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Effect of Staking Methods on the Growth and Yield of Tomato (*Solanum lycopersicum* L.) Cultivars in Raya Azebo District, Southern Tigray, Ethiopia

By

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A thesis

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DECLARATION

I, **<u>Mola Berhe Shayne</u>** hereby present for consideration by the Dryland Crops and Horticultural Science Department within the College of Dryland Agriculture and Natural Resources at Mekelle University, my dissertation in partial fulfilment for the requirement of the degree of Masters Science (M.Sc.) in "**Effect of Staking Methods on the Growth and Yield of Tomato (*Solanum lycopersicum* L.) Cultivars in Raya Azebo District, Southern Tigray, Ethiopia".** I sincerely declare that this thesis is the product of my own efforts. No other person has published a similar study which I might have copied, and at no stage will this be published without my consent and that of the Dryland Crops and Horticultural Science Department.

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Effect of Staking Methods on the Growth and Yield of Tomato (Solanum lycopersicum L.) Cultivars in Raya Azebo District, Southern Tigray, Ethiopia

ABSTRACT

In Ethiopia, tomato (Solanum lycopersicum L.) holds significant economic and nutritional value, but low productivity persists due to insufficient use of improved agronomic techniques, especially staking systems and hybrid cultivars. This study evaluated the effects of staking methods on the growth, yield, fruit quality, and economic returns of hybrid tomato cultivars under the semi-arid conditions of Raya Azebo District, Southern Tigray and Ethiopia. A field experiment was conducted during the 2024/2025 cropping season at Desta Farm using a 3 × 4 factorial arrangement in a split-plot design with three replications. Three hybrid cultivars (Abale F1, Gelilea F1, and Jarrah F1) were assigned to main plots, with four staking methods (non-staking, single-post, French-type, and vertical staking) allocated to sub-plots. Data on phenological traits, growth parameters, yield components, and economic performance were collected and analyzed using ANOVA in using a genstate18th edition with mean separation by the LSD test at the 5% significance level. Results indicated that staking methods, cultivars, and their interaction had significant ($p < 0.05$) effects on all parameters. French-type staking consistently outperformed the other methods by promoting earlier flowering (46.56 days), earlier maturity (77.11 days), and higher fruit set (71.5%), and improved fruit size (6.24 cm) and weight (103.3 g). Jarrah F1 exhibited superior vegetative growth and reproductive efficiency among the cultivars. The interaction of Jarrah F1 with French-type staking produced the highest marketable yield (136.0 t ha^{-1}), total yield (149.6 t ha^{-1}), net benefit (8,157,727 ETB ha^{-1}), and marginal rate of return (8,734%), whereas Abale F1 under non-staking produced the lowest marketable (59.3 t ha^{-1}) and total yield (76.1 t ha^{-1}). Overall, integrating Jarrah F1 with French-type staking substantially improves tomato productivity and economic returns in Raya Azebo District and was recommended for adoption, subject to further multi-location and multi-season validation.

Keywords: Economic Profitability, French Type Staking, Hybrid Cultivars, Jarrah F1, Marginal Rate of Return, Marketable Yield

DEDICATION

This M.Sc. thesis is dedicated to my family and close friends for their continuous support, encouragement, and sacrifices, which have greatly contributed to my success.

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Full Meaning
ANOVA	Analysis of Variance
CSA	Central Statistical Agency
D	Dominated
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GB	Gross Benefit
Ha	Hectare
LSD	Least Significant Difference
MhARC	Mehoni Agricultural Research Center
MRR	Marginal Rate of Return
NB	Net Benefit
SAS	Statistical Analysis Software

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CHAPTER- ONE

1 INTRODUCTION

Background

On a global scale, tomato ranks as the second most widely produced vegetable, trailing only potato. It is cultivated on all continents and holds considerable economic value. This crop belongs to the Solanaceae family and has its origin in western South America (Melkamu et al., 2016). Tomatoes are nutritionally dense, supplying essential vitamins (A, B, and C), minerals, dietary fibre, and antioxidants notably lycopene all of which contribute to better human health and a lower risk of chronic diseases (Falak et al., 2011; Tesfaye et al., 2023).

According to FAOSTAT (2024), China leads global tomato production with 70,119,694 tonnes (achieving a yield of 63.33 t/ha), followed by Egypt with 6,211,016 tonnes (at a yield of 36.36 t/ha). This vegetable plays a crucial role in food security, income generation, and job creation across numerous developing regions, where horticulture sustains millions of rural livelihoods (Jafar et al., 2024). Despite its worldwide importance, tomato productivity differs substantially among countries, owing to variations in cultivars, agronomic practices, and environmental limitations.In Ethiopia, tomato is an important vegetable crop, grown during both the rainy and dry seasons by smallholder farmers, private investors, and state-owned farms. However, the nation's average yield stands at only 6.76 t ha^{-1} (CSA, 2018/19), which is markedly below the global average of more than 37.1 t ha^{-1} (FAOSTAT, 2020/22). The causes of low yields include inadequate agronomic techniques, restricted access to improved cultivars, poor nutrient and water management, pest and disease pressures, and weak post-harvest handling systems (Tesfaye et al., 2023).

Tomato growth and yield are limited by a shortage of improved varieties and inefficient agronomic approaches, including staking (Wubetie & Wubetu, 2025). Staking refers to the technique of supporting tomato plants using wooden stakes, wires, trellises, or cages to keep them growing upright; this practice is essential for enhancing plant architecture and fruit quality (Njoku, 2023). It improves light penetration, facilitates air circulation, reduces contact between fruit and soil, and lowers the occurrence of diseases such as early blight and bacterial wilt (Masrie, 2023). Research conducted in Nigeria and Eastern Ethiopia has shown that staked tomato plants exhibit better vegetative growth, a higher rate of fruit set, greater marketable yield, and increased profitability compared to unstaked plants (Njoku, 2023; Jafar et al., 2024).

In spite of these proven benefits, the uptake of staking practices in Ethiopia particularly within the Tigray Region remains low. Smallholder farmers frequently depend on traditional production systems, pointing to limited knowledge, labour shortages, and a lack of staking materials as major obstacles. As a result, tomato productivity in the region stays far below its potential, with an average yield of roughly 5 t ha^{-1} (CSA, 2018/19). In the Raya Azebo district, where tomato farming is increasingly expanding for both market sale and household consumption, low productivity continues due to the restricted use of improved cultivars and ineffective staking systems.

Given these challenges, a clear need exists for systematic research to determine appropriate staking methods and high-performing tomato cultivars that are well-suited to the district's agro-ecological conditions. Consequently, this study was undertaken to assess the effects of various staking techniques on the growth and yield components of selected tomato cultivars under the production conditions prevalent in Raya Azebo districtt.

Statement of the Problem and Justification

Tomato (*Solanum lycopersicum* L.) is a key vegetable crop in Ethiopia, contributing to food security, income generation, and employment for both smallholder and commercial farmers (FAO, 2020 cited in MoA, 2021). According to FAOSTAT (2020–2022), the worldwide average tomato yield was 37.1 tonnes per hectare, while Africa's average was considerably lower at 13.4 tonnes per hectare. In the 2020/21 Meher season, tomatoes were grown on roughly 5,460.56 hectares across Ethiopia, with 366.10 hectares in the Tigray region alone underscoring the crop's importance at both national and regional levels.. Despite this, productivity remains low, with national and Tigray yields of 6.76 t ha^{-1} and 5 t ha^{-1}, respectively (CSA, 2018/19, 2022), far below attainable levels indicated by international and African yield benchmarks.

A primary cause of the yield gap is the low use of high yielding F1 hybrids and poor adoption of supportive agronomic measures such as staking (Wubetie & Wubetu, 2025). In Raya Azebo District, where conditions are highly suitable farmers mostly grow tomatoes without staking or use only on traditional support systems, and hybrid cultivar use is minimal. This exposes fruits to soil contact, causing cracking, rotting, mechanical damage, and increased disease, which substantially reduce marketable yield Compared to well-staked systems, unstaked tomato production can lead to yield losses of up to 65%. Additionally, hybrid varieties can achieve more than 50% higher yield and better quality than local ones (Wubetie & Wubetu, 2025). Staking also improves canopy structure, light interception, photosynthesis, and disease management. Nevertheless, adoption is constrained by high seed costs, limited availability, inadequate farmer awareness, and weak extension services (Islam et al., 2016; Bekele *et al*., 2024; Wubetie & Wubetu, 2025).

Despite the recognized benefits of staking practices and hybrid tomato cultivars in improving productivity, their combined performance under the specific agro-ecological conditions of Raya Azebo District remains poorly documented. The absence of locally generated, integrated evidence limits the ability of farmers and extension agents to make informed decisions on appropriate staking–cultivar combinations. This knowledge gap contributes to suboptimal yields, reduced fruit quality, increased postharvest losses, and lower economic returns, thereby constraining the sustainability and profitability of tomato production among smallholder farmers in the district.

Objectives

1.1.1 General Objective

- To assess the effect of different staking methods on growth and yield components of Tomato cultivars in Raya Azebo district

1.1.2 Specific Objective

- To evaluate the yield and yield components of tomato cultivars under different staking methods
- To determine the interaction effect of different staking methods and cultivars on yield and yield components of tomato
- To estimate the economic efficiency of staking materials and methods

Hypothesis of the Study

H_0; In Raya Azebo District, there are no significant differences in tomato growth, yield, and quality among the different cultivars, staking methods, or their interaction effects,

Ha; In Raya Azebo district, there is a significant difference in tomato growth, yield, and quality among different tomato cultivars, staking methods, or their interaction.

Scope of the Study

This study focused on examining how various staking techniques influence the growth and yield components of tomato cultivars within the Raya valley. Tomato cultivation is widespread in the Raya Azebo district. A comparison was made among four staking approaches (no staking, single-post staking, vertical staking, and French-type staking) across three distinct tomato culitvars.

Significance of the Study

The outcomes of this research are expected to assist scholars in conducting further investigations within this domain by offering insights into how various staking techniques affect different tomato varieties. Furthermore, agricultural advisors and extension personnel will obtain practical, evidence-based guidance regarding the most productive combination of staking approach and tomato cultivar, which will allow them to provide focused training and extension support

CHAPTER- TWO

2 LITERATURE REVIEW

Origin and Domestication of Tomato Plant

The wild predecessors of the tomato plant trace their origins to the Andes region, which corresponds to present-day Peru and Ecuador. Domestication of the crop occurred in Mexico, and it was later brought to Europe by Spanish explorers during the 16th century. From Europe, the tomato subsequently spread to other continents around the world (Blanca et al., 2015).

The taxonomic classification of tomato has undergone changes over time. Initially, Carl Linnaeus named the species Solanum lycopersicum in 1753. Later, Miller reclassified it as Lycopersicon esculentum. However, with the advent of molecular phylogenetic studies, researchers have returned to Linnaeus's original naming system. Consequently, Solanum lycopersicum is now the widely accepted scientific name (Peralta & Spooner, 2019). Wild relatives of the cultivated tomato continue to grow naturally in parts of South America. These wild species have been invaluable for contemporary breeding programmes because they possess substantial genetic diversity (Razali et al., 2022).

Tomato Introduction and Cultivation in Ethiopia

There is no precise historical record indicating the exact time when tomato was first introduced into Ethiopia. Nevertheless, historical accounts suggest that its introduction took place sometime between 1935 and 1940 (Samuel et al., 2009, as cited in Gemechis et al., 2012). Since that period, tomato has grown to become one of Ethiopia's most extensively grown vegetable crops. It is cultivated under both rain-fed and irrigated conditions, involving smallholder farmers as well as commercial producers (MoA, 2022; FAO, 2021).

Tomato farming is distributed across a range of agro-ecological zones within Ethiopia, typically at elevations between 700 and 2000 metres above sea level. The annual rainfall in these areas generally ranges from 700 to 1400 mm (Birhanu & Ketema, 2010; Gebremedhin et al., 2021). Production systems vary considerably, from small backyard gardens to large-scale commercial greenhouse operations. Although tomato is profitable and capable of improving the livelihoods of smallholder farmers, productivity remains low when compared to global benchmarks. The primary reasons for this include disease pressure, suboptimal agronomic practices, and post-harvest losses (Tadesse et al., 2023).

Ecological Requirement of Tomato

Tomato plants grow best as a warm-season crop, with optimal temperatures for growth falling between 20 and 28°C. When temperatures drop below 12°C, both the plants and their fruits become vulnerable to physiological damage (Heuvelink, 2018). The crop can adapt to various soil types, although it achieves the best performance in well-drained loamy soils with a pH ranging from 6.0 to 6.8. Due to its vigorous growth habit and extended fruit-bearing period, tomato is considered a heavy feeder that requires substantial nutrient inputs, especially nitrogen, phosphorus, and potassium (Dorais et al., 2021).

Global Tomato Production and Constraints

On a global scale, tomato (Solanum lycopersicum L.) ranks as one of the foremost vegetable crops, grown extensively both for fresh consumption and for processing. In 2023, worldwide harvest exceeded 192 million tonnes, making it the most produced vegetable crop in the world. China and Egypt dominate production, with China alone contributing more than one-third of the total volume (FAO, 2024).

