GROWTH, YIELD, QUALITY, AND ECONOMIC EVALUATION OF NITROGEN AND VERMICOMPOST INTEGRATION IN THREE TOMATO (*Lycopersicon esculentum Mill*.) VARIETIES

MSc. THESIS

BY

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SCHOOL OF GRADUATE STUDIES

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This is to certify that the thesis entitled **Growth, yield, quality and economic evaluation of tomato (*lycopersicon esculentum mill*.) nitrogen and vermicompost integration in three tomato varieties** is submitted in partial fulfillment of the requirements for the degree of Masters of Sciences with specialization in Horticulture Graduate Program of the School of Plant and Horticultural Sciences, College of Agriculture, and has been carried out by **Beyene Bekele**, under our supervision and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during this investigation have been well acknowledged. Therefore, we recommend that the student has fulfill the requirements and hence can submit the thesis to the department.

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We, the undersigned members of the Board of Examiners of the final open defense by **Beyene Bekele**, have read and evaluated her thesis entitled **Growth, yield, quality and economic evaluation of tomato (*lycopersicon esculentum mill*.) nitrogen and vermicompost integration in three tomato varieties** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the Master's degree in Horticulture.

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I seriously declare that this MSc thesis is an original report of my work and has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others. This thesis is submitted in partial fulfillment of the requirements for MSc. degree at Hawassa University, deposited in the Hawassa University library and made available to users under the rules of the library

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DEDICATION

I dedicate this thesis to my brother, Godana Bekele, who I lost during my experiments, a loyal supporter throughout my life's achievements.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
RCRD	Randomized Complete Block Design
EC	Electrical Conductivity
EFSA	European Food Safety Authority
EIAR	Ethiopian Institute of Agricultural Research
Ethio SIS	Ethiopian Soil Information System
FAO	Food and Agricultural organization
FAOSTAT	Food and Agricultural Organization Statistics
GLM	General Linear Model
INM	Integrated Nutrient Management
LSD	List Significance Difference
OC	Organic Carbon
SAS	Statistical Analysis System
SOC	Soil Organic Carbon
TN	Total Nitrogen
TVC	Total variable cos
TSP	Triple Super Phosphate
VC	Vermicompost
WHO	World Health Organization

Growth, yield, quality and economic evaluation of nitrogen and vermicompost integration in three tomato (*lycopersicon esculentum mill*) varieties

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ABSTRACT

Tomato is a major vegetable crop of high nutritional and economic value, yet its productivity in Ethiopia remains low mainly because growers apply nitrogen and VC inefficiently under declining soil fertility. Integration of vermicompost and mineral nitrogen enhanced soil health (higher organic matter and microbial activity), increased agronomic N use efficiency, improved fruit quality attributes and produced greater marketable yield and economic return. This study evaluated the effects of combined mineral nitrogen (N) and vermicompost (VC) fertilization on the growth, yield, fruit quality, and economic performance of three tomato varieties (GALILEA 39, NUN TOP, and ALBATROS) at Shallo Farm during the 2016 E.C. cropping season. Treatments consisted of three nitrogen rates (0, 175, and 350 kg N ha⁻¹) and three vermicompost levels (0, 5, and 7 t ha⁻¹) arranged in a randomized complete block design with three replications. Data were collected on phenology, growth, yield, and fruit quality parameters, while economic feasibility was assessed using partial budget analysis. The collected data were analyzed using ANOVA under the GLM procedure in SAS 9.4, and assumptions were verified by checking normality and variance homogeneity through diagnostic plots; percentage variables were normalized using the arcsine square-root transformation. Results revealed that variety, nitrogen, and vermicompost rates, as well as their interactions, significantly influenced most growth, yield, and quality traits. GALILEA 39 recorded the highest fruit set (78.26%) and total yield (14.02 t ha⁻¹) under 350 kg N ha⁻¹ + 5 t VC ha⁻¹. Nitrogen enhanced vegetative growth and fruit size, while vermicompost improved soil fertility, flower retention, and fruit development. Physical fruit quality improved with N and VC increased fruit length and fruit shape index, vermicompost increased fruit width, and the N × VC interaction produced the thickest pericarps, indicating greater firmness and better postharvest life . Chemical quality responded positively to integrated fertilization: moderate to high N rates and both VC levels raised TSS and SAR, whereas TA increased relative to the unfertilized control but plateaued beyond 175 kg N ha⁻¹, producing a net improvement in taste and processing quality. Partial budget analysis showed that the combination of 175 kg N ha⁻¹ and 7 t ha⁻¹ vermicompost generated the highest net field benefit (476,937.36 Birr) and marginal rate of return (2521.48%) for GALILEA 39, while NUN TOP achieved the greatest profitability (MRR = 5621.85%) under the same combination. For ALBATROS, 350 kg N ha⁻¹ with 5 t VC ha⁻¹ was most economical (MRR = 5210.50%). Therefore, under the agro-ecological conditions of Bishan Guracha, applying 175 kg N ha⁻¹ with 7 t ha⁻¹ vermicompost is recommended for GALILEA 39 and NUN TOP, while 350 kg N ha⁻¹ with 5 t ha⁻¹ vermicompost is optimal for ALBATROS. . Future studies should refine nitrogen–vermicompost ratios across soil types and assess long-term effects on soil health, productivity, and sustainability.

Keywords: Fruit, growth, integrated nutrient management quality, nitrogen *Solanum lycopersicum*, vermicompost, and yield

1. INTRODUCTION

Tomato (*Lycopersicon esculentum Mill*) is one of the important vegetable crops grown throughout the world and ranks next to the potato and sweet potato in terms of area, but ranks first as a processing crop (Mekouar, 2018). It belongs to the Solanaceae family with a diversity center in the Peruvian Highlands (Taylor, 1986). It is a self-pollinated annual crop from the Solanaceae family with the same chromosomal number 2n=2x=24 (Peralta *et al.*, 2008). A recent modification to the phylogenetic classification of the Solanaceae family resulted in the reintegration of the genus Lycopersicon into the genus Solanum, resulting in a new nomenclature (Peralta *et al.*, 2008). Consequently, the clade Lycopersicon encompasses the genus Solanum lycopersicum L, which is domesticated together with its 12 closest wild relatives (Peralta *et al.*, 2008). The fruit veggie tomato originated in Colombia, Bolivia, Chile, Peru, and Ecuador, all of which are part of the Andean area. Tomatoes were initially planted in Mexico. As a result, tomato was introduced to Europe shortly after the discovery of the New World and spread throughout the rest of the world (Blanca *et al.*, 2012; Lin *et al.*, 2014).

Tomatoes are extremely nutritious and include a high concentration of vitamins A and C as well as minerals (Center, 2004). In recent years, they have become known as an important source of lycopene, a powerful antioxidant with anti-cancer properties. They also provide vitamins and minerals (Kelley *et al.*, 2009). It is used for various dishes. Fresh produce is sliced and used in salads. It also cooked to prepare local stew (wot) in Ethiopia. Processed products such as tomato paste, tomato juice, ketchup, and whole peeled tomatoes are produced for the local market and for export (Drost, 2020). Tomatoes are an important income generating crop for smallholder farmers and also provide jobs in the manufacturing industry (Gemechis *et al.*, 2012). Smallholder farmers, commercial state farmers, and private farmers in Ethiopia cultivate tomatoes, which are among the most important and widely grown vegetable crops during the rainy and dry season (Emana *et al.*, 2014; Gemechis *et al.*, 2012).

The global output of tomatoes in 2005 was estimated by the FAO at approximately 123 million tons (Costa *et al.*, 2007). China contributes a significant portion of the global tomato yield, producing nearly 70 million tons annually and accounting for about 37% of the world's total production, making it the largest producer by a wide margin (Chen *et al.*, 2023). In comparison Ethiopia has only produced 3 35 340 t of fresh tomatoes in 2022 with an average of only 6.5 t ha^{-1}. This translates into a range of 68.20 million tons of production and 53.5 t ha^{-1} of yield difference between China and Ethiopia. Agronomic practices involved in tomato production have undergone tremendous improvements in the production of tomatoes worldwide, as the yield can go up to 60-80 t ha^{-1} under favorable conditions (Abebu, 2024; Ronga *et al.*, 2020). China, United States, India, Egypt, Turkey, Iran, Mexico, Brazil and Indonesia are major producers.

Ethiopia's climate and soils are suitable for a wide range of fruits and vegetables, including tomatoes, which are mainly grown in the eastern and central medium to lowland regions (Gemechis *et al.*, 2012). However its productivity remains low, averaging 6.18 t ha^{-1}, far below neighboring Kenya (14-17t ha^{-1}) (Mathobo, 2023), highlighting a critical yield gap. While small-scale production occurs in areas such as Koka, Ziway, Wondo Genet, Guder, and Bako, most production is concentrated in the irrigated upper Awash valley (Debela *et al.*, 2016).

Several improved tomato varieties, including Melka Shola, Marglobe, Fetan, Bishola, EShete, and Matedel, have been introduced in Ethiopia by the Melkassa Agricultural Research Center. Nevertheless, yield gaps persist due to poor soil fertility, suboptimal agronomic practices, limited-access to improved seeds, and inadequate nitrogen management. Soil fertility decline, driven by intensive farming and minimal organic amendments, remains a major constraint (Aytenew and Bore, 2020). Nitrogen deficiency is a key limiting factor for tomato growth and yield, exacerbated by inadequate amount of fertilization application and high leaching rates, despite the use of mineral fertilizers such as urea and DAP (Abebe *et al.*, 2022; Zhang *et al.*, 2018).

Organic amendments such as vermicompost have shown potential to enhance soil fertility and nutrient cycling while mitigating abiotic stresses like drought and salinity (Raza *et al.*, 2022; Mao *et al.*, 2024; Zhao *et al.*, 2024). Vermicompost supplies essential nutrients (nitrogen, phosphorus, and potassium) and promotes microbial activity, contributing to long-term soil health (Lim *et al.*, 2015; Oyege and Balaji Bhaskar, 2023). Despite its benefits, its combined use with mineral nitrogen under Ethiopian field conditions has been inadequately studied.

Most previous studies in Ethiopia have approached tomato production in isolation, focusing either on fertilizer rates or varietal performance (Degefa *et al.*, 2022; Etissa *et al.*, 2013), without adequately considering interactions between tomato genotypes and fertilizer regimes under variable soil conditions (Raza *et al.*, 2022). Genotype-specific responses influence nutrient uptake efficiency and tolerance to fertilization-induced stress, emphasizing the need for integrated approaches (Amare and Gebremedhin, 2020). Given these gaps, there is an urgent need to investigate the combined effect of nitrogen and vermicompost across tomato varieties under field conditions. Addressing this knowledge gap can enhance yield, fruit quality, and soil health, while promoting sustainable, economically viable tomato production. This study, therefore, aims to evaluate how integrating varietal differences with combined mineral nitrogen and vermicompost application can optimize tomato growth, yield, and quality.

1.2 Research questions

- What is the optimal integrated application of nitrogen (N) fertilizer and vermicompost (VC) for maximizing the growth, productivity, fruit quality and economic return of the tomato varieties?
- How N and VC affect the growth and yield across varieties?
- The specific impact of the N and VC on quality parameters (TA, TSS and SAR)
- What is the most economically efficient N and VC integration strategy for each variety, considering costs and the market value?
- Is there a significant differences in the cost- effectiveness of the N and VC integration strategies between the three different tomato varieties?

1.3 Objective

1.3.1 General objective was

To evaluate the effect of different levels of nitrogen and vermicompost on growth, yield and quality parameters of tomato varieties .

1.3.2 Specific objectives were

- To assess the interaction effects of nitrogen and vermicompost on the growth, yield, and fruit quality of tomato varieties
- To determine the optimal and economically feasible combination of vermicompost and nitrogen fertilizer for maximizing tomato growth, yield, and improving fruit quality under Bishana Guracha conditions.
- To identify the best-performing tomato varieties in terms of growth, and yield components under Bishana Guracha conditions.

1.4 Hypothesis

Null hypothesis

The integration of N and VC will have no significant effect on the growth, yield, and quality of any tomato varieties compared to N or VC alone.

There will be no significant differences in the economic evaluation of N and VC integration across the three tomato varieties

Alternative hypothesis

The integration of N and VC will significantly improve the growth, yield, and quality of the tomato as compared to using Nor Vc alone.

The economic evaluation of N and VC integration will differ significantly among the three tomato varieties, with one or more varieties showing a greater economic return on investment

2. LITERATURE REVIEW

2.1 The tomato crop

Tomato belongs to the Solanaceae family and the genus *Solanum*, which comprises a relatively small number of annual or short-lived perennial herbaceous plants. Its origin traces back to the South American Andes, particularly present-day Peru, where it grew wild at the foot of the hills (Grandillo *et al*., 2011). The first domestication and cultivation occurred in Mexico (Bassett, 1986). Tomatoes were introduced to Europe from Mexico or Peru in the early sixteenth century Smith (2001), initially grown as ornamental curiosities rather than as food, and were even considered toxic. It was only around 1840 that tomato was widely accepted as an edible crop in Europe (Paran and Van Der Knaap, 2007). Global tomato production expanded significantly during the 1920s due to technological advances that enabled mechanized processing.

Tomatoes require warm, clear, and dry conditions, growing best at altitudes between 700 and 2,000 m above sea level (Lemma, 2002). Optimal seed germination occurs at 18–24 °C, with maximum and minimum thresholds of 30 °C and 8–10 °C, respectively. Germination declines at temperatures above 35 °C. After transplanting, optimal daytime temperatures range from 25–28 °C, with 15 °C at night. Temperatures exceeding 30 °C can adversely affect fruit enlargement and color development, while prolonged exposure above 38 °C before and after anthesis causes poor fruit set and flower abortion (Stewart, 1986). Low temperatures (≤10 °C) also increase flower drop. Light intensity influences carotene content of tomato fruit; fruits from plants grown under high light intensity accumulate more carotene than those grown under shade (Ilić *et al*., 2012).

2.2 Overview of Tomato Varieties

Tomato varieties differ in size, shape, flavor, and growth habit. They are broadly classified into determinate and indeterminate types. Determinate plants are typically smaller and more compact than vining (indeterminate) types, resembling a bush. They usually reach a fixed height, generally between 0.6 and 1.2 meters. These require less support and can be planted at higher densities, making them suitable for commercial cultivation (Diver and Born, 1999). Indeterminate varieties grow taller, continue producing fruit until frost, and require stronger support systems such as stakes or trellises (Asante, 2022). Recommended planting densities vary: determinate varieties are spaced 30 to 60 cm in within rows and 60 to 90 cm (can be up to 100 cm) between rows, while indeterminate varieties require 45 to 90 cm in within rows and 90 to 120 cm (or more) between rows.

2.3 Nutrient Requirements of Tomato

Plant nutrition is concerned with the processes affecting the acquisition of nutrient elements by plants, the health of the plant with respect to its supply or content of essential elements, and the functions of those elements in the life of the plant (Morgan and Connolly, 2013).It is a well-known fact that adequate fertilizer is required by tomato for growth and high yield. The fertilizer does this through its ability to replenish the soil with nutrients that are lacking in the soil. As a result of this, adequate levels of nutrients are very vital to increasing the production and yield of tomato (Ogbomo and Egharevba, 2009). The quantity of nutrients to be applied depends on the yield potential of the cultivar, the level of available nutrients in the soil, and growing conditions (Hegde, 1997). Four major elements: Nitrogen (N), Calcium (Ca), Potassium (K), and Phosphorus (P) are particularly critical in the production of tomatoes in soil-field systems. Some micronutrients have been specifically studied to be critical for tomato. These are Boron (B), Iron

(Fe) and Zinc (Zn) (Abbasi *et al.*, 2002). A study by Hinman *et al.* (2012) showed that without an adequate supply of K and Ca for uptake and utilization by tomato plants, tomato fruits cannot accumulate soluble solids (sugars) and are susceptible to physiological disorders such as end-rot. According to Jones (2007), a lower requirement for the following elements: nitrogen (N), magnesium (Mg), phosphorus (P), boron (B) and copper (Cu) is also important for dry matter distribution and fruit set in tomatoes. The nitrogen requirement of tomatoes is generally considered to be moderately high, with some authors suggesting only about 150 kg N ha^{-1}, reducing this to 125 kg. However, in high rainfall areas, or for large scale production, a minimum of 250 kg N ha^{-1} should be considered, for target yields of about 50 tons ha^{-1}.

