

**SELECTED MICRONUTRIENTS EFFECTS ON PEST AND DISEASE
RESISTANCE, YIELD AND QUALITY OF TOMATO IN BOMET COUNTY,
KENYA**

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**A thesis submitted in partial fulfilment of the requirement for the award of the
degree of Master of Science in Crop Protection (Pathology) in the School of
Agriculture and Environmental Sciences, Kenyatta University.**

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DECLARATION

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

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DEDICATION

This thesis is dedicated to my father, Richard Chepkwony, my mother, Alpina Chepkwony, and my wife, Decla Koech, for their presence, love, support, and encouragement throughout the entire period of study.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AOAC	Association of Official Agricultural Chemists
ASE	Accelerated Solvent Extraction
B	Boron
BCIDP	Bomet County Integrated Development Plan,
C	Carbon
Ca	Calcium
Cl	Chlorine
CONTR	Control
CS	Copper sulphate
Cu	Copper
EU	European Union
FAO	Food and Agriculture Organization
FAOSTAT	Statistical database of FAO of the United Nations
Fe	Iron
FW	Fresh Weight
GLM	General Linear Models
H	Hydrogen

HPLC	High Performance Liquid Chromatography
IZA	International Zinc Association
K	Potassium
KAFACI	Korean-African Food and Agriculture Cooperation Initiative
KALRO	Kenya Agricultural & Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KSS	Kenya Soil Survey
LSD	Least Significance Difference
Mg	Magnesium
MLN	Maize Lethal Necrosis
Mn	Manganese
Mo	Molybdenum
MoALD	Ministry of Agriculture and Livestock Development.
N	Nitrogen
NAAIAP	National Accelerated Agricultural Inputs Access Programme
NICRA	National Initiative on Climate Resilient Agriculture
NPK	Nitrogen, Phosphorus and Potassium
O	Oxygen
P	Phosphorus

pH	potential hydrogen
PPO	Polyphenal oxidases
RCBD	Randomized Complete Block Design
S	Sulphur
SAS	Statistical Analysis System
SPSS	Statistical Package for Social Sciences
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
USA	United States of America
USAID	United States Agency for International Development
Zn	Zinc

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is an important horticultural crop in Kenya, widely grown for both household consumption and income generation. However, tomato production in Bomet County has been constrained by persistent arthropod pest infestations and diseases, as well as poor soil fertility characterized by micronutrient deficiencies. These challenges have led to increased reliance on chemical pesticides, which are costly and environmentally harmful. This study was conducted to evaluate the effects of selected micronutrients—copper (Cu) and zinc (Zn)—on pest and disease resistance, yield, and fruit quality of tomato varieties in Chepalungu Sub-County, Bomet County, Kenya. Objectives of the study were to: (i) determine the prevalence of tomato diseases and arthropod pests (ii) assess the influence of foliar-applied zinc and copper micronutrients on the incidence and severity of key tomato pests and diseases (iii) evaluate the antioxidant levels specifically vitamin C, beta carotene and vitamin K in three tomato varieties in relation to micronutrient application. A field survey was conducted among 100 tomato farmers to identify existing production practices, major pest and disease problems, and fertilizer use patterns. Field experiments were then established in a Randomized Complete Block Design (RCBD) with three replications with split plot arrangements. The main plots consisted of three tomato varieties (Cal-J, Rio Grande, and Royal Oxy), while the subplots consisted of micronutrient treatments: copper sulphate (CuSO_4), zinc sulphate (ZnSO_4), and their combination ($\text{Cu SO}_4 + \text{ZnSO}_4$), applied weekly as foliar sprays at 0.5% concentration beginning four weeks after transplanting until harvest. Data on arthropod pest infestation, disease incidence and severity, and yield components were collected through field observations and laboratory analyses. Vitamin C and beta-carotene levels were determined using High Performance Liquid Chromatography (HPLC). Data from the field survey were analysed using SPSS version 18.0, while experimental data were analysed using SAS version 9.4 under the General Linear Model (GLM), and treatment means separated using Least Significant Difference (LSD) at 5% probability level. Results indicated that *Frankliniella occidentalis* (thrips) and *Tuta absoluta* (tomato leaf miner) were the most prevalent pests, while late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) were the most widespread diseases. Application of zinc and copper micronutrients, either singly or in combination, significantly ($p < 0.05$) reduced pest infestation and disease incidence compared to untreated control plots. The combined treatment ($\text{CuSO}_4 + \text{ZnSO}_4$) elicited the highest vitamin C production and beta-carotene levels and led to the greatest marketable yield (up to 2.6 t ha^{-1}) in the Cal-J variety. The study concludes that zinc and copper micronutrients enhance tomato resistance to pests and diseases, improve fruit nutritional quality, and increase yield under field conditions in Bomet County. It recommends that farmers integrate foliar application of zinc and copper micronutrients at 0.5% concentration as part of sustainable tomato production practices to reduce chemical pesticide use and promote environmental and food safety.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated vegetable crops globally, valued not only for its nutritional and economic importance but also as a major crop for studying plant protection strategies against pests and diseases. The fruit is a rich source of vitamins A, C, and K, along with antioxidants such as lycopene, which are vital for human health (Kumar *et al.*, 2021). Worldwide, tomato production reached approximately 186 million tonnes in 2022, averaging 36 t ha⁻¹ (IndexBox, 2024). Despite this, pest and disease pressures remain a leading cause of yield loss, making crop protection an essential aspect of sustainable tomato production.

In Africa, tomato plays a crucial role in food security and income generation, yet yields average only 15–25 t ha⁻¹ due to biotic stresses such as early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), and arthropod pests like *Tuta absoluta* and thrips (*Frankliniella occidentalis*) (FAO, 2023; Science Agri, 2024) as well as abiotic stresses such as soil infertility which is likely to be exacerbated by current trends in climate change (Ntinyari and Gweyi-Onyango, 2021). These challenges often drive farmers to depend heavily on synthetic pesticides, which increase production costs and environmental risks. Therefore, enhancing inherent crop resistance through nutritional and physiological means forms an integral component of modern crop protection approaches (Bastakoti, 2023; Ahmed, 2024).

In Kenya, tomato ranks among the most important horticultural crops, with Bomet County being a notable producer. However, yields remain low because of declining

soil fertility, inadequate micronutrient management, and persistent pest and disease outbreaks (MoALD, 2023; Agcenture, 2023). Recent soil analyses in Bomet County indicate deficiencies in essential micronutrients such as zinc (Zn) and copper (Cu), which play vital roles in enzyme activation, chlorophyll synthesis, lignin formation, and plant defence mechanisms (NAAIAP & KSS, 2014; Dimkpa & Bindraban, 2018; Bastakoti, 2023). Adequate Cu and Zn nutrition enhances plant immunity and structural integrity, making plants less susceptible to pathogen invasion and pest damage (Ahmed, 2024; De *et al.*, 2024).

Consequently, this study integrates crop nutrition and protection by examining the effects of zinc and copper-applied singly or in combination-on tomato yield, fruit quality, and resistance to key pests and diseases in Bomet County. The study emphasizes sustainable crop protection practices that strengthen natural plant defences while reducing dependence on chemical pesticides.

1.2 Statement of the problem

Tomato production in Bomet County faces severe biotic and abiotic constraints that undermine its productivity and sustainability. Among the major challenges are pest and disease infestations-especially tomato leaf miner (*Tuta absoluta*), thrips (*Frankliniella occidentalis*), early blight (*Alternaria solani*), and late blight (*Phytophthora infestans*)-which cause significant yield losses and lower marketable quality (KALRO, 2023b; Marete *et al.*, 2020). Farmers often rely on frequent pesticide applications for control, leading to pesticide resistance, high costs, and contamination of the environment and produce, thus posing risks to human and ecological health.

While previous interventions have largely focused on agronomic improvements and macronutrient fertilization (N, P, and K), the role of micronutrients—particularly zinc (Zn) and copper (Cu)—in enhancing crop protection has received limited attention. These elements play key roles in plant defence by promoting enzyme systems responsible for detoxification of reactive oxygen species, strengthening cell walls, and limiting pathogen colonization (Ramegowda & Senthil-Kumar, 2014; Dimkpa *et al.*, 2016; Martín-Cardoso & San Segundo, 2025). Deficiencies in these micronutrients weaken natural defence mechanisms, predisposing tomato plants to pest and disease attacks (De *et al.*, 2024).

Thus, there is a need to explore integrated nutrient-based crop protection strategies that enhance tomato resistance to biotic stresses while improving fruit yield and quality. Understanding how Zn and Cu influence pest and disease resistance will provide a scientific basis for sustainable management practices that reduce pesticide dependence and promote environmentally friendly tomato production systems in Bomet County.

1.3 Justification of the study

Tomato holds high potential as an income-generating and nutrition-enhancing crop in Bomet County. Enhancing tomato productivity could contribute significantly to household food security and poverty reduction, especially if production constraints are addressed using sustainable methods (KAFACI, 2024).

Micronutrients such as zinc and copper are essential for photosynthesis, enzyme activation, structural integrity of plant cell walls, and improving plant tolerance to pests and diseases (Agrios, 2005; Dordas, 2008; Dimkpa *et al.*, 2016). Recent studies

show that foliar and soil application of Zn and Cu significantly improve tomato plant vigour, yield, and fruit nutritional quality (Abbasifar *et al.*, 2020). Similar findings in Kenya demonstrate that integrating micronutrient fertilization into tomato production enhances productivity while minimizing pesticide use and environmental damage (KALRO, 2023b; Kenyatta University Research, 2024).

Therefore, this study seeks to determine the effects of selected micronutrients (Zn and Cu) on pest and disease resistance, yield, and fruit quality of tomato varieties in Bomet County. The findings are expected to provide practical recommendations for sustainable, environmentally friendly, and cost-effective tomato production systems-contributing to food security, improved farmer income, and resilient agricultural practices in Kenya.

1.4 Research objectives

1.4.1 General objectives

To evaluate the role of zinc and copper micronutrients on pest infestation, disease incidence and yield and fruit quality of selected tomato varieties in Bomet County, Kenya.

1.4.2 Specific objectives

- i. To determine the prevalence of tomato diseases and arthropod pests
- ii. To assess the influence of foliar-applied zinc and copper micronutrients on the incidence and severity of key tomato pests and diseases
- iii. To evaluate the antioxidant levels specifically vitamin C, beta carotene and vitamin K in three tomato varieties in relation to micronutrient application

- iv. To evaluate the impact of zinc and copper micronutrient application on tomato yield, marketable fruit quality and the proportion of pest and disease damaged yield

1.5 Hypotheses

- i. Major tomato diseases and arthropod pests are not significantly prevalent in Chepalungu Sub- County, Bomet County
- ii. Application of zinc and copper micronutrients has no significant effect on the incidence and severity of tomato pests and diseases
- iii. Application of zinc and copper micronutrients has no significant effect on the concentrations of antioxidants in tomato fruits
- iv. Application of copper and zinc micronutrients does not significantly affect tomato yield, marketable fruit quality and pest and disease-damaged yield

1.6 Significance of the Study

This study is significant scientifically, practically, and socio-economically. Scientifically, it contributes to the growing body of knowledge on the role of micronutrients—particularly zinc (Zn) and copper (Cu)—in enhancing tomato (*Solanum lycopersicum* L.) resistance to pests and diseases, and in improving yield and fruit nutritional quality under open-field conditions. Recent studies have highlighted that micronutrient nutrition strengthens enzymatic defence systems, improves photosynthetic efficiency, and enhances plant tolerance to both biotic and abiotic stresses (Dimkpa & Bindraban, 2018; Kumar *et al.*, 2021; FAO, 2023). By integrating Zn and Cu supplementation into tomato production, this study provides

new empirical evidence supporting micronutrient-induced resistance as a sustainable complement to integrated pest management (IPM) (Egerton University, 2023; KALRO, 2023a).

Practically, the findings will benefit smallholder tomato farmers in Bomet County and similar agro-ecological zones by demonstrating the effectiveness of foliar-applied Zn and Cu at 0.5 % concentration in reducing pest and disease incidence while improving fruit quality. Such low-cost and environmentally friendly nutrient management strategies can reduce pesticide dependence, enhance soil health, and sustain productivity (Journal of Plant and Soil Science, 2024; Seed Farm, 2025).

Socio-economically, improved tomato yield and quality directly translate to higher farmer incomes, enhanced food and nutritional security, and reduced poverty at household level. Tomatoes enriched with vitamins C, beta-carotene, and K improve dietary diversity and contribute to human health (Abbasifar *et al.*, 2020; FAO, 2024). The study also supports national agricultural development frameworks that emphasize climate-smart, input-efficient, and environmentally safe production systems (MoALD, 2023; Kenya Agricultural & Livestock Research Organization [KALRO], 2023).

Overall, this research aligns with Kenya's Agricultural Sector Transformation and Growth Strategy (ASTGS, 2023) and the United Nations Sustainable Development Goals 2 (Zero Hunger), 3 (Good Health and Well-being), and 12 (Responsible Consumption and Production) by promoting sustainable crop protection, efficient nutrient use, and safer food systems for improved livelihoods.

1.7 Conceptual framework

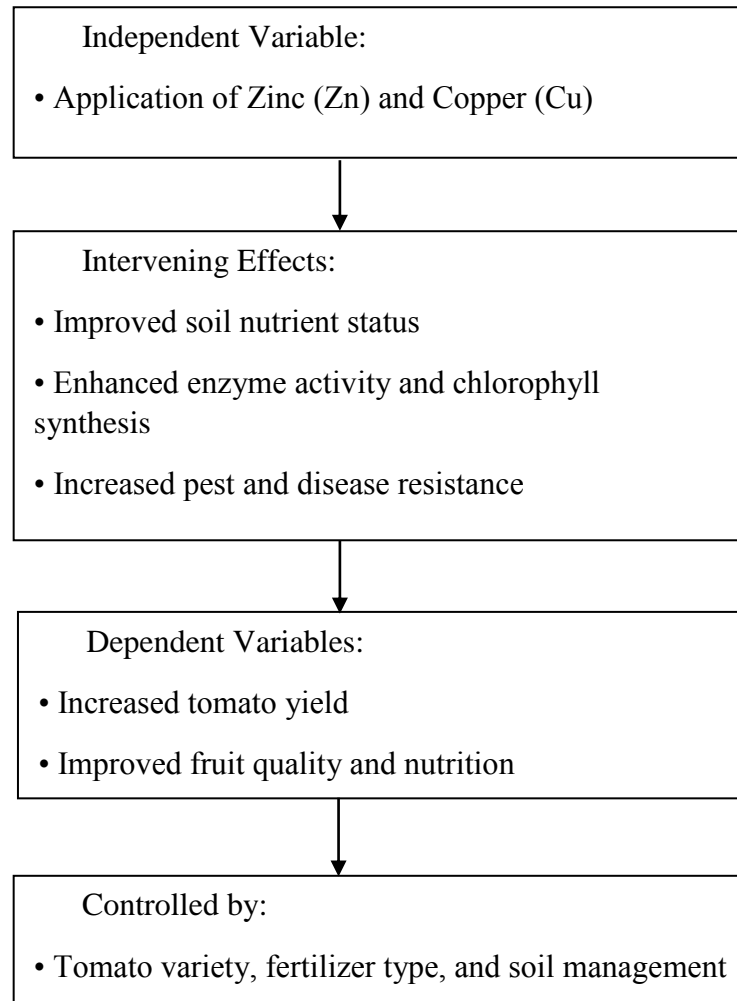


Figure 1.1 Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Production in Africa, East Africa and Kenya

Tomato (*Solanum lycopersicum* L.) production in Africa has expanded considerably in the last two decades, becoming one of the most important horticultural enterprises in both rural and Peri-urban systems. The crop was introduced into Africa in the 16th century through colonial and trade exchanges and has since become a staple horticultural commodity (Kumar *et al.*, 2021). Across the continent, tomato provides income and employment for millions of smallholder farmers, particularly women and youth (FAO, 2023). The leading producers in Africa are Egypt, Nigeria, Ethiopia, and Tanzania, which together contribute over 65% of the continent's total output (FAOSTAT, 2024).

In East Africa, tomato farming has shifted from traditional open-field systems to greenhouse and drip-irrigated production to address pest and disease pressure and mitigate rainfall variability (Chengo *et al.*, 2022; Gweyi, 2006). Kenya, Uganda, and Tanzania have recorded increasing production volumes over the past decade, with Kenya's production estimated at 283,000 tonnes annually (MoALD, 2023). However, national average yields remain between 18–25 t ha⁻¹, which is below the global average of 36 t ha⁻¹ (Seed Farm, 2025). The low yields are mainly due to pest and disease pressure, limited access to improved varieties, and widespread micronutrient deficiencies (KALRO, 2023a).

Recent innovations, including grafting onto resistant rootstocks, integrated pest management (IPM), and balanced fertilization, have improved tomato performance in various agro-ecological zones of East Africa (Egerton University, 2023).

Nevertheless, micronutrient use remains underutilized despite evidence that zinc (Zn), copper (Cu), and iron (Fe) enhance plant vigour, improve resistance to fungal pathogens such as *Phytophthora infestans* and *Alternaria solani*, and improve fruit nutritional quality (Rahi *et al.*, 2021; Dimkpa *et al.*, 2018).

2.2 Taxonomy and distribution

Tomato belongs to the *Solanaceae* family, which includes other economically important crops such as potato (*Solanum tuberosum*), eggplant (*S. melongena*), and pepper (*Capsicum spp.*). The species *Solanum lycopersicum* is the only domesticated member of its section, *Lycopersicon* (Peralta & Spooner, 2015). The crop is widely adapted to tropical and subtropical regions due to its high genetic variability and breeding improvement. Global tomato production reached approximately 186 million tonnes in 2022 (FAOSTAT, 2024), while African production remains below potential yields because of suboptimal management and environmental stress factors (Dimkpa & Bindraban, 2018).

2.3 Ecological requirements of tomato

Tomatoes grow best under warm temperatures ranging from 21°C to 27°C during the day and 14°C to 19°C at night. Optimal growth requires deep, well-drained loamy soils with a pH between 5.5 and 6.8 (Naika *et al.*, 2020). The crop performs well in both irrigated and rain-fed systems, but consistent soil moisture and adequate nutrient supply are critical for fruit quality and yield. Climate-smart production technologies such as drip irrigation, mulching, and greenhouse farming have been increasingly adopted in East Africa to reduce climatic and pest-related risks (KAFACI, 2024).

2.4 Botanical characteristics

Tomato (*Solanum lycopersicum* L.) is an annual or short-lived perennial herb belonging to the *Solanaceae* family, characterized by a branched, pubescent stem and compound leaves arranged alternately along the stem. The plant develops a vigorous taproot system that can extend up to one metre deep under favourable soil conditions, enabling efficient absorption of water and nutrients (KAFACI, 2024; Gweyi-Onyango *et al.*, 2009).

The leaves are pinnately compound with 5–9 lobed or serrated leaflets that emit a distinctive odour when crushed. The inflorescences are borne in racemes, each carrying 3–12 perfect (bisexual) yellow flowers with five petals and sepals (Naika *et al.*, 2020; Lin *et al.*, 2014). Pollination in tomato is primarily self-pollination, although cross-pollination by insects such as bees may occur under open-field conditions (Egerton University, 2023).

The fruit is a fleshy berry that varies in shape from globular to oblate and in colour from green to red, orange, or yellow upon ripening depending on the cultivar. Each fruit contains numerous flattened, kidney-shaped seeds surrounded by a gelatinous matrix (Peralta & Spooner, 2015). Fruit size and shape vary considerably among cultivars, ranging from small cherry types to large beefsteak varieties (Seed Farm, 2025).