Despite this remarkable production volume, tomato cultivation encounters several constraints that considerably reduce both yield and marketable output. Biotic stresses represent a major challenge; these include insect pests such as whiteflies and fruit borers, fungal pathogens like early blight, late blight, and

Fusarium wilt, bacterial diseases including bacterial wilt and canker, and devastating viral infections such as tomato yellow leaf curl virus. These remain among the most critical problems worldwide (Ofuya et al., 2023). In addition, abiotic stresses such as drought, salinity, and extreme temperatures further restrict productivity, especially in arid and semi-arid regions (Deribe et al., 2024). Post-harvest losses are also substantial, with estimates indicating that 25–42% of global tomato production is lost along the supply chain due to poor handling, inadequate storage, and the lack of cold-chain infrastructure (Deribe et al., 2024; Kitinoja & Thompson, 2019). While advanced greenhouse systems in developed countries, such as those in the Netherlands, can achieve yields exceeding 500 t ha^{-1}, smallholder farmers in Africa and Asia often obtain less than 20–30 t ha^{-1}. This disparity illustrates the vast global yield gap and the strong influence of production technology, seed quality, and management practices (WUR, 2023; FAO, 2024). Addressing these constraints demands integrated strategies that combine improved cultivars, sustainable pest and disease management, efficient irrigation, and strengthened post-harvest systems to enhance both yield and quality of tomato production worldwide.

Tomato Production and Constraints in Africa

Tomato (Solanum lycopersicum L.) is a key horticultural crop in Africa, making significant contributions to household nutrition, food security, and rural livelihoods. However, yields remain low, frequently ranging from 5 to 15 tonnes per hectare, compared to over 60 tonnes per hectare achievable under optimal management in advanced production systems (Shamil et al., 2017; Tabe-Ojong, 2022). This productivity gap is driven by multiple constraints. Farmers experience limited access to quality inputs such as improved seeds, fertilizers, and irrigation facilities. This is coupled with weak extension support that restricts the adoption of modern agronomic practices (Tabe-Ojong, 2022; Gwebu & Matthews, 2018). Biotic stresses, including the tomato leaf miner (Tuta absoluta) and fungal pathogens such as Fusarium spp. and Alternaria spp., cause severe pre-harvest yield losses (Campos et al., 2017; Tabe-Ojong, 2022). Abiotic constraints such as water scarcity, heat stress, and poor soil fertility further undermine productivity, particularly in semi-arid zones (Gwebu & Matthews, 2018). Beyond these, the absence of staking practices represents a critical agronomic limitation. Studies indicate that unstaked tomato plants are more prone to lodging, disease incidence, and fruit rotting due to contact with the soil, resulting in reduced marketable yields (Ogundare et al., 2016). Similarly, limited access to high-yielding and disease-resistant F1 hybrids constrains production potential, as many smallholders continue to rely on low-performing local varieties because of high seed costs and supply bottlenecks (Akinwale & Odiyi, 2021; Tabe-Ojong, 2022). Post-harvest losses, often exceeding 30% in African tomato value chains due to poor handling, storage, and transport, exacerbate these challenges (Shamil et al., 2017). Addressing these constraints requires integrated strategies that promote wider adoption of F1 cultivars, encourage low-cost staking systems, and strengthen input delivery, pest management, and post-harvest infrastructure.

Tomato Production and Constraints in Ethiopia

In Ethiopia, tomato is a key horticultural commodity grown across regions such as Oromia, Amhara, Tigray, and the Southern Nations, Nationalities, and Peoples' Region (SNNPR). It serves both home consumption and cash income purposes (Girma & Gemechu, 2020). However, national average yields remain low at about 4.37 t ha^{-1} (CSA, 2021), far below the crop's potential. This yield gap is influenced by multiple constraints encompassing biotic, abiotic, and socio-economic factors. Biotic factors include insect pests such as Tuta absoluta, whiteflies (Bemisia tabaci), and aphids, as well as fungal and bacterial diseases including early blight (Alternaria solani), late blight (Phytophthora infestans), Fusarium wilt, and bacterial wilt (Ralstonia solanacearum) (Mekonnen et al., 2019; Shamil et al., 2017). Abiotic constraints such as water scarcity, erratic rainfall, high temperatures, and low soil fertility further restrict production, particularly in rain-fed systems (Girma & Gemechu, 2020).

A critical factor contributing to low productivity is the lack of staking, which results in sprawling plants, increased fruit-soil contact, higher disease incidence, and reduced air circulation within the canopy (Shamil et al., 2017; Gwebu & Matthews, 2018). Studies in Ethiopia have demonstrated that non-staked systems can reduce marketable yields compared to staked plants, highlighting staking as a low-cost, high-impact intervention (Masrie & Girma, 2023; Mekonnen et al., 2019). Additionally, the adoption of F1 hybrid cultivars – which generally possess higher vigour, uniform fruit set, and disease tolerance – remains limited among smallholder farmers due to high seed costs and poor availability (Bekele et al., 2024; Masrie & Girma, 2023). The combination of a lack of improved cultivars, inadequate staking, pest and disease pressures, water and soil fertility constraints, and weak extension support collectively reduces yield potential and fruit quality. Addressing these challenges requires integrated management strategies that include the use of F1 hybrids, proper staking, optimized irrigation, fertilization, and pest/disease control. Such approaches can significantly improve both productivity and profitability in Ethiopian tomato production systems.

Tomato Production and Constraints in Tigray

The Tigray region of northern Ethiopia possesses suitable agro-ecological conditions for tomato cultivation, especially in irrigated lowland areas. Studies conducted in this region report varying yields among improved varieties. In Tigray, tomato (Solanum lycopersicum L.) plays an important role as a horticultural crop, supporting household food security and the incomes of small-scale farmers. The crop is grown across diverse agro-ecological zones, including highland and lowland areas, with irrigation supporting production in semi-arid zones. Despite its potential, tomato productivity in Tigray remains low, at approximately 5 t ha^{-1} (CSA, 2018/19, 2022). This yield gap is attributed to multiple biotic, abiotic, and socio-economic constraints mong the biotic constraints are insect pests like the tomato leaf miner (Tuta absoluta), aphids, and whiteflies, along with fungal and bacterial diseases such as early blight (Alternaria solani), late blight (Phytophthora infestans), Fusarium wilt, and bacterial wilt (Ralstonia solanacearum) (Mekonnen et al., 2019). Abiotic factors, particularly drought, erratic rainfall, high temperatures, and declining soil fertility, further reduce productivity, especially in rain-fed systems (Shamil et al., 2017). Socio-economic constraints, such as limited access to quality inputs, weak extension services, and poor post-harvest handling, exacerbate these challenges (Shamil et al., 2017). The absence of staking limits plant support, increasing fruit-soil contact and disease incidence, while the limited availability and adoption of high-yielding F1 hybrid cultivars restricts the potential for improved productivity and marketable fruit quality (Mekonnen et al., 2019). Addressing these constraints requires integrated strategies that combine improved agronomic practices such as staking, access to F1 hybrid seeds, efficient irrigation and fertilization, pest and disease management, and enhanced post-harvest handling. These measures are needed to boost both yield and profitability for smallholder tomato farmers in Tigray.

Tomato Production and Constraints in Raya Azebo District

Tomato (Solanum lycopersicum L.) is a major vegetable crop in Raya Azebo District, contributing to both household nutrition and cash income under small-scale irrigated systems. Despite favourable agro-ecological conditions, average yields remain low compared to the potential achievable under improved agronomic practices such as staking, pruning, and regulated irrigation (Tesfaye et al., 2020). Production is constrained by limited adoption of staking and hybrid cultivars, high pest and disease pressure including early blight, late blight, and tomato yellow leaf curl disease, emerging parasitic weeds such as broomrape (Orobanche spp.), irrigation challenges, and weak input and market systems (Hailu &

Gizachew, 2021). Addressing these constraints through integrated crop management, improved irrigation, and strengthened institutional and market support is essential to unlock the full productivity and profitability potential of tomato in Raya Azebo.

Staking Methods in Tomato Production

The selection of an appropriate support system is critical for tomato production because it influences plant architecture, fruit quality, and overall yield. Staking – using stakes, trellises, or strings – keeps vines upright, lifts fruit off the ground, improves light interception and air movement, and reduces disease pressure. These benefits collectively enhance vegetative growth and marketable output (Olasantan, 1985; Alam et al., 2016).

2.1.1 Single-Post (Single-Stake) Method

In the single-post staking system, each tomato plant is supported by a vertical stake made of bamboo, metal, or wood. The main stem is tied to the stake at regular intervals. This approach is labour-efficient for smallholder farmers and successfully maintains an upright plant structure, which enhances air circulation and sunlight penetration throughout the canopy. Research conducted in Ethiopia found that staked tomato plants exhibited better canopy management, lower disease incidence, and higher marketable yields compared to unstaked plants (Wubetie & Wubetu, 2025). In a similar vein, Alam et al. (2016) reported that staking combined with light pruning improved both average yield and fruit uniformity, as the fruits were kept off the ground and received even light exposure. Although it is simpler than trellis or French-type staking systems, the single-post method remains one of the most economical options for semi-commercial tomato production, especially when regular tying and pruning are carried out.

2.1.2 Vertical (String or Trellis) Staking

In vertical staking systems, strings, wires, or trellises are used to guide tomato vines upward. This promotes an orderly canopy and makes efficient use of vertical growing space. This approach improves light capture and airflow, lowers the incidence of foliar diseases, and simplifies pest management and harvesting. According to Wubetie and Wubetu (2025), vertically staked tomatoes in northwestern Ethiopia produced substantially higher total and marketable yields compared to unstaked plants, thanks to better fruit exposure and less contact with the soil. Supporting these results, Alam et al. (2016) found that vertically trained plants showed improved fruit quality traits, such as greater average fruit weight and reduced cracking, relative to unsupported plants. Although vertical staking demands more initial labour and materials, it is strongly advised for intensive tomato production aimed at maximising yield per unit area.

2.1.3 French-Type (Cross-Trellis) Staking

French-type staking uses intersecting horizontal and vertical supports to form a grid that holds several stems from each plant. This design prevents stems from breaking, supports large fruit clusters, and maintains an even canopy structure. Under the conditions in Jimma, Mohammed (2013) found that multi-point staking greatly increased both fruit size and total yield in indeterminate tomato varieties compared to unstaked plants. Gojeh et al. (2012) reported that, relative to single-stake or sprawling methods, French-type staking resulted in more marketable fruits and better fruit uniformity. Although this system requires more labour to construct, its ability to minimise fruit contact with the soil and improve light distribution makes it particularly effective for large-fruited and indeterminate tomato types.

2.1.4 Non-Staked (Sprawling) Cultivation

Non-staked or sprawling systems allow tomato vines to grow naturally across the ground. While this method reduces expenses for materials and labour, it leads to thicker canopies, poor air movement, and increased fruit contact with the soil – conditions that encourage rot, sunscald, and pest problems. Olasantan (1985) reported that unstaked tomato plants produced much lower yields and experienced greater disease pressure than staked ones. Similarly, Gojeh et al. (2012) found that sprawling cultivation raised the share of unmarketable fruits due to cracking and physical damage. Therefore, although non-staked production may work for low-input farming, it reduces fruit quality and overall yield.

Effect of Staking on Growth Parameters of Tomato

For hybrid tomato types, providing structural support through staking helps maintain upright growth, reduces lodging, and improves canopy exposure to light and air. These benefits lead to greater plant height, increased branching, and more leaf area, all of which contribute to stronger vegetative development (Jensen et al., 2019; Singh et al., 2021). Research findings indicate that providing structural support to tomato plants increases their height, branch count, and leaf area relative to unsupported plants (Melkamu et al., 2022). Research conducted in Ethiopia demonstrated that vertical string staking significantly increased plant height by 25–30% and the number of leaves per plant by 20% relative to non-staked controls, resulting in improved photosynthetic efficiency and stronger vegetative growth (Tilahun et al., 2022). The French or V-type staking system also supports better branch development and reduces stem breakage, particularly in heavily fruited plants, ensuring sustained vegetative growth throughout the production period (Melkamu et al., 2022). Conversely, non-staked plants often experience sprawling, reduced light exposure, higher humidity around the foliage, and increased susceptibility to diseases, all of which limit vegetative growth and compromise plant development (Singh et al., 2021). Thus, staking not only enhances structural stability but also significantly improves growth parameters, laying the foundation for higher fruit yield and quality.

Effect of Staking on Yield and Yield Components

Supporting crops with stakes, trellises, or other structures is a common practice to boost growth, productivity, and fruit quality. For indeterminate crops like tomato, cucurbits, and yams, such support is especially beneficial because it keeps plants upright, improves airflow, and allows better light distribution. These conditions promote plant health and ultimately increase yields (Jensen et al., 2019; Singh et al., 2020). Moreover, staking helps minimise contact between fruits and soil, reducing the incidence of soil-borne diseases and pest infestations, which can further improve marketable yield (Wubetie, 2023).

Several studies have demonstrated the positive influence of staking on yield components. In tomato cultivation, Wubetie (2023) reported that varieties subjected to single-string staking produced significantly higher numbers of fruits per plant compared to unstaked varieties. For instance, the Miya variety yielded 63.86 fruits per plant with staking, whereas the Cochero variety produced only 22.94 fruits per plant without support. Similarly, in cucurbitaceous crops, staking has been shown to increase fruit weight, length, diameter, and the number of marketable fruits per plant (Pradhan et al., 2021; Ekwu et al., 2017). In cucumber, Asamoah (2022) observed that staking methods significantly improved both vegetative growth and fruit yield, emphasising the importance of appropriate staking techniques for optimal crop performance.

The impact of staking on total yield has also been well documented. Wubetie (2023) found that the Metadel tomato variety under single-string staking recorded the highest fruit yield, reaching 96.25 t/ha in the 2021/22 season and 103.72 t/ha in 2022/23. In tuber crops such as yam (Telfairia occidentalis), staking increased tuber yield by 34–105% compared to unstaked plants, with the highest yields correlated with optimal stake density per hectare (Ndegwe et al., 1990). These findings indicate that staking not only improves individual yield components but also substantially enhances overall productivity.

