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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

FACULTY OF AGRICULTURE AND AGRO PROCESSING TECHNOLOGY

DEPARTMENT OF FRUIT AND VEGETABLE PROCESSING TECHNOLOGY

EFFECT OF PHOSPHORUS FERTILIZER RATES ON GROWTH, YIELD, AND YIELD COMPONENTS OF FENUGREEK (*Trigonella foenum-graecum* L.) VARIETIES IN CHELIYA DISTRICT, WEST SHEWA ZONE, ETHIOPIA

M.SC THESIS

GUDISA TEREFA GELE

JULY, 2026

ADDIS ABABA, ETHIOPIA

Effect of Phosphorus Fertilizer Rates on Growth, Yield, and Yield Components of Fenugreek (*Trigonella foenum-graecum* L.) Varieties in Cheliya District, West Shewa Zone, Ethiopia

Thesis Submitted to Department of Vegetable and Fruit Processing Technology

Directorate Graduate Studies, FDRE Technical and Vocational Training Institute

in Partial Fulfillment of the Requirements for the Degree of Master of Science in Coffee, Tea, and Spice Production Technology

M.Sc Thesis Research

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July, 2026

Addis Ababa, Ethiopia

FDRE TECHNICAL AND VOCATIONAL TRAINING INSTITUTE

POST GRADUATE PROGRAM

THESIS APPROVAL SHEET

I hereby certify that I have read and evaluated this thesis entitled' 'Effect of Phosphorus Fertilizer Rates on Growth, Yield, and Yield Components of Fenugreek (*Trigonella foenum-graecum* L.) Varieties in Cheliya District, West Shewa Zone, Ethiopia prepared under my guidance by Gudisa Terefa Gele ID No. TTMR 310/16. I recommend that it be submitted as fulfilling the Thesis requirement.

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As members of the Board of Examiners of the M.Sc. Thesis Open Defense Examination, we certify that we have read and evaluated the thesis prepared by **Gudisa Terefa Gele** and examined the candidate. We recommend that the thesis be accepted as it fulfills the thesis requirement for the Degree of Master of Science in Coffee, Tea, and Spices Production Technology.

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DEDICATION

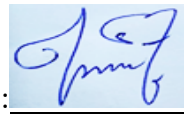
I dedicate this thesis to my beloved daughters, Martisin Gudisa, and my sons, Segni Gudisa and Keyofan Gudisa, for their love, patience, and prayers. I also dedicate this work to my beloved wife, Gutani Kebede; my sister, Simbo Dugasa; and my brother, Yonas Dugasa, whose unwavering love, encouragement, prayers, and support paved my way toward education and nurtured me with heartfelt affection throughout my life. Their contributions have played a significant role in my academic journey and the success of my life.

STATEMENT OF AUTHOR

First, I declare that this thesis is a genuine result of my own work, and I have duly acknowledged all sources of materials that I have used for writing this thesis. I have submitted this thesis in partial fulfillment of the requirements for the Master of Science degree at FTI and deposited it at the institution's library to make it available to borrowers for reference under the rules and regulations of the library. I declare that this thesis was not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHY SKETCH

The author, Gudisa Terefa Gele, was born on 1September 1995, at Bada Elamuu *Kebele*, in Cheliya District, West Shewa Zone, Oromia National Regional State, which is located 110 km West of Addis Ababa. When his age reached for school, he attended his primary school education at Cukala Wange Elementary School (Grades 1-8) from 2002 to 2009. In the subsequent years, he enrolled at Gedo Secondary and Preparatory School (Grade 9-10) from 2010 to 2011 in Gedo town. Finally, he joined Bako Agricultural Technical and Vocational Education Training College in 2013 and graduated with a level IV in Plant Sciences on 30 June 2014.Then he was employed at Bako Agricultural Polytechnic College as a trainer in 2015 and continued his studies at Wollega University through a weekend program and graduated with a B.Sc. in Plant Sciences on 30 March 2019. After a year of service in Bako Agricultural Polytechnic College, he joined the Federal Democratic Republic of Ethiopia Technical and Vocational Training Institute to pursue his Master of Science Degree in Coffee, Tea, and Spice Production Technology in February 2023.

ACKNOWLEDGEMENTS

First and foremost, I offer my deepest praise and gratitude to God, the Most Merciful and Gracious, for granting me the strength, wisdom, and perseverance necessary to complete this thesis. Next, I would like to express my deep and sincere gratitude to my major adviser, Dr. Tolera Abera (PhD.), for his professional guidance, constructive comments, close follow-up by spending his time, and continuous encouragement, insightful guidance, constructive feedback, and unwavering support throughout the entire research and writing process. I extend my special thanks to my lovely brothers, Instructor Gezagn Biru and Tekele Kusa, who gave me tireless support and guidance during the course of this work, starting from the field experiment to the final write-up of this thesis. My sincere appreciation also goes to the Federal Democratic Republic of Ethiopia Technical and Vocational Training Institute, Faculty of Agriculture and Agro-processing staff for their all-inclusive cooperation. Additionally, I am thankful to the Ambo Agricultural Research Center for their contribution to providing fenugreek varieties and to the Bako Agricultural Research Center for supporting the soil testing laboratory.

Finally, I thank all members of my brother and sister for their valuable ideas, encouragement, and financial support throughout my academic journey.

ACRONYMS AND ABBREVIATIONS

ATP	Adenosine triphosphate
BARC	Bako Agricultural Research Center
CSA	Central Statistical Agency
DZARC	Deberzeit Agricultural Research Center
EBI	Ethiopia Biodiversity Institute
EIAR	Ethiopian Institute of Agricultural Research
EthioSIS	Ethiopian Soil Information System
LDL	Low density lipoprotein
MC	Moisture content
OARI	Oromia Agricultural Research Institute
P_2O_5	Phosphorus Pentoxide
RCBD	Randomized Complete Block Design
SARC	Sinana Agricultural Research Center
LSD	Least Significant Difference
TSP	Triple superphosphate

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Effect of Phosphorus Fertilizer Rates on Growth, Yield, and Yield Components of Fenugreek (*Trigonella foenum-graecum* L.) Varieties in Cheliya District, West Shewa Zone, Ethiopia

ABSTRACT

Fenugreek (Trigonella foenum-graecum L.) is an economically important legume spice crop in Ethiopia. However, its productivity remains low due to poor soil fertility management, limited use of improved varieties, and inappropriate agronomic practices. Phosphorus deficiency is also a major constraint on fenugreek production in the study area. Hence, this experiment was conducted to investigate the effect of phosphorus fertilizer rates on the growth, yield, and yield components of Fenugreek (Trigonella foenum-graecum L.) Varieties in Cheliya District, West Shewa Zone, Ethiopia during the 2025 main cropping season. The treatments consisted of four phosphorus rates (0, 23, 46 and 69 kg P_2O_5 ha^{-1}) and four varieties (Bishoftu, Burqa, Jamma and Local) arranged in a 4x4 factorial randomized complete block design with three replications. The main effects of varieties and phosphorus fertilizer rates were highly significant($P<0.01$) effect on days to 50% flowering, days to 90% physiological maturity, and the number of branches per plant, seed per pod, and thousand seed weight of fenugreek Varieties. The interaction effect of the varieties and phosphorus fertilizer rates was also highly significant ($P<0.01$), effect the total number of nodules, the number of effective nodules, nodule fresh weight, taproot, pod per plant, dry biomass yield, and the seed yield of the fenugreek varieties. The highest (2.047 t ha^{-1}) seed yield was recorded for the Bishoftu variety at 69 kg P ha^{-1}. The seed yield of fenugreek varieties was positively and highly significantly associated with most of the yield-related parameters. The application of 46 and 69kg P ha^{-1} resulted in marginal rates of return of 2158 and 1961%, respectively, which are well above the minimum acceptable rate of return. This indicates that phosphorus fertilizer application is economically viable for fenugreek production under the study conditions. However, economic analysis showed that the application of 69 kg P_2O_5 ha^{-1} with Bishoftu variety gave the highest net benefit (627722). Therefore, the combination of Bishoftu variety and 69 kg P_2O_5 ha^{-1} is recommended for fenugreek production in Cheliya District and similar agro-ecologies.

