

**SILICON AND APPLICATION METHODS INFLUENCE ON GROWTH,
YIELD, NUTRITIONAL QUALITY, PEST AND PATHOGEN
MANAGEMENT OF TOMATO IN KIAMBU COUNTY, KENYA**

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SCIENCE IN AGRONOMY IN THE SCHOOL OF AGRICULTURE AND
ENVIRONMENTAL SCIENCES OF KENYATTA UNIVERSITY**

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DECLARATION

I hereby certify that this thesis is my original work and has not been presented for a degree or for any other award in any university.

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DEDICATION

I dedicate this thesis to my late mother Ruth Einda Musumba and late son Eden Fidel
Musumba

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ABBREVIATIONS AND ACRONYMS

AEZ	Agro-ecological zones
ANOVA	Analysis of Variance
ASL	Above sea level
APX	Ascorbate peroxidases
ATP	Adenosine triphosphate

BER	Blossom End Rot
B	Boron
Ca	Calcium
CaCO ₃	Calcium Carbonate
CaSiCO ₃	Calcium silicon Carbonate
Chol-sSA	Monosilicic acid and its oligomers stabilized by choline
DAP	Diamonium Phosphate
DNA	Deoxyribonucleic acid
DAT	Days after Transplanting
FAO	Food and Agricultural Organization
FW	Fresh weight
GDP	Gross Domestic Product
GFW	Grams per fresh weight
H	Hydrogen
H ₂ PO ₄ -	Orthophosphate ion
H ₄ SiO ₄ /Si(OH) ₄	Monosilicic acid or Orthosilicic
HPLC	High Performance Liquid Chromatography
IAA	Indole-3- acetic Acid
K ₂ O ₃ Si	Potassium silicate

LSD	Least Significant Difference
mM	Mili Molar
Mg	Magnesium
MOA	Ministry of Agriculture
MPA	medroxyprogesterone Acetate
N	Nitrogen
NIPHM	National Institute of Plant Heath Management
NPSWS	Number plants showing wilt symptoms
NPPT	Number of plants per treatment
P	Phosphorus
PEG-sSA	Polyethylene glycol
pH	Potential hydrogen
PPM	Parts per million
RCBD	Randomized complete block design
RNA	Ribonucleic acid
RSM	Red Spider Mites
SA	Salicylic Acid
Si	Silicon
SiO ₂	Silicon dioxide

sSA	Stabilized silicic acid
(Si(OH) ₄)	Silicic acid
OPV	Open Pollinated Variety
UM	upper midland
UV	ultraviolet radiation
Zn	Zinc

ABSTRACT

Tomato (*Solanum lycopersicum* L) is one of the most commonly consumed in Kenya. It is a natural part of the daily diet for the most of the populations and it is a crop of great economic importance. Low yields attained in Kenya are attributed to factors such as low mineral nutrition, low yielding cultivars, poor ago-techniques, pests and pathogen. The objective of the study is to contribute to tomato yield, quality performance, pests and pathogen management through silicon fertilization in tomato. The study was conducted at Kenyatta University school of Agriculture farm in Kiambu county- Kenya. The study was laid in a randomized complete block design with split - split plot arrangement where two tomato varieties Zara f1 and Eden f1 constituted the main plot, silicon application methods, basal and foliar sub-plots with different silicon rates 0, 50, 100, and 200 mg/L in sub-sub plot. I6 treatments were applied and replicated three times. The field trial was used to monitor the growth parameter like average fruit weights, shoot heights, root length, leaf area of tomato. A visual count was done to ascertain pest and disease severity and score in a scale of 1-5. The tissue samples were taken to the laboratory at Kenyatta University and various standard methods were used in the determination of nutrient status, antioxidants and in proximate analysis for photosynthetic pigments and soluble solutes. Growth,yield,Tissue nutrient analysis, disease and pest data collected was managed in excel and subjected to ANOVA using Genstat 15th edition, where significant differences were observed the means separated using Fischers' Protected least significance differences at 95% level of significance. Results from the research experiments were presented using tables, figures and graphs. Silicon application at (100 mg/L) recorded highest leaf area, number of fruits, fruit weight, and number of flower, Fruit quality perimeters included vitamin C, Ca, P and K also recorded highest values these was uniform across the entire harvesting period. Moreover, the results of the two seasons, showed that application of Silicon as soil drench at rate 200 mg/L recorded the highest mean values of the most data collected which include; shoot height, number of auxiliary stems, root area, stem diameter and number of marketable fruits and these results were significantly different at $p \leq 0.05$. Magnesium and nitrogen concentration were also significantly higher for the soil drenched concentration at 200mg/L. The number of pests' population and pathogen were significantly lower at $p \leq 0.05$ for silicon basal application at 100mg/L. The study concludes that Basal Si application performed better compared to foliar. Additionally, Si rates of 100mg/L gave better yields compared to other Si levels. Basal and foliar silicon application controlled pests and pathogens effectively in tomatoes however, Silicon applied at 200mg/L gave better results. Basal silicon at 100mg/L gave high nutritious fruits compared to control. The study finding could enable the formulation of fertilizer blend that will be able to boost tomato yields, nutritional quality as well as to manage pests and pathogen. The increased output will also improve farmers household income, food security and consumers health as well.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Tomato (*Solanum lycopersicum* L) is an herbaceous, usually sprawling plant in the Solanaceae or night shade family, grown widely for its edible fruits (Gweyi, 2006). It is one of the most widely cultivated horticulture crops worldwide, both in the open fields and in greenhouses environment. According to the Food and Agricultural Organization (FAO 2023), global tomato production reached approximately 189 million metric tonnes in 2022 making it one of the top vegetable's crops in terms of volume. Major producers included China which leads with over 30% of the total global output, followed by India, Turkey, USA and Egypt.

Globally, tomato siting issues often relate to poor alignment between suitable agro ecological zones and infrastructure, leading to inefficiencies in production. Unsuitable climatic condition, water availability, soil fertility and proximity to markets continues to hinder productivity (Gazai *et al.*, 2020). In Africa tomato production play a vital role in both food security and economic development across the continent. In 2022, Africa produced approximately 21 million metric tons of tomatoes accounting for about 11% of global production (FAO 2023).

The continent's diverse climatic conditions support the cultivation of tomato. Some of the leading producers of tomato in Africa include: Egypt 6,275,444, Nigeria 3,684,566, Algeria 1,661,664 tonnes and Mozambique 1299,051 tonnes (FAO 2023). In Africa low tomato yields are exacerbated by limited access to spatial agricultural data, insufficient investment in rural infrastructure and weak extension services (Kojo, 2015).

Tomato production in Kenya is a significant component of Kenyans agricultural sector, contributing to food security and rural livelihoods. In 2022, Kenya produced approximately 658,000 metric tonnes of tomatoes positioning it among the top ten producers in Africa. (FAO 2022).

The primary tomato producing counties in Kenya include; Kirinyaga, Kajiado, Taita Taveta and Kiambu. While the county has favourable climatic conditions for tomato farming, the lack of strategic land use planning, poor infrastructure and regional disparities in input access significantly reduce production efficiency. Additionally, most tomatoes are grown in open fields with limited disease and pathogen management without considering spatial variations in climate and soil condition (Gweyi-Onyango *et al.*, 2010). As a result, tomato farmers face challenges including high pest and disease prevalence, low quality and productivity and limited access to suitable markets.

Essential elements are nutrients without which plants cannot complete their life cycle. Among others, those include; nitrogen, phosphorus (Gweyi-Onyango *et al.*, 2006a) and potassium. But there are also non-essential elements that provide certain essential benefits to some plants. Tomato is one of the most demanding vegetables in nutrients and responds to high doses of chemical fertilizers (Fayad *et al.*, 2002; Gweyi-Onyango *et al.*, 2006b).

Considering the mineral nutrition, 14 mineral elements are essential for the plants (Epstein and Bloom 2005) and some elements are considered beneficial, because the lack of these elements is not considered a limiting factor to the normal growth and development of the plants. Among them, is silicon (Si), which has structural and metabolic functions in the plant physiology, generating numerous benefits which may increase the productivity of several plant species (Korndörfer *et al.*, 2001).

The beneficial effects of Si have been related to the tolerance to various biotic and abiotic stresses, such as salinity (Zhu *et al.*, 2004), toxicity caused by zinc excess (Ramos *et al.*, 2009), transpiration (Hattori *et al.*, 2005) penetration and development of fungal hyphae (Ma and Yamaji, 2006) stresses by high and low temperatures. Moreover, the adequate nutrition with silicon improves the plant architecture, by providing more erect leaves, increasing solar radiation interception and photosynthetic efficiency (Pereira *et al.*, 2003; Al-Aghabary *et al.*, 2004).

Silicon is the standard nutrient solution that improves calcium concentration in leaves and fruits, reducing the occurrence of blossom-end rot (Carvalho *et al.*, 2002; Stamatakis *et al.*, 2003), alter the metabolism of leaves exposed to salt stress (Al-Aghabary *et al.*, 2004; Kaaria *et al.*, 2023) and increased the total number of fruits and the productivity as the availability of Si in the soil (Fiori 2006). Regarding pests and diseases, the application of Si reduces approximately 50% the number of injuries caused by thrips (*Frankliniella schultzei*) (Almeida *et al.*, 2009) and in 56.2% the incidence of bacterial wilt (Dannon *et al.*, 2004).

1.2 Statement of the problem

Tomato production yields remain significantly low in many regions despite the crop's high demand and economic importance. Factors such as low mineral nutrition, inadequate access to quality seeds and credit, limited irrigation, pest and pathogen pressure, and inefficient post-harvest handling contribute to sub optimal productivity. Additionally, insufficient extension services and lack of modern farming techniques exacerbate these challenges. The low yields in tomato farming limits farmers' income, reduces food availability and security and constrains the development of the tomato value chain. To increase tomato productivity, it requires improvements in soil fertility,

nutrient management and disease control through, perhaps, use of soil applied fertilizer and foliar feed. Therefore, in light of these issues, a study was conducted to determine the growth yield, nutrient content, pathogen and pest management of tomato in relation to different rates and method of silicon application in Kiambu County.

1.3 Research objectives

1.3.1 General objective

The main objective of this study is to contribute to tomato yield, quality performance, pests, and pathogen management through silicon fertilization in Kiambu County.

1.3.2 Specific objectives

- i. To determine the effect of soil and foliar applied silicon fertilizer on the yield of tomato
- ii. To evaluate the effect of silicon fertilizer on pests and pathogens management of tomato
- iii. To determine the effect of soil and foliar applied silicon fertilizer on nutritional quality of tomato

1.4 Hypothesis of the study

- i. Soil and foliar applied silicon fertilizer significantly increases yield of tomato
- ii. Silicon fertilizer significantly suppresses pest and pathogens in tomato
- iii. Soil and foliar applied silicon fertilizer significantly increases nutritional quality of tomato

1.5 Significance of the study

The generated knowledge obtained from the research gave an insight into quality, yield and safety of tomato fruit as well as pest and pathogen management. A clear understanding of the response of crop on different modes of application, and doses of silicon is vital in the efforts to integrate it into the mainstream agriculture. The research empowers farmers who are engaged in small scale farming by presenting them with an opportunity to determine the best method to apply beneficial silicon fertilizer and its effect especially on the yield, quality nutrition, pest and pathogen management. The study also provided useful information to farmers to cut down on the cost of production especially pesticides and at the same time increasing the yields.

Silicon enhances the uptake and utilization of essential nutrients (such as nitrogen, phosphorus, and potassium) in plants. Evaluating this aspect can help optimize fertilization strategies and improve overall nutrient management in tomato production. With the rising demand for high-quality tomatoes in both local and global markets, investigating the benefits of silicon helped to meet consumer expectations for quality, flavor, and shelf life, ultimately benefiting producers and consumers alike. This study bridges the gap and provide practical recommendations based on rates, application method and tomato varieties. This contributes to household food and nutrition security.

In addition, the research strengthened linkages between institutions to enhance integrated agricultural research for development. Findings from the study inform agricultural policy makers and extension services, providing farmers with evidence-based recommendations, for incorporating silicon fertilizers into their farming practices. This can boost agricultural productivity on a broader scale and reduce over reliance on synthetic chemical. More so, this study served as a foundation for future research on silicon's role in other crops of economic importance, expanding its relevance across various agricultural fields.

CHAPTER TWO: LITERATURE REVIEW

2.1: Overview of tomato production

Tomatoes (*Solanum lycopersicum* L) are one of the most widely grown and consumed vegetable crops globally, valued for their nutrition content, culinary versatility and economic significance. It is rich in nutrients especially lycopene, vitamin C and potassium. They support millions of smallholder farmers and are a key crop in agro-industrial sectors (USDA, 2022). Tomatoes are cultivated in a variety of climates and production systems, include open fields, greenhouses and hydroponic setups. Globally, tomato production has been increasing due to rising demand from fresh consumption and processing, increase in population and changes in the living standards of population (FAOSTAT, 2023).

China is the leading producer, contributing to over 30% of global output. India, Turkey, Egypt and United States are also the major producers of tomato. In 2022, the global tomato production exceeded 189 million tones (FAOSTAT, 2023). Tomatoes are grown in both open fields and protected environments. The open field cultivation is dominant in developing countries in the tropics and subtropics. Cultivation mainly depends on seasonal rainfall and local agronomic practices. Greenhouse production is common in regions with harsh climatic conditions and is associated with higher yields, better pest and pathogen management and year -round production (Dorais *et al.*, 2001).

Tomatoes are adaptable plants but grow well in warm conditions with optimum temperatures of 15°C -25°C (Waiganjo *et al.*, 2006). Extremely low temperature can delay colour formation as well as ripening while temperatures above 30°C inhibit fruit set, flavor and lycopene development. Extremely low temperature can delay colour

formation as well as ripening while temperatures above 30oC inhibit fruit set, flavor and lycopene development Waiganjo *et al.* (2006). Tomatoes grow well in a wide range of soil types, which are high in organic matter, well- drained and with a pH range of 5 to 7.5 and moderate rains (Al-Omran *et al.*, 2010). Wet conditions increase disease incidences and affect fruit ripening.

With the greenhouse technology, farmers are now able to utilize small pieces of land to produce high quality tomato for specialized markets (Murungi *et al.*, 2016). Production of tomato is carried out in two main seasons based on availability of rains as well as anticipated pest and disease pressure. The main production areas for open field tomato types include Bungoma, Kirinyaga, Nyandarua, Kajiado and Narok counties with Mwea, Loitoktok and Rumuruti being the main production regions. Raised plastic tunnel production system is mainly practiced in the outskirts of Nairobi, Kajiado, Kiambu and Nakuru Counties (Ochilo *et al.*, 2019).

Some of the major challenges facing tomato production globally include: soil moisture deficiencies particularly during dry spells when irrigation resources are scares or unaffordable, soil fertility and nematodes adversely affects plant health and productivity. Disease pressure especially bacterial wilt and root knot nematodes contribute to significant yield losses. Limited access to inputs and credit often hinders the ability of farmers to adopt improved farming practices (Jones *et al.*, 2014). Addressing these challenges through target interventions, such as improving soil fertility through applications of beneficial nutrients like Silicon, improving irrigation systems, infrastructure, providing access to quality inputs and credit, strengthening extension services is crucial for increasing tomato yields and improving the livelihoods of farmers

2.2 Effect of silicon on tomato growth and yield

Integrating silicon into tomato cultivation has emerged as a promising practice for enhancing growth and yield. Research indicates that silicon positively influences plant stress tolerance, particularly in those facing biotic and abiotic challenges. By fortifying cell walls, silicon enhances structural integrity, thereby improving the tomato plants resistance against pests and pathogens-factors that directly affect yield. Moreover, silicon application has been shown to trigger physiological responses that boost nutrient absorption, leading to improved fruit quality and increased productivity.

As factors like soil composition play critical roles in plant health, the availability of silicon may mitigate adverse effects imposed by nutrient deficiencies. Thus, when strategically implemented, silicon can be a game-changer in optimizing tomato production. Such interventions highlight the necessity for tailored agricultural practices that consider both silicon application methods and specific field conditions to maximize the benefits for yield and nutritional quality (Stridh *et al.*, 2024; Sharma *et al.*, 2023; Gweyi-Onyango *et al.*, 2009). The role of Si on plant health has been tested under open field conditions, hydroponic cultures, and under greenhouse/glasshouse environment (Luyckx *et al.*, 2017). Still, presently there are a limited number of studies that demonstrate there are advantages of Si application for horticultural crops like tomatoes.

2.3 Mechanisms of silicon uptake in plants

The uptake of silicon (Si) by plants occurs primarily through the roots, where it is absorbed as monosilicic acid (H_4SiO_4) from the soil solution. This process is facilitated by specific transporters located in root cells, allowing for the movement of silicon into the plants vascular system. Once internalized, silicon plays a crucial role in enhancing plant physiology, influencing various growth parameters. It strengthens cell walls,

improving structural integrity and resistance to biotic stressors, such as pests and pathogens. For instance, studies have shown that silicon application can bolster plants defenses against pathogens, thus minimizing the adverse effects of diseases like fungal infections (Sharma *et al.*, 2023).

Monosilicic acid or orthosilicic acid (H_4SiO_4) is the Si forms that are absorbed by plants root (Rodrigues *et al.*, 2003). Consequently, Si accumulates in the epidermal tissues, and a layer of cellulose membrane-Si is created when Ca and pectin ions are present, which provides protection to the plant. Increasing of Si in the sap of plants leads to Si polymerisation, identified as Si gel hydrated with water molecules (Yamaji *et al.*, 2008). Amorphous silica is the final form of 90% of absorbed and transformed Si in Si-cellulose structures. Anemometer level of biogenic silica is produced as intercellular structures (Hodson *et al.*, 2005).

Concentration of Si differs significantly in the shoots and roots of plants, and this extensive variation in different plant tissues is related to differences in the mechanisms of Si uptake and transportation. Nutrient uptake by plants depends on the potential of water and the solubility of elements in the soils. The nutrients uptake pathway is from the soil solution with a higher solute concentration to plant tissues with a lower solute concentration. Although Si is found plentifully in both silicate and oxidase forms in the soil, Si solubility in the soil solution is an obstacle for plant absorption because monosilicic acid is the only form of Si that plants can absorb.

Additionally, silicon aids in nutrient balance and alleviates the negative impacts of heavy metal toxicity, promoting overall growth and yield Duarte *et al.* (2022). A germination experiment with citrus (*Citrus spp.*) has demonstrated that with increasing monosilicic acid concentration in irrigation water, the weight of roots increased more

than that of shoots. The same effect was observed for bahia grass (*Paspalumnotatum flügge*) (Matichenkov *et al.*, 2000) Consequently, integrating silicon into agronomic practices, particularly for crops like tomato, can significantly enhance both quality and productivity.

2.4 Nutritional quality of tomatoes enhanced by silicon

Silicon's role in enhancing the nutritional quality of tomatoes has garnered considerable attention in recent agricultural research. By improving physiological and biochemical processes in plants, silicon contributes to higher yields and better fruit composition. Specifically, the application of silicon can increase the levels of beneficial phytochemicals such as flavonoids and carotenoids, which are essential for human health.

These compounds are linked to reduced risks of chronic diseases, highlighting the relevance of silicon in promoting overall nutritional quality. Furthermore, silicon improves the plants resistance to stressors such as pathogens, mitigating the dependence on chemical pesticides and further enhancing the fruits health benefits (Rutto *et al.*, 2019). Recent studies indicate that tomatoes grown with silicon not only exhibit superior growth but also possess enhanced flavor and nutritional attributes when compared to their non-silicon-treated counterparts. Such findings underscore the potential of silicon as a sustainable approach to boosting the nutritional profile of tomatoes in modern agriculture.

2.5 Impact of silicon on nutrient composition and flavor profiles

The incorporation of silicon into agricultural practices has garnered attention for its potential to enhance both the nutrient composition and flavor profiles of crops,

particularly tomatoes. Research indicates that silicon can influence the accumulation of essential nutrients, thereby enriching the overall nutritional quality of the fruit. For instance, it has been shown that hydroponic methods, which often employ silicon, lead to higher yields and improved nutritional content compared to traditional soil-grown crops (Treftz *et al.*, 2017). It was found that the contents of total solid solutes such as beta-carotene, lutein and lycopene contents of the fruit were significantly increased by Si supplementation. The Silicon also enhanced the fruit firmness and vitamin C in the tomato fruit (Stamatakis *et al.*, 2003).

Silicate treatments increased fineness of fiber cells. In the studies conducted in Poland, application of Actisil as fertilizer to tomato growing on rock-wool mitigated manganese toxicity, which resulted in increased biomass production with lower content of manganese in the substrate (Kleiber *et al.*, 2005). In Greece, while growing tomatoes in hydroponics, it was found that fertilization with silicon increased fruit hardness, beta-carotene, and lycopene content as well as dry matter and vitamin C content (Stamatakis *et al.*, 2003).

This trend is not limited to quantitative metrics; the qualitative aspects, such as flavor, are similarly affected. Through metabolic alterations induced by silicon, vegetables exhibit enhanced flavor compounds, which are critical for consumer acceptance (Behera *et al.*, 2022). Consequently, the application of silicon not only fosters a better nutrient profile in tomatoes but also contributes to their organoleptic attributes, underscoring the importance of audience appeal alongside agricultural productivity.

2.6 Silicon pathogen management in crops cultivation

Effective management of pests and pathogens in tomato cultivation is crucial for improving yield and nutritional quality. Recent studies highlight the potential of silicon as an invaluable tool in this context, enhancing plants physical and biochemical defenses against various threats. For instance, silicon-treated plants exhibit increased resistance to biotic stresses such as fungal pathogens, which can lead to significant losses, similar to the challenges faced by potato farmers dealing with *Alternaria solani*, as noted in the findings regarding early blight management (Stridh *et al.*, 2024).

Si is able to decrease the susceptibility of rice against sheath blight diseases (Gong *et al.*, 2005). Plant opal or glass and hard coating of SiO₂ polymerisation in the plant cuticle layer is the possible mechanism for reducing disease susceptibility by Si (Rémus and Borel 2005). The physical hindrance created by SiO₂ enhances the incubation period in the leaf sheath of rice and results in impeding *R. solani* penetration to decrease the number and extension of sheath wounds.

In comparison to the physical hindrance to early penetration, the lesion extension is a more important factor in terms of resistance to sheath blight disease, particularly in susceptible cultivars (Zhange *et al.*, 2006). Silicon leads to increase the sheath blight resistance through creating a physical hindrance by SiO₂ and reduce the intensity of disease. It has been speculated that Si is able to decrease the effect of sheath blight by motivating the defense mechanisms of the crops against pathogenesis, increase the amounts of phenolic components and increase the activities of peroxidase, chitinases, polyphenoloxidase, β -1, 3-glucanases, and phenylalanine ammonialyase enzymes (Rodrigues *et al.*, 2003)

The intensity of neck and leaf blasts in both sensitive and partially resistant rice cultivars can be decreased via Si treatment depending on the rate of Si application and the disease severity (Hodson *et al.*, 2005). Superior inherent disease severity at specific sites needs a lot of Si fertilizer to decrease the neck and leaf blast disease as effectively as in resistant rice cultivars. The Si has been applied to prevent the occurrence of powdery mildew disease, one of the plant diseases created by *Sphaerotheca fuliginea*. Silicon has been reported to be an effective suppressor of powdery mildew (*Blumeria graminis*) (Rémus *et al.*, 2005).

Increasing the Si content in cucumber shoots leads to a decrease in powdery mildew incidence. Additionally, it has been reported that the occurrence of powdery mildew disease decreased after increasing the concentration of Si in the culture solution (Wang *et al.*, 2004). The macro element can decline infection efficiency, colony size, and conidia germination in cucumbers. Effective use of Si in a foliar approach has been reported to help the growth of leaves in grapes, cucumbers (*Cucumis sativus*), and muskmelons (*Cucumis melo*) (Liang *et al.*, 2005).

Furthermore, it has been documented that Si is able to increase the tolerance of sorghum (*Sorghum bicolor*) to anthracnose (Casey *et al.*, 2014). Si-treated plants had a reduction in the spread of viral symptoms as well as a delay in the onset of symptoms, compared to the controls. Si has the ability to protect plants through both physical and chemical means. Physically, Si helps strengthen cell walls and is present in protective layers, such as scales on the surface of epidermal tissue. This thickening protects the roots and allows for plants to better deal with adverse environmental conditions.

Chemical responses enhanced by Si include both the induction of the reactive oxygen species pathway and production of phenolic compounds. Therefore, integrating silicon application with tailored pest management strategies emerges as a promising approach, enabling tomato growers to reduce reliance on chemical treatments while fostering healthier crops in diverse agricultural settings, ultimately leading to sustainable practices.

2.7 Silicon pest management in crop cultivation

Insect herbivores represent one class of biotic stressors that Si can provide some defense against. Although Si deposition in the epidermal cells of plants is purportedly responsible for the protective effects of Si against plant diseases and insect herbivores (Ma, 2004), there is increasing evidence for Si-induced chemical defense against plant diseases (Hammerschmidt, 2005). Foliar application of lignite fly ash dust, which is high in silica content, to papaya led to a significant reduction in the disease, papaya leaf curl virus, and in vector, silver leaf whitefly (*B. tabaci*) populations (Eswaran and Manivannan, 2007). The resistance of rice to the brown plant hopper (*Nilaparvata lugens*) is related to the Si content of plant (Resende *et al.*, 2013)

2.8 Sap-feeding insect pests

Numerous studies have indicated that silicon application can reduce the performance of sap-feeding pest insects as whitefly (*Bemisia tabaci*) Gennadius (Hemiptera: Aleyrodidae) on cucumber (Correa *et al.*, 2005), and on soybean (Ferreira *et al.*, 2011) green peach aphid *Myzus persicae* Sulzer (Hemiptera: Aphididae) on potato Silvering thrips *Enneothrips flavens* Moulton (*Thysanoptera: Thripidae*) on peanut (Dalastra *et al.*, 2011), Mediterranean fruit fly *Ceratitiscapitata* Wiedemann (Diptera: Tephritidae)

on lemon (Mditshwa *et al.*, 2013), (He *et al.*, 2015), leaf aphid *Rhopalosiphum maidis* Fitch (Hemiptera: Aphididae) on maize (Almeida *et al.*, 2015) and citrus black-fly *Aleurocanthus woglumi* Ashby (Homoptera: Aleyrodidae) on mandarin orange (Vieira *et al.*, 2016).

Positive effects of silicon treatment were evident as reduced preference, longevity, and fecundity rates, nymph production- and feeding times by nymphs of green bug *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae) on wheat (Costa *et al.*, 2011). The effect of silicon on the control of plant diseases and insect pests, its mode of action, its properties, and its spectrum of efficacy in several biological systems is not entirely understood and require more research both under farm conditions and as tissue culture (Liang *et al.*, 2015a, b).

In the absence of abiotic and/or biotic stresses, silicon was believed to have a negligible effect on plant growth or development (Ma and Yamaji, 2006). However, beneficial and useful effects only manifest under stress conditions (Epstein, 2009). In general, the effect of silicon on resistance of plants to diseases and insect pests is considered to be due to either a deposition of silicon on cell walls acting as a mechanical barrier difficult the pathogens and insect pests attack, or biochemical changes related to plant defense (Fig.1.2) (Sakr, 2016a, b, 2017).

Importance of the two mechanisms of defense in enhancing silicon-treated-plant resistance may differ according to the biotic agents (Bockhaven *et al.*, 2013). On one hand, physical defense is most widely accepted mechanism for the action of silicon in augmenting plant resistance to insect pest infestation (Reynolds *et al.*, 2016).

2.9 Efficacy of silicon in enhancing plant resistance to biotic stressors

Silicon plays a crucial role in boosting tomato plants resistance to biotic stressors, reinforcing their defenses against pests and pathogens. By enhancing cell wall integrity, silicon contributes to overall plant strength and resilience, thereby decreasing susceptibility to infestations and infections. Its presence can stimulate the production of phenolic compounds and other phytoalexins, which are vital in mitigating the impacts of biotic stress.

Consequently, silicon application has been associated with improved plant health and yield outcomes in various studies. Moreover, research indicates that integrated strategies combining silicon with microbial biostimulants can yield synergistic effects, elevating overall plant defense mechanisms. (Sani *et al.*, 2021). Silicon has been demonstrated to stimulate chitinase activity and rapid activation of peroxidases and polyphenoxidasases after fungal infection. Glycosidically bound phenolics extracted from amended plants when subjected to acid or β -glucosidase hydrolysis displayed strong fungistatic activity.

Dann and Muir (2002) reported that pea (*Pisumsativum* L.) seedlings amended with potassium silicate showed an increase in the activity of chitinase and β -1,3-glucanase prior to being challenged by the fungal blight caused by *Mycosphaerella pinodes* Berk. In addition, fewer lesions were observed on leaves from silicon-treated pea seedlings than on leaves from pea seedlings not amended with silicon. More recently, flavonoids and momilactone phytoalexins were found to be produced in both dicots and monocots, respectively, and these anti fungal compounds appear to be playing an active role in plant disease suppression (Rodrigues *et al.*, 2003).

As highlighted in recent literature, biostimulants, including silicon, can optimize performance under stress conditions, bridging the yield gap between organic and conventional farming systems while maintaining ecological balance (Asif *et al.*, 2023), (Sani *et al.*, 2021). Thus, the strategic application of silicon not only enhances tomato resilience but also promotes sustainable agricultural practices. The integration of silicon into tomato cultivation, along with the evaluation of varied application methods, has demonstrated considerable implications for plant growth, yield, and nutritional quality, while simultaneously enhancing management of pests and pathogens.

Evidence suggests that strategic silicon application can bolster plant defenses against biotic stressors, providing a countermeasure to detrimental impacts from pests like the brown plant-hopper, which thrive under conditions of high nutrient availability (Ahmed *et al.*, 2017). Furthermore, the adaptability of plants to abiotic stresses is significantly improved through the use of novel engineered nanoparticles (NENPs), which not only enhance nutrient uptake but also fortify plants against pathogens (Sharma *et al.*, 2023). Consequently, optimizing silicon usage and application techniques offers a promising avenue for sustainable agricultural practices, ultimately contributing to higher productivity and resilience in tomato crops. Future research should continue exploring these relationships to refine application strategies further.

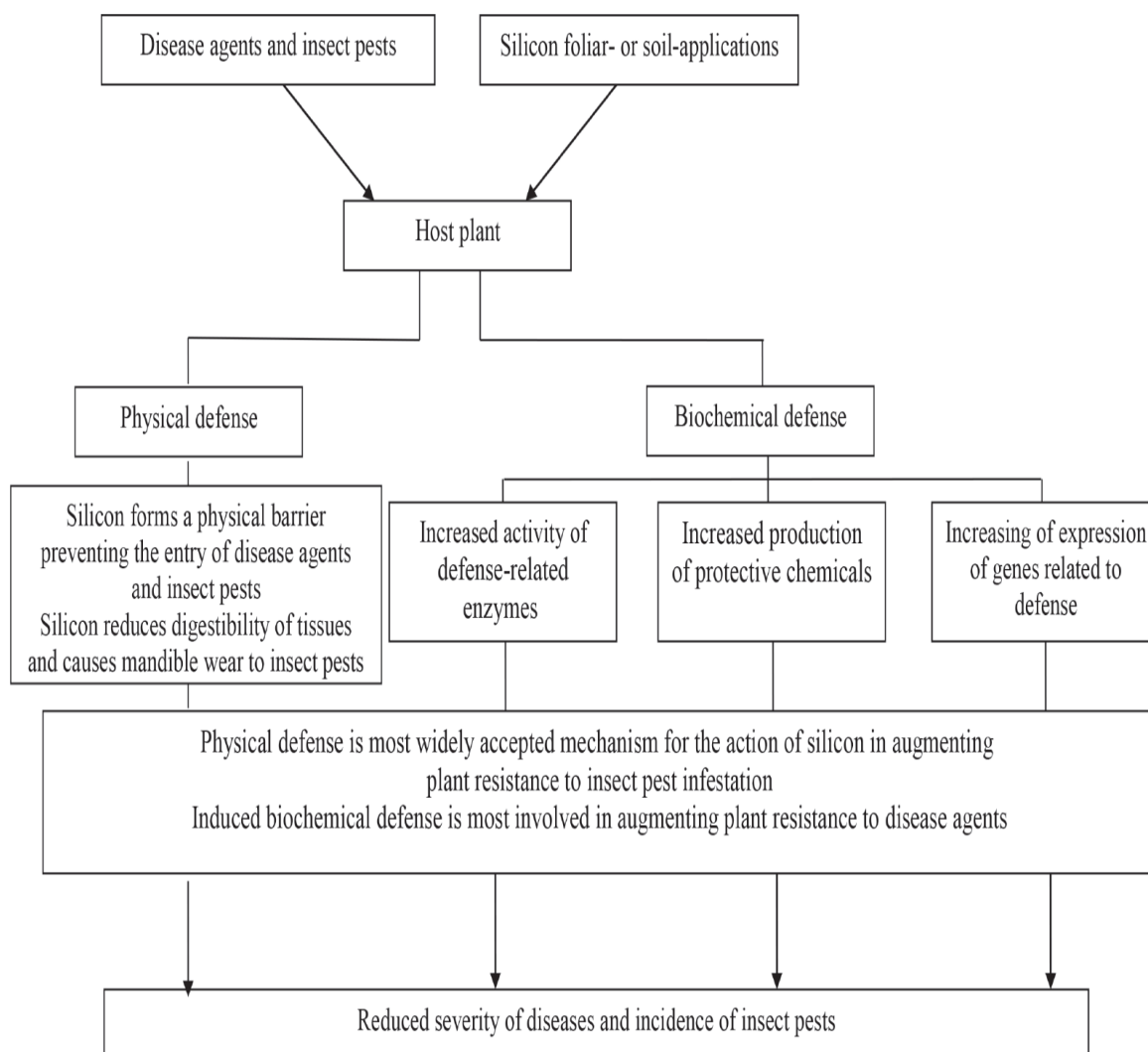


Figure 2.1: Possible mechanisms of silicon-enhanced resistance to disease agents and insect pests

CHAPTER THREE: MATERIALS AND METHOD

3.1 Study Area

The study area was located at Kenyatta University farm, School of Agriculture and Environmental Sciences, situated in Kiambu County, about 20km from Nairobi city along Nairobi-Thika Road. The experiment was done in two seasons, the first season running from September 2019 to December 2019, and the second season running from December 2019 to March 2020. The elevation of the main campus is 1720 meters above sea level (ASL).