In addition to yield improvements, staking provides ancillary benefits that support sustainable crop production. Elevated plants experience improved light interception, which enhances photosynthetic efficiency, while the structured growth reduces competition from weeds. Furthermore, by reducing fruit-soil contact, staking lowers the risk of rot and other soil-borne diseases, leading to higher quality produce suitable for market (Wubetie, 2023; Asamoah, 2022).

Interaction between Tomato Cultivars and Staking Methods in Semi-Arid and Smallholder Farming Systems

The interaction between tomato cultivars and staking methods is a key determinant of growth, yield components, and overall productivity, particularly in semi-arid regions where water scarcity and disease pressure are prevalent. Indeterminate cultivars, which continue vegetative growth throughout the season, generally benefit more from staking than determinate cultivars, as staking supports vertical growth, prevents lodging, and facilitates improved light penetration and air circulation (Wubetie & Wubetu, 2025; Asamoah, 2022). These improvements enhance fruit set, fruit size, fruit weight, and total yield.

Research in northwestern Ethiopia demonstrated that the Metadel cultivar, when combined with single-string staking, achieved the highest total fruit yield per hectare in consecutive seasons, with values of 96.25 t/ha and 103.72 t/ha, and marketable yields of 91.09 t/ha and 96.97 t/ha (Wubetie & Wubetu, 2025). In the same way, the Miya cultivar supported with French-type staking gave the greatest count of marketable fruits per plant. In contrast, plants grown without any support had the largest share of unmarketable fruits, mainly because they were more exposed to soil-borne diseases and physical injury (Wubetie & Wubetu, 2025). These results highlight that staking techniques should be matched with the specific characteristics of each variety in order to achieve the best possible yield and fruit quality.

In other semi-arid regions, such as India and Pakistan, indeterminate tomato cultivars grown on vertical trellis or string support systems produced larger and heavier fruits with improved yield compared to unstaked plants, while determinate cultivars benefited from staking methods suited to their compact growth habit (Kumar et al., 2019; Khan et al., 2021). Structural support reduces stem breakage, facilitates uniform nutrient distribution, and decreases fruit-soil contact, thereby enhancing fruit quality and productivity.

These interactions are highly relevant to smallholder farming systems, where resources and water are limited. Implementing appropriate staking techniques helps mitigate stress factors such as drought and disease, enabling smallholder farmers to increase productivity and income (JICA, 2021). In conclusion, the interaction of tomato cultivars with staking methods significantly affects fruit set, size, weight, and marketable yield. Understanding these interactions allows growers, particularly in semi-arid and smallholder systems, to select suitable cultivar-staking combinations to optimise productivity, fruit quality, and economic returns.

Tomato Diseases and the Role of Staking in Management

Tomato (Solanum lycopersicum L.) production is constrained by a wide range of economically important pathogens. These include fungal foliar pathogens such as Alternaria spp. (early blight), Phytophthora infestans (late blight), and Botrytis cinerea (gray mould); powdery and downy mildews; bacterial pathogens (Clavibacter, Pseudomonas); soil-borne fungi (Fusarium, Verticillium); and several viral agents (Panno et al., 2021). The severity of many foliar and fruit diseases is strongly influenced by environmental conditions, particularly canopy moisture, leaf wetness duration, and poor air circulation, which create favourable microclimates for pathogen development (Panno et al., 2021; Lamptey et al., 2021). Staking, trellising, and canopy management are widely recognised as effective cultural practices to mitigate disease risk by modifying the plant microclimate. By holding foliage and fruit off the ground and promoting vertical canopy architecture, staking improves air movement, reduces relative humidity and leaf wetness duration, and minimizes soil splash onto lower leaves and fruits – thereby limiting infections by foliar fungal and bacterial pathogens (Wubetie & Wubetu, 2025). Empirical studies in both field and greenhouse conditions have shown that staking, often combined with pruning, increases marketable yield and reduces foliar disease severity compared with non-staked systems. Staked canopies consistently exhibit lower within-canopy humidity and faster leaf drying after irrigation or rainfall – conditions that are unfavourable for fungal development, particularly in indeterminate and tall cultivars grown intensively under greenhouse, high-tunnel, or high-density field systems (Lamptey et al., 2021; Wubetie, 2025).

Although staking substantially reduces disease incidence, it is not a standalone solution; integrated disease management is essential. Cultural practices, including adequate plant spacing, controlled irrigation (preferably drip), sanitation, and timely pruning, should be combined with resistant cultivars and, where necessary, targeted fungicide or biorational applications. Recent research highlights that biological control agents and biorational products, such as antagonistic microbes, are more effective when the canopy microclimate is unfavourable to pathogens – demonstrating the synergistic benefit of staking with integrated management strategies (Esquivel-Cervantes et al., 2022; Lamptey et al., 2021).

For smallholder and semi-arid production systems, staking offers low-cost, high-impact benefits. Simple techniques such as single-stake, vertical thread, or French/truss supports are effective in reducing disease incidence and improving fruit quality, particularly where irrigation or rainfall creates prolonged leaf wetness and access to fungicides or cold storage is limited. Across both temperate and tropical contexts, staking combined with sanitation and microclimate management consistently reduces unmarketable fruit and enhances yield, reinforcing its role as a recommended, low-tech intervention for smallholder adoption (Purdue Extension, 2025; ScienceDirect, 2021).

Agronomic and Economic Importance of Staking

Supporting tomato plants with stakes or trellises is widely regarded as a key management practice that brings both agronomic advantages and economic gains, regardless of the production scale or system used.

By keeping stems upright and fruit off the ground, staking reduces contact with soil-borne pathogens and limits splash dispersal of diseases. This upright growth form improves light penetration, photosynthetic efficiency, and air circulation within the canopy, while reducing leaf wetness duration – conditions that collectively enhance vegetative growth, fruit set, and overall plant vigour (Njoku, 2023; Falodun & Bakare, 2023). Numerous studies have confirmed that staking substantially increases tomato yield and quality. Research carried out in Jimma, Ethiopia by Amina and colleagues (2011) revealed that the Metadel variety, when supported with either French-type or single-string staking, gave marketable yields exceeding 96 tonnes per hectare – a result far better than plots without staking. Later studies by Njoku (2023) and by Falodun & Bakare (2023) added that vertical trellising improves plant stature, boosts the number and mass of fruits, and lowers disease pressure. Collectively, these studies confirm that providing structural support to tomato plants is an indispensable practice across various agricultural settings. Beyond yield, staking also improves fruit quality by producing cleaner fruits with higher sugar content, better uniformity, and fewer blemishes, which are desirable for both fresh consumption and processing (Amina et al., 2011; Njoku, 2023). While Md. Liton et al. (2021) demonstrated that the combination increased yield and fruit quality compared to either practice alone.

From an economic perspective, staking significantly improves farm profitability by increasing both total and marketable yields. Although it requires extra labour and materials, the benefits outweigh the costs due to higher returns from improved fruit quality and reduced post-harvest losses. Amina et al. (2011) highlighted that French-type staking of the Metadel variety in Jimma generated the highest net returns compared to non-staked plants, while Md. Liton et al. (2021) found that staking produced the greatest yield and profitability in Bangladesh. For smallholder farmers in tropical and semi-arid regions, where tomato production is highly vulnerable to diseases and post-harvest losses, staking offers a cost-effective approach to secure higher-quality fruits and premium market prices (Falodun & Bakare, 2023). Overall, despite the additional input requirements, staking has been consistently proven to enhance yield stability, fruit quality, and profitability, making it a cornerstone practice for sustainable tomato production under both commercial and smallholder systems.

Research Gaps and Justification for the Study

Tomato (Solanum lycopersicum L.) production in Raya Azebo District, Southern Tigray, Ethiopia, is constrained by low adoption of improved agronomic practices and limited availability of high-yielding F1 hybrid cultivars. Non-staked tomato plants are particularly vulnerable to disease and pest incidence due to sprawling growth, poor air circulation, and increased contact of foliage and fruits with the soil, which favour pathogens such as Alternaria solani (early blight), Phytophthora infestans (late blight), and Botrytis cinerea (grey mould) (Lamptey et al., 2021; Panno et al., 2021). While staking has been shown to enhance growth, fruit set, and yield, most studies in Ethiopia have focused on conventional cultivars or controlled conditions, with limited attention to F1 hybrid cultivars under field conditions. Furthermore, the interaction between different staking methods and F1 cultivars, and their combined effects on disease and pest suppression, growth performance, and marketable yield, remains poorly understood in semi-arid, smallholder farming systems. This knowledge gap hinders the development of tailored recommendations for local farmers who face both resource constraints and high disease pressure. Therefore, this study aims to evaluate the impact of different staking methods on the growth, yield, and disease/pest incidence of F1 tomato cultivars in Raya Azebo District, providing evidence-based guidance to improve productivity, fruit quality, and economic returns under local production conditions (Wubetie, 2025; ResearchGate, 2022).

Effect of Hybrid Tomato Cultivar on Growth and Yield

F1 hybrid tomato cultivars are increasingly recognised for their superior growth and yield performance compared to open-pollinated varieties, largely due to hybrid vigour and heterosis. Studies have demonstrated that hybrids generally exhibit more vigorous vegetative growth, greater canopy uniformity, and enhanced photosynthetic efficiency, which contribute to improved reproductive development and assimilate partitioning (Asare-Addo et al., 2022; Turner et al., 2023). These advantages often translate into higher fruit set, more fruits per plant, and larger fruit size, resulting in greater marketable yields when supported with appropriate agronomic practices such as staking, irrigation, and nutrient management (Asare-Addo et al., 2022; Msogoya & Mamiro, 2016). Beyond yield, hybrids also consistently deliver desirable fruit quality attributes including shape uniformity, pericarp thickness, firmness, and extended shelf life – which are essential for market preference and post-harvest handling (Bihon et al., 2022; Melomey et al., 2022). Genetic studies confirm that heterosis in tomato yield is governed by polygenic and epistatic interactions, with favourable allele combinations enhancing reproductive efficiency and yield stability (Jiang et al., 2013; Turner et al., 2023). However, the performance of F1 hybrids is strongly influenced by genotype × environment interactions; while they generally outperform non-hybrids in well-managed or protected environments, their advantage can diminish under severe stress conditions such as drought (Ficiciyan et al., 2021; Kusumiyati et al., 2023). Regional evidence from sub-Saharan Africa further highlights that hybrids and improved cultivars provide higher yields and profitability compared to local varieties, but their success depends on access to inputs, proper management, and alignment with farmer and market preferences (Msogoya & Mamiro, 2016; Bihon et al., 2022; Melomey et al., 2022). In Ethiopia, recent studies emphasise that staking and improved cultivation techniques further enhance the yield potential of hybrid cultivars, making them a viable option to close existing yield gaps and improve farmer livelihoods (Wubetie & Wubetu, 2025**).**

CHAPTER- THREEE

3 MATERIALS AND METHODS

Description of the Study Area

The field experiment took place at Desta Farm, which is located in Fachagama, Kara Adishabo Kebele, within the Raya Azebo District of the Southern Tigray Zone in northern Ethiopia. The geographic coordinates of the experimental site range between 12°40′54.80″ and 12°41′67″ north latitude and between 39°43′54.02″ and 39°42′26″ east longitude. The elevation of the site is 1,537 metres above sea level. The farm lies approximately 668 km north of Addis Ababa and 128 km south of Mekelle, the regional capital (Figure 1).

The soil in the experimental field is deep black clay-loam, which has a good capacity for retaining water and nutrients, making it highly suitable for irrigated crop production (Girmay et al., 2022; Gebremedhin et al., 2023). A composite soil sample analysis yielded a pH value of 6.89, which falls within the optimal range of 6.0 to 7.0 for tomato growth and nutrient uptake (FAO, 2021). Although clay loam is the dominant soil type, the district also contains other soil varieties, including sandy loam patches and vertisols, which are influenced by local topography and drainage conditions (Hagos et al., 2023).

The climate of Raya Azebo District is classified as semi-arid, which supports a range of agro-ecosystems, from rain-fed cereal farming to irrigated horticulture (Mehari & Hailu, 2019; Berhe et al., 2023). Mean annual rainfall varies from 450 mm to 600 mm, and the precipitation pattern is erratic and unevenly distributed. Most of the rain falls as high-intensity storms between April and September (Hagos et al., 2023). The mean annual temperature ranges from 12.2°C to 23.6°C, creating favourable conditions for both cool-season and warm-season crops (Berhe et al., 2023; Lemma, 2023). These soil and climatic characteristics, together with the presence of irrigation infrastructure, make the area an important location for producing high-value crops, including tomatoes, in Southern Tigray (Gebremedhin et al., 2023).

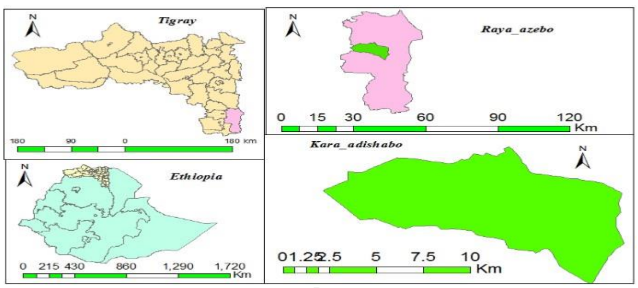

Figure 3.1 **Map of the study area (Fachagama, Desta farm)**

Treatments and Experimental Design

The experiment employed a 3 × 4 factorial arrangement, incorporating three tomato cultivars and four staking methods. The three cultivars used were Abale F1, Gelilea F1, and Jarrah F1. The four staking treatments consisted of: S0 (no staking, serving as the control), S1 (single-pole staking), S2 (French-type staking), and S3 (vertical staking). This factorial combination produced a total of twelve distinct treatment combinations.