Tomato plants typically grow to heights of 0.5–2.5 metres, depending on their growth habit. Determinate cultivars terminate growth after forming the terminal inflorescence, while indeterminate types continue to grow and flower throughout the

growing season, allowing for extended harvest periods (Kuo *et al.*, 2006; MoALD, 2023).

Advances in plant breeding and genomic research have broadened understanding of morphological diversity within *S. lycopersicum* and its wild relatives, resulting in improved cultivars with enhanced fruit quality, higher yields, and greater tolerance to pests, diseases, and environmental stresses (Lin *et al.*, 2014; Kenyatta University Research, 2024).

2.5 Nutrition value and health benefits of tomato

Tomatoes are an important source of vitamins A, C, and K, as well as essential minerals like potassium and iron. They also contain lycopene, an antioxidant linked to reduced cardiovascular disease and cancer risk (Kumar *et al.*, 2021). Studies show that micronutrient management can significantly enhance tomato nutritional value; for instance, zinc and copper application has been shown to improve vitamin C and beta-carotene content in tomato fruits (Abbasifar *et al.*, 2020; Ma *et al.*, 2019).

2.6 Symptoms of pest infestation and disease

Tomato (*Solanum lycopersicum* L.) is highly susceptible to a wide range of pests and diseases that significantly reduce yield and fruit quality. The main arthropod pests include tomato leaf miner (*Tuta absoluta*), tomato fruit borer (*Helicoverpa armigera*), whiteflies (*Bemisia tabaci*), aphids (*Aphis gossypii*, *Macrosiphum euphorbiae*), cutworms (*Agrotis ipsilon*), and thrips (*Frankliniella occidentalis*) (KALRO, 2023; Kenyatta University Research, 2024). Holes in stems, leaves or fruit and stripped foliage indicate pest infestation. Infestation symptoms vary by pest species. Leaf miners are identified by tunnels or zigzag patterns in leaves. *H. armigera* causes

circular holes on fruits and flower buds, leading to unmarketable produce. *B. tabaci* and aphids suck plant sap from the underside of leaves, resulting in curling, yellowing, and honeydew deposits that promote black sooty mould development (KAFACI, 2024; Egerton University, 2023). Thrips feeding causes silvery streaks and leaf distortion, often leading to flower abortion and reduced fruit set (Pamphero *et al.*, 2022). The chewed stem is a symptom of cutworms.

Common tomato diseases are mainly fungal, bacterial, and viral in nature. Fungal diseases such as early blight causal agent being *Alternaria solani* and late blight (*Phytophthora infestans*) are the most destructive, especially under humid conditions. Early blight symptoms begin as small, dark concentric rings on older leaves, which expand and cause leaf drop, while late blight causes irregular, water-soaked lesions that turn brown and spread rapidly to stems and fruits (Rattan *et al.*, 2021; FAO, 2023). Fusarium wilt (*Fusarium oxysporum*) and Verticillium wilt (*Verticillium dahliae*) are soil-borne pathogens that block the vascular tissues, leading to unilateral yellowing, wilting, and brown discoloration of the stem's internal tissues (Kumar *et al.*, 2021).

Bacterial wilt caused by *Ralstonia solanacearum* results in sudden plant collapse without leaf yellowing, and vascular browning becomes visible when the stem is cut. Viral infections, such as Tomato Leaf Curl Virus (ToLCV) transmitted by *B. tabaci*, produce upward leaf curling, vein thickening, and stunted growth (MoALD, 2023). Powdery mildew (*Oidium neolycopersici*) causes white powdery patches on leaf surfaces, which reduce photosynthetic activity and weaken the plant (Kenyatta

University Research, 2024). These biotic stresses cause significant yield losses of up to 80% under severe infestations (Sharabi *et al.*, 2015; KALRO, 2023).

Micronutrient deficiencies exacerbate pest and disease susceptibility because of reduced enzyme activity, weakened cell wall integrity, and impaired photosynthesis (Dimkpa *et al.*, 2016).

Proper identification of pest and disease symptoms is vital for integrated pest management (IPM) and resistance breeding programs aimed at developing tolerant tomato varieties (Egerton University, 2023; Seed Farm, 2025).

2.7 Micronutrients

Micronutrients, though required in small quantities, play vital roles in tomato (*Solanum lycopersicum* L.) growth, yield, fruit quality, and resistance to pests and diseases. Among them, zinc (Zn) and copper (Cu) are particularly essential due to their involvement in enzymatic activation, photosynthesis, hormone regulation, and defence mechanisms against abiotic and biotic stresses (Kumar *et al.*, 2021; Abbasifar *et al.*, 2020).

Zinc is a key element in enzyme activation, carbohydrate metabolism, and protein synthesis. It contributes to auxin production, pollen formation, and cell membrane integrity (Dimkpa & Bindraban, 2018). Zinc deficiency in tomato results in stunted growth, shortened internodes, chlorotic leaves, and delayed flowering (FAO, 2023). Adequate zinc supply enhances chlorophyll synthesis, photosynthetic rate, and fruit set, leading to improved yield and quality (Ahmed *et al.*, 2021). Furthermore, zinc plays a role in the production of antioxidant enzymes which reduce oxidative damage

under environmental stress (Rahi *et al.*, 2021). Recent research indicates that foliar application of zinc sulphate increases plant vigour and reduces early blight and fruit cracking in tomatoes (KALRO, 2023b)

Copper is another critical micronutrient that participates in photosynthetic and respiratory electron transport, lignin synthesis, and protein metabolism (Dimkpa *et al.*, 2016). It forms part of polyphenol oxidases (PPOs), enzymes responsible for the oxidation of phenolic compounds into quinones that contribute to plant structural defence against pathogens (Taranto *et al.*, 2017). Copper deficiency causes dieback of young shoots, leaf chlorosis, and poor fruit development (FAO, 2023). Conversely, adequate copper enhances disease resistance by strengthening cell walls and inhibiting fungal spore germination (Ma *et al.*, 2019). Studies in Kenya have shown that copper sulphate foliar sprays significantly reduce the severity of *Phytophthora infestans* and *Alternaria solani* infections in tomato fields (Kenyatta University Research, 2024).

Combined application of zinc and copper has been reported to have synergistic effects on tomato productivity and health. Zinc promotes root elongation and nutrient uptake, while copper contributes to improved structural integrity and pathogen defence (Abbasifar *et al.*, 2020; Egerton University, 2023). When applied as foliar micronutrients at low concentrations, Zn and Cu improve plant metabolism, enhance antioxidant capacity, and reduce dependence on chemical pesticides (KAFACI, 2024). Over-application, however, can result in toxicity symptoms such as leaf chlorosis and reduced root growth, hence correct formulation and timing of application are critical (FAO, 2023).

Overall, balanced application of zinc and copper micronutrients through soil or foliar supplementation enhances tomato yield, quality, and resilience against stress. Integration of these elements within sustainable fertilization programs provides a practical approach to improving productivity while minimizing chemical pesticide use in tomato cultivation (Kenyatta University Research, 2024).

2.8 Challenges and Opportunities in Micronutrient Utilization

Despite evidence linking micronutrient adequacy to improved yield and resistance, their use remains limited in sub-Saharan Africa. Farmers often focus on macronutrients (N, P, K), neglecting Zn and Cu due to limited awareness, high input costs, and lack of soil testing (Omwakwe *et al.*, 2023). Opportunities exist to integrate micronutrients into fertilizer blends and to use foliar feeding for efficient uptake. Incorporating micronutrient management into integrated pest management (IPM) programs could reduce pesticide dependence while enhancing productivity and resilience (KALRO, 2023; Egerton University, 2023).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

The study was conducted in Chepalungu Sub-County, Bomet County, located in the Rift Valley Region of Kenya. The field experiment was established at Kiriba Experimental Station (0°48'05" S, 35°18'09" E) at an altitude of approximately 1,980 m above sea level. The area experiences bimodal rainfall, averaging 1,000–1,400 mm annually, with mean temperatures ranging from 18°C to 24°C (Appendices II and III). The soils are predominantly vertisols with pH values of 5.4–6.7, moderately acidic and suitable for tomato cultivation (BCIDP, 2018; KALRO, 2023b). Figure 3.1 shows the map of the study area including the survey zones and experimental site.

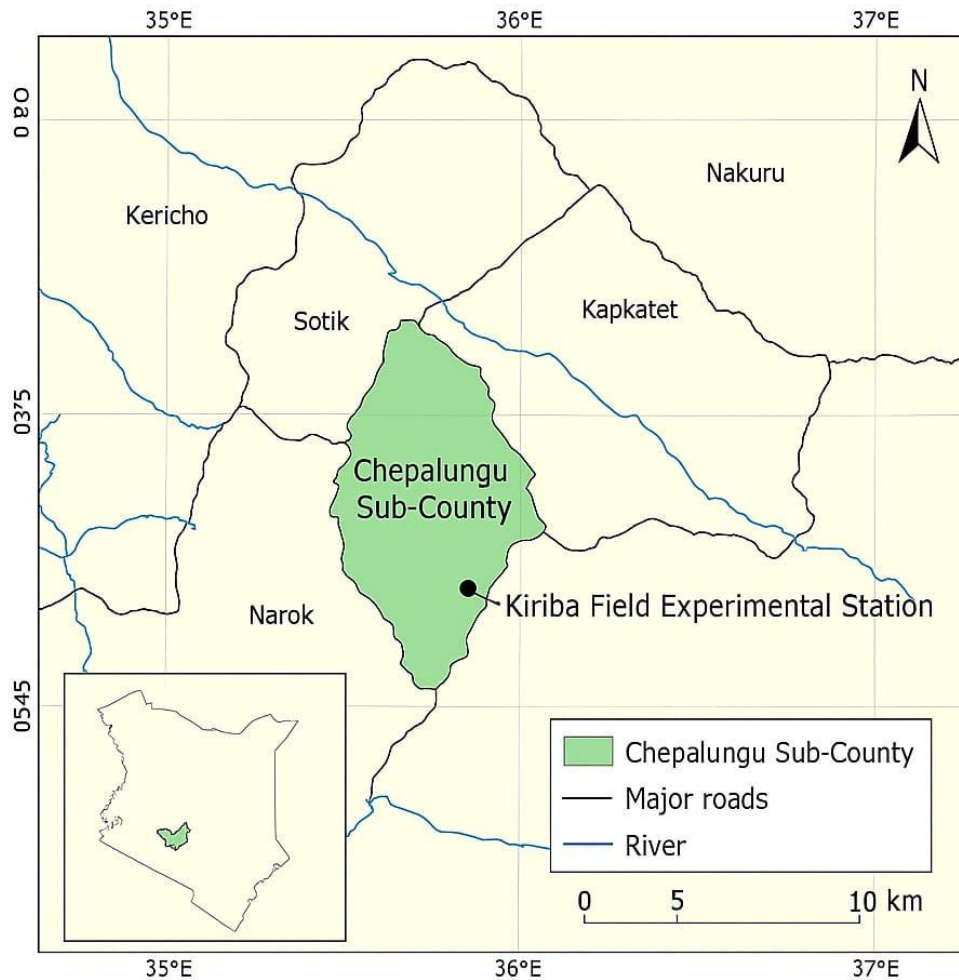


Figure 3.1: Location of the study area in Bomet county, Kenya
 (Source: Kenya GeoPortal)

3.2 Research Design

A mixed-method approach was adopted, combining a baseline farmer survey and a field experiment. The farmer survey provided contextual information on tomato production, pest and disease prevalence, and nutrient management practices in Bomet County, while the field experiment quantified the influence of micronutrients on tomato performance.

3.2.1 Farmer Survey

A structured questionnaire (Appendix I) was administered to 100 tomato farmers selected through stratified random sampling from Siongiroi, Nyongores, and Kong'asis wards. The survey captured demographic data, agronomic practices, tomato varieties grown, fertilizer and pesticide use, pest and disease occurrence, and awareness of micronutrient fertilization. Data were analysed using descriptive statistics with IBM SPSS Statistics version 18.0 (SPSS Inc., 2020).

3.2.2 Experimental Design

The field experiment was conducted at Kiriba Field Station during the short rains of 2019 and 2020 using a Randomized Complete Block Design (RCBD) in split plot arrangement with three replications. The main plots consisted of three tomato varieties: Cal-J, Rio Grande, and Royal Oxly. The subplots comprised four micronutrient treatments: Control (no micronutrient), Zinc sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), Copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$), and a combination of both. Each plot measured 3 m \times 4 m (12 m²) with 1 m alleys between plots and 0.5 m between blocks to minimize treatment interference. The design allowed evaluation of both varietal and micronutrient effects on tomato growth, yield, and resistance parameters (KALRO, 2023b).

3.3 Site Selection

The site was selected based on accessibility for continuous monitoring, homogeneity soil texture and fertility, and a history of tomato cultivation to ensure pest and disease presence. The area was previously fallow and manually cleared and prepared to minimize residual chemical interference prior to planting.

3.4 Field layout

The experimental area was divided into 36 plots arranged in three replicates. Each replicate contained all treatment combinations in a split-plot layout. The schematic layout is shown in Figure 3.2.

Block 1	Block 2	Block 3
T1-CS T2-ZS T3-BOTH	T1-ZS T2-CS T3-CON	
T2-BOTH T3-CS T1-CON	T2-CON T3-ZS T1-CS	
T3-ZS T1-BOTH T2-CON	T3-BOTH T1-CON T2-ZS	

T1 = Rio Grande, T2 = Royal Oxly, T3 = Cal-J

CS = Copper sulphate, ZS = Zinc sulphate, BOTH = $\text{CuSO}_4 + \text{ZnSO}_4$, CON = Control.

Figure 3.2: Field layout schematic of the tomato micronutrient trial at Chepalungu

(Source: Koech, 2025).

3.5 Crop Establishment and Management

3.5.1 Nursery and Transplanting

Certified seeds of Cal-J, Rio Grande, and Royal Oxly were raised in a nursery bed enriched with compost manure. Seedlings were transplanted at 5–6 weeks after emergence under moist conditions at a spacing of 75 cm × 50 cm. Each subplot (12 m²) accommodated 32 plants, giving a plant density of approximately 26,667 plants ha⁻¹. Transplanting was done in the late afternoon to reduce transplanting shock.

3.5.2 Fertilization and Treatment Application

Basal fertilization with DAP (18:46:0) was applied at 150 kg ha⁻¹ during transplanting, followed by CAN (26% N) at 100 kg ha⁻¹ four weeks later. The micronutrient solutions made in clean water were applied as foliar sprays using a hand sprayer at 0.5% concentration weekly from four weeks after transplanting until fruit

maturity. Zinc sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) was supplied as Zincate® (MEA Fertilizers Ltd., Nairobi), and Copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) as Osho Blue Copper® (Osho Chemical Industries Ltd., Nairobi). For the combined treatment, equal proportions (0.5% each) were mixed. Control plots were sprayed with 0.5% ammonium sulphate to account for the sulphate ion effect. The application rate and method followed previous trials conducted in Kenyan tomato production systems under similar agro-ecological conditions (KALRO, 2023b; Abbasifar *et al.*, 2020; Egerton University, 2023).

3.5.3 Field Husbandry

Uniform agronomic practices were maintained for all treatments. Manual weeding was performed thrice during the crop cycle. Plants were staked using wooden poles and pruned below the first inflorescence. Supplemental irrigation was provided by using sprinkler during dry spells. No synthetic pesticides were applied; cultural and physical control measures were used to assess micronutrient effects on pest and disease resistance.

3.6 Data Collection

Data from the survey included demographic, agronomic, and pest management information. Field data comprised pest incidence (*Frankliniella occidentalis*, *Tuta absoluta*), disease severity (*Alternaria solani*, *Phytophthora infestans*), and yield parameters. Ten plants per plot were randomly selected for observation. Fruit yield and quality parameters were measured at harvest following AOAC (2016) guidelines.

3.6.1 Micronutrient and Soil Analysis

Soil and foliar samples were collected from each plot at 0–30 cm depth before planting and after harvest. Samples were oven-dried, sieved, and digested using nitric-perchloric acid mixture. Zinc and copper concentrations were determined using an Atomic Absorption Spectrophotometer (Shimadzu AA-6200) as described by Mibei *et al.* (2012).

3.6.2 Determination of Vitamin C, Vitamin K and Beta-Carotene Content

3.6.2.1 Vitamin C (Ascorbic Acid) Determination

Vitamin C was quantified following AOAC (2016) procedures using a Shimadzu LC-20AT High-Performance Liquid Chromatograph (HPLC) equipped with a UV detector at 245 nm. Ten grams of tomato pulp were homogenized in 25 mL of 0.8% metaphosphoric acid, centrifuged at 10,000 rpm for 10 minutes at 4°C, and filtered through a 0.45 µm syringe filter. The mobile phase was 0.1% metaphosphoric acid (isocratic) at a flow rate of 1.0 mL min⁻¹. Quantification was done using L-ascorbic acid standards, and results were expressed as mg 100 g⁻¹ fresh weight.

3.6.2.2 Beta-Carotene Determination

Beta-Carotene content was analysed following Ha *et al.* (2010). Tomato pulp (5 g) was extracted with 50 mL of acetone:hexane (1:1 v/v) containing 0.1% BHT. The extract was washed with 10% NaCl, dried over anhydrous sodium sulphate, and evaporated under reduced pressure at 45°C. Samples were reconstituted in methanol and analysed using Shimadzu LC-20AT HPLC with a C30 reverse-phase column (250 × 4.6 mm). Detection was at 450 nm, and quantification was based on external calibration using beta-carotene standards. Results were expressed as mg 100 g⁻¹ fresh weight.

3.6.2.3 Vitamin K (Phylloquinone) Determination

Vitamin K was determined following Booth et al. (1994) using a modified post-column reduction method with fluorescence detection. Ten grams of tomato pulp were homogenized with isopropanol containing menadione as internal standard and partitioned with hexane. After optional saponification with 0.5 M ethanolic KOH, extracts were cleaned using silica gel solid-phase extraction (SPE). HPLC analysis was carried out on a C18 column with methanol as mobile phase at 1.0 mL min⁻¹. Post-column zinc reduction enabled fluorescence detection at excitation 248 nm and emission 430 nm. Results were expressed as µg 100 g⁻¹ fresh weight.

3.6.2.4 Quality Control

All analyses were done in triplicate. Calibration curves were prepared using certified standards. Matrix spikes, blanks, and QC samples were included in each batch. Recoveries between 80–110% were considered acceptable. Data were expressed as mean ± SD on a fresh weight basis.

3.7 Data analysis

Survey data were analysed using IBM SPSS Statistics version 18.0 (SPSS Inc., 2020). Experimental data were subjected to analysis of variance (ANOVA) using SAS 9.4 (SAS Institute Inc., 2022), and means were separated using LSD at p≤0.05.

CHAPTER FOUR: RESULTS

4.1 Prevalence of tomato diseases and arthropod pests

4.1.1 Demographic and production characteristics of tomato farmers

The baseline survey revealed that the majority of tomato farmers in Chepalungu Sub-County were male (88%) while female farmers accounted for 12% (Table 4.1). Most respondents (83%) cultivated tomatoes during the short rains (Table 4.2). Most farmers were middle aged (41-45 years). Majority of the respondents interviewed (62.3%) had attained primary education, followed by secondary (21.7%) and tertiary (9.5%) levels as shown in table 4.1.

4.1.2 Varieties and fertilizer use

Rio Grande (42.4%) and Royal Oxly (20.3%) were the most common varieties (Figure 4.1). Fertilizer use was dominated by diammonium phosphate (DAP) (80%), followed by NPK (12%) and farmyard manure (6%) (Figure 4.2). Plate 4.1 shows the growth stages of tomato plants from nursery to the ninth week after transplanting.