Nitrogen helps increase plant height, leaf area and number of flower. During ripening excess nitrogen an inhibiting effect example reduction in fruit size or delay in ripening. The sufficient amount of nitrogen promotes better growth and fruit set of flowers and fruits. A deficiency leads to poor absorption of other nutrients and affects root and shoot growth. Phosphorus is an important nutrient necessary for root and flower development and fruit setting, accelerates fruit ripening and ensures stronger growth, especially in young plants (De Moraes *et al.*, 2018). It also promotes early flowering and fruit setting.

One of the first symptoms of phosphorus deficiency in tomatoes is the appearance of a purple color on the underside of the leaves. The stems are thin and fibrous, the leaves are small, and the plants mature late (Kisetu and Heri, 2014).Tomato production need high amount of potassium. K is also important for the above and below-ground organs of plants and stimulates their growth. Plant analyses indicate that the plants take up about 50% more potassium than nitrogen. The major effect of high potassium is it effects on fruit quality, rather than yield. The color, taste, firmness, sugars, acids and solids of the fruit are all improved with adequate levels of potassium.

It also strengthens plant cells and makes the plant less susceptible to attacks by many diseases. An excess of potassium, on the other hand, leads to a decreased uptake of, especially, magnesium. This can result in a magnesium deficiency.

Tomatoes have a high calcium requirement. Ca stimulates plant growth in height and the number of leaves. The deficiencies of Ca may occur on acid soils, on soils with very high potassium levels, or under conditions of poor calcium uptake and translocation, such as drought conditions. The symptom is that of blossom-end rot of the fruit. The use of calcium nitrate sprays will decrease the incidence of this condition. Generally, the tomato crop requires a number of macro and micro nutrients in sufficient amount for their physiological growth and optimum crop yield and quality. These essential nutrient elements provides many functions to the crop including promotes better growth and better flower and fruit set, resistance to diseases, improves nutrient uptake of the crops (Kisetu and Heri, 2014).

2.4 Effect of Nitrogen on Growth, Yield, and Quality of Tomato

N is one of the major nutrients for the growth and development of crops that, if not consumed in enough amount, will limit plant growth (Fathi, 2022). It is a constituent of, influencing both vegetative and reproductive growth (Murneek, 1926). Side dressing of 22–34 kg N ha^{-1} at the appearance of first flower buds and fruit set is recommended to enhance yield (Hoque, 2019). Excessive nitrogen can overstimulate vegetative growth, delay maturity, reduce fruit firmness, and increase flower and fruit drop, including the risk of blossom-end rot (Pin and Nilsson, 2012). One of the key developmental processes in flowering plants is the differentiation of the shoot apical meristem into a floral meristem. This transition is regulated through the integration of environmental and endogenous stimuli, involving a complex, hierarchical signalling network. In arabidopsis, the FLOWERING LOCUS T (FT) protein, a mobile signal recognized as a major component of florigen, has a central position in mediating the onset of flowering. FT-like genes seem to be involved in regulating the floral transition in all angiosperms examined to date. Evidence from molecular evolution studies suggests that the emergence of FT-like genes coincided with the evolution of the flowering plants. Hence, the role of FT in floral promotion is conserved, but appears to be restricted to the angiosperms. Besides flowering, FT-like proteins have also been identified as major regulatory factors in a wide range of developmental processes including fruit set, vegetative growth, stomatal control and tuberization (Pin and Nilsson, 2012).

Nitrogen deficiency in the soil can result from nutrient removal by harvested biomass, absence of soil amendments, or losses via erosion, runoff, and leaching. Addition of high C: N plant residues can exacerbate deficiency due to immobilization (Kaleeem *et al.*, 2015). Adequate nitrogen not only supports growth and production but also generates sufficient foliage to protect fruits from sun damage (Souri and Dehnavard, 2017). High nitrogen application can lead to nitrate (NO_3^-) accumulation in soils, particularly sandy soils, increasing leaching potential and groundwater contamination (Kohler *et al.*, 2006). Ammonium-N (NH_4^+) can also be toxic to tomato if applied excessively due to limited mobility in soil (Pill *et al.*, 1978).

Nitrogen significantly affects fruit quality, including dry matter, soluble solids, titratable acidity, pH, and color, which influence taste, shelf life, and processing suitability (Jones, 2007; Tei *et al.*, 2002). Moderate nitrogen improves nutritional and quality traits, but excess can reduce vitamin content, carotenoids, and secondary metabolites, impairing flavor and marketability (Abu *et al.*, 2022). Low nitrogen often limits vegetative growth but enhances fruit quality, such as higher sugar content and vitamin C concentration (Bénard *et al.*, 2009). Nitrogen fertilization also increases nitrogen-derived compounds in fruit, such as nitrites and nitrates, which pose health risks if exceeding acceptable daily intakes (Ger *et al.*, 2024).

Total soluble solids represent the percentage of dissolved solids in fruit, serving as an important indicator of flavor; higher TSS corresponds to a stronger and sweeter taste. Most tomato fruits have TSS levels between 5 and 7 % (Jones , 2007). Nitrogen availability significantly influences TSS content. Plants grown under higher nitrogen concentrations often produce fruits with increased soluble solids compared to those grown in control conditions (Fandi *et al.*, 2010). Interestingly, reduced nitrogen supply can also enhance soluble sugar accumulation while reducing acidity in tomato fruits, improving the overall taste, as sugars and acids are the primary components of flavor perception (Bénard *et al.*, 2009; Khalil and Agah, 2017). Nitrogen fertilization can further modify other flavor components, including volatile organic compounds, affecting the aroma profile of tomato fruits (Wang *et al.*, 2007).

Nitrogen application generally increases titratable acidity along with soluble sugars and TSS, but excessive nitrogen can reduce fruit firmness and vitamin C content (Bénard et al., 2009b). Several studies have reported that titratable acidity rises with increasing nitrogen levels (Liao *et al.*, 2019), while others observed little effect of nitrogen but noted that low phosphorus levels could increase acidity (Mortley and Ntibashirwa, 2012). At the physiological level, nitrogen is a key component of proteins, while sulfur (S) is essential for amino acids like cysteine and methionine. Deficiencies in these elements can alter protein synthesis and plant metabolism, highlighting the importance of balanced fertilization (Nikiforova *et al.*, 2006).

2.5 Effect of Vermicompost on Growth, Yield, and Fruit Quality of Tomato

The overuse of synthetic fertilizers poses environmental risks, including soil acidification and reduction of humic acid content (Goel and Kaur, 2012). Vermicompost, an organically enriched fertilizer, offers a sustainable alternative, enhancing soil fertility and crop performance. Humic acids and plant growth regulators in vermicompost have been shown to improve dry matter production, seedling development, and overall growth in tomatoes even when added at 10–20% to potting media (Pathma and Sakthivel, 2012).

Integration of vermicompost with conventional fertilization can sustain growth while reducing reliance on chemical fertilizers. For example, vermicompost derived from goat manure improved growth during the first 60 days, a critical phase for tomato development (Wang *et al.*, 2017). Meta-analysis confirm that vermicomposting enhances plant biomass through improved soil structure and nutrient availability (Blouin *et al.*, 2019), while also suppressing soil-borne diseases such as *Fusarium* and *Phytophthora* due to its beneficial microbial communities. Studies under varying water conditions emphasize the importance of understanding the interaction between vermicompost and environmental factors for optimal performance (Abbamondi, 2016).

Vermicompost not only improves vegetative growth, fruit yield, and stem diameter, but also exhibits synergistic effects when combined with inorganic fertilizers, enhancing vitamin C content and overall productivity (Goel and Kaur, 2012). Optimal results were observed with approximately 15–20% vermicompost concentration.

Several studies indicate that vermicompost can increase TSS in tomato fruits, enhancing sweetness and consumer appeal (El-Sayed, 2024; Joshi et al., 2010). Increased electrical conductivity (EC) in the growth medium due to vermicompost may restrict water uptake in fruits, concentrating soluble solids (Atapatakar, 2016) . However, effects on TSS are context dependent; for example, sheep manure-based vermicompost showed no significant effect on TSS in one study (Jahanbakhshi and Kheiralipour, 2019), and soil water regimes can modulate the impact of vermicompost on soluble solids (Atiyeh *et al.*, 2000).

Vermicompost generally improves the sugar-to-acid ratio in tomato fruits, contributing to a more desirable flavor (Wang *et al.*, 2017; Zaman *et al.*, 2018) . This is attributed to its balanced nutrient supply and influence on metabolic pathways responsible for sugar and acid production. The slow release of nutrients favors sugar accumulation, while beneficial microbes may indirectly support these processes. However, the effect can vary depending on the type of vermicompost and environmental conditions. For instance, the highest sugar-to-acid ratio in vermicompost-treated tomatoes was observed under moderate soil moisture (50–60% field capacity) (Wang *et al.*, 2017) .

2.6 Tomato Variety Differences on Soil Nutrients under Organic and Inorganic Fertilization

Tomato varieties exhibit distinct interactions with soil nutrients, which are further influenced by the type of fertilization applied organic or inorganic. Organic fertilizers, derived from natural materials such as vermicompost and manure, enhance soil organic matter, microbial biomass, and enzyme activities that improve nutrient cycling. Studies show that tomato varieties respond variably to organic fertilization, with some varieties demonstrating improved nutrient uptake efficiency and enhanced soil nutrient profiles under organic inputs, reflecting an increase in soil carbon and nitrogen content that supports sustainable production systems (González *et al.*, 2022; Wu *et al.*, 2022).

In contrast, inorganic fertilization provides immediately available nutrients, often resulting in accelerated growth and higher nutrient concentrations in the soil during early stages. However, the response varies among tomato varieties; some respond effectively with increased emergence rates and plant vigor, while others show less adaptability, possibly due to differences in root architecture and nutrient use efficiency. Importantly, long-term reliance on inorganic fertilizers has been associated with soil acidification and reduced microbial diversity, potentially compromising soil health and nutrient sustainability (Song *et al.*, 2022; Wu *et al.*, 2022)

The integration of organic and inorganic fertilization strategies has shown promise in optimizing soil nutrient availability and tomato variety performance. The combined approach leverages the quick nutrient release from inorganic sources and the soil health benefits of organic amendments, thereby improving soil physicochemical properties, maintaining soil pH balance, and enhancing nutrient cycling dynamics. Consequently, this balanced fertilization regime supports diverse tomato varieties by maximizing growth, yield, and fruit quality while promoting long-term soil fertility (Wu *et al.*, 2022).

2.7 Organic and Inorganic Fertilizer and its Interaction with Tomato Production

The use of chemical fertilizers is currently one of the most commonly used methods in intensive agriculture (Mortley and Ntibashirwa, 2012). However, long-term use of artificial fertilizers can have many negative effects. For example, most nutrients added to the soil are not absorbed by plants. Studies have shown that more than 50% of the nitrogen and 90% of the phosphorus contained in chemical fertilizers enter the atmosphere or water sources (Simpson *et al.*, 2011), causing greenhouse effects, water eutrophication and others environmental problems (Lam *et al.*, 2017). In addition, excessive use of chemical fertilizer can lead to reduced food safety and lower vegetable quality, such as the accumulation of nitrates in plants (Hu *et al.*, 2022). Currently, the use of organic fertilizers is an effective method to achieve sustainable agricultural development. Organic fertilizers are characterized by have a low nutrient content, and their nutrient release rate depends on water and temperature conditions of the soil. The use of organic fertilizers not only improves soil physical and chemical properties (Maguire *et al.*, 2020), soil fertility, and soil water storage capacity (Beeby et al., 2020) but also can promote vegetative and reproductive plant growth effectively (Ali *et al.*, 2022), thereby improving plant quality (Ali *et al.*, 2022). The basic principle of integrated nutrient management is to maximize the use of organic inputs while minimizing nutrient losses and to make supplementary and additional use of chemical fertilizers. Good practices for integrated nutrient management practice often include a combination of organic and inorganic nutrients sources. Many types of research recommend. Farmers use integrated nutrient management approaches as risk integrated soil fertilization practices because a single application or practice cannot reverse the existing problem mitigation and survival tactics (Eichler *et al.*, 2008). It is important to increased crop productivity brought on by the use of mineral fertilizers does not necessarily translate into longer-term improvements in soil fertility when significant quantities of carbon and nutrients are removed from the fields each season with the crop harvest residue (Bekunda *et al.*, 2010). Organic amendments (e.g. crop residues, animal manure, and compost) are used to improve soil fertility and maintain agricultural fields in a productive state. Therefore, the use of integrated nutrient management is the very advantageous and best approach to maintaining and improving soil fertility (Abay and Tesfaye, 2012) thereby enhancing crop productivity in an efficient and environmentally friendly manner without affecting the soil productivity of future generations.

Stem height, leaf count, branch count, and dry matter are all improved by the application of integrated nutrient management practice. Additionally, there is a considerable rise in the number of tomato flower plants, fruit plants, percentage of fruit set, and average fruit weight. Similarly the application of integrated use of inorganic fertilizer and organic manure results in important yield attributes like fruit setting, plant height, number of primary branches per plant, and total soluble solid contents (Javaria and Khan, 2010). A large yield of tomatoes with excellent quality and nutrient status can be grown with the use of organic manure and inorganic fertilizers under ideal conditions (Arm and Mg, 2006). Due to deterioration in both physical and biological conditions brought on by low organic matter content in soils, high yield levels could not be sustained over time, even with balanced application of chemical fertilizers. In this context and as additional response to economic recession, and also to conserve and improve soil fertility the concept of INM system has been adopted (Javaria and Khan, 2010).

3. MATERIALS AND METHODS

3.1. Description of the experimental area

The experiment was conducted at Shallo Farm in Bishan Guracha, West Arsi Zone, Oromia Region, in 2016 E.C., approximately 266 km south of Addis Ababa. The soils in the area are predominantly sandy loam and clay, characterized by moderate fertility and suitability for sustainable agriculture. The site lies at an altitude of 2,050 meters meters within the Ethiopian Highlands. Bishan Guracha receives substantial annual rainfall, averaging 1,735.8 mm, which supports the cultivation of staple crops such as teff, wheat, barley, maize, sorghum, pulses, and oilseeds crop essential for local food security and the regional economy. The district experiences temperatures with local water points reaching 24.8°C, exceeding the WHO drinking water guideline of 15°C. Elevation within the district ranges from 840 to 2,448 meters, providing fertile soils and favorable conditions for diverse crops, including tomatoes.