***Keywords**: Fenugreek, Phosphorus fertilizer, Varieties, Nodulation, Seed yield*

1. INTRODUCTION

1.1. Background

Fenugreek (*Trigonella foenum-graecum L.*) is an annual leguminous crop belonging to the family Fabaceae (Camlica and Yaldiz, 2021). As a dicotyledonous and predominantly self-pollinated species, it is widely recognized for its adaptability to diverse and challenging growing conditions. Fenugreek exhibits considerable tolerance to drought and high temperatures, allowing it to grow successfully under a wide range of temperate and semi-arid environments (Aqeel *et al*., 2022). Moreover, as a legume, it possesses the capacity for biological nitrogen fixation through symbiotic association with *Rhizobium*, thereby enhancing soil fertility and contributing to sustainable agricultural production systems (Aqeel *et al*., 2022). Globally, India is the leading producer of fenugreek, accounting for more than 68% of total world production (Sahu, 2020). The crop is cultivated across diverse geographical and agroecological regions, including North Africa, Southeast Asia, Europe, Russia, Southern France, China, Egypt, Lebanon, Pakistan, Iran, Turkey, Morocco, Greece, Afghanistan, Australia, Canada, Argentina, Ethiopia, and the United States of America (Giridhar *et al*., 2023). Its widespread cultivation reflects both its adaptability to varied agro-climatic conditions and its increasing demand for food, medicinal, and industrial applications (Basu *et al*., 2019).

Fenugreek leaves and seeds are widely consumed for their nutritional and medicinal value. They possess numerous pharmacological properties, including antidiabetic effects through blood glucose regulation, cholesterol-lowering activity, antimicrobial properties, and anticancer potential (Yadav *et al.,* 2019). In addition to its medicinal uses, fenugreek serves as an important ingredient in various traditional food products. For example, it is used as a flavoring agent in cheese production in Switzerland, while in Egypt, seed powder is mixed with wheat flour to prepare traditional flatbread. In several African countries, roasted fenugreek seeds are used as a substitute for coffee. Furthermore, in India, fenugreek has long been incorporated into traditional medicinal practices (Yadav *et al.,* 2019; Rizvi *et al*., 2022). From a nutritional perspective, fenugreek is highly valued because of its high protein content, which is estimated at approximately 32% (Tura *et al*., 2023). Processed fenugreek seeds are also used in complementary infant feeding after four (4) to six (6) months of age, where the seeds are milled into flour and prepared with honey or sugar (Getu *et al*., 2022).

Ethiopia is recognized as the original homeland of fenugreek (*Trigonella foenum-graecum)* sub-species and the presence of fenugreek genetic variability (Roba and Tana, 2018). Fenugreek is a seed spice produced and largely used in Ethiopian dishes. It is grown in most high and midland areas, and its production and distribution are like those of other cool-season food legumes (Roba and Mohammed, 2024). In Ethiopia, the crop is produced either as a spice, food, or for other special purposes, such as for nursing mothers and infants as a breakfast beverage also, used in crop rotation for purpose of soil fertility, income generation, a flavoring for traditional bread, and maintains the soft texture of "tef-Injera" (Roba and Simion,2022). In Hararghe, it is known as 'Lafiso" and Harari people use fenugreek as 'Hulbat Meraq', used as their best dish (Usmael *et al.*, 2022).

According to CSA, (2022) report, the total area under production was 30,145.56 hectares and the production in quintals was 353,282.89 with productivity of 1.172 t ha^{-1} at national level, which is lower than the global potential yield of 1.8 t ha^{-1}. However, the area under production in Oromia region was 14,374.46 and the production in tone as 13.0613 with a productivity of 0.09 t ha^{-1}. The total production in the country, more than 98% of the production volume, is only from Oromia and Amhara regions (58.88 and 39.92%, respectively (Getu and Hirko, 2022). In West Shewa, where this study was conducted, during the 2021/22 cropping season, the area of production was 1395.62 ha^{-1} with a production of 8241 tons' ha^{-1}, which only contributes about 6.4% and has an average productivity of 0.591 t ha^{-1} (Endale,2022), which is lower than the attainable and national yield. Due to the lack of optimum Phosphorous rates, improved varieties, poor agronomic practices, and the presence of diseases and insect pests are the major factors that have contributed to lower crop yields in the study area (Abebe and Mitiku, 2025).

Phosphorus is one of the most important yield-limiting elements that are required by legume crops (Gerenfes and Negasa, 2021). Phosphorus is a critical macronutrient for fenugreek growth, development, and yield. It plays essential roles in energy transfer, photosynthesis, and the formation of nucleic acids and cell membranes (Yadav *et al*.,2020). In legumes like fenugreek, phosphorus is particularly important for nodule formation and nitrogen fixation.Phosphorus deficiency reduced root growth, nodulation, and nitrogen fixation in fenugreek, leading to decreased biomass and seed yield (Erman *et al*., 2025). Jain *et al.* (2021), found that adequate phosphorus supplies enhanced photosynthetic efficiency, chlorophyll content, and overall plant vigor in fenugreek. Phosphorus requirement of comparison of fenugreek accessions and varieties potential in terms of

growth, yield attributes, and seed yield in response to phosphorus rate application was not undertaken under Ethiopian conditions.

Moreover, in Ethiopia, fenugreek producers often lack information about which fenugreek varieties are best suited to local agro-ecological conditions and they are specific phosphorus fertilizer recommendations for fenugreek (Roba Tana, 2018; Serbessa *et al*., 2019). Tank (2021) reported that the application of 20 kg N with 40 kg P_2O_5 ha^{-1} resulted in the highest plant height at all the growth stages and seed, straw, as well as biological yields of fenugreek. He also observed an increase in growth parameters like plant height, dry matter accumulation, number branches per plant, and nodulation due to application of 40 to 60 kg P_2O_5 ha^{-1} in fenugreek. This research thesis was conducted to determine suitable fenugreek varieties and recommended phosphorus fertilizer rates for growth, yield, and yield attributes of fenugreek.

1.2. Statement of the Problem

Fenugreek (*Trigonella foenum-graecum L*.) is an important food, spice, medicinal, and forage legume that contributes significantly to household food security, nutritional improvement, and income generation for smallholder farmers in Ethiopia (Roba and Simion, 2022). Despite its economic and nutritional importance, the productivity of fenugreek in Ethiopia remains substantially below its genetic and global production potential. According to the (CSA, 2022), the national average grain yield of fenugreek is only 1.17 t ha^{-1}, which is considerably lower than the estimated global potential yield of 1.8 t ha^{-1} (Kibiru and Latera, 2025). The productivity gap is even more pronounced in West Shewa Zone, where the average yield is only 0.591 t ha^{-1}, substantially below both the Oromia Regional average (0.909 t ha^{-1}) and the national average (1.17 t ha^{-1}). This indicates the existence of considerable opportunities to improve fenugreek production through appropriate crop and nutrient management practices.

The low productivity of fenugreek in the Ethiopian highlands is attributed to several interacting biophysical and management-related constraints, including poor soil fertility, particularly phosphorus deficiency, the continued cultivation of low-yielding local landraces, inadequate agronomic management, and the occurrence of biotic and abiotic stresses (Fikreselassie *et al.,* 2012; Roba and Tana, 2018). Among these factors, phosphorus deficiency is considered one of the most critical constraints because phosphorus plays a fundamental role in root development, nodulation, biological nitrogen fixation, flowering,

seed formation, and overall crop productivity. However, phosphorus availability in many Ethiopian soils is severely limited by soil acidity, phosphorus fixation, continuous cultivation without adequate nutrient replenishment, and soil erosion (Gemada, 2021; Beshir, 2024). Consequently, phosphorus deficiency significantly restricts the growth, yield, and yield components of fenugreek.

In addition to nutrient limitations, the widespread cultivation of local fenugreek landraces has further constrained productivity. Although these landraces are generally well adapted to local environmental conditions, they often possess low genetic yield potential, poor seedling vigor, limited pod-setting capacity, and relatively weak responsiveness to fertilizer application compared with improved varieties (Kibiru and Latera, 2025). Furthermore, poor seedbed preparation, suboptimal crop management practices, use of low-quality seed, and inadequate adoption of improved production technologies continue to limit fenugreek productivity in many production areas.

