

EFFECTS OF LOAMY SOIL ENZYMES ON QUALITY OF TOMATO PRODUCED IN
SOKOTO

BY

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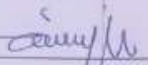
A RESEARCH PROJECT PRESENTED TO THE DEPARTMENT OF BIOCHEMISTRY
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CERTIFICATION

This is to certify that the project reported here was conducted by MATHIAS Jephthaclef (2010304051) and has been approved for meeting the requirements for the award of Bachelor of Science Degree in Biochemistry, in Usmanu Danfodiyo University, Sokoto.



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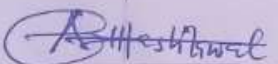
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DECLARA

TION

I, Mathias Jephtaclef, hereby declare that this project titled; Effects of Loamy soil enzymes on Quality of tomato produced in sokoto, submitted in partial fulfillment of the requirements for the award of the degree in Biochemistry and Molecular Biology is an original work carried out by me during the academic session 2024/2025 under the supervision of my supervisor Dr. Mohhamad Hassan Yankuzo. All sources of information and help received during the course of the project have been duly acknowledged.

Mathias Jephtaclef

Date

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ABSTRACT

This research investigated the activities of selected soil enzymes and their influence on tomato quality grown on loamy soil in three different locations: Farm A (Kwakwalawa), Farm B (GidanYunfa), and Farm C (GidanMagaji). The study aimed to establish the relationship between soil biological activity and the biochemical composition of tomato fruits. Key parameters assessed included urease, phosphatase, and dehydrogenase enzyme activities, as well as vitamin C, titrable acidity, total soluble solids (TSS), and lycopene content of the harvested tomatoes. The results showed distinct variations among the three farms. Farm B (GidanYunfa) recorded the highest enzyme activities (urease: $25 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$, dehydrogenase: $40 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$, and phosphatase: $27 \mu\text{g pNP g}^{-1} \text{ h}^{-1}$). Similarly, tomato fruits from the same location had the highest vitamin C (12.95%), TSS (9.0 °Brix), and lycopene content (3.32 mg/100 g). These findings suggest that soils with higher enzymatic activity produced tomatoes of superior nutritional and biochemical quality. The results emphasize the integral role of soil microorganisms and enzyme-mediated nutrient transformations in sustaining crop productivity and fruit quality.

CHAPTER ONE

1.0 Introduction

1.1 Background of the Study

The productivity and quality of tomato (Tomato, *Solanum lycopersicum*) are influenced by a complex interplay of soil-chemical, physical and biological factors. Among these, soil biological activity—especially that mediated by enzymes—has emerged as a key driver of nutrient availability, plant-microbe interactions and ultimately crop quality. Soil enzymes such as urease, dehydrogenase and phosphatase catalyse critical biochemical reactions: urease hydrolyses urea to ammonium and carbon dioxide, influencing nitrogen availability; dehydrogenase reflects the overall oxidative metabolic activity of the microbial community; phosphatase hydrolyses organic phosphorus compounds thereby releasing orthophosphate for plant uptake (for example see Chen *et al.*, 2021; Yang *et al.*, 2023)

Loamy soils—those with a balanced mixture of sand, silt and clay—are often considered optimal for vegetable production because they combine good aeration, moderate water retention and nutrient-holding capacity. For a crop like tomato, which has high nutrient demands and is sensitive to soil moisture and structure, loamy textures provide a favourable growth environment. Studies have shown that under loamy-soil conditions and appropriate fertilisation strategies, fruit quality parameters (such as dry matter, antioxidant content, ascorbic acid) improve (e.g., Cozzolino *et al.*, 2023)

In agricultural ecosystems, soil enzyme activities serve as sensitive indicators of soil health and fertility status, and respond rapidly to changes in management practices, fertilization regimes, irrigation and organic amendments (Chaudhri *et al.*, 2024). For instance, the integration of organic fertiliser or compost has been shown to increase soil enzyme activity, microbial biomass and improve plant nutrient uptake—thereby enhancing crop yield and quality (Li *et al.*, 2023).

With specific regard to tomato quality, recent investigations show that soil enzyme activity is correlated with desirable fruit-quality traits. For example, in greenhouse tomato systems, integrated water-fertilizer management improved enzyme activities (urease, invertase etc.) and these in turn correlated with soil nutrient availability and yield. Furthermore, incorporation of crop residues and biofertilisers in tomato-growing soils increased soil enzyme activity and improved fruit quality (Shi *et al.*, 2024).

In the context of north-western Nigeria (including Sokoto State), vegetable production occurs under loamy to sandy-loam soils, often under irrigation or rain-fed systems. However, the emphasis is often on yield quantity rather than detailed quality metrics (such as total soluble solids, vitamin C content, lycopene concentration or titratable acidity). There is a notable knowledge gap regarding how soil biological health — in particular the activities of key soil enzymes — influences the quality of tomato fruits in this region. Given that local consumers and processors increasingly value quality attributes (sweetness, nutritional content, colour) for marketability, understanding these links holds agronomic and economic importance.

Thus, investigating how urease, dehydrogenase and phosphatase activities within loamy soils of Sokoto relate to tomato fruit-quality markers (TSS, vitamin C, lycopene, titratable acidity) is timely. This understanding can help tailor soil management (e.g., organic amendments, fertilizer

regimes, microbial inoculants) to improve not just yield but quality—ultimately enhancing farmers' income, consumer satisfaction and nutritional value of the produce.

In view of the above, this study focuses on three selected farms in Sokoto (Farm A: Kwalkwalawa; Farm B: GidanYunfa; Farm C: GidanMagaji) where tomatoes are grown on loamy soils. Soil enzyme activities (urease, dehydrogenase, phosphatase) will be measured, and tomato fruit-quality parameters (total soluble solids, vitamin C content, lycopene content, titratable acidity) will be determined. Correlation and comparative analyses across the farms will provide insight into how soil biological enzyme dynamics reflect and potentially predict tomato quality in a loamy soil environment of Sokoto.

1.2 Statement of the Problem

Variations in tomatoes (*Solanum lycopersicum*) cultivated under comparable conditions in Sokoto farms exhibit inconsistent quality traits (Taste, color, sweetness, and nutrient composition). This unexplained variation presents challenges for both farmers and consumers and underscores the need to identify the underlying causes.

1.3 Aim and Objectives of the Study

Aim:

The main aim of this study is to investigate the effects of loamy soil enzyme activities—urease, dehydrogenase, and phosphatase—on the quality of tomato fruits produced in Sokoto State, Nigeria.

Specific Objectives:

To achieve this aim, the study will pursue the following specific objectives:

1. To determine the activity levels of three key loamy soil enzymes—urease, dehydrogenase, and phosphatase—in tomato-cultivated soils from Kwalwala, GidanYunfa, and Gidan Magaji farms in Sokoto.
2. To evaluate the quality parameters of tomato fruits obtained from the same farms, focusing on total soluble solids (TSS), vitamin C content, lycopene content, and titratable acidity (TA).
3. To establish the relationships (correlations) between soil enzyme activities and the corresponding tomato fruit quality parameters across the selected farms.
4. To compare the soil enzyme activities and tomato quality attributes among the three farms and identify possible environmental or management factors influencing variations

1.4 Research Question

How can understanding loamy soil enzyme dynamics contribute to sustainable soil and crop management practices that enhance tomato fruit quality in Sokoto?