The rainfall has a bimodal pattern with an average 989mm long rains occurring between mid-March and May, while the short rains set in between October and December. The major soils include nitisols, andosols and acrisols. The mean temperature within Kiambu where Kenyatta University is located is between 19- 20°C. Kiambu county is divided into four broad agro-ecological zones (AEZ); Upper highland (UH) zone which falls 1800M ASL, lower highland (LH) zone falls between 1500-1800M ASL, upper midland (UM) zone located at altitude of less than 1500 MASL while lower midland (LM) is at altitude of less than 1000M ASL. The county annual rainfall ranges between 750-1300mm, with a temperature range from 12- 20.50°C (Makokha, 2001).

Agriculture is a primary livelihood, with farmers cultivating various crops like coffee, tea, and horticulture. They also practice dairy farming. The adoption of agroecological practices such as using organic fertilizers and intercropping is increasing among smallholder farmers.

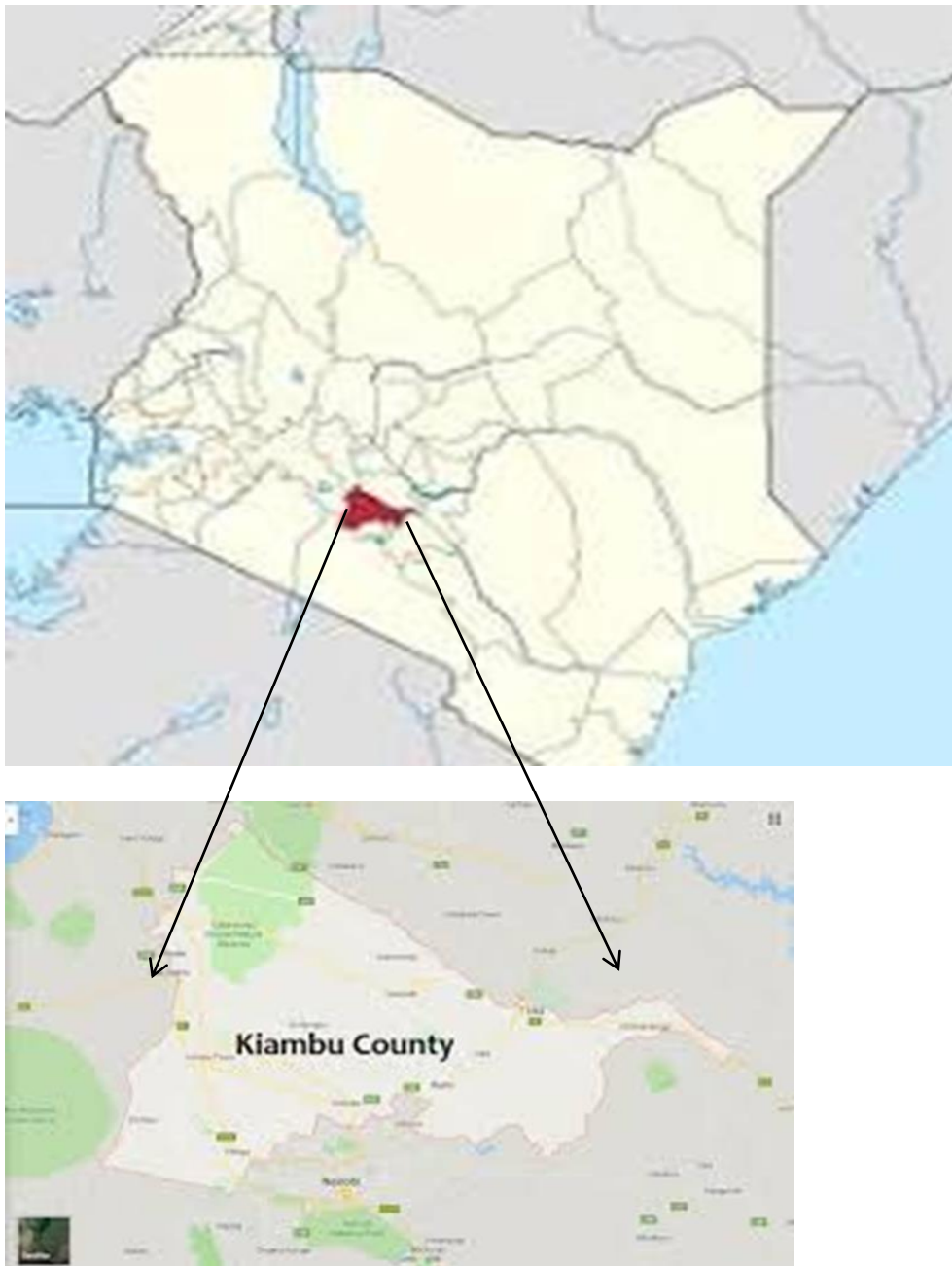


Figure 3.1: Map of the study area

3.2 Research design, treatment, and experimental layout

The field experiment was laid out in a Randomized Complete Block Design (RCBD) in split-split-plot arrangement with sixteen treatments replicated three times. Two tomato varieties namely Zara^{f1} and Eden^{f1} occupied the main plot, Silicon fertilizer application method basal and foliar being the sub-plot and varying levels of silicon

doses (0, 50, 100 and 200 mg/L) for root and foliar application constituting the sub-sub plot. The treatments were randomly allotted to different plots using random number table, with each experimental plot measuring (4x5) meters with 50cm walking path.

Zara ^{F1} is a determinate variety grown for both processing and fresh fruit in many regions in Kenya. It is mainly an open field commercial type growing to a height of 75 cm bearing up to 50 fruits per plant. The variety matures after 65 to 70 days after planting. Zara fruit is oval, bright red in colour, relatively stiff in firmness with a fruit average weight of about 120-130 grams. The potential yield for the variety goes up to 90 tons per hectare. It is a popular variety among the traders and farmers for its excellent growth and high yielding characteristics and long shelf life.

Eden ^{F1} is an hybrid tomato variety ideal for outdoor and greenhouse production. Its Strong and open plant with medium foliage and highly responsive to fertilizer and irrigation. First bloom appears in 35-40 days Mature 70- 75 days after transplanting Production. Yield Average production of 70 - 80 tons per hectare under good agronomic practice. Has a long harvesting period of 4 to 6 months Fruit Elongated firm and blocky oval fruit type, Good sweet flavor. Fruit size range between 100-130 grams, Shelf life is over 21 days when harvested at mature green stage.

3.3.1 Field preparation

The field was ploughed and harrowed to attain relatively fine tilth, well decomposed manure was applied at the rate of 2kg/m². Planting fertilizer DAP applied at the rate of 200 Kg/ha was incorporated in the soil two weeks before raising beds in readiness for planting. Appropriate rates of Triple Super Phosphate fertilizer were administered into 15 cm deep drilled holes on the respective plots at the time of transplanting. Diamonium Super phosphate (26%P₂O₅) at 30 KgPha⁻¹ Calcium Ammonium Nitrate (26% N) at 60 KgNha⁻¹ and Muriate of Potash (60 % K₂O) at 30 Kg K ha⁻¹ were uniformly administered and incorporated into the soil in both seasons (Shane and Lamber, 2005). The aim was to supply sufficient amounts of N, P and K to ensure that the nutrients were not limiting factors on plant. The tomatoes were established at the spacing of 90 cm x 60 cm on raised bed.

3.3.2 Seedling Raising

The seedlings were raised in a well-prepared nursery bed measuring 1m x 4m for four weeks in both the two growing seasons. Prior to transplanting, the seedlings were hardened off by gradually removing the shade and reducing watering.

3.3.3 Crop Management and Treatment Application

Twenty-four healthy seedlings of the respective tomato varieties were transplanted at a spacing of (30x45) cm in 48 plots on 3rd May, 2019 in the first season and 4th May, 2020 in the second season. The fields were kept weed free by manually weeding using a hoe. The source of inoculum was natural infection. Silicon aqueous solution was drenched one week after transplanting at the rate of 0.1 mg per hole as soil drench and foliar spray at different concentrations of 0, 50, 100 and 200 mg/L. The second and

third applications were after 21 and 27 days after transplanting respectively. The plots with foliar sprays were covered with polythene on the surface before application of treatment to avoid dripping of silicon at the roots. All concentrations were applied using a hand sprayer for the foliar and a syringe for basal. Non –ionic adjuvant between 80 at 0.05% (v/v) was added to all treatments to reduce the surface tension and increase the contact angle of the spray droplet. Each plant was sprayed individually, so that all foliage was moistened until the point of run off. The spray volume was 15 ml per plant. Considering the soil application, no watering was applied for two days before and after treatment application.

3.4 Data collection

In order to evaluate the effect of treatments on tomato growth components, yield components, incidences of pests, pathogens, physiological disorders and nutritional quality the following periodical data was collected on plant height, shoot weight dry and wet, stem diameter, number of branches, number of leaves, leaf area, root length, fruit sizes (small, medium and large), Fruit weight (marketable and non-marketable), Soil moisture content, red spider mites, Tuta absoluta, White flies, Bacterial wilt score, blossom end rot and powdery mildew incidence.

Measuring Tomato Growth Components five randomly selected plants were destructively sampled in each treatment plot and recorded for growth parameters and the mean of the observations on these plants was computed and recorded.

3.4.1 Shoot height

The height of selected plants was measured in centimeters from the soil surface to the apex of the youngest leaf of the main shoot at 14 DAT, 28 DAT, 42 DAT and 56 DAT.

A ruler was used to measure the height.

3.4.2 Stem diameter

The thickness of the main stem of all selected plant was measured in millimeters at 4 cm above the soil surface with the help of vernier caliper 14 DAT, 28 DAT, 42 DAT and 56 DAT

3.4.3 Number of branches

The number of branches on each selected plant was counted and mean number of branches per plant was recorded at 14 DAT, 28 DAT, 42 DAT and 56 DAT

3.4.4 Shoot dry weight

Electric oven dry weight (drying at 70°C for 72 hrs. to a constant weight) of whole plant after destructive sampling of sampled plants at 14 DAT, 28 DAT, 42 DAT and 56 DAT.

The weight was measured using an electronic balance.

3.4.5 Shoot fresh weight

The shoot fresh weight was measured using electronic balance immediately after destructive sampling after which their mean was recorded.

3.4.6 Root area

Root area was calculated (half width of the longest secondary root by length of the tap root) as recommended by Raghothana and Karthikeyan (2009). The resulting plant was

oven dried at 40°C for 72 hours (Watson, 2007) and stored for further analysis of total phenolic content and total antioxidant activity.

3.4.7 Measuring tomato yield components

Eight selected plants were used for recording yield parameters. The following data were recorded.

3.4.7.1 The number of open flowers

The total number of open flowers from five selected plants were counted and recorded.

3.4.7.2 Fruit weight and fruit size per plant

The fresh fruit weights of fruits harvested from two plants from each experimental plot were summed up and average was computed and recorded as fruits weight per plant. subsequently the fruits were grouped into grades as per their sizes were large sizes were fruits weighing over 85 grams medium sized fruits weighing between 60 and 84 grams and small fruits weight less than 60 grams The weight was taken by using electronic balance.

3.4.7.3 Marketable and non-marketable fruits per plant

Tomato fruits harvested from five selected plants were sorted into marketable and unmarketable counted and weighed. Small-sized Fruits below 60g, cracked fruits and damaged fruits were grouped as unmarketable. The Mean number and weight of marketable and unmarketable fruits were calculated from the total number and weight of marketable and unmarketable fruits.

3.5 Evaluating the incidence

3.5.1 Evaluating the incidence of tomato blight

Identification of the tomato diseases and physiological disorders was done using CABI Plant wise Diagnostic procedure (Tylor, 2015). Visual disease rating was used to score Diseases and physiological disorder incidence using Horsfall–Barratt Scale (Table 3.1) the diseased plant in a population of plants was scored as a percentage of diseased plants in a field.

Table 3.1 The Horsfall–Barratt Scale

Rating	Percent affected	Range
1	0	0
2	0-3	3
3	3-6	3
4	6-12	6
5	12-25	13
6	25-50	25
7	50-75	25
8	75- 87	12
9	87- 94	7
10	94-97	3
11	97-100	3

3.5.2 Bacterial wilt measurement

Symptom development was evaluated daily until the fourth day, then at, 10, 20, 40, 80 and 120 days after transplanting. A six-point rating scale (0–5) modified from Winstead and Kelman (2019) (Table 3.2) was used, where: 0 = no wilt symptoms, 1 = one leaf wilted, 2 = two or more leaves wilted, 3 = all leaves except the tip wilted, 4 = whole plant wilted and 5 = plant dead (collapse) of the whole plant. Disease incidence was assessed as a percentage of wilted plants within each treatment. Disease incidence was

calculated according to the formula, $(I = \text{NPSWS}/\text{NPPT} \times 100)$, where: I – wilt incidence, NPSWS – number plants showing wilt symptoms, NPPT – Number of plants per treatment. The ooze test was also carried out to confirm that in deed it was tomato bacterial wilt.

Table 3.2: Six-point Bacterial wilt severity rating scale

scale	Symptom
0	No symptoms (healthy plant)
1	1-25% of the plant shows wilting symptoms
2	26- 50% of the plant shows wilting symptoms
3	51- 75% of the plant shows wilting symptoms
4	76- 100% of the plant shows wilting symptoms, but not completely dead
5	Plant completely wilted and dead

3.5.3 Powdery mildew score

Five centrally located plants were rated for disease severity 14 days after treatment application. Leaves from nodes 3 to 4, 7 to 9, and 12 to 14, corresponding to low, intermediate and high heights, were evaluated for disease severity. Disease severity (percentage of the leaf surface covered with powdery mildew symptoms) was evaluated based on the scale of 0 to 6 (Yan et al., 2006); where: 0, no visible pustule; 1, pustules on less than 1% of leaf surface; 2, 1 to 5% leaf surface covered with pustule; 3, 6 to 20% leaf surface covered with pustule; 4, 21 to 40% leaf surface covered with pustule; 5, 41 to 60% leaf surface covered with pustule; 6, more than 60% of leaf surface covered with pustule. Disease severity index was determined using following Formula: $\{(0A + 1B + 2C + 3D + 4E + 5F + 6G) / 6 (A + B + C + D + E + F + G)\} \times 100$, where A, B, C, D, E, F and G are the number of leaves with the disease index scores of 0, 1, 2, 3, 4, 5 and 6, respectively Yan *et al.* (2006).

3.5.4 Red spider mites (*Tetrachy urticae*)

Five tomato plants were destructively sampled from respective plots and physically checked for the presence of eggs, honeydew, fecal material, cocoon and webbing on leaves. Adult red spider mites were physically counted and data was recorded at 14 DAT, 28 DAT, 42 DAT and 56 DAT. Each sampled leaf was placed under a dissecting microscope at $\times 10$ magnification, and the number of *T. urticae* that were present on the leaf surface was recorded. The observation of the leaf was done by moving the leaf from the right to the left side in a regular pattern and observations started from the top part of the leaf surface then moved systematically to the bottom part of the leaf ensuring that every part of the leaf surface was observed without repetition, thereby avoiding miscounting or double counting.

3.5.5 Tomato leafminer (*Tuta absoluta*)

Tuta absoluta larvae were physically counted on five selected tomato plants and data recorded at 14 DAT, 28 DAT, 42 DAT and 56 DAT

3.5.6. White flies (*Bemisia tabaci*)

The population density of *B. tabaci* was studied weekly during the growing season, starting from the second week after transplanting. All pests' infestations occurred naturally during growing season. Five fully expanded leaves (basal, middle and upper parts) were randomly collected from five plants per experimental unit. Then, the sampled leaves were put in plastic bags and brought to the lab for counting the number of white flies.

3.6 Plant nutrient content determination

Plant samples from the experimental plots were collected at the harvesting stage and taken to Kenyatta University Agricultural Science and Technology laboratory for nutrient analysis. The fruit samples collected were washed, rinsed with deionised water, chopped, and dried at 70 °C for 48 hours. A blender was used to grind the dried fruits, and the materials were stored ready for analysis.

Nutrient extraction was done by acid digestion of the samples followed by spectrometry analysis (Okalebo *et al.*, 2002). Zero point three grams (0.3 gm) of ground plant tissue sample from each experimental plot was weighed and put into a clean, dry digestion tube. A volume of 10 ml of digestion mixture that consisted of 3.2 gm of salicylic acid dissolved in 100 ml of sulphuric acid-selenium mixture were added to each sample and reagent blank tubes. The samples were digested by heating at 110°C for 1 hour. The temperature was raised to 360 °C for 4 hours until the solution was colorless. The sample digestates were then allowed to cool. After cooling, the content was topped to the 50 ml mark with distilled water and used for analysis of N, P, K, Ca and Mg concentrations following procedures described below.

3.6.1 Total phosphorus

The colorimetric method was used to determine plant tissue P following the procedure by Okalebo *et al.* (2002). 5 ml of the digestate solution was pipetted into a volumetric flask (50 ml) and to each flask starting with the standards 10 ml ascorbic acid was added. The content was topped to the 50 ml mark with distilled water, stopped, agitated well, and left to stand for 1 hour for colour development. Standards and sample absorbance were measured using u/v spectrophotometer at the wavelength of 880 nm.

A calibration curve of the standards series, concentration against absorbance was plotted. The slope was to calculate P concentration as shown in equation 1.

$$\% P = \frac{(a-b) \times V \times f \times 100}{1000 \times W \times 1000} \quad (1)$$

Where: %P- percentage of phosphorus in the sample

a- volume in ml of acid used for sample titration

b- volume in ml of acid used for blank titration

v- total volume of the digest

f- normality of the acid used in titration

w- weight of the sample (in grams)

3.6.2 Nitrogen concentration

Kjeldahl distillation method following protocols defined by Okalebo *et al.* (2002) was used to determine the total nitrogen in the digestate. Ten milliliters of the digested sample solution was transferred to a reaction chamber of the distiller and 10 ml of 1% sodium hydroxide added. Immediately, steam distillation into 5 ml 1% boric acid containing 4 drops of the mixed indicator was done and distillation continued until the indicator turned green. The distillate was titrated with hydrochloric acid up to the endpoint that when the indicator changed to pink. Percentage N in the plant tissue samples were calculated using equations 2.

$$\% N = \frac{(a-b)X V X f X 100}{1000 X W X 1000} \quad (2)$$

Where: N%- percentage of nitrogen in the sample

a- volume in ml of acid used for sample titration

b-volume in ml of acid used for blank titration

v-total volume of the digest

f- normality of the acid used in titration

W- Weight of the sample (in grams)

3.6.3 Potassium, Calcium, and Magnesium concentration

Nutrient extraction was done by acid digestion of the samples followed by spectrometry analysis (Okalebo *et al.*, 2002). Flame photometry following (Okalebo *et al.*, 2002) procedures was used to determine potassium concentration in the digestate samples. Here, into a volumetric flask measuring 50 ml, 2 ml of the digested sample solution was pipetted. The mixture was topped to the 50 ml mark using distilled water, shaken well, and the amount of potassium measured starting with the standards, the sample, and the blank solutions. The accumulation of the potassium in the plant tissue samples was expressed into percentage using equation 3.

$$\% K, Ca, Mg = \frac{(a-b)X V X f X 100}{1000 X W X 1000} \quad (3)$$

Where: % K,Ca, Mg - percentage of K, Ca and Mg in the sample

a -volume in ml of acid used for sample titration

b-volume in ml of acid used for blank titration

v-total volume of the digest

f- normality of the acid used in titration

W- Weight of the sample (in grams)

The concentration of total Ca and Mg in the digestate was determined using the atomic absorption spectrophotometry. For calcium, into a 50 ml volumetric flask 10 ml of the digested sample solution was pipetted. Ten ml of 0.15 % lanthanum chloride added and the mixture topped to the mark using distilled water. The content was shaken and measurements absorbance of Ca in samples at 422.7 nm. The concentration of Ca was determined using equation 3.

For magnesium, 5ml of previously digested sample solution was pipetted into a volumetric flask measuring 50 ml where distilled water was used to fill to the mark and the content was agitated well. Magnesium standard series, blank and sample were sprayed into the flame of atomic absorption spectrophotometer and magnesium concentration determined using equation 3.

3.6.4 Vitamin C concentration

Ascorbic acid content was quantified by weighing about 10gm of sample and extract with up to 20ml of 0.8% meta-phosphoric acid (MPA). The content was transferred into a 25ml volumetric flask and topped up to the mark using distilled water and homogenized. It was then centrifuged at 10,000rpm for 10 minutes using a centrifuge. The supernatant was filtered using a filter paper no 42 then micro-filtered 1ml with 0.45 um syringe for HPLC injection. 20 ul was injected into the HLPC with the following conditions;

- a) column: ODS C18 of 150 x 4.6mm with 5um particle size
- b) Mobile phase was 0.8% Meta- phosphoric acid at a flow rate of 0.5ml/min
- c) UV detector @ 266 nm

Preparation of standard Ascorbic Acid

A stock solution 1000ppm was prepared by weighing 100mg of ascorbic acid standard into 100ml of 0.8% MPA. A working solution of 10,20,40, 60, 80 and 100 ppm was made by diluting the stock using the following formula: $C1 \times V1 = C2 \times V2$ and made in 25 ml volumetric flasks. 20ul was injected of each standard into the HPLC. The concentration was prepared by comparing the peak areas of the standard and the samples. The results were expressed in mg per 100g fresh weight. Absorbance verse concentration graph was plotted to determine the equation of regression (R²).

3.7 Data analysis

Collected data was entered into an MS Excel sheet then cleaned and arranged for analysis. To determine significance difference among treatments, analysis of variance using Gen start computer software was done and means separated at 95% confidence level using Turkey's Protected LSD test, where significant differences were observed. All statistical analyses were performed using GenStat 15 Edition. Means were separated following the Turkey's Protected Least Significant Difference (LSD) at 5% Test. Figures and tables were generated using Excel and GenStat software version 15 edition for ease of results interpretation.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Effect of silicon rate, application method, and variety on growth parameters of tomato for two seasons under field conditions

4.1.1 Shoot height

The experimental findings of this study regarding shoot height indicated that different levels of silicon had a significant difference at ($p \leq 0.05$) on shoot height in both seasons under field conditions. Silicon application at 200 mg/L resulted in long stature plants (85.51 and 74.88 cm) followed by Si applied at 100 mg/L (82.71 and 70.73cm). Then Si applied at 50 mg/L (79.13 and 69.44cm) for season one and two respectively. However, it was observed that treatments without silicon had the lowest plant height across the weeks in the two growing seasons (Fig.4.1). These results suggest a dose-dependent effect of silicon on plant growth, particularly in enhancing vegetative development.

Shoot height was significantly affected at ($p \leq 0.05$) by different method of silicon application. Mean plots with silicon basal application had superior plant heights in both seasons one and two (69.07 and 75.23cm) as compared to plots with silicon foliar application (64.29 and 67.37cm) in both season one and two respectively. These results were consistent throughout the season.

There was no significant difference in plant height in terms of application method during the first week of harvesting in season two. Observations were not significantly different ($p \leq 0.05$) on shoot height as influenced by tomato variety for the two growing seasons.

Research findings indicate that, interactions between tomato varieties, method of application and silicon levels on shoot height, were not significantly different.

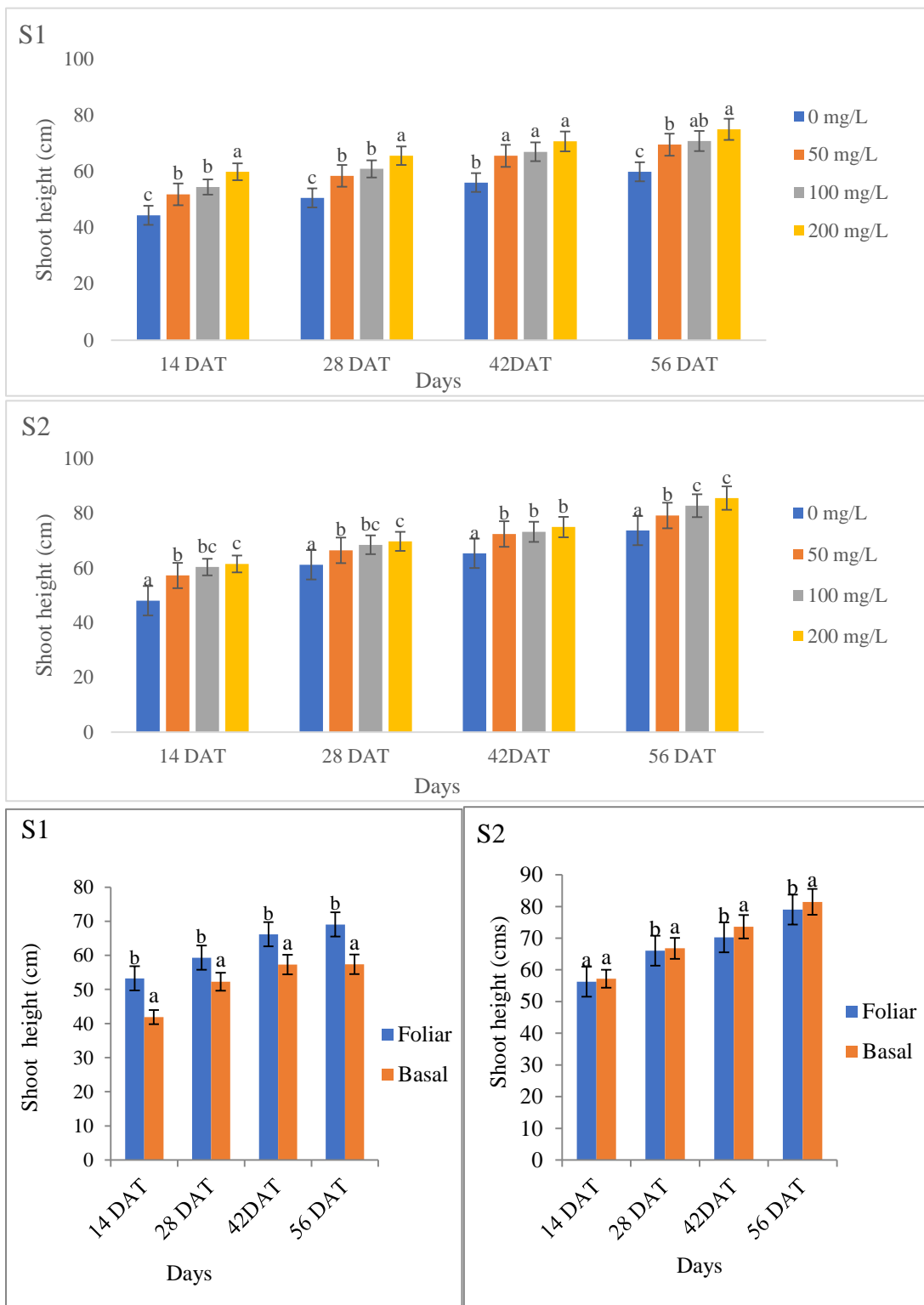


Figure 4.1: Mean shoot heights of two tomato varieties as influenced by silicon levels and application method over two seasons under field conditions

Current findings shows that silicon application significantly improved tomato shoot height, showing a direct correlation with increased application rates. Specifically,

tomato plants treated with silicon at 200 mg/L demonstrated greater plant height, followed by tomato silicon applied at 100mg/L, then silicon applied at 50mg/L and finally control which recorded lowest plant height across the two growing seasons.

Silicon application resulted in increased shoot height. This is in line with the findings of different researchers. Ahmad *et al.* (2007) and Kaaria *et al.* (2021) reported that silicon fertilizer extensively enhanced shoot height under water strain than well-watered conditions. Silicon is reported to improve leaf water potential of plants under low soil moisture due to its phytoliths that thickens the cuticle of the plant, forming cuticle double layer on the epidermal leaf tissue.

Additionally, the superior influence of Si treatments on stimulating the vegetative growth parameters like shoot height may be due to enhancing the uptake and transport of water and minerals in xylem sap, increasing antioxidant activity, concentration of IAA hormone and improving the function of the photosynthetic apparatus and photo-assimilate translocation (Lu *et al.*, 2002; Janmohammadi *et al.*, 2017), thus leading to augmentation of plant growth parameters.

The findings of this research on the application method “spray or soil drench” on shoot height, exhibited clearly that foliar application method exposed significant difference and gave higher mean value of shoot height per plant in both seasons as compared to basal application. Previous observations showed that foliar application of SiO₂ and TiO₂ nano-particles invigorated growth of safflower and barley plants in semi-arid region Janmohammadi *et al.* (2016). Additionally, Chaudhary and Singh, 2020 reported that Silicon foliar application is essential nutrient for plant growth and development and also improves the photosynthetic pigments in plants such as

chlorophylls, carotenoids and anthocyanins contents therefore, enhanced the crop growth and yield.

In a study with peppers conducted in India in 2015–2016, foliar application of silicon potassium silicate containing 18% Si, significantly increased plant height and biomass production both 45 days after planting and during fruit maturity. (Arkadiusz, 2018). Silicon applied directly to foliage allows for faster uptake and utilization, enhancing cell wall strength and photosynthetic efficiency, which contributes to more shoot growth.

Regarding the effect of silicon on different tomato varieties “Zara f1 and Eden f1” on shoot height, information clearly indicates no statistically significant difference in terms of tomato variety. These may be due to genetic factor where by some tomato varieties such as Eden f1 and Zara f1 may not respond strongly to addition of silicon. Or it may be due to interactions of silicon with other soil minerals present in the soil, where by Si influences their uptake potentially limiting or neutralizing its impact on growth.

Findings of these study indicates that shoot height of two tomato varieties as presented in (Table 4.1), show no significant interaction between variety, application method and silicon levels on mean shoot height of tomato. These indicates that varieties responded similarly to Si application in terms of shoot height. The study suggests that silicon application may respond based of specific tomato variety and environment condition.

Table 4.1: Interactive effects between silicon application levels, methods of application and varieties of tomato on plant height under field condition

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Eden ^{fl} x 0 mg/L x Foliar	45.80 ^a	51.22 ^a	56.50 ^a	59.37 ^a
Zara ^{fl} x 50 mg/L x Basal	51.88 ^a	59.18 ^a	65.23 ^a	69.07 ^a
Eden ^{fl} x 100mg/L x Foliar	54.95 ^a	61.20 ^a	67.50 ^a	71.72 ^a
Zara ^{fl} x 200 mg/L x Basal	59.20 ^a	64.42 ^a	69.22 ^a	73.85 ^a
Eden ^{fl} x 50 mg/L x Foliar	51.70 ^a	57.52 ^a	65.73 ^a	69.82 ^a
Zara ^{fl} x 0 mg/L x Basal	42.88 ^a	49.80 ^a	55.48 ^a	60.28 ^a
Eden ^{fl} x 200mg/L x Foliar	60.37 ^a	66.65 ^a	72.00 ^a	75.90 ^a
Zara ^{fl} x 100 mg/L x Basal	53.82 ^a	60.50 ^a	66.30 ^a	69.75 ^a
LSD	4.05	3.76	4.39	3.84
p-value	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) Significant F values at $P \leq 0.05$ and NS-Not significant.

Tomato varieties responded similarly across different Si application methods and levels, implying a general response pattern that is not variety-specific. Application method and Si levels did not differentially affect varieties, which may be due to uniform physiological responses among the tested tomato cultivars to silicon. Probably, silicon uptake and use efficiency might be governed more by plant physiological limits or environmental conditions than by treatment combinations. The present results seem to agree with the report of Santos *et al.* (2021), who reported that increasing Si application rate in the mitigation of ammonium toxicity in tomato did not affect growth rate. Suggesting that specific varieties might not respond significantly to additional Silicon.

Additionally, Gonçalves *et al.* (2020) found that different Si rates applied to various tomato varieties led to inconsistent results in terms of growth and fruit quality.

4.1.2 Leaf area and number of auxiliary stems

Application of silicon significantly triggered ($p < 0.05$) increase in leaf area of tomato in the two seasons as compared with treatments without silicon. Maximum leaf area (493 and 587.1 cm²/plant) was recorded on plants with Si applied at 100 mg/L, followed by Si at 200 mg/L (485 and 573.9 cm²/plant) then by Si at 50 mg/L (570.5 and 476.3 cm²/plant) and finally the control (Fig. 4.2) in both the initial and the subsequent seasons.