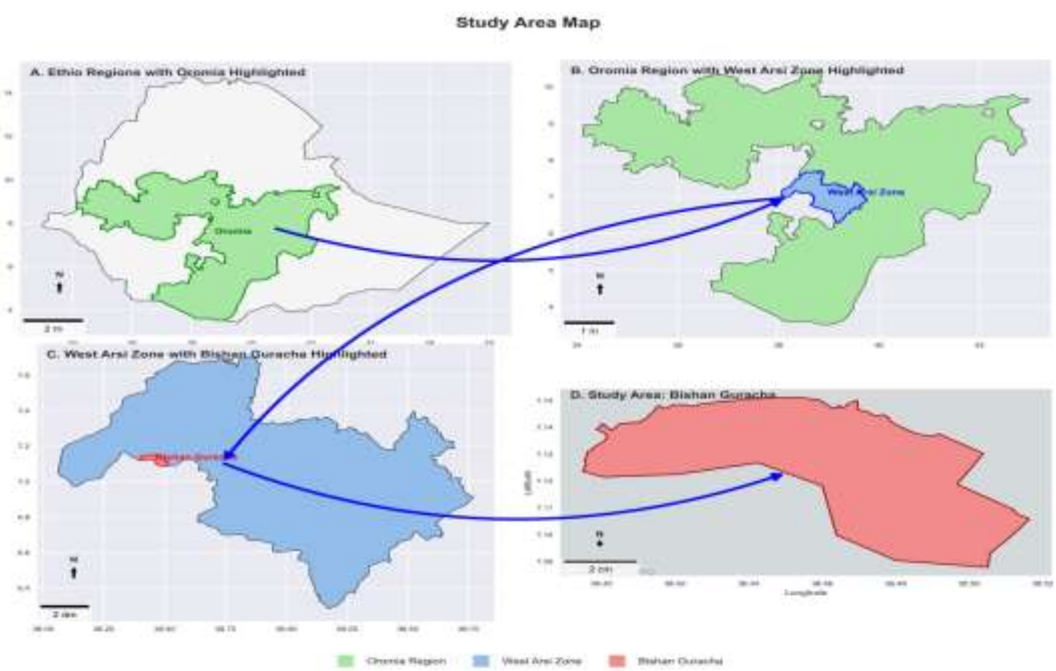

Figure 1. Map of the study area

3.2. Experimental Materials, Treatment and Design

Three tomatoes varieties (GALILAE 39, NUN TOP (F1 hybrid), and ALBATROS (F1 Hybrid)) were used in this study. The varieties selected based on their ability to adapt to the study area, their high performance, and their resistance to varies diseases.

Table 1. Description of tomato varieties used in the experiment

Variety	Production Status	Responsible company	Year of release	Fruit shape and size	Fruit Color	Growth Habit	Yield (t ha^{-1})	Disease Resistance
NUN TOP	Commercially available			Round, medium sized	Red	Determinate	50	Resistant to powdery mildew and bacterial spot
GALILEA 39	Commercially available	Axum Greenland PLC	2011	Oval, medium sized	Intense red	Determinate	69.5	Resistant bacterial spot
ALBATROS	Commercially available			Oblate, medium sized	Red	Determinate	B/n 4-7 t ha^{-1}	Resistant bacterial spot, early blight

Sources: Binalfew *et al*. (2016)

Nitrogen and Vermicompost Sources

Urea containing 46% nitrogen was used as the source of inorganic nitrogen fertilizer. Vermicompost was prepared between April 10 and May 25 by Elfora Agro-Industries PLC at Shallo Farm. The substrates included *Amaranthus* weed, common bean straw, animal dung, and Swiss chard (*Kosta*) leaves, mixed in a ratio of 3:1:4:6.

Seven cemented sunken beds with a standard dimension of 1 m width, 1 m length, and 0.5 m depth were built under a shade (opened from all sides) at the Elfora Agro Industry vermicompost preparation site . Healthy and adult Red Wiggler worm (Eisenia foetidia) were added in each bed at a rate of 12.5 g per 1 kg substrate material. Moisture was supplied continuously during the vermicomposting. Maturity reached after at 3 months and the color and smell were the major maturity indicators of vermicompost. Their respective dry matter contents were 20.47%, 61.08%, 16.97%, and 10.65%. Their measured fresh weights and dry matter (DM) contents were 1934 g (20.47%), 406 g (61.08%), 1360 g (16.97%), and 1690 g (10.65%), respectively. Based on these values, the dry matter contribution of each substrate was calculated as: amaranths weed: 1934 × 20.47% = 395.98 g DM, Common bean straw: 406 × 61.08% = 247.99 g DM, Animal dung: 1360 × 16.97% = 230.79 g DM Swiss chard leaves: 1690 × 10.65% = 179.99 g DM

The total dry matter of the mixture was therefore 1,054.75 g, while the total fresh weight was 5,390 g, giving an overall dry matter content of:

DM_{mix}= 1054.75/5390X100 = 19.57%

Table 2. Substrate Composition and Dry Matter (DM) Calculation

Substrate	Fresh Weight (g)	Dry Matter (DM) (%)	Dry Matter contribution of each substrate (g)
Amaranthus weed	1,934	20.47%	395.98
Common bean straw	406	61.08%	247.99
Animal dung	1,360	16.97%	230.79
Swiss chard leaves	1,690	10.65%	179.99
Substrate / Mixture	**5,390**	**19.57%**	**1,054.75**

Note: The overall mixture dry matter percentage (19.57%) is calculated as:
(Total Dry Matter / Total Fresh Weight) × 100 = (1,054.75 g / 5,390 g) × 100.

This indicates that the initial moisture content of the substrate mixture was approximately 80.43%, which falls within the ideal range (70–85%) for efficient vermicomposting. Such a moisture level promotes optimal microbial activity and facilitates earthworm feeding and decomposition.

Field based average values for vermicomposting of mixed organic residues using similar materials (amaranths weeds, common bean straw, animal dung, and Swiss chard residues) show 50–65% organic matter loss, corresponding to 35–50% residual organic matter after maturity.

If we apply this standard range to your mixture (initial DM = 1054.75 g):

Final DM (after decomposition) $\approx 1054.75 \times (1-0.55) = 474.64$ g

Then, Degree of Decomposition (DoD) = $1054.75 - 474.64 / 1054.75 =$ **55.0%**

Therefore, the degree of decomposition of the vermicompost mixture is about 55%.

The vermicompost prepared from Amaranthus weed, common bean straw, animal dung, and Swiss chard (Kosta) leaves (3:1:4:6 ratio) had an initial dry matter content of 19.57%, equivalent to about 80.43% moisture. Based on mass balance and standard organic matter reduction ranges during vermicomposting, the degree of decomposition of the mixture was estimated at approximately **55%**, indicating that more than half of the degradable organic components had been mineralized and stabilized. The final product was dark brown, granular, and emitted an earthy odor, confirming sufficient decomposition and maturity for field application.

3.2. Treatments and Experimental Design

The study tested three tomato cultivars (GALILEA 39, NUN 0279 TOP, and ALBATROS), three vermicompost rates (0, 5, and 7 t ha^{-1}), and three nitrogen fertilizer levels (0, 175, and 350 kg N ha^{-1}). A uniform phosphorus dose of 90 kg P ha^{-1} was applied.

A factorial combination of 3 × 3 × 3 having 27 treatments were arranged in a randomized complete block design (RCBD) with three replications. Each experimental plot was having 20 m^2 (4 m × 5 m) and consisted of five rows with ten plants per row, spaced 40 cm between plants and 100 cm between rows. The total experimental area was 2,430 m^2 (135 m × 18 m), accommodating 4,050 plants. Plots were separated by 1 m. Data were collected from the central 30 plants per plot, excluding border plants. Seedling gaps were filled within one week of transplanting to maintain plant density. Standard cultural practices (including weeding, irrigation, and pest control) were uniformly applied. In total, 648 kg of vermicompost and 61.64 kg of urea were used.

Table 3. Treatment combination and their description

Trt	Varieties	Fertilizer	Description
1	GELILEA 39	N_0VC_0	0 kg N ha^{-1} + 0 t VC ha^{-1}
2		N_1VC_0	175 kg N ha^{-1} + 0 t VCha^{-1}
3		N_2VC_0	350 kg N ha^{-1} + 0 t VC ha^{-1}
4		N_0VC_1	0 kg N ha^{-1} + 5 t VC ha^{-1}
5		N_1VC_1	175 kg N ha^{-1} + 5 t VC ha^{-1}
6		N_2VC_1	350 kg N ha^{-1} + 5 t VC ha^{-1}
7		N_0VC_2	0 kg N ha^{-1} + 7 t VC ha^{-1}
8		N_1VC_2	175 kg N ha^{-1} + 7 t VC ha^{-1}
9		N_2VC_2	350 kg N ha^{-1} + 7 t VC ha^{-1}
10	NUN TOP	N_0VC_0	0 kg N ha^{-1} + 0 t VC ha^{-1}
11		N_1VC_0	175 kg N ha^{-1} + 0 t VC ha^{-1}
12		N_2VC_0	350 kg N ha^{-1} + 0 t VC ha^{-1}
13		N_0VC_1	0 kg N ha^{-1} + 5 t VC ha^{-1}
14		N_1VC_1	175 kg N ha^{-1} + 5 t VC ha^{-1}
15		N_2VC_1	350 kg N ha^{-1} + 5 t VC ha^{-1}
16		N_0VC_2	0 kg N ha^{-1} + 7 t VC ha^{-1}
17		N_1VC_2	175 kg N ha^{-1} + 7 t VC ha^{-1}
18		N_2VC_2	350 kg N ha^{-1} + 7 t VC ha^{-1}
19	ALBATROS	N_0VC_0	0 kg N ha^{-1} + 0 t VC ha^{-1}
20		N_1VC_0	175 kg N ha^{-1} + 0 t VC ha^{-1}
21		N_2VC_0	350 kg N ha^{-1} + 0 t VC ha^{-1}
22		N_0VC_1	0 kg N ha^{-1} + 5 t VC ha^{-1}
23		N_1VC_1	175 kg N ha^{-1} + 5 t VC ha^{-1}
24		N_2VC_1	350 kg N ha^{-1} + 5 t VC ha^{-1}
25		N_0VC_2	0 kg N ha^{-1} + 7 t VC ha^{-1}
26		N_1VC_2	175 kg N ha^{-1} + 7 t VC ha^{-1}
27		N_2VC_2	350 kg N ha^{-1} + 7 t VC ha^{-1}

3.3. Experimental Procedures and Crop Management

The experimental field was ploughed with a tractor, leveled, and rows were prepared manually for irrigation. The layout followed RCBD, with treatments randomly assigned to plots. Tomato seedlings of the three varieties were raised in a well-managed nursery to ensure they are healthy, uniform, and hardened. At 35–40 days of age, pencil-sized seedlings with three to five true leaves were transplanted to the field.

Irrigation water was applied every two days after transplanting to maintain soil moisture near field capacity, except when adequate rainfall occurred. Vermicompost was incorporated into the soil before transplanting, while urea was applied in two equal splits: half at transplanting and half at 45 days after transplanting, according to the designated treatment levels. Recommended agronomic practices (including weeding, hoeing, staking, and pest control) were uniformly implemented. Bacterial diseases and leaf blight were managed with fungicides such as Dithene M-45, Altracole, Tutan, Yewag 70% WDG, Miniximal, Blue Golden, Mancozeb, and Ridomil MZ 68 WG, following crop protection guidelines.

3.4. Vermicompost Characterization

Vermicompost samples were collected before field application to determine their chemical properties. From each sample, composite samples were taken by mixing subsamples collected from the central and peripheral parts of the storage bags using clean scoops. The composite samples were placed in labeled polyethylene bags, transported to the laboratory on the same day and air dried at room temperature until constant weight. The dried samples were gently crushed, passed through a 2 mm sieve and thoroughly homogenized. Laboratory analyses were conducted following standard soil and compost analytical procedures. A 1 to 2.5 vermicompost to water suspension was prepared to measure pH using a calibrated glass electrode pH meter by Khadka *et al.* (2021). , while electrical conductivity was determined from the same extract using a digital conductivity meter. Total nitrogen was analyzed using the Kjeldahl digestion and distillation procedure, which involves wet digestion with concentrated sulfuric acid followed by titration of the distilled ammonia. Available phosphorus was determined using the Olsen sodium bicarbonate extraction and colorimetric reading with a spectrophotometer (Koralage *et al.*, 2015). Exchangeable potassium was quantified using normal ammonium acetate extraction followed by flame photometry, and organic carbon was measured using the Walkley and Black method.

3.5. Soil Sampling and Analysis

Soil samples were collected from the experimental site prior to planting. Composite samples (0–30 cm depth) were taken randomly in a zigzag pattern using an auger, air-dried, and sieved through a 2 mm sieve for laboratory analysis at Hawassa University. Soil properties analyzed included pH, total nitrogen, available phosphorus, potassium, organic matter, cation exchange capacity (CEC), and texture. Soil pH was measured in a 1:2.5 soil-to-water ratio with a pH meter, organic carbon by the methods of Walkley and Black (1934),available phosphorus by Olson *et al.* (2010), and total nitrogen by the Kjeldahl method (Kirk, 1950). The results were used to determine baseline soil fertility and guide nitrogen fertilizer application for tomato production.

Table 4. Physical and chemical Properties of the Experimental Soil

Physical property	Value	Class / Remark
Sand (%)	59	High sand, good drainage
Silt (%)	21.8	Moderate silt, fair water holding
Clay (%)	19.2	Low clay, low nutrient retention
Soil texture	Sandy loam	Medium texture, well-drained
Bulk density (g/cm^3)	1.09	Low, good porosity and structure
Soil color	10 YR 3/2	Very dark grayish brown, rich in organic matter
Chemical property		
pH.H_20 (1:2.5)	7.1	Neutral reaction, suitable for most crop growth
E.C(ds/M)	0.031	Very low salinity, no salt hazard for plant growth
Ava.P (ppm)	10.83	Medium phosphorus content,
Organic carbon (%)	0.92	Fair level of organic carbon, improves soil fertility and structure
Organic matter (%)	1.59	Medium organic matter, supports good microbial activity
Total Nitrogen (%)	0.04	Low nitrogen status, may require N fertilization
C:N ratio	23	Slightly wider ratio, slow mineralization

Table 5. Analysis of the components of the vermicompost

Components of vermicompost	Result	Remarks
pH.H_2O (1:2.5 ratio)	6.7	Neutral , which is ideal for availability to most plants
Electric Conductivity (ds/m)	0.175	Indicating a low concentration of soluble salts
Organic Carbon /OC/ (%)	0.51	Very Low. This value is significantly lower than the typical range for quality vermicompost (15%-25%)
Organic matter	0.89	High degree of mineralization
Total Nitrogen/TN/ (%)	0.04	Very Low. Value is much lower than the typical range t (often 1.0-2.5%or more)
Available Phosphors/P/(PPM)	20.85	
C:N ratio	13	Good/ideal for maturity , as it minimizes the risk of nitrogen immobilization when applied to soil

3.6. Data collection

Crop phenology

Phenological observations were recorded to monitor the growth stages of tomato plants. Days to flowering were determined as the number of days from transplanting until 50% of the plants in each plot had set flowers. Similarly, days to fruiting were recorded as the number of days from transplanting to the stage when 50% of the plants in each plot had produced fruits. Days to maturity were measured as the number of days from transplanting until 50% of the plants in each plot had reached physiological fruit maturity. In addition, the number of harvests was documented, beginning with the first harvest and continuing until the final harvest.

Growth Parameters

Several growth and yield parameters were recorded during the experiment. Plant height (cm) was measured from the soil surface to the tip of the main stem at 50% flowering. The number of primary branches was recorded by counting the branches emerging from the main stem on five randomly selected plants per plot at the flowering stage, while the number of secondary branches was recorded from branches emerging from the primary branches on the same plants. The number of clusters per plant was counted at full maturity from five randomly selected plants per plot. The number of flowers per cluster was recorded at full bloom, while the number of fruits per cluster was determined at the red ripening stage from five randomly selected plants per plot. Fruit set percentage (FSP) was calculated as:

$$\text{FSP (\%)} = \frac{\text{Number of fruits per cluster (FrPC)} \times 100}{\text{Number of flowers per cluster (FlC)}}$$

Leaf area (cm^2): A portable leaf area meter (LI-3000A, LI-COR, Lincoln, Nebraska, USA) was used to measure the leaf area (cm^2) of three representative leaves per treatment from three plants at 50% flowering

Yield and yield components of tomato

Fruit weight per plant was determined by measuring the weight of individual fruits using a digital scale. The number of fruits per plant was recorded by counting the mature fruits harvested from each plant. Fruit diameter (cm) was measured using a Vernier caliper on five representative fruits per treatment at peak harvest, and the average was taken to represent mean fruit size.

The marketable and unmarketable fruits per plot was recorded by weighing marketable fruits. Fruits damaged by disease, insect attack, cracking, or blossom end rot were classified as unmarketable.

Marketable fruit yield (t ha^{-1}**)** was obtained by weighing the total harvest of marketable fruits from each plot and converting it to t ha^{-1}. Similarly, unmarketable fruit yield (t ha^{-1}) was determined by weighing unmarketable fruits from each plot and converting to t ha^{-1}. Total fruit yield (t ha^{-1}) was calculated as the sum of marketable and unmarketable yields and expressed on a hectare basis.