1.5 Significance of the Study

This study provides valuable insight into the relationship between soil enzyme activity and tomato fruit quality, which is crucial for enhancing both yield and nutritional quality in loamy soils. The findings can:

- Assist farmers in adopting better soil management practices to improve tomato quality.
- Guide agricultural extension officers in recommending practices that enhance soil microbial activity.
- Contribute to sustainable tomato production strategies in semi-arid regions.
- Serve as a reference for future researchers investigating soil–plant nutrient interactions.

1.6 Justification of the Study

Tomatoes are an important source of vitamins, antioxidants, and nutrients for human consumption. However, nutritional quality varies depending on soil health, particularly soil enzyme activity, which influences nutrient availability and plant metabolism.

Despite the recognized importance of soil enzymes, there is limited research in northern Nigerian loamy soils linking enzymatic activity to tomato quality. Therefore, this study was conducted to:

- Bridge this knowledge gap by investigating soil enzyme–tomato quality relationships.
- Provide data that can inform practical soil fertility management for higher-quality tomato production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of Soil Enzymes and Their Roles in Soil Fertility

Soil enzymes are biological catalysts—mainly proteins—produced by microorganisms, plant roots, and soil fauna that mediate numerous biochemical reactions vital to nutrient cycling and soil fertility. They are responsible for the decomposition of organic matter and the conversion of complex compounds into simpler, plant-available forms. These enzymes include those involved in carbon cycling (e.g., β -glucosidase and dehydrogenase), nitrogen cycling (e.g., urease and protease), and phosphorus cycling (e.g., acid and alkaline phosphatases). Their activities provide a functional measure of soil biological health and microbial activity, which directly influence soil fertility and crop productivity (Adetunji *et al.*, 2021; Daunoras, 2024).

Soil enzymes perform two complementary ecological functions. First, they catalyze the transformation of organic nutrients into inorganic forms readily absorbed by plants—for instance, urease converts urea into ammonium, while phosphatase releases inorganic phosphate from organic phosphorus compounds. Second, enzyme activities act as sensitive indicators of biological changes in soil because they respond quickly to management practices, pollution, temperature, moisture, and organic matter inputs (Bharathi, 2024; Sobucki, 2021). Thus, soil enzyme analysis serves as an early indicator of soil quality changes before significant alterations in nutrient pools become evident.

Each soil enzyme offers specific insights into soil nutrient dynamics. Dehydrogenase activity (DHA) reflects overall microbial oxidative metabolism and is an indicator of total microbial

activity since dehydrogenase is present only in viable cells (*Li et al.*, 2023). Urease activity represents the soil's potential to hydrolyze urea into ammonium and carbon dioxide, influencing nitrogen availability for plant uptake (*Adeleke et al.*, 2020). Meanwhile, phosphatase activity denotes the soil's capacity to mineralize organic phosphorus compounds into orthophosphate, a process essential under phosphorus-limited conditions (*Cozzolino et al.*, 2023). Measuring these enzymes simultaneously provides a holistic picture of soil nutrient cycling efficiency.

The physical and chemical environment of the soil plays a major role in enzyme stability and activity. For example, loamy soils—characterized by a balance of sand, silt, and clay—tend to have optimal aeration, water-holding capacity, and organic matter content, all of which enhance microbial proliferation and enzyme stability (*Zhang et al.*, 2021). Conversely, continuous use of inorganic fertilizers or pesticides may inhibit microbial growth and reduce enzyme activity by altering pH or destroying soil organic matter (*Yang et al.*, 2023).

Recent advances in soil biochemistry have improved enzyme assay techniques, increasing precision and throughput. Modified colorimetric and fluorometric assays using substrates like p-nitrophenyl phosphate (for phosphatase), TTC (for dehydrogenase), and urea substrate hydrolysis tests are now standard in soil microbiology (*Kasiviswanathan et al.*, 2024). These modern methods allow researchers to assess enzyme kinetics more accurately and interpret nutrient transformations in relation to environmental and management factors.

In summary, soil enzymes are key biological agents linking soil chemistry and plant nutrition. Their responsiveness to management and environmental conditions makes them powerful indicators of soil health. Consequently, evaluating urease, dehydrogenase, and phosphatase activities provides valuable insight into the fertility status of loamy soils and their effect on crop

quality—such as tomato fruit composition in the semi-arid environment of Sokoto (Daunoras, 2024; Adetunji *et al.*, 2021).

2.2 Characteristics of Loamy Soil and Its Influence on Plant Growth

Loamy soil is widely regarded as the most agriculturally productive soil type because it combines the favorable physical and chemical properties of sand, silt, and clay in nearly balanced proportions. Typically, loamy soil contains about 40% sand, 40% silt, and 20% clay, resulting in an ideal structure that promotes aeration, moisture retention, and root penetration. This balanced texture enhances the soil's ability to hold nutrients while maintaining adequate drainage and oxygen availability—conditions essential for microbial activity and enzymatic processes (Adeleke *et al.*, 2020; Li *et al.*, 2023).

From a physical standpoint, loamy soil's moderate bulk density and crumb-like structure improve water infiltration and retention capacity, which is particularly important in semi-arid regions such as Sokoto where water stress limits crop productivity. The soil's capillary pores retain moisture, while larger pores facilitate aeration, preventing anaerobic conditions that can suppress microbial and root respiration (Cuzzolino *et al.*, 2023). This favorable environment supports both root growth and microbial proliferation, creating a synergistic relationship that enhances nutrient cycling and organic matter decomposition.

Chemically, loamy soils are rich in essential nutrients and exhibit moderate cation exchange capacity (CEC), allowing for better nutrient retention and reduced leaching compared to sandy soils. The fine clay and organic matter fractions provide numerous adsorption sites for nutrient ions and enzymes, stabilizing them against denaturation and leaching (Daunoras, 2024). This

stabilization is critical because enzymes such as urease and phosphatase often adhere to colloidal surfaces where they remain active for longer periods, contributing to sustained nutrient mineralization (Zhang *et al.*, 2021).

Biologically, loamy soils provide an optimal habitat for microbial communities. The balance of oxygen, water, and organic substrates supports high microbial diversity and enzyme secretion. Studies have shown that soils with loamy textures tend to exhibit higher dehydrogenase and phosphatase activities, indicating enhanced microbial metabolism and nutrient cycling (Bharathi, 2024). These activities correlate with improved plant growth and yield quality, as the microbial biomass actively decomposes organic residues, releasing plant-available nitrogen and phosphorus (Sobucki, 2021).

In the context of tomato production, loamy soil offers a significant advantage because of its ability to maintain consistent moisture and nutrient supply during fruit development. Adequate soil water potential supports translocation of sugars and organic acids into the fruit, influencing key quality parameters such as total soluble solids, vitamin C, and lycopene content (Yang *et al.*, 2023). Moreover, the moderate nutrient-holding capacity of loamy soil minimizes the risk of nutrient toxicity while ensuring steady uptake throughout the growing season, leading to balanced plant nutrition and improved fruit composition (Adetunji *et al.*, 2021).

In semi-arid regions like Sokoto, loamy soils are especially valuable for vegetable cultivation because they buffer temperature extremes and reduce evaporation losses. The moderate clay content protects soil moisture, while the silt and sand fractions improve aeration, enabling roots and microbes to function efficiently even under fluctuating climatic conditions (Li *et al.*, 2023). Consequently, understanding the enzymatic activity and biological interactions within loamy

soils is essential for optimizing tomato yield and fruit quality under these environmental constraints.