Observations of the study indicated that leaf area was significantly affected ($p \leq 0.05$) by different method of silicon application. Maximum leaf area (245.2 cm² and 475.9 cm²) was recorded in plots with silicon applied at the soil level, as compared to foliar application (388.7 cm² and 436.8 cm²) in both seasons respectively (Fig. 4.2). There was no statistical significance difference ($p \leq 0.05$) on leaf area as influenced by tomato variety. The observed patterns persisted over the entire experimental period.

Interactions among tomato varieties, silicon application method and silicon level, were significantly different ($p \leq 0.05$) on leaf area. All factors combined resulted in maximum leaf area of (602.8 cm²). Eden f1 variety, applied as basal silicon at the rate of 200 mg/L posted the highest mean values for leaf area in both seasons, suggesting a synergistic effect between Eden f1 variety, soil silicon application at 200 mg/L under field conditions.

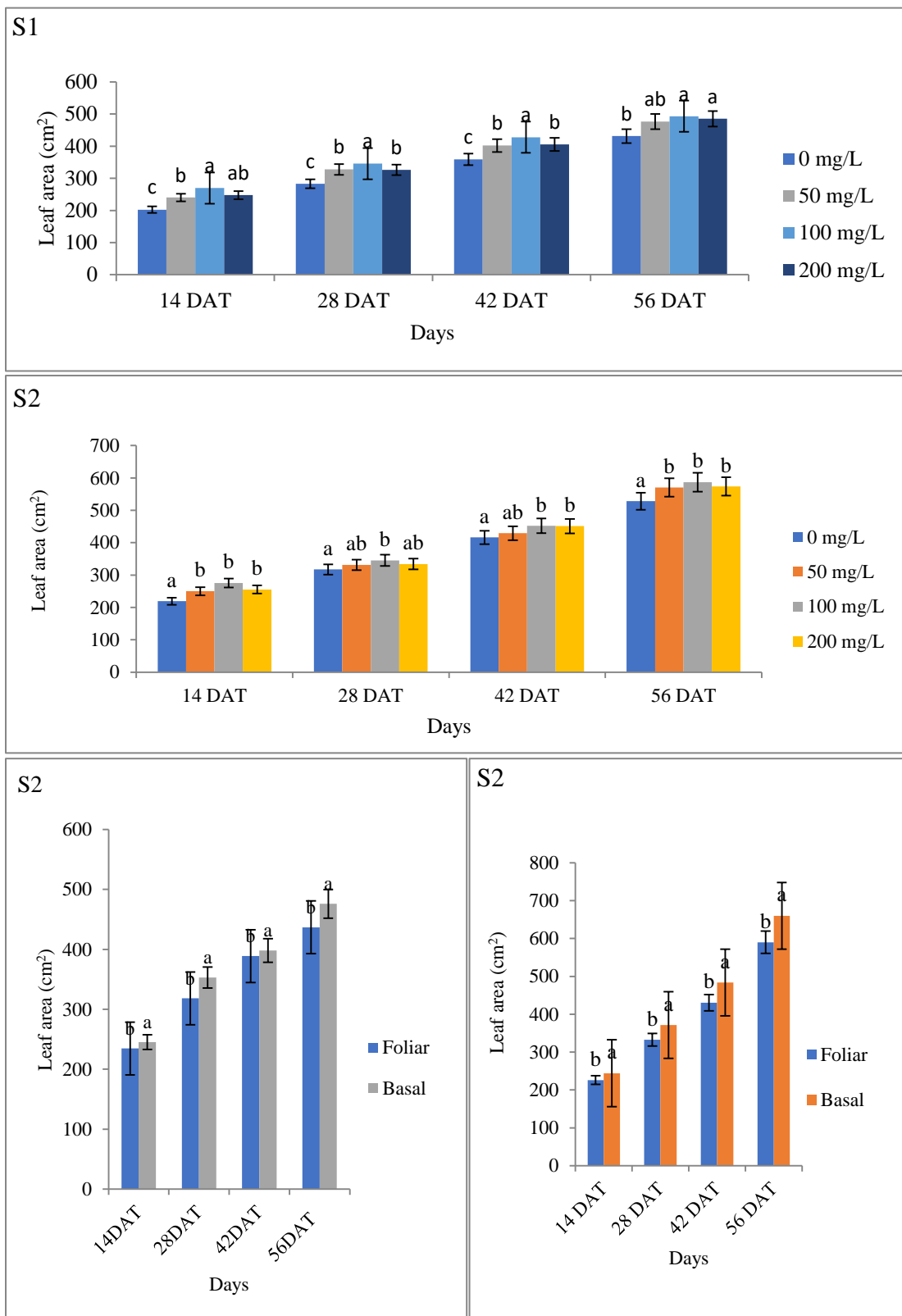


Figure 4.2: Mean leaf area of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Regarding the effect of different levels of silicon application on leaf area, Findings in Fig (4.2) indicated that application of silicon significantly enhanced leaf area in plants compared to control treatment in both seasons. Silicon at (100 mg/L) was the optimum rate for best results for maximum leaf area. This was because increasing Si level from 100 to 200 mg/L had a directly proportional effect on the maximum leaf area but with no statistically significant difference, hence silicon amendment caused a significant increase in leaf area. This could be attributed to the plants response to silicon supplementation through increased photosynthesis, better tissue strength and low plant transpiration (Ali and Hassan, 2016).

These results are similar to those obtained by Pati *et al.* (2016) who observed that higher silicon rates positively influenced leaf area in tomatoes, indicating that optimal silicon supplementation can maximize leaf growth. Additionally, Wang *et al.* (2020) reported that silicon's impact on leaf morphology includes promoting leaf area expansion by enhancing water use efficiency and structural integrity in leaves. In addition to benefits of Si in increasing cell turgor by keeping water in the tissues, Si could also be involved in cell wall metabolism improving the ability of the cell wall to expand and consequently enhancing cell enlargement (Romero *et al.*, 2006).

Concerning application methods “spray and soil drench” on leaf area, research findings in Fig (4.2) indicated that soil drench method showed a significant difference with higher mean value of leaf area in both seasons than the spray method. This may be attributed to the absorption of silicon element available in the soil solution. This element moves through the flow of water transpiration in the xylem to the aerial part and stabilize on the epidermal tissues as silica (Ma and Yamaji, 2006). The layer of silica that settled on the plant strengthens the plants cell wall, making the leaves

straighter. Consequently, there is an increase in light interception, which an optimization of the photosynthetic apparatus (Tamai and Ma, 2008). Moreover, the beneficial effects of silicon may also be attributed to the amelioration in the water use efficiency and to the cell elongation, which, promoting the plant's growth and consequently, the increase of biomass Hossain *et al.* (2002). The aforementioned results are in good accordance with those postulated by Ahmad *et al.* (2013), Gonzalez-Peres *et al.* 2014) and Khenizy and Ibrahim (2015) on gladiolus.

Table 4.2: Interactive effects between silicon application levels, methods of application and varieties of tomato on leaf area under field condition

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Eden ^{f1} x 100 mg/L x Basal	256.8 ^{ab}	333.30 ^{abc}	462.30 ^{bc}	602.80 ^c
Zara ^{f1} x 50 mg/L x Basal	247.20 ^a	333.20 ^{abc}	427.00 ^{abc}	564.70 ^{abc}
Eden ^{f1} x 200mg/L x Basal	258.80 ^{ab}	341.50 ^{bc}	438.00 ^{abc}	547.00 ^{ab}
Zara ^{f1} x 200 mg/Lx Foliar	216.70 ^a	321.50 ^{ab}	415.20 ^a	513.30 ^a
Eden ^{f1} x 50 mg/L x Foliar	221.70 ^a	313.30 ^a	417.30 ^{ab}	543.50 ^{ab}
Zara ^{f1} x 0 mg/L x Basal	292.50 ^b	349.30 ^c	464.20 ^c	600.80 ^c
Eden ^{f1} x 0mg/L x Foliar	254.20 ^{ab}	335.20 ^{abc}	442.00 ^{abc}	571.30 ^{bc}
Zara ^{f1} x 100 mg/Lx Foliar	253.30 ^{ab}	329.70 ^{abc}	431.80 ^{abc}	576.30 ^{bc}
LSD	28.43	17.39	28.47	32.95
p-value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * Significant F values at $P \leq 0.05$ and NS-Not significant.

A significant interaction was seen among all the factors on leaf area. Effect of combined soil silicon application level at 100mg/L, on Eden^{f1} variety, resulted in maximum leaf area suggesting synergistic effects between silicon and variety. The results showed that the maximum growth improvement was seen in plants that received silicon at the soil

level than foliar application for Eden variety (Table 4.2). These may be attributed to their inherent morphological characteristics; Eden^{f1} has inherently bigger leaves than Zara^{f1}. These findings seem to contradict the findings by Lux *et al.* (2002) whose report indicated that foliar-applied silicon on sorghum cultivar (*Sorghum bicolor*) had a positive result in promoting leaf area due to its action on the foliage.

Research revealed that different levels of Silicon had a significant effect ($p \leq 0.05$) on number of auxiliary stems in tomato (Fig. 4.3). The application of silicon at 200 mg/L resulted in the highest mean number of auxiliary stem (18.08 and 19.2), this was consistent with all other treatments of Si application except control (15.25 and 16.17) which recorded least number of auxiliary stems both in two season respectively. The present study indicates that Si at 200 mg/L was the ideal rate for improvement in a number of auxiliary stems which ultimately had a direct effect on the number of leaves.

Silicon application method had significant differences ($p \leq 0.05$) in the mean number of auxiliary stems. Finding of the study indicates that mean maximum number of auxiliary stems were observed 42 and 56 days after transplanting at silicon basal application (18.75 and 18.79) as compared to silicon foliar application (17.25 and 17.79) in both seasons respectively. There was no significant difference on the mean number of auxiliary stems in relation to tomato variety.

The numbers of auxiliary stems of tomato in relation to variety, mode of application and silicon level presented in Table 4.3 show no significant interaction ($p \leq 0.05$) between application method, variety and silicon level indicating that variety responded similarly to Si application in terms of mean number of auxiliary stems.

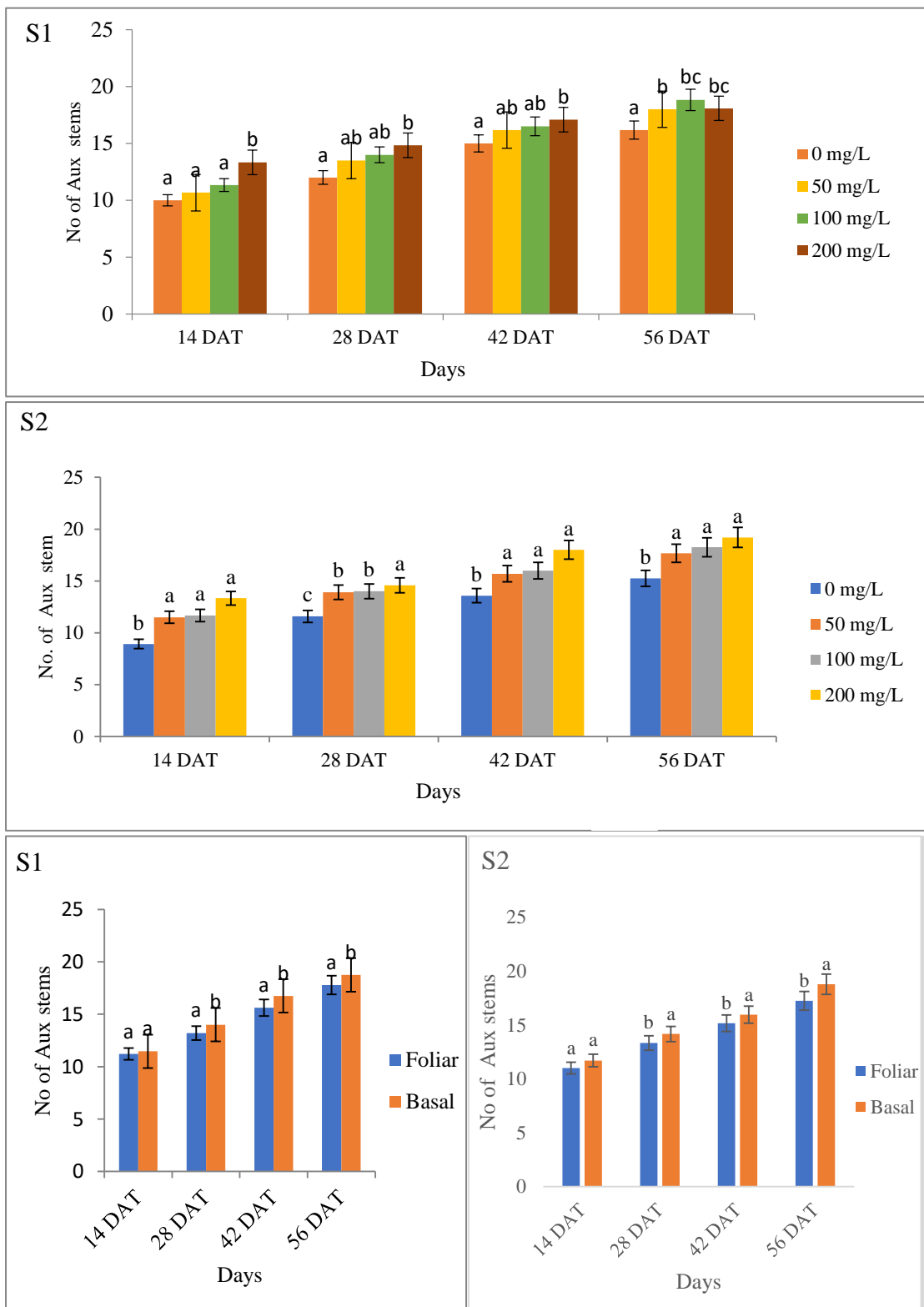


Figure 4.3: Mean number of auxiliary stems of two tomato varieties in relation to silicon levels and application method over two seasons under field conditions

Increasing silicon application rates has been shown to impact the development of axillary stems in tomato plants positively. In the present study, Silicon use improved the number of auxiliary stems per plant. This is in collaboration with findings from research by Ahmad and Haddad, (2011); Ming *et al.* (2012) who indicated that silicon application led to increase in leaf water potential and water content in the plant, therefore, enhancing crop growth. A similar study by Gunes *et al.* (2007) and Shen *et al.* (2010) also demonstrated that Si use improved water contents in chickpea.

These results were also in agreement with the report of Gerami *et al.* (2012) who reported that in rice, increase of Si levels, positively results in an increase in the dry weight of the plant together with its height and number of tillers, Zhu *et al.* (2004) noted that silicon supplementation improved overall structural strength in plant stems and branches, indirectly supporting axillary stem development. Silicon influences hormonal balances, particularly auxin and cytokinin levels, which are crucial in regulating the growth of axillary stems.

Higher silicon levels can enhance the structural integrity and vigor of stems, potentially leading to increased axillary stem growth. While studying the effect of silicon on cucumber plants grown in recirculating nutrient solution. Adata and Besford (1986) found that silicon application reduces physiological disorders incidences and improved growth in tomato stems, suggesting that higher silicon rates can benefit axillary stem development by promoting overall plant growth. The increases in numbers of auxiliary stems per plant is that Addition of Si to the tissue culture medium improves organogenesis, embryogenesis, growth traits, morphological, anatomical, and physiological characteristics of leaves (Sivanesan *et al.*, 2014).

Statistical difference of the mean number of auxiliary stems was observed as the tomato crop was aging. These results were in accordance with those reported by Hodson and White (2005) on Phylogenetic variation in the Silicon composition of plants. They found out that silica content of rice plant increased with the age of the crop from transplanting to harvest. These means that silicon accumulation is a dynamic process that continues throughout the growing period.

Basal application of silicon positively influences the development and numbers of axillary stems in tomato plants as compared to foliar application (Fig 4.3). These findings are consistent with the study by Ahmed *et al.* (2011) on growth and yield of tomato applied with silicon supplements with varying material structures, found that soil-applied silicon improved stem strength and branching in tomato by enhancing cell wall deposition and alleviating stress effects. Similarly, Liang *et al.* (2007) reported that soil application of silicon enhanced auxin distribution and promoted growth in stems and lateral branches under various environmental stresses, making soil-applied silicon beneficial for axillary stem development.

Table 4.3: Interactive effects between silicon application levels, methods of application, and varieties of tomato on auxiliary stems under field condition

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Foliar x 100 mg/Lx Eden ^{f1}	12.00 ^a	14.17 ^a	15.67 ^a	17.83 ^a
Basal x 50 mg/Lx Eden ^{f1}	11.33 ^a	13.83 ^a	15.67 ^a	17.50 ^a
Foliar x 0 mg/L x Zara ^{f1}	08.67 ^a	10.83 ^a	13.67 ^a	15.17 ^a
Basal x 200 mg/Lx Eden ^{f1}	12.50 ^a	14.83 ^a	16.83 ^a	18.50 ^a
Basal x 0 mg/L x Eden ^{f1}	09.17 ^a	12.33 ^a	13.50 ^a	15.33 ^a
Basal x 100 mg/Lx Zara ^{f1}	11.33 ^a	13.67 ^a	16.33 ^a	18.67 ^a
Foliar x 50 mg/L x Zara ^{f1}	11.67 ^a	14.17 ^a	15.67 ^a	17.83 ^a
Foliar x 200 mg/L x Zara ^{f1}	14.17 ^a	16.33 ^a	17.17 ^a	19.33 ^a
LSD	2.11	1.85	1.55	1.49
P- Value	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The interaction between silicon (Si) application rate, tomato variety and method of silicon application had no significant difference on auxiliary stems. A study by Wanxing *et al.* (2023) on the effects of foliar application of silicon and selenium on tomato growth found that there was no correlation between silicon application rate and method of application on the numbers of auxiliary stems.

4.1.3 Root area

The findings of this study reveal that root area was significantly affected ($p \leq 0.05$) by different levels of silicon application. Mean values of data showed maximum root area was recorded at Si applied at 200 mg/L (52.88 and 69.94 cm²), followed by Si applied at 100 mg/L (48.68 and 65.33cm²), then at 50 mg/L (44.60 and 67.28cm²). Minimum root area was recorded in treatments without silicon application (41.62 and 57.68cm²) across seasons one and two respectively (Fig 4.4).

The information of this study revealed that different methods of Si application had significant effect at ($p \leq 0.05$) on the root area of two tomato varieties throughout the harvesting period. Silicon application at the soil level resulted to maximum root area of (48.78 and 65.46cm²) as compared to silicon foliar application which had (46.15 and 63.65cm²) in the respective first and second seasons. Research observations were not significantly different ($p \leq 0.05$) on root area in relation to tomato variety. Silicon application did not significantly affect root areas of both Zara^{f1} and Eden^{f1} varieties of tomato.

As shown in (Table 4.4), the interaction of varieties, silicon application levels and silicon application methods were significant ($p \leq 0.05$) across the experimental period. Eden^{f1} with 0 mg/L applied foliar, had lowest root area (40.58cm²) as compared to Zara^{f1} variety combined with silicon at 200mg/L basal silicon application that showed superiority in root area recording (54.73 cm²) days after planting.

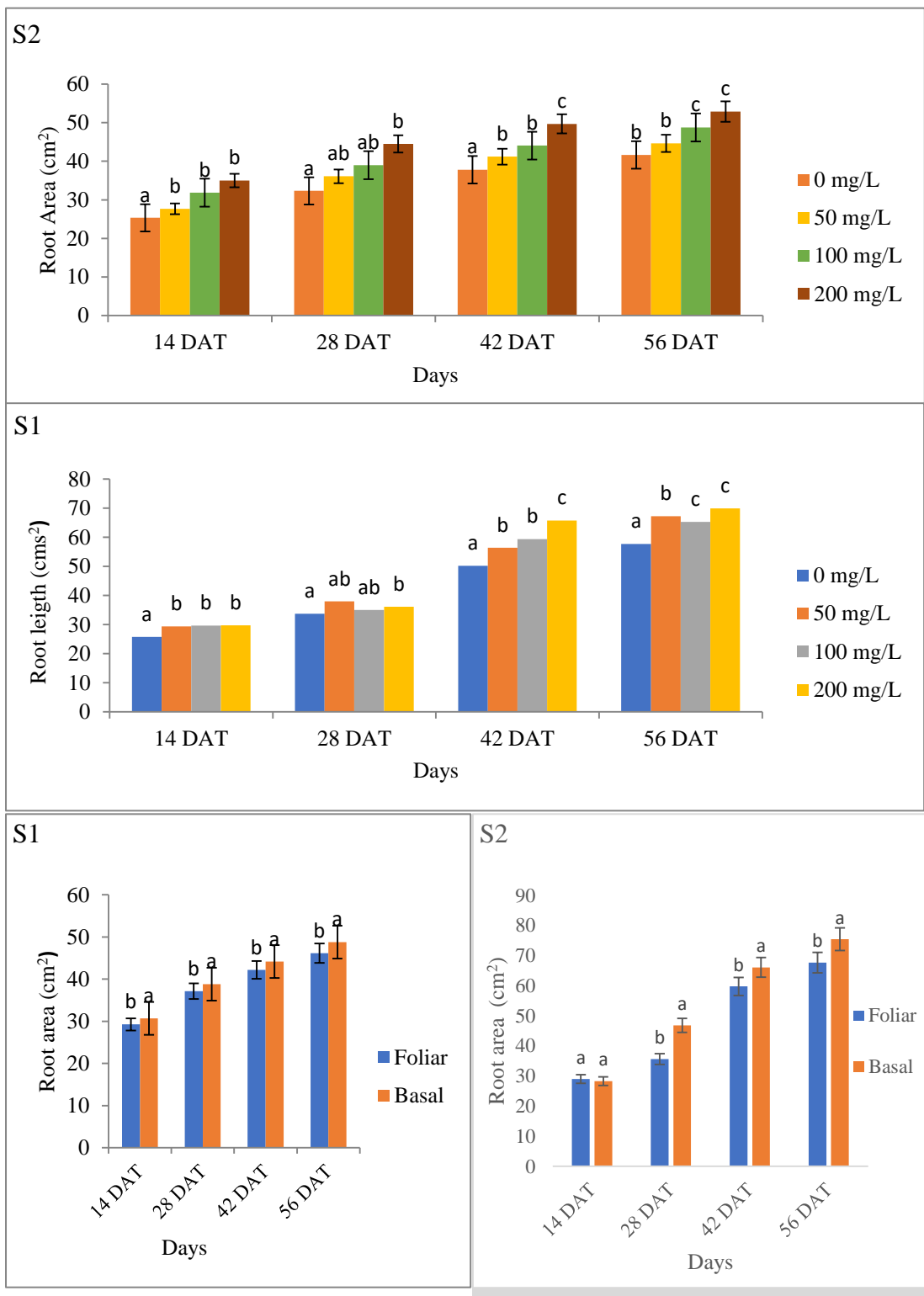


Figure 4.4: Mean root area in (cm²) of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Regarding the effect of different rates of silicon on root area, findings of the study indicated that application of silicon significantly enhanced root area of tomato plants compared to the control treatment in both seasons. Silicon application at 200 mg/L was the optimum rate to cause a desirable increase in root area. Increased root area on silicon treatments showed the benefits of silicon in improving cell turgor, cell wall metabolism and enhancement of cell enlargement as reported by (Ramy and Atef, 2019).

The present results are in accordance with those documented by Romero *et al.* (2006) They reported that addition of Si to salt stressed soybean greatly improved plant growth, enhancing root structural stability. An improvement in growth may be due to the improved photosynthesis, chlorophyll content, and enhanced ribulose biphosphate carboxylase activity caused by silicon. Similarly, Savvas *et al.* (2009) reported that silicon application on cucumber led to specific root length, root surface area and root volume.

This could be attributed to benefits of silicon in root development by promoting root elongation and increasing root density. This enhanced root structure allows for more efficient water and nutrient uptake, which is crucial for overall plant health and growth. Increase in root proliferation due to Si application was also documented in a germination experiment with citrus (*Citrus spp.*).

Observation on application methods “spray and soil drench” on root area, results in Fig (4.4) indicated that soil application showed significant difference and higher mean root area in both first and second seasons respectively as compared to foliar application. These results were consistent with those reported by Zhu *et al.* (2004) observed that tomato plants fertigated with the nutrient solution enriched with silicon showed significantly higher total root area compare to plant grown in control treatments.

Additionally, Kaya *et al.* (2006) found that silicon application in the root zone enhanced root growth and structure in tomatoes exposed to saline conditions. This indicates that soil-based silicon can mitigate environmental stress and foster more extensive root growth.

Moreover, Soil application of silicon has been shown to improve root area in tomato plants by promoting root length, density, and overall biomass (Zhu *et al.*,2004). Silicon absorbed through the roots strengthens cell walls, enhances resistance to biotic and abiotic stress, and improves water and nutrient uptake efficiency, all of which contribute to a larger, more developed root system. Ahmad *et al.* (2013) reported that application of Si fertilizers enhanced the growth parameters, increased yield, yield attributes and quality of rice crop.

Table 4.4: Interactive effects between silicon application levels, methods of application and varieties of tomato on root area in (cm²) under field condition

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Basal x 100 mg/Lx Zara ^{f1}	31.43 ^{abc}	38.12 ^{abc}	43.38 ^{bc}	48.30 ^{abcd}
Foliar x 0 mg/L x Eden ^{f1}	26.82 ^{bc}	32.95 ^c	38.62 ^c	40.58 ^{cd}
Foliar x 200 mg/L x Eden ^{f1}	33.30 ^{ab}	42.65 ^{ab}	47.43 ^{ab}	51.03 ^{bc}
Basal x 50 mg/L x Zara ^{f1}	28.43 ^{abc}	36.08 ^{bc}	40.85 ^{bc}	44.62 ^{bcd}
Foliar x 100 mg/L x Eden ^{f1}	32.27 ^{abc}	39.83 ^{abc}	44.68 ^{abc}	49.22 ^{abc}
Basal x 200 mg/Lx Zara ^{f1}	36.67 ^a	46.30 ^a	51.87 ^a	54.73 ^a
Foliar x 50 mg/L x Eden ^{f1}	26.90 ^{bc}	36.07 ^{bc}	41.48 ^{bc}	44.58 ^{bcd}
Basal x 0 mg/L x Zara ^{f1}	23.85 ^c	31.67 ^c	36.97 ^c	40.67 ^d
LSD	5.44	5.26	4.93	4.96
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different (P≤0.05) *Significant F values at P≤0.05 and NS-Not significant

There was a significant difference in interaction between tomato variety, silicon application rate and method on the root area of tomato. The combined treatment of soil application and silicon at 200mg/L on Zara^{f1} recorded the highest mean values (54.73cm²) for root area as compared to treatments that did not receive silicon application. Similar trends were observed throughout the growing seasons. This study suggests that the high number of roots present, lead to more Si and other nutrient absorption. Increase in root area as a result of silicon application at 200mg/L at the root level, showed the benefits of silicon in improving cell turgor, cell wall metabolism, and enhancement of cell enlargement as reported by Ramy and Atef, (2019).

4.1.4 Stem diameter

Silicon application levels influenced significantly ($p \leq 0.05$) stem diameter in both seasons under field conditions (Fig 4.5). The stem diameter was significantly different in all the weeks for the two planting seasons. Silicon application at 200 mg/L resulted in maximum stem diameter (1.48 and 1.54 cm) followed by Si at 100 mg/L (1.28 and 1.32 cm) then Si at 50 mg/L (1.24 and 1.25 cm) and finally Si applied at 0 mg/L (1.12 and 1.15 cm) in the first and second cropping seasons respectively.

Stem diameter was significantly affected ($p \leq 0.05$) by different method of silicon application. Findings of the study revealed that stem diameter in plots with silicon basal application were bigger (1.31 and 1.35 cm) than in plots with silicon foliar application (1.25 and 1.29 cm) across seasons one and two respectively. The trend remained the same across the weeks after transplanting. Findings were not statistically significant different at ($p \leq 0.05$) on stem diameter as influenced by tomato variety.

Stem diameter was significantly ($p \leq 0.05$) affected by the interactions between silicon application levels, method of application and varieties of tomato (Table 4.5). Results revealed that bigger stems (1.53) were recorded in plots that received silicon rate at 200 mg/L on Eden^{fl} tomato variety as basal application.

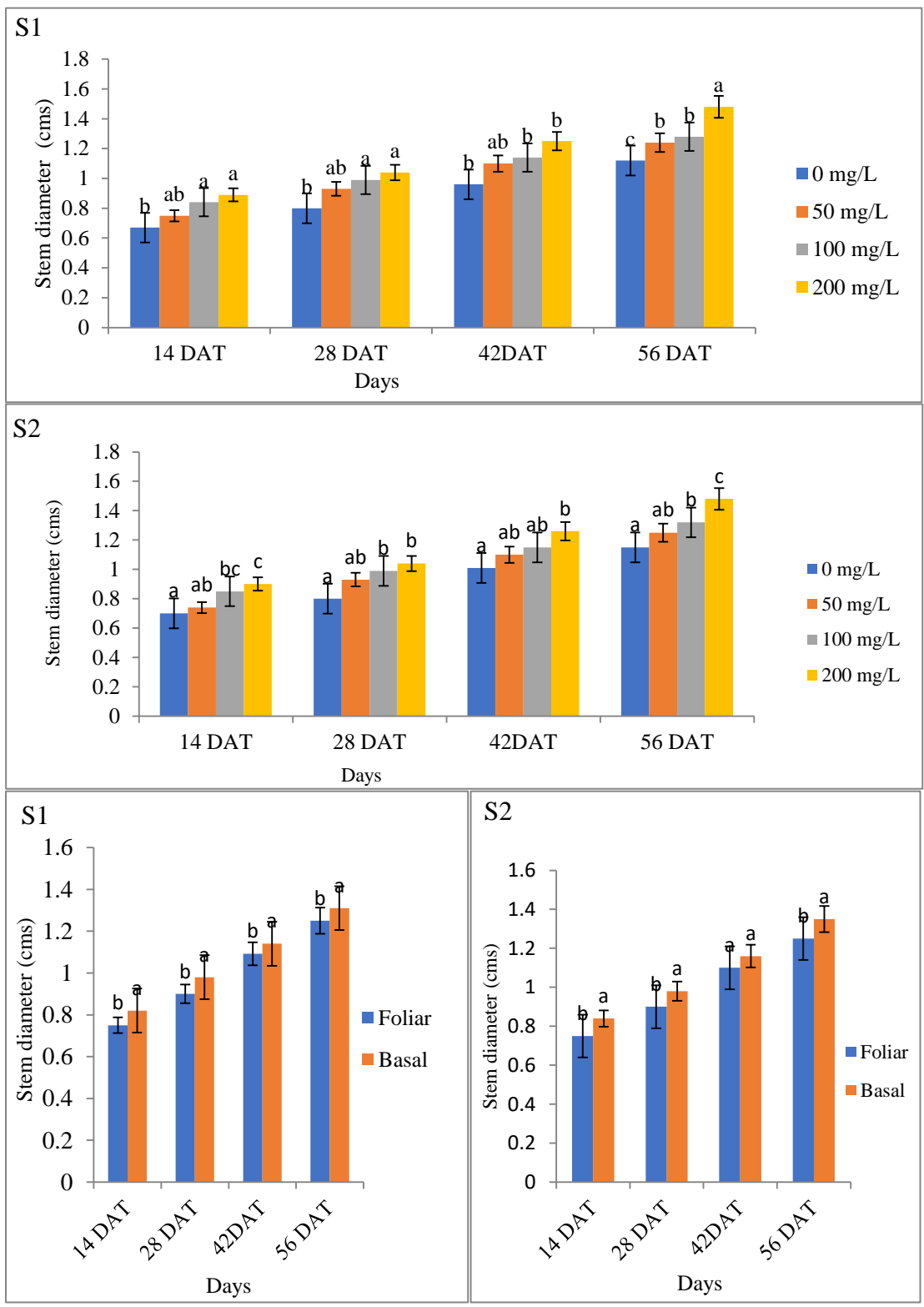


Figure 4.5: Mean stem diameter of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Silicon amendment elicited a higher number of leaves per plant than non-amended plants and as reported by Ahmad *et al.* (2007) that silicon application increased plant growth significantly, therefore the increase in stem diameter in the study was owed to silicon effects. Considering the maximum stem diameter in silicon supplied plants than non-silicon applied plants, it is expected that the photosynthesis of silicon applied sorghum plants was higher than that of plants not supplied with silicon. Increase in silicon application leads to an increase in the mean stem diameter. Maximum stem diameter was recorded at Si application of 200 mg/L, followed by Si at 100 mg/L then Si at 50 mg/L. treatments with 0 mg/L of silicon application recorded lowest mean stem diameter.

These findings corroborate with Olle *et al.* (2016) on the study of efficacy of three foliar PEG-sSA sprays of 4 mL/L (30 ppm Si) on the early growth and the composition of mineral elements in tomato transplants. It was observed that sprayed tomato transplants were taller with larger stem diameters. Moon *et al.* (2008) also reported that Si supplementation was responsible for the increase in stem diameters of chrysanthemum (*Chrysanthemum*), spray rose 'Pinocchio' (Hwang *et al.*, 2005) and gerbera (Savvas *et al.*, 2002).

In a study conducted in Pakistan, on the effect of Si application on maize in drought-stressed plants of hybrid P-33H25 and FH-810 silicon application significantly increased plant height, stem diameter, number of leaves, cob length, number of grains per cob, 100 grain weight, grain yield, and biological yield. Silicon application to drought stressed maize plants improved the growth and yield, which are caused by higher photosynthetic rate and lowered transpiration (Amin *et al.*, 2016).