Fruit Physical and Chemical Quality traits

Physical quality traits

Fruit length (cm): It was recorded by measuring from the peduncle end to the blossom end of three mature fruits at the 2nd and 3rd harvest from three plants per each treatments by using Digital a Varnier Caliper and it was summed and divided into the number of fruits.

Fruit width (cm): It was recorded by measuring the largest diameter of the cross-sectioned fruits simultaneously during fruit length measurement by using a Digital Varnier Caliper and it was summed and divided into the number of fruits.

Fruit shape index**:** fruit length and width were recorded from five randomly selected fruits at 2^{nd} and 3^{rd} harvest and the fruit shape index was calculated by the ratio of fruit length to width.

Pericarp thickness (mm**):** It was recorded fruits from each treatment at each harvesting stage by cutting the cross-section of fruit and measuring the pericarp thickness using a Digital Varnier Caliper.

Chemical quality traits

Titratable acidity: Aliquot of juice was prepared according to Teka (2013). Extracted tomato juice from three plants was filtered from fruits of three plants of each treatment through cheesecloth and decanted clear juice was used for titration. Ten ml of the tomato juice sample was titrated gradually with 0.1N NaOH using a burette to the pink endpoint (persisted for 15 seconds). Titrable acidity was expressed as percent citric acid using the formula developed by Teka (2013).

Titrable acidity can be expressed as percent citric acid using the formula.

$$TA\ (\%) = \frac{\text{Titre} \times 0.1N\ NaOH \times 0.64 \times 100}{10ml}$$

Where: titre is the volume of NaOH titrant used and 0.1N is the normality of NaOH titrant in mol/L , 10ml is the amount of tomato juice sample(ml) and 0.64 is the molecular weight of the predominant acid in the sample to the number of acid proton (+3).

Total soluble solids (TSS) (ºBrix): The total soluble solid was determined by using each treatment of tomato fruit following the procedure described by Teka (2013). Aliquot of juice has been extracted using a High-Performance Commercial Blender. A Palette digital refractometer ATAGO® PR32α with a range of ºBrix 0 to 32% was used to determine the TSS by placing two drops of clear juice on the prism. Between samples, the prism of the refractometer was washed with distilled water and dried with tissue paper before it was used for another reading. The refractometer was calibrated against distilled water at 0 per cent TSS.

Sugar to acid ratio (SAR): It was calculated by dividing the value of total soluble solids to the value of titratable acidity

$$SAR = \frac{TSS}{TA}$$

3.7. Partial Budget Analysis

Gross average fruit yield (kg ha^{-1}) (AvY): is an average yield of each treatment.

Adjusted yield (AjY): is the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers.

$$\mathbf{AjY = AvY - (AvY \times 0.1)}$$

Gross field benefit (GFB): it was computed by multiplying field/farm gate price that farmers receive for the crop when they sale it as adjusted yield.

GFB = AjY × field/farm gate price for the crop

Total variable cost (TVC): refers to the cost associated with fertilizers (specifically nitrogen and vermicompost) and other treatments used in the experiment. The costs related to additional inputs and production practices, including labour for land preparation, planting, weeding, and harvesting, were considered to remain consistent or were deemed insignificant across the different treatments.

Net benefit (NB): this can be calculated by subtracting the total costs from gross field benefits for each treatment.

NB = GFB – TVC

The dominance analysis procedure as described in CIMMYT (1988) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique was referred to as dominated and nominated treatments, respectively.

For each pair of ranked treatments, % marginal rate of return (MRR) was calculated using the formula

MRR (%) = $\Delta ChangeNB$ $(NBb{-}NBa)$ divided by $\Delta ChangeTCV$ $(TCVb{-}TCVa)$ × 100;

Where, NBa = NB with the Change TCV (TCVb–TCVa) immediate lower TCV, NBb = NB with the next higher TCV; TCVa= the immediate lower TCV and TCVb = the next highest TCV. Thus, a MRR of 100% implied a return of one Birr on every Birr spent on the given variable input. The fertilizer cost was calculated for the cost of two fertilizer sources that is fertilizer of vermicompost (Birr 46 kg-1) and urea (Birr 70 kg-1) during sowing time and the average open price of tomato fruit Hawassa market be 40 Birr kg-1 during harvesting time but, it may vary from time to time.

3.8. Data Analysis

The data were subjected to analysis of variance (ANOVA) in SAS version 9.4 software using the General Linear Model (GLM), and mean separation was made based on the least significant difference (LSD) at a 5% level of significance (SAS institute, 2016).

To ensure that inferential statistics (ANOVA) met their underlying assumptions, data normality and variance homogeneity were checked. For the Percentage data (bounded 0–100) and other non-negative measurements often violate the assumptions of normality and homoscedasticity required for parametric ANOVA. To stabilize variances and improve approximate normality, unbiased variance-stabilizing transformations were applied specifically the square-root and the arcsine square root transforms before performing ANOVA.

For percentage/proportion data the arcsine square-root transformation was applied using the standard form for proportions in percent:

Arcsine square root transformation for percentage .where P is the observed percentage (0–100). For count-type or markedly right-skewed non-percentage variables the square-root transform was used, i.e. y′=sqrt(y+1/2) (the small constant reduces bias for small counts). The choice between square-root and arcsine was made according to the variable type and the initial diagnostic results.

4. RESULTS AND DISCUSSIONS

4.1 Phenological parameters

4.1.1 Days to Flowering

The results presented in Appendix Table 1 indicate that days to flowering were significantly affected by tomato variety ($p < 0.05$) and by nitrogen and vermicompost application ($p < 0.01$), while the interaction effects among these factors were not significant. Tomato variety significantly influenced days to flowering and maturity. Flowering was delayed in NUN 0279 TOP (28.51 days), which was statistically similar to ALBATROS (27.88 days), whereas the earliest flowering and maturity were observed in GALILEA 39 (26.48 days). Nitrogen application had a graded effect on flowering time. Plants receiving no nitrogen flowered earliest (26.03 days), those receiving 175 kg ha^{-1} flowered at 27.44 days, and plants supplied with the highest nitrogen rate (350 kg ha^{-1}) flowered latest (29.41 days) (Table 6). Vermicompost application also significantly influenced flowering time. The control (0 t ha^{-1}) flowered earliest (25.33 days), while plants receiving 5 t ha^{-1} and 7 t ha^{-1} flowered at 28.22 and 29.33 days, respectively, indicating that high vermicompost rates delayed flowering (Table 6).

The observed variation in flowering time among tomato varieties can be attributed to inherent genetic differences. NUN 0279 TOP and ALBATROS exhibited delayed flowering compared to GALILEA 39, suggesting that these varieties have a longer vegetative phase and reproductive cycle. Such differences may reflect variations in genes regulating flowering time, photoperiod sensitivity, or hormone production (Pin and Nilsson, 2012).

Time to flowering increased with applied nitrogen, suggesting that elevated N delayed reproductive onset by promoting vegetative growth. High nitrogen availability promotes vigorous shoot and leaf development, delaying the transition to flowering, as observed in many plant species (Zhang *et al.*, 2023; Sarma *et al.*, 2010). Conversely, nitrogen-limited plants flowered earlier, likely as a survival strategy to complete reproduction under nutrient constraints, reflecting nutrient-mediated regulation of reproductive development. From a practical perspective, this indicates that moderate nitrogen application can optimize flowering timing, while excessive nitrogen may extend the vegetative stage at the cost of delayed reproduction.

Similarly, vermicompost application delayed flowering, likely due to its nutrient-rich composition and presence of growth-promoting substances such as auxins and gibberellins (Piya *et al.*, 2018). Although vermicompost can sometimes accelerate flowering under nutrient-limited conditions (Makkar *et al.*, 2023), in this experiment the additive nutrient effect combined with basal nitrogen likely prolonged vegetative growth, delaying flowering. This is consistent with previous reports showing that incorporation of vermicompost enhances nutrient availability and overall plant growth, thereby influencing phenological events (Chanda *et al.*, 2011; Srivastava *et al.*, 2012).

4.1.2 Days to Fruiting

Days to fruiting were significantly affected ($p < 0.001$) by the main effects of tomato variety, nitrogen, and vermicompost (Appendix Table 1), whereas the interaction effects among these factors were not significant. Among the varieties, ALBATROS (35.70 days) and NUN TOP (35.00 days) exhibited longer fruiting durations compared to GELILEA 39 (34 days) (Table 6). Nitrogen produced a clear dose-dependent delay in fruiting: plants receiving 350 kg N ha^{-1} reached fruiting latest (36.82 days), those at 175 kg N ha^{-1} were intermediate (34.59 days), and the unfertilized control fruited earliest (33.92 days) (Table 6).Vermicompost application also affected fruiting time, with higher rates delaying fruiting compared to the control, although specific values were consistent with the trends observed in nitrogen application.

The observed differences in fruiting time among varieties are likely driven by genetic factors that extend vegetative growth, allowing ALBATROS and NUN TOP to accumulate more biomass before transitioning to reproductive stages. Differences in flowering and fruiting-related genes, including those controlling photoperiod sensitivity and hormone production, may explain these variations. Pin and Nilsson (2012) reported that allelic diversity in flowering-time genes, such as FLOWERING LOCUS T (FT), can delay reproductive transitions, thereby prolonging vegetative growth and subsequent fruiting phases. Similarly, Conesa *et al*. (2017) noted that cultivars with extended fruiting periods often allocate more resources to structural growth during early development, a trait adaptive in semi-arid environments.

Nitrogen mediated delays in fruiting can be attributed to its role in enhancing vegetative growth. High nitrogen availability promotes chlorophyll synthesis, leaf expansion, and overall biomass accumulation, which prioritizes vegetative development over reproduction. This is consistent with the findings of Teferi *et al.* (2022), who reported that excessive nitrogen prolongs vegetative growth, delaying fruiting. Wang *et al.* (2008) further emphasized that both nitrogen deficiency and excess can adversely affect fruiting time, highlighting the importance of balanced fertilization to optimize reproductive development. Vermicompost likely contributed similarly by providing additional nutrients that supported prolonged vegetative growth, thereby extending the period before fruiting. This aligns with previous studies demonstrating that organic amendments can enhance growth and influence phenological stages in tomatoes (Ghorbani *et al.*, 2008).

4.1.3 Days to Maturity

The main effects of variety, nitrogen, and vermicompost significantly influenced days to maturity of tomato ($p \leq 0.001$; Appendix Table 1). Among the varieties, GALILEA 39 matured earliest (87.74 days), followed by NUN TOP (90.41 days) and ALBATROS (91.92 days), indicating a shorter reproductive cycle in GALILEA 39 (Table 6). Nitrogen application significantly affected maturity. Plants receiving 350 kg ha^{-1} matured later than the control, while the shortest maturity period was recorded in plants without nitrogen. Days to maturity decreased from 94.81 days at 0 kg N ha^{-1} to 85.15 days at 350 kg N ha^{-1}. Vermicompost also influenced maturity. Higher vermicompost rates (7 t ha^{-1}) delayed maturity compared to the control (0 t ha^{-1}), indicating that increased organic nutrient input extended the vegetative growth phase.

The variation in days to maturity among tomato varieties can be attributed to genetic differences that control growth rates and developmental transitions (Tanksley, 2004) . GALILEA 39, being early maturing, is advantageous in regions with short growing seasons or where early market access is desired.

Nitrogen's effect on maturity reflects its role in promoting vegetative growth. High nitrogen levels enhance leaf area and photosynthetic capacity, allowing plants to accumulate sufficient resources before transitioning to reproductive stages (Escudero and Mediavilla, 2003). Conversely, nitrogen deficiency can trigger premature flowering and reduced fruit development due to limited resource availability (Bénard *et al.*, 2009). The reduction in days to maturity under optimal nitrogen (236–354 kg ha^{-1}) is consistent with prior findings that appropriate nitrogen application can accelerate phenological transitions while maximizing yield. Similarly, the delay in maturity with higher vermicompost rates can be explained by its nutrient-rich composition and slow-release characteristics, which sustain vegetative growth for longer periods. Vermicompost also supports root development and nutrient uptake through beneficial microorganisms, thereby extending the vegetative phase and influencing the timing of reproductive transition (Chanda *et al.*, 2011; Umaru *et al.*, 2019). These findings align with the general understanding that nutrient-rich organic amendments can prolong vegetative phases, ultimately affecting crop maturity.

Table 6. Effect of variety, nitrogen and vermicompost on days to fruiting, flowering and days to maturity

Variety	Days to flowering	Days to fruiting	Days to maturity
GALILEA39	26.48[b]	34.00[b]	104.33[a]
NUN 0279 TOP	28.52[a]	35.00[a]	102.55[a]
ALBATROS	27.88[a]	35.70[a]	98.18[b]
LSD (0.05)	1.10	0.39	3.50
Nitrogen (kg ha^{-1})			
0	26.03[c]	33.29[c]	91.99[b]
175	27.44b	34.59[b]	105.03[a]
350	29.41[a]	36.82[a]	108.04[a]
LSD (0.05)	1.10	0.39	3.50
Vermicompost (t ha^{-1})			
0	25.33[b]	33.51[b]	87.34[c]
5	28.22[a]	35.14[a]	102.22[b]
7	29.33[a]	36.04[a]	92.51[a]
LSD (0.05)	1.10	0.39	3.50
CV (%)	7.29	4.52	6.32

4.2 Growth parameters

4.2.1 Number of leaves per plant

The analyzed results indicate that the interaction effect of variety, nitrogen fertilizer, and vermicompost significantly influences tomato leaf production ($P < 0.05$) (Appendix Table 2). The results in clearly show that increasing the nitrogen (N) rate from 0 to 175 to 350 kg ha^{-1} produced a substantial increase in the number of leaves across all three varieties (GALILEA39, NUN TOP, ALBATROS) (Table 7). The synergistic effect of N and VC is evident when the two inputs are combined. In the same manner Benti *et al.* (2021) reported, the highest leaf numbers were recorded for the treatment combining 2.8 t ha^{-1} VC with 150 kg ha^{-1} N, indicating that organic amendments can amplify the response to mineral N. Data show an analogous pattern: at the highest N (350 kg ha^{-1}) and VC (7 t ha^{-1}) levels, leaf numbers reached their peak values (Table 7). The interaction likely stems from VC supplying a slow-release source of N and other nutrients (e.g., Ca, Mg, micronutrients) that complement the rapid N supply from fertilizer, thereby sustaining prolonged leaf development.

The three varieties responded differently to the same input levels. GALILEA consistently produced more leaves than NUN TOP and ALBATROS at each N-VC combination (Table 7). Such genotype-specific responses have been reported in tomato. Beyene and Mulu (2019) found that ARP Tomato d2 yielded the greatest number of primary branches and leaves among six varieties under similar N regimes. The superior leaf response of GALILEA may be linked to its genetic background, which appears more efficient in converting available N and organic nutrients into vegetative biomass.

The interaction of variety, nitrogen, and vermicompost is evident in the maximum number of leaves obtained from the application of 350 kg ha^{-1} of nitrogen with 7 t ha^{-1} of vermicompost on the GELILEA and ALBATROS varieties, while the minimum was recorded from untreated ALBATROS plants (Table 7). This suggests that specific variety responses are enhanced by optimal nitrogen and vermicompost levels.