Although phosphorus fertilization and improved varieties have individually been reported to enhance the productivity of grain legumes, limited information is available regarding their combined effects on fenugreek under the agroecological conditions of Cheliya District. In particular, the interaction between phosphorus fertilizer rates and fenugreek varieties has not been adequately investigated to identify the optimum combination capable of maximizing growth, yield, and economic returns. Consequently, farmers in the study area lack location-specific recommendations on appropriate phosphorus fertilizer rates for different fenugreek varieties, leading to inefficient fertilizer use, reduced productivity, and lower farm profitability.

Therefore, generating site-specific information on the optimum phosphorus fertilizer rate for improved and local fenugreek varieties is essential to enhance nutrient-use efficiency, increase grain yield, improve economic returns, and promote sustainable fenugreek production. Accordingly, this study was conducted to evaluate the effects of different phosphorus fertilizer rates on the growth, yield, and yield components of selected fenugreek varieties and to determine the economically optimum phosphorus fertilizer rate under the agroecological conditions of Cheliya District.

1.3. Significance of the Study

This study provides valuable information on the response of different fenugreek varieties to varying rates of phosphorus fertilizer in the Cheliya District. The findings help farmers and agricultural extension workers choose suitable fertilizer rates and varieties, which can improve fenugreek yield and support the livelihoods of smallholder farmers in the Cheliya district. Finally, the study served as a reference for other researchers who were interested in similar work and also helped to identify areas that required further investigation.

1.4. Objectives

1.4.1. General Objective

- To improve the yield of fenugreek varieties using phosphorus fertilizer rates in the Cheliya District, West Shewa Zone of Oromia, Ethiopia.

1.4.2. Specific Objectives

- To evaluate the effects of phosphorus fertilizer rates on the growth, yield, and yield components of fenugreek varieties
- To determine the economically optimum phosphorus fertilizer rates for fenugreek production in Cheliya District

2. LITERATURE REVIEW

2.1. Origin and Distribution

Fenugreek is believed to have originated in the Mediterranean region, specifically in the countries surrounding the eastern Mediterranean (Seal *et al*., 2025). It has been cultivated for thousands of years and is now widely distributed across various parts of the world, including North Africa, the Middle East, Southern Europe, and parts of Asia (Basu *et al.,* 2014). Now, fenugreek is an important cash crop in India (the leading fenugreek-producing country), Morocco, China, Pakistan, Spain, Tunisia, Turkey, Lebanon, Israel, Egypt, Ethiopia, Kenya, and Tanzania (Hilles and Mahmood, 2021).

Ethiopia is the original homeland of a fenugreek subspecies known as the Mediterranean ecotype, which has a distribution extending from Eritrea to Somalia (Roba and Simion, 2022). In Ethiopia, fenugreek-growing regions are located at 1,800-2,300 m.a.s.l. and are characterized by a subtropical climate, including wet and dry seasons (Abebe and Mitiku, 2025). The production and distribution of fenugreek is similar to those of other cool-season food legumes such as faba bean, field pea, lentil, chickpea, and grass pea (Kibiru and Latera, 2025)

2.2. Description of Fenugreek

2.2.1. Botanical Description of Fenugreek

Fenugreek is an annual herb belonging to the Fabaceae family (Giridhar *et al*., 2023). Its stems are branched, thick, erect, hairy, or green to purplish in color. The leaves are trifoliate, composed of three toothed, and ovate leaflets (Khan, 2023). The flowers are solitary or in groups of two, borne on the axils, and are white or pale yellow to light purple, presenting a triangular shape. It is a self-pollinated diploid annual species with a chromosome number of 2n=16, highlighting its genetic stability and reproductive strategy (Ravi *et al*., 2025). Its matured seeds are very hard, flat, light brown to reddish brown in color, and marked by grooves that delineate two unequal parts (Giridhar *et al.,* 2023). The plant typically reaches a height of 60-90 cm, and it has a strong tap root system and beaked pods containing 10-20 small, hard, yellowish-brown seeds 10-20 seeds per pod (Singh, 2023). The plants radiate a spicy odor, which persists on the hands after touching. Wild and cultivated varieties exist. fenugreek collection from Yemen and Ethiopia, which he called Abyssinia.

2.3. Ecological Requirements of Fenugreek

2.3.1. Climate Requirements

Fenugreek is fundamentally a cool-season, long-day crop whose growth is highly sensitive to temperature, rainfall, and sunlight (Yaldiz and Camlica, 2021). It thrives in Ethiopia's highlands at altitudes of 1,800 to 2,600 meters above sea level, where subtropical climates feature distinct wet and dry seasons similar to those suited for other pulse crops (Muluken *et al*., 2022). This range provides ideal temperate conditions, with average daily temperatures of 18 to 25°C that support vegetative growth and seed development.

High temperatures, particularly during flowering and pod-filling, trigger forced maturity, leading to shriveled seeds and reduced yields (Basu *et al*., 2022). Successful harvests require a shift to dry, cool, and sunny conditions during flowering, maturation, and harvesting, as full sunlight drives optimal photosynthesis and seed production. Excessive rain or humidity at these stages promotes fungal diseases like powdery mildew and rust, causes lodging, and complicates harvesting and drying (Getachew *et al.,* 2020)

2.3.2. Soil Requirements

Fenugreek performs best in well-drained loamy or clay-loam soils with a neutral to slightly alkaline pH (6.0–7.5) (Alemayehu *et al*., 2022). It adapts well to Ethiopia's common highland soils: heavy black clay Vertisols and red-brown Nitisols.While Vertisols offer high water-holding capacity, their poor drainage risks waterlogging, often managed with broad-bed and furrow systems for better aeration (Wubetu,2017). As a legume, fenugreek forms symbiotic relationships with Rhizobium bacteria to fix atmospheric nitrogen, reducing its N demands while enhancing soil fertility. However, it requires ample phosphorous often deficient in Ethiopian soils for root development, nodulation, energy transfer, and yield gains (Bekele *et al.,* 2021). It performs best on well-drained Alluvial or black soils without water-logging issues; productivity depends on consistent soil moisture. Optimal conditions include 8-27°C temperatures, 400 -1,500 mm annual precipitation, and rich, well-drained soils (pH 5.3-8.2); cold, wet conditions stunt growth (NidhiVerma *et al*., 2020).

2.4. Agronomic Practices for Fenugreek

2.4.1. Land Preparation

Land preparation for fenugreek production begins with deep primary tillage using animal-drawn or tractor plows to 20–30 cm depth, breaking soil compaction and incorporating residues from previous crops like cereals or pulses (Roba and Simion, 2022). This is followed by 2–3 harrowing passes with disk or tine harrows to achieve a fine, uniform seedbed that promotes even germination and root penetration (Beze and Shumbulo, 2024). Final leveling with a planker or roller firms the surface, reducing clods and minimizing erosion on sloped highland fields. In Ethiopian practice, preparation occurs 2 to 4 weeks before late Meher planting to conserve residual soil moisture while allowing weed seeds to germinate for shallow cultivation (Berhe *et al.,*2025). Crop rotation is integrated, with fenugreek following non-legumes to enhance yields by 15–20%; common sequences include sorghum-fenugreek.