These positive effects on growth might have been attributed to effect of silicon on plant cell walls and enhancement on lignification, contributing to thicker and stronger more stems. Research by Kaya *et al.* (2006) found that higher Si treatments in maize largely improved the above physiological parameter, with a similar effect anticipated in tomatoes, as silicon application improved structural resilience.

Additionally, Pilon *et al.* (2013), reported that silicon application led to thicker stem diameters in tomato plants by enhancing the deposition of structural compounds, making the stems stronger and more capable of supporting fruit weight. Increased stem diameter on silicon treatments showed the benefits of silicon in improving cell turgor, cell wall metabolism and enhancement of cell enlargement as reported by (Ramy and Atef, 2019).

On silicon application method, the result indicates that soil drench silicon application showed better results on the mean stem diameter both seasons as compared foliar application method. These results are in accordance to Zhu and Gong (2014) who reported that soil application of silicon positively influenced stem diameter in tomatoes, attributing this effect to enhanced lignification and cell wall thickness resulting from silicon uptake. Silicon taken up by the roots and translocated to the stems reinforces cell wall structure, leading to thicker and more resilient stems. This enhancement in stem diameter is especially beneficial, as it improves plant stability and support for fruit bearing. Moreover, the beneficial effects of silicon may also be attributed to the amelioration in the water use efficiency and to the cell elongation and expansion, which, promoting the plant's growth and consequently, increasing biomass (Hossain *et al.*, 2002).

The interactive effect of silicon level, application method and tomato varieties on stem diameter showed a positive significant interaction indicating that different levels of Si responded similarly to application methods and variety in terms of stem diameter.

Table 4.5: Interactive effects between silicon application levels, methods of application and varieties of tomato on stem diameter under field condition

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Basal x 100 mg/L x Zara ^{f1}	0.9 ^{ab}	1.04 ^{ab}	1.15 ^{abc}	1.30 ^{bc}
Foliar x 0 mg/L x Zara ^{f1}	0.7 ^{abc}	0.83 ^{bc}	0.98 ^{bc}	1.10 ^d
Basal x 200 mg/L x Eden ^{f1}	0.93 ^a	1.12 ^a	1.300 ^a	1.53 ^a
Basal x 50 mg/L x Eden ^{f1}	0.82 ^{abc}	1.00 ^{ab}	1.15 ^{abc}	1.28 ^{bc}
Foliar x 100 mg/L x Zara ^{f1}	0.78 ^{abc}	0.95 ^{abc}	1.13 ^{abc}	1.27 ^{bcd}
Foliar x 200 mg/Lx Eden ^{f1}	0.85 ^{abc}	0.97 ^{abc}	1.20 ^{ab}	1.43 ^{ab}
Foliar x 50 mg/Lx Zara ^{f1}	0.68 ^{bc}	0.85 ^{bc}	1.05 ^{bc}	1.20 ^{dc}
Basal x 0 mg/L x Eden ^{f1}	0.63 ^c	0.77 ^c	0.97 ^c	1.13 ^{cd}
LSD	0.16	0.15	0.14	0.11
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) *Significant F values at $P \leq 0.05$ and NS-Not significant

The present results are in line with Pulz *et al.* (2008) who observed higher stem diameter on potato and lupin plants, respectively, with soil-applied Si, regardless of water availability.

Similarly, Gong *et al.* (2003) verified increase in stem length of wheat (*Triticum aestivum* L.) and cowpea, respectively, when plants were supplied with Si in the soil under well-watered conditions. According to Hossain *et al.* (2002), Si promotes cell

elongation but not cell division in rice, probably as a result of Si-enhanced extensibility of the cell wall.

4.2 Effect of Silicon rate, application method and variety on yield parameters of tomato

4.2.1 Fruit number

Number of fruits were significantly affected ($p \leq 0.05$) by different levels of silicon. The highest mean numbers of tomato fruits were recorded under recommended treatment of 100 mg/L (39 and 33.90), followed by Si at 200 mg/L (30.75 and 36.75) then by Si at 50 mg/L (33.09 and 34.17) and finally the control (18.25 and 26.75) (Fig. 4.6). This trend was consistent throughout the harvest period for two growing seasons respectively.

Research observations revealed that silicon application methods had significant differences at ($p \leq 0.05$) on the number of fruits in both seasons under field conditions. Silicon soil application had the maximum mean number of fruits (34.85 and 29.83) compared to foliar application (31.79 and 33.05) for season one and two correspondingly. The number of fruits were high for the foliar application as compared to basal on 81st days after harvesting (Fig. 4.6).

There was a significant ($p \leq 0.05$) interactive effect between silicon level, application methods and tomato varieties on fruit number as presented in (Table. 4.6) in two seasons.

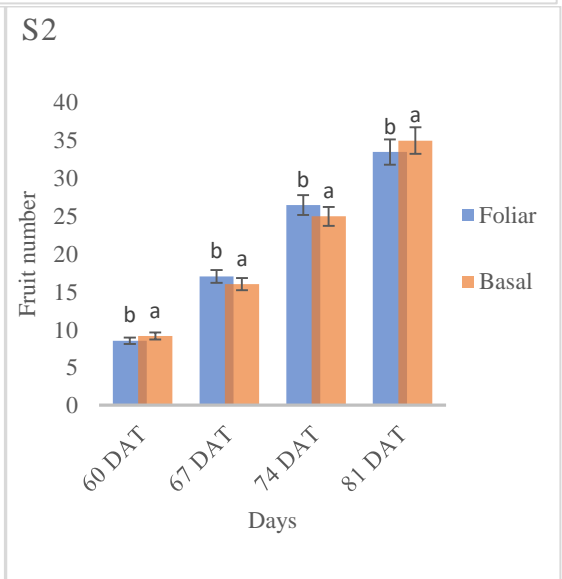
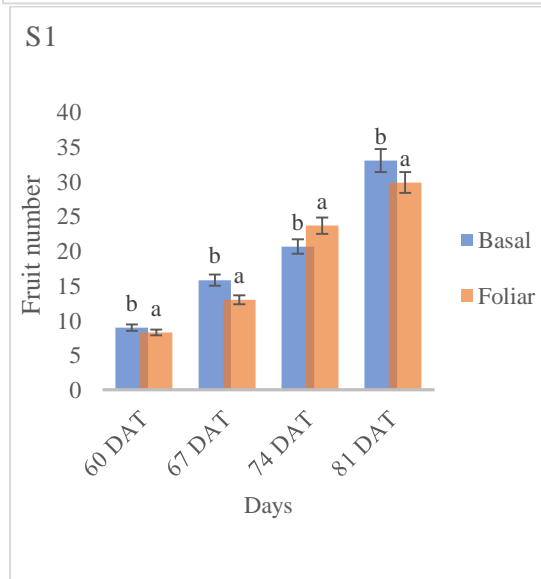
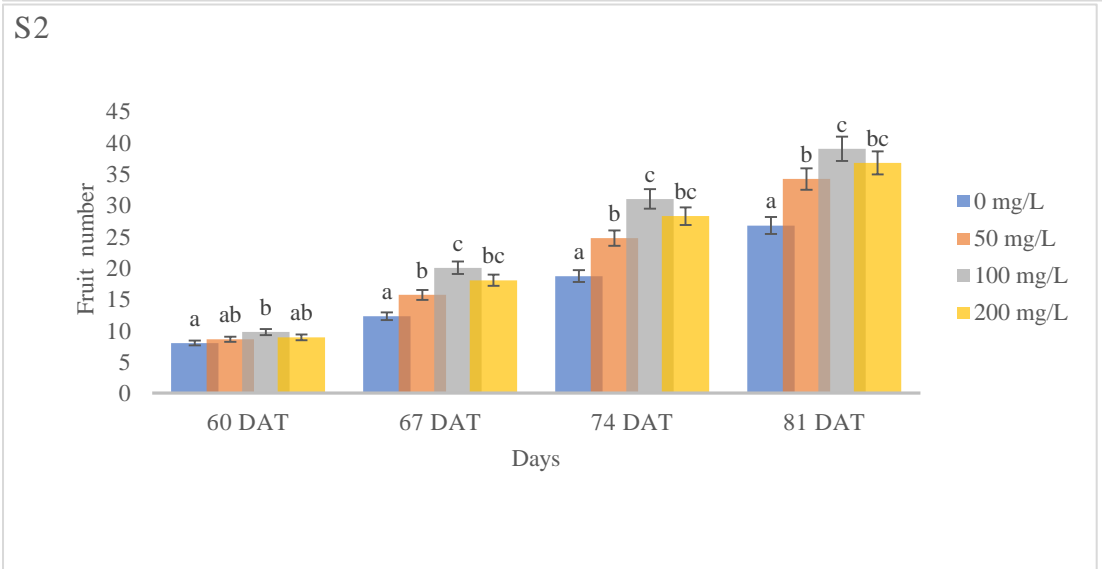
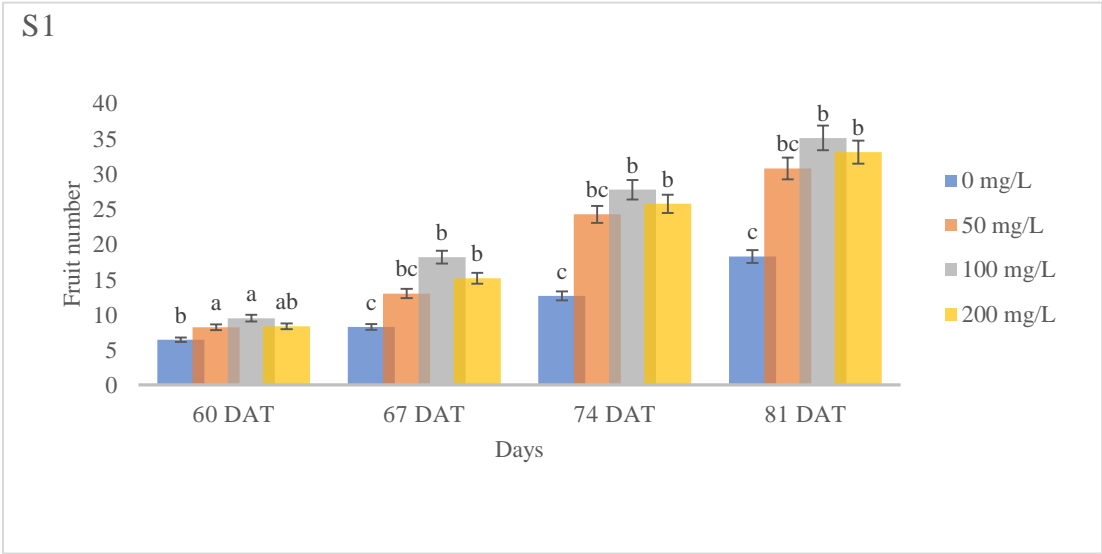


Figure 4.6: Mean number of fruits of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Silicon application at 100 mg/L resulted in the greatest number of fruits as compared to other levels. This indicated that Si at 100 mg/L was the optimum rate that led to desirable increase in production per unit area. However, at 200 mg/L, there was a decrease in the number of fruits rendering it uneconomical and a waste of resources. These results are in accordance to those observed by Fiori (2006), in which optimum application of basic slag, as source of Si, promoted an increase in the total number of fruits and its productivity.

A study conducted by Montes *et al.* (2022) indicated that applying 20 grams of silicon per plant led to a slight increase in number of harvested fruits compared to control. However, higher doses resulted in a decrease in fruit number, suggesting that optimal silicon dosage is crucial for maximum yield. This may be attributed to the benefit effects of Si in the plant, as an improve of architecture for showing more erect leaves, which intercept higher solar luminosity increasing photosynthetic efficiency (Pereira *et al.*, 2003) and higher chlorophyll content.

Additionally, Jarosz (2014) indicates that silicon is the only element that does not harm plants when taken up in higher amount and it improves plant fertilization, plant growth and yield. Silicon application helped in improving fruit set and minimizing fruit drop of tomato as same as the result found by Dattatray (2018).

On application methods “spray or soil drench” on the number of fruits, information obtained in Fig (4.6) exhibited clearly that the application method of soil drench exposed significant difference and gave higher mean values of fruit number than foliar spray in both seasons. These results are in line with a study conducted in Poland where a significant increase in the yield of cucumber fruit was obtained by providing nutrition to roots of plants with silicon in the form of a silicate sol and using two substrates with

a different content of silica at a dose of 500 and 750 mg in comparison to plants from the control treatment (Jarosz, 2013).

Ma *et al.* (2024) demonstrated that applying 45kg of sodium silicate per hectare to the soil before transplanting significantly improves tomato plant growth. Additionally, Rajapaksha *et al.* (2021) reported that application of silicon as magnesium silicate, improved yield parameters such as; number of flowers, number of fruits, fruit weight and fruit yield. These may be attributed to the ability of silicon to optimize photosynthetic efficiency and enhances nutrient uptake thus contributing to increased fruit set and yield.

Table 4.6: Interactive effects between silicon application levels, methods of application and varieties of tomato on fruit number under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Eden ^{fl} x 0 mg/L x Basal	8.33 ^a	14.67 ^{abc}	24.50 ^{bc}	34.00 ^b
Zara ^{fl} x 50 mg/L x Foliar	9.50 ^a	18.67 ^{cd}	30.17 ^{cd}	38.50 ^b
Eden ^{fl} x 100mg/Lx Foliar	9.33 ^a	17.50 ^{bcd}	29.00 ^{cd}	38.00 ^b
Zara ^{fl} x 200 mg/L x Folia	9.33 ^{ab}	11.67 ^{0a}	17.33 ^a	27.00 ^a
Eden ^{fl} x 100 mg/L x Basal	10.00 ^b	21.33 ^d	31.83 ^d	39.50 ^b
Zara ^{fl} x 0 mg/L x Foliar	7.67 ^a	12.83 ^{ab}	20.00 ^{ab}	26.50 ^a
Eden ^{fl} x 50 mg/L x Basal	8.50 ^a	18.50 ^{cd}	27.50 ^{cd}	35.50 ^b
Zara ^{fl} x 200 mg/L x Basal	8.83 ^a	16.60 ^{bcd}	25.00 ^{bc}	34.33 ^b
LSD	1.64	3.15	4.29	4.31
p-value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) *Significant F values at $P \leq 0.05$ and NS-Not significant

The statistical analysis revealed that the highest mean value of fruit number was achieved when Eden^{fl} variety received 100 mg/L of silicon as basal application. These

results are in line with the findings of Thimmappa *et al.* (2021) who revealed that soil drenching of silicic acid at 4 ml L⁻¹ at 15, 30 and 45 days after planting significantly increased the yield attributes including number of fruits per plant. Similarly, Fiori observed increased total number of fruits and enhanced productivity in tomato with the application of silicic acid. According to Yang *et al.* (2000), increased number of fruits is controlled by both genetic and environmental factors a confirmation that the two varieties in the present study differed in terms of their genotypic make up. For the current study it's presumed that Eden ^{f1} has inherently more numbers of fruits as compared to Zara ^{f1}

4.2.2 Fruit weight

The findings of these study regarding fruit weight indicated that different levels of silicon had significant difference ($p \leq 0.05$) on fruit weight. It was observed that maximum fruit weight was recorded in plots applied with Si at 100 mg/L (520.4 and 516.8 gms), There after by Si at 200mg/L (502.6 and 455.6 gms), then Si applied at 50 mg/L (184.9 and 430.4 gms). The control (192.9 and 185.4 gms) resulted in minimum mean fruit weight (Fig. 4.7) in both season one and two respectively.

Mean fruit weight was significantly affected ($p \leq 0.05$) by different method of application in season one and respectively under field condition. Heavier fruits were recorded in plots with basal silicon application (619 and 625 gms) as compared to treatments with foliar applied silicon (452 and 462 gms). This trend was observed as from the fourth week on words (Fig 4.7). Results of fruit weight of both seasons under field conditions, showed no significant difference ($p \leq 0.05$) as influenced by tomato variety.

There was a significant ($p \leq 0.05$) interactive effect between silicon level, application methods and tomato varieties on fruit weight as presented in (Table 4.7.) in two seasons under field condition.

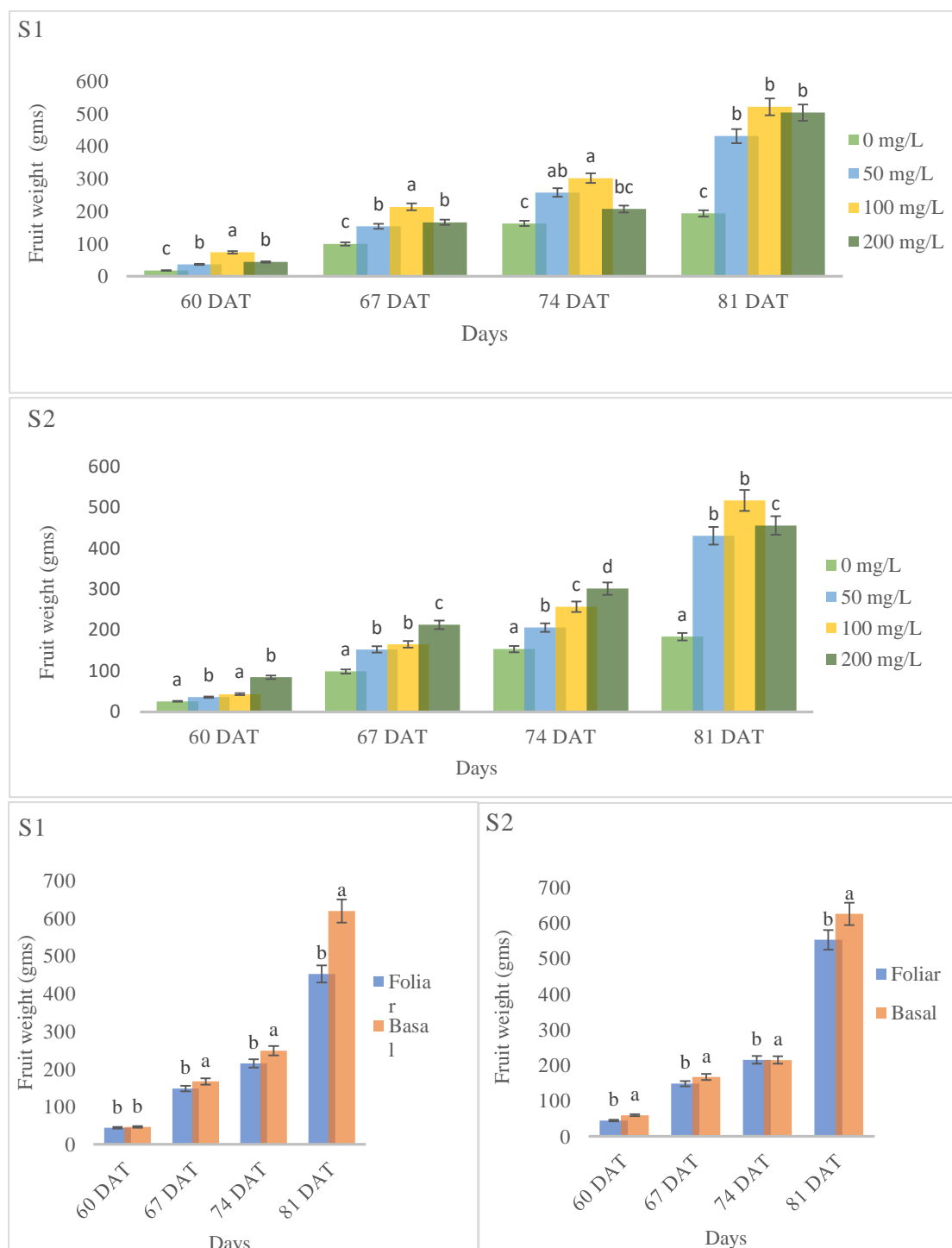


Figure 4.7: Mean fruit weights of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Silicon application at 100 mg/L resulted in the greatest fruit weight as compared to other Si levels. This indicated that Si at 100 mg/L was the optimum rate that led to desirable increase in production per unit area. However, at 200 mg/L there was a decrease in fruit weight rendering it uneconomical.

These findings correlate the findings of Jarosz *et al.* (2006) who observed that standard application of silicon in lettuce had a significantly higher weight of heads and a higher dry matter content in plants fed with silicon at a dose of 250 mg/dm³ compared to 350mg/dm³ of silicon solution. Similarly, research by Savvas *et al.* (2009) indicated that higher silicon rates resulted in heavier fruit in tomatoes grown under saline conditions, attributing this effect to improved water and nutrient absorption as well as enhanced photosynthetic activity.

Similarly, a study by Pilon *et al.* (2013) demonstrated that elevated silicon levels significantly increased fruit weight, indicating that silicon application can enhance fruit development and quality in tomatoes. These could be probably be due to nutritional imbalance caused by Si or by the accompanying ions previously in the soil that compete for the same absorption sites of other nutrients (Korndörfer *et al.*, 2002). It may also be due to the role of Si on promoting the synthesis of more assimilates stored in the new fruits and make them relatively greater and heavier.

Concerning the effect of application methods “spray or soil drench” on fruit weight, the obtained results presented in Fig (4.7) showed that the two application methods of silicon significantly affected fruit weight. The research did not significantly affect fruit weight for the first harvest (60 DAT) in season two. The statistical analysis from these results revealed that the highest mean value of fruit weight was achieved when plants were applied with silicon at root level than foliar application in both seasons. In similar

studies, Crusciol *et al.* (2009) in a study conducted in Brazil, reported that silicon fertilization of the soil increased the average tuber weight, dry tuber weight, and tuber yield, especially in the absence of water deficit.

Kaya *et al.* (2006) reported that soil-applied silicon significantly increased the number of grains per cob and their masses. Additionally, Kalandyk *et al.* (2014) also reported that a higher yield of soybean caused by application of silicon resulted from the increase in the number of pods per plant, the number of seeds in the pod, and the weight of 1000 seeds. These may be attributed to the ability of silicon to enhance plant's ability to absorb water and nutrients, which are critical for fruit development.

Pilon *et al.* (2013) reported that basal application of magnesium silicate led to increased fruit weight in tomatoes grown under stress condition, indicating that the application method effectively supports fruit growth and yield. In Poland after application of Actisil as fertilizer, it was found that standard silicon doses significantly affected the yield of lettuce grown in mineral wool using fertigation at a high content of manganese in the nutrient medium.

Silicon can also help in retaining water in plant tissues by reducing transpiration and partial blocking the transpiration bypass flow (Gunes *et al.*, 2008) which improves water economy of plant and maintain an efficient absorption of mineral elements, therefore, improving yield. Additionally, when silicon is applied to the soil, it is absorbed through the roots and contributes to structural integrity and physiological functions, ultimately leading to improved fruit development.

Table 4.7: Interactive effects between silicon application levels, method of application and varieties of tomato on fruit number under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/L x Zara ^{f1}	35.85 ^a	169.40 ^{bcd}	263.9 ^{bc}	1129.00 ^a
Foliar x 0 mg/L x Eden ^{f1}	22.90 ^a	101.70 ^{ab}	145.20 ^a	187.00 ^a
Basal x 200 mg/L x Zara ^{f1}	37.77 ^a	135.50 ^{abc}	202.7 ^{ab}	520.70 ^a
Basal x 50 mg/L x Eden ^{f1}	36.75 ^a	161.30 ^{abcd}	250.3 ^{bc}	504.50 ^a
Foliar x 100 mg/L x Eden ^{f1}	81.80 ^{bc}	229.60 ^d	207.70 ^c	599.50 ^b
Foliar x 200 mg/L x Eden ^{f1}	49.32 ^{ab}	170.00 ^{bcd}	210.00 ^{ab}	440.20 ^a
Foliar x 50 mg/L x Zara ^{f1}	29.12 ^a	96.00 ^a	162.30 ^a	198.70 ^a
Basal x 0 mg/L x Zara ^{f1}	35.85 ^a	169.40 ^{bcd}	263.9 ^{bc}	105.70 ^b
LSD	21.84	43.21	51.55	218.2
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) *Significant F values at $P \leq 0.05$ and NS-Not significant.

The effect of interaction between the tomato variety, application methods “spray or soil drench” and silicon levels on fruit weight was significant in both seasons. The statistical analysis revealed that the highest mean values of tomato fruit weight was achieved when Zara ^{f1} received 100 mg/L silicon as basal application in both seasons. In studies conducted in Poland by Artyszak *et al.* (2018) reported that increasing doses of silicon caused increase of yield of Fabaceae (red clover and white clover) and decrease in yield of other dicotyledonous plants.

The present results were in parallel to those reported by Fageria *et al.* (2015) that silicon basal application did not have significant differences in total and marketable yield as well as in mean fruit weight between plants grown in rockwool and straw mediums

4.2.3 Marketable fruits

Mean number of marketable fruits were significantly affected ($p \leq 0.05$) by different levels of silicon. Research observation showed that mean maximum marketable fruits were recorded in plots with Si applied at 200 mg/L (39.75 and 40.23) There after by Si at 100mg/L (31.5 and 40.23) then Si at 50 mg/L (30.75 and 35.2). Control (13.17 and 30.45) resulted in minimum number of marketable fruits (Fig 4.8) in both season one and two respectively. The findings of the study revealed that application of silicon at 100mg/L and 200mg/L produced a constant number of marketable fruits in week 74 and 84 DAT for the two seasons in both tomato varieties.

There was a significance ($p \leq 0.05$) increase in the number of marketable fruits in relation to application method. Research findings showed maximum number of marketable fruits (37.25 and 42.25) was recorded in plots with silicon foliar application as compared to plots with silicon basal application (32.12 and 38.12) for both season one and two respectively. These results were consistent throughout the harvest period (Fig 4.8). There was no statistical significance difference at ($p \leq 0.05$) in relation to tomato variety.

The interaction effects between variety, application methods and silicon level on the marketable fruits of tomato plants presented in (Table 4.8) were not significantly different. This indicates that application method responded differently to silicon levels in terms of marketable fruits numbers.

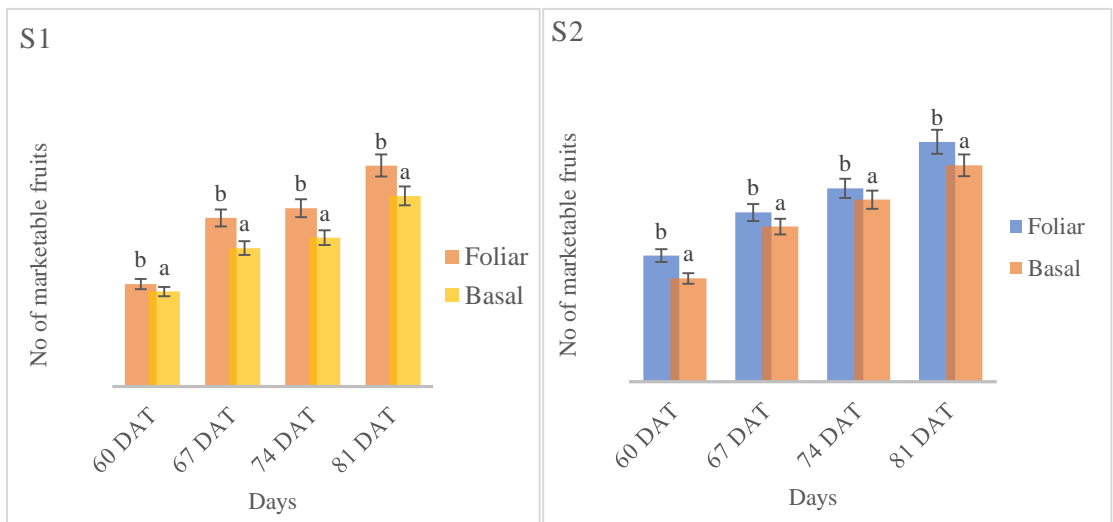
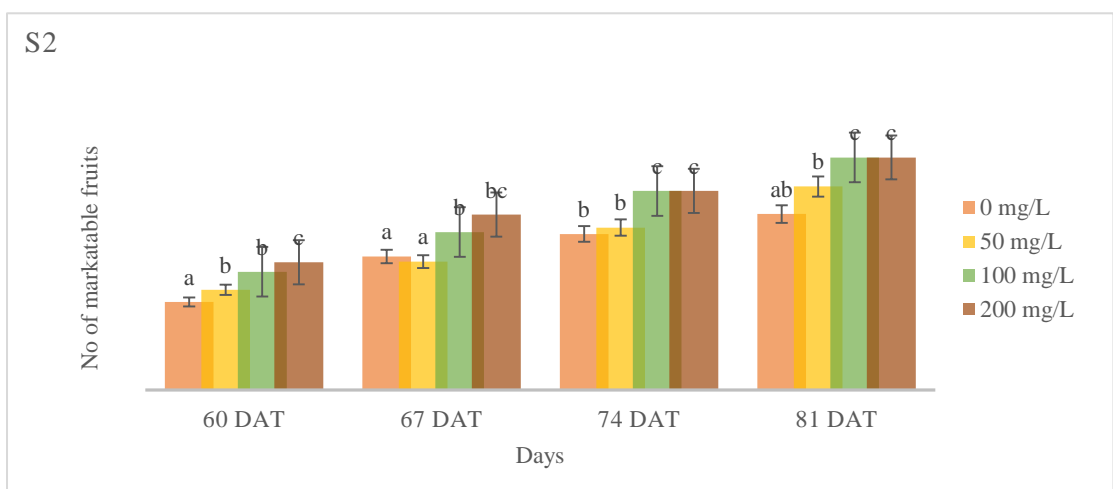
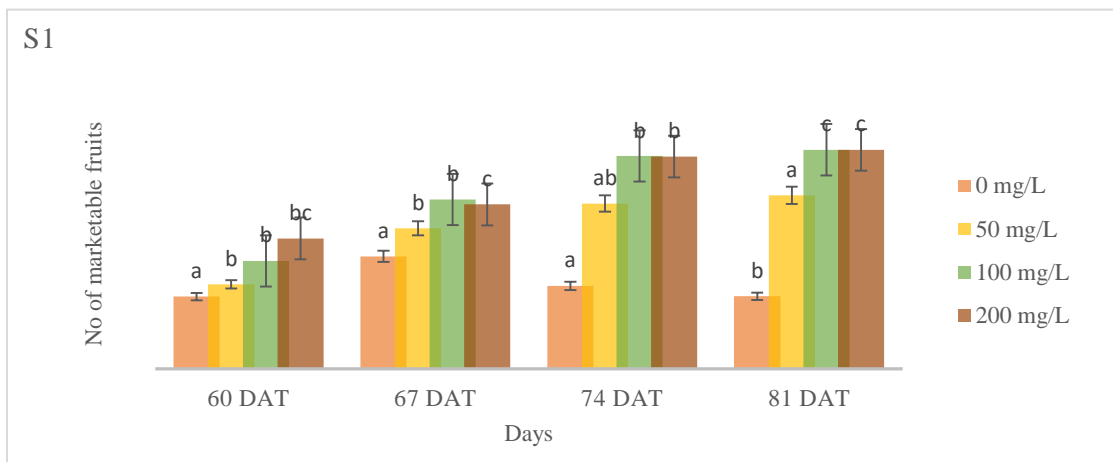


Figure 4.8: Means of marketable fruits of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

The number of marketable fruits increased with an increase in silicon levels, therefore, mean marketable fruits was more pronounced at Si applied at (200 mg/L). These results are consistent with the reports of Savvas *et al.* (2009) who found that silicon applications in soil less systems significantly increased the number of marketable fruits in tomatoes. Additionally, Lana *et al.* (2003) observed that in soil with no silicon fertilization, the productivity of commercial tomato fruits were 40.1t ha⁻¹ and non-commercial was 26.6t ha⁻¹. However, when the calcium silicate was applied at the dose of 4000 kg ha⁻¹ the commercial productivity increased to 56.0 t ha⁻¹.

In Greece, Stamatakis *et al.* (2003) while growing tomatoes in hydroponics, it was reported that fertilization with silicon increased fruit hardness, beta-carotene, and lycopene content, as well as dry matter and vitamin C content. These may be probably be due to physiological performance of plants, contributing to a higher yield of commercially viable fruit. Moreover, it may also be attributed to rapid influx of solutes and water in the fruit, usually at the time of ripening, when the strength and elasticity of the skin are reduced and the pressure of the locule is incremented occurring tiny cracks, expanding thereafter during ripening.

The analysis of the results obtained in the present study showed a significant increase in marketable fruits of plants fertilized with silicon foliar as compared to silicon basal application. Figueira *et al.* (2021) demonstrated that foliar application of silicon under water deficit conditions resulted in an increase in the number of marketable fruits, indicating that silicon plays a crucial role in improving fruit yield and quality. Silicon foliar spray influenced firmness, because the minerals may cross-link the pectin molecules in plant cell walls and the metal binding's cell-wall structure stabilize by the

pectin web (Weerahewa and David 2015). The Si foliar sprays retained visual quality, improved the shelf life, and maintained the fruit freshness by suppressing respiration and reducing internal breakdown Ouzounidou *et al.* (2016).