Table 7. Interaction effects of variety, nitrogen and vermicomposts for number of leaves

Variety	N rate (kg ha^{-1})	VC rate (t ha^{-1})	Number of leaves per plant
GALILEA39	0	0	36.14^{gh}
		5	36.60^{gh}
		7	46.69^{fgh}
	175	0	50.52^{efg}
		5	81.92^{bc}
		7	94.99^{ab}
	350	0	58.29^{def}
		5	86.74^{b}
		7	102.44^{a}
NUN TOP	0	0	36.13^{gh}
		5	36.58^{gh}
		7	48.23^{efgh}
	175	0	45.02^{fgh}
		5	82.73^{bc}
		7	82.14^{bc}
	350	0	55.38^{def}
		5	84.41^{b}
		7	95.13^{ab}
ALBATROS	0	0	34.33^{h}
		5	39.87^{gh}
		7	62.52^{de}
	175	0	44.78^{fgh}
		5	81.19^{bc}
		7	84.69^{b}
	350	0	68.46^{d}
		5	83.23^{bc}
		7	95.13^{ab}
LSD (0.05)			3.89
CV (%)			2.47

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.2.2. Number of Primary branches

The data presented in Tables 8 showed that increasing rates of nitrogen and vermicompost significantly enhanced the growth of all three tomato cultivars (GALILEA, NUN TOP, and ALBATROS). As nitrogen increased from 0 to 175 kg ha^{-1}, the number of primary branches increased by 30–45 %, with a further 20–35 % increase observed at 350 kg ha^{-1}. These increases can be attributed to the role of nitrogen in promoting vegetative growth by enhancing cell division, leaf area expansion, and nutrient assimilation, while vermicompost improves soil structure, moisture retention, and microbial activity, further supporting growth. The differential responses among cultivars may reflect inherent genetic variation in nutrient use efficiency and growth potential.

These results are consistent with findings from Benti *et al.* (2021), where primary branch numbers increased from 4.67 to 10.00 branches plant^{-1} as nitrogen increased from 0 to 1.5 g pot^{-1} (≈300 kg ha^{-1}) in a vermicompost -nitrogen integration study. Similarly, Zeleke *et al.* (2023) reported enhanced primary branching and vegetative growth in greenhouse tomatoes with higher nitrogen fertilization. The agreement with these studies suggests that nitrogen and organic amendments consistently promote tomato vegetative growth, although environmental conditions and cultivar characteristics may modulate the magnitude of response.

Table 8. Interaction effect of variety, nitrogen and vermicompost on the number of primary branches

Variety	N rate (kg ha^{-1})	Vermicompost rate (t ha^{-1})	Number of primary branches
GALILEA39	0	0	3.63^{l}
		5	5.13^{jk}
		7	6.76^{hi}
	175	0	4.80^{k}
		5	7.53^{g}
		7	8.13^{f}
	350	0	6.46^{i}
		5	8.43^{ef}
		7	9.53^{c}
NUN TOP	0	0	3.63^{l}
		5	5.50^{j}
		7	7.30^{gh}
	175	0	5.40^{j}
		5	8.33^{ef}
		7	8.86^{de}
	350	0	7.33^{g}
		5	9.267^{cd}
		7	10.13^{b}
ALBATROS	0	0	3.70^{l}
		5	5.33^{jk}
		7	7.33^{g}
	175	0	5.16^{jk}
		5	8.20^{f}
		7	9.23 ^{cd}
	350	0	7.00^{ghi}
		5	10.43^{b}
		7	11.50^{a}
LSD (0.05)			0.14
CV (%)			2.47

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.2.3. Number of secondary branches

The interaction between tomato variety and vermicompost amendment markedly influenced the development of secondary branches (Appendix Table 2). Across the three varieties, the highest secondary branch counts were recorded at the 7 t ha^{-1} vermicompost level secondary branch (GALILEA 39 = 12.40, NUN TOP = 12.96, ALBATROS = 12.20). Compared with the control, these values represent increases of 24.5 % (GALILEA 39), 60.7 % (NUN TOP) and 25.9 % (ALBATROS (Table 9). Such enhancements are consistent with the stimulatory effect of organic amendments on shoot architecture reported for tomato. Comparable outcomes were observed study by Ravindrakumar (2023) on chilli, where vermicompost increased secondary branch numbers by 30 % relative to control . The magnitude of the response, however, varied among varieties, indicating variety specific sensitivity to organic nutrient supply. NUN TOP displayed the greatest relative gain (≈61 %), suggesting a higher inherent plasticity to exploit the enhanced N availability, a pattern also reported for high yielding tomato cultivars under integrated nutrient management (Benti *et al*., 2021).

Table 9. Interaction effects of variety and vermicompost on number of secondary branches

Variety	Vermicompost rate (t ha^{-1})	Number of secondary branches
GELILEA39	0	9.96^{cd}
	5	11.589^{abc}
	7	12.40^{ab}
NUN TOP	0	8.067^{d}
	5	12.20^{ab}
	7	12.96^{a}
ALBATROS	0	9.689^{cd}
	5	10.878^{bc}
	7	12.20^{ab}
LSD(0.05)		0.64
CV (%)		12.32

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.2.4 Plant height

Plant height of tomato was significantly influenced by the interaction effect of variety, N and VC fertilizers (Appendix Table 2). The longest plant height was recorded from 350kg ha^{-1} of nitrogen with 7 t ha^{-1} of vermicompost, and it increased plant height by 68.63 % as compared to the control plot (Table 10). In contrast, the shortest plants (75.27 cm) were obtained from the control treatment under the variety ALBATROS, which was statistically similar with the treatments of N0 kg ha^{-1} and VC0 t ha^{-1} under the variety GALILEA and NUN TOP (Table 10).

The reason for this result might be due to the fact that organic and inorganic fertilizers had a great effect on plant height, which might have been due to the presence of major nutrients from the organic fertilizer combined with the instantaneous, readily soluble nutrients from the inorganic fertilizers (Naidu *et al.*, 2001). The cause of the rise in plant height could be increased fertilizer uptake throughout the growth period, resulting in increased cell size, elongation, and cell division, all of which improve plant growth (Taranet *et al.*, 2017). Other researchers also stated that too little N in the soil stunts plant growth (Etissa *et al.*, 2013)

The significant increment in plant height in response to the increased application of N and VC might be attributed to the synergic promotion of enhanced vegetative growth with cell elongation and division as well as cell expansion as suggested by Ahmed *et al.* (2012).

The highest heights were obtained in the combination of high rates of nitrogen and vermicompost treatments, so there was a synergistic relationship. In all varieties, the highest plants were recorded from a combination of 350 kg ha^{-1} of N and 7 t ha^{-1} of vermicompost. This is in line with Nejatzadeh (2024) who established that the combination of vermicompost and nitrogen had the highest plant height (and leaf area) in Aloe vera.

4.2.5 Leaf area

The interaction effects of variety, nitrogen and vermicompost had a highly significant ($p \leq 0.01$) effect on leaf area (Appendix Table 2). The widest leaf area (37.21 cm^2) was recorded from the combined application of 350 kg ha^{-1} of N, 7 t ha^{-1} of VC with variety GALILEA39, while the smallest (8.293 cm^2) was recorded from the control plot with variety ALBATROS (Table 10). This result might be due to the fact that the application of both organic and inorganic fertilizers promotes leaf elongation and explanation by regulating the rate of cell division. Increased individual leaf area with additional N could be due to increased cell size, cell number, or changes in leaf architecture. The application of organic fertilizers increases nitrogen in the soil, which significantly influences the leaf fresh weight and quality of the leaves because nitrogen stimulates plant vegetative growth and increases leaf area, resulting in an increment in the leaf area as well as an increase in the rate of photosynthesis (Khalil and Agah, 2017).

According to the result presented, there is a varietal difference with GALILEA39 having a better leaf area development with increased nutrient inputs than the NUN TOP and ALBATROS (Table 10). This indicates that GALILEA39 has more genetic potential to optimize a given set of available resources. Other past research also indicated that there was a high level of genotypic diversity in tomato to grow leaf expansion and canopy architecture, which are the direct factors in determining the level of light interception and photosynthetic efficiency (Haruna *et al.*, 2024; Sánchez *et al.*, 2010).

The nitrogen element is crucial in promoting cell elongation and division, which leads to an increase in plant height and, in turn, an increase in the number of leaves and leaf area per plant. According to Ojeniyi *et al.* (2007), the addition of organic matter and N fertilizers improved the leaf area of tomatoes when compared to the control.

Table 10. Interaction effects of variety, nitrogen and vermicomposts for number of plant height and leaf area

Variety	N rate (kg ha^{-1})	VC rate (t ha^{-1})	Plant height (cm)	Leaf area (cm^2)
GALILEA39	0	0	75.93^{l}	9.460^{mno}
		5	102.83^{efgh}	9.270^{no}
		7	107.60^{de}	15.047^{gh}
	175	0	90.83^{ij}	12.800^{ijk}
		5	108.07^{cde}	28.807^{e}
		7	122.67^{ab}	31.153^{cd}
	350	0	96.53^{fghi}	16.537^{g}
		5	107.53^{de}	34.480^{b}
		7	126.93 ^{a}	37.210^{a}
NUN TOP	0	0	79.57^{kl}	11.433 ^{kl}
		5	95.13^{ghi}	10.907^{lmn}
		7	112.47^{bcde}	15.050^{gh}
	175	0	89.07^{ijk}	13.530^{hij}
		5	103.30^{defgh}	25.327^{f}
		7	119.80 ^{ab}	30.557^{cd}
	350	0	93.00^{hij}	14.127^{hi}
		5	108.33^{cde}	31.577^{c}
		7	122.30 ^{ab}	31.590^{c}
ALBATROS	0	0	75.27^{l}	8.293^{o}
		5	83.27^{jkl}	11.117^{lm}
		7	95.87^{ghi}	11.663 ^{kl}
	175	0	91.73^{ij}	12.140^{jkl}
		5	113.60^{def}	29.563^{de}
		7	113.40^{bcd}	27.940^{e}
	350	0	94.10^{hi}	13.753^{hij}
		5	110.43^{b}	31.070^{cd}
.		7	118.47^{abc}	31.900^{c}
LSD (0.05)			5.24	0.83
CV (%)			6.32	5.24

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.3 Yield components

4.3.1. Number of flowers per cluster

The number of flowers per cluster was significantly influenced by vermicompost amendment ($P < 0.05$), demonstrating a clear positive effect on tomato reproductive morphology (Appendix Table 3). Specifically, application of 7 t ha^{-1} vermicompost increased flower number per cluster by approximately 29.8 % compared to the control (Table 11), indicating that higher organic input enhances reproductive output. The trend shows a progressive increase in flower number with increasing vermicompost rates, suggesting a dose-dependent response within the evaluated range.

This response can be attributed to the enrichment of soil with slowly released nitrogen, phosphorus, potassium, and essential micronutrients, as well as improvements in soil structure and root proliferation, which collectively enhance nutrient uptake during the critical flowering phase (Suthar, 2009). Improved nutrient availability likely supports the development of more flowers per inflorescence.

The observed increase aligns closely with a ~30 % rise in flower number reported for chili under a combined vermicompost biofertilizer regime. Densilin *et al.* (2011), reinforcing the beneficial effect of organic amendments on reproductive performance. Conversely, some studies have reported a plateau or decline in reproductive traits at very high organic amendment rates, potentially due to excessive vegetative growth that shades developing buds (Alabi, 2006). In this experiment, vermicompost rates up to 7 t ha^{-1} did not reach a saturation point, indicating that the tested levels remain within the optimal range for the three tomato varieties, whereas negative effects elsewhere may reflect higher amendment levels or cultivar-specific physiological responses.

Table 11. Effect of vermicompost on number of flowers per cluster

VC (t ha^{-1})	Number of flowers per cluster
0	6.58^{c}
5	7.60^{b}
7	8.54^{a}
LSD (0.05)	0.26
CV (%)	12.88

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.3.2. Number of fruits per cluster

Data on the numbers of fruit clusters per plant are shown in Table 13 and Appendix Tables 3, and it is evident from these tables that nitrogen and vermicompost had a significant ($P \leq 0.001$) effect on it.

Fruit per cluster was significantly increased when nitrogen (N) fertilizer was applied with the highest mean values of 175 kg ha^{-1} (6.31) and 350 kg ha^{-1} (6.40), which were significantly different than each other but all significantly higher than the control (0 kg ha^{-1} N) which produced 4.66 as the mean (Table 13). This strongly suggests that nitrogen availability is a limiting factor for fruit set and development in the studied tomato variety. Nitrogen is a crucial component of amino acids, proteins, and nucleic acids, directly influencing the plant's overall vigor, leaf area, and photosynthetic capacity.

According to the study of Ogundare *et al.* (2015), the number of fruits per plant, fruit yield per plant, fruit yield per plot and tomato yield were significantly affected by combined use oforganic and inorganic fertilizer. The results also align with numerous studies that emphasize the positive correlation between optimum N supply and higher fruit cluster production in tomatoes (Marschner, 2012; Marschner, 2011; Petropoulos *et al.*, 2020). Fallah *et al.* (2021) similarly reported that increasing N rates up to a certain threshold significantly enhanced the number of flowers and subsequent fruit set per cluster. The lack of a significant difference between the 175 kg ha^{-1} and 350 kg ha^{-1} rates suggests that the optimal N requirement for this trait may lie at or slightly below 175 kg ha^{-1}, indicating potential diminishing returns or even approaching a luxury consumption level at the higher rate, where further N application does not translate to additional benefit for this specific parameter.

Similarly, the application of vermicompost (VC) significantly enhanced the number of fruits per cluster. The highest rate, 7 t ha^{-1} VC, resulted in the maximum number of fruits per cluster (6.95), which was significantly greater than the intermediate rate of 5 t ha^{-1} VC (5.98), which itself was significantly higher than the control (4.40) (Table 13). Vermicompost, beyond supplying essential macro and micronutrients in a readily available form, acts as a soil conditioner, improving soil structure, water holding capacity, and aeration (Lazcano and Domínguez, 2011). More importantly, VC contains beneficial microbial populations and a variety of plant growth promoting substances (PGPS), such as humic acids and plant hormones (e.g., auxins and gibberellins) (Atiyeh *et al.*, 2000). These PGPS are known to stimulate flowering, pollen viability, and fruit development, directly contributing to a higher number of successful fruit sets per cluster (Kour *et al.*, 2022).

4.3.3. Fruit set percentages

The results presented in Table 12 showed significant differences among the three tomato varieties tested (Appendix Table 3). GALILEA39 recorded the highest fruit set percentage (78.26%), followed by ALBATROS (75.30%) and NUN TOP (73.78%). These differences suggest that varieties vary in their reproductive success under similar growing conditions, likely reflecting genetic variation in fruit set capacity. In addition, both nitrogen (N) fertilizer and vermicompost (VC) applications significantly enhanced fruit set compared to the control. The fruit set increased sharply from 68.17% in the control to 79.23% with 175 kg N ha^{-1} (Table 13). Similarly, VC application improved fruit set from 68.77% in the control to 78.00% at 5 t ha^{-1} and 80.57% at 7 t ha^{-1}, although the difference between the two VC levels was statistically significant.

The varietal differences in fruit set indicate genetic control of reproductive efficiency, with GALILEA39 showing superior flower fertilization, pollen viability, and fruit retention. Nitrogen fertilization significantly enhanced fruit set by supporting vegetative and reproductive growth, boosting chlorophyll, photosynthesis, carbohydrate accumulation, and hormone synthesis to reduce flower and fruit abscission. Vermicompost also improved fruit set by enhancing soil fertility, structure, moisture, and microbial activity, providing a steady nutrient supply, and supplying humic substances and phytohormones that promote flower retention and fruit development.

The varietal variation observed in this study aligns with Elsayed *et al.* (2015), who reported wide differences in fruit set among tomato lines (12.7%–66.5%) under heat stress, demonstrating strong genetic influence on reproductive success. Panthee *et al.* (2018) also found that fruit set traits in tomato exhibit high broad-sense heritability, often nearing 100%, confirming that much of the observed variation is genetically controlled. The enhancement of fruit set through nitrogen fertilization agrees with Al-Farisi *et al.* (2023) and Marschner (2011), who emphasized nitrogen's central role in protein synthesis, photosynthesis, and hormone regulation that support fruit retention and development. Similarly, the significant improvement due to vermicompost application supports findings by Mukta *et al.* (2015) and Theunissen *et al.* (2021), who reported that vermicompost improves soil biological activity and nutrient dynamics, enhancing plant reproductive performance.