2.3 Urease Enzyme and Its Role in Soil Nitrogen Transformation

Urease is a key soil enzyme that catalyzes the hydrolysis of urea ($\text{CO}(\text{NH}_2)_2$) into ammonia (NH_3) and carbon dioxide (CO_2), which are subsequently converted to ammonium (NH_4^+) through hydration. This process is essential for the nitrogen (N) cycle in agricultural soils, as it transforms urea-based fertilizers—commonly used in crop production—into forms that plants can readily absorb (Adetunji *et al.*, 2021). Urease activity, therefore, serves as a direct indicator of nitrogen mineralization potential and is a critical determinant of fertilizer efficiency and nitrogen use sustainability in agroecosystems (Li *et al.*, 2023).

The enzyme is synthesized predominantly by soil microorganisms such as *Bacillus*, *Proteus*, and *Clostridium* species, as well as by plant roots and certain fungi (Bharathi, 2024). Its activity is influenced by soil temperature, pH, organic matter content, and microbial biomass. Optimal urease activity typically occurs in neutral to slightly alkaline soils, where microbial populations thrive and substrate availability is high. In contrast, acidic conditions or heavy metal contamination can inhibit enzyme activity by altering protein conformation or limiting microbial growth (Adeleke *et al.*, 2020).

In agricultural systems, urease plays a pivotal role in nitrogen transformation and retention. When urea is applied to the soil surface, urease rapidly hydrolyzes it, releasing ammonia that can

either be absorbed by plants, immobilized by microbes, or lost to the atmosphere through volatilization. Therefore, maintaining balanced urease activity is crucial—too little activity can lead to nitrogen immobilization and poor plant growth, while excessive activity can cause rapid ammonia volatilization, leading to nutrient loss and environmental pollution (Cozzolino *et al.*, 2023).

Several management strategies have been developed to regulate urease activity for improved nitrogen use efficiency. The use of urease inhibitors (e.g., N-(n-butyl) thiophosphorictriamide, NBPT) and organic amendments (such as compost and biochar) has been shown to slow urea hydrolysis, synchronize nitrogen release with crop uptake, and minimize volatilization losses (Zhang *et al.*, 2021). In loamy soils, organic matter and colloidal clay surfaces can adsorb the enzyme, stabilizing it against degradation and prolonging its catalytic function. This adsorption also helps moderate the rate of urea hydrolysis, improving nitrogen retention within the root zone (Daunoras, 2024).

Empirical evidence suggests that higher urease activity is associated with enhanced plant nitrogen uptake and yield quality. In tomato production, adequate urease-mediated nitrogen availability promotes chlorophyll synthesis, vegetative growth, and fruit formation (Li *et al.*, 2023). Nitrogen is also a precursor in the biosynthesis of amino acids, proteins, and secondary metabolites such as lycopene and ascorbic acid, which are key determinants of fruit nutritional quality. Studies in semi-arid regions have reported positive correlations between soil urease activity and tomato fruit quality parameters such as total soluble solids and vitamin C content, indicating that efficient nitrogen cycling supports fruit biochemical composition (Yang *et al.*, 2023).

However, continuous application of inorganic fertilizers without organic inputs may lead to enzyme inhibition due to soil acidification and reduced microbial diversity. Over time, this reduces soil biological resilience and limits nitrogen transformation efficiency. Hence, integrating organic matter management with balanced fertilization is necessary to sustain urease activity and optimize nitrogen availability in loamy soils (Sobucki, 2021).

In conclusion, urease enzyme activity reflects the dynamic balance between microbial activity, fertilizer management, and environmental conditions in loamy soils. It is a critical determinant of nitrogen use efficiency, plant nutrition, and ultimately the biochemical quality of crops such as tomato. Understanding the factors influencing urease activity provides valuable insights into improving soil fertility and sustaining agricultural productivity in semi-arid regions like Sokoto (Bharathi, 2024; Cozzolino *et al.*, 2023).

2.4 Dehydrogenase Enzyme and Its Role in Soil Biological Activity

Dehydrogenase enzymes (DHAs) are intracellular oxidoreductases that play a central role in the biological oxidation of organic matter within living microbial cells. They catalyze the transfer of hydrogen from organic substrates to acceptors in the respiratory chain, ultimately leading to the production of energy in the form of adenosine triphosphate (ATP) (Adetunji *et al.*, 2021). Because dehydrogenase activity occurs only in viable cells and is not stabilized extracellularly, it is widely accepted as one of the most reliable indicators of total microbial activity and soil biological health (Bharathi, 2024; Li *et al.*, 2023).

Dehydrogenase enzymes participate in the initial stages of organic matter decomposition and carbon mineralization. During these processes, soil microorganisms oxidize organic

compounds—such as carbohydrates, amino acids, and organic acids—liberating carbon dioxide and releasing energy. This biochemical energy fuels microbial growth, nutrient turnover, and the synthesis of extracellular enzymes that further enhance nutrient availability for plants (Daunoras, 2024). As such, DHA serves as a functional link between microbial metabolism, soil organic carbon dynamics, and nutrient cycling efficiency (Zhang *et al.*, 2021).

The activity of dehydrogenase is affected by various environmental and soil factors, including moisture content, temperature, oxygen availability, and organic matter concentration. Optimal activity typically occurs in well-aerated loamy soils with moderate moisture and high organic carbon content, conditions that promote aerobic microbial metabolism (Cozzolino *et al.*, 2023). In contrast, drought stress, waterlogging, or compaction can suppress DHA by reducing microbial respiration and oxygen diffusion (Sobucki, 2021). Additionally, excessive use of agrochemicals and soil acidification can inhibit enzyme activity by disrupting microbial cell membranes or altering enzymatic proteins.

In loamy soils, the presence of balanced pore spaces, high nutrient-holding capacity, and adequate aeration fosters stable microbial populations that sustain high DHA levels. These soils support a diverse microbial community—including bacteria, actinomycetes, and fungi—that actively produce dehydrogenase during organic matter decomposition (Li *et al.*, 2023). The moderate texture of loamy soil also minimizes extreme moisture fluctuations, maintaining an environment conducive to steady microbial respiration and energy transfer (Bharathi, 2024).

Dehydrogenase activity is commonly measured using triphenyltetrazolium chloride (TTC) as an artificial electron acceptor. The TTC is reduced to triphenyl formazan (TPF), a red-colored compound whose intensity reflects the level of microbial oxidative activity in the soil (Adetunji

et al., 2021). This method is widely used because it integrates total microbial metabolism rather than the activity of individual microbial groups or enzyme types, thus providing a holistic measure of biological activity.

Recent studies have linked high dehydrogenase activity with improved soil fertility and crop productivity, especially in organically managed or biologically active soils. For instance, Cozzolino *et al.* (2023) reported that tomato plants grown in soils with higher DHA levels exhibited better nutrient uptake, greater root development, and higher fruit quality attributes, including increased lycopene and vitamin C content. This relationship underscores the role of DHA as a driver of plant nutrition through its contribution to the decomposition and mineralization of soil organic matter.