2.4.2. Sowing and Planting

The optimal planting window is during the Meher season, from late June to early August, aligned with the rainfall pattern. While broadcasting is a common traditional practice, between row and plant spacing at 20-30 cm and 10cm is the recommended method. It ensures a more uniform plant population, reduces the seed rate from 25-35 $kgha^{-1}$ (broadcasting) to 20-25 $kgha^{-1}$, and greatly facilitates subsequent operations like weeding

The optimal planting window for fenugreek occurs during the Meher season (late June to early August), aligning with local rainfall patterns; while broadcasting remains a common traditional practice, row planting with 20-30 cm between rows and 10 cm between plants is recommended, ensuring uniform plant population, reducing seed rates from to 20-25 kg ha^{-1}, and facilitating weeding (Bekele *et al*., 2021). In Ethiopia, fenugreek primarily suffers from powdery mildew (Erysiphe polygoni) the most damaging disease affecting flowering and pod stages with 20 to 80% severity in central highlands, causing up to 40% yield loss, alongside leaf spot (Cercospora traversiana), rust (Uromyces trigonellae), and wilt in humid conditions; major pests include aphids and pod borers (Helicoverpa spp.), potentially reducing yields by 25 to 30% in untreated fields. Chemical controls involve sulfur-based fungicides (wettable sulfur 50% WP at 2–3 $kgha^{-1}$) or propiconazole (0.1%) for powdery mildew at first symptoms (70–85% efficacy, repeat every 10-14 days), mancozeb (0.25%) alternated with hexaconazole for leaf spot/rust, and imidacloprid (0.3 ml/L) for

aphids/borers at 10-day intervals (max 2 sprays/season to prevent resistance and protect pollinators), best integrated with resistant varieties like Bishoftu, Burqa and Jamma

2.4.3. Nutrient and Weed Management

Although fenugreek fixes its own nitrogen as a legume, a small starter dose of 18 to 20 kg N ha^{-1} benefits early growth in soils with low organic matter (Getachew *et al*., 2020). Phosphorus remains the most critical nutrient, applied at 46 to 69 kg P_2O_5 ha^{-1} during planting to boost root development, nodulation, and seed yield, with Ethiopian trials confirming optimal responses up to 150 kg phosphorus per ha for fenugreek varieties.

Fenugreek competes poorly against weeds, especially during the first 30 to 45 days' post-emergence, where uncontrolled growth can cause 30 to 50% yield losses. Effective management relies on hand weeding and 30 days after sowing, supplemented by row planting to comfort access; pre-emergence herbicides like pendimethalin 1Lit ha^{-1} offer alternatives in larger fields, though manual methods predominate in Ethiopian smallholder systems (Getachew *et al.,*2020).

2.4.4. Harvesting and Post-Harvest Handling

Fenugreek typically matures in 120–150 days, depending on variety and conditions. Harvesting should begin when pods turn yellowish-brown and lower leaves start dropping, as delays cause significant seed loss from pod shattering (Tsegaye *et al*., 2023). Plants are manually cut with sickles or uprooted, then stacked in the field for drying under sun to reduce moisture content below 10%. Threshing follows traditionally by beating dried plants with sticks or animal trampling, yielding clean seeds for market. Seeds are then thoroughly dried and stored in bags to prevent pest damage and mold growth (Tsegaye *et al*., 2023). Timely operations preserve quality and minimize losses up to 20–30% from shattering or improper drying.

2.5. Economic Importance of Fenugreek

2.5.1. Medicinal importance

Fenugreek is one of oldest medicinal plants; its leaves, seeds and sometimes even the whole plant have been used as medicine (Sun *et al*., 2021) Powdered fenugreek seed extracts are used to treat a wide range of conditions, including as skin irritations, head lice, wounds, and high blood sugar (Hamza *et al.,*2019). Fenugreek seed extract can be used as an anti-diabetic to lower blood sugar and cholesterol levels (Singh *et al*.,2023). Extracts from fenugreek seeds can be used to make teas to reduce fever and reduce menstrual discomfort (Salman and Qadeer,2021).

Fenugreek seeds and leaves are anti-cholesterol, anti-tumor, anti-inflammatory, and uterine tonic and useful in burning sensation, bone and muscles, respiratory system, gastrointestinal and reduce cholesterol, reduce cardiovascular cancer prevention, appropriate for kidney trouble, skin infection, increase milk production. It is also an appetite suppressant that helps in weight loss (Sun *et al*., 2021). Taken internally, fenugreek is used to treat bronchitis, coughs, respiratory problems and sinus conditions (Al-Saady *et al.,* 2018). Fenugreek, as most of the species of the genus *Trigonella*, is strongly anti-fungal and can be used as an insect repellent *(*Ruwali *et al.,* 2022).

2.5.2. Nitrogen fixation

Fenugreek, a legume of great value, has the unique property of nitrogen fixation from the atmosphere in symbiotic relationship with Rhizobium bacteria. The bacteria infect the roots of the plant and develop specialized structures, the nodules, where the process of nitrogen fixation takes place. In these nodules, the bacteria reduce atmospheric nitrogen, which is not usable by plants in gaseous form, to ammonia, a form of nitrogen readily available to fenugreek for development (Rigobelo *et al*., 2020). This is made possible by the nitrogenous enzyme of the bacteria. When fenugreek plants rot, immobilized nitrogen is freed in the soil, and the soil is fertilized. Natural nitrogen fertility reduces the necessity for synthetic fertilizers and makes fenugreek a precious ingredient in sustainable agriculture practice, especially in crop rotation agriculture (Mechri *et al*., 2025).

2.5.3. Forage crop

Fenugreek has forage value with a more sustained release of nitrogen in the rumen for cattle feeding and greater mass digestion than alfalfa (Niu *et al*., 2020). High quality and dry land-adapted forage crops such as fenugreek have the potential to help the cattle industry by reducing feed needs by improving feed efficiency and reducing water consummation for fodder production(Zeng *et al*.,2024). It can produce a high yield with high quality fodder without putting cattle at risk of bloat. At 10% bloom or maturity, fenugreek showed a greater proportion of readily soluble dry matter than alfalfa(Narayana *et al*., 2022).Fenugreek forage is highly digestible, has a crude protein content of 15-20%, and consistently produces forage of high quality for ruminants (Sakr *et al.,* 2025). Fenugreek has a nutritive value, it has been shown to be more digestible and have a higher nutrient content than other competing forages (Wijekoon *et al*.,2021). Fenugreek has been used as forage due to its stimulating and improving of milk production in mammals (Sevrin *et al.,*2019)

2.5.4. Functional food

In the south and central Asia, both ripe and unripe seeds as well as green leaves have been eaten as food (Mir-Makhamad *et al*., 2023). The protein content of Fenugreek is high (43.8g/100g) and most of the time it is used to supplement low-protein foods such as cereal crops (Legesse *et al.,* 2020). Fenugreek is commonly consumed by nursing mothers, who often increase their intake of pulses to help maintain an adequate breast milk supply. The leaf of fenugreek contains 86.1% moisture, 4.4% protein, 0.9% fats, 1.5% minerals, 1.1% fiber and 6.0% carbohydrates (Huggins, 2022). Its mineral and vitamin contents are calcium, phosphorus, iron, carotene, riboflavin, niacin and vitamin C (Hoque *et al.*, 2023). The seed contains 13.7% moisture, 26.2% protein, 5.8% fat, 3.0% mineral, 7.2% fiber and 44.1%carbohydrate (Roba and Mohammed 2024). Fenugreek seeds are mixed into flour, boiled and sweetened with sugar or honey before being fed to babies aged 4-6 months (Getu *et al*.,2022).

2.5.5. Spice uses

Fenugreek is known as a spice. It has been used as flavoring agent, curry powder, tea, and as a food preservative (Sarwar *et al.,*2020). In Ethiopia, the seeds are used for preparing some traditional sauces (“wot”), the seeds are usually roasted, finely ground and the powder is used during non-fasting periods. Moreover, fenugreek flour is used to flavor and soft

“injera” (thin pancake-like bread usually made of teff, sorghum, maize, wheat or other cereal (Kamimura, 2024).Fenugreek seeds and leaves are mixed with maize and wheat to make food more flavorful (Gazebo *et al.,*2019).

2.5.6. Income source

Spices have a significant role in the nation's production system and foreign exchange gains. The spice sub-sector has immense potential for economic development and poverty reduction (Tesfa *et al.,*2017*)* among which fenugreek is an important one. They have a significant impact on farmers' transition from subsistence to market-oriented production. Among seed spices, fenugreek is one of which provides various purposes in developing and underdeveloped countries as they shouldn’t stay back for capturing the potential emergent global markets for fenugreek (Basu *et al.,*2019).Roba and Simion (2022) reported that fenugreek is found in nearly every market in Ethiopia and has been cultivated in Ethiopia since ancient times for use as food, spices and medicinal purpose.