The experiment utilized a split-plot arrangement with three replicates, resulting in 36 plots in total. The main plots were assigned to the three cultivars, while the four staking methods were randomly distributed to the sub-plots within each main plot. The field layout occupied an area of 16 m by 72 m (equivalent to 1,152 m²). Each individual plot measured 5 m in length and 4 m in width, providing a net plot area of

20 m². To reduce edge effects and prevent interference between treatments, the following spacings were maintained: 2.0 m between replications, 1.5 m between main plots, and 1.0 m between sub-plots.

Every plot had four rows of tomato seedlings. The transplanting distance was 50 cm along the row and 1.0 m between rows, giving 40 plants per plot. Thus, the whole experiment included 1,440 tomato plants.

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Table 3.1 Treatment combinations

Cultivar (main plot)	Staking Methods (sub plot)
Abale F1	S0. without staking (control)
	S1. Single pole staking
	S2. French type staking
	S3. vertical staking
Gelilea F1	S0. without staking (control)
	S1. Single pole staking
	S2. French type staking
	S3. vertical staking
JarrahF1	S0. without staking (control)
	S1. Single pole staking
	S2. French type staking
	S3. vertical staking

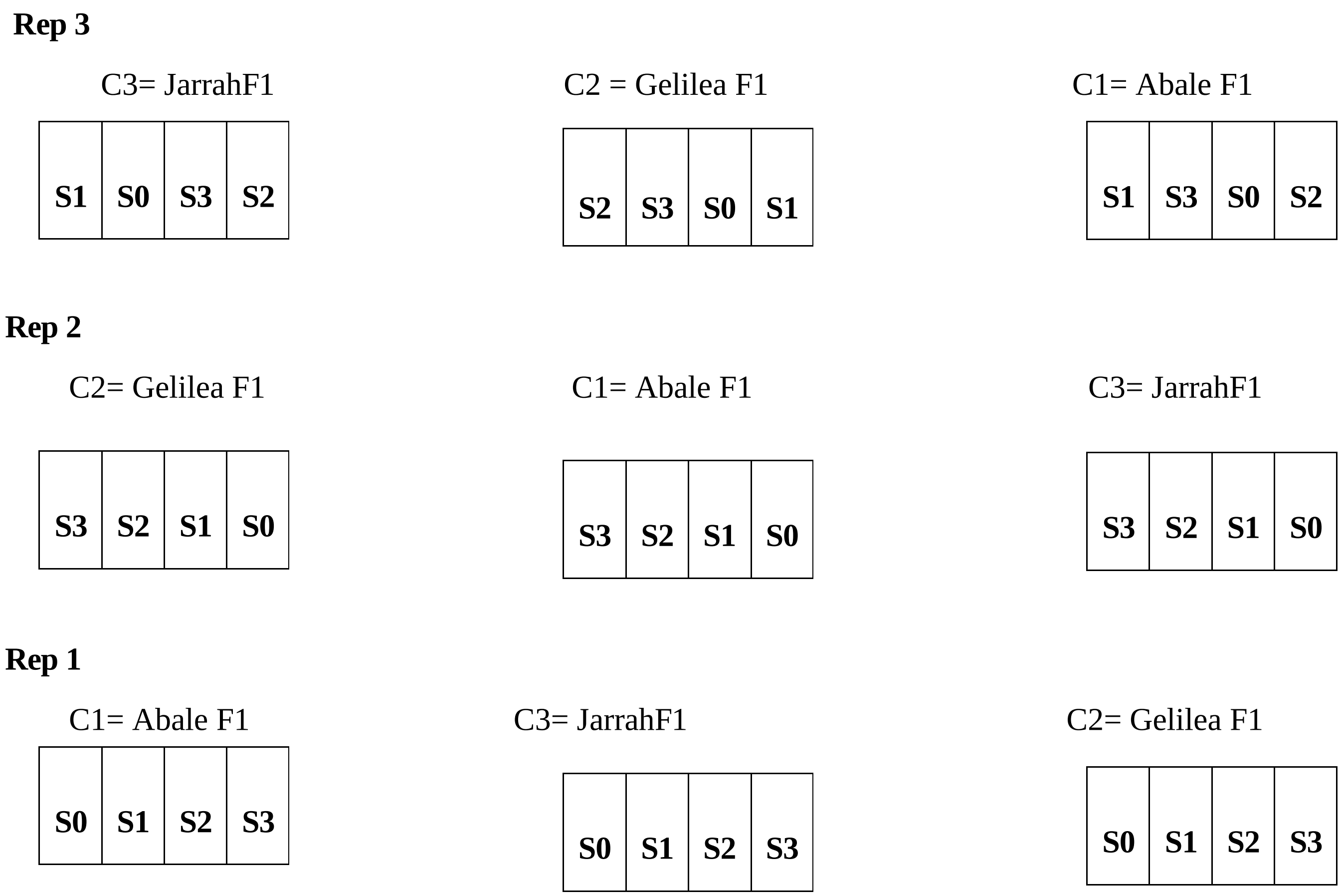

Figure 3.2 **Lay out of the experimental design**

Description of Experimental Materials

For this investigation, three hybrid tomato varieties — namely Abale F1, Gelilea F1, and Jarrah F1 — were selected. Their selection was guided by factors including accessibility in the commercial market, suitability to local growing conditions, and differences in key agronomic traits such as time required for maturity and potential fruit yield (Ethio-SHEP, 2019; Rijk Zwaan, 2024). All seeds were obtained from a certified commercial seed distributor.

Table 3.2 **Agronomic performance and adaptive traits of the tomato varieties evaluated in the study.**

Characteristic	Abale F1	Gelilea F1	Jarrah F1
Growth Habit	Determinate	Determinate	Semi determinate
Days to Maturity	65-70 days	80-85 days	65-70 days
Fruit Type	Large, Round	Deep Round, Beefsteak	Oval, Plum
Average Fruit Weight	180-220 g	160-200 g	90-110 g
Fruit Color	Deep Red	Bright Red	Deep Red
Fruit Firmness	Very Firm	Excellent	Very Firm
Prime Use	Fresh Market	Garden-fresh Market	Fresh Market & Handling
Reported Yield Potential	54.3 t/ha	50.0 t/ha	80.0 t/ha
Adapted Altitude Range	800 - 1,800 m.a.s.l.	1,500 - 2,200 m.a.s.l.	0 - 1,600 m.a.s.l.
Recommended Agro-Ecology	Mid to Low Altitudes	Mid to High Altitudes	Low to Mid Altitudes

Source: (Rijk Zwaan, 2024)

Experimental Procedure and Agronomic Management

Seed sowing of tomatoes was carried out inside a greenhouse during December 2024. Seedling raising followed standard protected cultivation procedures. These procedures included specifications for seedling tray type, sterilization and mixture of the growing medium, irrigation frequency, fertilizer application schedule, and the hardening-off process – all documented to ensure reproducibility. After 40 days, once the seedlings had produced 4–5 true leaves and shown strong growth, they were hardened off and then transferred to the carefully prepared field.

The field was subjected to both primary and secondary tillage (i.e., ploughing and harrowing) to obtain a fine seedbed. Beds were then prepared according to the experimental layout. Transplanting took place during the late afternoon hours to reduce transplant shock. All cultural practices, including weed control and pest monitoring, were applied uniformly across every plot following the regionally recommended guidelines for tomato production.

Irrigation was delivered using the furrow method. Scheduling was determined by the visual and tactile "feel and appearance" approach, which is a common and validated technique among smallholder farmers in semi-arid Ethiopia (Asmamaw et al., 2021; Habtu, 2024). Irrigation was started when the soil at a depth of 10–20 cm felt dry to the touch, or when plants showed signs of temporary wilting that did not recover by evening. Water was applied equally to all plots to avoid bias. A basal dose of Di-Ammonium Phosphate (DAP) was applied, followed by top-dressing with Urea, both at recommended rates and uniformly across all plots.

3.1.1 Staking of Tomato

o provide structural support, tomato plants were secured with wooden stakes made from Eucalyptus camaldulensis and ordinary tying twine. The experiment evaluated four different support techniques: single-stake support, French-type trellising, vertical stringing, and an unsupported control. For all staked treatments, 2-metre-long wooden posts were used. Each post was inserted 30 cm into the soil. Once the plants had grown to about 40 cm tall, strings were fastened at a height of 25 cm above the ground surface.

3.1.1.1 Single-Post Staking

For the single-post staking treatment, one wooden stake (2 m long) was inserted 30 cm into the soil at a distance of about 5 cm from each plant. A string was looped loosely around the main stem just below a node and then fastened to the stake. As the plants grew taller, the stem was trained upward by wrapping the string around it. Additional ties were added when primary branches developed and fruit clusters began to appear, ensuring sufficient support.

3.1.1.2 French-Type Staking

In the French-type staking system, two stakes (2 m in height) were placed on opposite sides of each row, 5 cm away from the plants, and driven 30 cm into the soil. Within each row, stakes were spaced 1 m apart, resulting in six stakes per row. A crossbar was positioned horizontally across each pair of stakes at a height of roughly 1 m, and the intersection was tied firmly to prevent shifting. Plants were loosely attached to the crossbar using string, and as they continued to grow, the string was extended upward with four wraps at 40 cm intervals to support the vines.

3.1.1.3 Vertical Staking

Vertical staking involved placing a row of 2-m stakes 5 cm from each plant, with five stakes per row. Two horizontal beams, each 5 m long, were fastened to the stakes on both sides of the row to create a trellis. When the plants reached 40 cm in height, a string was tied just below a node and then run vertically upward to the horizontal beam, providing support for upward growth.

Data Collected

To reduce edge effects, data were gathered only from the two middle rows of each plot. From these rows, ten plants were randomly chosen and marked for recording the following parameters.

Plant Height (m): Plant height is a basic agronomic characteristic, defined as the distance from the soil surface to the tip of the main stem. This measurement is important for assessing growth and development. In the work of Amare et al. (2020), height was recorded from the plant base to the terminal growing point of the main stem at the conclusion of the third harvest.

Number of Primary Branches: This refers to the count of branches arising directly from the main stem, indicating the plant's branching pattern. Saini et al. (2021) recorded the number of primary branches on randomly selected plants from each plot.

Days to 50% flowering: This parameter measures the time from transplanting until half of the plants in a given plot have produced at least one open flower. The Food and Agriculture Organization (FAO, 2006) describes this as a standard procedure for determining the flowering time in tomato cultivation.

Flower Count Per Cluster: Recording the number of flowers in each cluster from various positions on the plant – namely lower, middle, and upper nodes – provides valuable information about its reproductive capacity. According to Ahmad et al. (2015), flower counts were taken from clusters at three distinct stages: the basal level (during the initial two weeks), the middle level (the following two weeks), and the apical level (the final period), based on the ten selected plants.

Fruit Count Per Cluster: This measurement indicates how many fruits develop from each flower cluster, serving as an indicator of reproductive effectiveness. Prasad et al. (2013) counted the number of fruits that set per cluster using the same selected plants and the identical growth stages as those used for flowering evaluation.

Fruit Set Percentage (%): The fruit set percentage is derived from the following equation:

Fruit Set % = (Total Fruits Set / Total Flowers) × 100

This calculation indicates pollination efficiency and fruit development. Kumar & Rai (2017) employed this method to evaluate fruit set in tomato production.

Mean Fruit Count Per Plant: This metric provides an estimate of the total fruits produced by each plant and acts as an important measure of yield potential. Asare-Addo and colleagues (2022) documented the fruit count per plant in order to evaluate how well different tomato varieties performed agronomically.

Average Fruit Weight (g): Weighing individual fruits provides data on fruit size, which is important for marketability. Asare-Addo et al. (2022) measured average fruit weight to evaluate the quality of tomato fruits.

Fruit Length (cm): Measuring fruit length helps determine fruit size and conformity to market standards. Aliyu et al. (2014) used a digital caliper to measure fruit length when assessing morphological traits of tomato fruits.

Fruit Diameter (cm): Diameter measurement complements length to give a complete picture of fruit size. El-Tohamy et al. (2009) recorded fruit diameter to assess quality and marketability.

Number of Marketable Fruits per Plant: This count reflects fruits that satisfy quality standards for sale. According to the United States Department of Agriculture (USDA, 2019), marketable fruits must be clean, disease-free, uniform, properly ripened, and well-shaped. These criteria ensure that fruits meet consumer expectations and market requirements.

Number of Unmarketable Fruits per Plant: Unmarketable fruits are those that are diseased, physically damaged, misshapen, unevenly ripened, or immature. Hossain et al. (2010) categorized and counted unmarketable fruits to assess quality and yield losses in tomato cultivation.

Marketable Fruit Yield (t/ha): This yield estimate is derived from the weight of marketable fruits per hectare. Alemayehu et al. (2017) recorded the weight of marketable fruits from sampled plants and extrapolated to tonnes per hectare to estimate yield.

Yield of Non-Marketable Fruits (t/ha): In a similar manner, the mass of fruits that are not suitable for sale is measured and then expressed as tonnes per hectare. Wakjira and his coworkers (2019) determined the weight of unmarketable fruits in order to assess both yield reductions and quality problems in tomato cultivation.