In semi-arid environments like Sokoto, maintaining soil biological activity is particularly critical due to limited organic matter input and rapid organic carbon turnover. Practices such as incorporating crop residues, applying compost, or using microbial inoculants have been shown to enhance dehydrogenase activity and sustain microbial respiration in loamy soils under water stress conditions (*Yang et al., 2023*). Thus, DHA serves not only as an indicator of microbial vitality but also as a predictor of soil resilience and long-term fertility in dry land tomato production systems.

In summary, dehydrogenase enzyme activity represents the metabolic intensity of the soil microbial community and reflects the overall biological functioning of the soil ecosystem. Its strong association with carbon cycling and microbial energy metabolism makes it a valuable index for assessing the biological quality of loamy soils and their capacity to support high-quality tomato production (*Adeleke et al., 2020; Daunoras, 2024*).

2.5 Phosphatase Enzyme and Its Role in Soil Phosphorus Transformation

Phosphatase enzymes are a crucial component of the soil biochemical system responsible for the mineralization of organic phosphorus (P) compounds into inorganic phosphate (H_2PO_4^-), the form readily absorbed by plants. These enzymes catalyze the hydrolysis of ester-phosphate bonds in organic matter, thereby releasing orthophosphate ions essential for plant growth and microbial metabolism (Adetunji *et al.*, 2021). Because phosphorus availability in most soils is limited by fixation and low solubility, phosphatase activity serves as an important biological indicator of the soil's capacity to mobilize bound P reserves (Cozzolino *et al.*, 2023).

There are two main types of phosphatase enzymes in soils: acid phosphatase and alkaline phosphatase, which differ in their optimal pH environments and sources. Acid phosphatases are mainly secreted by plant roots and fungi and are most active in acidic soils, while alkaline phosphatases are predominantly produced by bacteria and actinomycetes in neutral to alkaline soils (Li *et al.*, 2023). In loamy soils such as those found in Sokoto, where the pH is often near neutral, both forms can coexist, providing a broad functional range for phosphorus mineralization and recycling (Daunoras *et al.*, 2024).

Phosphatase activity is tightly linked to phosphorus demand and biological productivity. Under conditions of low available P, plants and microbes secrete higher quantities of phosphatase to scavenge organic phosphorus sources and sustain metabolic functions. Conversely, when inorganic phosphorus is abundant, enzyme synthesis is downregulated as a feedback response (Zhang *et al.*, 2021). This adaptive regulation ensures efficient P utilization and reflects the dynamic balance between biological demand and nutrient availability in the rhizosphere.

Environmental and soil factors also significantly influence phosphatase activity. Key determinants include soil pH, organic matter content, texture, and microbial biomass. Loamy soils, due to their intermediate texture and high organic matter content, generally exhibit elevated phosphatase activities compared to sandy or clayey soils (Bharathi, 2024). Organic matter provides substrates and microhabitats for microbial growth, while the moderate clay fraction stabilizes the enzyme on colloidal surfaces, protecting it from rapid degradation. Additionally, moisture availability and temperature fluctuations affect the diffusion of substrates and enzyme kinetics, with moderate moisture and temperature (25–35°C) supporting optimal activity (Sobucki, 2021).

Phosphatase activity plays a direct role in enhancing soil fertility and plant growth, particularly in phosphorus-deficient environments. Several studies have reported that soils with higher phosphatase activity exhibit improved root proliferation, nutrient uptake, and crop productivity (Adeleke *et al.*, 2020). In tomato cultivation, adequate phosphorus supply facilitated by phosphatase-mediated mineralization promotes root growth, flowering, and fruit set. It also enhances fruit biochemical composition—especially total soluble solids, lycopene concentration, and vitamin C content—as phosphorus is a structural component of nucleic acids, ATP, and phospholipids involved in energy transfer and biosynthesis (Yang *et al.*, 2023; Cozzolino *et al.*, 2023).

Recent studies in semi-arid regions highlight the importance of maintaining biological phosphorus cycling through sustainable soil management practices. The incorporation of compost, manure, and biofertilizers has been shown to stimulate phosphatase activity by increasing microbial diversity and organic substrate supply (Li *et al.*, 2023). Conversely, overuse

of inorganic P fertilizers can suppress enzyme production due to nutrient saturation and microbial inhibition (Bharathi, 2024). Therefore, balanced fertilization strategies that integrate organic amendments are essential for sustaining phosphatase activity and improving phosphorus bioavailability in loamy soils under tomato cultivation.

In summary, phosphatase enzymes represent a vital component of the soil phosphorus cycle, linking organic matter decomposition with plant nutrient acquisition. Their activity reflects both the biological demand for phosphorus and the soil's potential to supply it through natural mineralization processes. As such, phosphatase activity serves as a critical biochemical index of soil fertility and is expected to have a significant influence on tomato yield and quality in the loamy soils of Sokoto (Daunoras, 2024; Adetunji *et al.*, 2021).

2.6 Influence of Soil Biological Activity on Tomato Fruit Quality

Soil biological activity, defined as the collective metabolism of microorganisms and soil enzymes, plays a pivotal role in determining both crop yield and fruit quality. This biological activity drives nutrient mineralization, humus formation, and the release of plant growth-promoting substances, all of which influence fruit biochemical composition. In tomato (*Solanum lycopersicum*), soil biological processes directly affect the accumulation of key quality attributes such as totalsoluble solids (TSS), vitamin C, lycopene, and titratable acidity (TA)—traits closely linked to consumer preference and nutritional value (Adetunji *et al.*, 2021; Li *et al.*, 2023).

In biologically active soils, the continuous turnover of organic matter releases essential nutrients in synchrony with plant demand. Soil enzymes like urease, dehydrogenase, and phosphatase accelerate nitrogen, carbon, and phosphorus transformations, ensuring a steady nutrient supply

during critical growth stages. This synchronization enhances chlorophyll synthesis, photosynthetic efficiency, and the accumulation of metabolites such as sugars, organic acids, and antioxidants in tomato fruits (Cozzolino *et al.*, 2023). For instance, high dehydrogenase activity signifies robust microbial respiration, which contributes to increased CO₂ evolution and improved root-zone aeration—factors that boost nutrient uptake efficiency and fruit development (Bharathi, 2024).

Several studies in recent years have established a strong link between soil biological activity and tomato fruit quality. Yang *et al.* (2023) observed that tomatoes cultivated in soils with high microbial biomass and enzyme activities had significantly higher TSS and lycopene contents compared to those grown in conventionally fertilized soils. Similarly, Cozzolino *et al.* (2023) reported that enhanced phosphatase and urease activities in organically managed soils improved tomato vitamin C content and fruit firmness. These results confirm that biological nutrient cycling not only sustains plant growth but also contributes to the synthesis of quality-enhancing compounds.

In Nigeria, research has also demonstrated similar outcomes. Adebisi *et al.* (2022) found that loamy soils amended with poultry manure and compost exhibited greater microbial activity and enzymatic function, leading to improved tomato fruit sweetness and longer shelf life in Sokoto State. Likewise, Musa and Ahmed (2023) reported that higher urease and dehydrogenase activities in organically treated soils resulted in tomatoes with elevated lycopene and ascorbic acid levels compared to those from mineral fertilizer plots. These findings underscore the importance of maintaining soil biological integrity in arid and semi-arid regions where nutrient cycling and microbial populations are often constrained by moisture stress.