2.6. Improved Variety of Fenugreek in Ethiopia

Ethiopia has rich fenugreek genetic diversity, with both local landraces and improved varieties. Yimer *et al*. (2021) characterized 144 Ethiopian fenugreek accessions and identified significant variation in agronomic traits and nutrient composition. The Ethiopian Institute of Agricultural Research has released improved varieties such as 'Chala' and 'Burka', which show higher yield potential and disease resistance compared to local landraces (Fikreselassie *et al*., 2022). Only three varieties (Chala, Hund’ol, and Ebbisa) were released in 2016 from regional and federal research institutes (Sinana Agricultural Research Center and Debrezeit Agricultural Research Center) for specific and wider cultivation. Nowadays more than seven varieties (Chala, Hundaol, Ebisa, Burka, Jamma, Wera illu, and Teru) were released for yield potential and oleoresin content, and two varieties (Bishoftu and Chefe) were released for seed quality (white/cream color and black seed).

Table 1. list of Improved Variety of Fenugreek in Ethiopia

Varieties	Year of release	Area of adaptation				Production t ha^{-1}	
		Altitude(m)	Rainfall (mm)	Breeder/ Maintainer	Days Maturity	Research Field	At farm
Burqa	2016	1650-2400	120-500	Sinana,	129	2.08 -	-
Jamma	2016	2300–2800	668 -1000	SARC	147	1.2-2.3	1.1
Bishoftu	2017	1800-2500	980- 1200	TEPI, NS	128	1.19	1.0
Chala	2005	1800–2400	700–1000	Debrezeit		0.9-18	8-15
Hundaol	2006	1800–2600	800–1200	Sinana ARC		1.2-2.2	0.6-.8
Ebisa	2012	1700–2400	750–1100	Sinana ARC		1.3-2.1	-
Wereillu	016	2300-2800	868-1000	Sirinka ARC	148	1.1-2.1	1.2
Turu	2021	1900-2450	780- 1027	EIAR,TNSC	140	1.2	1.1
Chefe	2021	1900-2450	800 –	TNSC,DZA	145	1.3	1.15
Arganne	2021	1650 – 2400	120 – 500	Sinana, ARC	121	1.5-2.6	1-2.0

Source: Getu *et al*. (2022); Ethiopia Crop Varieties Register (2016)

2.7. Role of Phosphorus on Fenugreek

Phosphorus is a key macronutrient that has a central position in the growth and development of fenugreek (*Trigonella foenum-graecum L*). Energy transfer is one of its major roles since phosphorus is an integral constituent of ATP (Adenosine Triphosphate). ATP is necessary for energy transfer in plant cells, facilitating metabolic activities like photosynthesis and the absorption of nutrients. In the absence of sufficient phosphorus, these processes can be inefficient, which results in stunted growth and low yield. Legumes have a more intense need for phosphorous compared to cereals because they have less-branched and less-fibrous root systems (Vanlauwe *et al*., 2010). Enough phosphorus can grow a healthy root system, essential for fenugreek's growth potential (Ali *et al*., 2023). Apart from root establishment, phosphorus is critical for flowering and pod development. A recent publication indicated that phosphorus supply significantly increased pods per plant, resulting in better total yield (Khan *et al*., 2023).

Phosphorus also assists in the process of photosynthesis through the development of chlorophyll, the pigment that absorbs light energy. Increased photosynthetic activity leads to more biomass production, which is essential for fenugreek growth. In addition,

phosphorus enhances the effectiveness of other nutrients, including nitrogen and potassium, by enabling their acquisition and use. phosphorus plays a vital role in the growth and development of fenugreek, affecting energy transfer, root growth, flowering, photosynthesis, nutrient utilization, and resistance to stress. Its use is essential for maximizing fenugreek production.

2.8. Effect of Phosphorus on Phenology and Growth of Fenugreek

Phosphorus application generally exerts modest effects on phenological traits but consistently enhances vegetative growth parameters. genotype-dependent. Phosphorus application also increased plant height, branching, root growth, and biomass accumulation. Regarding vegetative development, phosphorus fertilization significantly increases plant height, number of branches per plant, root development, dry matter accumulation, and total biomass. Serbessa *et al*. (2019) observed positive genotypic responses to P_2O_5 levels across these growth parameters. These findings with Ahmad *et al,* (2005) reported that application rates of 40–60 kg P_2O_5 ha^{-1} produced taller plants and more branches. Similarly, Raghuwanshi, (2021) found that 40–60 kg P_2O_5 ha^{-1} resulted in increased plant height (up to 44.0 cm) and branch numbers (up to 4.27 per plant). Moreover, Mitoo (2016) showed that 40–60 kg P_2O_5 ha^{-1} produced taller plants (up to 49.8 cm) and more branches, with 40 kg often at par with 60 kg.

2.9. Effect of Phosphorus on Yield and Yield Components of Fenugreek

Phosphorus significantly improves pods per plant, seeds per pod, 1000-seed weight, biological yield, and seed yield. Serbessa *et al*. (2019) reported a that increase in pods per plant at 26 kg P ha^{-1} over the control. Similarly, Nahar (2021) reported that phosphorus application at 45–60 kg P_2O_5 ha^{-1} significantly increased seeds per plant, 1000-seed weight, biological yield, and seed yield. The highest 1000-seed weight (22.89 g) and seed yield (1358.29 kg ha^{-1}) were obtained at 60 kg P_2O_5 ha^{-1}, although the yield was statistically similar to that obtained at 45 kg P_2O_5 ha^{-1} (1326.47 kg ha^{-1}). Likewise, Baldaneeya *et al. (*2022) and Ahmed (2025) confirmed that phosphorus fertilization enhances pod formation, seed filling, and final seed yield. Overall, optimum phosphorus rates improve reproductive growth and productivity.

2.10. Effect of Varieties on Phenology and Growth of Fenugreek

Fenugreek varieties significantly affect flowering time, maturity, plant height, branching, and biomass production due to genetic variation. Serbessa et al. (2019) reported that Chala observed earlier flowering and better growth performance than other genotypes. Finding with Abebe and Mitiku (2025) found that Burka flowered earlier (44.6 days) and produced the highest number of primary branches (6.73). Similarly, Abdi et al, (2021). Bishoftu and Chala demonstrated superior growth and phosphorus-use efficiency.

2.11. Effect of Varieties on Yield Components and Yield of Fenugreek

Fenugreek varieties significantly influence yield components and seed yield due to genetic variation. Serbessa *et al.* (2019) reported significant differences among genotypes in pods per plant, seeds per pod, biological yield, and seed yield, with Chala showing superior yield performance. Similarly, Kena and Latera (2025) found that Ebbisa produced the highest number of seeds per pod (8.2), while Jamma recorded the lowest (4.63). Abebe and Mitiku (2025) and Abdi *et al.* (2021) also reported that improved varieties Chala, Bishoftu, Burka, and Ebbisa outperformed local cultivars in yield components and seed yield.

3. MATERIALS AND METHODS

3.1. Description of Experimental Area

The study was conducted in Bada Elamu kebele of Cheliya District, West Shewa Zone, Oromia Regional National State of Ethiopia, approximately 188 km from Addis Ababa and 68 km from the zone capital, Ambo town. Geographically, it lies between 8°-9° N latitude and 37°-38° E longitude, with elevations ranging from 1500 to 3051 m.a.s.l.

The district experiences annually mean temperature range from 8°C to 25°C, with an average temperature of approximately 16°C and Annual rainfall varies between 750 to 1000 mm. The predominant soil type of the area was Chromic Luvisols (28%), Eutric Luvisols (27%), and Eutric Nitisols (45%), with textures of clay loam, silt clay loam, and clay. The major crops grown widely in the area are cereals (wheat, barley, maize and teff), pulses (chickpea, field pea, faba bean, and lentil), seed spices (coriander, Fenugreek, basil and Roe) (Cheliya Agricultural Office, 2014).