Table 12. Effect of variety of the fruit set percentage

Variety	Fruit set percentage
GALILEA39	78.26^{a}
NUN TOP	73.78^{b}
ALBATROS	75.30^{ab}
LSD (0.05)	0.21

CV (%)	8.68

Table 13. Effects of nitrogen and vermicomposting on number of fruits per cluster and fruit set percentage

Rates of fertilizer N (kg ha^{-1})	Number of fruits per cluster	Fruit set percentage
0	4.66^{b}	68.17^{b}
175	6.31^{a}	79.23^{a}
350	6.40^{a}	79.94^{a}
LSD (0.05)	0.21	1.70
Rates of VC fertilizer (tha^{-1})		
0	4.40c	68.77^{b}
5	5.98^{b}	78.00^{a}
7	6.95^{a}	80.57^{a}
LSD(0.05)	0.21	1.70
CV (%)	13.76	8.26

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.4. Fruit yield

4.4.1. Number of harvests

In accordance with Table 3 in the appendix, the interaction effect of nitrogen and vermicompost was significant on the effect on the number of harvests. In the control group, the least number of harvests (2.55) was recorded. On the other hand, the greatest number of harvests (5.88) was attained with 350 t ha^{-1} nitrogen and vermicompost at a ratio of 5 or 7 t ha^{-1} of vermicompost and with 175 t ha^{-1} nitrogen and vermicompost at a ratio of 7 t ha^{-1} (Table 14). These results imply that nitrogen and vermicompost have a synergetic relationship with promoting harvest frequency, which is consistent with the previous studies that revealed that balanced availability of nutrients increases the productivity of plants (Smith and Jones, 2020).

The increased harvest obtained after the application of both nitrogen and vermicompost can be explained by the enhanced soil fertility and plant vigor. Nitrogen is essential in vegetative growth and vermicompost improves the soil structure, microbial activities, and efficiency of nutrient uptake (Williams, 2021). This encountering emphasizes that applying individual amendments is unlikely to produce the best outcomes and, instead, it is the combination of them in a synergy.

Table 14. Interaction effects of nitrogen and vermicompost on number of harvests

Nitrogen (t ha^{-1})	Vermicompost rate (t ha^{-1})	Number of harvests
0	0	2.55^{d}
	5	3.44^{c}
	7	3.88^{c}
175	0	3.44^{c}
	5	5.00^{b}
	7	5.77^{a}
350	0	3.44^{c}
	5	5.88^{a}
	7	5.88^{a}
LSD (0.05)		0.33
CV (%)		16.50

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.4.2. Individual fruit mean weight

The interaction effect of variety, nitrogen, and vermicompost on individual fruit mean weight was highly significant ($P<0.01$) (Appendix Table 3). The highest fruit weight (178.23 g and 175.97 g) was obtained from variety ALBATROS supplied with 350 kg N ha^{-1} combined with 5 and 7 t ha^{-1} vermicompost, respectively, while the lowest (63.07 g) was recorded from NUN TOP under unfertilized control conditions (Table 15). This clearly demonstrates that tomato fruit size is highly dependent on the combined effects of genetic potential and nutrient availability.

The significant rise in the weight of individual fruit with the combined application of nitrogen and vermicompost could be explained by adequate nutrient supply, especially nitrogen, which improves vegetative development, photosynthesis, and assimilate translocation to the growing fruit (Sarker, 2020). Nitrogen promotes syntheses of chlorophyll and leaf development, which leads to higher source capacity, and vermicompost enhances soil structure, mineralization of nutrients and microbial activity, which guaranteed a continuous supply of nutrients during the fruit development process (Arancon *et al.*, 2004; Edwards *et al.*, 2010). The combination of mineral and organic amendments to the soils would have increased the rate of vegetation growth as well as sustained nutrient flow, resulting lager fruits.

The varietal differences also contributed significantly to fruit weight determination. The other varieties performed poorly in high nutrient input, which indicates that ALBATROS has a genetic background that enables it to translocate and partition assimilates to enlarge fruits better. Khan *et al.* (2022) also reported similar results and found that varietal differences and integrated nutrient management had a significant impact on tomato fruit size. GALILEA39 was also highly sensitive to the combined use of 175/350 kg N ha^{-1} and 5/7 t ha^{-1} of vermicomposts, as the fruit weights of 159.93-167.00 g were statistically similar to the highest ones (Table 15). Comparatively, NUN TOP had comparatively smaller fruits in all treatments, which showed low genetic ability to increase fruit size despite better nutrition.

Table 15. Interaction effects of variety, nitrogen and vermicompost on individual fruit weight

Variety	N rate (kg ha^{-1})	VC rate ($t\ ha^{-1}$)	Individual fruit weight (g)
GALILEA39	0	0	70.23gh
		5	101.03efg
		7	86.30fgh
	175	0	95.67efgh
		5	159.93abc
		7	160.03abc
	350	0	93.10fgh
		5	167.00ab
		7	145.43abcd
NUN TOP	0	0	63.07h
		5	86.90fgh
		7	81.23fgh
	175	0	77.87gh
		5	85.47fgh
		7	113.30def
	350	0	85.17fgh
		5	95.87efgh
		7	127.40cde
ALBATROS	0	0	83.93fgh
		5	68.63gh
		7	79.73fgh
	175	0	101.80efg
		5	146.03abcd
		7	158.20abc
	350	0	137.27bcd
		5	178.23a
.		7	175.97ab
LSD (0.05)			8.65
CV (%)			9.47

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.4.3 Fruit diameter

The results showed that fruit diameter was significantly influenced by tomato variety (Appendix Table 3). Among the tested varieties, GALILEA produced the largest fruit diameter, while NUN TOP and ALBATROS recorded the smallest values (Table 16). This indicates that fruit size varied substantially among varieties, reflecting inherent genetic differences. In addition, nitrogen application significantly affected fruit diameter ($P < 0.001$). The application of 350 kg N ha^{-1} resulted in the largest fruit diameter, representing a 24.35% increase compared to the control (Table 16). Similarly, vermicompost application had a highly significant effect ($P < 0.001$) on fruit diameter, where 7 t VC ha^{-1} produced the maximum diameter, increasing it by 17.02% relative to the control (Table 16).

The observed varietal differences in fruit diameter can be attributed to genetic variability among cultivars, which determines fruit morphology, sink strength, and assimilate partitioning. Varieties like GALILEA may possess superior cell expansion capacity or more efficient assimilate translocation to fruits, leading to greater fruit size. The increase in fruit diameter with higher nitrogen levels is likely due to enhanced vegetative vigor, leaf area development, and photosynthetic efficiency, which supply more assimilates for fruit growth. Nitrogen is a key component of chlorophyll and amino acids and promotes cell division and enlargement, directly contributing to fruit size development. Similarly, the significant effect of vermicompost on fruit diameter can be explained by its ability to improve soil fertility, moisture retention, and microbial activity, ensuring a steady release of macro- and micronutrients throughout plant growth. This balanced nutrient supply supports uniform cell expansion and sustained growth during fruit development, thereby enhancing fruit size.

The varietal differences observed align with Tanksley (2004), who emphasized that genetic factors play a crucial role in determining fruit size and morphology in tomatoes. Wang *et al.* (2015) also reported that genetic variation significantly influences fruit size, shape, and overall yield potential. The positive response of fruit diameter to nitrogen fertilization agrees with Biswas *et al.* (2015) and Karthika *et al.* (2018), who found that adequate nitrogen supply enhances nutrient uptake and cell expansion, leading to larger fruit sizes in tomatoes. Likewise, the beneficial effect of vermicompost corroborates previous findings that organic amendments enhance fruit size by improving soil nutrient dynamics and biological activity (Mukta *et al.*, 2015; Theunissen *et al.*, 2021).Vermicompost provides a slow and continuous release of nutrients, prevents nutrient losses, and promotes a favorable root environment that optimizes nutrient use efficiency and fruit development.

Table 16. Effect of variety, nitrogen and vermicompost on fruit diameter

Variety	Fruit diameter (mm)
GALILEA39	53.93^{a}
NUN TOP	52.55^{b}
ALBATROS	52.54^{b}
LSD (0.05)	0.38
Rates of fertilizer N (kg ha^{-1})	
0	46.64^{c}
175	54.37^{b}
350	58.00^{a}
LSD (0.05)	0.38
Rates of VC fertilizer (t ha^{-1})	
0	48.70^{c}
5	54.33^{b}
7	55.99^{a}
LSD (0.05)	0.38
CV (%)	2.65

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.4.3 Fruit length

Nitrogen significantly influenced fruit length, with average lengths reaching 5.81 cm and 5.89 cm at 175 and 350 kg N ha^{-1}, respectively (Table 18). The results indicate that 175 and 350 kg N ha^{-1} are significantly greater than 0 kg N ha^{-1}, while 175 and 350 kg N ha^{-1} do not differ significantly from each other. Similarly, vermicompost (VC) application increased fruit length: 0 t ha^{-1} = 5.37 cm, 5 t ha^{-1} = 5.78 cm, and 7 t ha^{-1} = 5.96 cm; the 5 and 7 t ha^{-1} treatments are significantly larger than the control (Table 18)

Nitrogen is a primary nutrient that promotes vegetative growth, leaf area development, and photosynthetic capacity. Greater canopy development and photosynthate production provide a larger assimilate that can be translocated to developing fruits, promoting cell division and expansion and longitudinal fruit growth. Vermicompost may have increased fruit length by improving soil physical properties (aeration and water-holding capacity), slowing macro- and micro-nutrient release, and stimulating beneficial microbial activity that increases nutrient availability and root growth.

The positive effect of increasing N on tomato growth and fruit dimensions has been repeatedly observed and reported that applying N markedly increased fruit length and other fruit size parameters compared with zero-N controls, while very high rates sometimes produced no additional gain or even reduced size beyond the optimal range (Shewangizaw *et al.*, 2024). Vermicompost and other organic amendments have been shown to improve tomato fruit size, yield and quality by improving soil fertility, photosynthetic capacity and carbohydrate transport to fruits (Wang *et al.*, 2017).

4.4. 4 Total fruit yield (t ha-1)

The results indicate that the integrated application of mineral nitrogen fertilizer and vermicompost produced the highest total fruit yields compared to the sole application of either input. Among the tested varieties, GALILEA39 recorded the maximum yield of 14.02 t ha^{-1} with 350 kg N ha^{-1} and 5 t VC ha^{-1}, followed by NUN TOP with 13.32 t ha^{-1} at 175 kg N ha^{-1} and 7 t VC ha^{-1}, and ALBATROS with 13.27 t ha^{-1} at 350 kg N ha^{-1} and 7 t VC ha^{-1} (Table 17). This pattern demonstrates that yield performance was not only influenced by individual fertilizer rates but also by the specific combination of nitrogen and vermicompost, which varied across varieties.

The superior performance under combined treatments suggests a synergistic effect between mineral nitrogen and vermicompost. Nitrogen fertilizer provides an immediate and concentrated source of essential nutrients, particularly during early vegetative and reproductive stages, whereas vermicompost improves soil structure, aeration, and microbial activity, leading to enhanced nutrient mineralization and uptake efficiency. The integrated application ensures a balanced nutrient supply, maintaining sustained plant growth and higher fruit development throughout the growing period. Moreover, the variation among varieties may reflect genotypic differences in nutrient utilization efficiency, root system development, and photosynthetic capacity. Varieties such as GALILEA39 and ALBATROS appear to benefit most from high nitrogen levels complemented by vermicompost, whereas NUN TOP responds optimally to moderate nitrogen with higher vermicompost, suggesting differential nutrient absorption strategies. These interactions indicate that the ideal N and VC balance for maximizing yield may vary depending on genetic and physiological traits of each variety.

Similar outcomes have been widely reported in previous studies. Chumyani *et al.* (2012) who found that integrating vermicompost with recommended NPK fertilizer rates significantly improved yields in tomato and okra compared to either source alone. Vermicompost functions not only as a nutrient source but also as a soil conditioner that enhances the effectiveness of chemical fertilizers (Mukta *et al.,* 2015). It improves soil porosity, water retention, and microbial biomass, leading to increased nutrient cycling and availability (Abushita *et al.,* 2000). Additionally, vermicompost contains plant growth regulators such as gibberellins, cytokinins, and auxins, which stimulate root proliferation, photosynthetic activity, and early flowering (Goel and Kaur, 2012). These mechanisms explain the observed yield advantage under integrated nutrient management. Furthermore, Akef *et al.* (2024) emphasized that varietal differences in nutrient absorption and translocation efficiency can influence responsiveness to organic and inorganic inputs. The present findings, therefore, reinforce the view that combining vermicompost with mineral nitrogen creates a nutritionally balanced and biologically active soil environment, enabling each tomato variety to express its full genetic yield potential.

4.4.6 Marketable fruit yield (t ha^{-1})

The analysis of variance (Appendix Table 4) revealed a highly significant three-way interaction among variety, nitrogen rate, and vermicompost rate ($p < 0.001$) for marketable fruit yield. This indicates that the yield response of tomato depends on the specific combination of these factors rather than on any single input. As presented in Table 16, GALILEA39 recorded the highest marketable fruit yield (13.22 t ha^{-1}) when treated with 350 kg N ha^{-1} and 5 t VC ha^{-1}. Conversely, the lowest yield (4.14 t ha^{-1}) was obtained from NUN TOP under both the control treatment (0 N and 0 VC) and when 175 kg N ha^{-1} was applied without vermicompost (Table 17). This pattern demonstrates considerable variability in yield performance among varieties and treatment combinations.

The superior yield performance of GALILEA39 at the combined level of 350 kg N ha^{-1} and 5 t VC ha^{-1} suggests a synergistic interaction between inorganic nitrogen and vermicompost. The mineral nitrogen likely provided a readily available nutrient source during the crop's rapid vegetative and reproductive phases, while vermicompost improved soil physical properties, enhanced microbial activity, and ensured a slow and sustained nutrient release. Such a combination could have optimized nutrient uptake efficiency and promoted better fruit set and development. However, increasing vermicompost to 7 t ha^{-1} at the same nitrogen level slightly reduced yield (11.63 t ha^{-1}), implying a threshold or saturation point beyond which additional organic matter may not further enhance productivity. This reduction might be linked to nutrient imbalance, increased salinity, or micronutrient antagonism at excessive application rates. On the other hand, the varieties NUN TOP and ALBATROS achieved their highest yields (12.02 t ha^{-1} and 11.72 t ha^{-1}, respectively) at 7 t VC ha^{-1} in combination with 175–350 kg N ha^{-1}, indicating that these genotypes may possess higher nitrogen use efficiency (NUE) or a greater ability to benefit from the gradual nutrient release associated with higher organic inputs.

These findings align with previous studies reporting that integrating organic and inorganic fertilizers enhances tomato productivity through complementary nutrient dynamics. Rashid *et al.* (2021) highlighted that mineral N supplies immediate plant nutrition, while vermicompost improves soil fertility and microbial processes, leading to sustained nutrient availability. Similarly, Maji *et al.* (2017) found that humic substances and beneficial microbes in vermicompost stimulate root proliferation and improve nutrient absorption. Collectively, these studies support the current findings that a balanced combination of organic and inorganic fertilizers optimizes tomato yield performance.