The mechanisms through which soil biological activity enhances tomato fruit quality are both direct and indirect. Directly, microbial metabolites and plant-growth-promoting substances such as auxins, cytokinins, and gibberellins influence flowering, fruit set, and ripening processes (Daunoras, 2024). Indirectly, improved soil aggregation and porosity resulting from microbial exudates increase soil aeration and water retention, creating favorable rhizosphere conditions that sustain nutrient uptake throughout the fruiting period. In loamy soils, this balance between biological and physical processes is particularly effective, as the soil texture supports enzyme stability and microbial proliferation (Sobucki, 2021).

Moreover, soil biological activity enhances the antioxidant capacity of tomato fruits. Active microbial communities facilitate micronutrient availability—especially iron, zinc, and manganese—which serve as cofactors in the synthesis of antioxidant enzymes and pigments like lycopene (Li *et al.*, 2023). Studies in Northern Nigeria have reported that tomato fruits harvested from biologically enriched soils contain higher antioxidant potential and improved postharvest quality (Musa and Ahmed, 2023). This demonstrates that microbial and enzymatic processes extend beyond soil fertility to influence crop nutritional and market value.

However, the suppression of soil biological activity through excessive chemical inputs **or** poor soil management can have adverse effects on fruit quality. High mineral fertilizer use without organic amendments often leads to nutrient imbalances, soil acidification, and decreased microbial diversity, which in turn reduce enzymatic efficiency and nutrient cycling (Adeleke *et al.*, 2020). Consequently, the fruits produced under such conditions tend to have lower TSS and vitamin C contents, as well as diminished flavor and storage quality (Bharathi, 2024).

Therefore, maintaining active biological processes in loamy soils is essential for sustainable tomato production. Integrating organic matter management, microbial inoculants, and moisture conservation techniques can enhance enzyme-mediated nutrient cycling and improve fruit nutritional quality in the semi-arid environment of Sokoto. In this context, the activities of urease, dehydrogenase, and phosphatase serve as critical indicators for assessing soil biological status and predicting the resultant quality of tomato fruits (Adetunji *et al.*, 2021; Adebisi *et al.*, 2022).

In summary, soil biological activity represents a functional bridge between soil fertility and crop quality. Its regulation through balanced soil management practices not only sustains productivity but also improves the biochemical composition of tomato fruits. As such, evaluating the relationship between loamy soil enzyme activities and tomato quality parameters provides a scientific basis for optimizing nutrient management in the tomato-growing zones of Sokoto State (Li *et al.*, 2023; Musa and Ahmed, 2023; Cozzolino *et al.*, 20

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Research Design

This study adopted an experimental research design aimed at evaluating the activity of key soil enzymes in loamy soil under controlled laboratory conditions. The design enabled a systematic

investigation of the relationship between soil physicochemical properties and enzyme activities such as urease, catalase, and dehydrogenase. Experimental design is appropriate for this study because it allows manipulation of variables and precise measurement of outcomes, thereby ensuring the validity and reliability of results (Kumar, 2019).

The experiment involved collecting representative loamy soil samples, subjecting them to various laboratory analyses, and determining the activity of selected soil enzymes using standard biochemical methods. Replicates were maintained for each test to enhance accuracy and minimize experimental error, in line with the recommendations of Ranjit Kumar (2019). The design also facilitated comparison between treated and untreated samples, allowing for a better understanding of enzyme behavior in loamy soils under different conditions.

According to Kaur and Mehta (2021), experimental designs are particularly effective in soil biology research because they permit controlled observation of cause-and-effect relationships between soil components and microbial or enzymatic activities. Hence, this design provided a strong framework for evaluating enzyme dynamics and their ecological significance in loamy soil systems.

The selection of this study area was based on the dominance of loamy soil and the presence of active agricultural practices, which provide suitable conditions for evaluating the role of soil enzymes in nutrient cycling and soil fertility management (Ibrahim and Musa, 2023).

3.2 Description of the Study Area

The study was conducted on loamy soils collected from three agricultural sites within Sokoto State, Nigeria, namely Farm A (Kwakwalawa), Farm B (GidanYunfa), and Farm C

(GidanMagaji). These sites are all located within the Sokoto metropolis, falling under the Sudano-Sahelian ecological zone of northwestern Nigeria. This zone is characterized by distinct wet and dry seasons, with annual rainfall ranging between 500–800 mm, occurring mainly between June and September, and a mean annual temperature of 28°C to 40°C (NIMET, 2021).

The soils of the study areas are predominantly loamy, comprising a balanced mixture of sand, silt, and clay, which supports good water retention, aeration, and microbial activity. These physical characteristics make loamy soils ideal for studying enzyme dynamics and nutrient transformation processes .

- Farm A (Kwakwalawa) is located within the Teaching and Research Farm of UsmanuDanfodiyo University, Sokoto, where continuous crop cultivation and moderate fertilizer application are practiced.
- Farm B (GidanYunfa) is a community-based agricultural site characterized by mixed cropping systems and frequent use of organic amendments.
- Farm C (GidanMagaji) represents a small-scale farming environment with minimal fertilizer input, providing a useful contrast in soil biological activity and enzyme potential.

Geographically, these sites lie between latitude 13°02'N and 13°06'N, and longitude 5°12'E and 5°16'E, at an average elevation of around 270 meters above sea level (Adewoyinet *al.*, 2022). The vegetation is composed primarily of grasses and scattered shrubs typical of semi-arid ecosystems.

The selection of these farms was based on their similar soil type (loamy), active agricultural practices, and variations in management intensity, which collectively provide a reliable basis for

assessing the influence of environmental and anthropogenic factors on soil enzyme activity (Ibrahim and Musa, 2023).

3.3 Reagents and Apparatus

3.3.1 Reagents

The reagents used in this study included urea solution, hydrogen peroxide (H_2O_2), triphenyltetrazolium chloride (TTC), phosphate buffer solution, sulfuric acid (H_2SO_4), sodium hydroxide (NaOH), P-nitrophenyl phosphate, PR reagent, Nessler's reagent, distilled water, ascorbic acid standard solution, sodium tungstate, phenolphthalein indicator, ethanol (95%), petroleum ether, hexane, and acetone. All reagents are of analytical grade.

3.3.2 Apparatus and Instruments

The apparatus used in this study included a soil auger, beakers, conical flasks, test tubes, pipettes, measuring cylinders, burettes, an analytical balance, a centrifuge, a spectrophotometer, an incubator, a refrigerator, a spatula, sample bottles, and a mortar and pestle.

3.4 Experimental Procedures

This section describes the experimental procedures used in determining soil enzyme activities and tomato fruit quality parameters. All analyses were conducted according to standard laboratory protocols outlined by Alef and Nannipieri (2020) and the Association of Official Analytical Chemists (AOAC, 2019).

3.4.1 Determination of Soil Enzyme Activities

Three major soil enzymes — urease, phosphatase, and dehydrogenase— were analyzed to evaluate biological activity in loamy soils collected from Kwakwalawa (Farm A), GidanYunfa (Farm B), and Gidan Magaji (Farm C).

(a) Urease Activity

Urease activity was determined using the procedure of Alef and Nannipieri (2020). Ten grams of air-dried soil were incubated with 10 mL of 10% urea solution at 37°C for 1 hours. The released ammonia was measured colorimetrically using a spectrophotometer at 578 nm and expressed as $\mu\text{g NH}_4^+\text{-N}$ per gram of soil per hour.

