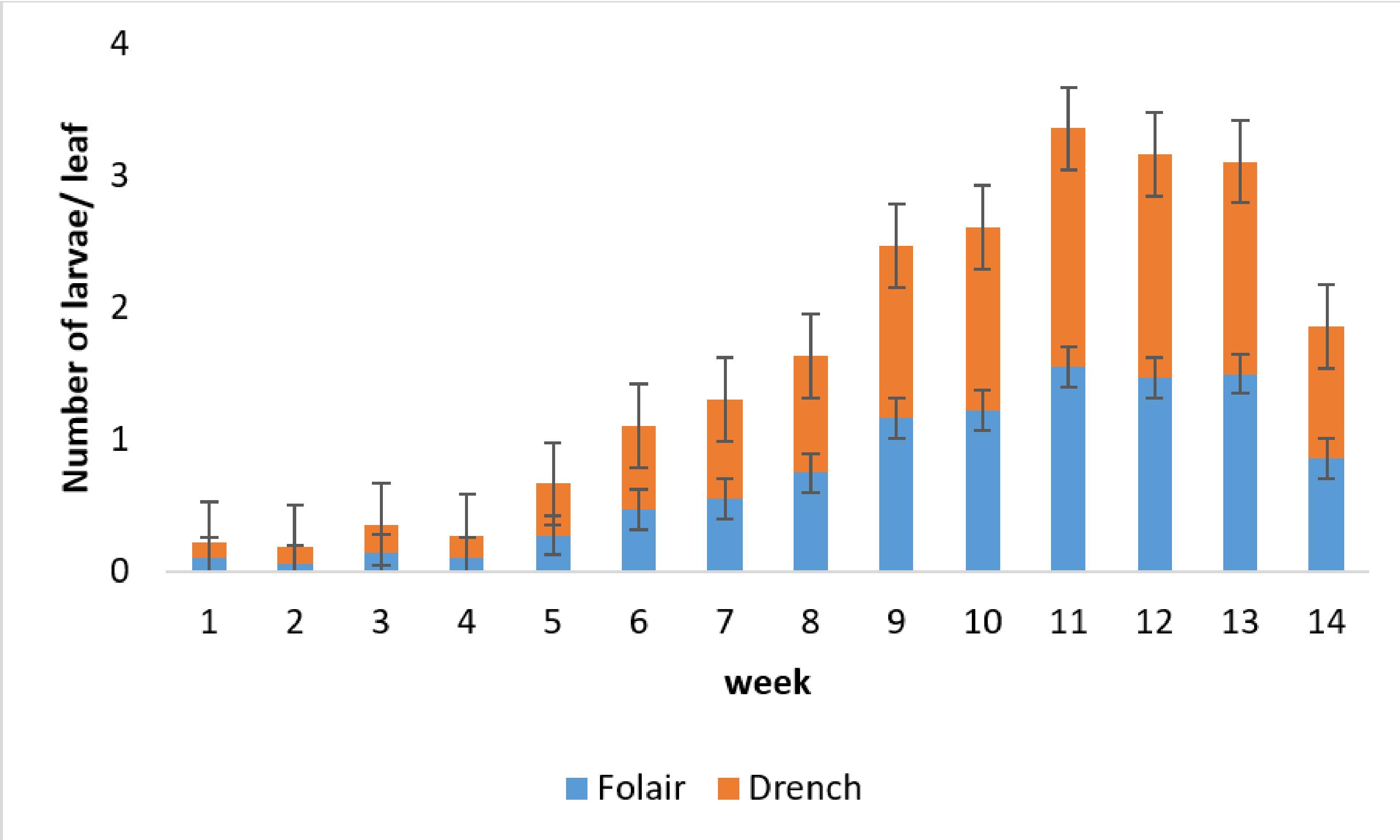

Figure 6

Effect of Silicon application on the population density of tomato leaf miner during the growing season of 2019/2020, (LSD ($P \leq 0.05$) = NS)