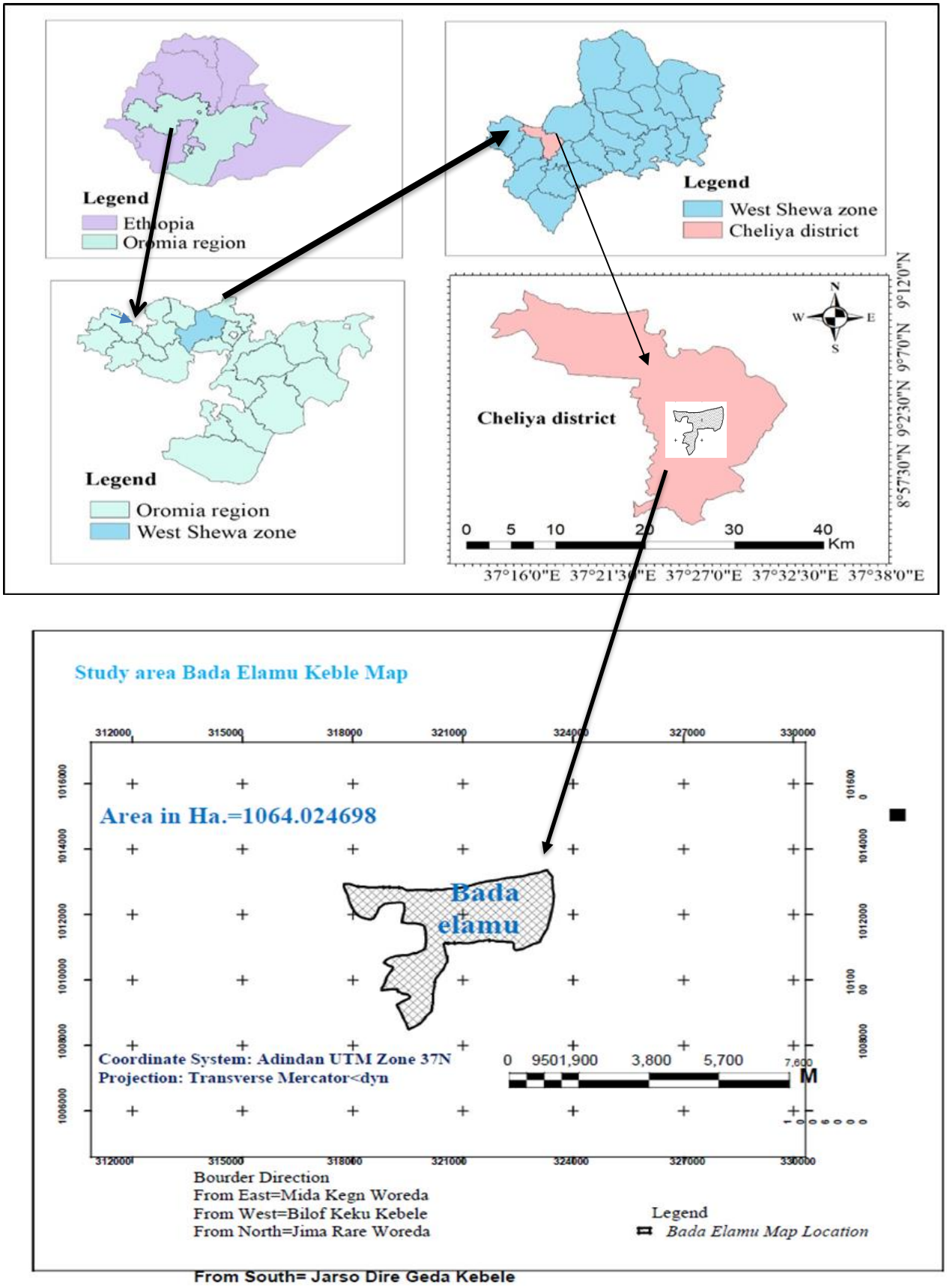


Figure 1.Description of Experimental Area

3.2. Description of Experimental Materials

3.2.1. Planting material

Three improved fenugreek varieties and a local cultivar, namely, Bishoftu, Burqa, Jamma, and local, were collected from Ambo Agricultural Research Centre and used for the experiment. These varieties were selected based on their yield performance, disease tolerance, and adaptability to the study area.

Table 2. Description of fenugreek varieties

Varieties	Year of release	Area of adaptation				Production (t ha^{-1})	
		Altitude(m)	Rainfall (mm)	Breeder/ Maintainer	Days to Maturity	Research Field	At farm
Burqa	2016	1650-2400	120-500	Sinana,	129	2.08 -2.22	-
Jamma	2016	2300–2800	668 -1000	SARC	147	1.2-2.3	1.1
Bishoftu	2017	1800-2600	400-1500	TEPI, NS	130	1.19	1.0
Local	-	1,800–2,300	400–1500	By local farmers	120	-	1.375

Source: Ethiopia Crop Variety Register (2016)

3.2.2. Fertilizer material

Triple superphosphate (TSP), containing 46% P_2O_5, was used as the source of phosphorus. The phosphorus fertilizer rates of 0, 23, 46, and 69 kg P_2O_5 ha^{-1} were applied in the study. These rates were selected to encompass the current blanket recommendation for cool-season pulses in the region and to allow assessment of both phosphorus deficiency and the potential response plateau. This approach is consistent with prior work on fenugreek and other legumes in the Ethiopian highlands (Serbessa et al., 2019).

3.3. Experimental, Treatments and Design

The experiment consists of two factors, namely, four levels of phosphorus (0, 23,46 and 69kg P_2O_5 ha-1) as Factor A and three improved and one local cultivar (Bishoftu, Burqa, Jamma and Local cultivar) used as Factor B. The treatments were laid out in a randomized complete block design (RCBD) with factorial arrangement in three replications (Gomez and Gomez, 1984). The 4 x 4 treatment combinations with a total of 16 treatments were used for the study. The gross plot size of each plot was 2m length and 3m in width (6 m^2). The space between plots and blocks was 0.5 m and 1m, respectively. Each plot consisted of ten rows, and each row it contained 20 plants, and each plot contained 200 plants. The space between rows is 30 cm, and between plants is 10 cm. Two of the outermost rows on both sides of the plot were considered as border. Four rows next to the border rows were used for destructive sampling. The middle 4 rows were used as net rows, and the net plot size was 1.2 m x 2 m = 2.4 m^2

3.4. Experimental Procedure and Field Management

The experimental field was ploughed three times using oxen and pulverized to a fine tilth by hand digging. The field was leveled manually and divided into three blocks, each of which was further divided into 16 treatment plots. sowing of seeds was conducted at uniformly at a rate of 25 kg ha^{-1} by drilling, with space 30 cm between rows and 10 cm between plants. The seeds were sown into rows on the prepared fine seedbed on the 20th August, 2025. Phosphorus fertilizer was applied at sowing time according to the treatment using the band placement method and covered with soil. Nitrogen was applied uniformly at a rate of 23 kg N ha^{-1} in the form of urea (46% N) as a starter dose to stimulate early growth and nodulation, in line with standard recommendations for grain legumes (MoA, 2014).

Agronomic practices including weed control, all broadleaf and grass weeds were cleared manually to all treatments uniformly. Disease were carried out uniformly for all plots as per weeded crop protection, fenugreek plants were treated with Mancozeb at a rate of 2.5 kg ha^{-1}, diluted in 200 liters of water ha^{-1}.The fungicide was applied to control powdery mildew. Harvesting was performed at maturity on 12th, December, 2025. The crop was harvested manually when 90% physiological maturity was reached, as indicated by the yellowing of leaves and pods, and was dried under the sun before threshing. Finally, threshing was done separately for each plot.

3.5. Soil Sampling and Analysis

Before sowing, soil samples (0-30 cm depth) was collected diagonally from 10 spots from the entire experimental field and mixed to have one composite sample. The composite sample was air-dried, ground using a pestle and a mortar, and allowed to pass through a 2-mm sieve. Samples were sent to Bako Agricultural Research Center (BARC) for analysis Working samples were obtained from submitted bulk samples and analysis for soil pH soil pH, total nitrogen (N), organic carbon (OC), available phosphorus and cation exchange capacity (CEC), were conducted using the appropriate laboratory procedures at Bako Agricultural Research Center Soil Laboratory. The total nitrogen was determined by the Kjeldahl method (Jackson,1958) and available Phosphorous was estimated by Olsen's method (Olsen *et al.,*1954). The organic carbon was estimated with wet digestion method (Walkley and Black, 1934). The CEC was determined by ammonium acetate method (Scollenberger and Simon, 1945). The soil pH was measured in 1:2.5 soil water ratios using an electrodes pH meter (Benton,2003). The particle size distribution was determined by hydrometer method (Day,1965).

3.6. Data Collected and Measurement

3.6.1. Crop phenology

Days to 50% emergence: Were recorded as number of days from date of sowing to the time when 50% of the seeds emerged in each plot.