.**Total Fruit Yield (t/ha):** The sum of the weights of saleable and non-saleable fruits represents the total output per hectare. As reported by FAOSTAT (2020), this approach is a conventional way of presenting total fruit production in tomato growing systems.

Economic Analysis

Economic analysis is a systematic process for assessing the financial performance and feasibility of alternative agricultural practices. It does so by comparing the costs incurred against the benefits obtained. This approach integrates agronomic results, such as yield and input efficiency, with economic indicators to determine which technologies offer the highest profitability under realistic farming conditions (CIMMYT, 1988). By examining how resources like labour, capital, and inputs translate into net financial returns, economic analysis supports evidence-based decisions and ensures that recommended technologies are not only agronomically effective but also economically advantageous.

Adjusted Yield (AY): Adjusted yield is a corrected version of the experimental yield that accounts for inevitable differences between research settings and actual farm environments. Because experimental plots often produce higher yields due to better management and controlled conditions, an adjustment factor is applied to reduce the yield to a more realistic level for farmers.

Adjusted Yield (AY) = (Average mean yield – 10%)

Gross Benefit (GB): Gross benefit represents the total revenue generated from the adjusted yield before subtracting production costs. It is calculated as:

GB = Average yield × farm gate price

Total Variable Cost (TVC): This term encompasses all expenses that change depending on the quantity of output or the specific cultivation technique employed. Such costs cover labor, stakes and tying materials, seeds, and transportation.

TVC = Σ (Cost of Each Variable Input)

Net Benefit (NB): Net benefit measures the financial return remaining after total variable costs are deducted from gross benefit. The formula is:

NB = GB – TVC

Dominance Analysis (DA): Dominance analysis is an essential step that identifies economically inferior treatments before marginal analysis is performed. A treatment is classified as dominated when it incurs greater costs while generating lower net benefits compared to another alternative. Such treatments are excluded from further analysis so that only economically viable and competitive options are considered in the evaluation.

Marginal Rate of Return (MRR): The marginal rate of return measures how much additional net benefit is gained for each extra unit of money invested when moving from one non-dominated treatment to another. It is calculated as:

$$MRR\ (\%) = (\Delta NB / \Delta TVC) \times 100$$

Where ΔNB and ΔTVC are the differences in net benefit and total variable cost between two practices.

According to the training manual published by CIMMYT in 1988, which focuses on converting agronomic findings into practical advice for farmers using economic principles.

Data Analysis

Statistical evaluation of the experimental data was performed using analysis of variance (ANOVA) under the General Linear Model, with the help of Gen Stat (release 18). Whenever the observed treatment effects reached statistical significance at the 5% level, the Least Significant Difference (LSD) test was applied to separate the means**.**

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CHAPTER- FOUR

4 RESULT AND DISCUSSIONS

Influence of Staking Techniques and Tomato Varieties on Growth Parameters

4.1.1 Plant Height

The analysis of variance showed very significant variation ($P < 0.01$) among both the tomato cultivars and the staking methods concerning plant height. No significant interaction ($P \geq 0.05$) was detected between the two factors for this characteristic (see Appendix Table 7.1).

The tallest plants were observed in the Jarrah F1 variety (1.71 m), followed by Gelilea F1 (1.24 m). The shortest plants were recorded in Abale F1 (1.23 m), though this value was statistically comparable to that of Gelilea F1 (Table 4.1). This variation is likely attributable to inherent genetic differences among the cultivars, which significantly influence plant height. This result is consistent with the observations of Lendabo and colleagues (2021) as well as Meseret et al. (2012), who similarly reported considerable differences in the height of tomato plants.

Regarding staking methods, the greatest plant height was achieved using a single pole (1.42 m), followed by the French-type (1.40 m) and vertical staking (1.40 m) methods, with the latter two being statistically similar. The smallest plant height was recorded for non-staked plants (1.35 m) (Table 4.1). This outcome may be explained by the fact that staking provides vertical support, reducing lodging and improving light interception, which in turn promotes greater plant height. These results are consistent with Njoku (2023), who documented a minimum plant height of 25.80 cm for unstaked tomato plants.

Table 4.1 .Effect of cultivar and staking methods on plant height, days to 50% flowering and days to maturity of tomato

Cultivar	**PH(cm)**	**DF(50%)**	**DM**
Abale F1	1.23b	40.53c	73.00b
Gelilea F1	1.24b	55.36a	86.67a
Jarrah F1	1.71a	49.06b	78.75ab
LSD ($P \leq 0.05$)	0.04	0.13	3.74
CV (%)	1.6	1.8	2.3
Staking			
Non-staking	1.35c	50.00	82.44a
Single pole staking	1.42a	48.89	79.76b
French type	1.4b	46.56	77.11c
Vertical staking	1.4b	47.78	78.56bc
LSD ($P \leq 0.05$)	0.02	1.251	1.82
CV (%)	1.6	1.8	2.3

Any figures within a column that are marked with the identical letter(s) do not show statistically significant differences at the 5% possibility level. The following abbreviations apply: CV stands for Coefficient of Variance, LSD refers to Least Significant Difference, PH means plant height, Dm indicates days to maturity, and DF denotes days to flowering

4.1.2 Days to Reach 50% Flowering

Analysis of variance showed highly significant differences among tomato cultivars ($P < 0.01$) for the number of days required to reach 50% flowering. In contrast, neither the staking methods nor the interaction between cultivars and staking methods had a significant effect ($P \geq 0.05$) on this trait (Appendix Table 7.4).

The time to 50% flowering varied across cultivars. Gelilea F1 took the longest (55.36 days), followed by Jarrah F1 (49.06 days), while Abale F1 flowered the earliest (40.53 days) (Table 4.1). This variation is likely due to genetic differences among the cultivars. These findings are consistent with Lendabo et al. (2021) and Parvej et al. (2010), who noted that flowering time is a key phenological trait influencing subsequent growth and yield.

4.1.3 Days to Maturity (Maturation Period)

According to the ANOVA, days to maturity was strongly affected by staking technique ($P < 0.01$) and moderately affected by cultivar choice ($P < 0.05$). No meaningful interaction between these two factors was found ($P \geq 0.05$; see Appendix Table 7.4).

Among cultivars, Gelilea F1 took the longest to reach maturity (86.67 days), followed by Jarrah F1 (78.75 days), with Jarrah F1 being statistically similar to Gelilea F1. Abale F1 matured the earliest (73.00 days) and showed a statistically significant difference from Jarrah F1 (Table 4.1). The observed variation is likely attributable to genetic factors influencing maturity. These results are in agreement with Lendabo et al. (2021), Weng et al. (2015), and Emami and Eivazi (2013), who reported that genotypic traits largely determine whether fruit maturity occurs early or late.

With respect to staking methods, non-staked plants required the most days to reach maturity (82.44 days), followed by plants staked with a single pole (79.76 days). The shortest maturity period was recorded under the French-type staking system (77.11 days), followed by vertical staking (78.56 days) (Table 4.1). The notable reduction in days to maturity, particularly under the French-type system, may be due to improved canopy architecture — specifically, enhanced light interception and air circulation — which optimizes photosynthetic efficiency and accelerates fruit development. These findings align with Wubetie and Wubetu (2025), who observed earlier maturity in staked tomato plants compared to non-staked ones. Similarly, Falodun and Bakare (2023) reported significant variation in days to 50% maturity among different staking methods.

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4.1.4 Combined Influence of Cultivars and Staking Methods on Number of Primary Branches of Tomato

Table 4.2 reports that the highest lateral branch count occurred for Jarrah F1 under French-type support (16.4), then Jarrah F1 with single-post staking (15.83), and this value was statistically similar to Gelilea F1 under French-type staking (15.8). ANOVA (Appendix Table 7.1) revealed a significant interaction between variety and staking system for primary branch number ($P < 0.05$). The combination of genetic background and support method strongly affected branching in tomato plants.

On the other hand, the lowest branch number was obtained from non-staked Abale F1 plants (10.17), followed by Abale F1 with single-post staking (11.7); however, this value did not differ significantly from the vertical staking yield (11.83) for the same cultivar.

Table 4.2 combined outcome of cultivars and staking methods on number of primary branches of tomato

Cultivars	Staking	NPB
Abale F1	Non staking	10.17g
	Single pole staking	11.7f
	French type	12.77e
	Vertical staking	11.83f
Gelilea F1	Non staking	12.77e
	Single pole staking	14.63d
	French type	15.8ab
	Vertical staking	15.43bcd
Jarrah F1	Non staking	14.9cd
	Single pole staking	15.83ab
	French type	16.4a
	Vertical staking	15.53bc
LSD ($P \leq 0.05$)		0.45
CV (%)		3.2

Within any given column, values that share the same letter are not significantly different at the 5% probability level.

CV = Coefficient of Variation, LSD = Least Significant Difference, NPB = primary branch counted.

Genetic factors, along with improved light penetration and better air movement through the canopy, may explain differences in the number of primary branches, as enhanced photosynthetic efficiency results. This finding agrees with Wubetie & Wubetu (2025), who reported that the Miya variety produced the highest number of primary branches per plant, while the Eshet variety produced the lowest. Similarly, Njoku (2023) obtained the lowest branch count (6.7) from unstaked tomato varieties.

The Jarrah RZ F1 tomato is a high-yielding, semi-determinate hybrid developed by Rijk Zwaan (2025). It is characterized by vigorous vegetative growth, abundant lateral bud formation, and a balanced semi-determinate growth habit. When grown with French-type staking, this variety reaches its maximum branching potential. The structured support system keeps the plant upright, reduces mechanical stress, and prevents branches from overlapping, allowing axillary buds to develop fully into primary branches. In addition, better light penetration and improved canopy airflow boost photosynthetic efficiency and lower disease pressure at branch initiation sites, resulting in a well-structured and productive canopy (Amina et al., 2012; Wubetie & Wubetu, 2025). This interaction demonstrates that inherently vigorous cultivars can take full advantage of staking systems to maximize vegetative development.

In contrast, Abale F1, which has only moderate vigor, shows limited primary branch development when grown without staking. Without structural support, plants sprawl, lateral buds become shaded, canopy ventilation is reduced, and susceptibility to fungal infections and mechanical injury increases. These conditions inhibit lateral bud activation and restrict branch initiation. Furthermore, nutrients are allocated mainly to maintaining existing structures and coping with stress rather than supporting new branch growth, while unbalanced apical dominance further suppresses the outgrowth of lateral buds (Sowley & Yahaya, 2013; Alem et al., 2016).

Taken together, these results show that both cultivar traits and staking systems are key factors determining branching performance. Using a strong, semi-determinate variety like Jarrah F1 with French-type support gives the maximum lateral branch count, while a less vigorous type such as Abale F1 with no staking results in the lowest branch number. These findings highlight the importance of selecting staking strategies that match cultivar growth habits in order to optimize vegetative development, improve canopy structure, and support maximum productivity in tomato production.

Influence of Risking Methods and Tomato Cultivars on Yield Attribute

4.1.5 Average Fruit Width

ANOVA showed that average fruit diameter was significantly affected by both tomato variety and staking technique ($P < 0.05$), but their interaction was not significant ($P > 0.05$; see Appendix Table 7.3).Among the cultivars, Abale F1 produced the largest fruits (6.20 cm), followed by Gelilea F1 (5.57 cm), while Jarrah F1 gave the smallest fruit diameter (5.07 cm) (Table 4.3). These findings are in agreement with Lendabo et al. (2021) and Rashidi and Gholami (2011), who also observed substantial differences in fruit diameter among tomato varieties, indicating significant genetic variation across cultivars.

Regarding staking methods, French staking resulted in the largest fruit diameter (6.24 cm), followed by single-pole staking (5.91 cm) and vertical staking (5.87 cm), with the latter two being statistically similar. Non-staked plants produced the smallest fruit diameter (5.45 cm) (Table 4.3). This difference may be explained by improved canopy architecture, which increases light penetration and photosynthetic activity, thereby influencing overall plant performance.

Table 4.3 Main effect of cultivar and staking methods on average fruit diameter in centimeter and average fruit weight of tomato

Cultivar	AfrDm	AFrWt
Abale F1	6.200 a	103.25a
Gelilea F1	5.57b	89.6b
Jarrah F1	5.07c	79.4c
LSD (P≤0.05)	0.28	4.71
CV (%)	5.3	5.7
Staking		
Non staking	4.600c	70.3c
Single pole staking	5.74b	95.3b
French type	6.24a	103.3a
Vertical staking	5.86b	93.9b
LSD (P≤0.05)	0.29	5.08
CV (%)	5.3	5.7

ANOVA showed that average fruit diameter was significantly affected by both tomato variety and staking technique ($P < 0.05$), but their interaction was not significant ($P > 0.05$; see Appendix Table 7.3). Average Fruit Weight

ANOVA revealed that average fruit weight was highly significantly affected by both tomato variety and staking technique ($P < 0.01$), but their interaction was not significant ($P \geq 0.05$; see Appendix Table 7.3).

Among cultivars, Abale F1 produced the heaviest fruits (103.25 g), followed by Gelilea F1 (89.6 g), whereas Jarrah F1 had the lowest average fruit weight (79.4 g) (Table 4.3). The higher fruit weight of Abale F1 is attributed to genetic factors, resulting in larger and heavier fruits. Fruit weight is an important parameter for variety selection and consumer preference (Meneberu *et a*l., 2011).