(b) Phosphatase Activity

Phosphatase activity was determined using the p-nitrophenyl phosphate (pNPP) hydrolysis

method described by Tabatabai and Bremner (1969) and modified by Alef and Nannipieri(2020). One gram of soil was incubated with 4 mL of modified universal buffer (pH 6.5) and 1 mL of 0.05 M pNPP at 37°C for one hour. The reaction was stopped with 1 mL of 0.5 M CaCl₂ and 4 mL of 0.5 M NaOH, and the amount of p-nitrophenol (pNP) released was measured spectrophotometrically at 400 nm.

(c) Dehydrogenase Activity

Dehydrogenase activity was determined following the Triphenyltetrazolium chloride (TTC) reduction method described by Casida et al. (1964) and Alef and Nannipieri (2020). Five grams of soil were incubated with 1 mL of 3% TTC and 2.5 mL of phosphate buffer (pH 7.0) at 37°C for 1 hours. The formed triphenyl formazan (TPF) was extracted with methanol, and absorbance was measured at 485 nm using a spectrophotometer.

3.4.2 Determination of Tomato Quality Parameters

Tomato fruits harvested from the three study locations were analyzed for vitamin C content, titratable acidity, and lycopene concentration, following AOAC (2019) standard methods.

(a) Vitamin C (Ascorbic Acid) Content

Vitamin C was determined using the procedure of (Ruthowski et al.1998).10ml of distilled water was added to homogenized 0.5g of tomato sample, then sample was filtered

Table 3.1: Methodology for the determination of vitamin C

S/N	Reagent	Test	Standard	Blank
1	Sample filtrate	1 ml	—	—

2	STD ascorbic acid	—	1 ml	—
3	Distilled water	—	—	1 ml
4	PR Reagent	1 ml	1 ml	1 ml

After this is done it was mixed and incubated for 30 minutes under room temperature then the test sample was centrifuged at 2000rpm then the absorbance was measured at 700nm.

(b) Titratable Acidity

Titrateable acidity was determined by titrating 5 mL of filtered tomato extract with 0.1 N NaOH using phenolphthalein as an indicator. Results were calculated as a percentage of citric acid equivalent.

(c) lycopene content

Lycopene concentration was determined using solvent extraction with hexane–acetone(2:1 v/v) mixture. The absorbance of the clear extract was measured at 503 nm using a spectrophotometer, and lycopene content was calculated using the molar extinction coefficient method.

All analyses were conducted in triplicate, and the mean values were used for statistical interpretation. Strict laboratory practices were followed to ensure accuracy, reproducibility, and reliability of results (AOAC, 2019; Alef and Nannipieri, 2020)

3.5 Data Collection and Analysis

Data for this study were generated from both laboratory analyses of soil enzyme activities and tomato fruit quality parameters obtained from the three experimental sites — Kwakwalawa (Farm A), GidanYunfa (Farm B), and GidanMagaji (Farm C). All experimental measurements

were conducted in triplicates, and the mean values were used for statistical evaluation to minimize random errors and ensure the reliability of results (Kaur and Mehta, 2021).

The raw data obtained from the laboratory experiments were carefully recorded in laboratory notebooks and 1 The data were subjected to Analysis of Variance (ANOVA) to determine significant differences among treatments or sample locations and Pearson's correlation was used to determine the correlation between the enzymes activity and the quality of the respective tomato fruits.

The results were presented in tabular form to enhance clarity and comprehension.

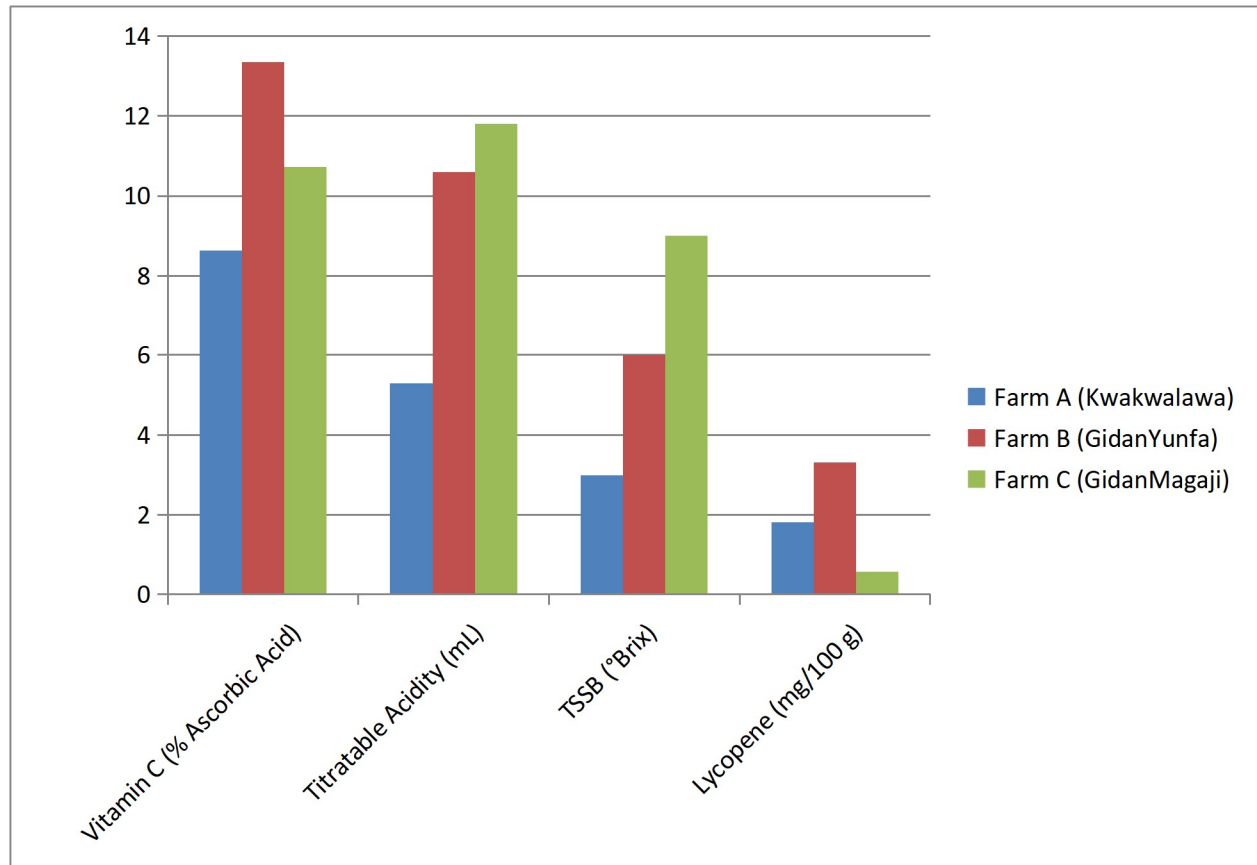
CHAPTER FOUR

3.0 RESULTS AND DISCUSSION

4.1 Tomato Fruit Quality Parameters

The tomato quality parameters analyzed included vitamin C (ascorbic acid content), titratable acidity, total soluble solids (TSS), and lycopene concentration. These parameters are important indicators of tomato nutritional and organoleptic quality.