Table 4.1 Gender, education levels, and time of planting tomato crop in Chepalungu Sub-County

Variable	Category	Percent respondents
Gender	Male	88%
	Female	12%
Level of education	None	6.5%
	Primary	62.3%
	Secondary	21.5%
	Tertiary	9.5%
Age in years	< 30	9%
	31-35	16%
	36-40	14%
	41-45	31%
	46-50	13%
	>50	17%

Table 4.2 Time of planting tomato crop in Chepalungu Sub-County

Long rains	17%
Short rains	83%

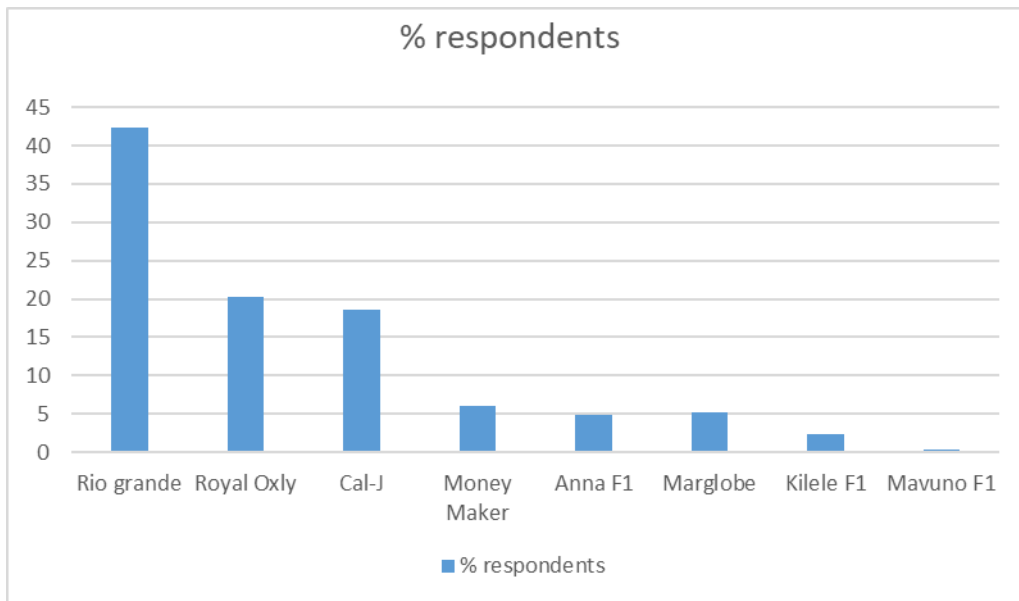


Figure 4.1: Tomato varieties cultivated in Chepalungu Sub County. Source: Koech, 2025.

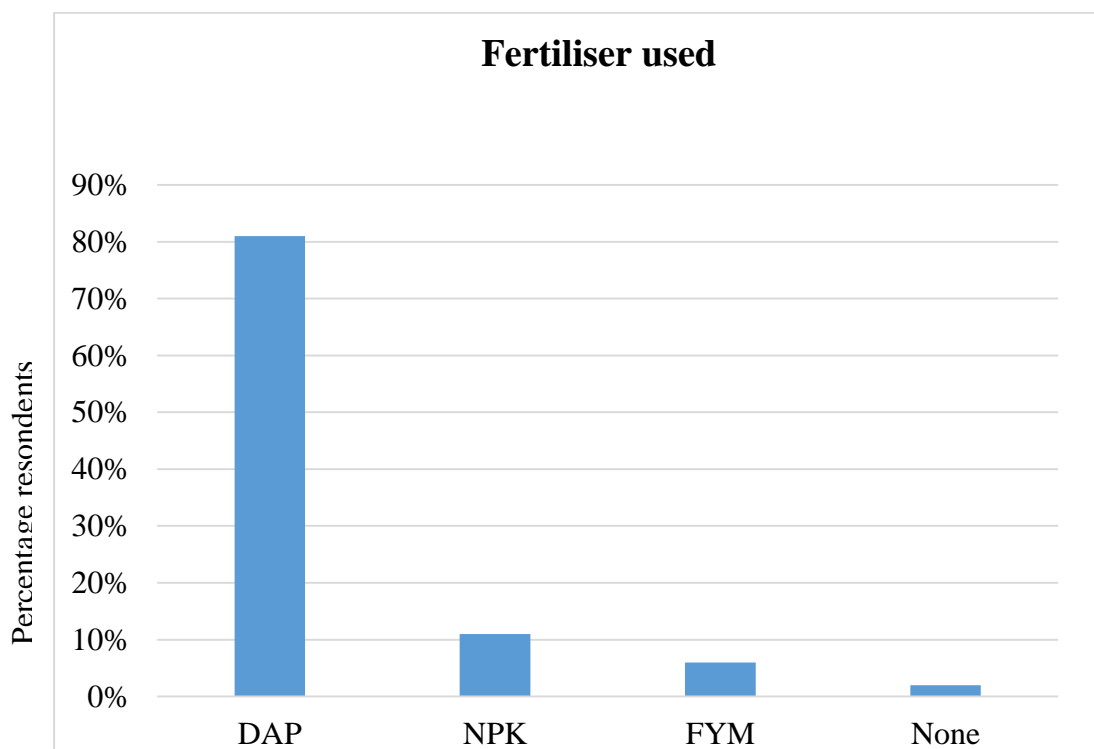


Figure 4.2: Fertilizer used in Chepalungu Sub County.



A



B



C



D



E



F

Plate 4.1: Tomato plants at different stages. (A) Four weeks in nursery; (B) First week after transplanting; (C) Third week after transplanting; (D) Fifth week after transplanting (E) Seventh week after transplanting and (F) Ninth week after transplanting.

4.1.3 Pesticide use and prevalence of pests and diseases

Regarding pest and disease management, farmers primarily relied on synthetic pesticides. Insecticides such as flubendiamide, imidacloprid, acephate, lambda-cyhalothrin, and cypermethrin were commonly used against thrips, whiteflies, aphids,

and tomato leaf miner (*Tuta absoluta*) (Table 4.3). Fungicides including mancozeb, metalaxyl-M, propineb, cymoxanil, and carbendazim were used to control fungal diseases like early and late blight (Table 4.4).

Table 4.3 Pesticides used in the management of tomato pests

Active ingredient	Target pest	% use
Flubendiamide	Leaf miner moth	33.5
Imidacloprid	Thrips, whiteflies	22.7
Acephate	Thrips, aphids	11.2
Lambda-Cylothrin	Thrips, whiteflies	13.7
Cypermethrin	Thrips	19.9

Table 4.4 Fungicides used in tomato production

Active ingredient	Target disease(s)	% use
Mancozeb	Blight	41.3
Metalaxyl-M	Blight, leafspot	13.3
Propineb and Cymoxamil	Blight, leafspot	20.8
Propineb	Blight, blackspot	16.6
Carbendazim	Leaf spot, mildew	8.0

The survey identified four major arthropod pests: thrips (*Frankliniella occidentalis*) (42%), tomato leaf miner (*Tuta absoluta*) (31%), whiteflies (*Bemisia tabaci*) (12%), and aphids (*Aphis gossypii*) (11%) (Figure 4.3). Late blight (*Phytophthora infestans*) was the most prevalent disease (72%), followed by early blight (*Alternaria solani*) (61%), bacterial wilt (*Ralstonia solanacearum*) (21%), and Fusarium wilt (*Fusarium oxysporum f.sp. lycopersici*) (15%) (Figure 4.4). Plates 4.2–4.4 show characteristic symptoms of major pest and disease infestations.



Plate 4.2: Leaf attacked by *Tuta absoluta*.



Plate 4.3: Tomato plant attacked by *Alternaria solani*



Plate 4.4: Tomato plant attacked by *Phytophthora infestans*

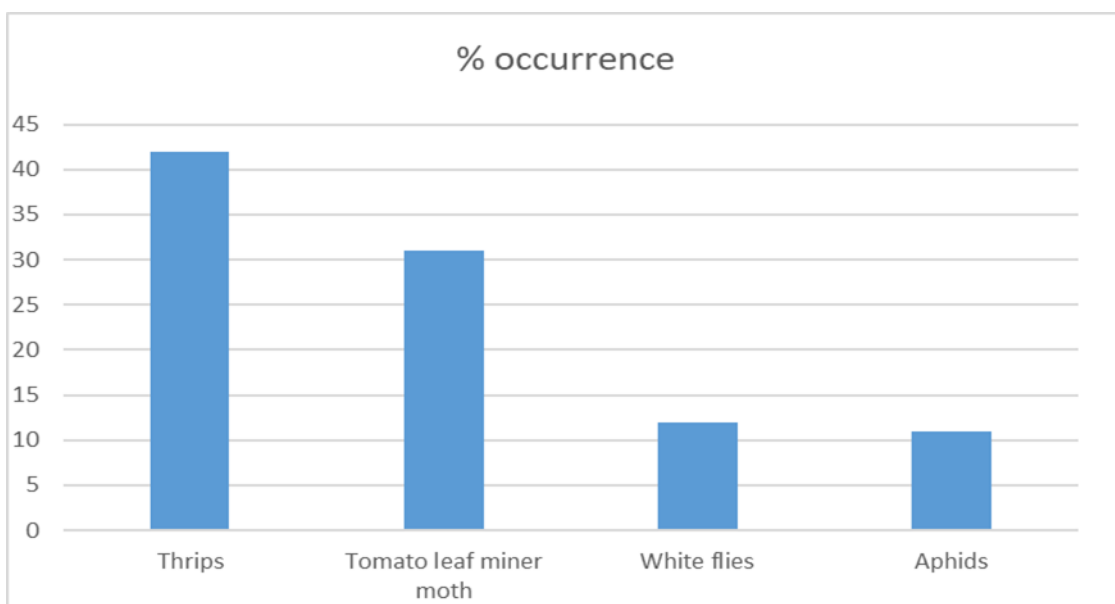


Figure 4.3: Arthropod pests reported in Chepalungu Sub county

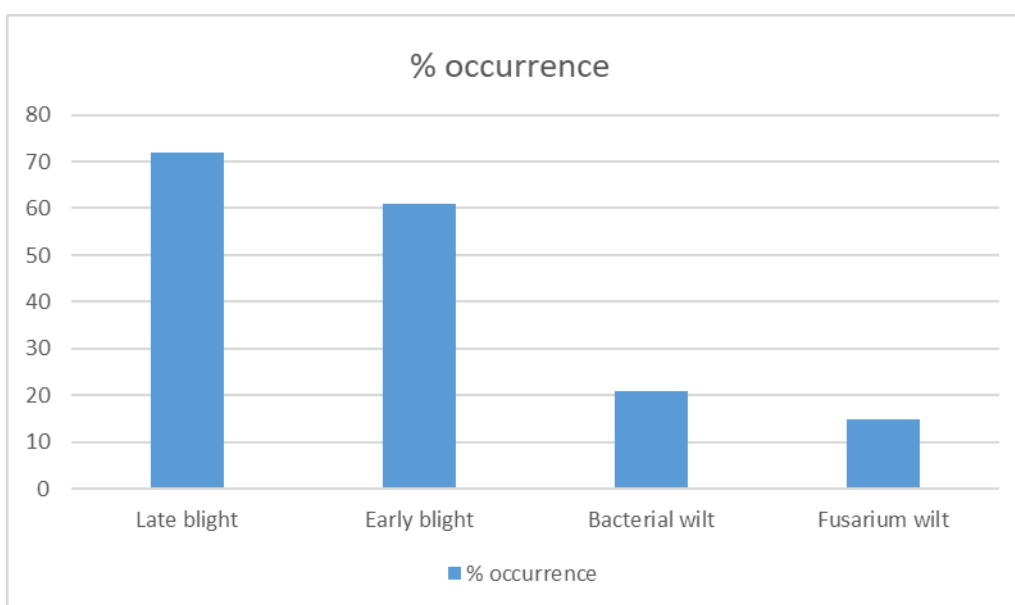


Figure 4.4: Percentage incidence of tomato diseases

4.2 Assessment of resistance of the arthropod pests, diseases and response of three varieties of tomatoes to the selected micronutrients in Chepalungu, Bomet County

4.2.1 Incidence and severity of early blight disease on tomato

The tested treatments significantly ($P \leq 0.05$) reduced the incidence of early blight disease compared to the control. Zinc sulphate resulted in the least mean incidence of early blight disease on Rio Grande and Cal-J tomato varieties recording 27.9% and 16.3%, respectively (Table 4.5). On the other hand, Copper sulphate recorded the lowest disease incidence in Royal Oxly variety. The effect of these treatments was comparable to copper sulphate+Zinc sulphate. The highest incidence of early blight disease was recorded in the control plots in all the three tomato varieties evaluated (Table 4.5).

The tested treatments significantly ($P \leq 0.05$) suppressed the severity of early blight disease compared to the control (Table 4.5). Zinc sulphate resulted in the least severity of early blight disease on Rio Grande and Cal-J tomato varieties recording 7.4% and 3.6%, respectively whereas Copper sulphate recorded the least disease severity (8.3%) in Royal Oxly variety. The effect of these two treatments was comparable to copper sulphate + Zinc sulphate (Table 4.5).

Table 4.5: Mean incidence and severity of early blight disease on tomato

Tomato variety	Treatment	Incidence (%)	Severity (%)
Rio Grande	Copper sulphate	40.5b	10.1b
	Zinc sulphate	27.9bc	7.4b
	Copper sulphate +Zinc sulphate	32.6b	8.5b
	Control	92.5a	35.3a
Royal Oxly	Copper sulphate	26.9bc	8.3b
	Zinc sulphate	32.1b	10.3b
	Copper sulphate +Zinc sulphate	35.3b	10.5b
	Control	89.0a	36.7a
Cal-J	Copper sulphate	28.0bc	8.1b
	Zinc sulphate	16.3c	3.6b
	Copper sulphate +Zinc sulphate	29.3bc	8.0b
	Control	92.0a	34.5a
P-value		<0.0001	<0.0001
LSD		15.2	7.3

Means followed by the same letter (s) in each column are not significantly different according to Fisher's Least Significant (LSD) test at $P \leq 0.05$.

4.2.2 Incidence and severity of late blight disease

The tested micro-nutrients significantly ($P \leq 0.05$) reduced the incidence of late blight disease compared to the control. Zinc sulphate resulted in the least mean incidence of late blight disease on Rio Grande and Cal-J tomato varieties with 37.4% and 29.7%, respectively (Table 4.6). However, the effect of this treatment was comparable to copper sulphate + zinc sulphate. Copper sulphate-treated plots recorded the least late blight disease incidence (32.3%) in the Royal Oxly variety. The control plots recorded

the highest incidence of late blight disease in all the three tomato varieties evaluated (Table 4.6).

The tested micro-nutrients had a significant ($P \leq 0.05$) reduction on severity of late blight disease compared to the control. Zinc sulphate treated plots resulted in the least mean severity of late blight disease on Rio Grande and Cal-J tomato varieties recording 9.7% and 6.4%, respectively followed by copper sulphate+zinc sulphate (Table 4.6). Copper sulphate-treated plots recorded the lowest late blight disease severity (9.6%) in Royal Oxly variety. The control plots recorded the highest severity of late blight disease in all the three tomato varieties (Table 4.6).

Table 4.6: Mean incidence and severity of late blight disease

Tomato variety	Treatment	Incidence (%)	Severity (%)
Rio Grande	Copper sulphate	57.5b	20.4c
	Zinc sulphate	37.4cd	9.7ef
	Copper sulphate +Zinc sulphate	42.5bcd	12.9de
	Control	89.5a	40.3ab
Royal Oxly	Copper sulphate	32.3d	9.6ef
	Zinc sulphate	47.4bc	16.5cd
	Copper sulphate +Zinc sulphate	49.3bc	16.5cd
	Control	86.0a	45.6a
Cal-J	Copper sulphate	40.7cd	12.3def
	Zinc sulphate	29.7d	6.4f
	Copper sulphate +Zinc sulphate	36.3cd	11.1def
	Control	86.0a	36.1b
P-value		<0.0001	<0.0001
LSD		15.0	6.2

Means followed by the same letter (s) in each column are not significantly different according to Fisher's Least Significant (LSD) test at $P \pm 0.05$.

4.2.3 Incidence of arthropod pests of tomato

4.2.3.1 Infestation and population of *Frankliniella occidentalis*

The tested micro-nutrients significantly ($P \leq 0.05$) reduced *Frankliniella occidentalis* infestation compared to the control. Plots treated with copper sulphate +zinc sulphate resulted in the least *F. occidentalis* infestation on Rio Grande tomato variety (40.9%) while zinc sulphate lowered *F. occidentalis* infestation on Royal Oxly and Cal-J tomato varieties recording 55.1% and 50.7%, respectively (Table 4.7).

The tested treatments significantly ($P \leq 0.05$) reduced *F. occidentalis* population compared to the control. Copper sulphate +Zinc sulphate treated plots had the least population of *F. occidentalis* on Rio Grande and Cal-J tomato varieties compared to the rest of treatments but were comparable in effect to copper sulphate and Zinc sulphate. Application of zinc sulphate resulted in the lowest *F. occidentalis* population on Royal Oxly tomato variety (1.9) compared to the rest of treatments. The control plots recorded the highest infestation of *F. occidentalis* in all the three tomato varieties (Table 4.7).

Table 4.7: Mean infestation and population of thrips

Tomato variety	Treatment	Infestation (%)	No. Thrips per plant
Rio Grande	Copper sulphate	63.5b	2.2b
	Zinc sulphate	60.4bc	1.5b
	Copper sulphate +Zinc sulphate	40.9c	1.4b
	Control	95.0a	6.5a
Royal Oxly	Copper sulphate	57.6bc	1.9b
	Zinc sulphate	55.1bc	1.9b
	Copper sulphate +Zinc sulphate	62.3b	2.3b
	Control	88.3a	5.6a
Cal-J	Copper sulphate	54.0bc	1.6b
	Zinc sulphate	50.7bc	2.4b
	Copper sulphate +Zinc sulphate	51.3bc	1.6b
	Control	92.0a	5.3a
P-value		<0.0001	<0.0001
LSD		20.2	1.7

Means followed by the same letter (s) in each column are not significantly different according to Fisher's Least Significant (LSD) test at $P \leq 0.05$

4.2.3.2 Infestation and population of *Tuta absoluta*

The tested micro-nutrients significantly ($P \leq 0.05$) reduced *Tuta absoluta* infestation compared to the control. Copper sulphate +Zinc sulphate treated plots had the least *T. absoluta* infestation on Rio Grande and Cal-J tomato varieties recording 22.1% and 12.3%, respectively. On the other hand, Copper sulphate significantly ($P \leq 0.05$) reduced *T. absoluta* infestation on Royal Oxly tomato variety compared to the control. However, this treatment was comparable in effect to zinc sulphate and Copper sulphate +zinc sulphate (Table 4.8).

The tested treatments significantly ($P \leq 0.05$) reduced the population of *T. absoluta* compared to the control. Copper sulphate +zinc sulphate treated plots recorded the least population of *T. absoluta* on Rio Grande tomato variety followed by zinc sulphate and copper sulphate in the second and third position, respectively. Zinc

sulphate resulted in the lowest population of *T. absoluta* in Royal Oxly and Cal-J tomato varieties compared to the rest of the treatments. This treatment was comparable in effect to copper sulphate and copper sulphate + zinc sulphate (Table 4.8).