Regarding staking methods, French staking resulted in the heaviest fruits (103.3 g), followed by single-post staking (95.3 g); however, fruit weight under single-post staking was statistically similar to that under vertical staking (93.9 g). On the other hand, the lowest fruit weight was measured for non-staked plants (81.8 g) (Table 4.3). This might be due to increased contact with soil moisture, reduced light exposure, and higher disease pressure, all of which limit fruit development. The results of this study support the findings of Njoku (2023), who observed that tomato plants grown without staking had the smallest average fruit weight. Likewise, Amina et al. (2012) explained that French staking increases fruit weight by improving canopy structure, allowing better access to light, enhancing photosynthetic efficiency, and facilitating the movement of nutrients factors that encourage uniform fruit development and reduce foliage-fruit competition..

4.1.6 Fruit Set Percentage

ANOVA indicated that fruit set percentage was highly significantly affected by staking technique ($P < 0.01$) and significantly affected by tomato variety ($P < 0.05$), but their interaction was not significant ($P \geq 0.05$; see Appendix Table 7.1).

Among the cultivars, Jarrah F1 recorded the highest fruit set percentage (71.35%), followed by Gelilea F1 (67.70%), with no statistical difference between them. Abale F1 had the lowest fruit set percentage (65.35%), which was also statistically similar to Gelilea F1 (67.70%) (Table 4.4). The better fruit set in Jarrah F1 may be explained by its semi-determinate growth habit, which provides a balanced distribution of assimilates between vegetative and reproductive parts and supports an extended flowering period. This finding agrees with Meseret et al. (2012), who reported that the number of fruits per cluster is influenced by the number of flowers per cluster.

Regarding staking methods, French staking gave the highest fruit set percentage (71.5%), followed by vertical staking (71.4%), with French staking being statistically similar to both vertical staking and single-pole staking (70.1%). Non-staked plants produced the lowest fruit set percentage (59.5%), which was significantly lower than all staking treatments (Table 4.4). The success of French staking is due to its ability to create an organized canopy that enhances light penetration and air circulation while reducing flower shading and flower drop. By preventing lodging, this system keeps flowers and developing fruits away from soil contact. In contrast, the low fruit set in non-staked plants is likely caused by lodging, which brings flowers and fruits into contact with the soil, increasing pest and disease pressure and reducing canopy aeration.

Table 4.4 Main effect of cultivar and staking methods on fruit setting percentage of tomato

Cultivar	FSP
Abale F1	65.35b
Gelilea F1	67.7ab
Jarrah F1	71.35a
LSD (P≤0.05)	4.15
Staking	
Non staking	59.5b
Single pole staking	70.1a
French type	71.5a
Vertical staking	71.4a
LSD (P≤0.05)	4.29
CV (%)	6.4

Within any column, values annotated with the same letter are not statistically different at the 5% significance level.

CV = Coefficient of Variation, LSD = Least Significant Difference, FSP = Fruit Set Percentage.

4.1.7 Flower count per cluster.

Analysis of variance showed that both cultivar and staking method had a highly significant independent effect on flower production ($P < 0.01$). The interaction between tomato cultivars and staking methods was not significant ($P > 0.05$) for the number of flowers per cluster (Appendix Table 7.1).

Among the cultivars, Jarrah F1 produced the highest number of flowers per cluster (4.589), followed by Gelilea F1 (4.508), with no statistical difference between them. Abale F1 had the lowest flower count (3.615) (Table 4.5). This variation may be explained by Jarrah F1's superior genetic potential for floral initiation, high pollen viability, balanced hormonal regulation that supports floral meristem activity, and efficient distribution of assimilates. The low flower number in Abale F1 is likely due to its limited genetic capacity for flower bud initiation, weaker hormonal regulation, reduced photosynthetic efficiency, smaller canopy size, poor nutrient translocation, and greater susceptibility to environmental stresses, all of which restrict flower cluster size and vigor. These findings are consistent with Wubetie and Wubetu (2025) and

Hasan et al. (2017), who observed significant genotypic differences in flowers per cluster among tomato varieties. Among the staking treatments, the French-type support produced the most flowers per cluster (4.436), followed by vertical (4.224) and single-post (4.220) staking, which were statistically equivalent. Plants grown without staking had the fewest flowers per cluster (4.070) (Table 4.5).

Influence of staking technique and tomato cultivar on flower count and fruit number per cluster

Table 4.5 **Influence of staking technique and tomato cultivar on flower count and fruit number per cluster**

Cultivar	**№. flowers per cluster**	**№. fruits per cluster**
Abale F1	3.615b	1.695c
Gelilea F1	4.508a	2.027b
Jarrah F1	4.589a	2.45a
LSD (P≤0.05)	0.12	0.19
CV (%)	2.9	8.5
Staking		
Non staking	4.070c	1.413c
Single pole staking	4.220b	2.173b
French type	4.436a	2.41a
Vertical staking	4.224b	2.237b
LSD (P≤0.05)	0.12	0.17
CV (%)	2.9	8.5

Within the same column, any values sharing an identical letter are not significantly different at the 5% confidence level.

CV = Coefficient of Variation, LSD = Least Significant Difference, No. flowers per cluster = flower count per cluster, No. fruits per cluster = fruit count per cluster.

The higher flower production observed in staked plants, especially under the French-type system, likely represents a physiological response to an improved canopy microclimate. This improvement is mainly driven by mechanical support, which enhances light distribution and air circulation, thereby reducing both abiotic and biotic stress on flowers and encouraging the movement of assimilates toward reproductive growth. These findings are in line with Amina et al. (2012), Alam et al. (2016), and Ali and Moniruzzaman (2017), all of whom documented the highest flower numbers per cluster under well-supported staking systems. Furthermore, this result agrees with Wubetie and Wubetu (2025), who found the lowest flower count per cluster in non-staked tomato varieties.

4.1.8 Fruit Count per Cluster

The analysis of variance revealed highly significant differences ($P < 0.01$) among both tomato cultivars and staking methods with respect to the number of fruits per cluster. However, the interaction between these two factors was not statistically significant ($P > 0.05$) for this trait (see Appendix Table 7.1).

Among the cultivars evaluated, Jarrah F1 produced the greatest number of fruits per cluster (2.45), followed by Gelilea F1 (2.027). In contrast, Abale F1 yielded the lowest value (1.695) (Table 4.5). These observed differences among tomato cultivars may be attributed to genetic variations in reproductive efficiency, which directly influence fruit load per cluster. These results support Lendabo et al. (2021), who observed that both genetic makeup and growing conditions influence the number of fruits per plant. Other researchers have documented wide variability in this trait, ranging from 4.46 to 98.3 (Eshteshabul et al., 2010; Falak et al., 2011) and from 9.70 to 158.9 (Agong et al., 2001).

Among the staking treatments, the French-type support yielded the most fruits per cluster (2.41), with vertical (2.237) and single-post (2.173) staking producing successively fewer). The fruit counts for vertical and single-post staking were statistically similar. In contrast, plants grown without stakes had the lowest fruit count (1.413) (Table 4.5). These findings align with those of Amina et al. (2012), who also observed a higher number of fruits per cluster under French staking compared to non-staked conditions.

French staking provides mechanical support that stabilizes both plants and fruit clusters, reduces fruit drop, enhances light penetration and air circulation, lowers the incidence of humidity-related diseases, and directs more assimilates toward fruit development (Wubetie & Wubetu, 2025; Chaudhari, Barot, &

Nadoda, 2023). Raising fruit clusters off the ground helps avoid soil-borne pests and physical damage, while improved canopy microclimate and pollen dispersal promote better fertilization and fruit retention. In contrast, plants grown without staking produced the fewest fruits per cluster. This results from structural weakness, higher fruit drop, light obstruction, poor air movement, ineffective nutrient distribution, elevated moisture levels, greater susceptibility to pests and diseases, and inadequate canopy organization (Wubetie & Wubetu, 2025; Amina et al., 2012).

4.1.9 I Effect of Cultivar–Staking Interaction on Mean Fruit Length in Tomato.

Significant differences in tomato fruit length were detected among both the cultivars and the staking techniques used, emphasizing the combined importance of genetic traits and crop management practices ($P < 0.05$) (Appendix Table 7.3). The longest average fruit length came from Gelilea F1 when grown with French type staking (7.3 cm), with Abale F1 under the same staking method ranking next (7.17 cm). This value for Abale F1 was not statistically different from that of Jarrah F1 also under French staking (7.1 cm). At the other extreme, the shortest average fruit length was observed in Abale F1 grown without stakes (4.17 cm), followed by non-staked Gelilea F1 (4.7 cm). The figure for Gelilea F1 under non-staking did not differ significantly from the mean fruit length of non-staked Jarrah F1 (5.13 cm) (Table 4.6).

Table 4.6 The combined influence of tomato variety and staking technique on the mean fruit length

Cultivars	Staking	AFrL
Abale F1	Non staking	4.17h
	Single pole staking	6.7cd
	French type	7.17ab
	Vertical staking	6.63d
Gelilea F1	Non staking	4.7g
	Single pole staking	6.7bcd
	French type	7.3a
	Vertical staking	6.9bcd
Jarrah F1	Non staking	5.13f
	Single pole staking	6.6d
	French type	7.1abc
	Vertical staking	6.2e
LSD ($P \leq 0.05$)		0.4
CV (%)		3.4

In each column, any values marked with an identical letter do not show significant differences at the 5% confidence level.CV = Coefficient of Variation, LSD = Least Significant Difference, AFrL = mean fruit length

These outcomes prospective arise from the combined constraints of intermediate cultivar vigor and insufficient plant support. When plants were left unstaked, their fruits lay on the soil, where ground pressure, shading, and elevated disease pressure inhibited cell expansion. This aligns with the work of Hossain et al. (2010), who documented mean tomato fruit lengths between 3.35 and 5.14 cm. Fruit length is a key trait for cultivar selection and consumer acceptance (Meneberu et al., 2011). Additionally, Amina et al. (2012) observed that the Miya tomato variety produced shorter fruits (4.50 cm) when grown without staking).

4.1.10 The Combined effect of tomato cultivar and staking method on the numbers of marketable, unmarketable, and total fruits per plant

4.1.11 Interactive impact of tomato cultivar and staking system on the number of marketable fruits per plant.

Tomato variety and staking method showed a highly significant interaction effect on marketable fruit yield per plant ($P < 0.01$; see Appendix Table 7.2).

The maximum marketable fruit count per plant (57.00) was observed in Jarrah F1 grown with French-type staking. Next came Jarrah F1 under single-pole staking (53.00), which did not differ statistically from the same cultivar under vertical staking (52.00). At the other extreme, the lowest value (18.67) was obtained from non-staked Abale F1, followed by non-staked Gelilea F1 (27.00) and non-staked Jarrah F1 (35.00) (Table 4.7).

Table 4.7 Interaction effect of cultivars and staking methods on number of marketable fruit/plant, number of unmarketable fruit /plant and total number of fruit/plant of tomato

Cultivars	Staking	NMFr/P	NUMFr/P	TFN/P
Abale F1	Non staking	18.67i	24.00de	42.7i
	Single pole staking	30.20g	18.10fg	48.3g
	French type	32.00f	15.00g	47.0h
	Vertical staking	28.97g	18.60g	47.6h
Gelilea F1	Non staking	27.00h	30.87bc	57.87f
	Single pole staking	40.00d	20.70ef	60.7e
	French type	43.00c	21.10ef	64.1d
	Vertical staking	39.00d	21.47ef	60.5e
Jarrah F1	Non staking	35.00e	59.50a	94.5a
	Single pole staking	53.00b	30.47bc	83.5c
	French type	57.00a	27.20cd	84.2c
	Vertical staking	52.00b	34.87b	86.9b
LSD ($P \leq 0.05$)		1.81	4.64	3.2
CV (%)		2.1	9.7	0.4

Any two figures within a column that share the same letter are not statistically different at the 5% significance threshold.

CV = Coefficient of Variation, LSD = Least Significant Difference, NMFr/P = marketable fruits per plant, NUMFr/P = unmarketable fruits per plant, TFN/P = total fruits per plant.

The observed patterns can be attributed to the fact that Jarrah F1 exhibits strong vegetative vigor, yielding abundant flowering branches. Meanwhile, the French staking method supplies upright support, preventing branch breakage and improving light distribution, which in turn boosts photosynthesis and fruit formation. This finding agrees with Amina et al. (2012), who observed that French-type staking allows effective pruning, which limits unnecessary vegetative growth that would otherwise take resources away from fruit production. According to the same authors, the better canopy microclimate achieved through staking lowers humidity and curtails fungal diseases, while also enhancing air movement and sunlight exposure; these conditions favor flower retention and subsequent fruit set.

The current findings are also in line with Wubetie & Wubetu (2025), who found that when staking is omitted, branches collapse and spread across the soil surface, diminishing light capture and leaving fruits vulnerable to soil-borne diseases and pests, which causes considerable fruit losses. A dense canopy at ground level impedes air circulation, raises ambient humidity, and encourages fungal infections, all of which harm flower and fruit development (Alam et al., 2016). Overly vigorous vegetative growth outcompetes reproductive tissues for available nutrients, thereby constraining fruit set (Ibrahim & Derbew, 2012). Furthermore, harvesting becomes more prone to mechanical injury, and irregular fruit ripening further cuts down marketable yield. The lack of supportive structures worsens plant lodging and fruit shedding, eventually lowering the quantity of marketable fruits (Wubetie & Wubetu, 2025).

4.1.12 Joint effect of tomato cultivar and staking method on the number of unmarketable fruits per plant

Tomato variety and staking technique exhibited a highly significant interaction ($P < 0.01$) for unmarketable fruit count per plant (see Appendix Table 7.2).