Table 17. Interaction effects of variety, nitrogen and vermicompost on total fruit yield and marketable fruit yield (t ha^{-1})

Variety	N rate (kg ha^{-1})	VC rate (t ha^{-1})	Total fruit yield (t ha^{-1})	Marketable fruit yield (t ha^{-1})
GALILEA39	0	0	5.97^{ef}	4.64^{gh}
		5	7.08^{def}	5.83^{fgh}
		7	9.35^{bcd}	8.03^{def}
	175	0	8.053^{def}	6.66^{fg}
		5	12.88^{a}	11.66^{abc}
		7	13.55^{b}	12.66^{ab}
	350	0	7.55^{def}	6.00^{fgh}
		5	14.02^{a}	13.22^{a}
		7	12.89^{b}	11.64^{bcd}
NUN TOP	0	0	5.41^{f}	4.14^{h}
		5	9.05^{cd}	7.80^{ef}
		7	9.13^{cd}	7.917^{ef}
	175	0	7.50^{def}	4.14^{h}
		5	11.88^{ab}	10.49^{bcd}
		7	13.32^{a}	12.02bc
	350	0	8.24^{de}	6.97^{fg}
		5	11.47^{abc}	10.14^{cde}
		7	12.27^{a}	11.00^{abc}
ALBATROS	0	0	6.16^{ef}	5.27^{gh}
		5	7.07^{def}	5.92^{fgh}
		7	8.30^{de}	7.03^{fg}
	175	0	8.47^{de}	6.49^{fgh}
		5	11.38^{abc}	10.19^{bcde}
		7	12.05^{ab}	11.13^{abc}
	350	0	8.30^{de}	6.47^{fgh}
		5	12.60^{a}	11.38^{abc}
.		7	13.27^{a}	11.72^{bc}
LSD (0.05)			1.25	1.19
CV (%)			7.76	8.43

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.5 Physical Fruit quality parameters

4.5.1 Fruit width

Fruit width was significantly affected only by the main effect of vermicompost ($P < 0.05$), while variety and nitrogen rate had no significant influence (Appendix Table 5). As shown in Table 18, even at the highest nitrogen level (350 kg ha^{-1}), fruit width (4.23 cm) did not differ statistically from the control, indicating that nitrogen levels were below the physiological threshold required to affect fruit expansion. According to Cheng *et al.* (2021), nitrogen-induced fruit wall expansion in tomato typically plateaus above 400 kg N ha^{-1}.

Vermicompost application, however, increased fruit width from 4.00 cm (control) to 4.28 cm (5 t ha^{-1}) (Table 18). This improvement may be attributed to the supply of readily available macro- and micronutrients (particularly calcium, potassium, and magnesium) that are essential for cell expansion and pericarp development. Benti *et al.* (2021) noted that vermicompost releases nutrient with plant demand, preventing excessive nitrogen uptake that can disrupt the balance of other minerals essential for fruit development. The steady nutrient supply enhances source -sink relationships during rapid fruit growth, thereby increasing fruit width. Although nitrogen significantly influenced plant height, leaf area, and branching in related datasets (Benti *et al.*, 2021) , these vegetative effects may not directly translate to increased fruit diameter.

Table 18. Effect of nitrogen and vermicompost fruit length, width, shape index and pericarp thickness

Rates of N (kg ha^{-1})	Fruit length (cm)	Fruit width (cm)	Fruit shape index	Pericarp thickness (mm)
0	5.40^{b}	4.02^{a}	1.35^{b}	6.99c
175	5.81^{a}	4.18^{a}	1.41^{a}	8.90^{b}
350	5.89^{a}	4.23^{a}	1.44^{a}	10.38^{a}
LSD (0.05)	0.10	0.09	0.02	0.20
Rates of VC fertilizer (t ha^{-1})				
0	5.37^{b}	4.00^{b}	1.36^{b}	6.31^{c}
5	5.780^{a}	4.28^{a}	1.39^{ab}	9.40^{b}
7	5.96^{a}	4.15^{ab}	1.44^{a}	10.56^{a}
LSD (0.05)	0.10	0.09	0.02	0.20
CV (%)	6.75	12.56	5.84	8.69

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.5.2 Fruit shape index (FSI)

The observed fruit shape index (FSI) values, defined by the ratio of polar to equatorial diameter, serve as a direct metric for the intended purpose and market utility of the fruit, where values greater than 1 signify an elongated phenotype. The data clearly established that both N rates and vermicompost (VC) fertilizer application significantly modulated fruit morphology, leading to commercially desirable elongation across all optimal treatment groups. Specifically, increasing N rates from 0 kg ha^{-1} (FSI=1.35) to 175 kg ha^{-1} (FSI=1.41) resulted in a statistically significant increase in fruit shape index, with the maximum observed FSI (1.44) achieved at the highest N rate of 350 kg ha^{-1} (Table 18). This morphological response is physiologically grounded, as N is a primary nutrient involved in the synthesis of proteins and critical phytohormones, particularly auxins. Elevated N availability can stimulate auxin biosynthesis and transport to the developing fruit, which is known to preferentially promote cell elongation along the polar axis, thus increasing the FSI and conferring the target elongated shape (Banjare *et al.*, 2023).

The application of VC fertilizer demonstrated an equally pronounced, dose-dependent effect on fruit elongation, providing a sustainable pathway to achieving optimal fruit morphology. FSI increased from 1.36 at the 0 t ha^{-1} control, through the intermediate 5 t ha^{-1} (1.39), the maximum FSI of 1.44 at the 7 t ha^{-1}rate (Table 18). The mechanism for this is VC likely extends beyond simple nitrogen contribution; as an organic amendment, it improves soil structure, enhances water holding capacity, and fosters beneficial microbial activity that facilitates the slow, consistent release of micronutrients essential for robust cell wall formation and hormonal signaling (Srivastava *et al.*, 2012). Therefore, the VC not only optimized the FSI to meet the intended purpose (elongated fruit for specialized markets/processing) but also did so through mechanisms that promote soil health and resource efficiency, which strongly addresses considerations of sustainable agronomic practice. These findings collectively establish that both high N fertilization and optimal VC application are effective strategies for precision fruit shape control.

4.5.3 Fruit pericarp thickness

The interaction between nitrogen and vermicompost significantly influenced fruit pericarp thickness ($P \leq 0.001$) (Appendix Table 5). As shown in Table 19, tomato plants treated with 350 kg N ha^{-1} and 7 t ha^{-1} vermicompost recorded the thickest pericarps (12.75 mm), whereas the lowest value (5.15 mm) was obtained from the control. The increase in pericarp thickness with combined nitrogen and vermicompost applications reflects improved nutrient bioavailability and soil health, promoting enhanced cell division during early fruit development.

Nitrogen plays a vital role in reproductive development and protein synthesis, both of which contribute to structural tissue formation within the pericarp. Vermicompost complements this effect by enhancing soil moisture retention and microbial activity, creating optimal conditions for sustained cell growth. These findings align with Alam *et al*. (2018), who reported thicker tomato pericarps (4.3–5.4 mm) under vermicompost based fertilization. The synergistic interaction between nitrogen and vermicompost, therefore, promotes both fruit size and firmness key determinants of tomato market and postharvest quality.

Pericarp thickness is an important determinant of fruit firmness, texture, and shelf life (Yang *et al.*, 2016). Thicker pericarps resist mechanical injury, moisture loss, and pathogen invasion during postharvest handling and transportation, thereby improving marketability (Bisht and Singh, 2024). The current result therefore suggests that the combined use of 7 t ha^{-1} vermicompost and 350 kg N ha^{-1} enhances not only fruit structural quality but also postharvest performance. Similar findings were reported by Islam *et al*. (2013), who observed increased firmness and shelf life of tomato fruits with integrated nutrient management involving organic amendments and nitrogen fertilizer.

Table 19. The interaction effects of vermicompost and nitrogen on fruit pericarp thickness

Nitrogen rate (kg ha^{-1})	Vermicompost rate (t ha^{-1})	Fruit pericarp thickness (mm)
0	0	5.15^{g}
	5	7.56^{de}
	7	8.257^{d}
175	0	6.36^{f}
	5	9.70^{c}
	7	10.66^{b}
350	0	7.423^{e}
	5	10.96^{b}
	7	12.75^{a}
LSD(0.05)		0.35
CV (%)		8.76

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.6 Chemical quality parameters

4.6.1 Total soluble solids (TSS)

The analysis revealed that nitrogen and vermicompost significantly influenced the total soluble solids (TSS) content (P $\leq$0.001) (Appendix Table 6).Total soluble solids (TSS, °Brix) were significantly affected by nitrogen and vermicompost (Table 20). The rise in TSS with moderate to high N rates is consistent with multiple reports showing that increasing N up to an optimum range raises soluble solids and sugar/acid balance in tomato fruit, likely via enhanced leaf photosynthesis and carbohydrate production and improved translocation of assimilates to fruit (Cheng *et al.*, 2021; Mao *et al.*, 2024). At the same time, several studies reported variable or context-dependent responses: some experiments found little or no change in TSS with N or responses that depended on N form, irrigation and crop management, indicating that soil water status and N timing can modify the effect of N on fruit soluble solids (Huang *et al.*, 2023; Ronga *et al.*, 2020). In short, our data fit the common pattern that supplying N from zero to agronomically moderate levels increases TSS, but further increases beyond an optimal range may give progressively smaller benefits or depend on other factors.

Vermicompost at 5 and 7 t ha^{-1} produced higher TSS than the control (3.26–3.36 °Brix vs 2.93 °Brix) (Table 20), suggesting that organic amendment improved fruit quality. This outcome agrees with that vermicompost and other well-matured organic amendments can improve tomato fruit quality by enhancing soil biology, nutrient availability (particularly N, P and K), and plant physiological status, thereby promoting carbohydrate accumulation in fruit (Wang *et al.*, 2017; Wu *et al.*, 2022). However, under some water regimes or where vermicompost increases fruit water content, soluble solids may be diluted and TSS can decline (Yang *et al.*, 2015). Taken together, the weight of evidence indicates vermicompost commonly benefits tomato fruit quality, but interactions with irrigation, salinity and baseline soil fertility determine the final TSS response.

4.6.2 Sugar -to -acid ratio (SAR)

The sugar-to-acid ratio (SAR) increased with applied nitrogen and with vermicompost. Specifically, SAR values were 5.15 0 kg N ha^{-1}, 5.31 at 175 kg N ha^{-1}, and 5.59 at 350 kg N ha^{-1} (Table 20). This indicates that the highest N rate produced a statistically higher SAR than the unfertilized control. Similarly, vermicompost raised SAR from 5.09 in the control to 5.45 at 5 t ha^{-1} and 5.52 at 7 t ha^{-1}, showing both vermicompost rates significantly improved SAR relative to control (Table 20).

The observed rise in SAR with increasing nitrogen likely reflects changes in the balance between soluble solids (sugars) and organic acids in fruit. Higher N availability can enhance canopy photosynthesis and carbohydrate production and/or accelerate fruit maturation processes that reduce acidity, thereby increasing TSS/TA ratio. At the same time, excessive N can favor vegetative growth at the expense of fruit quality in some systems, so the positive effect here suggests that 350 kg N ha^{-1} provided sufficient assimilate supply without excessive dilution of fruit sugars in this trial. The vermicompost effect is almost certainly driven by improved soil physical, chemical and biological condition. Vermicompost enhances nutrient availability, microbial activity and root function, which together increase carbohydrate synthesis and translocation to fruit and can lower titratable acidity, resulting in higher SAR.

The positive response of SAR to organic amendments, particularly vermicompost, is consistent with studies showing vermicompost increases carbohydrate transport to fruit and improves SAR and related quality traits under stress and non-stress conditions. Vermicompost has been reported to improve tomato fruit quality and to raise sugar/acid ratio by promoting photosynthetic efficiency and carbohydrate allocation to fruit (Wu *et al.*, 2023).

Studies of mineral nitrogen effects on tomato quality report variable outcomes depending on rate, timing and local conditions. Some researchers have observed increased SAR with increased N within the agronomic range interpreted as greater carbohydrate supply relative to acid synthesis while other studies find that reduced or moderate N can maximize SAR because very high N sometimes dilutes fruit sugars through excessive vegetative growth (Cheng *et al.*, 2021).

Table 20. Effect of nitrogen and vermicompost on total soluble solid (TSS) and sugar-to- acid ratio (SAR)

Rates of Nitrogen(kg ha^{-1})	TSS (^{0}Brix)	SAR
0	2.87^{b}	5.15^{b}
175	3.26^{a}	5.31^{ab}
350	3.43^{a}	5.59^{a}
LSD (0.05)	0.16	0.35
Rates of vermicompost(t ha^{-1})		
0	2.93^{b}	5.09b
5	3.26^{a}	5.45^{a}
7	3.36^{a}	5.52^{a}
LSD (0.05)	0.16	0.35
CV (%)	9.71	12.13

4.6.3. Titratable acidity (TA)

The control (0 kg N ha^{-1}) produced the lowest titratable acidity (0.55%), whereas both 175 and 350 kg N ha^{-1} produced higher TA (0.62%) and did not differ from each other (Table 21). In short, supplying mineral nitrogen raised fruit TA relative to the zero-N control, but increasing N beyond 175 kg ha^{-1} did not further increase TA in this experiment.

The observed increase in titratable acidity with N application indicates that nitrogen availability in the control was limiting processes that contribute to organic acid accumulation in tomato fruit. Several field and postharvest studies report similar outcomes: nitrogen fertilization can increase concentrations of organic acids and titratable acidity in tomato, often alongside increases in certain volatile compounds and soluble solids (Frías-Moreno *et al.*, 2020; Siueia Júnior *et al.*, 2020).

Nitrogen affects primary carbon and nitrogen metabolism in source leaves and sinks, altering synthesis and partitioning of carbohydrates and organic acids. Nitrogen supply modulates activities of enzymes (those involved in glycolysis and the tricarboxylic acid cycle) and amino-acid synthesis, which can change fruit acid pools and the measured TA (Luo *et al.*, 2023).our finding that TA plateaus at moderate N (175 kg ha^{-1}) with no further increase at 350 kg ha^{-1} is consistent with the concept that many tomato quality responses increase with N up to an optimum range.

Some trials report small or no changes in TA with N when soils are already fertile, when cultivar and maturity differences overcome N effects, or when altered irrigation/dilution dynamics change fruit water content (responses linked to harvest maturity and site fertility). For instance, studies on tomato harvest maturity emphasize that TA changes with stage of ripening and can decline with later harvests, which can interact with fertilization effects and confound simple N and TA relationships (Barringer *et al.*, 1999). While our data show a clear positive effect of adding N relative to zero, differences between zero and fertilized treatments may partly reflect initial soil N status, cultivar-specific responsiveness, and harvest timing..

Table 21. Effect of nitrogen on titrable acidity (TA)

Rates of fertilizer N (kg ha^{-1})	Titrable acidity (%)
0	0.55[b]
175	0.62[a]
350	0.62[a]
LSD(0.05)	0.03
CV (%)	9.20

Mean values followed by the same letter (s) in the same column are not significantly different at 5% level of significance.

4.7 Partial Budget Analysis

The partial budget analysis presented in Table 22 revealed notable differences in the economic viability of tomato production as influenced by nitrogen (N) and vermicompost (VC) fertilizer rates across the three tested varieties (GALILEA39, NUN TOP, AND ALBATROS). The analysis indicated that fertilizer combinations substantially affected both the net field benefit (NFB) and the marginal rate of return (MRR), reflecting the profitability of each treatment.

For the GALILEA39 variety, the combination of 175 kg N ha^{-1} and 7 t VC ha^{-1} produced the highest gross field benefit (487,800 Birr) and net field benefit (476,937.36 Birr) with a remarkable MRR of 2521.48%. Although a slightly higher N rate (350 kg ha^{-1} with 5 t VC ha^{-1}) resulted in a marginally higher gross benefit (504,720 Birr), the increase in total variable cost (11,984.55 Birr) reduced the marginal return (1408.14%). This implies that beyond the moderate N level (175 kg ha^{-1}), the economic gain diminished due to the increasing cost of fertilizer inputs. Hence, the 175–7 combination was the most economically efficient for GALILEA39.

Similarly, for the Nun Top variety, the combination of 175 kg N ha^{-1} and 7 t VC ha^{-1} provided the highest NFB (468,821.36 Birr) and an exceptionally high MRR of 5621.85%, indicating that this rate combination offered the best return per unit investment. Increasing N and VC rates beyond this point (350 kg N ha^{-1} and 7 t VC ha^{-1}) led to higher production costs without proportional yield or benefit increases, thus lowering profitability. This shows that moderate input levels optimized economic returns for this variety.