Table 4.8: Mean infestation and population of *Tuta absoluta*

Tomato variety	Treatment	Infestation (%)	<i>Tuta absoluta</i> population
Rio Grande	Copper sulphate	32.3b	0.8c
	Zinc sulphate	25.6bc	0.6c
	Copper sulphate +Zinc sulphate	22.1bc	0.4c
	Control	61.0a	1.9ab
Royal Oxly	Copper sulphate	19.9bc	0.5c
	Zinc sulphate	21.5bc	0.4c
	Copper sulphate +Zinc sulphate	26.0bc	0.6c
	Control	61.0a	2.5a
Cal-J	Copper sulphate	13.7c	0.3c
	Zinc sulphate	14.0c	0.2c
	Copper sulphate +Zinc sulphate	12.3c	0.3c
	Control	58.3a	1.7b
P-value		<0.0001	<0.0001
LSD		18.2	0.6

Means followed by the same letter (s) in each column are not significantly different according to Fisher's Least Significant (LSD) test at $P \leq 0.05$.

4.3 Evaluation of the antioxidant levels specifically vitamin C, beta carotene and vitamin K in three tomato varieties in relation to micronutrient application

4.3.1 Effect of micronutrient application on antioxidant concentrations

The tested micro-nutrients showed varied effect on the levels of Vitamin C in tomato fruit compared to control. Copper sulphate +zinc sulphate resulted in significantly ($p \leq 0.05$) higher level of Vitamin C in Rio Grande variety followed by zinc sulphate and Copper sulphate in the second and third position, respectively. In both Royal

Oxly and Cal-J tomato varieties, copper sulphate treated plots recorded the highest Vitamin C content followed closely by copper sulphate +zinc sulphate whereas the least vitamin C content was recorded in zinc sulphate treated plots (Table 4.9).

The tested treatments had no effect on the beta-carotene level in Rio Grande tomato variety compared to the control. However, copper sulphate +zinc sulphate recorded slightly higher beta-carotene content than the rest of treatments. The least beta-carotene level in this variety was recorded in copper sulphate treated plots (Table 4.9).

The tested treatments significantly ($p \leq 0.05$) reduced the beta-carotene level in Royal Oxly tomato variety compared to the control with the least recorded in copper sulphate treated plots. Copper sulphate recorded the highest Beta-carotene level in Cal-J tomato variety followed by zinc sulphate and were significantly ($p \leq 0.05$) different from copper sulphate +zinc sulphate and the control (Table 4.9).

Table 4.9: Effect of application of copper sulphate and zinc sulphate on levels of vitamin C and beta carotene in tomato fruit

Tomato variety	Treatment	Vitamin C	Beta-carotene
		(mg/100g fruit pulp)	(mg/100g fruit pulp)
Rio Grande	Copper sulphate	5.28d	0.03e
	Zinc sulphate	8.05c	0.11c
	Copper sulphate +Zinc sulphate	9.25a	0.12c
	Control	2.70e	0.11c
Royal Oxly	Copper sulphate	8.87ab	0.00f
	Zinc sulphate	0.19g	0.08d
	Copper sulphate +Zinc sulphate	8.86ab	0.09cd
	Control	2.93e	0.23a
Cal-J	Copper sulphate	8.20bc	0.17b
	Zinc sulphate	0.11g	0.16b
	Copper sulphate +Zinc sulphate	8.09bc	0.03e
	Control	1.63f	0.08d
P-value		<0.0001	<0.0001
LSD		0.80	0.02

Means followed by the same letter (s) in each column are not significantly different according to Fisher's Least Significant (LSD) test at $P \leq 0.05$.

4.3.2 Correlation between vitamin concentrations and prevalence of pests and diseases

The data of treatment-level means averaged across tomato varieties computed from tables 4.5–4.9 are shown in table 4.10.

Table 4.10 Correlation of vitamin C and beta-carotene and prevalence of pests/diseases

Vitamin	Target (prevalence)	Pearson r	p-value
Vitamin_C_mg100g	Early Blight Incidence_pct	-0.523	0.4772
Vitamin_C_mg100g	Late Blight Incidence_pct	-0.527	0.4729
Vitamin_C_mg100g	Thrips Infestation pct	-0.634	0.3665
Vitamin_C_mg100g	<i>Tuta absoluta</i> Infestation_pct	-0.600	0.4004
Beta_carotene_mg100g	Early Blight Incidence_pct	0.712	0.2876
Beta_carotene_mg100g	Late Blight Incidence_pct	0.709	0.2907
Beta_carotene_mg100g	Thrips Infestation_pct	0.751	0.2490
Beta_carotene_mg100g	<i>Tuta absoluta</i> Infestation_pct	0.760	0.2396

The figures below illustrate the scatter plots that represent correlations between vitamin C and early blight (Fig. 4.5), late blight (Fig. 4.6), thrips (Fig. 4.7) and leaf miner moths (Fig. 4.8).

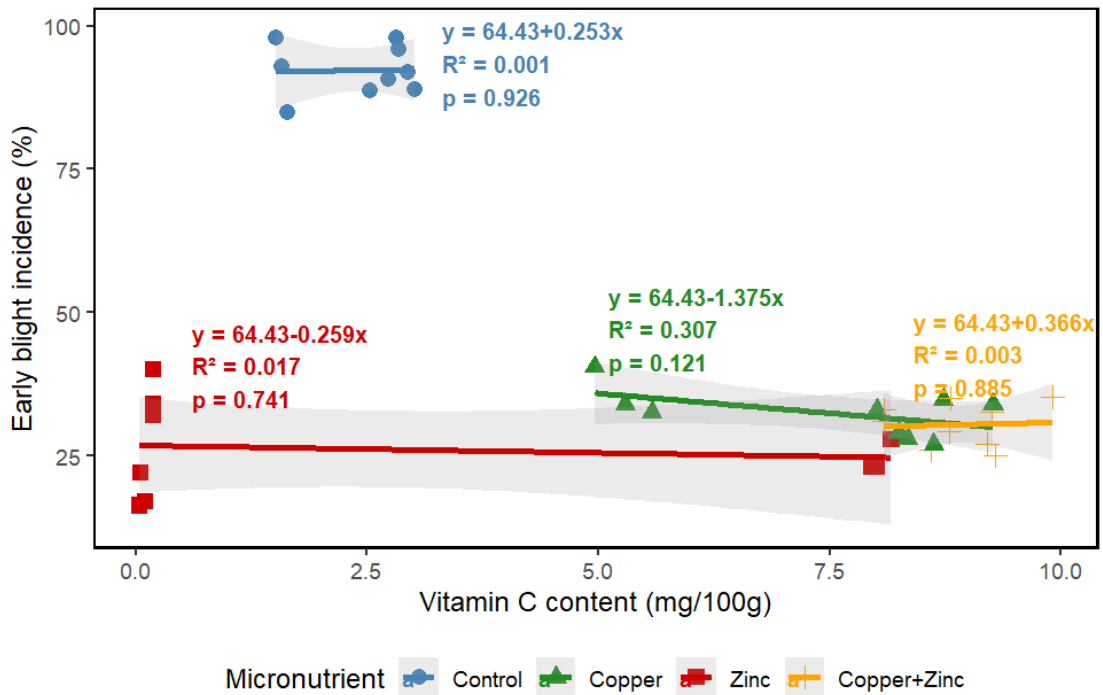


Figure 4.5 Relationship between vitamin C and early blight incidence

The relationship between vitamin C concentration in plant tissues and the incidence of early blight disease, caused primarily by *Alternaria solani*, reveals nuanced patterns when modulated by micronutrient amendments, as illustrated in the scatter plot with overlaid regression lines. Across all treatment groups, control, copper-supplemented, zinc-supplemented, and combined copper-zinc application, the mean early blight incidence was around 64–65%, with no statistically significant deviation from this baseline regardless of ascorbic acid levels ranging from approximately 1.5 to 9.5 mg/100 g fresh weight. From the results it can be concluded that less than 1% to at most 37% of the variability in disease expression can be attributed to differences in foliar vitamin C content within the observed range.

In the control group, disease incidence remains tightly clustered between 85% and 100% at lower vitamin C levels, then plateaus near 90–95% even as ascorbic acid approaches 6 mg/100 g. This suggests that under standard nutritional conditions,

endogenous vitamin C does not exert a detectable protective or exacerbating effect on early blight susceptibility within the physiological concentrations measured. Similarly, copper supplementation produces a shallow negative slope, implying a weak tendency toward reduced disease with rising vitamin C, though the relationship falls short of statistical significance.

Zinc application alone mirrors the control in terms of slope direction and magnitude, with disease levels largely confined between 25% and 45% across the vitamin C gradient. Notably, the combined copper-zinc treatment exhibits the most variable response yielding a weakly positive slope.

The lack of significant trends across treatments suggests that ascorbic acid may function more as a general stress indicator than a direct determinant of *Alternaria* infection dynamics. Alternative mechanisms, such as altered phenolic metabolism, cuticle thickness, or stomatal regulation induced by copper and zinc, likely dominate disease outcomes.

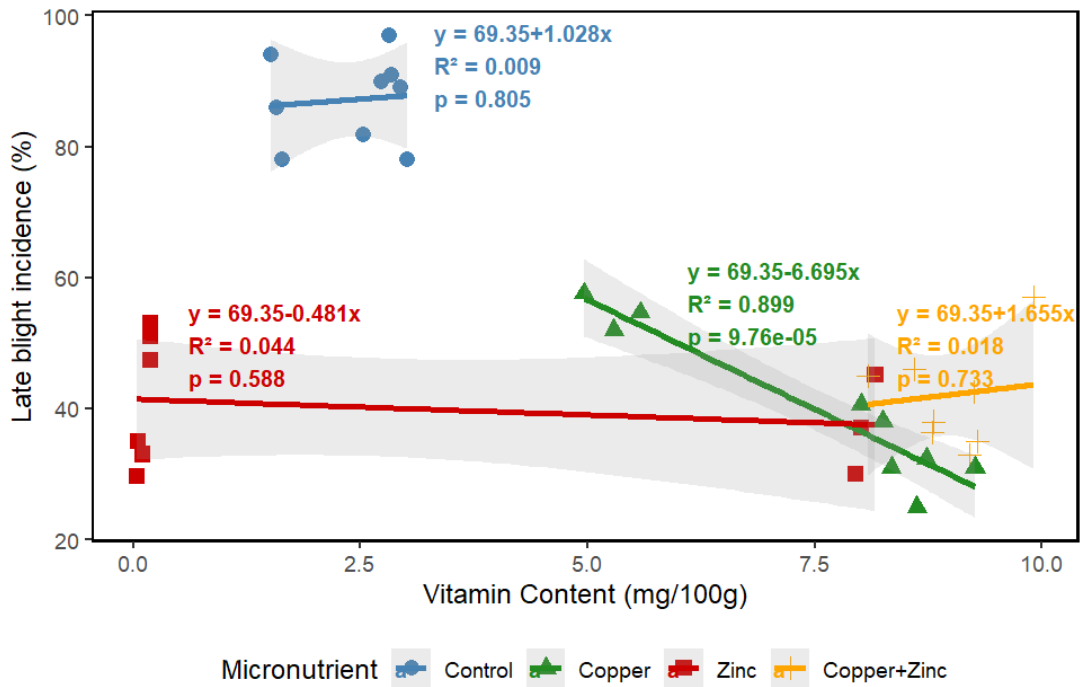


Figure 4.6 Relationship between vitamin C and late blight incidence

Late blight (*Phytophthora infestans*) exhibits a treatment-dependent relationship with vitamin C; most pronounced under copper supplementation. By contrast, late blight responses reveal a striking divergence, particularly under copper supplementation. Here, the Cu-treated group displays a steep negative regression, indicating that approximately 90% of the reduction in disease incidence. This highly significant relationship suggests that copper enhances ascorbic acid biosynthesis or stability in plants. The control group shows no meaningful correlation, with incidence fluctuating irregularly regardless of vitamin C level. Zinc application alone yields a weak negative slope, mirroring its negligible impact on late blight and suggesting limited involvement of Zn in vitamin C-mediated late blight resistance. The combined Cu+Zn treatment produces a shallow decline, with incidence stabilizing near 30–40% at higher ascorbic acid levels.

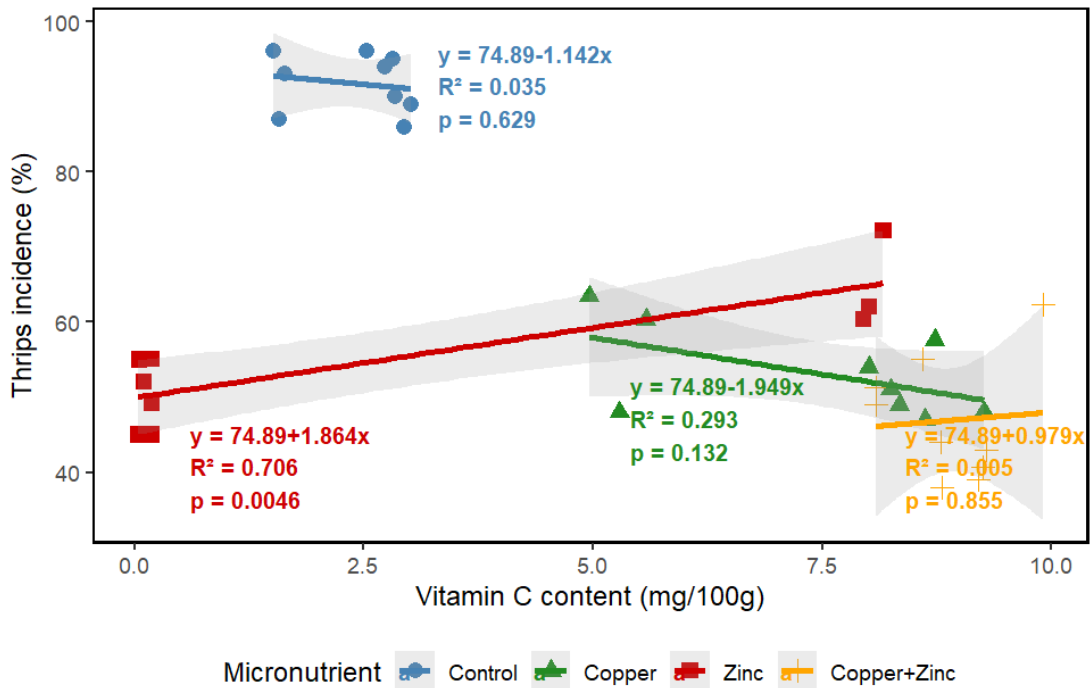


Figure 4.7 Relationship between vitamin C and thrips incidence

The incidence of thrips injury on tomato foliage, as influenced by ascorbic acid concentration across four micronutrient regimes, control, copper (Cu), zinc (Zn), and combined Cu+Zn, reveals a striking treatment-specific pattern that contrasts sharply with the fungal blight responses previously observed. While early and late blight showed either negligible or conditionally protective associations with vitamin C, thrips damage demonstrates a statistically robust positive correlation exclusively under zinc supplementation, suggesting that Zn-mediated elevation of foliar ascorbic acid may enhance host susceptibility to this pest.

Across the control treatment, thrips incidence remains largely independent of vitamin C content. The fitted regression indicates that less than 4% of variation in pest damage is explained by ascorbic acid, with no evidence of a directional trend. Copper application alone produces a shallow negative slope, hinting at a modest reduction in thrips injury, though the relationship falls short of statistical significance. The

moderate spread in data points and wide confidence bands suggest that any suppressive effect of copper is inconsistent. The combined Cu+Zn treatment shows near-zero slope, with incidence fluctuating without clear linkage to ascorbic acid, implying that zinc masks any mild benefit conferred by copper.

Zinc supplementation elicits a strong and highly significant positive linear relationship, where approximately 71% of the increase in thrips incidence is attributable to rising vitamin C concentration. The tight clustering of data points along the regression line, coupled with a narrow confidence envelope, underscores the reliability of this association.

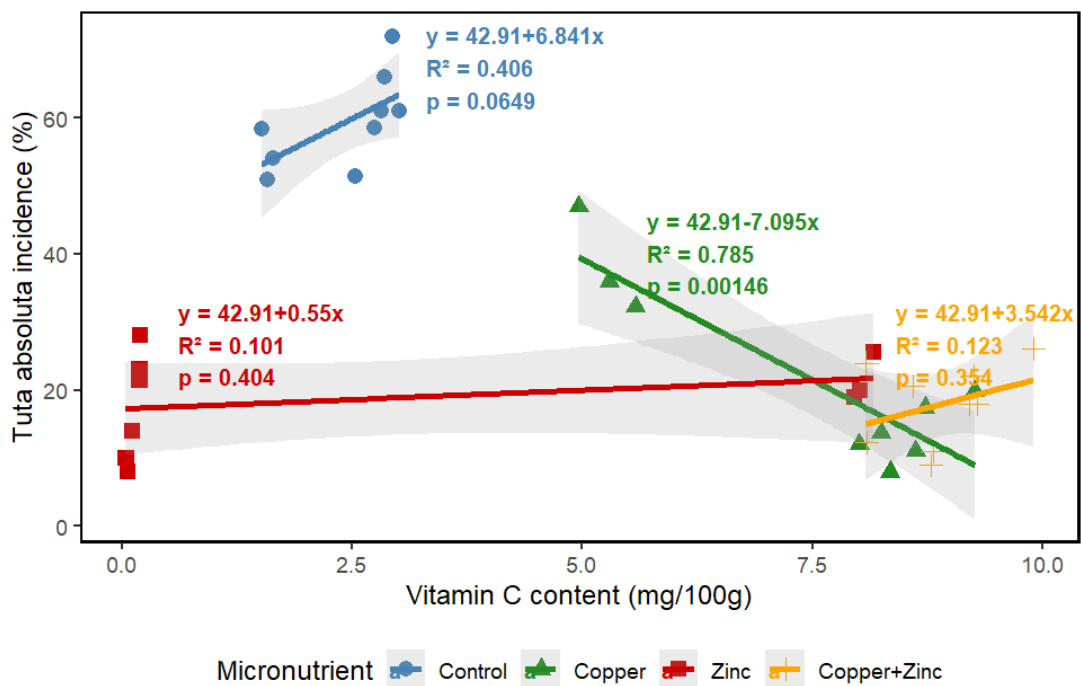


Figure 4.8 Relationship between vitamin C and *Tuta absoluta* incidence

The incidence of leaf mining by *Tuta absoluta* exhibits a micronutrient-dependent relationship with foliar ascorbic acid concentration. *Tuta absoluta* damage reveals two statistically significant opposing trends, a moderate positive correlation in the control treatment and a steep negative correlation under copper application. In the control

group, *Tuta absoluta* incidence rises steadily with increasing vitamin C content, described by the regression equation. The tight clustering of data points along the upward-sloping line, combined with a relatively narrow confidence band, suggests biological relevance despite marginal statistical significance.

By sharp contrast, copper supplementation induces a highly significant negative linear relationship. Damage declines from over 50% to below 20% with data points tightly aligned along the regression line and minimal scatter. Zinc application alone yields a near-horizontal regression, with incidence fluctuating between 20% and 35% across the vitamin C gradient. The combined Cu+Zn treatment produces a weakly positive slope with incidence stabilizing at higher vitamin C levels.

4.3.3 Correlation between beta-carotene concentrations and prevalence of pests and diseases

The relationship between beta-carotene concentration and early blight (*Alternaria solani*) incidence in tomato plants under varying micronutrient regimes reveals a concentration-dependent. Across the control treatment, early blight incidence remains high and stable over a narrow beta-carotene gradient, described by a nearly flat regression.