The greatest count of non-marketable fruits per plant came from non-staked Jarrah F1 (59.50), followed by Jarrah F1 under vertical staking (34.87). The figure for vertically staked Jarrah F1 did not differ statistically from those of non-staked Gelilea F1 (30.87) nor from Jarrah F1 with single-pole staking (30.47). In contrast, the smallest number of unmarketable fruits per plant was found in Abale F1 grown using French-type staking (15.00), next was Abale F1 under vertical staking (18.60), and the value for Abale F1 with single-pole staking (18.10) was not significantly different (Table 4.7).

This outcome may be attributed to how the combination of genetic characteristics and French-type staking improves fruit retention, lowers unmarketable yield, and maintains consistent fruit quality in Abale F1.

The present study points to the vulnerability of this cultivar to mechanical injury and disease when structural support is absent. For unstaked Jarrah F1, heavy fruit clusters collapse under their own weight, causing fruit drop and physical damage. The prostrate canopy retains moisture, which encourages fungal infections such as gray mold, thereby raising fruit rot rates. Fruits lying directly on the soil are also at risk of contamination by soil-borne pathogens, which reduces quality (Ibrahim & Derbew, 2012). Furthermore, pests like cutworms and thrips easily reach ground-level fruits, leading to feeding damage and surface blemishes (Birhanu & Tilahun, 2010). Fruits resting on uneven ground often crack and become deformed, lowering marketability (Alam et al., 2016). The lack of pruning in unstaked plants increases leaf density, restricts air movement, and promotes secondary infections (Wubetie & Wubetu, 2025). Irregular sunlight within sprawling canopies also causes uneven ripening, which reduces grading outcomes (Ibrahim & Derbew, 2012). Finally, the extra difficulty in handling sprawling plants results in bruising and pedicel breakage, further diminishing fruit quality (Amina et al., 2012).

On the other hand, the fact that Abale F1 under French-type staking produced the fewest unmarketable fruits demonstrates how effective this method is at reducing fruit losses. Lifting fruits off the soil lowers their exposure to pathogens and physical harm (Wubetie & Wubetu, 2025). Proper canopy management through pruning decreases humidity and disease pressure, preserving fruit health in this moderately vigorous cultivar (Alam et al., 2016). Adequate spacing between branches minimizes clustering and mechanical injuries, while better light interception encourages uniform ripening and consistent fruit color (Ibrahim & Derbew, 2012). The staking system also restricts pest access to fruits, prevents deformation, and stops cracking of medium-sized fruits (Amina et al., 2012). Optimized nutrient distribution under supported growth avoids physiological disorders and ensures high-quality fruit development (Alam et al., 2016). Moreover, harvest efficiency improves, reducing handling-related losses and preserving fruit integrity (Wubetie & Wubetu, 2025).

4.1.13 Combined Influence of Varieties and Staking Methods on Total Number of Fruits per Plant

Tomato variety and staking method showed a highly significant interaction ($P < 0.01$) for unmarketable fruit count per plant (see Appendix Table 7.2).

The greatest count of non-marketable fruits per plant came from unstaked Jarrah F1 (59.50), followed by Jarrah F1 under vertical staking (34.87). The figure for vertically staked Jarrah F1 did not differ statistically from those of non-staked Gelilea F1 (30.87) nor from Jarrah F1 with single-pole staking (30.47). In contrast, the smallest number of unmarketable fruits per plant was found in Abale F1 grown using French-type staking (15.00), next was Abale F1 under vertical staking (18.60), and the value for Abale F1 with single-pole staking (18.10) was not significantly different (Table 4.7).

This outcome may be attributed to how the combination of genetic characteristics and French-type staking improves fruit retention, lowers unmarketable yield, and maintains consistent fruit quality in Abale F1. The present study points to the vulnerability of this cultivar to mechanical injury and disease when structural support is absent. For unstaked Jarrah F1, heavy fruit clusters collapse under their own weight, causing fruit drop and physical damage. The prostrate canopy retains moisture, which encourages fungal infections such as gray mold, thereby raising fruit rot rates. Fruits lying directly on the soil are also at risk of contamination by soil-borne pathogens, which reduces quality (Ibrahim & Derbew, 2012). Furthermore, pests like cutworms and thrips easily reach ground-level fruits, leading to feeding damage and surface blemishes (Birhanu & Tilahun, 2010). Fruits resting on uneven ground often crack and become deformed, lowering marketability (Alam et al., 2016). The lack of pruning in unstaked plants increases leaf density, restricts air movement, and promotes secondary infections (Wubetie & Wubetu, 2025). Irregular sunlight within sprawling canopies also causes uneven ripening, which reduces grading outcomes (Ibrahim & Derbew, 2012). Finally, the extra difficulty in handling sprawling plants results in bruising and pedicel breakage, further diminishing fruit quality (Amina et al., 2012).

On the other hand, the fact that Abale F1 under French-type staking produced the fewest unmarketable fruits demonstrates how effective this method is at reducing fruit losses. Lifting fruits off the soil lowers their exposure to pathogens and physical harm (Wubetie & Wubetu, 2025). Proper canopy management through pruning decreases humidity and disease pressure, preserving fruit health in this moderately vigorous cultivar (Alam et al., 2016). Adequate spacing between branches minimizes clustering and mechanical injuries, while better light interception encourages uniform ripening and consistent fruit color (Ibrahim & Derbew, 2012). The staking system also restricts pest access to fruits, prevents deformation, and stops cracking of medium-sized fruits (Amina et al., 2012). Optimized nutrient distribution under supported growth avoids physiological disorders and ensures high-quality fruit development (Alam et al., 2016). Moreover, harvest efficiency improves, reducing handling-related losses and preserving fruit integrity (Wubetie & Wubetu, 2025).

Effect of the Interaction between Tomato Cultivar and Staking Technique on Marketable, Unmarketable, and Total Fruit Yield (Tons/Ha)

Tomato fruit marketable yield (tons/ha)

According to the ANOVA, there were highly significant differences ($P < 0.01$) in marketable tomato fruit yield among cultivars and also among staking methods. The interaction between these two factors was also significant at $P < 0.05$ (Appendix Table 7.2).

Among all treatments, French-type support combined with Jarrah F1 produced the highest marketable yield (136.0 t ha^{-1}). The second highest came from single-pole staking with the same cultivar (126.9 t ha^{-1}), and this was statistically similar to French-type staking with Gelilea F1 (123.5 t ha^{-1}). On the lower end, unstaked Abale F1 gave the smallest marketable yield (59.3 t ha^{-1}), followed by unstaked Gelilea F1 (71.5 t ha^{-1}). The latter did not differ significantly from unstaked Jarrah F1 (84.2 t ha^{-1}) (see Table 4.8).

Table 4.8 . Combined impact of cultivar type and support method on saleable, unsaleable, and overall tomato fruit yield measured in tons per hectare

Cultivar	Staking	Marketable Fruit Yield (t ha⁻¹)	Unmarketable Fruit Yield (t ha⁻¹)	Total Fruit Yield (t ha⁻¹)
Abale F1	Non staking	59.3k	16.80c	76.1j
	Single pole staking	101.5g	12.60h	114.1g
	French type staking	105.5f	10.50i	116.0f
	Vertical staking	96.3h	13.1 gh	109.4h
Gelilea F1	Non staking	71.5j	21.60b	93.1i
	Single pole staking	117.0d	15.53de	132.2d
	French type staking	123.5c	14.70f	138.3c
	Vertical staking	113.9e	15.96d	129.9e
Jarrah F1	Non staking	84.2i	29.76a	114.0g
	Single pole staking	126.9b	15.96d	141.9b
	French type staking	136.0a	13.60g	149.6a
	Vertical staking	123.0c	17.3e	140.3b
LSD ($P \leq 0.05$)		6.23	0.63	1.49
CV (%)		3.5	2.4	0.8

Within any column, values that share the same letter are not significantly different at the 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation, t ha^{-1} = tons per hectare.

The performance of Jarrah F1 under French-type staking may be explained by its vigorous growth habit, which demands proper canopy management to reduce shading, improve light capture, and direct photosynthetic products efficiently toward fruit development. This observation is consistent with Amina et al. (2012), who found that the staked Metadel tomato variety gave the highest marketable yield compared to non-staked Miya varieties under the same production conditions. Likewise, Wubetie and Wubetu (2025) reported the lowest marketable fruit yield from the combination of the Eshet variety grown without stakings.

4.1.14 Unmarketable Fruit Yield (t ha^{-1})

Highly significant differences were detected among staking methods ($P < 0.05$) and among cultivars ($P < 0.01$) for unmarketable tomato yield expressed in tons per hectare. The cultivar-by-staking method interaction was also highly significant for this trait (Appendix Table 7.2).

The highest unmarketable yield per hectare came from non-staked Jarrah F1 (29.76 t ha^{-1}), followed by non-staked Gelilea F1 (21.60 t ha^{-1}) and non-staked Abale F1 (16.80 t ha^{-1}). In contrast, the lowest unmarketable yield per hectare was recorded for Abale F1 under French-type staking (10.50 t ha^{-1}), then Abale F1 with single-post staking (12.60 t ha^{-1}) and Jarrah F1 under French-type staking (13.60 t ha^{-1}) (Table 4.8).

The significance of the interaction likely stems from the varying responses of different tomato cultivars to staking systems, which arise from differences in genetic background, growth form, and canopy structure, ultimately affecting light interception, air movement, and assimilate distribution. Wubetie & Wubetu (2025) and Asante et al. (2022) noted that staking reduces fruit contact with the soil, lessens bruising, improves ventilation, and limits pest and fungal problems. These findings also agree with Amina et al. (2012), who observed the highest unmarketable fruit yield from non-staked tomato plants. The elevated unmarketable yield in unstaked plants is mainly caused by lodging, poor air circulation within dense foliage, increased mechanical damage, direct sun exposure, higher fruit temperatures, and greater vulnerability to fungal infections (Wubetie & Wubetu, 2025; Asante et al., 2022).

4.1.15 Combined Marketable and Non-marketable Tomato Yield (t/ha)

According to Appendix Table 7.2, the combination of tomato type and support method had a significant effect on overall fruit yield at the 95% confidence level. In the present study, the highest total fruit yield (149.6 t ha^{-1}) was obtained from Jarrah F1 combined with French-type staking, whereas the lowest (76.1 t ha^{-1}) came from non-staked Abale F1 (Table 4.8).

This variation may be attributed to the interplay between cultivar vigor and staking support; better canopy management in Jarrah F1 improves resource use and fruit development, while the lack of support in Abale F1 reduces productivity. These outcomes match earlier reports. Wubetie and Wubetu (2025) found the highest total fruit yield (103.72 t ha^{-1}) for the staked Metadel variety, and the lowest for the non-staked

Eshet variety, which they explained by the latter's sprawling growth that increases fruit-soil contact, mechanical injury, and branch movement. Additionally, Amina et al. (2012) reported that unstaked tomato plants have lower photosynthetic efficiency, poorer assimilate allocation, and greater susceptibility to pests and diseases, all of which limit fruit set, size, and overall productivity. The same author also noted that the lowest total fruit yield was recorded for the non-staked Miya variety.

Labor and material costs and returns associated with different staking techniques and tomato cultivars.

The economic assessment was carried out using the CIMMYT (1988) approach, which combines partial budgeting with marginal analysis. This method reveals the economic performance of each treatment based on marketable tomato fruit yield. Gross return (calculated as adjusted yield multiplied by price) and net return (gross return minus total variable costs) were computed to perform a marginal rate of return (MRR) analysis, which is essential for properly evaluating alternative practices. The variable costs included staking materials (stakes, string, and their installation labor), seed, transport, and farm labor, all estimated using prevailing market prices in the Raya Azebo District during the 2024/2025 growing season. Marketable tomato yields from the plots were converted to a per-hectare basis, and the market values for both components (staking methods and cultivars) were determined using the local market price of 70.00 Ethiopian Birr. Prior to the economic analysis, a statistical analysis was conducted to obtain reliable yield estimates for each treatment, and the economic evaluation was performed for all treatments regardless of their statistical significance. Costs that did not vary across treatments such as fertilizers, pesticides, greenhouse rent, and farm site rent were excluded from the analysis.

A stepwise MRR analysis was used here for both dominated and non-dominated treatment comparisons. Farquharson (2006) together with Shah et al. (2009) suggest that a 100% return threshold is appropriate, especially for resource-limited growers in developing regions or when new practices require substantial changes to established farming routines. Accordingly, the present study used a 100% marginal rate of return as the threshold for farmers to adopt a new technology without hesitation. As shown in Table 4.9, treatments were ordered by total variable cost and net benefit to identify dominated ones. A dominated treatment is defined as any treatment whose net benefit is less than that of another treatment having a lower variable cost (CIMMYT, 1988). After removing dominated treatments from the full set, MRR was calculated for the remaining treatments.

The partial budget analysis of tomato cultivars and staking systems indicates that production efficiency is shaped by the interaction among cultivar performance, input costs, and staking technique. A 10% yield reduction was applied to account for post-harvest losses and unmarketable fruits, providing a realistic estimate of saleable yield. Seed costs differed by cultivar: Abale F1 (3 ETB), Gelilea F1 (4 ETB), and Jarrah F1 (2.70 ETB). Although these differences are small per unit, higher-yielding cultivars with slightly elevated seed costs may still generate larger net benefits. Total variable costs covering seed, labor, transport, and staking materials are strongly influenced by the staking method. Techniques like vertical or French-type staking demand more labor and materials than non-staked systems, but they generally increase marketable fruit yield and quality. Net benefit, defined as revenue from adjusted yields minus total variable costs, showed that cultivars with high yields and moderate input expenses, when paired with efficient staking methods, maximize profitability. Although non-staked systems lower labor and material costs (Table 4.9), they often produce lower marketable yields because fruits are more exposed to soil contact, disease, and reduced quality. Transportation costs were minimal, whereas labor costs were substantial, underscoring the need for staking methods that enhance labor efficiency. Overall, the analysis shows that choosing the right cultivar-staking combination one that balances input costs, labor requirements, and marketable yield is essential for maximizing economic returns in tomato production under the specified conditions.