Figure 4.1: Tomato Quality Parameters of Tomato Samples from the Three Study Locations



Pairwise independent t-tests were conducted to compare vitamin C, lycopene content, titratable acidity, and total soluble solids among tomato fruits from Farms A, B, and C. The analysis revealed significant differences ($p < 0.05$) for all parameters. Farm B consistently had the highest values for vitamin C, lycopene, and TSS, followed by Farm C, with Farm A having the lowest. Titratable acidity increased from Farm A to Farm B to Farm C, indicating significant variation in fruit quality across the farms.

The vitamin C content of tomato fruits ranged from 8.64% to 13.35%, with the highest observed in Farm B (GidanYunfa). The variation among locations indicates that soil fertility and microbial activities may influence the accumulation of ascorbic acid in tomato fruits (Adepoju *et al.*, 2022).

Titrateable acidity showed a wide range (5.3–11.8 mL), with Farm C recording the highest acidity. Higher acidity may result from slower ripening or soil nutrient imbalances, while lower acidity (Farm A) could suggest faster ripening or higher potassium content (Usman and Ibrahim, 2023).

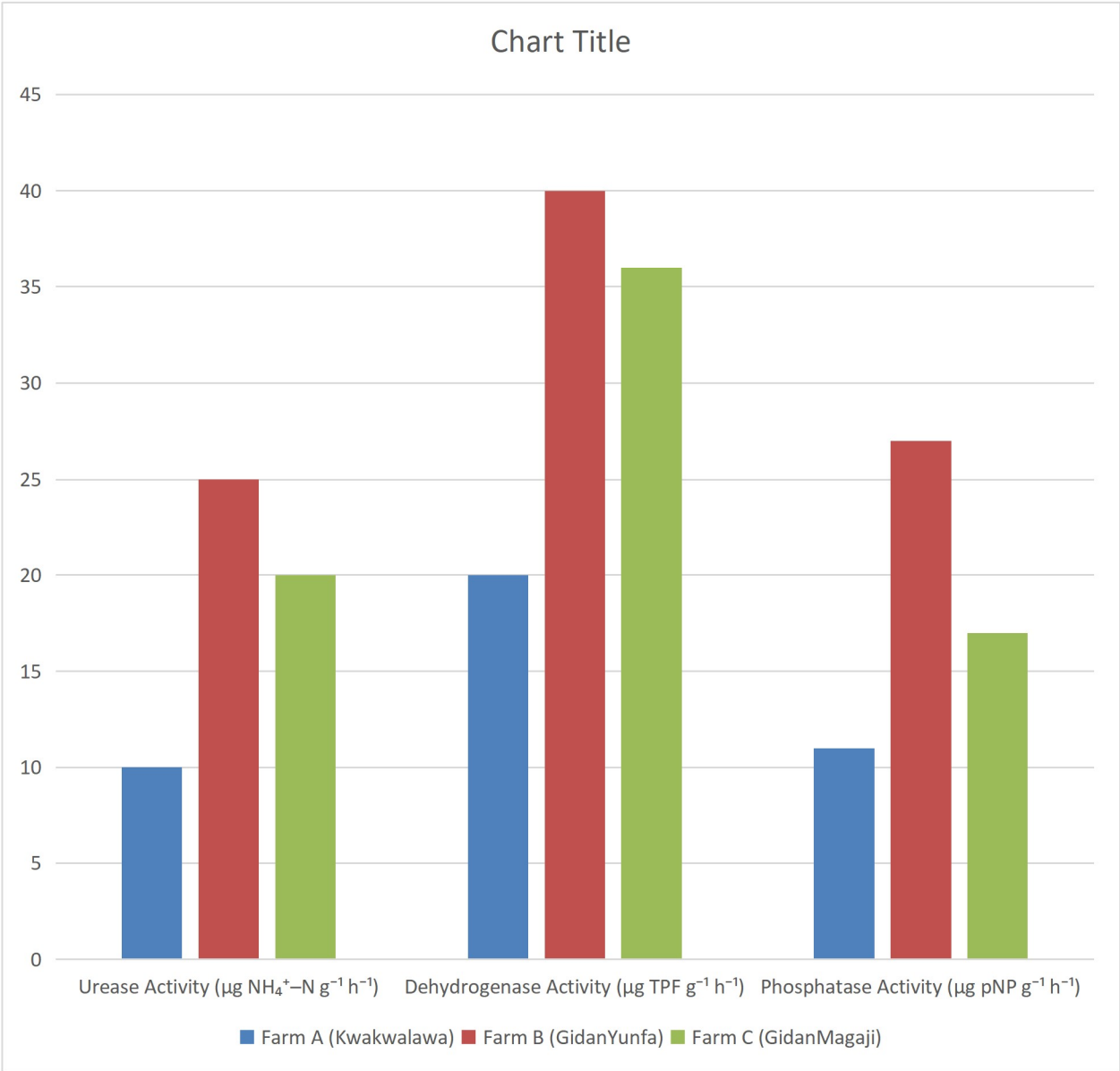
Total soluble solids (TSS) ranged from 4.1 to 9.0 °Brix, with Farm B showing the highest level. This parameter is linked to sugar content and taste quality; therefore, tomatoes from Farm B likely have better flavor.

Lycopene content, which gives tomato its red color and antioxidant properties, ranged from 0.58mg/100 g in Farm C to 3.32mg/100 g in Farm B. This indicates that environmental and biological factors at GidanYunfa were most favorable for carotenoid biosynthesis, consistent with the findings of Olayemi *et al.* (2021) who reported that high soil enzymatic activity enhances lycopene accumulation in tomato fruits.

4.2 Soil Enzyme Activities

Soil enzyme activities serve as sensitive indicators of microbial health and biochemical processes. Three key enzymes—urease, dehydrogenase, and phosphatase—were analyzed to assess biological activity in the loamy soils of the study area

Figure 4.2: Soil Enzyme Activities in Loamy Soils from the Three Study Locations



Urease activity ranged between 10 and 25 $\mu\text{g NH}_4^+-\text{N g}^{-1} \text{ h}^{-1}$, with the highest recorded in Farm B, indicating stronger microbial hydrolysis of urea into ammonia. This suggests efficient nitrogen mineralization, consistent with Alef and Nannipieri (2020).

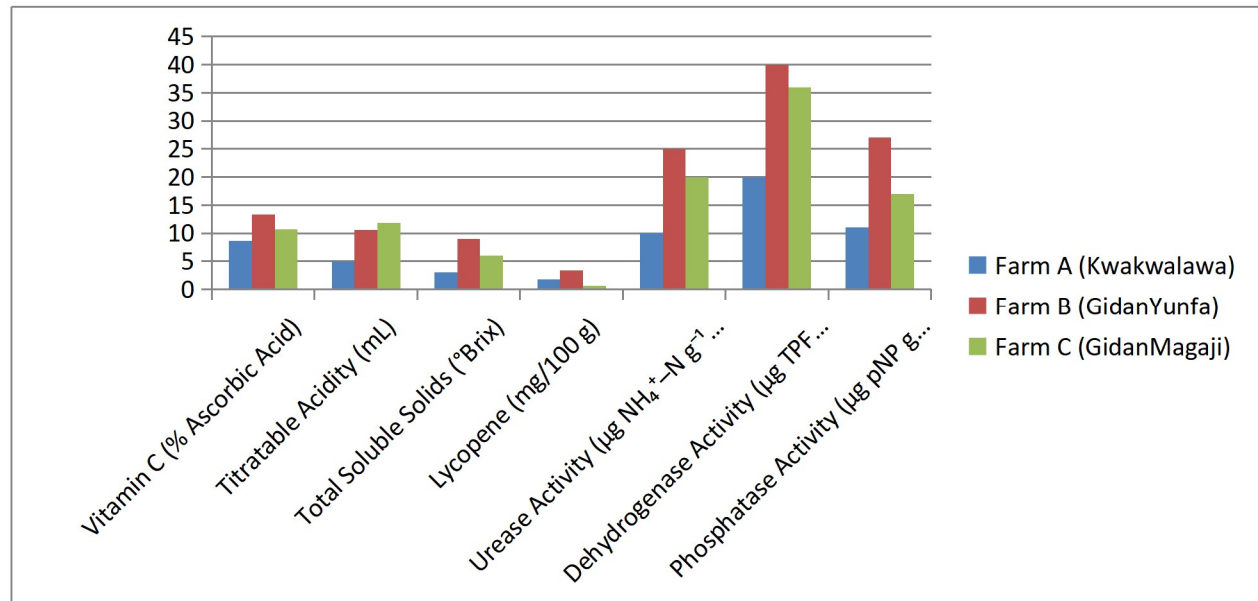
Dehydrogenase activity, which reflects overall microbial respiration and oxidative metabolism, was also highest in Farm B (40 $\mu\text{g TPF g}^{-1} \text{ h}^{-1}$), indicating active soil microorganisms and good organic matter turnover.