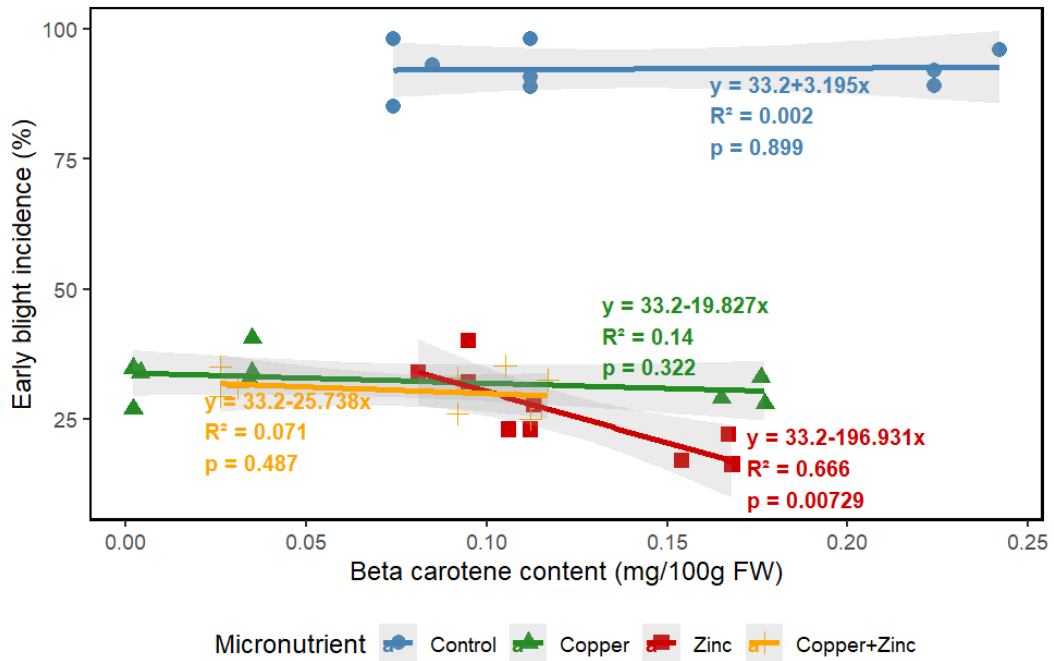


Figure 4.9: Correlation between beta-carotene and early blight incidence in tomato under different micronutrient treatments.

Copper application alone yields a shallow, non-significant negative trend with incidence dropping before plateauing. Zinc supplementation produces a steep and highly significant negative regression. The combined copper+zinc treatment generates a moderate negative slope.

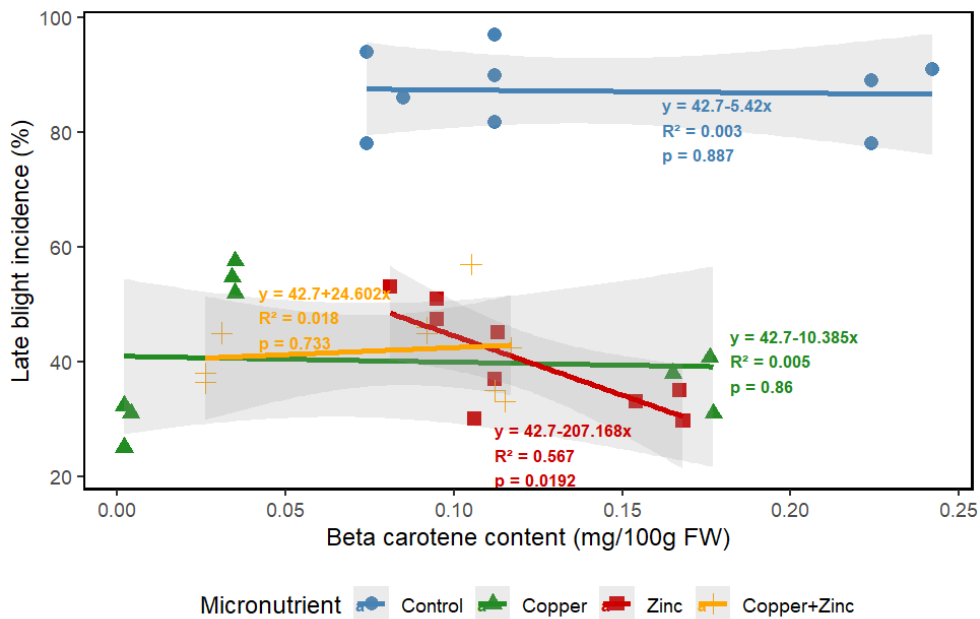


Figure 4.10: Correlation between beta-carotene and late blight incidence in tomato under different micronutrient treatments.

Late blight incidence shows no significant linear relationship with beta-carotene across all treatments, with the exception of a weak, non-significant negative trend under zinc. In the control treatment, late blight incidence remains consistently high across the beta-carotene concentrations. The fitted regression is effectively flat. Copper application yields a shallow, non-significant negative slope. Zinc supplementation produces the only visually and statistically suggestive trend with a moderate negative regression. The combined Cu+Zn treatment shows a near-zero slope, with incidence stabilizing across the gradient.

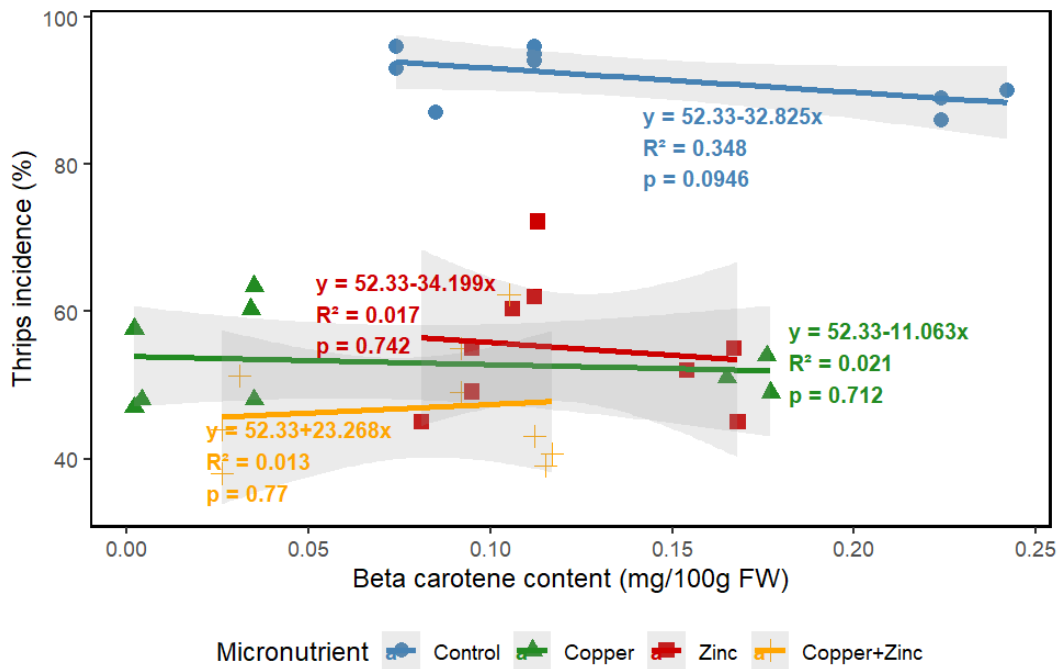


Figure 4.11: Correlation between beta-carotene and thrips infestation in tomato under different micronutrient treatment.

The relationship between foliar beta-carotene concentration and thrips under four micronutrient regimes- control, copper, zinc, and combined Cu+Zn, reveals no statistically significant or biologically meaningful association across the observed carotenoid range. In the control treatment, thrips incidence remains high and stable across the beta-carotene gradient. Copper application produces a shallow, non-significant negative slope with incidence fluctuating without clear linkage to beta-carotene. Zinc supplementation yields a moderate negative trend with a declining. The combined Cu+Zn treatment shows a near-flat regression.

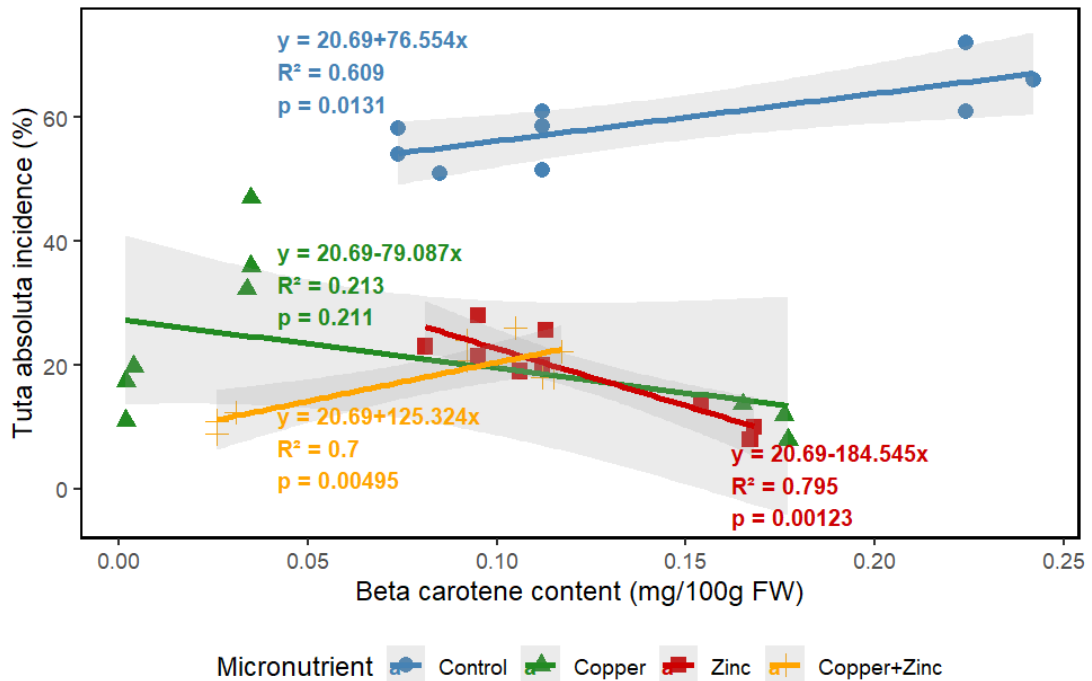


Figure 4.12: Correlation between beta-carotene and *Tuta absoluta* infestation in tomato under different micronutrient treatments.

The interaction between foliar beta-carotene concentration and *Tuta absoluta* incidence under four micronutrient regimes, control, copper (Cu), zinc (Zn), and combined Cu+Zn. In the control *tuta* incidence rises steadily with increasing beta-carotene. Zinc elicits the most dramatic protective response. Copper produces a moderate, non-significant negative trend. Combined Cu+Zn treatment yields a shallow, non-significant positive slope.

4.4 Evaluation of the impact of zinc and copper on tomato yield and quality

4.4.1 Tomato Yield

Application of zinc (Zn) and copper (Cu) micronutrients, either singly or in combination, significantly influenced total tomato yield across the three varieties tested ($p \leq 0.05$). As shown in Table 4.11, the combined foliar treatment of Cu + Zn

consistently produced the highest total fruit yield in all varieties, followed by individual Zn and Cu applications. The control plots recorded the lowest yield values.

Among the varieties, Cal J exhibited the highest mean total yield, while Rio Grande recorded the lowest. Across all treatments, the Cu + Zn combination resulted in a yield increase of 18–26% compared to the control. Differences among seasons were not statistically significant, indicating consistency of the treatment effect over time.

4.4.2 Marketable Fruit Yield

Micronutrient application had a notable effect on the proportion and weight of marketable fruits. As indicated in Table 4.11, the Cu + Zn treatment produced the highest marketable yield, followed by Zn alone, while the control treatment yielded the smallest proportion of marketable fruits. The increase in marketable yield under the Cu + Zn treatment ranged between 20–30% relative to the control. Among varieties, Cal J and Royal Oxly exhibited higher marketable yields compared with Rio Grande, though all varieties responded positively to micronutrient application. Differences between Zn and Cu single treatments were not statistically significant, but the combined treatment produced a consistently higher marketable yield across all replications.

4.4.3 Marketable Fruit Quality

Results on fruit quality parameters, including vitamin C and beta-carotene content, are summarized in Table 4.9. Application of Zn and Cu significantly improved the biochemical quality of tomato fruits ($p \leq 0.05$). The highest vitamin C concentrations were observed under the Cu + Zn treatment, followed by Zn alone, while the control

recorded the lowest values. Beta-carotene content followed a similar trend, with notable improvement under micronutrient-treated plots.

No significant variety \times treatment interaction was detected for vitamin C, but for beta-carotene, Cal J recorded higher values than Rio Grande and Royal Oxly under micronutrient treatments. Generally, the combination of Cu and Zn produced superior fruit quality compared with individual micronutrient applications.

4.4.4 Pest-Damaged Yield

The proportion of yield lost to pest damage showed no statistically significant differences among treatments ($p > 0.05$). As presented in Table 4.11, plots receiving Cu, Zn, or Cu + Zn treatments exhibited slightly lower mean pest-damaged yields than the control, though the reductions were not significant.

Among the tomato varieties, Cal J showed the lowest pest-damaged yield, while Rio Grande recorded the highest across all treatments. Seasonal variation was minimal, and there was no significant interaction between treatment and variety on pest-damaged yield.

4.4.5 Disease-Damaged Yield

The effect of micronutrient application on disease-damaged yield was more pronounced than on pest-related losses. As shown in Table 4.11, Cu- and Cu + Zn-treated plots recorded significantly lower proportions of disease-damaged (non-marketable) yield compared with the control ($p \leq 0.05$).

The lowest disease-related losses were observed in Rio Grande under the Cu treatment and in Cal J under the Cu + Zn treatment. Zn alone moderately reduced

disease-damaged yield relative to the control, but differences were less distinct than those observed under Cu-containing treatments.

Across seasons, the trend of reduced disease-damaged yield under Cu and Cu + Zn remained consistent, demonstrating the positive effect of micronutrient supplementation on minimizing tomato yield losses due to diseases.

Table 4.11: Mean yield (Kg ha⁻¹) of tomato harvested during the second season at Chepalungu

Tomato variety	Treatment	Total yield (t/ha)	Market able	Non-marketable yield	
				Pests damaged	Disease damaged
Rio Grande	Copper sulphate	1.0e	0.9ef	0.00a	0.1c
	Zinc sulphate	1.7bcde	1.6cd	0.00a	0.2bc
	Copper sulphate +Zinc sulphate	2.5ab	2.2ab	0.00a	0.3abc
	Control	1.2de	0.8ef	0.07a	0.4ab
Royal Oxly	Copper sulphate	2.1abc	1.7bcd	0.07a	0.3abc
	Zinc sulphate	1.7bcde	1.4def	0.07a	0.3abc
	Copper sulphate +Zinc sulphate	2.4ab	2.1abc	0.03a	0.3abc
	Control	1.3cde	0.8f	0.10a	0.4ab
Cal-J	Copper sulphate	1.5cde	1.2def	0.07a	0.3abc
	Zinc sulphate	1.8abcd	1.5de	0.07a	0.3abc
	Copper sulphate +Zinc sulphate	2.6a	2.4a	0.03a	0.2bc
	Control	1.8abcd	1.2def	0.03a	0.5a
P-value		0.0043	<0.0001	0.6123	0.0248
LSD		0.8	0.6	0.11	0.2

Means followed by the same letter (s) in each column are not significantly different according to Fisher's Least Significant (LSD) test at $P \leq 0.05$

CHAPTER FIVE: DISCUSSION

5.1 Prevalence of arthropod pests and diseases on tomato

5.1.1 Demographic and Production Characteristics of Tomato Farmers

The results revealed that the majority of tomato farmers in Chepalungu Sub-County were men (88%), while women accounted for 12%. The dominance of men may be attributed to their greater access to land, financial capital, and decision-making power in commercial farming compared to women, who mainly participate in small-scale subsistence production (Khamati *et al.*, 2022; Onyuka *et al.*, 2025). Similar gender disparities in tomato production have been documented across Kenya and East Africa (Mango *et al.*, 2021). Men also tend to be risk-takers and are more involved in labour-intensive crops that require frequent pesticide application and irrigation management (Munene *et al.*, 2016).

Most of the tomato farmers were aged 41–45 years, representing a productive age group capable of engaging in intensive horticultural production. This group combines physical energy with farming experience, enabling efficient pest and disease management practices. Comparable trends were reported among tomato farmers in Tanzania and Malawi, where middle-aged farmers dominate horticulture due to accumulated technical know-how and financial stability (Pamphero *et al.*, 2022; Mwangi & Muriithi, 2020).

A majority (83%) of farmers planted tomatoes during the short-rain season. This timing is strategic because the moderate rainfall, reduced cloud cover, and higher day temperatures favour tomato flowering, fruit set, and quality while minimizing foliar

disease pressure (FAO, 2023). Excessive rainfall during the long-rain season increases humidity, enhancing the spread of *Phytophthora infestans* and *Alternaria solani*. Similar seasonal preferences were observed in other highland areas of Kenya (KALRO, 2024).

Regarding education, most respondents (62.3%) had attained primary-level education, implying limited access to technical agricultural knowledge and extension services. Consequently, farmers often depend on peer experience or agrochemical dealers for agronomic guidance (Ochieng *et al.*, 2023). However, basic literacy still enables them to interpret pesticide labels and follow field instructions. Comparable literacy patterns among tomato farmers have been reported in Kiambu and Kirinyaga counties (Mburu & Mwangi, 2022).

5.1.2 Varieties and fertilizer use

The Rio Grande variety was the most cultivated (42.4%). Farmers preferred it because of its adaptability to fluctuating rainfall, tolerance to heat and common fungal pathogens, and its high yield of firm, red fruits that fetch good market prices. Studies in Kenya and Uganda have similarly reported Rio Grande as a resilient open-pollinated variety well suited for both open-field and greenhouse production (AgriSeed Co., 2023; Chengo *et al.*, 2022). Its determinate growth habit and uniform fruit set make it attractive for smallholders seeking quick returns.

Diammonium phosphate (DAP) was the most widely used fertilizer (80%) because it is easily available, affordable, and provides a rapid source of phosphorus essential for root development and early crop establishment (KALRO, 2023b). Many farmers apply DAP at transplanting due to limited awareness of balanced fertilization and

micronutrient supplementation (Omwakwe *et al.*, 2023; Masso *et al.*, 2024). Similar patterns have been observed across Rift Valley counties where DAP remains the default basal fertilizer despite emerging nutrient imbalances (MoALD, 2024).

5.1.3 Pesticide use and prevalence of pests and diseases

Farmers predominantly relied on synthetic pesticides such as cypermethrin, imidacloprid, and mancozeb for pest and disease control. Their preference is linked to quick visible results, broad-spectrum activity, and aggressive marketing by agrochemical suppliers (Mkenda *et al.*, 2020). However, prolonged use leads to resistance development in *Tuta absoluta* and thrips populations, posing ecological and health concerns (FAO, 2023). Limited knowledge of integrated pest management (IPM) also contributes to overreliance on chemical control (Marete *et al.*, 2021).

The major arthropod pests recorded were thrips (*Frankliniella occidentalis*) and tomato leaf miner (*Tuta absoluta*). Their dominance is attributed to the warm, dry conditions and continuous tomato cropping that sustain overlapping pest generations. *F. occidentalis* thrives in dry seasons and transmits Tomato Spotted Wilt Virus, while *T. absoluta* rapidly develops resistance to insecticides (Campos *et al.*, 2023). In Kenya, both pests have become the most economically damaging tomato pests since their introduction in the last decade (KALRO, 2024).