Table 4.8: Interactive effects between silicon levels, method of application and varieties of tomato on marketable fruit under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/L x Zara ^{f1}	32.05 ^a	35.27 ^a	38.65 ^a	41.65 ^a
Foliar x 0 mg/L x Zara ^{f1}	24.33 ^a	21.47 ^a	25.95 ^a	29.82 ^a
Basal x 200 mg/L x Zara ^{f1}	35.00 ^a	38.90 ^a	42.33 ^a	45.37 ^a
Basal x 50 mg/L x Eden ^{f1}	28.18 ^a	29.85 ^a	31.53 ^a	39.32 ^a
Foliar x 100 mg/L x Eden ^{f1}	32.00 ^a	33.45 ^a	39.93 ^a	41.07 ^a
Foliar x 200 mg/L x Eden ^{f1}	49.32 ^{ab}	170.00 ^{bcd}	210.00 ^{ab}	440.20 ^a
Foliar x 50 mg/L x Zara ^{f1}	28.63 ^a	33.62 ^a	35.90 ^a	37.73 ^a
Basal x 0 mg/L x Eden ^{f1}	22.22 ^a	23.67 ^a	28.02 ^a	30.03 ^a
LSD	6.17	7.05	9.04	8.26
P- Value	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) *Significant F values at $P \leq 0.05$ and NS-Not significant.

Research indicates that the interaction between silicon (Si) application rates and methods of application does not always result in significant differences in the marketable yield of tomatoes. The present study is in line with a study by Zhang *et al.* (2024) reported that Si application improved certain quality parameters. There were no significant interactive effects between the application method and Si levels on the marketable yield of tomatoes.

4.2.4 Number of flowers

Silicon application led to a reduced number of days to flowering and compared to the control that recorded more days in two growing seasons. The number of flowers were significantly affected ($p \leq 0.05$) by the different levels of silicon. Highest mean numbers of flowers were recorded in plots that received 100mg/L of silicon (26.7 and 35.32), followed by Si at 200 mg/L (24.91 and 24.81), then by Si at 50 mg/L (13.25, and 22.3) and finally the control. (Fig.4.9) for season one and two season respectively.

The findings of the study revealed that application methods had significant difference at ($p \leq 0.05$) in number of flowers in both seasons under field conditions. Silicon soil application had maximum mean number of fruits (27.81 and 32.81) compared to foliar application (23.06 and 23.86), these results were consistent across the harvest period. There was no significant difference in the number of fruits in relation to tomato variety.

Treatment interaction between tomato variety, application methods “spray or soil drench” and different levels of silicon on the number of flowers show significance ($p \leq 0.05$) in both seasons (Table 4.9).

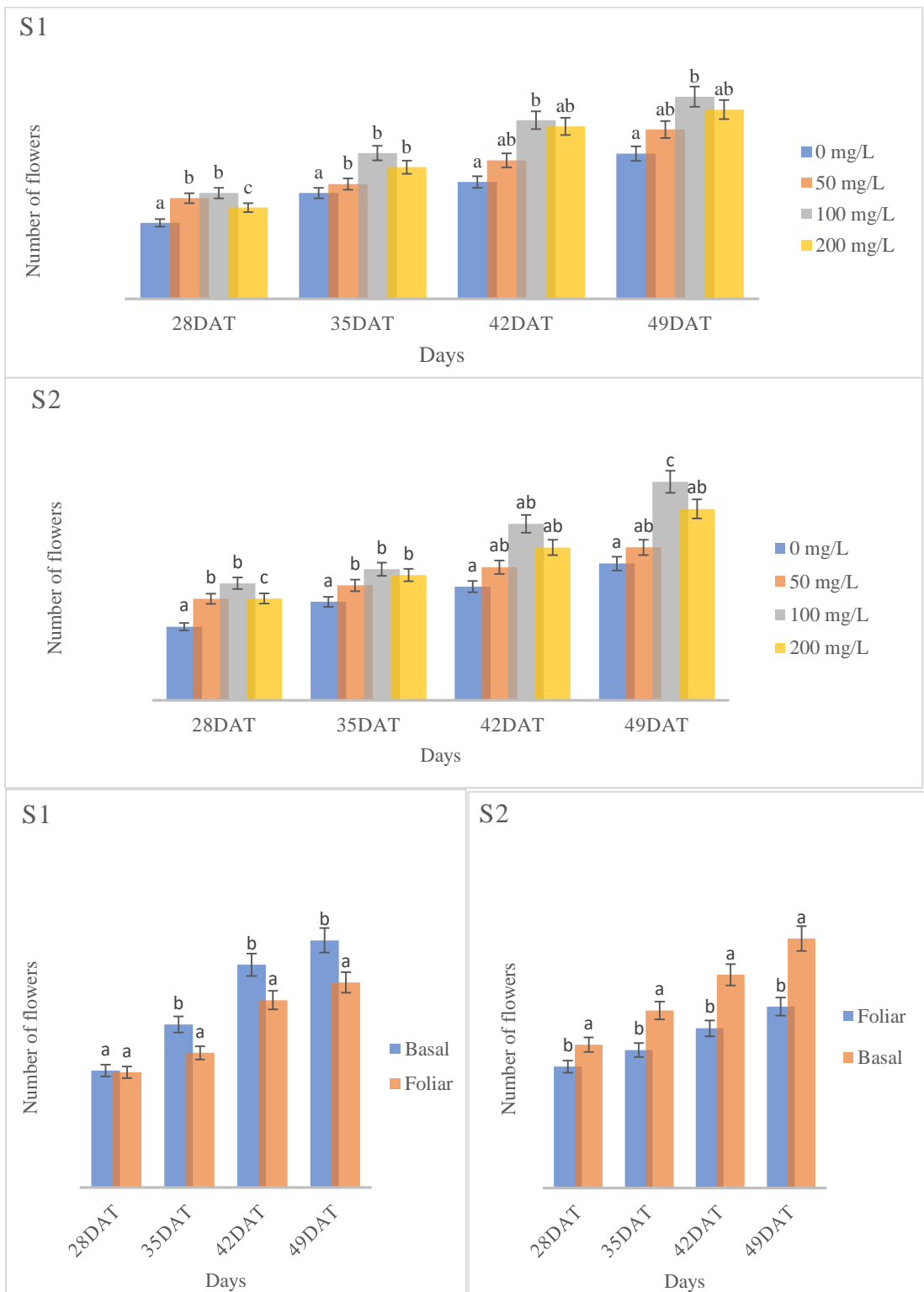


Figure 4.9: Mean number of flowers of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Pertaining on the effect of different rates of silicon on the number of flowers, results in Fig (4.9) indicated that application of silicon significantly increased number of flowers compared to control treatments in both seasons. Silicon at 100 mg/L was the optimum rate for best results for the maximum number of flowers. This was because increasing Si level from 100 to 200 mg/L had a directly proportional effect on the number of flowers with no significant difference. The obtained data on the number the flowers were in agreement with those obtained by Moulick *et al.* (2021) who reported that various rates of silicon application significantly affected the number of flowers in tomato plants.

Their findings indicated that optimal silicon levels led to increased flower formation, contributing to improved yield potential. Increasing number of flowers per plant by application of Si could be explained through the role of Si in improving water balance and increasing chlorophyll content and more photosynthesis resulted in increasing carbohydrates content in stems and leaves which consequently increased the number of flowers (Ma and Takahashi, 2002). Moreover, silicon provides the plants with macro- and micro-nutrients necessary for best growth and high quality (Epstein, 1994).

On the effect of application method “spray or soil drench” on the number of flowers, the obtained results presented in Fig (4.9) showed that the two application methods of silicon significantly affected the number of flowers in both seasons. Present results show that basal application of silicon had positive affect on the number of flowers produced by tomato as compared to foliar application. Current findings were in agreement with the results obtained by Kaya *et al.* (2006) who found that basal application of silicon positively influenced flower development in tomatoes by enhancing the plant's ability to uptake water and nutrients, leading to improved

flowering and fruiting. Similarly, Zhu *et al.* (2015) in their study on effect of Silicon on water Stress Tolerance by Improving root Hydraulic conductance in *Solanum lycopersicum* L, they demonstrated that soil application of silicon significantly increased flower number in tomato plants.

The researchers noted that silicon improved the physiological performance of the plants, which contributed to increased flower production. This may be attributed to ability of silicon to enhance root development, improving nutrient uptake, and increasing overall plant vigor, silicon

Table 4.9: Interactive effects between silicon levels, method of application and varieties of tomato on number of flowers under field condition

Interactions between variety, silicon application levels, and application method	28 DAT	35 DAT	42 DAT	49 DAT
Basal x 100 mg/L x Zara ^{f1}	16.42 ^c	20.68 ^c	26.42 ^b	30.82 ^c
Foliar x 0 mg/L x Zara ^{f1}	9.50 ^a	13.13 ^a	19.32 ^a	22.02 ^a
Basal x 200 mg/Lx Eden ^{f1}	13.88 ^{bc}	18.33 ^{bc}	24.25 ^{ab}	25.63 ^{abc}
Basal x 50 mg/Lx Eden ^{f1}	13.97 ^{bc}	18.85 ^{bc}	22.78 ^{ab}	27.57 ^{abc}
Foliar x 100 mg/L x Eden ^{f1}	16.52 ^c	21.83 ^c	27.00 ^b	29.00 ^{bc}
Foliar x 200 mg/Lx Zara ^{f1}	12.72 ^{abc}	18.88 ^{bc}	22.08 ^{ab}	25.10 ^{abc}
Foliar x 50 mg/L x Zara ^{f1}	10.48 ^{ab}	14.70 ^{ab}	21.45 ^{ab}	22.20 ^a
Basal x 0 mg/L x Eden ^{f1}	13.78 ^{bc}	19.50 ^{bc}	20.97 ^{ab}	24.37 ^{ab}
LSD	6.17	7.05	9.04	8.26
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) *Significant F values at $P \leq 0.05$ and NS-Not significant. on can lead to better flowering and fruit set.

The combined treatment of basal application method and silicon treatment at the rate of 100 mg/L on Zara^{fl} variety recorded the highest mean values for the number of flowers as compared to the control which recorded 22.0 and 22.02 respectively in both season one and two. The results from this study revealed that silicon reduces the number of days to flowering.

This could be attributed to silicon ability to improve photosynthesis; reduction of transpiration and hormones changes thus leading to accelerated flowering (Ma and Takahashi, 2002). The present results are in parallel with those reported by Ahmad *et al.* (2013), Gonzalez-Peres *et al.*, (2014) and Khenizy and Ibrahim (2015) on gladiolus.

4.3 Effect of Silicon levels, application method and variety on pests of tomato

4.3.1 Red spider mites

The numbers of red spider mites (*Tetranychus urticae*) were significantly affected at ($p \leq 0.05$) by the different levels of silicon. Findings of the study indicated that minimum numbers of red spider mites (2.92 and 1.1) were recorded on plants with silicon treatment applied at 200mg/L, followed by Si at 100 mg/L (4.25 and 2.08) then by Si at 50 mg/L (4.67 and 2.58) and finally the control (Fig.4.10) for both season one and two respectively.

The number of red spider mites increased steadily on 28 and 45 days after transplanting when silicon was applied at 100mg/L. similarly, there was a slight increase in the population of red spider mites as from 28 days after transplanting when silicon was applied at 200 mg/L. On the contrary, the number of red spider mites decreased as from 28th days after transplanting when silicon was applied at 50mg/L. this was observed in both season one and two.

Finding of the study revealed that red spider mites were significantly affected at ($p \leq 0.05$) by different methods of silicon application. It was observed that the lowest number of red spider mites were recorded in silicon basal application (3.0 and 1.2) as compared to silicon foliar application (5.1 and 4.2) both seasons respectively. The number of red spider mites reduced further as from 42 days after transplanting in season one when silicon was applied both as basal and as foliar. Results on the mean number of red spider mites show no significant difference ($p \leq 0.05$) as influenced by tomato variety.

The findings of this study led to significant ($p \leq 0.05$) differences in the interaction between silicon application level, tomato variety and silicon application method on the mean number of red spider mites as presented in (Table 4.10).

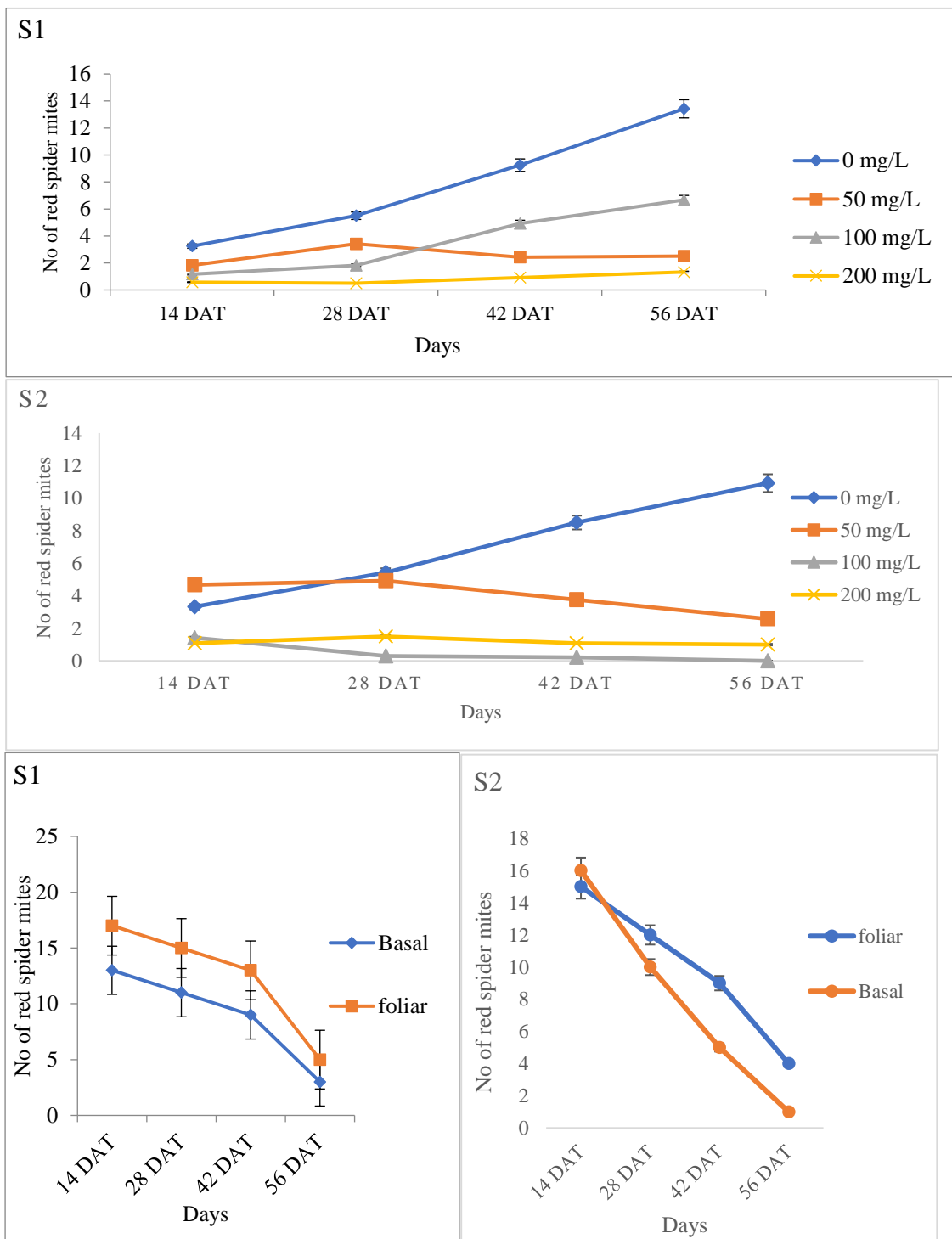


Figure 4.10: Mean numbers of red spider mites (RSM) on two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Regarding the effect of different rates of silicon on the mean number of red spider mites, research findings in Fig (4.10) indicated that application of silicon significantly reduced the number of red spider mites in tomato plants compared to the control treatment in

both seasons. The work reported here has shown that tomato plants treated with silicon at 200 mg/L recorded few numbers of red spider mites as compared to other applications. Studies have shown that silicon can enhance the plant's resistance to pest infestations, including spider mites.

These findings were similar to Kumar *et al.* (2018) who found that increasing silicon rates reduced the population of red spider mites in tomatoes. Additionally, a study by Agarwal *et al.* (2020) reported that foliar application of silicon reduced the number of red spider mites on tomato plants. Korndörfer *et al.*, (2011) also reported that high concentration of silicon in sugarcane had been observed to extend the nymphal stage of spittlebug *Mahanarva fimbriolata* Stal and shorten the adult life.

This may be attributed to the deposition of silica on epidermal layers which offers a physical barrier to insects. Sucking pests like mites and leaf eating caterpillars have a low preference for the silicified plant tissues or silicon treatment improved plant health and vigor, thereby decreasing the susceptibility to spider mite infestations.

Silicon supplementation generally enhances plant resistance to pests infestation by reinforcing physical barriers and inducing biochemical defenses. However, under condition of nutritional imbalance, silicon may indirectly contribute to plant stress which could increase susceptibility to certain pests like red spider mites as observed when silicon was applied at 100 and 200 mg/L especially in season one.

While both basal and foliar applications of silicon effectively reduce red spider mite population in tomato the information in Fig (4.9) exhibited clearly that basal application exposed significant difference and gave lowest mean values for fewer numbers of red spider mites as compared to foliar application in both seasons. This is attributed to

prolonged availability and systematic uptake, which may offer more consistent protection against mite infestations.

These results seemed to agree with those reported by Dallagnol *et al.* (2012) who found that when silicon was applied through the fertigation system; it was absorbed by plant roots, and transported through the xylem and finally deposited in the leaf epidermal cells and xylem vessels. Many other studies have also reached similar conclusions; root silicon application stimulated plants both to form physical barriers and to interact with stress response metabolism, whereas foliar applied silicon may only create a chemical–physical barrier (e.g. a change in surface pH) through its deposition on the leaf surface (Ma and Yamaji, 2015).

Table 4.10: Interactive effects between silicon levels, method of application and varieties of tomato on mean number of red spider mites under field conditions

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Basal x 100 mg/L x Zara ^{f1}	1.17 ^a	2.33 ^a	2.33 ^a	0.83 ^a
Foliar x 0 mg/L x Eden ^{f1}	2.17 ^{ab}	3.17 ^{ab}	6.50 ^{abc}	5.00 ^{ab}
Basal x 200 mg/L x Eden ^{f1}	2.83 ^{ab}	3.00 ^a	3.83 ^a	3.67 ^a
Basal x 50 mg/L x Zara ^{f1}	3.50 ^{abc}	6.17 ^{bc}	11.50 ^{de}	10.67 ^c
Foliar x 100 mg/L x Eden ^{f1}	5.50 ^c	9.50 ^d	9.33 ^{cd}	14.33 ^{cd}
Foliar x 200 mg/L x Zara ^{f1}	1.00 ^a	2.67 ^a	4.33 ^{ab}	3.17 ^a
Foliar x 50 mg/L x Eden ^{f1}	3.50 ^{abc}	6.33 ^c	8.17 ^{bcd}	9.83 ^{bc}
Basal x 0 mg/L x Zara ^{f1}	4.50 ^{bc}	10.00 ^d	15.17 ^e	17.00 ^d
LSD	1.72	1.94	2.66	3.2
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The combined treatment of soil drench at 100mg/L recorded the lowest mean values of red spider mites (0.83) on Zara^{f1} as compared to the control (17.00). These depicts that application method responded similarly to silicon levels, The differences in the mean number of red spider mites at different silicon rates could be attributed to the location where silicon is deposited in the plant and how it is deposited significantly influence plant resilience.

The effect of Si on plant resistance to pests is considered to be due to accumulation of absorbed Si in the epidermal tissue or expression of pathogenesis-induced host-defense responses. Inanaga, Okasaka, Tanaka (1995) reported that accumulated monosilicic

acid polymerizes into polysilicic acid then is transformed to amorphous silica, which forms a thickened silicon–cellulose membrane and gets associated with pectin and calcium ions. By this means, a double-cuticular layer protects and mechanically strengthens plants. Silicon also gets associated with lignin–carbohydrate complexes in the cell wall of epidermal cells.

4.3.2 Leaf miner (*Tuta absoluta*)

The numbers of *Tuta absoluta* larvae, were significantly affected ($p \leq 0.05$) by different levels of silicon. Mean values of data showed that maximum number of *T. absoluta* larvae was recorded on plants with Si applied at 0 mg/L (8.45 and 17.1), there after by Si at 50 mg/L then Si at 200 mg/L. The lowest numbers of *Tuta absoluta* were recorded at Si applied at recommended rate 100 mg/L (1.32 and 0.58). These results were consistent throughout for the two-growing season respectively (Fig. 4.11).

Finding of the study revealed that the least numbers of *T. absoluta* larvae were recorded in plots with mean foliar silicon application (5.71 and 4.5) as compared to plots with soil silicon application (4.68). Findings were statistically not significantly different ($p \leq 0.05$) on the numbers of *Tuta absoluta* larvae as influenced by different tomato variety.

Results of the mean number of *T. absoluta* larvae presented in Table 4.11 show no significant interaction at ($p \leq 0.05$) between variety, silicon rate and method of application on the mean numbers of *T. absoluta* larvae, indicating that varieties responded similarly to Si application in terms of numbers of *T. absoluta* larvae.

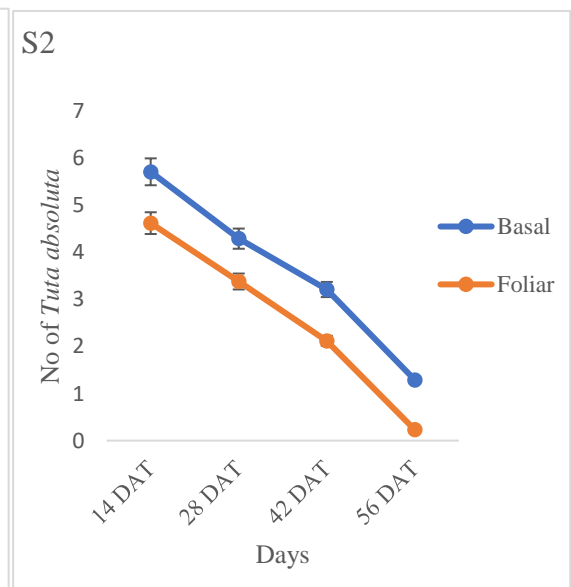
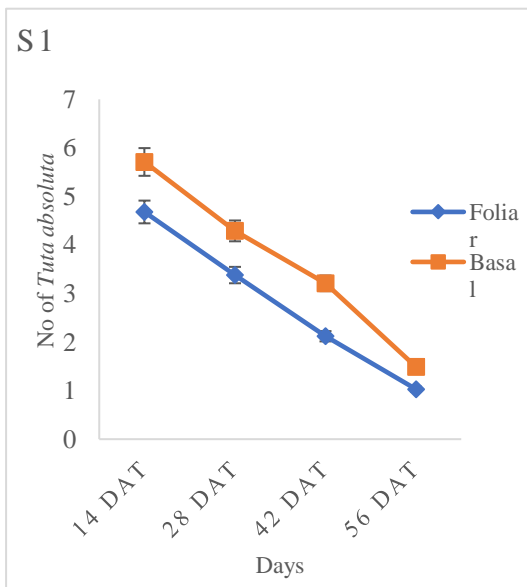
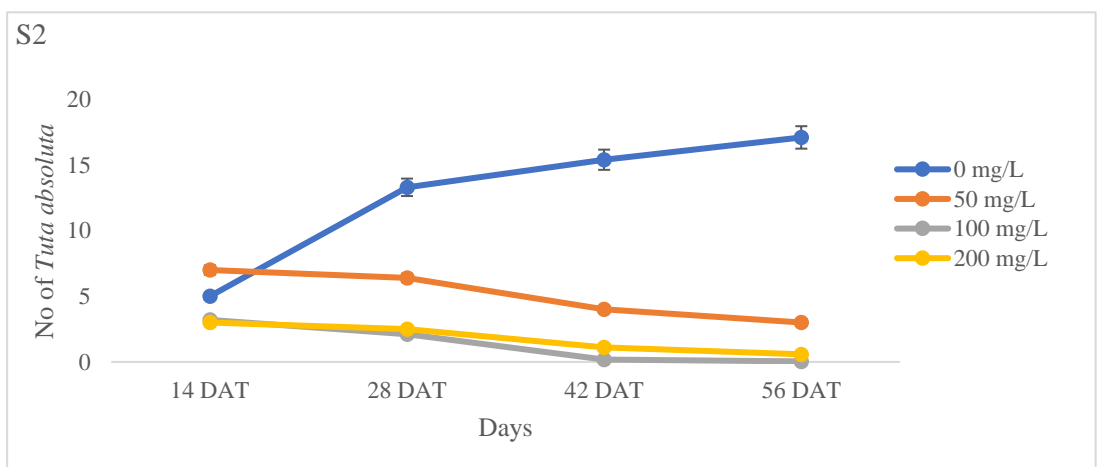
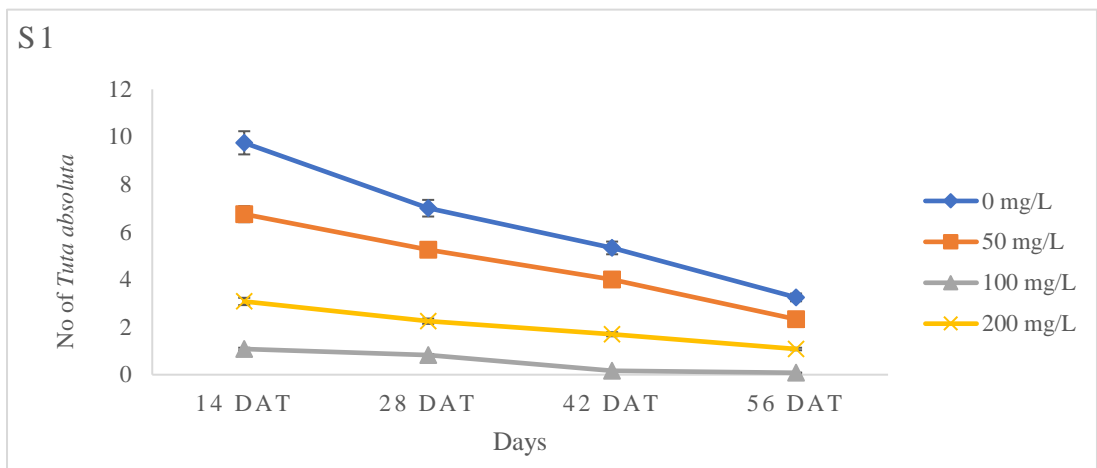


Figure 4.11: Mean numbers of *Tuta absoluta* in two tomato varieties as influenced by silicon levels and application method over two seasons under field conditions.

Concerning the effect of different levels of silicon on the numbers of *Tuta absoluta* larvae, data in Fig (4.10) indicated that silicon at 100 mg/L was the optimum rate for management of *T. absoluta* larvae. This was because increasing Si level from 100 to 200 mg/L had a directly proportional effect on mean numbers of *T. absoluta* but with no significant difference rendering it uneconomical and a waste of resources. Similar results were obtained by Hafez *et al.* (2020) who found that increasing silicon rates reduced the incidence of *Tuta absoluta* in tomato plants.

The study indicated that silicon applications improved leaf toughness and increased the production of defensive compounds, which deterred the pest and reduced its population. Another study by Ghafoor *et al.* (2021) on the effect of silicon application on tomato plants infested with *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) reported that higher rates of silicon significantly decreased the number of *Tuta absoluta* in tomatoes. The research highlighted that silicon-treated plants exhibited enhanced resistance to the pest, leading to lower infestation levels.

Sidhu *et al.* (2013) also found that Si application at recommended rate, contributed to the management of the sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), reducing the feeding injury by advertising the suitable host plant acceptance by the borers. The efficiency of silicon-containing products to control *T. absoluta* has been suggested to occur due its toxic and anti-feeding effect to the larval stage, playing a role as activator of tomato plants resistance Rodrigues *et al.* (2004). The use of silicon in controlling defoliator insects occurs due to the action of the mechanical barrier provided by the deposition of silicon mineral in the cell wall of leaves (Goussain *et al.*, 2002).

The present study shows that both foliar and basal applications of silicon can effectively control *Tuta absoluta* (the tomato borer) in tomato plants, but Silicon foliar application resulted in significantly decrease number of *T. absoluta* larvae population. These results seemed to agree with those reported by Hafez *et al.* (2020) who found that foliar silicon applications reduced *T. absoluta* infestation by improving the physical and biochemical defenses of tomato plants.

Dos Santos *et al.* (2015) indicated that application of silicon in the form of liquid foliar treatment on tomato leaves affected the mid-gut of the treated larvae of *T. absoluta* due to the toxic effect of some biochemical that simulated by the Si-foliar application. Pereira *et al.* (2003) reported that tomato is a non-accumulating silicon plant because it absorbs little silicon through the roots and the increasing level of this compound in tomato leaves is not proportional to their availability in the soil. The effect of mechanical protection of silicon in plants is attributed to its storage as amorphous silica ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) in the cell wall (Datnoff *et al.*, 2001).

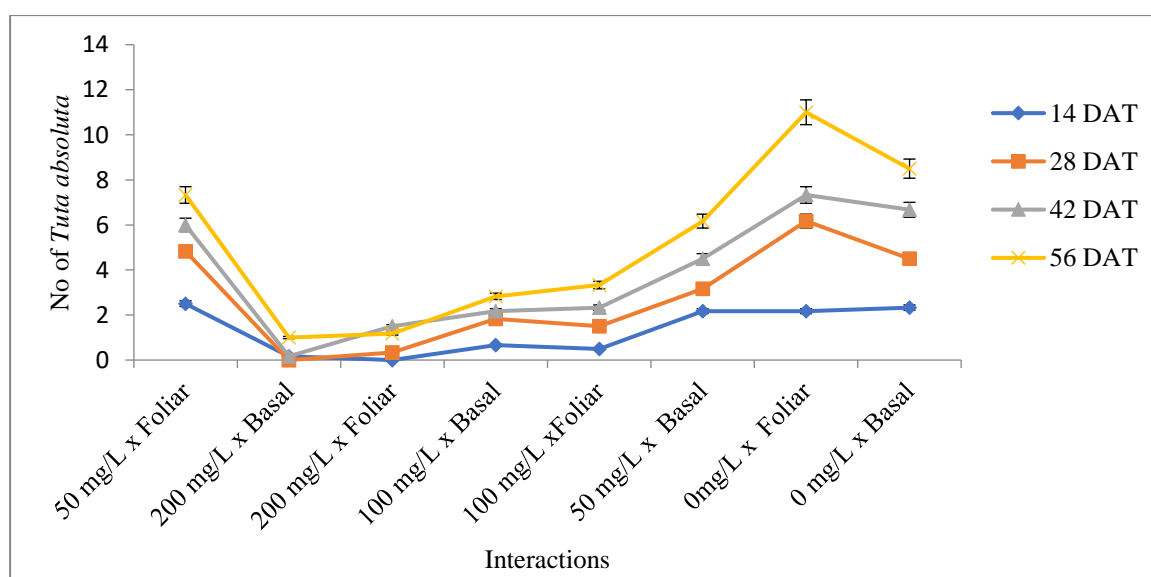


Figure 4.12: Interactive effects between silicon levels and method of application of silicon on mean number of *Tuta absoluta* under field condition

These results are similar to the finding of Daniela *et al.* (2021) on the study of tomato transcriptomic response to *Tuta absoluta* infestation, reported that the interaction between silicon (Si) application levels and tomato variety does not always result in significant differences in the population of *Tuta absoluta*. These suggests that while Si application can implore crop defenses mechanism, the combined effect of silicon level and tomato variety does not consistently lead to significant differences in *T. absoluta* populations.

This suggests that the efficacy of Si in management of *T. absoluta* may depend on specific plant-pest interactions and other environmental factors. A study on evaluation of effects of Si supplementation on different tomato cultivars, found that while Si application improved plant resistance to *T. absoluta*, the interaction between Si levels and tomato variety did not significantly influence the pest's population density.

Similarly, research on the impact of Si on various tomato genotypes (Nicolus *et al.*, (2021) reported that as much as application of silicon enhances overall plant health, the combined effect of Si levels and tomato variety did not lead to significant differences in *T. absoluta* infestation rates and these is similar to the results obtained in this study.

4.3.3 White flies

Findings of the study revealed that different levels of Silicon had significant effect ($p \leq 0.05$) on mean score of white flies (*Bemisia tabaci*). The application of silicon at the rate of 200mg/L resulted in the lowest mean score of white flies, (1.08 and 1.1) which was consistent with all the other application except the control (5 and 6) in season one and two respectively. This indicates that Si at 200 mg/L was the optimum rate for reduction in the numbers of white flies in tomato (Fig. 4.12). In season two it was

observed that the population of white flies increased between 14 DAT and 28 DAT before it started reducing again when silicon was applied at 200 mg/L as compared to the control whose population kept on increasing steadily.

White flies numbers were significantly different at ($p \leq 0.05$) by different methods of application. The research findings revealed that foliar Silicon application registered low numbers of white flies, with an average of (2.25 and 1.5) as compared to basal application (Fig. 4.12) in both season one and two respectively. There was no significant difference in the number of white flies in relation to tomato variety. Mean score of white flies presented in Table 4.12 showed significant interaction at ($p \leq 0.05$) between application method and silicon rate on the number of white flies indicating that application methods responded similarly to levels of silicon in terms of white fly numbers.