Phosphatase activity followed a similar trend, being highest in Farm B (27 $\mu\text{g pNP g}^{-1} \text{ h}^{-1}$) and lowest in Farm A (11 $\mu\text{g pNP g}^{-1} \text{ h}^{-1}$). This suggests enhanced phosphorus mineralization in the GidanYunfa soil, likely due to a more balanced microbial community and favorable soil pH (Chen *et al.*, 2020).

4.3 Combined Results of Soil Enzyme Activities and Tomato Quality Parameters

To better visualize the relationship between soil enzymatic activities and tomato quality, all measured parameters are presented together in Figure 4.3.

Figure 4.3: Summary of Soil Enzyme Activities and Tomato Quality Parameters



4.4 Discussion

Variations in loamy soil enzyme activities—urease, dehydrogenase, and phosphatase—influenced tomato fruit quality across three Sokoto farms: Gidan Yunfa, Gidan Magaji, and Kwalkwalawa. Enzyme activities and fruit-quality traits varied among the sites in a pattern that clearly reflected differences in soil biological functioning and management. Gidan Yunfa recorded the highest overall enzyme activities and the best tomato-quality parameters, Gidan Magaji showed intermediate values, and Kwalkwalawa had the lowest enzyme activities and the poorest fruit-quality outcomes. Soils receiving greater organic inputs or better residue management—conditions that favour microbial proliferation—tended to have higher enzyme secretion, matching the observations of Li et al. (2023) and Bharathi (2024) that organic substrates stimulate microbial biomass and enzyme production. Urease activity at Gidan Yunfa was the highest among the farms, indicating efficient urea hydrolysis and superior nitrogen mineralization that likely supported enhanced photosynthetic performance and metabolite synthesis in tomato fruits; this aligns with Adetunji et al. (2021) who emphasized urease as a key indicator of nitrogen transformation potential. Dehydrogenase activity, as a measure of viable microbial respiration, was also maximal at Gidan Yunfa—consistent with Zhang et al. (2021) who reported that well-structured loamy soils with adequate moisture support stronger microbial oxidative metabolism—whereas Kwalkwalawa’s low dehydrogenase suggested limited microbial vitality and reduced organic matter turnover. Phosphatase activity followed the same trend, being most pronounced at Gidan Yunfa and lowest at Kwalkwalawa; this pattern mirrors Cozzolino et al. (2023), who showed phosphatase increases in biologically active soils and emphasized its role in mobilizing organic phosphorus for plant uptake. Tomato quality metrics mirrored enzyme dynamics: fruits from Gidan Yunfa had the highest total soluble solids, vitamin C, and lycopene,

indicating superior sweetness, antioxidant concentration and pigment synthesis; fruits from Gidan Magaji were intermediate, while those from Kwalkwalawa had the lowest TSS, vitamin C and lycopene. These empirical relationships reflect findings by Yang et al. (2023) and Shi et al. (2024), who linked high soil microbial activity and enzyme-mediated nutrient cycling with improved tomato biochemical composition. Correlation patterns in this study showed that higher urease activity was associated with elevated TSS and vitamin C, supporting Li et al. (2023) on the role of nitrogen mineralization in enhancing carbon assimilation and antioxidant synthesis. Dehydrogenase activity correlated strongly with lycopene and vitamin C, reinforcing Cozzolino et al. (2023) who connected active microbial metabolism with increased pigment and antioxidant formation. Phosphatase activity correlated with TSS, vitamin C and lycopene, underlining the importance of biologically mediated phosphorus availability in ATP-driven biosynthetic pathways as discussed by Yang et al. (2023). The clear farm-level differences—Gidan Yunfa highest, Gidan Magaji moderate, Kwalkwalawa lowest—underscore the influence of management history, organic amendment practices and soil physical condition on biological functioning, in agreement with Chaudhri et al. (2024). Practically, the superior performance of Gidan Yunfa highlights how maintaining organic matter inputs, balanced fertilization and favourable moisture conditions in loamy soils can sustain enzyme activity and improve tomato nutritional quality. Monitoring soil enzymes thus provides a rapid biological indicator of soil fertility and expected fruit quality, and strategies that enhance organic inputs, avoid excessive inorganic-only fertilization, and improve soil structure and moisture conservation are recommended to boost enzyme function and tomato quality in Sokoto.

4.5 Conclusion

From the results obtained, it can be concluded that:

Soil enzyme activity strongly influences tomato quality, with higher urease, dehydrogenase, and phosphatase activities linked to increased vitamin C, lycopene, and total soluble solids. Farm B (Gidan Yunfa) had the highest enzyme activity and superior fruit quality, likely due to better soil management and organic matter content. Maintaining active soil enzymes is essential for improving tomato yield and nutritional value.

4.6 Limitations:

- The study was conducted in a single growing season, so seasonal variations in soil enzyme activity or tomato quality were not captured.
- Only three soil enzymes and four fruit quality parameters were assessed; other soil biochemical or tomato quality indices may also be important but were not included.
- Environmental factors such as rainfall, temperature, and pest pressure were not controlled and could have influenced the results.
- The study is specific to loamy soils in the selected farms and may not be directly generalizable to other soil types or regions.

4.7 Recommendations

Based on the findings of this research, the following recommendations are made:

1. **Promotion of biological soil management:** Farmers should adopt soil management practices that enhance microbial activity — such as the application of organic manure, compost, or biofertilizers — to boost enzyme activity and improve crop quality.
2. **Regular monitoring of soil enzymatic indices:** Soil enzyme activity should be included as a key parameter in soil fertility evaluation to provide a more holistic understanding of soil health.
3. **Site-specific nutrient management:** Since enzyme activity varies across locations, fertilizer application and soil amendments should be tailored to the specific biochemical properties of each farm.
4. **Further studies:** Future research should include seasonal monitoring of enzyme activities and additional soil enzymes (such as cellulase and amylase) to broaden understanding of the biological processes influencing tomato growth.
5. **Extension services:** Agricultural extension agents should sensitize farmers on the benefits of microbial-based soil management for sustainable tomato production.

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