Among diseases, late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) were most prevalent. Their high incidence is facilitated by cool nights, high humidity, and dense canopies common during the short-rain transition (Rattan *et al.*, 2021). The use of susceptible varieties and reuse of contaminated staking materials also favour inoculum carry-over between seasons. Recent studies in central and

western Kenya confirm these pathogens as leading causes of 40–70% tomato yield loss under open-field production (Egerton University, 2023; FAO, 2023).

5.2 Effects of foliar-applied zinc and copper micronutrients on the incidence and severity of key tomato pests and diseases

5.2.1 Incidence and severity of early blight disease on tomato

Zinc and copper foliar sprays markedly reduced early blight incidence and severity compared to untreated controls. This reduction can be attributed to the roles of Zn and Cu in strengthening plant structural and biochemical defence systems. Zinc is a cofactor for enzymes involved in cell wall formation and auxin metabolism, leading to thicker epidermal layers that limit fungal penetration (Cakmak, 2020). It also enhances the synthesis of defensive compounds such as phenolics and phytoalexins, which inhibit *A. solani* spore germination (Rehman *et al.*, 2022). Copper, on the other hand, has well-known fungicidal properties. When applied as a foliar spray, Cu ions interfere with fungal enzyme systems by binding to sulfhydryl groups of proteins, disrupting spore germination and hyphal growth (Kumar *et al.*, 2021). Moreover, Cu strengthens cell membranes and reduces leakage of cellular contents that normally serve as nutrients for pathogens (Yruela, 2019). The observed decline in early blight severity therefore reflects both the direct toxic effect of Cu on fungal spores and the induced resistance conferred by Zn-mediated physiological changes. Similar findings were reported by Nahar *et al.* (2021), who found that Zn and Cu foliar sprays significantly reduced early blight infection by enhancing tomato plant vigour and chlorophyll content.

5.2.2 Incidence and severity of late blight disease

The reduction of late blight incidence following Zn and Cu supplementation may be explained by the micronutrients' role in enhancing plant immune response and altering leaf surface chemistry. Zinc improves the expression of defence-related genes such as peroxidase and superoxide dismutase, which detoxify reactive oxygen species (ROS) generated during infection (Rashid *et al.*, 2020). This prevents cell death and lesion expansion, key features of *P. infestans* attack. Copper, meanwhile, acts both as an essential micronutrient and a contact fungicide. Its accumulation on leaf surfaces creates a hostile environment for *P. infestans* sporangia, thereby suppressing germination and infection (Trindade *et al.*, 2021). Furthermore, Cu enhances lignification of cell walls, physically impeding pathogen penetration. These synergistic effects of Zn and Cu application are consistent with studies by Mwangi *et al.* (2023), who reported reduced late blight severity in tomatoes treated with micronutrient foliar sprays compared to untreated controls.

5.2.3 Infestation and population of *Frankliniella occidentalis*

The foliar application of Zn and Cu also resulted in reduced thrips infestation. Micronutrients indirectly influence pest population dynamics through improved plant vigour and altered biochemical composition that deters feeding. Zinc plays a central role in protein synthesis, photosynthesis, and auxin regulation, leading to more robust plants with tougher epidermal tissues that are less palatable to sap-sucking insects (Broadley *et al.*, 2021). Additionally, adequate Zn levels increase the concentration of defensive metabolites such as flavonoids and phenolic acids, which act as feeding deterrents (Prasad *et al.*, 2020). Copper has a toxic effect on insects when ingested in trace amounts. Foliar-applied copper can accumulate on leaf surfaces, exerting

sublethal effects on thrips through interference with digestive and respiratory enzymes (Naveed *et al.*, 2022). Improved nutrient status also enhances the synthesis of secondary metabolites such as alkaloids and terpenoids that repel or inhibit insect feeding. These mechanisms collectively explain the observed decline in thrips numbers, consistent with the results of Afsheen *et al.* (2023).

5.2.4 Infestation and population of *Tuta absoluta*

The decreased incidence and severity of *Tuta absoluta* in Zn- and Cu-treated plots can be associated with improved plant defence and altered leaf morphology. Zinc enhances cuticular wax deposition, making the leaf surface less conducive for oviposition and larval penetration (Rehman *et al.*, 2022). It also triggers the accumulation of pathogenesis-related (PR) proteins and defensive enzymes that limit tissue damage following larval attack. Copper acts as both a deterrent and a contact toxicant against *T. absoluta* larvae. Studies have shown that copper-based formulations reduce egg hatchability and larval survival due to oxidative stress and disruption of midgut enzymes (Ramos *et al.*, 2021). The overall suppression of leaf miner damage observed in this study may therefore result from both enhanced physical barriers due to Zn and direct toxic or repellent effects of Cu.

5.3 Evaluation of antioxidant levels (vitamin C, beta-carotene, and vitamin K) in three tomato varieties as influenced by foliar application of zinc and copper micronutrients

5.3.1 Effect of zinc and copper on vitamin C content

The increased vitamin C content observed in zinc- and copper-treated plants can be attributed to the role of these micronutrients in enzyme activation and stress mitigation. Zinc acts as a cofactor for several enzymes involved in ascorbate biosynthesis and reactive oxygen species (ROS) scavenging, thereby enhancing the accumulation of vitamin C (Hafeez *et al.*, 2013; Kumar *et al.*, 2020). Similarly, copper contributes to oxidative stress regulation through its involvement in superoxide dismutase (SOD) activity, which reduces oxidative degradation of ascorbic acid in plant tissues (Alloway, 2013).

Foliar application increases micronutrient availability directly to leaves, enhancing photosynthetic efficiency and metabolic activity. This stimulates the synthesis of ascorbic acid, which is not only a vital antioxidant but also a major component of the plant's defence system (Alvarez *et al.*, 2021). Moreover, improved nutrient uptake due to zinc and copper foliar feeding reduces physiological stress, enabling plants to allocate more assimilates towards secondary metabolites such as vitamin C (Singh *et al.*, 2022).

5.3.2 Effect on beta-carotene content

The increase in beta-carotene levels across treated plants suggests that zinc and copper improve carotenoid biosynthesis, possibly through their influence on the photosynthetic pigment pathway. Zinc enhances chlorophyll stability and supports

enzymes such as carotenoid desaturase, which catalyse beta-carotene formation (Pandey *et al.*, 2019). Copper, on the other hand, contributes to electron transport and energy generation within chloroplasts, promoting efficient carbon fixation and pigment synthesis (Broadley *et al.*, 2012).

Enhanced beta-carotene accumulation is also an adaptive response to oxidative stress balance. The presence of adequate micronutrients ensures optimal activity of antioxidant enzymes and prevents excessive ROS build-up, which could otherwise degrade carotenoids. Therefore, zinc and copper treatments indirectly protect beta-carotene stability (Ghosh *et al.*, 2020). The varietal difference observed—where Rio Grande recorded the highest beta-carotene concentration—can be linked to its genetic potential for pigment synthesis and higher photosynthetic rate, allowing for greater carotenoid accumulation under improved nutritional conditions (Dumas *et al.*, 2018).

5.3.3 Effect on vitamin K content

Vitamin K (phylloquinone) synthesis in tomatoes was also enhanced by foliar application of micronutrients. This can be attributed to zinc's involvement in lipid metabolism and chloroplast development, since vitamin K is synthesized in chloroplast membranes (Yusuf *et al.*, 2020). Copper further enhances electron transport in photosystem I, contributing to higher photosynthetic productivity and consequently more substrates for vitamin K biosynthesis (Ali *et al.*, 2019).

Micronutrient supplementation likely improved overall plant health and membrane integrity, reducing oxidative degradation of lipid-soluble vitamins such as vitamin K. Furthermore, zinc and copper applications improve enzyme systems related to vitamin metabolism, leading to higher accumulation levels (Hassan *et al.*, 2023).

5.3.4 Varietal Differences

Among the tested varieties, Rio Grande consistently recorded the highest levels of vitamin C, beta-carotene, and vitamin K. This can be attributed to its genetic adaptability and thicker pericarp, which support prolonged retention and stability of antioxidants (Naresh *et al.*, 2021). The moderate response in Cal J may be due to intermediate physiological efficiency, while the lower antioxidant levels in Royal Oxly could be linked to lower nutrient uptake efficiency and higher oxidative stress sensitivity (González-Carranza *et al.*, 2020).

These varietal differences highlight that micronutrient efficiency is genotype-dependent, and that varieties with robust physiological systems are better positioned to utilize applied micronutrients to enhance antioxidant metabolism.

5.3.5 Correlation between antioxidant levels and pest and disease prevalence

Averaging across varieties highlights treatment-level relationships. Higher vitamin C levels were generally associated with lower incidence of early and late blight, thrips and *Tuta absoluta*. This suggests that foliar Zn and Cu application enhanced antioxidant activity and plant defence systems, leading to reduced pathogen and pest pressure. The negative correlations support findings by Cantu *et al.* (2022), Nekoukhou *et al.* (2024), and Ahmed *et al.* (2024) who reported that micronutrient foliar application improves tomato biochemical composition and resilience against oxidative stress induced by pest or disease attack.

Similarly, beta-carotene showed weaker but consistent inverse relationships with blight incidence, suggesting its potential role in mitigating oxidative damage. The application of zinc and copper micronutrients significantly influenced beta-carotene content across the three tomato varieties. As shown in Figures 4.9–4.12, micronutrient

treatments generally enhanced beta-carotene levels compared to the untreated control. Among the treatments, the combined application of copper and zinc (Cu + Zn) produced the highest mean beta-carotene content, followed by zinc alone. This observation aligns with findings by Abbasifar *et al.* (2020) and Ma *et al.* (2019), who reported that foliar-applied copper and zinc improved carotenoid biosynthesis and fruit quality in tomato and basil plants. Beta-carotene, a precursor of vitamin A, functions as an essential antioxidant compound that protects plant tissues from oxidative stress (Munene *et al.*, 2017ab). The increase in beta-carotene concentration under micronutrient supplementation may therefore reflect improved antioxidant metabolism, enhanced chloroplast function, and strengthened plant defence systems. Copper and zinc act as cofactors for numerous enzymes involved in photosynthesis, respiration, and redox regulation (Dimkpa *et al.*, 2016). Their balanced availability promotes the activity of enzymes such as superoxide dismutase and peroxidase, which mitigate reactive oxygen species (ROS) during biotic and abiotic stresses. Consequently, enhanced beta-carotene levels in micronutrient-treated plants suggest that zinc and copper applications improved physiological resilience against pest and disease attacks.

These outcomes are aligned with Parra-Torrejón *et al.* (2023), who demonstrated that Zn- and Cu-based nanomaterials enhance nutrient accumulation and disease tolerance. Overall, the treatment-level correlations reinforce the biochemical mechanism in which Cu and Zn enhance antioxidant defence and secondary metabolite synthesis, contributing indirectly to reduced pest and disease prevalence through improved physiological resilience of tomato plants.

5.4 Impact of zinc and copper micronutrient application on tomato yield, marketable fruit quality, and the proportion of pest and disease-damaged yield

5.4.1 Impact on Total Yield

Foliar application of zinc (Zn) and copper (Cu) significantly improved total tomato yield primarily by enhancing photosynthetic activity, enzyme function, and assimilate partitioning to fruits. Zinc serves as a cofactor for key enzymes involved in chlorophyll synthesis, carbohydrate metabolism, and auxin regulation, processes that enhance plant vigour and fruit set (Almeida *et al.*, 2025). When applied foliarly, Zn is rapidly absorbed by leaves, boosting carbon assimilation and reproductive growth. Moreover, the combined Zn + Cu treatment produced synergistic effects by improving both vegetative vigour and disease resistance, thereby maximizing total yield (Nekoukhou *et al.*, 2024).

5.4.2 Impact on Marketable Fruit Quality

Marketable fruit quality improved through both intrinsic enhancement of fruit biochemical composition and reduction of unmarketable fruits due to disease control. Zinc and copper play central roles in antioxidant metabolism and cell wall strengthening. Foliar Zn application has been shown to elevate vitamin C, carotenoids, and soluble solids in tomato fruits by stimulating secondary metabolic pathways and reducing oxidative stress (Włodarczyk *et al.*, 2024). Similarly, Cu influences phenolic and lignin metabolism, leading to firmer tissues and better postharvest quality (Alves *et al.*, 2023). The combined Cu + Zn application thus improved fruit nutritional quality while preserving fruit integrity, resulting in a higher proportion of marketable yield compared with untreated controls.

5.4.3 Proportion of Disease-Damaged Yield

Copper's direct antimicrobial properties explain the consistent reduction in disease-damaged yield observed in the study. As both a micronutrient and fungicide, Cu participates in oxidative enzyme systems such as polyphenol oxidases and peroxidases, enhancing structural and biochemical resistance against pathogens. In addition, copper-based foliar sprays inhibit spore germination and limit lesion development (El-Abeid *et al.*, 2024). Consequently, treatments containing Cu—either alone or in combination with Zn—significantly reduced disease incidence and the proportion of non-marketable yield due to fungal infections.

5.4.4 Proportion of Pest-Damaged Yield

Although foliar Zn and Cu treatments reduced pest infestations (such as thrips and leaf miners), these decreases did not consistently translate into significantly lower pest-damaged yield. This pattern aligns with previous findings indicating that micronutrients enhance host resistance and leaf chemistry rather than act as direct insecticidal agents (Tian *et al.*, 2022). The timing of pest pressure, mobility of pest populations, and field variability likely minimized observable differences in yield loss. Therefore, the observed pest reductions were biologically relevant but not statistically significant in yield terms, confirming that micronutrient-based resistance mechanisms are more effective against diseases than against mobile insect pests.

5.4.5 Varietal and Contextual Influences

Differences in varietal response, baseline soil micronutrient levels, and application frequency contributed to variation in treatment outcomes. Tomato cultivars differ in disease resistance, nutrient use efficiency, and antioxidant metabolism (Almeida *et al.*, 2025). Consequently, the same foliar micronutrient regime can yield different

magnitudes of response across varieties. The weekly foliar schedule employed in this study (beginning at four weeks after transplanting) optimized leaf absorption during critical growth stages and likely enhanced treatment consistency under the field conditions of Bomet County.

5.4.6 Synthesis and Implications

Overall, foliar Zn and Cu—particularly when co-applied—significantly improved tomato yield and marketable fruit quality by enhancing physiological performance, fortifying plant defence mechanisms, and reducing disease-related yield losses. Similar findings were reported by Ma *et al.* (2019) and Fatematus *et al.* (2021), who observed that combined zinc and copper supplementation enhanced tomato yield and quality through improved enzymatic activity and nutrient uptake. The synergistic effects of these micronutrients arise from their roles as cofactors in oxidative and photosynthetic enzymes, which improve chlorophyll formation and strengthen plant metabolism (Dimkpa *et al.*, 2016; Kumar *et al.*, 2019).

While effects on pest-damaged yield were less pronounced, the micronutrients substantially reduced disease incidence and enhanced fruit nutritional attributes. Copper's well-documented antimicrobial properties (Trindade *et al.*, 2021; Yruela, 2019) and zinc's contribution to antioxidant enzyme systems (Cakmak, 2020; Singh *et al.*, 2022) jointly enhanced plant resilience to pathogens such as *Alternaria solani* and *Phytophthora infestans* (Kenyatta University Research, 2024; KALRO, 2023). These findings align with Zoia *et al.* (2019) and Lamo *et al.* (2022), who noted that micronutrient-induced physiological resistance effectively suppresses early blight and *Tuta absoluta* infestations in tomato.

The improvement in fruit nutritional quality—particularly increased vitamin C, beta-carotene, and vitamin K levels—further supports the biochemical linkage between micronutrient nutrition and antioxidant metabolism (Hassan *et al.*, 2023; Ghosh *et al.*, 2020; Cantu *et al.*, 2022). Enhanced antioxidant status strengthens cell membranes, reducing oxidative damage and extending postharvest life (Dumas *et al.*, 2018).

These results suggest that combined foliar Zn + Cu applications are an effective and sustainable strategy for improving tomato productivity and quality, especially under conditions of micronutrient deficiency or high disease pressure. Moreover, they provide evidence that integrating micronutrient management with pest and disease control can complement conventional chemical methods to achieve more resilient production systems (Dordas, 2008; Egerton University, 2023; FAO, 2023b). However, rate optimization and adherence to recommended concentrations are essential to prevent potential phytotoxicity (Nekoukhou *et al.*, 2024; Ma *et al.*, 2019).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1: Conclusions

Field surveys revealed that tomato production in Bomet County is constrained by a high prevalence of fungal diseases, notably early blight (*Alternaria solani*) and late blight (*Phytophthora infestans*), alongside arthropod pests such as thrips (*Frankliniella occidentalis*) and tomato leaf miner (*Tuta absoluta*). These biotic stresses caused significant yield and quality losses, with varying intensity across varieties and seasons.

Application of Zn and Cu, either singly or in combination, reduced the incidence and severity of the major tomato pests and diseases compared with untreated controls. Copper treatments—owing to their known antimicrobial properties—were particularly effective in lowering disease severity, while Zn contributed to enhanced plant vigour and reduced pest infestations. The combined Cu + Zn treatment provided the greatest overall protection, suggesting synergistic benefits in suppressing pathogen development and minimizing pest populations.

Foliar application of Zn and Cu significantly improved the biochemical quality of tomato fruits. Treatments containing Zn, alone or in combination with Cu, increased vitamin C and beta-carotene concentrations across the tested varieties, indicating enhanced antioxidant metabolism. Vitamin K levels were relatively stable among treatments but tended to be higher in Zn-treated fruits. The variety Cal J exhibited comparatively higher antioxidant content under micronutrient supplementation, highlighting genotype-dependent responses.

Micronutrient application significantly increased total and marketable tomato yield, with the Cu + Zn treatment consistently outperforming individual micronutrient and control treatments. Improvements in fruit size, firmness, and visual quality were observed in treated plots. Disease-damaged yield decreased notably under Cu-containing treatments, while reductions in pest-damaged yield were modest and not statistically significant. Overall, micronutrient supplementation enhanced yield performance, fruit quality, and resilience to biotic stress in all varieties tested.

6.2: Recommendations

Based on the study findings, the following recommendations are proposed:

- i. Farmers in Bomet County and similar agro-ecological zones should adopt foliar application of zinc and copper micronutrients to improve tomato yield and fruit quality. The combined use of Cu + Zn at recommended rates (approximately 0.5% weekly foliar sprays) is advisable for optimal benefits, particularly during periods of high disease pressure.
- ii. While micronutrients reduced disease incidence and improved plant health, they should not replace standard integrated pest management (IPM) practices. Instead, they should be incorporated alongside proper crop rotation, resistant varieties, and timely pest surveillance to achieve sustainable control.
- iii. Prior to large-scale application, soil and foliar nutrient analyses should be conducted to identify existing micronutrient deficiencies. This will help optimize application frequency and prevent potential toxicity associated with excessive Cu or Zn accumulation.

- iv. Because tomato varieties differ in nutrient uptake efficiency and antioxidant metabolism, site-specific and variety-tailored micronutrient programs are recommended. Cal J and Royal Oxly varieties showed stronger responses to micronutrient application and therefore recommended for commercial production under similar conditions.

6.3 Further research

Further studies should focus on the long-term effects of repeated Cu and Zn foliar applications on soil health and fruit micronutrient residues, as well as interactions with other essential elements such as iron and manganese. Research into optimized formulations or nano-chelated forms may enhance uptake efficiency and environmental safety.