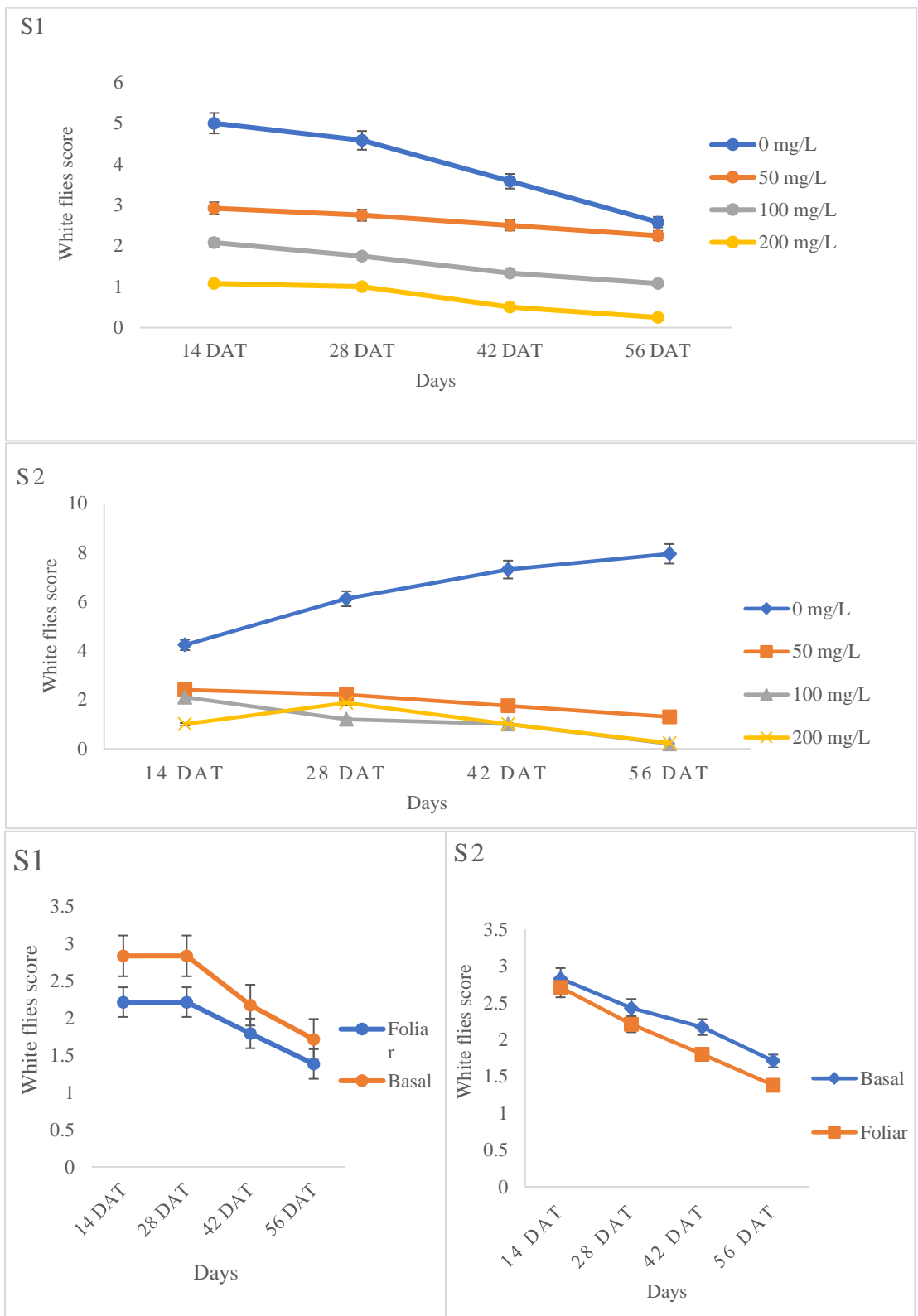


Figure 4.12: Mean score of white flies in two tomato varieties as influenced by silicon levels and application method over two seasons under field conditions

Regarding the main effect of different rates of silicon on the numbers of white flies, findings of the study, indicated that as silicon levels increases, the population density of white flies reduced significantly in both seasons. Silicon at 200 mg/L gave the best result in controlling white flies as compared to control. These results are in accordance with Alyousuf *et al.* (2022) who reported that increasing the concentration of silicon, lead to a significant decrease in the population of immature of both white-flies and tomato leaf miner on tomato crop in the greenhouse.

Agarwal *et al.* (2020) also reported that increasing silicon rates significantly reduced the number of white flies on tomato plants. The study suggested that silicon-treated plants exhibited enhanced leaf toughness and biochemical changes that deterred white fly feeding and reproduction. Additionally, Kumar *et al.* (2021) reported that the application of silicon led to a decrease in white fly populations in tomatoes, indicating that higher silicon rates could improve the plant's ability to withstand pest infestations. Correa *et al.* (2005) also reported that silicon fertilization significantly affected the pest and enhanced nymphs' mortality on cucumber.

The direct proportionality of silicon and the mean number of white flies was explained by the functions of silicon in plant to 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 (Costa *et al.* 2006).

The results of foliar-applied versus drench-applied Si showed a significant difference in white flies' numbers. The populations of the white flies in the plots with foliar application were the lowest throughout the growing season as compared to basal application. These results were in accordance with Agarwal *et al.* (2020) found that

foliar application of silicon significantly reduced white fly populations in tomatoes. Dawood *et al.* (2019) also reported that Si-foliar spraying was more effective in reducing the population density of white flies and *Tuta absoluta* compared to Si- soil drench application. Callis-Duehl *et al.* (2017) reported that application of potassium silicate solution could reduce number of *B.tabaci* on cucumber leaves. Silicon-treated plants developed tougher leaves and increased production of secondary metabolites that deterred white fly infestations.

Table 4.12: Interactive effects between variety, silicon levels and method of application on mean number of white flies under field condition

Interactions between variety, silicon application levels, and application method	14 DAT	28 DAT	42 DAT	56 DAT
Basal x 100 mg/L x Zara ^{f1}	1.00 ^{bc}	1.50 ^{bc}	1.17 ^c	2.00 ^{cd}
Foliar x 0 mg/L x Eden ^{f1}	2.67 ^a	3.67 ^a	4.83 ^a	5.00 ^a
Basal x 200 mg/L x Eden ^{f1}	0.33 ^c	0.67 ^{cd}	1.17 ^c	1.33 ^{de}
Basal x 50 mg/L x Zara ^{f1}	1.83 ^{ab}	1.83 ^b	2.50 ^b	3.00 ^b
Foliar x 100 mg/L x Eden ^{f1}	1.17 ^{bc}	1.17 ^{bcd}	2.33 ^b	2.17 ^{bcd}
Foliar x 200 mg/L x Zara ^{f1}	0.17 ^c	0.33 ^d	0.83 ^c	0.83 ^e
Foliar x 50 mg/L x Eden ^{f1}	2.67 ^a	3.17 ^a	3.00 ^b	2.83 ^{bc}
Basal x 0 mg/L x Zara ^{f1}	2.50 ^a	3.50 ^a	4.33 ^a	5.00 ^a
LSD	0.61	0.63	0.66	0.71
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The combined treatment of silicon foliar application at 200 mg/L on Zara f1 recorded, generally, the lowest mean values of white flies in tomato plants in both seasons. The

respectively estimated mean value was (0.83) as compared to control treatment. These results seemed to agree with those reported by Ramirez *et al.* (2018) and Desher *et al.* (2022) who demonstrated that foliar silicon applications significantly decreased populations of white flies and tomato leaf miners in greenhouse-grown tomatoes.

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 Liang *et al.* (2015) that preventing the feeding of phytophagous insect and reducing the host acceptance and suitability. Moreover, Si applications enhances chemical plant resistance against pests by increasing the levels of vital biochemical such as phenols (Hall *et al.*, 2020)

4.4 Effect of Silicon rate, application method and variety on pathogens in tomato

4.4.1 Bacterial wilts (*Ralstonia solanacearum*)

Population of *R. solanacearum* was significantly ($p \leq 0.05$) reduced by different levels of silicon fertilizer. Mean severity score was significantly lower at Si application of 200 mg/L (1% and 1.17%) in both season one and two respectively. From 60 to 80 days after transplanting, disease progression slowed in all treatments particularly in plots treated with 50, 100 and 200 mg/L in season one. Fluctuations were also observed in plots that were treated with 50 mg/L as from day 20 to 60 days after transplanting in season two. These could be attributed to environmental factors or host response variability. The increase in disease incidences was minimal in plots with 100 and 200 mg/L throughout the second season, suggesting that silicon may have temporarily enhanced the plant resistance or showed pathogen progression. Meanwhile, control plots continued rise steadily.

Bacterial wilt incidence reduced steadily in all treatments over 80 days after transplanting. However, research findings revealed that mean wilt incidence were significantly ($p \leq 0.05$) lower in plots with soil silicon application as compared to plots with foliar silicon application. By 40th days after transplanting, control plots have 50% wilted plants, foliar-treated plots had (4 and 4.5 5%) while basal treated plots had only (0 and 2%) respectively. There was no significant difference in the wilt incidence and severity index in relation to tomato variety.

The finding of the interaction between the application methods “spray or soil drench” silicon levels and variety on bacterial wilt incidences were significant ($p \leq 0.05$) in both seasons (Table 4.13).

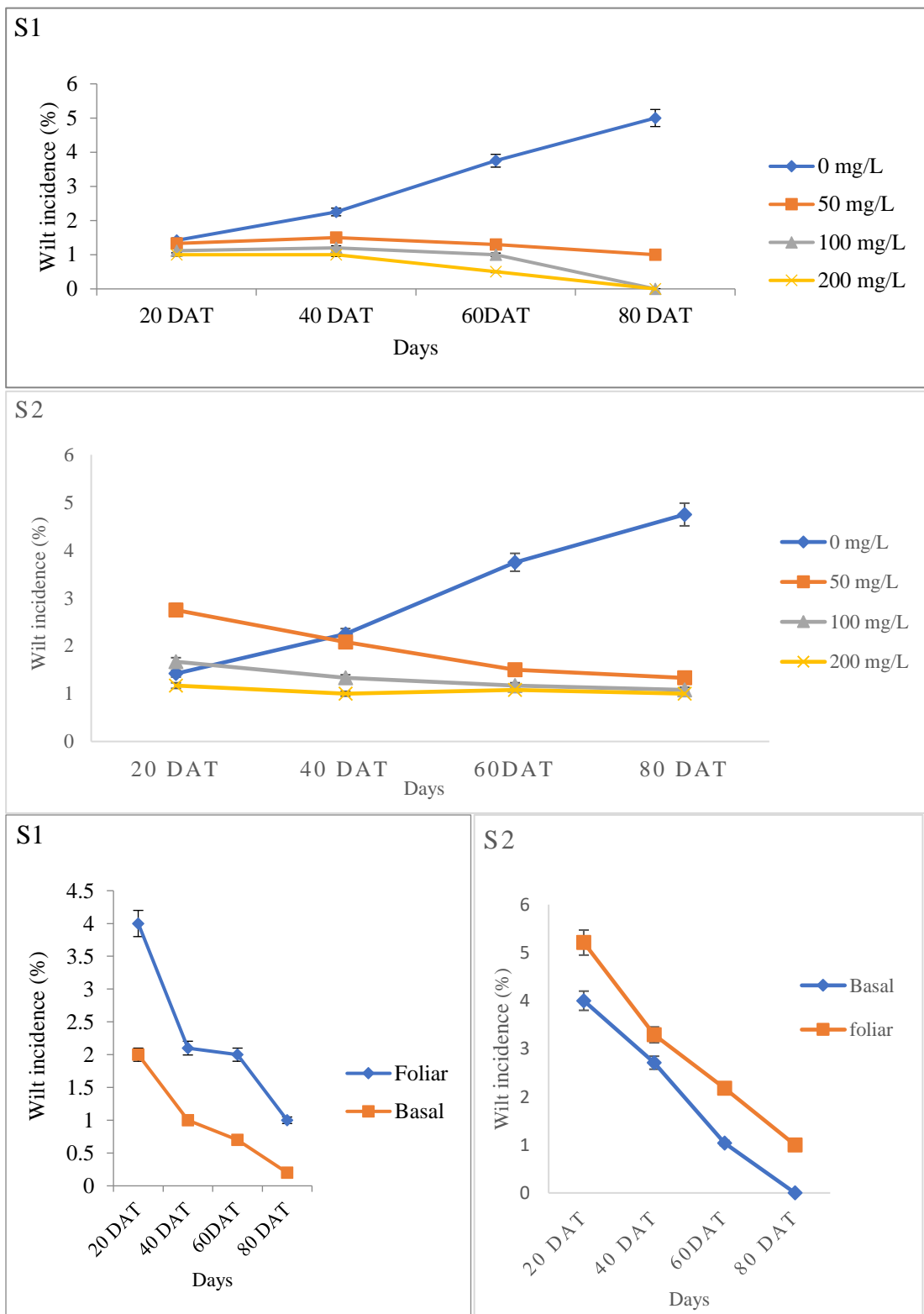


Figure 4.13: Mean bacterial wilt incidence in two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Mean wilt incidence in tomato plant was significantly lower for plots with silicon fertilizer applied at 200 mg/L. Therefore, *R. solanacearum* concentration was less pronounced at higher silicon treatment as compared to the control in both seasons. The results compliment the reports of Wang et al., (2022) found that applying silicon to tomato plants significantly reduced the incidence and severity of bacterial wilt by 46.2-72.2% and inhibits the Virulence-Related Gene Expression of *Ralstonia solanacearum*. The study emphasized that silicon applications enhanced the overall health of the plants, making them less susceptible to infection.

Dannon and Wydra (2004) reported that silicon (Si) has a significant effect in reducing bacterial wilt incidence in tomato in a hydroponics culture system, and peat substrate. They also reported an induced basal resistance on cell wall level, in silicon treated tomato plants compared to non-treated plants. Some studies suggest that the enhanced resistance to disease in Si-accumulating plants has been linked with mechanical barriers, due to accumulation and polymerization of Si in different organs and limited pathogen penetration and invasion Ghareeb *et al.* (2011).

Research also indicated that silicon improved the plant's defense mechanisms, including increased production of phenolic compounds and enhanced root structure, which contributed to better resistance against bacterial pathogens. Studies also showed that Si may play a more active role in enhancing plant resistance to pathogen infection by activating the defense responses in the host, including the production of defense proteins, antimicrobial compounds Kiiirika *et al.* 2013.

Concerning the effect of application methods “spray or soil drench” on the number of tomato plants affected with bacterial wilt, obtained results presented showed that the two application methods of silicon significantly reduced the disease severity index.

However, drench application gave the lowest mean value of plants affected by bacterial wilt as compared to foliar application in both seasons. The difference became more pronounced over time, suggesting a cumulative protective effect of basal silicon. In contrast, foliar application reduced disease incidence compared to the control but was less effective than basal application.

These results were in agreement to those reported by (Dannon and Wydra 2004; Diogo and Wydra 2007). They found that Si amendments reduced disease incidence and bacterial populations in tomato stems, suggesting that Si contributes to plant resistance mechanisms. Research further explored this by showing that Si-induced resistance is associated with modifications in the pectic polysaccharide structure of cell walls, which may hinder pathogen progression within the plant.

A significant interaction was found between silicon application, method of application, and tomato variety ($p < 0.05$), indicating that silicon's effectiveness varies depending on how it is applied and which variety is used. The Zara variety responded best to soil-incorporated silicon, demonstrating the importance of optimized nutrient delivery strategies for specific cultivars.

Table 4.13: Interactive effects between variety, silicon levels and method of application on mean population of *Ralstonia solanacearum* under field condition

Interactions between variety, silicon application levels, and application method	20 DAT	40 DAT	60 DAT	80 DAT
Basal x 100 mg/Lx Zara ^{f1}	1.00 ^a	1.17 ^{bc}	2.00 ^{bc}	2.30 ^{bc}
Foliar x 0 mg/L x Eden ^{f1}	1.17 ^a	2.17 ^{ab}	3.33 ^{ab}	4.83 ^a
Basal x 200 mg/L x Zara ^{f1}	1.00 ^a	1.00 ^c	1.00 ^c	1.17 ^d
Basal x 50 mg/Lx Eden ^{f1}	1.33 ^a	1.33 ^{abc}	2.17 ^{bc}	2.67 ^{bc}
Foliar x 100 mg/L x Eden ^{f1}	1.00 ^a	1.16 ^{bc}	1.33 ^c	1.50 ^d
Foliar x 200 mg/L x Zara ^{f1}	1.00 ^a	1.17 ^{bc}	1.00 ^c	1.17 ^d
Foliar x 50 mg/Lx Zara ^{f1}	1.33 ^b	1.67 ^{abc}	2.00 ^{bc}	2.83 ^b
Basal x 0 mg/L x Zara ^{f1}	1.67 ^a	2.33 ^a	4.17 ^a	4.67 ^a
LSD	0.44	0.65	0.89	0.9
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The statistical analysis revealed that the lowest mean values of *R. solanacearum* population was achieved when plants received 200mg/L silicon as soil drench in Zara ^{f1} plots in both seasons. At 200 mg/L the estimated population was (1.17) compared to the control treatment. These results suggest that the response of tomato plants to silicon is not uniform across application methods or cultivars. The Zara variety, in particular, appears more responsive to soil-incorporated silicon, possibly due to improved root uptake or varietal-specific physiological traits. This highlights the importance of selecting both the appropriate application method and variety to maximize the benefits of silicon supplementation.

The present results corroborate with the findings of Ayana *et al.* (2011) who reported that silicon fertilizer at a rate of 15 kg per 100 m² significantly reduced the mean wilt incidence caused by *R. solanacearum*.

Given that the application method responded similarly to Si application rate, the differences in *R. solanacearum* population may be attributed to the application method where by applying silicon to the roots was more effective in decreasing several bacterial diseases (bacterial blight and bacterial streak on rice, bacterial streak on wheat, bacterial wilt on tomato and sweet pepper, bacterial spot-on passion fruit, and bacterial blotch melon). In tomato plants, Si mainly accumulates in the roots rather than stems or leaves, and Si is involved in induced resistance against *R. solanacearum* on cell wall level (Dannon and Wydra 2004; Diogo and Wydra, 2007).

4.4.2 Powdery mildew

The incidence of powdery mildew (*Leveillula taurica*) was significantly affected by silicon application levels ($p \leq 0.05$). as silicon concentration increased, disease incidence decreased consistently. Mean PM incidence in the control treatment 0 mg/L was (4.58% and 4.2%), whereas plants treated with silicon at 200 mg/L had a significantly lower incidence of (1.25% and 2%) in both seasons one and two respectively. Intermediate interactions were observed at 50 mg/L (3.00 % and 1.08%) and 100 mg/L (1.58% and 1.08%) silicon treatments. In season two, the results showed a significant reduction in disease incidence from 4.58% (control) to 4% silicon application. However, at 200mg/L Si, a slight but statistically significant increase in PM incidence was observed between 40 and 60 days after transplanting, there after it remained constant.

The effect of silicon application method on powdery mildew incidence was assessed across the entire season. The study revealed that foliar application of silicon significantly ($p \leq 0.05$) controlled powdery mildew disease in tomato compared to silicon soil application (Fig 4.14) powdery mildew incidences for foliar application recorded least score of (1.00% and 1.08%) while basal application had the highest powdery mildew score (2.6% and 1.09%) in both season one and two respectively. In foliar treated plants, disease progression was noticeably delayed and remained low throughout the experiment.

Mean score of powdery mildew presented in Table 4.14 showed significant interaction ($p \leq 0.05$) between silicon application method, silicon levels and tomato variety on the powdery mildew score. Indicating that the effect of silicon on plant performance varied depending on both the application method, silicon rate and the variety used.

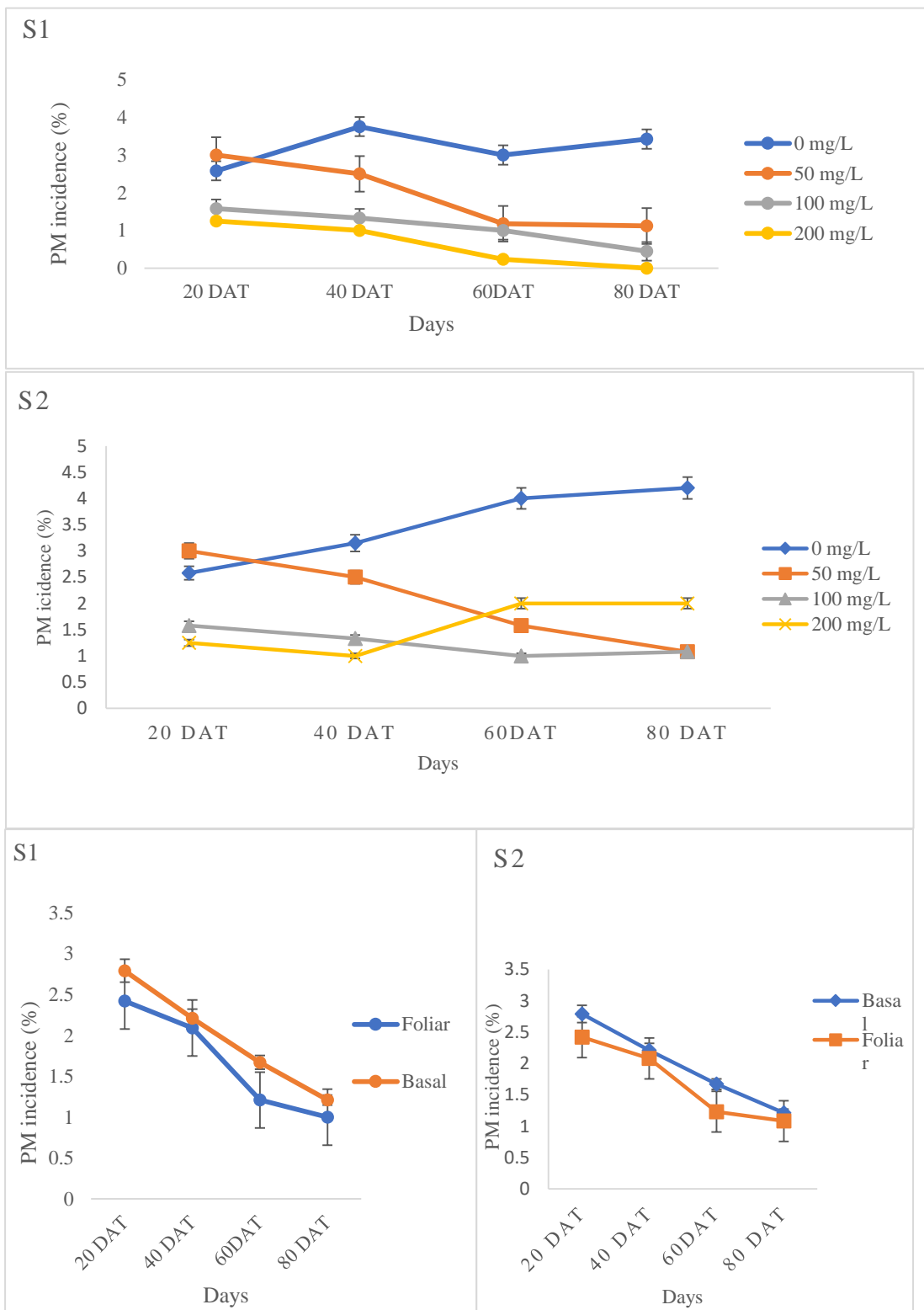


Figure 4.14: Mean powdery mildew score of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

The findings of the study demonstrated a clear inverse relationship between silicon concentration and powdery mildew incidence in tomato. The observation trend suggests that silicon supplementation enhances plant resistance, likely by strengthening cell walls and activating systemic defense response. These findings are consistent with prior studies showing the protective role of silicon against foliar pathogens like powdery mildew.

Sahli *et al.* (2019) found that higher rates of silicon application significantly reduced the incidence and severity of powdery mildew in tomato plants. Additionally, Seyed *et al.* (2020) reported similar findings, where different rates of silicon application resulted in reduced powdery mildew severity in tomatoes. Studies showed that plants that received silicon were more resilient under the stresses of fungal diseases such as powdery mildew, rust, and leaf spot.

One explanation for this is that the accumulation of silicon in the form of amorphous silica forms a barrier to prevent penetration by the pathogen. Research has shown that silicon treatment of strawberry plants increased leaf cuticle thickness, density of leaf wax and numbers of leaf trichomes (Jin, 2016). Silicon treated coffee seedlings developed a thicker epicuticular wax layer Pozza *et al.* (2015), suggesting that silicon induces the formation of physical defense barriers against attack by pathogens and pests (Wang *et al.*, 2017).

The findings of the research indicated a non-linear response of powdery mildew incidence to silicon supplementation. While low to moderate Si levels significantly reduces powdery mildew incidence likely due to enhanced structural and biochemical defenses, the application of 200mg/L of silicon resulted in a modest increase in powdery mildew compared to the other rates of silicon. These may be attributed to

nutrient imbalance induced by high levels of silicon or it may be due to altered plant physiology that dampens stress responses (Debona *et al.*, 2017).

Concerning the effect of application methods “spray or soil drench” on powdery mildew, obtained results presented in (Fig 4.14) show that the two application methods of silicon significantly affected the disease incidence. Spray application gave the lowest mean value of powdery mildew spores as compared to soil application in both seasons. Current findings were in agreement with the results of Bowen *et al.* (1992) who reported that Powdery mildew severity in grape leaves was reduced to 11% of the control leaves when foliar Si sprays were used. Also, foliar application of soluble Si reduced the powdery mildew severity of common beans (Rodrigues *et al.*, 2005a) and soybeans (Rodrigues *et al.*, 2005b).

In powdery mildew of wheat (Bélanger *et al.*, 2003) reported a suppressive effect of silicon and its mode of action against powdery mildew on wheat. Si applied on foliage was effective even without establishing a physical barrier (Morales *et al.*, 2006). Thus, increased plant resistance to diseases through Si treatment is associated with active and/or passive mechanisms Datnoff *et al.* (2007) and Rodrigues *et al.* (2004) reported that plant’s defense mechanisms have been triggered by silicon.

Table 4.14: Interactive effects between variety, silicon levels and method of application on powdery mildew under field condition

Interactions between variety, silicon application levels, and application method	20 DAT	40 DAT	60 DAT	80 DAT
Basal x 100 mg/L x Zara ^{f1}	9.67 ^{ab}	17.33 ^{bcd}	28.50 ^{bc}	38.50 ^b
Foliar x 0 mg/L x Eden ^{f1}	10.67 ^b	20.50 ^d	31.67 ^c	40.50 ^b
Basal x 200 mg/Lx Eden ^{f1}	8.00 ^a	11.17 ^a	17.00 ^a	26.67 ^a
Basal x 50 mg/Lx Zara ^{f1}	9.00 ^{ab}	16.50 ^{bcd}	27.00 ^{bc}	34.33 ^b
Foliar x 100 mg/L x Eden ^{f1}	8.83 ^{ab}	19.50 ^{cd}	30.33 ^c	37.50 ^b
Foliar x 200 mg/L x Zara ^{f1}	8.00 ^a	13.33 ^{ab}	20.33 ^a	26.83 ^a
Foliar x 50 mg/L x Eden ^{f1}	8.17 ^a	14.83 ^{abc}	22.50 ^{ab}	34.00 ^b
Basal x 0 mg/L x Zara ^{f1}	8.17 ^a	18.67 ^{cd}	28.00 ^{bc}	35.00 ^b
LSD	1.48	3.21	4.02	4.14
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * Significant F values at $P \leq 0.05$ and NS-Not significant

The combined treatment of silicon at 200 mg/L on Eden variety as soil drench recorded generally, the lowest mean values of powdery mildew in both seasons. Disease suppression was correlated with treatment type, suggesting that direct foliar uptake is more critical in defense activation than root-mediated silicon translocation.

This finding agrees with the findings of Seyed *et al.* (2020) who postulated that silicon basal application at high rate, reduced powdery mildew in cucumber (*Cucumis sativus*). Sahli *et al.* (2019) reported that basal application of silicon led to a significant reduction in powdery mildew severity in tomato plants. Silicon plays a role in inducing plant natural defense responses, by interacting with a number of key components of plant stress signaling systems Fauteux *et al.* (2005). For example, soluble silicon treated

cucumber and rice demonstrated increased accumulation of phenolics and phytoalexins when infected by powdery mildew and blast.

4.4.3 Tomato Blight (*Phytophthora infestans*)

The application of silicon at varying concentrations significantly ($p \leq 0.05$) influenced the development and severity of tomato blight (*Phytophthora infestans*) over 80 days experimental period under field condition for the two seasons. The control treatment (0 mg/L) recorded the highest severity at (40% and 50%) while silicon application at 200mg/L exhibited the lowest severity at (10% and 6.75%) respectively in two seasons respectively (Fig 4.16).

Tomato blight was significantly affected ($p \leq 0.05$) by different method of silicon application. Mean plots with silicon basal application had few numbers of tomatoes affected with blight (and 60% and 58%) as compared to mean plots with silicon foliar application (70% and 68 %) in both season one and two respectively (Fig.4.15).

Results of tomato blight for two tomato varieties carried out in the field for both seasons, presented in Table 4.15 show significant interaction ($p \leq 0.05$) between tomato variety, application method and silicon levels on tomato blight infection, indicating that indicating that the effect of silicon on plant performance varied depending on both the application method, silicon rate and tomato variety used.

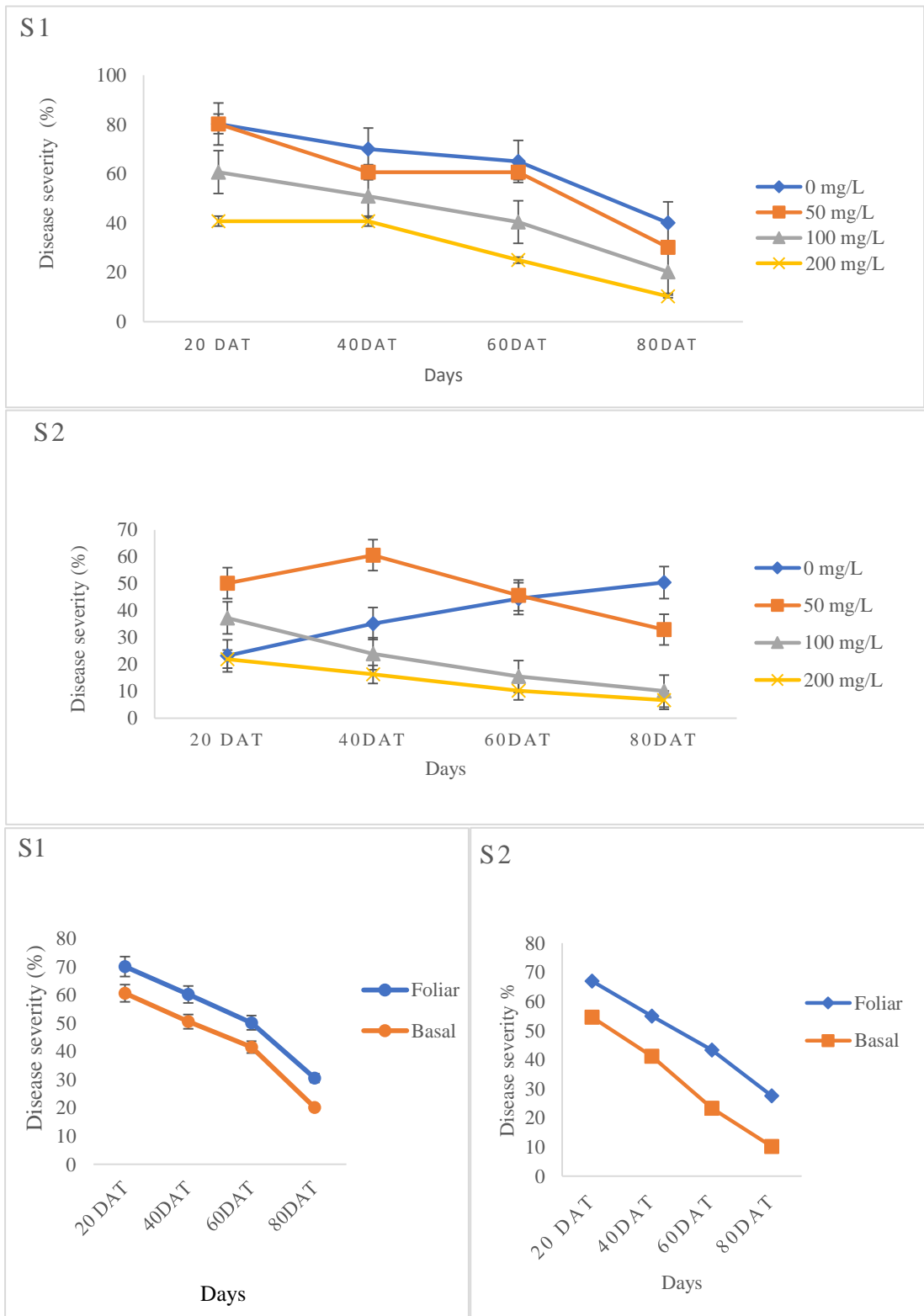


Figure 4.15: Mean tomato blight incidence of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Relating to the effect of different levels of silicon on tomato blight, results indicated a clear inverse relationship between silicon concentration and disease severity. The control treatment (0 mg/L) of silicon exhibited the highest blight severity. In contrast, plants treated with silicon showed reduced disease severity, with the most pronounced effect observed at the highest concentration (200 mg/L). Severity decreased progressively from 50 mg/L to 100 mg/L and it was lowest at 200 mg/L.

Present results are in accordance to Jia *et al.* (2020) found that silicon application reduced the severity of late blight caused by *Phytophthora infestans* in tomato plants. Additionally, Gulzar *et al.* (2021) reported that Si-treated tomato plants showed improved resistance to *Alternaria solani* as there was delay in symptoms and reduced disease severity than non-Si-treated plants.