For ALBATRROS, the combination of 350 kg N ha^{-1} and 5 t VC ha^{-1} recorded the highest MRR (5210.50%) and a substantial NFB (441,999.45 Birr), suggesting that this combination achieved a favorable balance between input cost and yield benefit. However, a comparable performance was also noted at 175 kg N ha^{-1} and 5 t VC ha^{-1}, which yielded a slightly lower NFB (399,221.36 Birr) but still high MRR (4231.51%). This demonstrates that both moderate and high N applications could be economically beneficial for ALBATROS, though excessive N did not guarantee proportionate economic returns.

Thus, the results indicate that integrating moderate nitrogen rates (175 kg N ha^{-1}) with vermicompost rates between 5–7 t ha^{-1} provided the highest economic efficiency across all varieties. The elevated MRR values across treatments further confirm that combining organic and inorganic fertilizers enhances nutrient availability, improves soil health, and promotes yield stability, ultimately translating into greater profitability. Translating the research in to practice is challenging but, it doesn't matter how to recommend one of varieties for the farmers even the data is single season and single site data accordance with remarkable MRR.

These findings are consistent with previous reports that integrating vermicompost with inorganic nitrogen enhances fertilizer use efficiency and economic return by improving soil nutrient balance and microbial activity (Sharma *et al.*, 2019; Tesfaye *et al.*, 2021). Studies on tomato production also emphasize that moderate nitrogen rates combined with organic amendments enhance yield and economic gain without incurring high input costs (Yeshanew *et al.*, 2020; Ayalew *et al.*, 2022). Therefore, under the agro-ecological conditions of Bishana Guracha, applying 175 kg N ha^{-1} with 7 t VC ha^{-1} is recommended for GALILEA39 and Nun Top, while 350 kg N ha^{-1} with 5 t VC ha^{-1} is optimal for Albatros. These combinations maximize yield, profit, and resource use efficiency, ensuring sustainable tomato production.

Table 22. Partial budget analysis for tomato varieties as it affected by nitrogen (N) and vermicompost fertilizer rates in Bishana Guracha

Variety	N rate (kg ha^{-1})	VC rate (t ha^{-1})	Total variable cost (TVC) (Birr)	Change in TVC (Birr)	Gross field benefit (Birr)	Net Field Benefit (Birr)	Change in NFB (Birr)	Marginal rate of return (%)
GALILEA39	0	7	6,000.64		336,600	330,599.36		0
	175	5	9,942.55	3,941.91	463,680	453,737.45	123,138.09	3123.818
	175	7	10,862.64	920.09	487,800	476,937.36	23,199.91	2521.483
	350	5	11,984.55	1,121.91	504,720	**492,735.45**	15,798.09	1408.142
NUN TOP	0	5	4,367.64	----	325,800	321,432.36	-	0
	175	5	9,792.64	5,425.00	427,680	417,887.36	96,455.00	1777.972
	175	7	10,698.64	906.00	479,520	468,821.36	50,934.00	5621.854
	350	7	12,622.55	1,923.91	441,720	429,097.45	-	-
ALBATROS	0	5	4,400.64	---	254,520	250,119.36	-	0
	0	7	7,900.64	3,500.00	298,880	290,979.36	40,860.00	1167.429
	175	5	10,458.64	2,558.00	409,680	399,221.36	108,242.00	4231.509
	175	7	11,600.55	1,141.91	433,800	422,199.55	22,978.19	2012.259
	350	5	11,980.55	380	453,600	441,999.45	19,799.90	**5210.5**
.	350	7	12486.64	506.09	477,720	465,233.36	23,233.91	4590.865

5. SUMMARY AND CONCLUSION

5.1 Summary

The study was conducted at Shallo Farm, Bishan Guracha, during the 2016 E.C. main cropping season to evaluate the effects of integrated nitrogen and vermicompost fertilization on the growth, yield, fruit quality, and economic performance of tomato (*Lycopersicon esculentum mill.*) varieties. Three tomato varieties (GALILEA 39, NUN TOP, and ALBATROS) were tested under three nitrogen levels (0, 175, and 350 kg N ha^{-1}) and three vermicompost rates (0, 5, and 7 t ha^{-1}) in a factorial randomized complete block design with three replications. Data were collected on phenological, growth, yield, and fruit quality traits, while partial budget analysis was used to assess economic feasibility.

Results revealed significant effects of nitrogen and vermicompost levels, variety, and their interactions on most traits. Growth and quality parameters, including plant height, number of branches, leaf area, fruit set, and total yield, were markedly enhanced by the integrated application of nitrogen and vermicompost. GALILEA 39 exhibited superior performance, recording the highest fruit set (78.26%) and total yield (14.02 t ha^{-1}) under 350 kg N ha^{-1} combined with 5 t ha^{-1} vermicompost.

Nitrogen and vermicompost significantly influenced fruit quality: the chemical quality parameter TSS, SAR are significantly influenced by the main factor nitrogen and vermicompost whereas TA significantly influenced by the main factor nitrogen only. TA, on the other hand, responded only to nitrogen, rising from the control to the moderate and high N rates and then stabilizing, which reflects the role of nitrogen in supporting organic acid formation up to an optimal level.

The economic analysis demonstrated that integrated fertilizer use was more profitable than either source applied alone. The combination of 175 kg N ha^{-1} with 7 t ha^{-1} vermicompost generated the highest net field benefit (476,937.36 Birr) and marginal rate of return (2521.48%) for

GALILEA 39, whereas NUN TOP achieved an even higher profitability (MRR = 5621.85%) under the same treatment. For ALBATROS, the combination of 350 kg N ha^{-1} with 5 t ha^{-1} vermicompost was most economical (MRR = 5210.50%). These results confirm that moderate nitrogen levels integrated with vermicompost optimize both agronomic performance and economic returns.

5.2 Conclusion and recommendation

The study clearly demonstrated that integrating mineral nitrogen with vermicompost has a synergistic effect, enhancing tomato growth, yield, fruit quality, and profitability while improving soil fertility. The combination of 175 kg N ha^{-1} with 7 t ha^{-1} vermicompost proved most economically efficient for GALILEA 39 and NUN TOP, whereas 350 kg N ha^{-1} with 5 t ha^{-1} vermicompost was optimal for ALBATROS. This integrated nutrient approach ensures a balanced nutrient supply, and supports sustainable tomato production under Bishan Guracha conditions. However, excessive organic inputs (≥7 t ha^{-1}) did not provide additional benefits, emphasizing the importance of maintaining an optimal balance between organic and inorganic fertilizers.

For farmers, applying 175 kg N ha^{-1} with 7 t ha^{-1} vermicompost for GALILEA 39 and NUN TOP, and 350 kg N ha^{-1} with 5 t ha^{-1} vermicompost for ALBATROS, is recommended to achieve higher yields, improved fruit quality, and greater profitability. For soil fertility management, the continuous use of integrated nutrient sources should be encouraged to sustain soil fertility, enhance microbial activity, and improve long-term productivity. For researchers, future studies should focus on optimizing nitrogen–vermicompost ratios across different soil types, cropping seasons, and agro-ecological zones, and assess the long-term effects on soil health, carbon dynamics, and environmental sustainability. For extension services, strengthening farmer training and on-farm demonstrations on integrated nutrient management practices is vital to increase adoption, promote sustainable production systems, and enhance the profitability and resilience of tomato farming in Ethiopia.

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7. **APPENDICES**

Appendix Table 1. Analysis of variance for days to flowering, days to fruiting and days to maturity

Source of variation	DF	DTFL	DTFR	DTMR
Var	2	29.37*	19.79***	121.19***
N	2	77.37***	85.49***	625.97***
VC	2	115.11***	44.04***	154.97***
Var*N	4	0.85ns	1.32ns	0.34ns
Var*VC	4	0.75ns	0.99ns	0.84ns
N*VC	4	3.14ns	2.53ns	0.40ns
Var*N*VC	8	3.85ns	0.80ns	0.24ns
Error	52	4.05	2.09	0.42

*, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively, and ns stands for non-significant (p > 0.05). The abbreviations DTF L= days to flowering, DTFR= days to fruiting, and DTMR =days to maturity, DF= degree of freedom.

Appendix Table 2. Analysis of variance for plant height, leaf area, and number of primary branches, secondary branches, number of clusters per plant and number of fruit set percentages

Source of variation	DF	PH	LA	NPB	NOH	NSB	NOL
Var	2	32.78**	25.45***	5.03ns	0.11***	29.14***	147.0***
N	2	369.80***	1807.43***	84.32***	24.11***	1048.45***	10959.4***
VC	2	161.42***	1378.73***	86.56***	31.37***	167.20***	6546.6***
Var*N	4	29.65ns	15.06***	0.90ns	0.77ns	3.51	88.8*
Var*VC	4	35.69*	12.01***	0.56ns	0.64**	5.42	53.0ns
N*Vc	4	37.38*	221.57***	1.07ns	1.70**	7.36*	680.3***
Var*N*Vc	8	37.70*	3.74***	0.21	0.14	1.82ns	77.0***
Error	52	18.33	1.07	0.03	0.51	1.40	23.4

*, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively, and ns stands for non-significant (p > 0.05). The abbreviations PH= plant height, LA= leaf area, NPB= Number of primary branches, NOH= number of harvests, NSB= number of secondary branches, NOL = number of leaves

Appendix Table 3**.** Analysis of variance for number for number of flowers per cluster number of fruit per cluster, fruit set percentages, individual fruit weight and fruit diameter

Source of variation	DF	NFLPC	NFRPC	FSP	IFMW	FD
Var	2	1.11*	2.15***	195.65**	9433.3***	17.13***
N	2	11.09***	23.25***	1361.52***	21577.4***	908.39***
Vc	2	39.15***	82.44***	4374.05***	10140.2***	394.06***
Var*N	4	1.47***	0.38	22.74ns	2600.5***	3.29ns
Var*C	4	0.32ns	0.07	12.31ns	1173.2***	2.45ns
N*VC	4	0.26**	1.0189***	79.45ns	230.5***	4.818ns
Var*N*Vc	8	0.29ns	0.26	27.57ns	402.4**	2.94ns
Error	52	0.26	0.18	29.01	112.5	4.08

*, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively, and ns stands for non-significant ($p > 0.05$). The abbreviations stand for NOFLPC= number of flowers per cluster, NOFRPC= number of fruits per cluster, FSP =fruit set percentage, IFMW =individual fruit weight, and FD= fruit diameter, respectively.

Appendix Table 4. Analysis of variance for total and marketable fruit yield

Source of variation	DF	TFY (t ha^{-1})	MRFY (t ha^{-1})
Var	2	1.32ns	2.02ns
N	2	116.25***	110.17***
Vc	2	140.97***	155.39***
Var*N	4	1.66ns	1.63ns
Var*C	4	1.42ns	1.24ns
N*VC	4	5.29**	7.77**
Var*N*Vc	8	2.09**	2.47**
Error	52	0.738	0.629

*, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively, and ns stands Non-significant ($p > 0.05$). The abbreviations stand for TF= total fruit yield and MRFY =marketable fruit yield

Appendix Table 5. Analysis of variance for fruit length, width, pericarp thickness and shape index

Source of variation	DF	FL	FW	FSI	FPT
Var	2	0.01ns	0.28ns	0.02ns	0.62ns
N	2	1.86***	0.33ns	0.05*	78.04***
Vc	2	2.46***	0.51*	0.04*	130.26***
Var*N	4	0.27ns	0.07ns	0.01ns	1.02ns
Var*C	4	0.27ns	0.16ns	0.01ns	0.43ns
N*VC	4	0.15ns	0.05ns	0.01ns	2.90***
Var*N*Vc	8	0.11ns	0.31ns	0.01ns	0.82ns
Error	52	0.14	0.12	0.01	0.58

*, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively, and ns stands for non-significant ($p > 0.05$). The abbreviations stand for FL= fruit length, FW= fruit width, FSI= fruit shape index and FPT = precarpy thickness.

Appendix Table 6. Analysis of variance for TSS, TA and SAR

Source of variation	DF	TSS	TA	SAR
Var	2	0.01ns	0.00ns	0.05ns
N	2	2.20***	0.03**	1.36*
Vc	2	1.36***	0.01ns	1.44*
Var*N	4	0.04ns	0.001ns	0.33
Var*C	4	0.01ns	0.002ns	0.13
N*VC	4	0.17ns	0.007ns	0.35
Var*N*Vc	8	0.15ns	0.001ns	0.65
Error	52	0.09	0.001	0.42

*, **, and *** are significant at 5%, 1%, and 0.1% probability levels, respectively, and ns stands for non-significant ($p > 0.05$). The abbreviations stand for precarppy total TSS= total soluble solid and TA= titrable acidity.

Appendix Table 7. Partial budget analysis of tomato varieties to varying levels nitrogen (N) and vermicompost fertilizer in Bishana Guracha

Variety	N rate (kg ha^{-1})	VC rate (t ha^{-1})	Avy (kg ha^{-1})	Adjy (kg ha^{-1})	TVC (Birr)	GFB (Birr)	NFB (Birr)
GALILEA39	0	0	5970	5373	3,000.64	214,920	211,919.36D
		5	7080	6372	4,800.64	254,880	250,079.36D
		7	9350	8415	6,000.64	336,600	330,599.36N
	175	0	8053	7247.7	8,564.64	288,988	280,423.36D
		5	12880	11592	9,942.55	463,680	453,737.45N
		7	13550	12195	10,862.64	487,800	476,937.36N
	350	0	7550	6795	9,253.64	271,800	262,546.36D
		5	14020	12618	11,984.55	504,720	492,735.45N
		7	12890	11601	12,713.86	464,040	451,326.14D
NUN TOP	0	0	5410	4869	2,643.55	194,760	192,116.45D
		5	9050	8145	4,367.64	325,800	321,432.36N
		7	9130	8217	5,900.55	328,680	322,779.45D
	175	0	7500	6750	8,360.69	270,000	261,639.31D
		5	11880	10692	9,792.64	427,680	417,887.36N
		7	13320	11988	10,698.64	479,520	468,821.36N
	350	0	8240	7416	8,800.55	296,640	287,839.45D
		5	11470	10323	11,842.64	412,920	401,077.36D
		7	12270	11043	12,622.55	441,720	429,097.45N
ALBATROS	0	0	6160	5544	2,500.64	221,760	219,259.36D
		5	7070	6363	4,400.64	254,520	250,119.36N
		7	8300	7470	7,900.64	298,880	290,979.36N
	175	0	8470	7623	8,200.05	304,920	296,719.95D
		5	11380	10242	10,458.64	409,680	399,221.36N
		7	12050	10845	11,600.55	433,800	422,199.55N
	350	0	8300	7470	8684.64	298,800	290,115.36D
		5	12600	11340	11600.55	453,600	441,999.45N
.		7	13270	11943	12486.64	477,720	465,233.36N

Price of 1 kg tomato fruit = 40 birr kg-1, price of total seed of three varieties = 26,325, Avy = average yield, Adjy = 10% adjusted yield, TVC = Total variable cost, GFB = Gross field benefit, NFB = Net field benefit, N = Non-dominated, D = dominated whereas AB, GL AND NT where stands variety of tomato (ALBATROS, GALILEA and Nun Top) and (0,175 and 350 kg ha^{-1}) are the levels of nitrogen and (0, 5 and 7 t ha^{-1}) levels of vermicompost

BIOGRAPHICAL SKETCH

The author, Beyene Bekele, was born on 18 July 1990 in the Konta Zone South, West Regional State of Ethiopia, to his father, Bekele Gudeta, and his mother, Melate Mekuria. He attended elementary school at Ameya Primary School from 2002 to 2009 and Ameya Secondary and Preparatory School. After completing her primary and secondary education, he joined Ameya Preparatory School from 2007 to 2009. Then, after successfully passing his Higher Education Entrance Qualification Examination, he joined Debark University College of Agriculture in 2010 to pursue a study leading to the degree of Bachelor of Science. He graduated with a B.Sc. degree in horticulture in February 2014. Soon after graduation, he was employed by Debark University as a graduate assistant lecturer in the department of horticulture. After serving for one year, he joined the School of Graduate Studies of Hawassa University in October 2015 to pursue a study leading to the degree of Master of Science in plant science (Specialization: Horticulture).