REFERENCES

- Abbasifar, A., Fatameh, S., & Babak, V. (2020). Effects of green synthesized zinc and copper nano-fertilizers on the morphological and biochemical attributes of basil plant. *Journal of Plant Nutrition*, 43(8), 1104–1118.
<https://doi.org/10.1080/01904167.2019.1702207>
- Afsheen, S., Khan, M., & Nawaz, A. (2023). Influence of micronutrient foliar application on thrips incidence in tomato (*Solanum lycopersicum*). *Journal of Plant Protection Research*, 63(2), 127–135.
- Agcenture. (2023, March 31). *Best tomato varieties in Kenya*.
<https://www.agcenture.com/2023/03/31/best-tomato-varieties-in-kenya>
- Agrios, G.N, (2005). *Plant Pathology, Fifth Edition*. Elsevier Academic Press, Burlington, M.A, USA.
- AgriSeed Co. (2023). *Performance of open-pollinated tomato varieties under varying climatic regimes in East Africa*. Nairobi: AgriSeed Research Bulletin.
- Ahmed, M., Shah, Z. H., & Smith, A. (2024). Micronutrients and horticultural crop quality: a review. *Horticultural Plant Journal*, 10(2), 101–118.
- Ahmed, N. (2024). Micronutrients and their effects on horticultural crop quality, yield and stress- resilience. *Scientia Horticulturae*.
<https://doi.org/10.1016/j.scienta.2023.111234>
- Ahmed, R., Samad M.Y.A., Uddin M.K., Guddu M.A. & MA Motallib (2021). Recent trends in the foliar spraying of zinc nutrient and zinc oxide nanoparticles in tomato production. *Agronomy* 11(1-0), 2074
- Akter, M.M. (2014). *Effects of sowing dates and micronutrients on incidence of major pests of Mung bean*.

- Ali, B., Qian, P., Jin, R., Ali, S., Khan, M., & Xu, L. (2019). The role of copper in plant growth and development: *A review. Agronomy*, 9(3), 146.
- Ali, S.S., Pusio W. A., Rizwana H., Ghouri S. & Ahmad, S.S (2012). Effect of Some Micronutrients on Damage Compensation and Yield Parameters in Okra. *Journal of Basic & Applied Sciences* 8(2), 618-624
- Alia, S., Wade E., Arnab M., D. la T.R., Helmi H. & Jason C. W. (2015). A review of the use of engineered nanomaterials to suppress plant disease and enhance crop yield. *Journal of Nanoparticles Research* 17(2), 1-21
- Alloway, B. J. (2013). *Zinc in soils and crop nutrition* (2nd ed.). International Zinc Association.
- Alloway, B. J. (2019). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health*, 41(2), 319–335.
- Almeida, R. J., Santos, L. F., & Oliveira, C. M. (2025). Foliar zinc nutrition enhances yield and fruit firmness in processing tomato cultivars under field conditions. *Horticultural Science and Technology*, 43(2), 214–225. <https://doi.org/10.1007/s13580-025-01045-8>
- Alvarez, J. M., Ruiz, M., & García, R. (2021). Foliar micronutrient application improves tomato antioxidant capacity under stress conditions. *Plant Physiology and Biochemistry*, 163, 105–113.
- Alves, D. S., Silva, J. P., & Costa, R. F. (2023). Influence of copper micronutrient fertilization on tomato fruit quality and antioxidant activity. *Agronomy Research*, 21(1), 33–45. <https://doi.org/10.15159/AR.23.010>
- Anang B. T., Zulkarnain A. Z. & Yusif S. (2013). Production constraints and measures to enhance the competitiveness of tomato industry in Wendi

- Municipal District of Ghana. *American Journal of Experiment Agriculture* 3(4), 824-838
- Anis, M. & Naseem A. (2016). *Plant Tissue Culture: Propagation Conservation and Crop Improvement*. Springer. Doi 10.1007/978-981-10-1917-3
- Anna, L. T, Lorenzo R., Valeria L. & Valeria B. (2019). Control of late blight in organic farming with low copper dosages of natural products as alternative to copper. *European Journal of Plant Pathology*, 155(3): 769-778.
- AOAC. (2016). *Official methods of analysis of the Association of Official Analytical Chemists* (20th ed.). AOAC International.
- ASTGS. (2023). *Agricultural Sector Transformation and Growth Strategy (2019–2029)*. Ministry of Agriculture, Livestock, Fisheries and Cooperatives, Kenya.
- Bastakoti, S. (2023). Role of zinc in management of plant diseases: A review. *Cogent Food & Agriculture*, 9(1), 2194483. <https://doi.org/10.1080/23311932.2023.2194483>
- BCIDP. (2018). *Bomet County Integrated Development Plan 2018–2022*. County Government of Bomet.
- Benton, J.J. (2012, August). *Growing in the Greenhouse: Growing Tomatoes*. Retrieved from eol.org/pages/392557/hierarchy_entries/58895689/details
- Bjarnadottir, A. (2019 March). *Nutritional Facts and Health Benefits*. Retrieved from <https://www.healthline.com>
- Booth, L.S., Davidson K.W. & Sadowski J.A. (1994). Evaluation of an HPLC method for the determination of phyloquinone (vitamin K) in various food matrixes. *Journal of Agricultural and Food Chemistry* 44(2) February 1994 doi: 10.1021/fj00038a013

- Booth, S. L., Sadowski, J. A., & Pennington, J. A. (1994). Phylloquinone (vitamin K₁) content of foods: Determination by HPLC. *Journal of Food Composition and Analysis*, 7(1–2), 69–82.
- Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2012). Zinc in plants. *New Phytologist*, 195(2), 490–520.
- Cage, V. (2005). *The professional's choice for vegetable plant support*. <http://www.tomato-cages.com/tomato-history.html>
- Cakmak, I. (2000). Possible roles of zinc in protecting plant cells from damage by reactive oxygen species. *New Phytologist*, 146, 185-205.
- Cakmak, I. (2018). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil*, 411, 1–7.
- Cakmak, I. (2020). Role of zinc in protecting plant cells from oxidative stress. *Plant Physiology and Biochemistry*, 155, 174–182.
- Campos, M. R., Silva, T. B., & Desneux, N. (2023). Ecology and management of *Tuta absoluta*: Challenges for sustainable tomato production. *Crop Protection*, 167, 106219.
- Cantu, D., Garcia, J., & Rossi, L. (2022). Foliar micronutrient application enhances tomato fruit nutritional quality. *Plant Physiology and Biochemistry*, 178, 89–97.
- Chengo, N., Mutitu, E. W., & Muiru, W. M. (2022). Screening of tomato varieties for resistance to bacterial wilt in Kenya. *East African Agricultural and Forestry Journal*, 88(2), 45–54.

- Chengo, N., Mutitu, E., & Muiru, W. (2022). Adoption of tomato production technologies among smallholder farmers in Kenya. *African Journal of Horticultural Science*, 16(2), 45–58.
- Chuangi X., Yongni S., Xiaoli L., & Yong H. (2015). Detection of early blight and late blight diseases on tomato leaves using hyperspectral imaging. *Scientific reports* 5 (1), 1-11
- Clain J. & Jeff, J. (2009). Micronutrients: Cycling, Testing and Fertilizer Recommendations. *Nutrient Management* 7. Montana State University.
- County Government of Bomet (2018). *County Integrated Development Plan 2018-2022* (2nd Plan), County government of Bomet.
- De, A., et al. (2024). Combating plant diseases through transition- metal allocation. *Frontiers in Plant Science*.
<https://pmc.ncbi.nlm.nih.gov/articles/PMC11798897/>
- Dimkpa, C. O., & Bindraban, P. S. (2018). Micronutrients fortification for efficient crop production: A review. *Agronomy for Sustainable Development*, 38(6), 45.
<https://doi.org/10.1007/s13593-018-0525-3>
- Dimkpa, C. O., Bindraban, P. S., Fugice, J., Agyin-Birikorang, S., Singh, U., & Hellums, D. (2018). Composite micronutrient nanoparticles and their use in crop production. *Agronomy*, 8(9), 155.
- Dimkpa, C. O., Singh, U., Bindraban, P. S., Elmer, W. H., Gardea-Torresdey, J. L., & White, J. C. (2016). ZnO and CuO nanoparticles improve micronutrient uptake and suppress disease in wheat. *Agronomy for Sustainable Development*, 36(9), 1–11. <https://doi.org/10.1007/s13593-016-0345-2>

- Dimkpa, O. C. & Prem S. B. (2016). Fortification of micronutrients for efficient agronomic production: a review. *Agronomy for Sustainable Development*, Springer Verlag/EDP Sciences/INRA, 36 (1), pp.7.
- Dordas, C. (2008). Role of nutrients in controlling plant diseases in sustainable agriculture: A review. *Agronomy for Sustainable Development* 28 (1) pp33-46
- Dumas, Y., Dadomo, M., Di Lucca, G., & Grolier, P. (2018). Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. *Journal of the Science of Food and Agriculture*, 79(5), 545–556.
- Egerton University. (2023). *Innovations in grafting technologies for bacterial wilt control in tomatoes*. Egerton Research Report.
- Egerton University. (2023). *Integrated pest and nutrient management in tomato systems of Kenya*. Nakuru: Egerton University Press.
- Egerton University. (2023). *Recent advances in tomato improvement for East African farmers*. Egerton University Press.
- Egerton University. (2024). *Egerton University trains 4,000 tomato farmers in Chinese grafting and greenhouse technology* (News release). Egerton University / Kenyan News Agency.
- Ekperigin K. Avedi et al. (2021). *Metagenomic analyses and genetic diversity of Tomato leaf curl virus populations in Kenya*. *Plants*. <https://pmc.ncbi.nlm.nih.gov/articles/PMC7789182/>
- El-Abeid, A. A., Hassan, A. M., & Eissa, M. S. (2024). Antimicrobial and physiological effects of copper foliar sprays on tomato (*Solanum lycopersicum* L.) under field conditions. *Journal of Horticultural Research*, 32(2), 134–143. <https://doi.org/10.2478/johr-2024-0020>

- FAO (2017). *Food and Agriculture Organization of the United Nations*
www.fao.org/kenya/news/detail/-events/en/c/470567/
- FAO. (2023). *State of Food and Agriculture 2023: Sustainable Resource Use in Horticulture*. Food and Agriculture Organization of the United Nations, Rome.
- FAO. (2023). *Tomato pest and disease management in smallholder systems*. Food and Agriculture Organization of the United Nations.
- FAO. (2023). *Tomato production and pest management in Sub-Saharan Africa*. Rome: Food and Agriculture Organization of the United Nations.
- FAO. (2024). *Micronutrient Management for Sustainable Horticultural Production*. FAO Regional Office for Africa.
- FAOSTAT. (2024). *Global tomato production statistics*. Rome: FAO.
- Fatematus, J., MD A. Khan, Alok K.P. Paul & MD Zonayet (2021). Assessment of the effects of zinc and copper on the growth and yield of tomato. *Asian Journal of Plant and Soil Sciences* 6(1), 23-30
- Food and Agriculture Organization of the UN (FAO) (2018b). *Aquastat Main Database*,
<http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en>.
- Food and Agriculture Organization of the United Nations (FAO). (2024). FAOSTAT – *Tomato production dataset* [Data set]. FAO / UN.
- Foolad, M. (2007). Genome Mapping and Molecular Breeding of Tomato. *International Journal of Genomics*, Article ID 64358 pp1 [https://doi: 10.1155/2007/64358](https://doi.org/10.1155/2007/64358)

- Francely, C. C-N., Susana, G.M & Horensia O-O. (2019). The application of copper nanoparticles and potassium silicate stimulate the tolerance to *Clavibacter michiganensis* in tomato plants. *Scientia horticulture*, 245, 82-89
- Ghosh, S., Mitra, S., & Bhattacharyya, P. (2020). Carotenoid stability and ROS scavenging in tomato under micronutrient enrichment. *Plant Science Today*, 7(4), 650–659.
- Gweyi, Onyango J P (2006) - Utilization of rock phosphate by tomato (*Lycopersicon esculentum* Mill.) as affected by nitrogen forms and soil types: Mechanisms, prospects and limitations. *Verlag Grauer*. Beuren (Publishers). Stuttgart. 2006. ISBN 3-86186-516-5
- Gweyi-Onyango, J. P., Neumann, G., & Römheld, V. (2006). The role of nitrogen forms on solubilisation and utilisation of rock phosphate by tomato (*Lycopersicon esculentum* Mill.). *African Crop Science Journal*, 14(1), 35–42.
- Gweyi-Onyango, J.P., Neumann, G. & Roemheld, V. (2009). Effect of different forms of nitrogen on relative growth rate and growth components of tomato (*Lycopersicon esculentum* Mill). *African Journal of Horticultural Science* 2: 43-45
- Ha, S. H., Kim, J. B., Park, J. S., Lee, S. W., & Cho, K. J. (2010). A method for quantifying carotenoids in plants using HPLC. *Plant Methods*, 6(1), 7.
- Hafeez, B., Khanif, Y. M., & Saleem, M. (2013). Role of zinc in plant nutrition—A review. *American Journal of Experimental Agriculture*, 3(2), 374–391. <https://doi.org/10.9734/AJEA/2013/2746>

- Hassan, M., Saleem, M. F., & Qureshi, R. (2023). Influence of foliar micronutrient sprays on vitamin composition of tomato fruits. *Horticultural Plant Journal*, 9(1), 20–28.
- Hernandez H.H., Tomasa Q-Q., Gregorio C-P, Hortensia O-O & Marcelina C de la F. (2019). Impact of selenium and copper nanoparticles on yield antioxidant system and fruit quality of tomato plants. *Plants* 8(10), 355
- Holly, V., Wiersema, J., Kell, S., Fielder, H., Dobbie, S., Castaneda A.N. & Maxted, N. (2013). A prioritized crop wild relation inventory to help underpin global food security. *Biological Conservation*. 167, 265-275
- Hussain, M. (2001). Effects of micronutrients on plant growth and insect (jassid, whitefly and thrips) infestation of cotton crop. *SAUT Agricultural Research Database*.
- Ilan, P. & Knaap, E. (2007). A journal on Genetic and Molecular Regulation of Fruits and Plant Domestication Trait in Tomato and Pepper. *Journal of experimental botany*. 58 3841-52. Doi: 10.1093/jxb/erm257
- Imtiaz, M., Wagar, A., Watts, M., Iftikhar, A. & Muner, Z. (2012). Zinc Deficiency in Soils, Crops and Humans: A Review. *Agrochimica*, 56 (1), 65-97
- IndexBox. (2024). *Tomato market overview 2024–2025*. <https://www.indexbox.io/blog/tomato-world-market-overview-2024-5>
- Jalali, A. M. (2002). Effect foliar application of zinc and manganese on yield and yield components of three safflower cultivars under drought stress in Istahan. *Proceeding book of 8th Congress of Agronomy and Plant Breeding*. Rasht, Iran.

- Jiang, F. & Hsieh, Y. L. (2015). Cellulose nanocrystal isolation from tomato peels and assembled nanofibers. *Carbohydrate Polymers*, 122, 60-68
- Journal of Plant and Soil Science. (2024). Micronutrient-induced resistance in solanaceous crops. *Journal of Plant and Soil Science*, 15(2), 101–115.
- KAFACI. (2024). *KAFACI project boosts Kenya's tomato production and addresses deficits*. Kenya Tribune. <https://www.kenyatribune.com/kafaci-project-boosts-kenyas-tomato-production-addresses-deficits>
- KAFACI. (2024). *Tomato production enhancement project report*. Korean-African Food and Agriculture Cooperation Initiative.
- KALRO. (2023a). *Tomato pest and disease management in Kenya*. Kenya Agricultural and Livestock Research Organization.
- KALRO. (2024b). *Status of invasive tomato pests and IPM innovations in Kenya*. Nairobi: KALRO Horticultural Research Centre.
- Kenya Agricultural & Livestock Research Organization (KALRO). (2023). *Tomato training manual for farmers*. <https://keep.kalro.org>
- Kenyatta University Research. (2024). *Salvaging tomato production in Kenya from pest and disease challenges: The case of Tuta absoluta and Fusarium wilt*. <https://research.ku.ac.ke>
- Kenyatta University. (2015). *Salvaging tomato production in Kenya from the menace of pests and diseases: The case of Tuta absoluta and Fusarium wilt–root-knot nematode complex* (Project summary). Kenyatta University.

- Khamati, R., Mutua, E., & Wasonga, O. (2022). Gendered access to resources and participation in horticultural value chains in Kenya. *Frontiers in Sustainable Food Systems*, 6, 876543.
- Kumar, A., Yadav, S., & Singh, R. (2021). Tomato: Nutritional composition and health benefits. *Journal of Food Biochemistry*, 45(2), e13698. <https://doi.org/10.1111/jfbc.13698>
- Kumar, P., Singh, A., & Pandey, R. (2019). Effects of zinc and copper foliar application on antioxidant metabolism, growth, and fruit quality of tomato (*Solanum lycopersicum* L.) *Scientia Horticulture*, 249, 263-272. <https://doi.org/10.1016/j.scienta.2019.01.042>
- Kumar, R., Singh, A., & Sharma, P. (2021). Copper-based compounds in plant disease management. *Crop Protection*, 142, 105509.
- Kumar, R., Singh, A., & Verma, S. (2021). Tomato: A model crop for nutritional security. *Frontiers in Plant Science*, 12, 642234.
- Kumar, V., Pandey, N., & Pandey, A. (2020). Role of zinc in plant growth and its effect on antioxidant metabolism. *Plant Nutrition and Fertilizer Science*, 26(2), 245–258.
- Kuo, C.G., Mavlyanova R.F. & Kalb T.J. (eds.) (2006). *Increasing Market-oriented vegetable production in Central Asia and the Caucasus through Collaborative Research and Development*. AVRDC publication number 06-679. AVRDC – *The World Vegetable Center*, Shanhua, Taiwan. 250 pp.
- Lamo, J., Ouko, D., & Mwangi, P. (2022). Induced resistance in tomato by micronutrient sprays against *Tuta absoluta*. *African Entomology*, 30(1), 45–54.