The study indicated that silicon improved plant health and increased resistance to bacterial infection. Research has proven that higher rates of silicon enhanced the plants' defense mechanisms, including increased production of defensive compounds and improved leaf structure, which contributed to better disease resistance. These may also be due to resistance of tomato plants to *Phytophthora* blight or may be due to host morphological changes and a decrease in the amounts of mineral nutrients such as nitrogen, phosphorus, potassium, calcium and magnesium.

Concerning the effect of application methods “spray or soil drench” on blight incidence, the obtained results presented in (Fig 4.15) showed that the two application methods of silicon significantly affected the disease severity index. However, soil application method gave the lowest mean value of blight incidence as compared to spray application in both seasons. The observed superior efficacy on basal silicon application

in mitigating tomato blight, can be attributed to several physiological mechanism. When silicon is applied basically, it becomes readily available for uptake by the tomato plant root system. This uptake is primary through passive absorption and facilitated by silicon transporters in the root cells. Once absorbed, silicon is then translocated via the xylem to the aerial parts of the plant where it is deposited. (Ma and Yamaji 2006, Mitani *et al.*, 2009)

Current findings were in agreement with the results of Voogt and Sonneveld (2001), for plants of sweet pepper (*Capsicum frutescens*) grown in soil or in a soil-less medium and supplied only with ambient Si in the root environment. Moreover, Ronald *et al.* (2010) suggested that supplying Si to bell pepper can suppress Phytophthora blight development while enhancing plant development.

Table 4.15: Interactive effects between variety, silicon levels and method of application on tomato blight under field condition

Interactions between variety, silicon application levels, and application method	20 DAT	40 DAT	60 DAT	80 DAT
Basal x 100 mg/L x Zara ^{f1}	3.72 ^{ab}	5.05 ^{bc}	5.83 ^{bc}	6.60 ^{bc}
Foliar x 0 mg/L x Eden ^{f1}	4.28 ^a	6.58 ^a	7.33 ^{ab}	7.77 ^{ab}
Basal x 200 mg/Lx Eden ^{f1}	2.47 ^b	4.45 ^{bc}	4.73 ^c	5.78 ^c
Basal x 50 mg/L x Zara ^{f1}	4.62 ^a	4.97 ^{bc}	6.75 ^{ab}	7.93 ^{ab}
Foliar x 100 mg/L x Eden ^{f1}	3.9 ^{ab}	5.63 ^{ab}	7.32 ^{ab}	8.52 ^a
Foliar x 200 mg/L x Zara ^{f1}	2.39 ^b	3.95 ^c	4.88 ^c	5.82 ^c
Foliar x 50 mg/L x Eden ^{f1}	4.53 ^a	5.33 ^{abc}	6.10 ^{bc}	6.75 ^{bc}
Basal x 0 mg/L x Eden ^{f1}	5.12 ^a	6.75 ^a	8.00 ^a	9.38 ^a
LSD	1.09	0.94	1.00	1.23
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * Significant F values at $P \leq 0.05$ and NS-Not significant

The interaction effects between silicon application method “spray or soil drench” and silicon levels on tomato blight were significant in both seasons (Table 4.15). The combined treatment of soil drench and silicon at 200 mg/L recorded the lowest mean values for tomato infected with blight. The present results agree with the findings of Jia *et al.* (2020) found that high silicon rate applied at the root zone led to a notable reduction in the severity of late blight caused by *Phytophthora infestans*. These may be due to prophylactic effects against pathogens induced by Si are hypothesized to act through tissue fortification at the sites of deposition, and are believed to activate defense mechanisms against pathogens (Cherif *et al.*, 1992; Datnoff *et al.*, 2001).

Furthermore, basal silicon application appears to enhance the plant's natural defense responses. Studies suggest that silicon can activate various signaling pathways within the plant, leading to the priming of defense genes and the accumulation of defense related compounds. This induces systemic resistance means that the plant is better prepared to mount a rapid and robust defense response when challenged by the blight pathogen. (Liang *et al.*,2015).

4.5 Effect of Silicon levels, application method, and variety on tomato fruit quality parameters

4.5.1 Vitamin C

Research finding regarding ascorbic acids indicated that different levels of silicon had significant difference at ($p \leq 0.05$) on fruit chemical quality. The findings showed highest ascorbic acid accumulation recorded in plants applied with Si at 100 mg/L (21.25 and 22.12 mg/100g). There after followed by Si at 200 mg/L (15.97 and 16.44 mg/100g), then Si at 50mg/L (14.02 and 11.12 mg/100g). The control (1.9 and 5.88mg/100g) resulted in minimum ascorbic acid concentration(Fig.4.15). These findings were consisted throughout the harvesting period for the two growing seasons respectively. Results of ascorbic acids based on application method basal and foliar in two seasons under field conditions, showed no significant difference at ($p \leq 0.05$). There was also no statistical significance difference at ($p \leq 0.05$) on ascorbic acid concentration as influenced by tomato variety.

Results of Vitamin C concentration for two tomato varieties carried out in the field for both seasons, presented in Table 4.16 show significant interaction at ($p \leq 0.05$) between application method tomato variety and Silicon rate, indicating that application methods

responded similarly to Si application in terms of Vitamin C concentration.

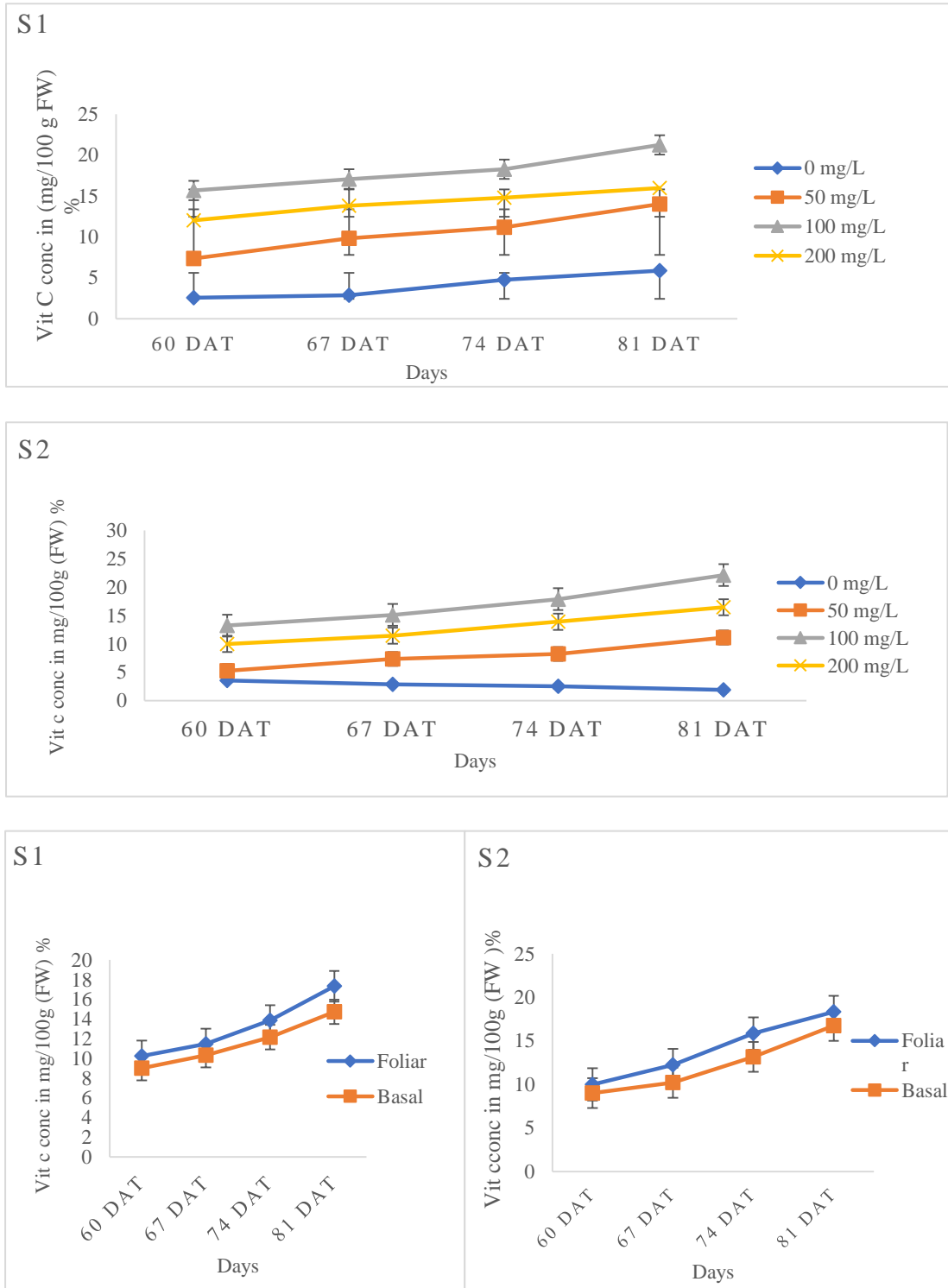


Figure 4.16: Mean Vitamin C concentration of two tomato varieties in response to silicon levels and application method over two seasons under field conditions

Silicon at 100 mg/L was the optimum rate for best results in maximum vitamin C accumulation. This was because increasing Si level from 100 to 200 mg/L had a directly proportional effect on the maximum Vitamin C concentration but with no significant difference. Silicon treated tomatoes showed the highest Vitamin C at harvest time thereby noting the control recorded the lowest vitamin C. these suggest a dose dependent relationship where silicon initially promotes vitamin C synthesis or accumulation, reaching an optimal point before higher concentration potentially become less effective.

The present results are in agreement with those obtained by several authors; Khan *et al.* (2021) investigated the effects of varying silicon levels on the nutritional quality of tomatoes and found that higher silicon rates significantly increased the vitamin C content in tomato fruits. (Islam *et al.*, 2018) reported that Si treatment showed the highest vit C content in a dose-dependent manner in comparison with treatment control in tomato. The Si treatment at 0.35g showed the highest vitamin content C probably due to a lower metabolic activity. Nonetheless, the vitamin C content also could be dependent on the tomato cultivar, temperature, and maturity stages additionally; Fageria *et al.* (2016) also reported that silicon application increased the vitamin C concentration in tomatoes.

The Si-treated pomegranate showed the highest vitamin C content as compared to the control. In Greece, while growing tomatoes in hydroponics, it was found that fertilization with silicon increased fruit hardness, beta-carotene, and lycopene content, as well as dry matter and vitamin C content Stamatakis *et al.* (2003). These results were also similar to Abd-Alkarim *et al.* (2017) that reported application of potassium silicate at all growth stages significantly increased ascorbic acid content in cucumber fruits.

These may be due to the ability of silicon to enhance photosynthetic activity and nutrient uptake, leading to higher levels of vitamin C or silicon ability to improve the overall stress tolerance of the plants, contributing to better fruit quality, including higher vitamin C levels.

Concerning the effect of application methods “spray or soil drench” on vitamin C concentration, results presented in (Fig 4.16) showed that the two application methods of silicon significantly affect vitamin C concentration. Research indicates that silicon (Si) application can enhance the ascorbic acid (vitamin C) content in tomatoes. A study by Lei *et al.* (2024) demonstrated that Si application increased vitamin C levels in cherry tomatoes under both high and low nitrogen conditions.

However, the study did not specify whether the Si was applied via foliar sprays or soil amendments. Similarly, another study found that foliar spraying of $1.2 \text{ mmol}\cdot\text{L}^{-1}$ Si improved the nutritional quality of tomato fruits, including increased vitamin C content. This suggests that Si application, regardless of the method, can positively influence ascorbic acid levels in tomatoes. The effect of Si supplements on ascorbic acid content varied; both foliar and soil Si treatments significantly increased the ascorbic acid content compared with the control.

Table 4.16: Interactive effects between variety, silicon levels and method of application on vitamin C concentration in mg/100g under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/L x Eden ^{F1}	15.44 ^a	16.67 ^a	19.00 ^b	24.39 ^a
Foliar x 0 mg/L x Zara ^{f1}	1.58 ^f	1.74 ^e	4.41 ^e	5.51 ^a
Basal x 200 mg/L Zara ^{f1}	13.30 ^b	14.05 ^b	15.07 ^c	18.35 ^a
Basal x 50 mg/L x Eden ^{F1}	8.21 ^c	10.34 ^c	11.68 ^d	15.21 ^b
Foliar x 100 mg/L x Zara ^{f1}	15.92 ^a	17.49 ^a	23.50 ^a	29.54 ^a
Foliar x 200 mg/Lx Eden ^{F1}	12.55 ^b	13.59 ^b	14.53 ^c	16.23 ^b
Foliar x 50 mg/L x Zara ^{f1}	6.49 ^d	9.33 ^c	10.70 ^d	12.84 ^a
Basal x 0 mg/L x Eden ^{F1}	3.54 ^e	3.98 ^d	5.13 ^e	6.24 ^a
LSD	1.06	0.68	1.01	1.11
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * Significant F values at $P \leq 0.05$ and NS-Not significant

The interaction effects between the application methods “spray or soil drench” and silicon levels on vitamin C concentration were significant in both seasons (Table 4.16). The combined treatment of soil drench and silicon at 100 mg/L recorded the highest mean values for ascorbic acid concentration. The findings of the present investigation are in close conformity with (Mady, 2009) revealed that the Silicon application treatment at 50 ppm with vitamin E has significant and better effect on tomato yield and fruits quality parameters comparing with using 100 ppm of Silicon application.

This enhancement effects of Si and SA 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 (Al-Aghabary *et al.*, 2005) and (Liang *et al.*, 2005).

4.5.2 Calcium

Application of silicon significantly affected calcium concentration in tomato fruits ($p \leq 0.05$). Calcium content increased with increasing silicon levels, reaching maximum at 100 mg/L (16.46 and mg/100g). which was significantly higher than the control (0 mg/L) and 50 mg/L treatments in both season one and two respectively. However, further increase to 200 mg/L did not result in a statistically significant difference compared to 100 mg/L, indicating a plateau in calcium accumulation beyond this concentration in both seasons (Fig 4.17).

There was significance ($p \leq 0.05$) in the mean calcium concentration in fruits for plants grown under field condition in response to application method. The findings of this study showed a high mean Ca concentration (13.51 and 15 mg/100g) for silicon soil application as compared to silicon foliar application (10.82 and 12.51 mg/100g) in both two seasons (Fig 4.17) in both seasons respectively. Results of calcium concentration in relation to tomato varieties in two seasons under field conditions, showed no significant difference at ($p \leq 0.05$).

The study results showed significant interactive dissimilarities ($p \leq 0.05$) between tomato varieties, Si application method and silicon application levels on the Ca concentration in fruits, indicating that application method responded similarly to levels of silicon in terms of Ca uptake Table 4.17.

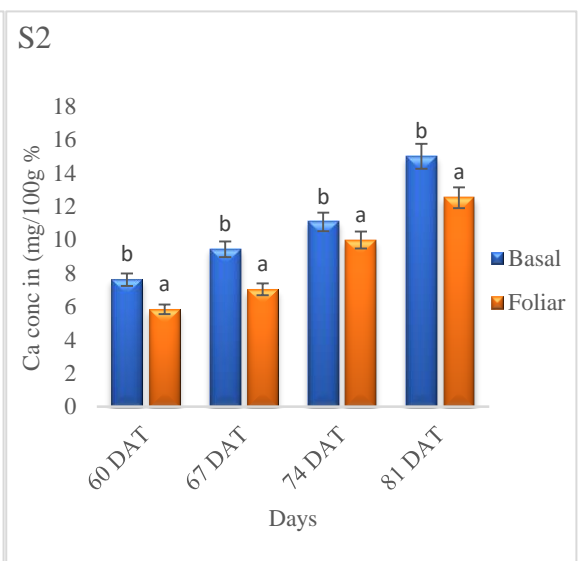
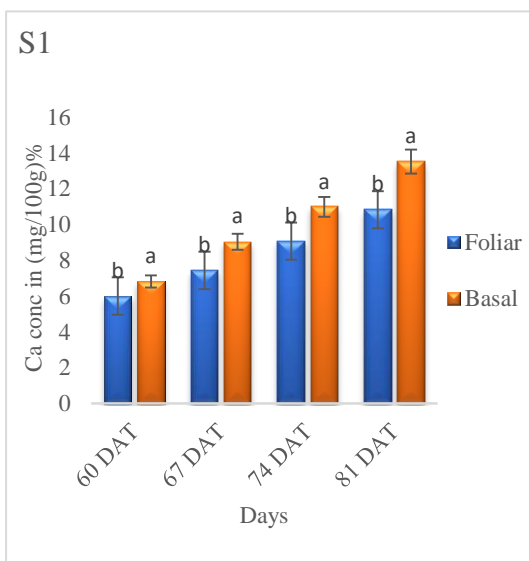
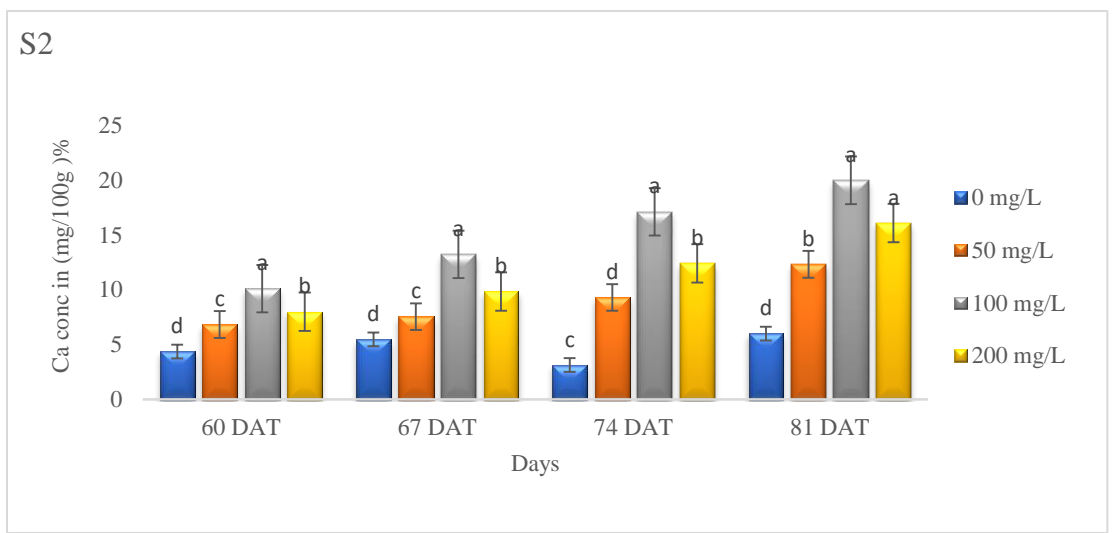
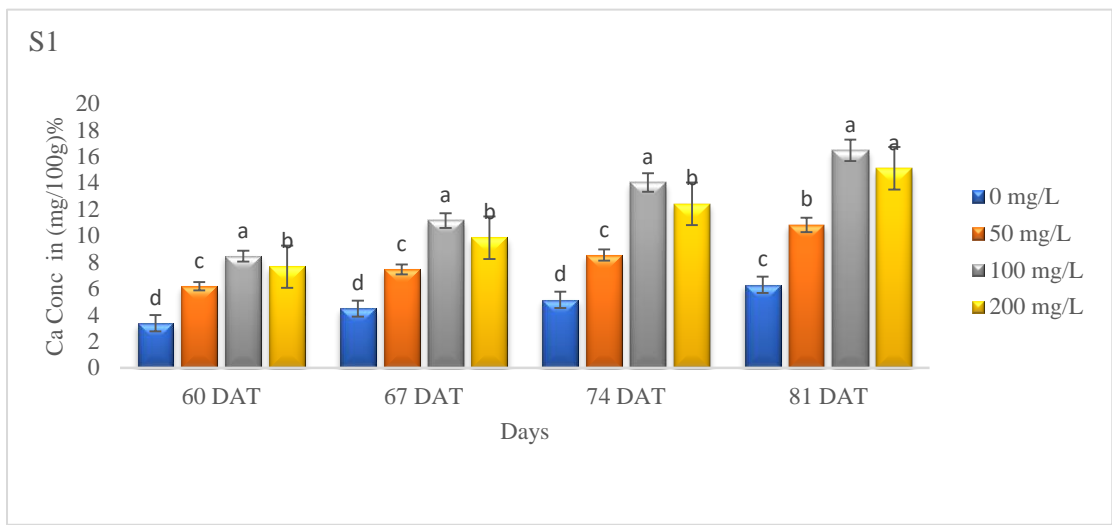


Figure 4.17: Mean Calcium concentration of two tomato varieties in relation to silicon levels and application method over two seasons under field conditions

Pertaining the main effect of different rates of silicon on calcium concentration, data in Fig (4.17) indicated that optimum application of silicon significantly increased calcium concentration in tomato fruits. Silicon application at 100mg/L was the optimum rate for best results for maximum calcium concentration. This was because increasing Si level from 100 to 200 mg/L had a directly proportional effect on the maximum Ca concentration but with no significant difference. The study demonstrated that the presence of silicon improved the plants' ability to absorb calcium from the soil, resulting in higher calcium concentrations in fruits. Moreover, this effect can result from binding of calcium by silicates both in the rhizosphere and in the plant structures (Ma and Takahashi 2002)

The present results are in agreement with Pérez-López *et al.* (2017) who found that silicon application significantly increased calcium uptake in tomato plants. Marodin *et al.*, (2014) reported that calcium and potassium silicates increased the Si content in the leaves linearly, with maximal response at the highest dose (800 kg ha⁻¹ of SiO₂), with contents of 3.49 g kg⁻¹ and 2.27 g kg⁻¹ of silicon. Zhang *et al.* (2019) also reported that silicon application enhanced calcium concentration in tomatoes.

Their research highlighted that silicon not only improved overall plant health but also contributed to better calcium assimilation, leading to improved fruit quality and reduced incidence of blossom end rot. Yin *et al.* (2020) reported that silicon treatments increased both calcium concentration and overall nutrient status in tomato plants, suggesting a synergistic effect between silicon and calcium in enhancing plant nutrition. The plateau observed at 200 mg/L may indicate saturation of silicon-mediated transport mechanism in calcium assimilation.

Pertaining application methods “spray or soil drench” on calcium concentration, the obtained results presented in Fig (4.16) showed that the two application methods of silicon significantly affected calcium concentration. However, the drench method gave the highest mean value of (13.51 and 15 mg/100g) as compared to spray application. These could be attributed to the more direct and sustained availability of silicon to the root system, which facilitates its uptake and transport through the xylem to developing fruits. Root applied silicon has been shown to influence the expression of transporter genes and enhance calcium uptake efficiency (Liang *et al.*, 2005; Ma *et al.*, 2006)

In contrast, foliar application often leads to limited translocation of silicon and associated nutrients due to its poor phloem mobility (Tuna *et al.*, 2008). Furthermore, silicon supplied through the root system may strengthen the cell wall and improve vascular function indirectly aiding calcium to be transported into fruits (Guntzer *et al.*, 2012). The present results were in agreement to those reported by (Epstein, 1994; Jarosz, 2013), significant decrease in calcium content in plants with an increasing concentration of orthosilicic acid in the root environment.

Table 4.17: Interactive effects between variety, silicon levels and method of application on Calcium concentration in mg/100g under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/L x Eden ^{f1}	8.68 ^a	12.05 ^a	14.85 ^a	18.19 ^{bc}
Foliar x 0 mg/Lx Zara ^{f1}	2.90 ^g	4.18 ^f	4.78 ^d	5.76 ^{ab}
Basal x 200 mg/Lx Zara ^{f1}	7.89 ^{bc}	10.73 ^{ab}	13.93 ^a	16.63 ^{bc}
Basal x 50 mg/L x Eden ^{f1}	6.87 ^d	8.56 ^d	9.63 ^b	12.41 ^c
Foliar x 100 mg/L x Zara ^{f1}	7.41 ^{cd}	8.94 ^{cd}	10.9 ^b	13.57 ^d
Foliar x 200 mg/L x Eden ^{f1}	8.22 ^{ab}	10.26 ^{bc}	13.19 ^a	14.74 ^d
Foliar x 50 mg/Lx Zara ^{f1}	6.49 ^d	9.33 ^c	10.70 ^d	12.84 ^a
Basal x 0 mg/L x Eden ^{f1}	3.84 ^f	4.78 ^f	5.51 ^d	06.8 ^a
LSD	1.44	0.96	0.93	1.17
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different (P≤0.05) * Significant F values at P≤0.05 and NS-Not significant

The combined treatment of soil drench and silicon at 100mg/L recorded, generally, the highest mean values of calcium concentration in tomatoes in both seasons. The Ca absorption increased optimally with an increase in the supply of Si at the root zone. This result indicates a synergistic effect of Si on the increase of Ca absorption, possibly because Si favors the growth rate of the root system Ribeiro *et al.* (2011) and the molecular effect of Si on the increasing ATPase activity in the membranes involved in Ca absorption (Liang *et al.*, 2006). The present results were in parallel to those reported by Kaya *et al.* (2006), Barreto *et al.* (2018); Silva Júnior *et al.* (2019).

4.5.3 Magnesium

Research findings regarding Magnesium indicated that different levels of silicon had significant difference ($p \leq 0.05$) on fruit magnesium concentration. The research showed highest magnesium concentration was recorded in plants applied with Si at 200 mg/L (85.21 and 90.21 mg/100g). There after followed by Si at 100 mg/L (88.46 and 88.46 mg/100g), then Si at 50 mg/L (85 and 85.51 mg/100g). The control (28.62 and 12.62 mg/100g) resulted in minimum Mg concentration level (Fig 4.18) in both season one and two respectively. It was also observed that beyond 100 mg/L of silicon, magnesium concentration remained constant at 85 mg/L, as from 85th day after transplanting indicating a plateau effect.

Research findings on Mg concentration was significantly affected ($p \leq 0.05$) by different method of application in two seasons under field condition. Maximum Mg concentration was recorded in plots with silicon basal application (68.26 and 70.14 mg/100g) as compared to plots with silicon foliar application (68.14 and 68.26 mg/100g) in both season one and two respectively (Fig 4.18).

There was no significant difference in magnesium concentration between foliar and basal application methods as from 81st days after transplanting. Mg levels remained constant across both treatments. Results of Mg concentration in tomato varieties for two seasons under field conditions, showed no significant difference at ($p \leq 0.05$). Mean Magnesium concentration of two tomato varieties, under field conditions presented in Table (4.18) showed significant interaction ($p \leq 0.05$) between variety, application method and silicon rate on Mg concentration indicating that the effect of silicon on plant performance varied depending on both the application method and the variety used.

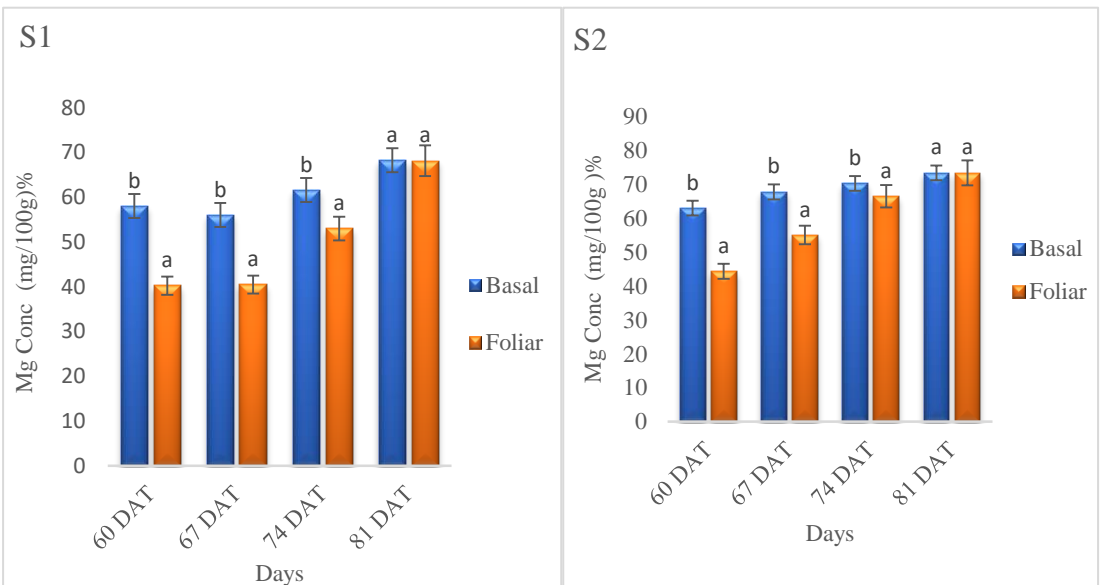
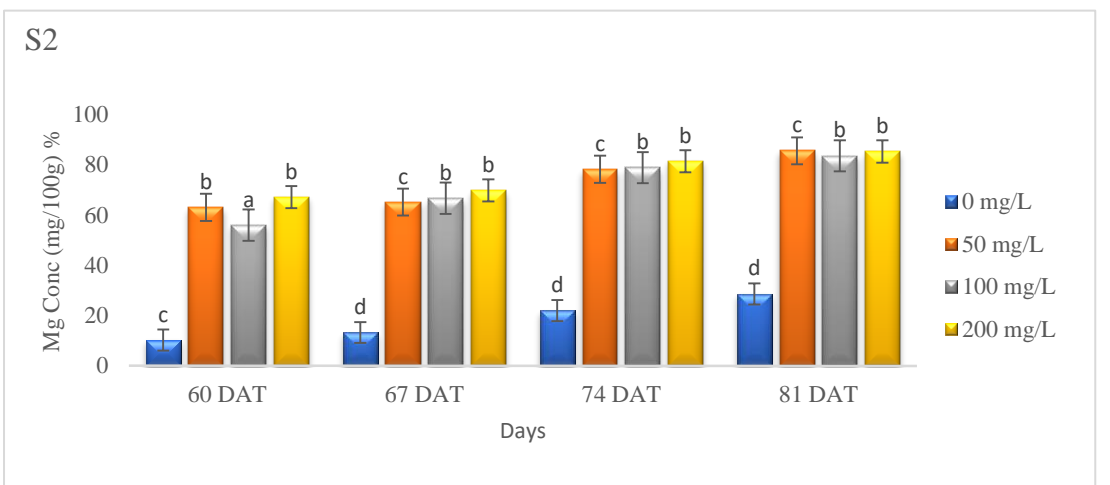
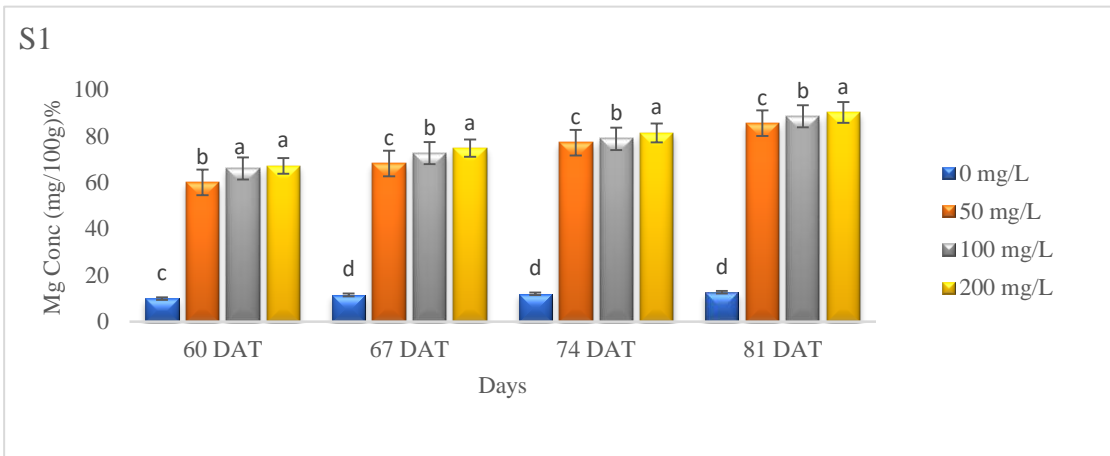


Figure 4.18: Mean Mg concentration of two tomato varieties in relation to silicon levels and application method over two seasons under field conditions

Relating to the main effect of different levels of silicon on Mg concentration in fruits, Fig (4.18) indicated that, as silicon levels increased the Mg concentration in fruits significantly increased in both seasons compared to control treatment. Fruit Mg concentration was more pronounced at higher Si treatment (200mg/L) that recorded 90.21mg/100g dry weight across the growing period.

This might be due to ability of silicon to improve the absorption of nutrients, including magnesium, by enhancing root development and function. The study emphasized the role of silicon in improving overall nutrient status. Findings also suggested that silicon aids in better nutrient assimilation and enhances the physiological functions of the plants, leading to higher magnesium content in the fruits. These results were consistent with the findings of Ghanem *et al.* (2019) who reported that silicon treatments not only improved the nutritional quality of tomatoes but also resulted in increased magnesium concentrations.

The effect of silicon on magnesium concentration was evaluated across a concentration range of 0- 200mg/L. Magnesium concentration remained unchanged between 100 and 200 mg/L at 85th day after transplanting. This indicates a potential threshold beyond which silicon has no further influence on magnesium levels. This finding suggests a saturation point that limits further variations

Regarding the main effect of application methods “spray or soil drench” of silicon on Mg concentration, Research findings in Fig (4.18) displayed clearly that the application method of soil drench exposed significant difference and gave the highest mean values of Mg concentration in fruits as compared to spray method in both seasons. This finding is in agreement with those reported by Korndörfer *et al.* (2010) who conducted a study evaluating the effects of the surface application of calcium silicate (CaSiO_3) maximum

rate 2 t ha⁻¹ on Si concentrations in grass shoots. They reported that the Si concentration within the leaves of grass grown in soil treated with calcium silicate was twice that of grass grown in the control soil (no silicate).