Days to 50% flowering: were determined by counting the number of days from sowing to the time when the first flowers appeared in 50% of the plants in a plot (Serbessa *et al*., 2019).

Days to 90% physiological maturity: Were determined as the number of days from planting to the time when 90% of the plants started senescence of leaves (yellowing of the foliage) and pods started to lose its pigmentation (Minjaro *et al*.,2023).

3.6.2. Growth Parameters

Number of branches per plants: Was recorded from ten randomly selected and pre-tagged plants at physiological maturity. The average value was expressed as the number of branches per plant (Singh, 2023)

Plant height: Was measured from the ground to the tip of ten plants. The average was calculated and expressed plant height by centimeters (cm)(Minjaro *et al*., 2023).

Tap root length:Taproot length was measured from the ground level to the tip of root from randomly selecting ten plants of the destructive rows.(Serbessa *et al*., 2019).

3.6.3. Nodule Parameter

Number of total nodules per plant: It was determined by counting randomly taken ten plants from the 4 middle rows of each plot at flowering time. Roots were carefully washed using water on a sieve, and total nodules were separated and counted (Gutema and Alemu, 2024).

Number of effective nodules per plant: Was measured by observing the color inside of nodules was observed by cutting with a sharp blade, and a pink to dark-reddish color was considered effective; whereas inactive nodules (non-effective nodules) were black, gray or greenish, and white on the inside of nodules (Singh, 2016).

Nodule fresh weight per plant: The nodules collected from ten plants in each plot, including the nodules separated for color determination, were combined, and their fresh

weight was measured using a sensitive balance until a constant weight was obtained (Tesfaye *et.al*., 2020).

Nodule dry weight per plant: Was measured after ten sample plant roots nodules oven dried at 70 ^{0}C for 48 hours, then the dry weight was taken measured by a sensitive balance to constant weight and expressed as an average of ten plants reported in gram per plant (Serbessa *et al*., 2019).

3.6.4. Yield and Yield Components

Plant stand count: The number of plants from harvestable plot area (net plot area) was counted at harvesting and converted to hectare basis.

Number of pods per plant: Was recorded from 10 pre-tagged plants in each net plot area at harvest and the average was taken as number of pods per plant (Serbessa *et al.*, 2019)

Number of seeds per pod: The total number of seeds in the pods of the ten plants were counted and divided by the total number of pods to find the number of seeds on pod (Lal *et al.*, 2025).

Thousand seed weight: Was sampled from each plot and weighed using sensitive balance, the weight was adjusted at 10 % standard moisture content and expressed as gram per plot (Abebe and Mitiku, 2025).

Seed yield: Seed yield was measured by harvesting the crop from the net plot area. The harvested fenugreek was sun-dried for eight days and threshed manually by placing the dried crop in sacks and beating it with sticks, followed by winnowing using manual labor. The seed moisture content was adjusted to 10%, and the seed yield was converted to t ha^{-1} as described by Biru (1979).

Dry biomass yield: To determine above ground dry biomass yield, above ground dry biomass were weighted after harvested and dried in the field for 8 days (Gupta and Sharma, 2021).

Harvest Index: Was calculated as the ratio of seed yield adjusted to 10% moisture content to the total aboveground dry biomass yield and expressed as a percentage (Chala *et al*., 2019).

$$\text{HI}\ (\%) = \left(\frac{\text{Grain Yield}}{\text{Aboveground dry biomass}}\right) * 100$$

3.7. Data analysis

The collected data were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD using R studio software, version 4.5 (2026) and interpretations were made following the procedure described by Gomez and Gomez, (1984). Effects of the treatments were compared using least significance difference test at 5% level of significance.

3.8. Economic Analysis

The partial budget analysis was conducted following the procedure described by CIMMYT (1988), using prevailing market prices for inputs at planting and outputs at harvesting. All costs and benefits were calculated on a hectare basis in Ethiopian Birr (ETB). The analysis considered the Adjusted grain yield of each treatment, gross field benefit (GFB ha^{-1}), total variable costs (including the cost of TSP fertilizer and its application), and marginal rate of return (MRR).

The average grain yield was adjusted downward by 10% to account for the difference between experimental yields and those expected under farmers' field conditions. The economic analysis used current market prices, with seed costs ranging from ETB 395 kg^{-1} depending on variety, fertilizer prices of ETB 6000 per 100 kg for Urea and ETB 9000 per 100 kg for TSP, and 4-person labor cost of ETB 300 per person per day. Grain seed and straw prices were ETB of 390 kg^{-1} and ETB 2 kg^{-1}, respectively.

3.9. Estimation of correlation on growth, yield and yield component of fenugreek

Correlation analysis was conducted to determine the strength and direction of the relationships among growth, yield, and yield component traits of fenugreek. The analysis helps identify the traits that are most strongly associated with seed yield and can therefore serve as reliable selection criteria for improving productivity. The Pearson correlation technique, which is provided by in R software, was used to create a test of significance. Pearson's correlation coefficients (r) were calculated to estimate the strength and direction of linear relationships among growth traits, yield components, and grain yield. The significance of the correlation coefficients was tested at the 5% ($P \leq 0.05$) and 1% ($P \leq 0.01$) probability levels. Correlation analysis was performed using R software, version 4.2. following the procedures described by Gomez and Gomez (1984).

4. RESULTS AND DISCUSSIONS

4.1. Soil physicochemical properties of the experimental site

The particle size distribution of the soil contained 2% sand, 34% silt, and 64% clay (Table 4). According to the soil textural class determination triangle, the soil of the experimental site is classified as clay. This high clay content indicates that the soil has essential characteristics for producing legumes, such as fenugreek, due to its high water and nutrient retention capacity.

The soil reaction at the experimental site (pH =5.16) is strongly acidic, according to the rating by Benton (2003). Cation Exchange Capacity (CEC) is an important soil parameter as it indicates the type of clay minerals present and the soil's ability to retain nutrients against leaching. The CEC of the soil at the experimental site had 23.96 meq/100g and rated as medium (Murphy, 2007).

The organic carbon (OC) content of the experimental site was 2.86%, which is rated as High according to Tekalign (1991). The total nitrogen (N) content of the experimental site was 0.18% and rated as moderate Tekalign (1991), though it may still be a limiting factor for reaching optimum crop growth potential.

The available phosphorus content was 8.27ppm, which is low according to the rating by Cottenie (1980). This indicates a need for the external application of phosphorus fertilizers to ensure healthy crop growth and high yields (FAO, 2008). The overall status of the soil may be attributed to poor farm management practices and continuous cropping with little to no fertilizer input, resulting in a decline in soil fertility in the area.

Table 3. Soil physico chemical properties of the experimental

Properties	Result	Rating	References
1. Physical properties			**-**
Sand (%)	2		-
Silt (%)	34		-
Clay (%)	64		-
Textural Class	Clay		-
2. Chemical properties			
pH (H_2O) (1: 2.5)	5.16	Strong acid	Benton(2003)
Organic Carbon (%)	2.86	High	Tekalign (1991)
Organic matter (%)	3.64	High	Tekalign (1991)
CEC (cmol Soil kg^{-1})	23.96	Moderate	Murphy(2007)
Total nitrogen (%)	0.18	Moderate	Tekalign (1991))
Available phosphorus (ppm)	8.27	Low	Cottenie (1980)

4.2. Phenological Parameters of fenugreek

4.2.1. Days to 50 % Emergence

The analysis of variance indicated that fenugreek varieties had a significant (<0.05) effect on the days to 50% emergence but the main effects phosphorus fertilizer rates and the interaction between varieties and phosphorus rates had non-significant (P> 0.05) effect on the days to 50% emergence of fenugreek (Table.5, and Appendix.1).

The local variety emerged earliest (6.67 days), while Burqa and Bishoftu took the longest days to 50% emergence (7.75 days) which was statistically at par with Jamma variety. The differences in emergence timing among varieties could be due to genetic factors, such as seed coat thickness and seed vigor, which influence the rate of water imbibition and metabolic activation during germination. These results are consistent the report by Mamo *et al*. (2021), who reported that varietal differences in pulse crops are the primary drivers of emergence timing regardless of nutrient application. Furthermore, Bekele (2018) found that varieties significantly affected emergence duration due to differences in seed size and internal reserve.