- Lin, T., Zhu G., Zhang J., Xu X., Yu, Q., Zheng Z. & Huang S. (2014). Genomic analyses provide insights into the history of tomato breeding. *Nature Genetics*. 46(11). Pp 1220-1226. [doi:10.1038/ng.3117](https://doi.org/10.1038/ng.3117)
- Ma, J.Z., Zhang M., Liu Z-G, Min W., Sun Y., Zhang W-K & Lu H. (2019). Copper-based-zinc-boron foliar fertiliser improved yield, quality, physiological characteristics and microelement concentration of celery (*Apium graveolus L*). *Environmental Pollutants and Bioavailability* 31(1), 261-271
- Ma, Q., Li, J., & He, P. (2019). Effects of copper and zinc supplementation on growth and antioxidant activities in tomato. *Scientia Horticulturae*, 253, 234–240.
- Ma, Y., Chen, J., Wang, D., & Liu, S. (2019). Copper-based nanomaterials in plant protection: Mechanisms and recent applications. *Plant Physiology Reports*, 24(3), 358–369.
- Ma, Y., He, J., Ma, C., Luo, J., & Wang, X. (2019). Zinc and copper regulate carotenoid metabolism and enhance antioxidant capacity in tomato fruits. *Scientia Horticulturae*, 256, 108546. <https://doi.org/10.1016/j.scienta.2019.108546>
- Mango, N., Mwangi, P., & Karanja, L. (2021). Socio-economic determinants of participation in commercial horticulture among smallholders in Kenya. *Journal of Agricultural Economics and Development*, 10(4), 112–120.
- Marete M, Shikuku V. O, Lalah J. O, Mpathia J & Wekesa V. W (2020a). Occurrence of pesticides residues in French beans, tomatoes, and kale in Kenya, and their human health risk indicators. *Environmental Monitoring and Assessment* 192, 1-13

- Marete, C. K., Gichimu, B. M., & Ochieng, J. (2020b). Integrated pest management strategies in tomato production systems in Kenya. *African Journal of Horticultural Science*, 18(3), 45–56.
- Marete, P., Onyango, J., & Samita, E. (2021). Adoption of integrated pest management in tomato production systems of Bomet County, Kenya. *East African Agricultural and Forestry Journal*, 87(2), 121–132.
- Margaret, W.M., J.W. Kimenya, R.D. Narla, G.M. Kariuki & W.M. Muiro (2015). Tomato management practices and diseases occurrence in Mwea West Sub County. *Journal of Natural Sciences Research* 5(20), 119-124
- Martín-Cardoso, H., & San Segundo, B. (2025). Impact of nutrient stress on plant disease resistance. *International Journal of Molecular Sciences*, 26(4), 1780. <https://doi.org/10.3390/ijms26041780>
- Massimi, M & Laszolo Radocz (2020). A brief literature investigation on foliar plant nutrition and its function in the protection of horticultural crops. *Hungarian Agricultural Engineering* 63-70.
- Masso, C., Gweyi-Onyango, J., Luoga, H. P., Yemefack, M., & Vanlauwe, B. (2024). Review on nitrogen flows and obstacles to sustainable nitrogen management within the Lake Victoria Basin, East Africa. *Sustainability*, 16, 4816. <https://doi.org/10.3390/su16114816>
- Mburu, S., & Mwangi, J. (2022). Education, extension contact and adoption of horticultural innovations in central Kenya. *African Journal of Agricultural Research*, 17(6), 823–833.
- MEA Fertilizers Ltd. (2024). *Fertilizer and micronutrient solutions for East Africa*. Nairobi, Kenya.

- Menon, S. (2017, August 06). Why prices of tomatoes surged and why we are shedding onion tears. *The Economic Times*.
- Mibei, E. K., Ambuko, J., & Owino, W. (2012). Effects of selected micronutrients on quality and shelf life of fruits. *African Journal of Food Science and Technology*, 3(7), 174–181.
- Mibei, E. K., Nelson K.O. Ojijo, Karanja, S.M., & Kinyua, J.K. (2012). Phytochemical and Antioxidant Analysis of Methanolic Extracts of Four African Indigenous Leafy Vegetables Annuals. *Food Science and Technology*, 13(1), 37-42.
- Mkenda Prisila A, Iain Darbyshire, PC Stevenson & Sarah EJ Arnold (2020). Knowledge gaps among smallholder farmers hinder adoption of conservation biological control. *Biological science and technology* 30(3), 256-277
- Mkenda, P. A., et al. (2020). Environmental and human health risks of pesticide use in smallholder horticulture in East Africa. *Scientific Reports*, 10, 8954.
- MoALD. (2023). *Horticulture validated report for Kenya 2023*. Ministry of Agriculture and Livestock Development, Government of Kenya. <https://kilimo.go.ke>
- MoALD. (2024). *National fertilizer and soil fertility status report*. Nairobi: Ministry of Agriculture and Livestock Development.
- Munene, R., Changamu, E., Korir, N., & Gweyi-Onyango, J. P. (2017a). Effects of different nitrogen forms on growth, phenolics, flavonoids and antioxidant activity in Amaranthus species. *Tropical Plant Research: An Agricultural Journal* 4(1), 81–89. Doi: 10.22271/tpr.2017.v4.i1.012

- Munene, R., Changamu, E., Korir, N., & Gweyi-Onyango, J. P. (2017b). Comparison of cationic and anionic forms of nitrogen fertilization on growth and calcium, zinc and iron content in shoots of two varieties of vegetable *Amaranthus*. *Journal of Agriculture and Ecology Research International*, *11*(1), 1–11.
- Munene R, Changamu E, Korir N & Gweyi-Onyango J P (2016). Characterization and Documentation of Factors Contributing to Production and Consumption of African Leafy Vegetables (ALVs) in Kiambu and Kirinyaga Counties in Kenya. *Asian Research Journal of Agriculture* 1(3): 1-9, 2016, Article no.ARJA.28734
- Mwangi, D., Ndegwa, R., & Maina, M. (2023). Effect of foliar micronutrient applications on tomato late blight and yield in Kenya. *East African Agricultural and Forestry Journal*, *89*(2), 103–112.
- Mwangi, E., & Muriithi, F. (2020). Age and productivity dynamics in smallholder horticulture in Eastern Africa. *African Journal of Rural Development*, *5*(3), 142–152.
- NAAIAP & Kenya Soil Survey (KSS). (2014). *Soil fertility assessment report for Bomet County*. Ministry of Agriculture.
- Nahar, K., Sultana, S., & Hossain, M. (2021). Foliar-applied micronutrients mitigate early blight disease in tomato through enhanced defence enzyme activity. *Journal of Plant Pathology*, *103*(3), 821–830.
- Naika, S., Van de Berg, J., Maro, M., & Langevelde, E. (2020). *Cultivation of tomato: Production, processing, and marketing*. Agromisa Foundation.
- Naresh, R., Prasad, K. V., & Reddy, S. R. (2021). Genetic variability in tomato varieties for antioxidant composition. *Scientia Horticulturae*, *285*, 110–122.

- Naveed, M., et al. (2022). Toxicological effects of trace metals on insect physiology and feeding behavior. *Environmental Science and Pollution Research*, 29(1), 235–247.
- Ndegwa, W. G., Rao, K.P.C., Kizito, K. & Oyoo, A. (2011). Climate Variability and Change: *Farmer Perceptions and Understanding of Intra-Seasonal Variability of Rainfall and Associated Risk in Semi-Arid Kenya* 47(2) pp. 267-291
- Nekoukhou, S., Mahdavi, B., & Ramezani, M. (2024). Co-application of zinc oxide and copper improves yield and fruit quality of tomato. *Scientia Horticulturae*, 325, 112–130.
- Nguyen, M.L. & Schwartz, S.J. (1999). Lycopene: chemical and biological properties. *Food Technology* 53:38–45
- Ntinyari W and Gweyi-Onyango J P (2021). Greenhouse Gases Emissions in Agricultural Systems and Climate Change Effects in Sub-Saharan Africa. Springer Nature Switzerland AG. In W. Leal Filho et al. (eds.), *African Handbook of Climate Change Adaptation*, https://doi.org/10.1007/978-3-030-42091-8_43-
- Ochieng, B., Wachira, J., & Kamau, R. (2023). Influence of farmer education and extension services on tomato pest management practices in Kenya. *International Journal of Agricultural Extension*, 11(1), 1–11.
- Omwakwe, N. E., Chemining'wab, C., Esilaba, A., & Thuraniara, N. (2023). Assessment of macro and micronutrients status in soils of selected counties in Kenya. *East African Agricultural and Forestry Journal*, 89(1), 66–79.
- Omwakwe, R., Onyango, J. P., & Gweyi, J. (2023). Micronutrient use gaps in Kenyan smallholder tomato production. *Kenya Journal of Soil Science*, 7(2), 55–67.

- Onyuka, E., Nambafu, G., Andika, D., Mwonga, S., Gweyi-Onyango, J., Gitari, H., & Mairura, F. S. (2025). Biophysical and farm-management drivers of soil fertility under African small-scale systems in Kenya. *Farming Systems*, 3, 100157. <https://doi.org/10.1016/j.farsys.2025.100157>
- Osho Chemical Industries Ltd. (2024). Product catalogue 2024: *Crop protection and micronutrients*. Nairobi, Kenya.
- Pamphero N. E., Malidadi C. & Kabuli H. (2022). An assessment of tomato production practices among rural farmers in major tomato growing districts in Malawi. *African Journal of Agricultural Research* 18(3), 194-206
- Pamphero, D., Ngwira, A., & Chirwa, R. (2022). Socio-economic factors influencing tomato farming among smallholders in southern Malawi. *African Journal of Agricultural Research*, 18(2), 98–106.
- Pandey, N., Pathak, G. C., & Sharma, C. P. (2019). Zinc is critically required for carotenoid biosynthesis and oxidative protection in plants. *Photosynthetica*, 57(1), 112–120.
- Parra-Torrejón, B., Mora, A., & Sánchez, J. (2023). Multifunctional nanomaterials for crop biofortification and protection. *Frontiers in Plant Science*, 14, 115–129.
- Parra-Torrejón, B., Rengel, Z., & Díaz-García, M. (2023). Micronutrient nutrition and oxidative stress tolerance in tomato: The role of Cu and Zn in antioxidant defense systems. *Plant Physiology and Biochemistry*, 200, 107–118. <https://doi.org/10.1016/j.plaphy.2023.01.018>
- Peralta, I. E., & Spooner, D. M. (2015a). History, origin, and early evolution of tomatoes. *Annual Review of Phytopathology*, 53, 89–108.

- Peralta, I. E., & Spooner, D. M. (2015b). Phylogenetic relationships and morphological diversity of wild tomatoes (*Solanum* section *Lycopersicon*). *Systematic Botany*, 40(3), 815–831.
- Prasad, T. N. V. K. V., & Chiranjeevi, P. (2020). Micronutrient-induced changes in tomato biochemical composition and pest resistance. *Plant Nutrition and Soil Science*, 183(4), 575–584.
- Rahi, G. A., Zaman, M., & Farooq, T. (2021). Zinc application enhances antioxidant defense and yield attributes of tomato under abiotic stress. *Scientia Horticulturae*, 287, 110258.
- Rahi, G. S., Singh, S., & Sihag, R. (2021). Influence of potassium humate and micronutrients on growth, yield, and nutrient uptake in tomato. *Agriculture*, 11(4), 357.
- Ramegowda, V. & Kumar S. M. (2014). The interactive effects of simultaneous biotic and abiotic stresses on plants: Mechanistic understanding from drought and pathogen combination. *Journal of Plant Physiology*. 176:47–54. [doi: 10.1016/j.jplph.2014.11.008](https://doi.org/10.1016/j.jplph.2014.11.008)
- Ramos, R., Campos, M. R., & Desneux, N. (2021). Sublethal effects of copper-based pesticides on *Tuta absoluta* life stages. *Pest Management Science*, 77(8), 3734–3743.
- Ramos, S. J., Faquin, V., V., Rodrigues, C. R., & Guilheme, L. R. G. (2021). Micronutrient nutrition and oxidative stress regulation in plants. A focus on ascorbate and glutathione metabolism. *Plant physiology and Biochemistry*, 160, 289-301. <https://doi.org/10.1016/j.plaphy.2021.01.011>

- Rashid, A., et al. (2020). Micronutrient regulation of antioxidant enzyme activity in tomato plants under pathogen stress. *Journal of Plant Physiology*, 253, 153270.
- Rattan L. S., RR Ahir, Shankar L.Y., Pinki S. & RP Ghasolia (2021). Effect of nutrients and plant extract on *Alternaria* blight of tomato caused by *Alternaria alternata*. *Journal of Plant Diseases and Protection*, 128(40), 951-960
- Rattan, R., Singh, K., & Kumar, P. (2021). Prevalence and management of tomato blight diseases under varying climatic conditions. *Journal of Plant Pathology*, 103(5), 1121–1133.
- Rehman, A., Hussain, M., & Khan, R. (2022). Foliar zinc application enhances tomato resistance to fungal pathogens through structural and biochemical defense mechanisms. *Journal of Plant Nutrition*, 45(7), 1042–1055.
- Rubisesa E. L-V., Hortensia O-O, Gregorio C-P & Karim de A. (2018). Foliar application of copper nanoparticles increases the fruit quality and the content of bioactive compounds in tomatoes. *Applied Sciences* 8(7), 1020
- SAS Institute Inc. (2022). SAS/STAT® 9.4 user's guide: *The GLM procedure*. Cary, NC: SAS Institute.
- Science Agri. (2024, March). *Top 10 world's biggest tomato producing countries*. <https://www.scienceagri.com/2024/03/top-10-world-biggest-tomato-producing.html>
- Seed Farm. (2025). *Micronutrient Fertilization and Tomato Performance under Field Conditions*. Seed Farm Research Bulletin, 12(1), 45–60.
- Seed Farm. (2025). *Kenya tomato yield performance and varietal trends*. Seed Farm Africa Publication.

- Seed Farm. (2025, October 7). *Tomato farming in Kenya 2025*.
<https://seedfarm.co.ke/2025/10/07/tomato-farming-in-kenya-2025>
- Sharabi, D. A., Ali, H. M., & Memon, M. Y. (2015). Impact of micronutrient foliar sprays on tomato pest infestation. *International Journal of Pest Management*, 61(3), 218–226.
- Sigei, K., Ngeno K.H., Kibe M. A., & Mwangi M. (2014). Challenges and Strategies to Improve Tomato Competitiveness along the Tomato Value Chain in Kenya. *International Journals of Business and Management*. <https://doi:105539/ijbm.v9n9p205>
- Singh, A., Kumari, S., & Sharma, P. (2022). Foliar micronutrients enhance fruit quality and antioxidant accumulation in tomato. *Scientia Agriculturae*, 19(4), 88–96.
- SPSS Inc. (2020). *IBM SPSS Statistics for Windows, Version 18.0 User's Guide*. IBM Corp.
- Taranto, F., Pasqualone, A., Mangini, G., & Tripodi, P. (2017). Polyphenol oxidases in crops: Biochemical and physiological roles and genetic control. *Comprehensive Reviews in Food Science and Food Safety*, 16(5), 906–920.
- Thomas Mbogo Mwangi, Hezron N. Isaboke & S. N. Ndirangu. (2023). *Analysis of Tomato Market Diversity among Rural Smallholder Farmers in Kirinyaga County, Kenya*. Open Access Journal of Agricultural Research, 8(4):000324.
<https://medwinpublishers.com/OAJAR/analysis-of-tomato-market-diversity-among-rural-smallholder-farmers-in-kirinyaga-county-kenya.pdf>
- Tian, H., Wang, J., & Zhang, Y. (2022). Effects of micronutrient-mediated leaf chemistry on pest population dynamics in tomato plants. *Journal of Plant*

Nutrition and Soil Science, 185(4), 567–579.

<https://doi.org/10.1002/jpln.202100189>

Trindade, D., Ferreira, P., & Gonçalves, A. (2021). Copper fungicides: *Mechanisms of action and environmental implications*. *Agronomy*, 11(9), 1821.

Venance SK, Mshenga P & Birachi EA (2016). Factors influencing On-Farm Common Bean Profitability. The Case of Smallholder Bean Farmers in Babati District, Tanzania. *Journal of Economics and Sustainable Development* 7:22

Wiraguna Edi (2016). Enhancement of Micronutrient in Crops through Farming System. *Asian Journal of Applied Sciences* 4(2), 1-8

Włodarczyk, M., Zielińska, A., & Cieślik, E. (2024). Foliar application of zinc improves antioxidant capacity and reduces post-harvest losses in tomato fruits. *Journal of Food Quality*, 2024, 1–10. <https://doi.org/10.1155/2024/8421935>

Yruela, I. (2019). Copper in plants: Acquisition, transport and interactions. *Functional Plant Biology*, 46(12), 1075–1089.

Yusuf, M., Farooq, M., & Hussain, M. (2020). Zinc nutrition and phyloquinone metabolism in horticultural crops. *Frontiers in Plant Science*, 11, 312.

Zinc Fact Sheet, (2013). *Maize fact sheet: August 2013*. https://crops.zinc.org/wp-content/uploads/sites/11/2016/12/pdf_Maize-Fact-Sheet-August-2013.pdf

Zoia A.A., Amna S. & Kashif A. K. (2019). Crosstalk of Zn in combination with other fertilizers underpins interactive effects and induces resistance in tomato plant against early blight disease. *The Plant Pathology Journal* 35(4), 330

APPENDICES

Appendix I: Field Work Questionnaires

PARTICULARS OF THE STUDY AREA

COUNTY _____ SUBCOUNTY _____

DISTRICT _____ LOCATION _____

SUBLOCATION _____ VILLAGE _____

AGRO-ECOLOGICAL ZONE _____ SOIL

TYPE _____ GENDER: MALE FEMALE

AGE: LESS THAN 20 20-40 40-60 OVER 60

NAME (OPTIONAL)

CELL PHONE (OPTIONAL) _____

QUESTIONS

1. a) Do you grow tomatoes? Yes No

b) What is the size of your tomato farm?

a) Why do you grow tomato? Home consumption.

b) For sale

c) Both

d) Others _____

2. When do you plant these tomatoes? Long rain Short rain

Dry season Others

3. Which variety of tomato do you grow? Cal J Rio Grande super

Royal Seed Oxly

Others _____

4. Where do you obtain your seedlings?

5. Do you use any fertilizer during planting?

a) Yes No

b) If yes, which one?

DAP DSP TSP SSP

NPK

Others _____

6. a) Do you use manure on tomatoes? Yes No

b) If yes, which type of manure do you use?

Compost manure Green manure Cow dung

Goat manure Sheep manure Chicken manure

Others _____

7. a) Do you top dress? Yes No

b) If yes, which fertilizer do you use?

8. a) How do tomatoes get water? Irrigation Rain

b) If irrigation, where do you get water from?

9. Which tomato pests and diseases are common in your farm?

10. How do you control pests and diseases?

11. a) Do you carry out crop rotation? Yes No

b) If yes, which crops do you rotate with?

13. Which crop was in the farm before you planted tomatoes?

14. a) Do you fallow your farm? Yes No

b) If yes, how long does your farm remain fallow?

15. Is tomato cultivation profitable? Yes No

16. What is the other comment about tomato cultivation?

Thank you for allowing us to visit your farm and for responding to our questions.

Appendix II: Meteorological data recorded at Chepalungu during field trials in 2019

Month	Temperature (⁰C)			Rainfall (mm)
	Maximum	Minimum	Average	
January	33.0	16.0	26.0	19.7
February	33.0	17.0	26.0	25.6
March	32.0	15.0	25.0	17.8
April	30.0	15.0	24.0	92.5
May	28.0	14.0	21.0	58.6
June	24.0	14.0	18.0	27.7
July	25.0	13.0	18.0	18.4
August	25.0	14.0	20.0	24.2
September	27.0	14.0	20.0	26.3
October	26.0	13.0	20.0	25.5
November	27.0	15.0	20.0	44.8
December	25.0	16.0	20.0	50.4

Appendix III: Meteorological data recorded at Chepalungu during field trials in 2020

Month	Temperature (0C)			Rainfall(mm)
	Maximum	Minimum	Average	
January	28.0	17.0	23.0	98.5
February	31.0	18.0	26.0	29.6
March	30.0	16.0	24.0	77.5
April	30.0	14.0	23.0	51.8
May	25.0	14.0	20.0	52.0
June	24.0	14.0	19.0	24.9
July	24.0	13.0	19.0	15.6
August	26.0	14.0	21.0	29.7
September	28.0	14.0	22.0	32.4
October	28.0	14.0	23.0	30.0
November	28.0	16.0	23.0	35.3
December	30.0	17.0	25.0	11.6

Source: <https://tcktcktck.org/bomet>

Accessed on 04/01/2021

Appendix IV: Photo-cards of some arthropod pests and field practices



Plate A: Field Assessment for pests and diseases. Source: Koech



Plate C: Leaf miner moth



Plate D: Aphid



Plate E: Flower thrip



Plate F: White fly

Plate B: Key pests observed during the evaluation period. Source: Koech