Table 4.18: Interactive effects between variety, silicon levels and method of application on Magnesium concentration in mg/100g under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/L x Eden ^{fl}	8.68 ^a	12.05 ^a	14.85 ^a	18.19 ^{bc}
Foliar x 0 mg/L x Zara ^{fl}	7.75 ^e	10.19 ^e	10.56 ^f	11.31 ^e
Basal x 200 mg/Lx Zara ^{fl}	67.35 ^a	75.46 ^a	82.01 ^a	90.77 ^a
Basal x 50 mg/Lx Eden ^{fl}	66.37 ^a	73.43 ^{ab}	79.21 ^{bc}	89.21 ^b
Foliar x 100 mg/L x Zara ^{fl}	65.54 ^{ab}	71.81 ^b	78.35 ^{cd}	87.71 ^d
Foliar x 200 mg/Lx Eden ^{fl}	66.84 ^a	74.12 ^a	80.7 ^{ab}	89.66 ^b
Foliar x 50 mg/Lx Zara ^{fl}	56.95 ^c	68.03 ^c	76.83 ^d	84.37 ^d
Basal x 0 mg/Lx Eden ^{fl}	12.11 ^d	12.74 ^d	13.29 ^e	13.92 ^e
LSD	2.03	1.37	1.32	1.66
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * Significant F values at $P \leq 0.05$ and NS-Not significant

The combined treatment of soil drench and silicon at 200 mg/L recorded the highest mean values for Mg concentration in both seasons. The study found out that Under Si deficiency, the root Mg content was significantly higher when the concentration of Si was reduced in the medium compared to high levels of Si- and also Mg-sufficient plants. These could be attributed to absorption sites.

The higher Mg concentration in Si treated tomato might be due to an increase in the water uptake, as Si was shown to increase the leaf water potential in sorghum plants imposed to K deficiency by up-regulating the expression of aquaporin genes and alleviating the decrease of aquaporin activity caused by ROS (reactive oxygen species). Si supply restored the chlorophyll level in Mg-deficient plants to levels comparable to those of Mg-sufficient plants.

4.5.4 Phosphorus

Phosphorus concentration was significantly ($p \leq 0.05$) affected by different levels of silicon as observed the field study for two seasons. The research findings showed that maximum P concentration in fruit was recorded in plants with Si applied at 100 mg/L (20.78 and 28.78 mg/100g) followed by Si at 200 mg/L (19.3 and 24.3 mg/100g) then Si at 50 mg/L (17.41 and 20.41mg/100g) respectively for the two seasons. Control recorded minimum P concentration (0.93 and 0.91 mg/100g) Fig 4.19 in season one and two respectively. These observations were consistent throughout the research period for two seasons

Mean Phosphorus concentration was significantly affected at ($p \leq 0.05$) by different method of application in two seasons under field condition. Maximum P concentrations were recorded in plots with basal applied silicon (15.44 and 18.4 mg/100g) as compared to plots with Silicon foliar application (13.77 and 15.27mg/100g) in both seasons respectively. Results of P concentration in tomato varieties for two seasons under field conditions, showed no significant difference at ($p \leq 0.05$).

Phosphorus concentration of two tomato varieties in both seasons as Presented in Table (4.19) showed significant interaction at ($p \leq 0.05$) between method of application and

phosphorus rate in tomato fruit indicating that the effect of silicon on plant performance varied depending on both the application method and the variety used.

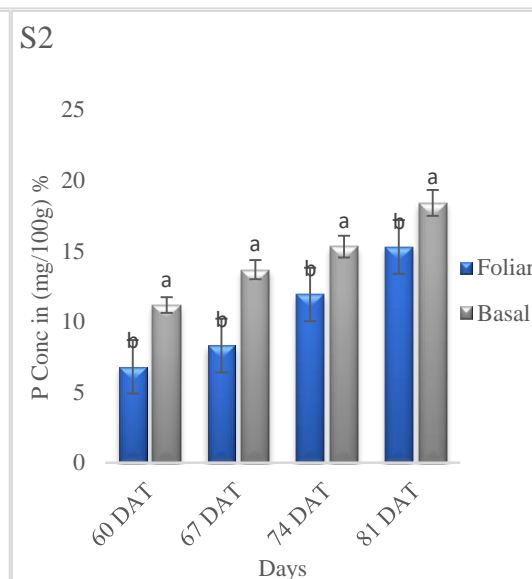
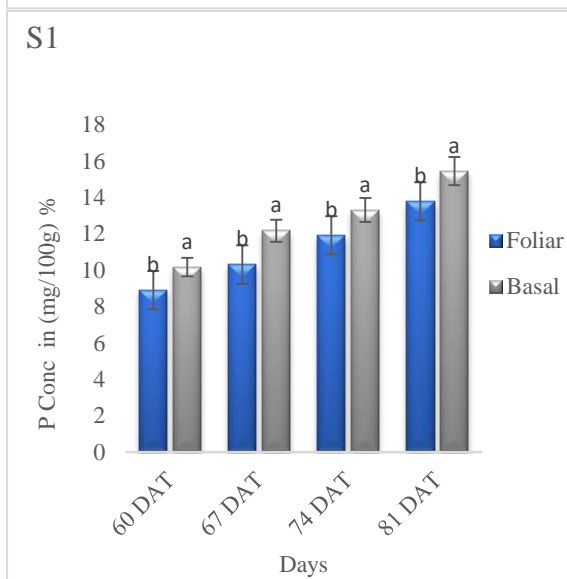
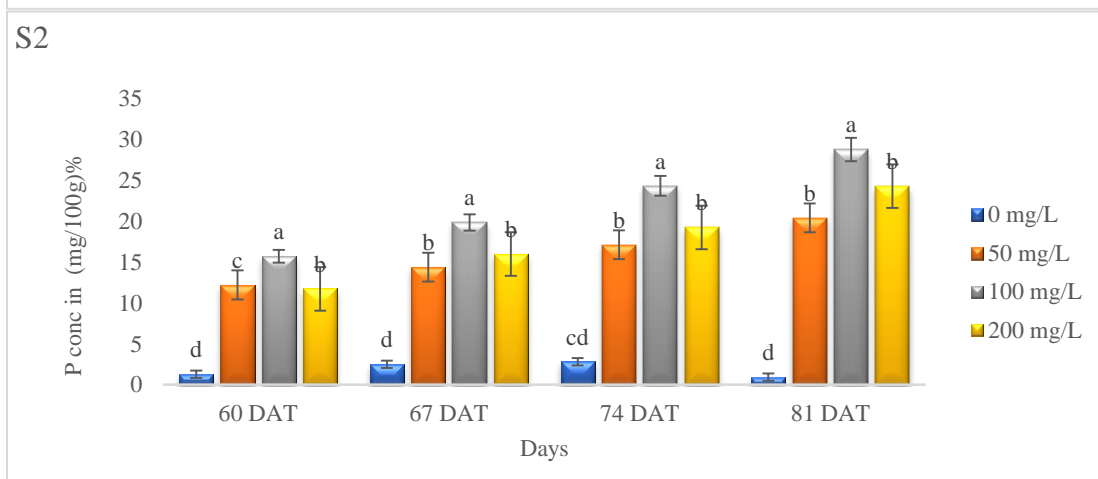
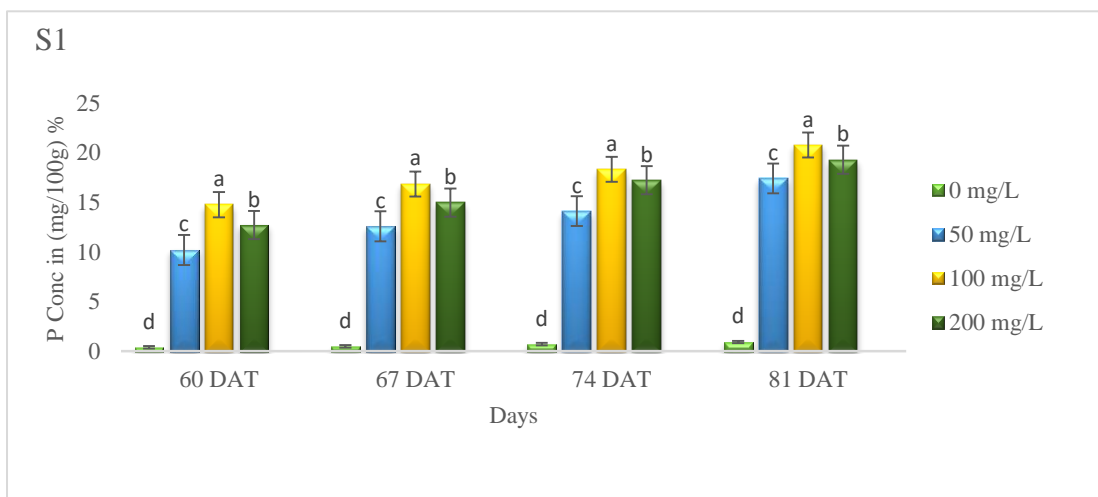


Figure 4.19: Mean Phosphorus concentration of two tomato varieties in relation to silicon levels and application method over two seasons under field conditions

Regarding the main effect of different rates of silicon on phosphorus concentration, research findings in Fig (4.19), indicated that the application of silicon significantly enhanced the P concentration of tomato fruits compared to the control treatment in both seasons. Silicon at 100 mg/L was the optimum rate for best results for phosphorus concentration. This was because increasing Si level from 100 to 200 mg/L had a directly proportional effect on the maximum P concentration with no significant difference.

These results were consistent with those obtained by Owino and Gascho (2004) that Si concentration in the soil solution improved growth of maize resulting greater P uptake and utilization. The application of Si also significantly increased the P uptake in both P deficient soils. Sahoo and Panda (2001) indicated that soils low in Si will adsorb large amounts of P leaving little for plants, and higher P dose increased its availability allowing less adsorption and so improved uptake of P. Increase of the plant P status by Si was explained by a mobilization of P from strong binding to soil minerals by silicic acid increasing P availability for plants (Schaller *et al.*, 2019).

In terms of application methods “spray or soil drench” Phosphorus concentration in fruits, the observation in (Fig 4.19) exhibited clearly that the application method of soil drench exposed significant difference and gave higher mean values of P concentration in both seasons as compared to foliar application. The present results are in agreement with those obtained by Junior *et al.* (2010), silicon introduced into the root environment of plants absorbs aluminum hydroxides reducing their mobility; thereby, the chemical absorption of phosphates is reduced from 40 to 70 percent think that the presence of

silicon in the root environment of plants also reduces the risk of formation of insoluble iron and manganese phosphates.

Table 4.19: Interactive effects between variety, silicon levels and method of application on phosphorus concentration in mg/100g under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/Lx Zara ^{f1}	15.73 ^a	18.41 ^b	18.99 ^a	22.05 ^a
Foliar x 0 mg/L x Zara ^{f1}	0.40 ^f	0.46 ^e	0.67 ^a	0.89 ^d
Basal x 200 mg/Lx Eden ^{f1}	13.12 ^{bc}	15.08 ^b	18.14 ^c	19.83 ^{ab}
Basal x 50 mg/Lx Zara ^{f1}	11.39 ^d	13.89 ^c	15.29 ^b	18.88 ^b
Foliar x 100 mg/L x Eden ^{f1}	12.32 ^{cd}	14.14 ^c	16.35 ^c	18.76 ^b
Foliar x 200 mg/Lx Zara ^{f1}	13.81 ^b	15.3b ^c	17.67 ^a	19.51 ^b
Foliar x 50 mg/Lx Eden ^{f1}	9.03 ^e	11.03 ^d	12.96 ^a	15.93 ^c
Basal x 0 mg/L x Eden ^{f1}	0.38 ^f	0.53 ^e	0.76 ^a	0.98 ^d
LSD	0.61	1.01	1.07	1.46
P- Value	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The combined treatment of soil drench and silicon at 100 mg/L recorded the highest mean values for P concentration in both seasons as compared to control. These may be attributed to adsorption sites. Owino and Gascho (2004) showed that uptake of P was increased as a result of Si and P interaction, which could be due to increase in soil pH that made P more available and better plant growth because of improved P uptake and utilization. Similar results were also recorded by Ma *et al.* (2001). Who reported that overall beneficial effect of Si may be attributed to a higher P: Mn ratio in the shoot due

to the decreased manganese and iron uptake, and thus indirectly improved phosphorus utilization within the rice plant.

4.5.5 Nitrogen

Research findings regarding mean nitrogen concentration indicated that different levels of silicon had significant difference at ($p \leq 0.05$) for both seasons under field condition. Application of silicon at 100mg/L, had a maximum N concentration level (4.34 and 4.94 mg/100g), followed by Si at 200mg/L (3.75 and 3.95 mg/100g), then 50 mg/L (4.08 and 3.08 mg/100g) and finally Si applied at 0 ml/L (1.81 and 0.41 mg/100g) in seasons one and two respectively (Fig 4.20)

Significant differences ($p \leq 0.05$) were observed between basal and foliar applies silicon on nitrogen concentration. Maximum N concentration was recorded in plots with silicon basal application (4 and 3.02 mg/100g) as compared to plots with silicon foliar application (3.4 and 2.76 mg/100g) in both seasons one and two respectively (Fig 4.20). There was no statistically significant difference on variety in terms of Nitrogen concentration levels in both seasons as influenced by silicon fertilizer.

Results presented in Table (4.20) show no significant interaction ($p \leq 0.05$) between application method and silicon levels on the N concentration levels, indicating that both foliar sprays and soil drenches of Si have the potential to increase tomato fruit quality in terms of N concentration.

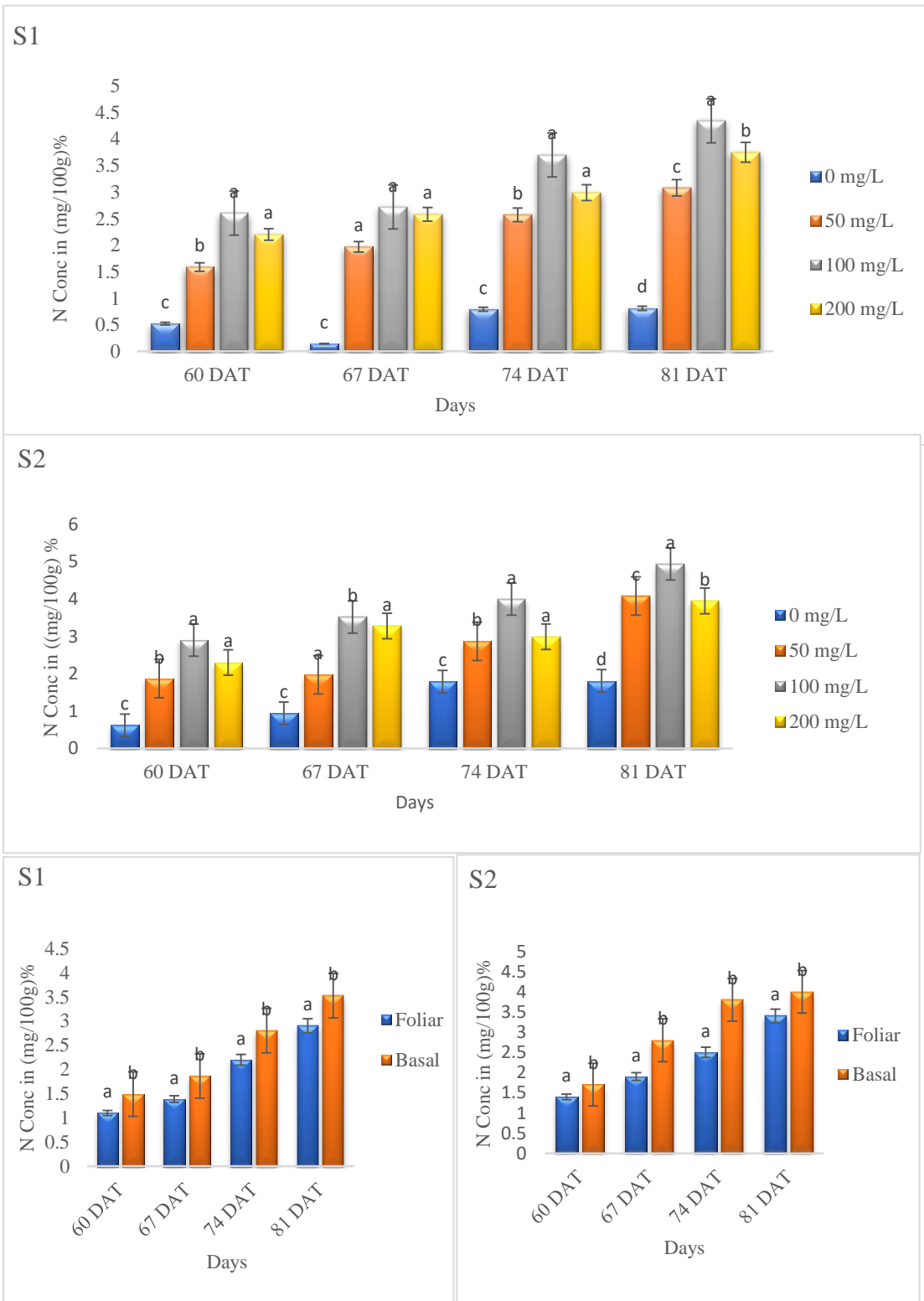


Figure 4.20: Mean Nitrogen concentration of two tomato varieties in relation to silicon levels and application method over two seasons under field conditions

Judicious use of N is quite crucial especially with climate change since excess amount would go into water bodies causing pollution and there are other loss pathways through emissions and hence need for climate-smart approach to nutrient use (Gweyi-Onyango and Ntinyari, 2022; Ntinyari and Gweyi-Onyango 2021). Increase in Si levels lead to an increase in N concentration levels in the tomato fruits. Optimum N concentration was recorded when Si was applied at 100 mg/L as compared to control. In this study, silicon amendments increased N uptake in tomato plant buttressing the study of Kamenidou (2010) on gerbera plant supplemented with silicon sources such as rice hull ash and potassium silicate that showed a significant increase in the N content of the plant.

Alsaedi *et al.* (2019) also stated that treating wheat plants with silicon amendments boosted nitrogen use efficiency of the plant at all levels. Pati *et al.* (2016) found that higher concentrations of soluble Si enhanced the uptake and concentration of N in potato. Others have noted that Si has the potential to raise available N and N-use efficiency in plants (Savant *et al.*, 1996 and Singh, (2005). It has been demonstrated that Si-induced biosynthesis of amino acids and remobilization of N (Detmann *et al.*, 2012). Enhanced growth of Si-fed plants exposed to high N concentration was often attributed to increased photosynthetic efficiency, antioxidant capacity and improved water status.

A study by Reithmaier *et al.* (2017) further showed that silicic acid can also mobilize N from soils. The authors suggest that this may be a result from either Si competing for binding sites or from stronger reducing conditions. In addition to a direct effect on N metabolism, Si supply induces changes in carbon (C) and P stoichiometry in shoots (Schaller *et al.*, 2012) and increase nutrient acquisition by roots (Barreto *et al.*, 2017),

which in turn can contribute to improving N utilization within plant tissues. Johnson *et al.* (2017) observed that Si addition was beneficial not only for nodule growth but also for plant growth in terms of relative yield of root and shoot, and the increasing in root yield led to an enhancement of root nodulation.

In terms of application methods “spray or soil drench” N concentration, Research in Fig (4.20) exhibited clearly that the application method of soil drench exposed significant difference and gave higher mean values of N concentration in both seasons than the foliar spray. The present results are in agreement with those obtained by Savant, Datnoff, and Snyder (1997) found that application of soil Si enhanced the use of applied N to rice. This might be due to the role of silicon in the uptake, translocation, and availability of other nutrients like; nitrogen (N) which is an essential element that is increased in the presence of silicon.

Table 4.20: Interactive effects between variety, silicon levels and method of application on Nitrogen concentration in mg/100g under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/Lx Zara ^{fl}	2.07 ^a	2.84 ^a	3.78 ^a	4.71 ^a
Foliar x 0 mg/L x Zara ^{fl}	0.05 ^a	0.21 ^a	0.11 ^a	0.40 ^a
Basal x 200 mg/Lx Eden ^{fl}	2.39 ^a	2.73 ^a	3.48 ^a	3.80 ^a
Basal x 50 mg/Lx Zara ^{fl}	1.43 ^a	1.81 ^a	2.50 ^a	3.15 ^a
Foliar x 100 mg/L x Eden ^{fl}	2.22 ^a	2.59 ^a	3.23 ^a	3.97 ^a
Foliar x 200 mg/Lx Zara ^{fl}	2.21 ^a	2.63 ^a	3.19 ^a	3.69 ^a
Foliar x 50 mg/Lx Eden ^{fl}	1.75 ^a	2.13 ^a	2.64 ^a	3.02 ^a
Basal x 0 mg/L x Eden ^{fl}	0.06 ^a	0.07 ^a	0.36 ^a	0.42 ^a
LSD	0.32	0.37	0.44	0.45
P- Value	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The present results indicate that silicon (Si) application can influence nitrogen (N) concentration in tomato plants with no significant difference.

4.5.6 Potassium

Mean potassium concentration in tomato fruits was significantly affected ($p \leq 0.05$) by different levels of silicon. Mean values of the data showed that mean maximum potassium concentration in fruits was recorded in plants with Si applied at 100mg/L (1.1 and 1.1 mg/100g), there after by Si at 200 mg/L (0.1 and 1.00 mg/100g) then Si at 50 mg/L (0.7 and 0.85 mg/100g). The control (0.1 and 0.19 mg/100g) resulted in less potassium concentration levels in both season one and two respectively (Fig 4.21).

Mean K concentration was significantly affected at $p \leq 0.05$ by different method of application in two seasons under field condition. Maximum K concentrations were recorded in plots with basal applied silicon (0.7 and 0.87 mg/100g) as compared to plots with Silicon foliar application (0.05 and 0.07 mg/100g) in both seasons Fig 4.21. Results of P concentration in tomato varieties for two seasons under field conditions, showed no significant difference at ($p \leq 0.05$).

There was no significant interaction ($P \leq 0.05$) between application method and silicon levels on the K concentration as shown in Table (4.21) indicating that both foliar sprays and soil drenches of Si have the potential to increase tomato fruit quality in terms of K concentration.

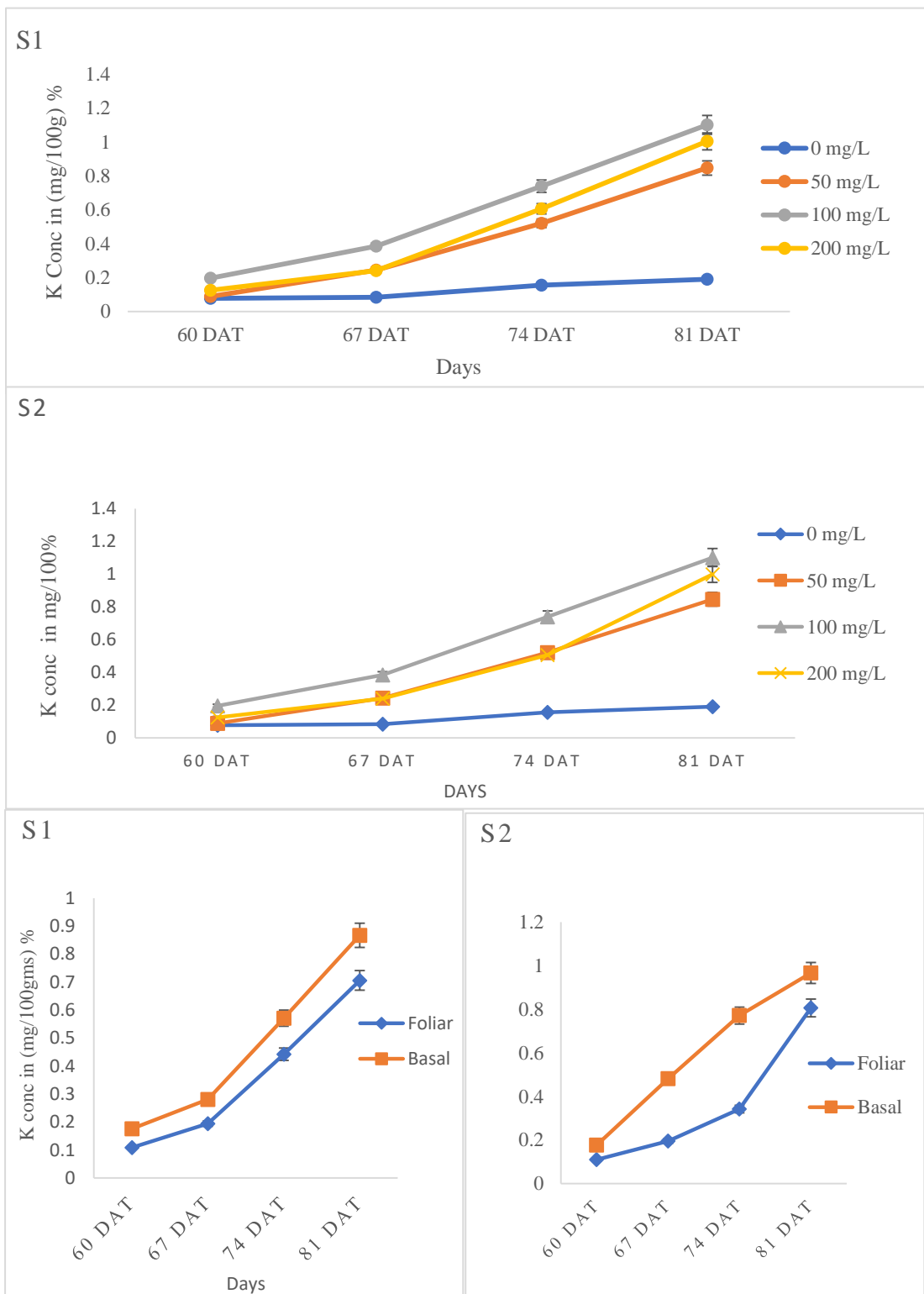


Figure 4.21: Mean potassium concentration of two tomato varieties in relation to silicon levels and application method over two seasons under field conditions

Relating to the main effect of different levels of silicon on K concentration in tomato fruits, research findings in Fig (4.21) indicated that, as silicon levels increased the K concentration significantly increased up to optimum levels in both seasons.

Results showed that silicon level at 100mg/L recorded the highest mean values for the K concentration in both seasons. These results seem to agree with the findings of Alsaeedi *et al.* (2018) who revealed that silicon addition increased K uptake in cucumber, sugarcane and barley. Furthermore, Sudhakar *et al.* (2006) demonstrated that silicon enhances uptake of K. This could be attributed to the capacity of silicon to increase the activity of H⁺-ATPase which in turn accelerates cellular uptake of K by activating K⁺ channels and carriers across the plasma membrane (Liang *et al.*, 2006)

In terms of application methods “spray or soil drench”, research findings in Fig (4.21) exhibited clearly that the application method of soil drench exposed significant difference and gave higher mean values of K concentration as compared to foliar in both seasons. The present results are in agreement with those reported by Usngh *et al.*, (2005) that use of full quantity of Si as basal was superior to other silicon application. time with respect to growth, yield attributes, and nutrient uptake. Positive response of basal silicon application towards potassium can be linked to silicification of cell wall.

The concentration of K in the tomato plants remains relatively consistent regardless of whether Si is applied through soil or foliar methods. This could indicate that K uptake or accumulation is independent of the Si application method. The present results are consistent with A study to investigated the effects of different application methods and pH levels of potassium silicate on nutrient uptake and bacterial spot disease in tomatoes (Chien *et al.*, 2021). The researchers found that the application method (foliar spray vs. growth medium application) and pH levels of K₂O₃Si did not significantly interact to

affect the potassium (K) concentration in tomato plants. This suggests that K uptake remained consistent regardless of the application method or pH level of K₂O₃Si used.

Table 4.21: Interactive effects between variety, silicon levels and method of application on potassium concentration in mg/100g under field condition

Interactions between variety, silicon application levels, and application method	60 DAT	67 DAT	74 DAT	81 DAT
Basal x 100 mg/L x Eden ^{f1}	0.11 ^a	0.25 ^a	0.53 ^a	0.86 ^a
Foliar x 0 mg/L x Zara ^{f1}	0.08 ^a	0.09 ^a	0.21 ^a	0.25 ^a
Basal x 200 mg/L x Zara ^{f1}	0.07 ^a	0.23 ^a	0.52 ^a	0.83 ^a
Basal x 50 mg/L x Eden ^{f1}	0.12 ^a	0.24 ^a	0.61 ^a	0.98 ^a
Foliar x 100 mg/L x Zara ^{f1}	0.13 ^a	0.24 ^a	0.59 ^a	1.02 ^a
Foliar x 200 mg/L x Eden ^{f1}	0.20 ^a	0.39 ^a	0.75 ^a	1.16 ^a
Foliar x 50 mg/L x Zara ^{f1}	0.19 ^a	0.38 ^a	0.72 ^a	1.04 ^a
Basal x 0 mg/L x Eden ^{f1}	0.07 ^a	0.08 ^a	0.10 ^a	0.14 ^a
LSD	0.03	0.09	0.11	0.16
P- Value	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$) * and NS-Not significant

The effect of silicon on tomato performance was consistent across different application methods and varieties. This indicates that the effect of silicon on plant performance did not significantly differ across application methods or among the tomato varieties Eden and Zara. These may be due to tomato varieties which may respond similarly to silicon application, or the application methods might not differ enough in how they deliver silicon to cause distinct responses. The Environmental conditions or experimental limitations may have masked potential differences.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study concludes;

Basal silicon application performed better compared to foliar. Additionally, the recommended application rates of 100mg/L gave better yields.

Both basal and foliar silicon application methods-controlled pests and pathogens effectively in tomatoes. Silicon applied at double recommended rate (200mg/L) gave better results.

Basal silicon application elicited better nutritional quality in tomatoes, and the recommended application rate 100mg/L gave high nutritious fruits compared to the rest.

5.2 Recommendations

Adoption of silicon basal application method at the recommended rate to achieve better tomato yields

Combination of basal soil and foliar application method, when possible, for optimal pest and pathogen management in tomatoes.

Basal silicon application at recommended rate for high quality tomato fruits

5.3 Further research

To conduct further research that will allow for the determination of optimal times for silicon application.

Research should be done to explore the potential benefits of silicon in other crops or in different environmental condition.

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APPENDICES

Appendix I: Bacterial wilt incidences in Zara F1 variety



Appendix II: Blossom end rot incidence in Eden F1



Appendix III: Approval of Research proposal letter- Kenyatta University



KENYATTA UNIVERSITY OFFICE OF THE EXECUTIVE GRADUATE SCHOOL

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Internal Memo

FROM: Executive Dean, Graduate School

DATE: 18th October 2024

TO: Mr. Musumba Orinda
Department of Agricultural Science & Technology

REF: A144/31032/2015

SUBJECT: APPROVAL OF RESEARCH PROPOSAL
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We acknowledge receipt of your Research Proposal after fulfilling recommendations raised by the Graduate School Board of 27th March 2019.

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking and Progress Report Forms per semester. The forms are available at the University's Website under Graduate School webpage downloads.

Also, please ensure that you publish article(s) from your thesis before submitting it to Graduate School for examination as per the Commission for University Education and Kenyatta University guidelines.

Thank you.


REUBEN MURIUKI

FOR: EXECUTIVE DEAN, GRADUATE SCHOOL


CC. Chairman, Department of Agricultural Science & Technology

Supervisors:

1. Dr. Joseph P. Onyango Gweyi
C/o Department of Agricultural Science & Technology
Kenyatta University
2. Dr. Samita Namikoye
C/o Department of Agricultural Science & Technology
Kenyatta University

Appendix IV: Research Authorization letter- Kenyatta University

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KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke P.O. Box 43844, 00100
Website: www.ku.ac.ke NAIROBI, KENYA
Tel. 020-8704150

Our Ref: A144/31032/2015 **DATE:** 18th October 2024

Director General,
National Commission for Science, Technology and Innovation
P.O. Box 30623-00100
NAIROBI

Dear Sir/Madam,

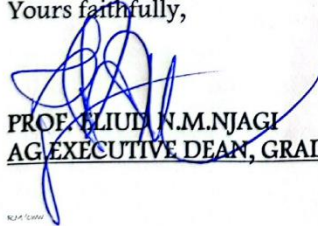
RE: RESEARCH AUTHORIZATION FOR MR. MUSUMBA ORINDA – REG. NO. A144/31032/2015

I write to introduce Mr. Musumba Orinda who is a Postgraduate Student of this University. He is registered for M.Sc. degree programme in the Department of Agricultural Science and Technology.

Mr. Orinda intends to conduct research for a M.Sc. Thesis Proposal entitled, *“Influence of Silicate and Application Methods on Yield, Nutritional Quality, Pest, and Pathogen Management in Kale and Tomato in Kiambu County, Kenya.”*

Any assistance given will be highly appreciated.

Yours faithfully,


PROF. ELIUD N.M. NJAGI
AG. EXECUTIVE DEAN, GRADUATE SCHOOL

KU/MS/00000