Table 4.9 **Partial budget analysis of tomato cultivars and staking methods on mean marketable fruit yield of tomato**

Cultivar	Staking Method	Av. Yield (t ha^{-1})	Adj. Yield (t ha^{-1})	Adj. Yield (kg ha^{-1})	TVC (ETB ha^{-1})	Gross Benefit (ETB ha^{-1})	Net Benefit (ETB ha^{-1})
Abale F1	Non-staking	59.333	53.400	53400	179946	3738000	3558054
Jarrah F1	Non-staking	84.200	75.780	75780	197091	5304600	5097509
Gelilea F1	Non-staking	71.533	64.380	64380	211327	4506600	4295273
Abale F1	French-type staking	105.533	94.980	94980	388546	6648600	6260054
Jarrah F1	French-type staking	136.000	122.400	122400	410273	8568000	8157727
Abale F1	Single-pole staking	101.467	91.320	91320	415418	6392400	5976982
Gelilea F1	French-type staking	123.533	111.180	111180	424673	7782600	7357927
Jarrah F1	Single-pole staking	126.933	114.240	114240	433055	7996800	7563745
Gelilea F1	Single-pole staking	117.033	105.330	105330	459130	7373100	6913970
Abale F1	Vertical staking	96.333	86.700	86700	482818	6069000	5586182
Jarrah F1	Vertical staking	123.333	111.000	111000	501709	7770000	7268291
Gelilea F1	Vertical staking	113.933	102.540	102540	518618	7177800	6659182

A 10% adjustment was applied to yields. Seed costs varied by cultivar: 3 ETB for Abale F1, 4 ETB for Gelilea F1, and 2.70 ETB for Jarrah F1. Tomatoes sold at 70 ETB per kilogram. Yield units: tons per hectare (t ha^{-1}) and kilograms per hectare (kg ha^{-1}). Transport added 0.05 ETB per kilogram. Labor cost 350 ETB per person daily. Key abbreviations: Av. yield = average yield; Adj. yield = adjusted yield; TVC = total variable cost; NB = net benefit.

The dominance analysis of tomato cultivars and staking methods on mean marketable fruit yield highlights the economic efficiency of different production practices. Total variable costs (TVC) increased with staking intensity, ranging from 179,946 ETB ha^{-1} for non-staked Abale F1 to 518,618 ETB ha^{-1} for Gelilea F1 with vertical staking. Gross benefits, calculated from marketable yield and tomato price, were highest for Jarrah F1 with French-type staking (8,568,000 ETB ha^{-1}) and lowest for non-staked Abale F1 (3,738,000 ETB ha^{-1}) (Table 4.10), reflecting the positive effect of staking on fruit yield and quality. Net benefits (NB) further indicate that staking methods generally improved economic returns compared to non-staked treatments, although the degree varied among cultivars. Dominance analysis revealed that certain treatments were undominated (UD), such as non-staked Jarrah F1 and French-type staking of Abale F1 and Jarrah F1, indicating these options provide relatively higher net benefits without being economically inferior to any other combination. Conversely, dominated (D) treatments, including single-pole and vertical staking for some cultivars, were less efficient in terms of net benefit relative to their additional cost. Overall, the analysis demonstrates that selecting the appropriate cultivar and staking method is crucial for maximizing profitability; for instance, Jarrah F1 with French-type staking consistently provided the highest net benefit, while non-staked or dominated treatments, though cheaper in TVC, were less economically efficient due to lower marketable yield and revenue. This emphasizes the importance of balancing input costs, labor requirements, and yield enhancement to achieve optimal economic returns in tomato production.

Table 4.10 Dominance analysis of tomato cultivars and staking methods on mean marketable fruit yield of tomato

Cultivar	Staking Method	TVC (ETB ha^{-1})	Gross Benefit (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Dominance
Abale F1	Non-staking	179946	3738000	3558054	-
Jarrah F1	Non-staking	197091	5304600	5097509	UD
Gelilea F1	Non-staking	211327	4506600	4295273	D
Abale F1	French-type staking	388546	6648600	6260054	UD
Jarrah F1	French-type staking	410273	8568000	8157727	UD
Abale F1	Single-pole staking	415418	6392400	5976982	D
Gelilea F1	French-type staking	424673	7782600	7357927	D
Jarrah F1	Single-pole staking	433055	7996800	7563745	D
Gelilea F1	Single-pole staking	459130	7373100	6913970	D
Abale F1	Vertical staking	482818	6069000	5586182	D
Jarrah F1	Vertical staking	501709	7770000	7268291	D
Gelilea F1	Vertical staking	518618	7177800	6659182	D

TVC: Total variable cost, NB: Net benefit, GB: Gross Benefit, D: Dominated, and UD= un-dominated treatment.

The marginal rate of return (MRR) analysis of tomato cultivars and staking methods provides insight into the economic efficiency of different production practices by comparing additional costs and benefits. Total variable costs (TVC) increased with more intensive staking, ranging from 179,946 ETB ha^{-1} for non-staked Abale F1 to 410,273 ETB ha^{-1} for Jarrah F1 with French-type staking. Net benefits followed a similar trend, with the highest value observed for Jarrah F1 under French-type staking (8,157,727 ETB ha^{-1}) and the lowest for non-staked Abale F1 (3,558,054 ETB ha^{-1}) (Table 4.11), reflecting the positive impact of staking on marketable yield. Non-dominated (ND) treatments indicate combinations that are economically efficient, as they provide higher net benefits relative to their additional costs without being inferior to any other option. The marginal rate of return, calculated as the additional net benefit per unit increase in total variable cost, was highest for Jarrah F1 with French-type staking at 8,734%, indicating that every additional birr invested in this treatment generated substantial economic returns. Other ND treatments, such as non-staked Jarrah F1 and French-type staking of Abale F1, also showed very high MRR values (5,708% and 635%, respectively), suggesting strong profitability compared to their incremental costs. Overall, the analysis emphasizes that while more intensive staking increases costs, the associated gains in marketable yield and net benefit far outweigh these expenditures, making combinations like Jarrah F1 with French-type staking the most economically efficient and attractive for maximizing returns in tomato production.

Table 4.11 Marignal rate of return (MRR) of tomato cultivars and staking methods on mean marketable fruit yield of tomato

Cultivar	Staking Method	TVC (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Dominance	CTC	CNB	MRR (%)
Abale F1	Non-staking	179946	3558054	-	-	-	-
Jarrah F1	Non-staking	207091	5107509	UD	27145	1549455	5708
Abale F1	French-type staking	388546	6260054	UD	181455	1152545	635
Jarrah F1	French-type staking	410273	8157727	UD	21727	1897673	8734

Abbreviations used: total variable cost (TVC); net benefit (NB); marginal rate of return (MRR); dominated treatment (D); un dominated treatment (UD); change in total cost (CTC); change in net benefit (CNB)

CHAPTER- FIVE

5 CONCLUSION AND RECOMMENDATION

Conclusion

The present research assessed how various staking techniques influenced the agronomic and economic performance of three hybrid tomato varieties Abale F1, Gelilea F1, and Jarrah F1under the local environmental conditions of Raya Azebo District throughout the 2024/2025 growing season. A factorial experiment (3 × 4) arranged in a split-plot design with three replications was carried out to evaluate phenology, growth, yield, yield components, fruit quality, and economic traits.

The results indicated that staking methods, cultivars, and their interaction significantly ($p < 0.05$) influenced all measured parameters. Among staking methods, French-type staking consistently `outperformed others by promoting earlier flowering (46.56 days), earlier maturity (77.11 days), higher fruit set (71.5%), improved fruit size (6.24 cm) and fruit weight (103.3 g). Among cultivars, Jarrah F1 exhibited superior vegetative growth and reproductive efficiency.

The interaction of Jarrah F1 with French-type staking produced the highest marketable yield (136.0 t ha^{-1}), total yield (149.6 t ha^{-1}), net benefit (8,157,727 ETB ha^{-1}), and Marginal Rate of Return (8,734%), whereas Abale F1 under non-staking recorded the lowest marketable (59.3 t ha^{-1}) and total yield (76.1 t ha^{-1}). As a second option, the Abale F1 cultivar combined with single post staking can also be considered these results highlight that optimal tomato performance depends on aligning cultivar genetic potential with suitable staking practices.

Overall, the study provides strong empirical evidence that integrating high-performing hybrid cultivars, particularly Jarrah F1, with French-type staking substantially enhances tomato productivity, fruit quality, and profitability.

Recommendation

Based on the current study, the Jarrah F1 hybrid tomato with French-type staking is recommended for Raya Azebo District and similar agro-ecological zones due to its superior yield and economic returns. From the staking methods evaluated, single post staking can be considered as a second option, while from the cultivars tested, Abale F1 can also serve as a second alternative. Farmers and investors are encouraged to adopt these systems with proper access to quality seeds, staking materials, and training in crop management practices to maximize productivity and profitability. Investors and commercial producers should support the supply chain for seeds and staking materials and promote adoption at scale to achieve high economic returns. Future research should validate the system across multiple locations and seasons and develop low-cost staking alternatives to enhance sustainability and adoption

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7 APPENDICES

Appendix Table 7.1 Analysis of variance (ANOVA) for plant height (m), number of primary branch, number of flowers per cluster, number of fruit per cluster and number of fruits set per plant in (%) of tomato

Source of variation	d.f.	Mean square				
		PH(m)	**NPb**	**NFl/C**	**NFr/C**	**Frs/P(%)**
Rep	2	0.001	0.0311	0.01570	0.002	27.28
Cultivar	2	0.89 **	53.34**	3.507**	1.734**	109.71*
Staking	3	0.008**	8.939**	0.203**	1.75**	301.11**
Cultivar x Staking	6	0.0006 NS	0.597*	0.011NS	0.0064NS	9.70NS
Error	22	0.000608	0.2057	0.01445	0.03015	17.84
Total	35					

Significance levels: * indicates $p < 0.05$, ** indicates $p < 0.01$, and NS means $p \geq 0.05$ (not significant level

Measured traits: plant height (PH, m); number of primary branches (NPb); flowers per cluster (NFl/C); fruits per cluster (NFr/C); fruit set rate expressed as a percentage (Frs %).

Appendix Table 7.2 Appendix Table 7.2 Summary of variance analysis for tomato fruit traits: number of fruits per plant (all, saleable, and unsaleable) together with yield expressed as metric tons per hectare (total, marketable, and non-marketable

Source of variation	d.f.	Mean square					
		NMFr/P	**NUMFr/P**	**TNFr/P**	**MFy (tha)**	**UMFrY(t ha)**	**TFrY (t ha)**
Rep	2	0.0024	29.396	133.02	10.85	2.0071	1.1006
Cultivar	2	1429.5**	1189.87**	78.13NS	1595.54**	102.24**	3233.01**
Staking	3	518.4**	533.32**	619.03 **	3723.73**	168.95**	2987.66**
Cultivar x Staking	6	11.38**	113.04**	12.07 *	78.06*	21.182**	25.078**
Error	22	0.002065	7.244	18.02	2.839	21.1822	0.8015
Total	35						

Significance codes: one asterisk denotes $p < 0.05$, two asterisks denote $p < 0.01$, and "NS" indicates

no statistical significance at the 5% level

Appendix Table 7.3 Appendix Table 7.3 Summary of variance analysis for tomato fruit traits: average length (cm), average width (cm), and average mass per fruit (grams).

Source of variation	d.f.	Mean square		
		AFrL	AFrD	AFrWt
Rep	2	0.03111	0.05861	122.15
Cultivar	2	0.02*	3.871**	1725.42**
Staking	3	11.135**	4.503**	1818.53**
Cultivar x Staking	6	0.318**	0.198NS	14.35 NS
Error	22	0.0529	0.08889	26.31
Total	35			

***&**= Significant and highly significant at p<0.05 & 0.01 probability levels. NS=Non-significant at p<0.05 probability level**.

Appendix Table 7.4 Summary of variance analysis for flowering time (50% of plants) and maturity duration in tomato

Source of variation	d.f.	Mean square	
		DF	DM
Rep	2	20.028	31.361
Cultivar	2	665.07**	565.028*
Staking	3	1.023NS	46.028**
Cultivar x Staking	6	1.8NS	2.139 NS
Error	22	0.74	3.324
Total	35		

Significance codes: one asterisk = p < 0.05; two asterisks = p < 0.01; "NS" means p ≥ 0.05 (not significant).

Appendix Figure 7.1 Lay outing the main field

Appendix Figure 7.2 Tomato seedlings ready for transplanting

Appendix Figure 7.3 **Field status after transplant at irrigation time**

Appendix Figure 7.4 Non-staked tomato plants

Appendix Figure 7.5 **Single post staking tomato plants**

Appendix Figure 7.6 Vertical staking of tomato plants

Appendix Figure 7.7 French types staking of tomato plants

Appendix Figure 7.8 Marketable tomato fruits

Appendix Figure 7.9 Unmarketable tomato fruits