Table 4. Main effects of phosphorus fertilizer rates and varieties on days to 50% emergence, days to 50% flowering, and days to 90% maturity

Varieties	Days to 50% Emergence	Days to 50% Flowering	Days to 90% Maturity
Bishoftu	7.75[a]	55.67[a]	117.08[a]
Burqa	7.75[a]	54.33[b]	107.83[b]
Jamma	7.25[a]	53.25[b]	107.91[b]
Local cultivar	6.67[b]	45.00[c]	101.00[c]
LSD (5%)	0.57	1.19	0.97
P_2O_5 ($kgha^{-1}$)			
0	7.42	53.33[a]	111.17[a]
23	7.33	53.00[a]	109.83[b]
46	7.33	51.17[b]	107.00[c]
69	7.33	50.75[b]	105.83[d]
LSD (5%)	NS	1.19	0.97
CV (%)	6.97	2.05	0.81

Values followed by the different letters within the column are significantly different at 0.05 probability level

4.2.2. Days to 50% Flowering

The analysis of variance showed that the main effect of varieties and phosphorus have highly significant ($P<0.01$) effects on days to 50% flowering of fenugreek. However, the interaction effect of varieties and phosphorus had a non-significant effect on days to of 50% flowering of fenugreek (Table 5 and Appendix 1).

The earliest days to 50 % flowering (45 days) was observed for the local cultivar, whereas the longest days to flowering was recorded by the Bishoftu a variety (55.67 days) (Table 5). The days to 50% flowering of fenugreek were significantly influenced by the varieties of fenugreek might be due to their genetic difference in response to flowering. In line with the report Kena and Latera (2025) that significant variation in days to 50% flowering among fenugreek varieties and the earliest days to flowering (37.33) were recorded from local check, while the latest (46.67) days to flowering were recorded from the Bishoftu variety. Dejene *et al.* (2020) also reported that released Bishoftu variety took the longest

days for flowering compared to local cultivar. Kibiru and Latera (2025) reported that local variety recorded the shortest days to flowering, whereas Bishoftu took the longest to flowering days.

The longest period to 50% flowering (53.33 days) was recorded in the control treatment (0 kg P_2O_5 ha^{-1}). However, it was statistically at par with the phosphorus application rates of 23 kg P_2O_5 ha^{-1}, which recorded the shortest periods to flowering of 51.17 and 50.75 days. The decrease in days to flowering at the highest P_2O_5 fertilizer might be due to the fact that phosphorus enhances the reproductive phase through fastened flowering. In line with result Serbessa *et al.*(2019) reported earlier flowering with increased phosphorus application. Similarly, Han *et al*. (2022) explained that phosphorus improves metabolic activity and energy transfer, thereby promoting early flowering. In addition, phosphorus has been widely reported to shorten flowering time in legumes. Application of 69 kg P_2O_5 ha^{-1} reduced days to physiological maturity in common bean compared with the control (Olika and Alemu, 2024). Likewise Khan *et al*., (2021) increasing the rate of P_2O_5 fertilizer from nil to 120 kg ha^{-1} significantly decreased the number of days required to reach 50% flowering rate from 55.57 days to 54.43 days.

4.2.3. Days to 90% physiological maturity

The days to 90% physiological maturity of fenugreek was highly significantly ($P<0.01$) affected due to the main effect of varieties and phosphorus fertilizer rates. But the interaction effects of varieties x P2O5 fertilizer were non-significant ($P>0.05$) on days to 90% physiological maturity (Table 5 and Appendix 1).

The longest days 90% physiological maturity (117.08 days) was observed under the Bishoftu variety, followed by Jamma and Burqa varieties, and the shortest days (101 days) 90% physiological maturity was observed under the Local cultivar (Table 4). The variation in days to maturity among fenugreek varieties may be attributed to inherent genetic differences that regulate the rate of crop development, thereby influencing the duration of the life cycle and resulting in early or late maturity. In agreement with this Kibiru and Latera, (2025) reported a highly significant difference in days to 90% physiological maturity among fenugreek varieties, where the local variety matured earlier (80.56 days) than the Bishoftu variety (86.67 days). Similarly, Kelemu and Gedamu (2026) indicated that differences in maturity among fenugreek varieties are primarily governed by genetic

factors affecting growth duration, with the local variety maturing earlier than the Bishoftu variety.

The shortest days required to attain physiological maturity (105.83 days) was recorded for the highest rate of P_2O_5 application (69 kg ha^{-1}), while the longest number of days to reach physiological maturity (111.17days) was recorded at the control (Table 4). The days to 90% physiological maturity showed a decreasing trend with increased Phosphorus fertilizer rates, which might be due to phosphorus fertilizer attributed to the enhanced availability of the nutrient in the soil and its uptake by the fenugreek plants, which might be resulted in early maturity. This result is in line with that of Serbessa *et al.* (2019), who reported that days to 90% physiological maturity was highly significantly affected by the application of Phosphorus fertilizer rate. Similarly, Jobie *et al*.(2017) reported that increasing the rate of P_2O_5 fertilizer significantly decreased the duration to reach physiological maturity; plants receiving the lowest P_2O_5 rate required the greatest number of days (117.7 days) to attain physiological maturity, whereas those supplied with the highest rate of P_2O_5 fertilizer 120 kg ha^{-1} reached physiological maturity in the shortest time.

4.3. Growth Parameter of Fenugreek

4.3.1. Plant Height

The analysis of variance indicated that the main effects of phosphorus, varieties, and their interaction had a highly significant ($P<0.01$) effect on plant height of Fenugreek (Table 6 and Appendix 3)

The tallest plant height was recorded with the Burqa variety (46.50 cm), followed by the Jamma (44.50cm) under application of highest rate of P_2O_5 fertilizer (69 kg ha^{-1}); while the shortest plant height (24.83cm) was recorded with the local variety under application of 0kg ha^{-1} P_2O_5 rate. This might be due to the contribution of phosphorus to plant growth attributes to increasing of inter nodal length and greater dry matter. Moreover, it could be due to genetic height potential of the improved varieties allows it to translate nutrients into vertical growth more efficiently than local variety. The result is in agreement with, Özyazici *et al.* (2020) who revealed that higher application of phosphorus increased plant height. Similarly,Chalchissa and Chala (2020), reported a significant increase in growth parameters with application of 46.5 kg P_2O_5 ha^{-1}, where the maximum plant height (45.34cm) was obtained at this rate, the lowest was recorded in the control treatment.

Table 5. Mean of plant height (cm) of Fenugreek as influenced by the interaction effect of Phosphorous fertilizer rates and varieties

	P_2O_5 ($kgha^{-1}$)				
Varieties	0	23	46	69	Mean
Burqa	28.50^{def}	35.50^{c}	44.50^{ab}	46.50^{a}	38.75
Jamma	26.43^{efg}	37.17^{c}	42.50^{b}	44.50^{ab}	37.65
Bishoftu	24.93^{g}	25.57^{fg}	28.90^{de}	30.50^{d}	27.48
Local cultivar	24.83^{g}	26.57^{efg}	28.07^{defg}	30.80^{d}	27.57
Mean	26.18	31.20	35.99	38.08	32.86
	Varieties	P_2O_5 Rate	Varieties *P_2O_5		
LSD (5%)	1.19	1.19	3.25		
CV (%)			3.25		

Values followed by the different letters within the column and rows are significant different at 0.05 probability level

4.3.2. Number of Branches per Plant

The number of branches per plant of fenugreek was highly significant ($P<0.01$) influenced by the main effect of varieties, phosphorus rates, and their interaction (Table7 and Appendix 3).

The highest number of branches per plant (7.30) of fenugreek was recorded for Bishoftu variety at 69 kg P_2O_5 ha^{-1}, whereas the lowest number of branches per plant (3.10) was obtained from the local variety under the control treatment (0 kg P_2O_5 ha^{-1}). The increase in branches could be due to the improved varieties have higher genetic plasticity to fertilizers and the role of phosphorus in stimulating improved cell division in lateral buds. This is consistent with the report form Nahar *et al*.(2021), who reported that the branches were a plastic trait governed by the interaction between available mineral nutrients and the variety's canopy architecture. Similarly, Jabborova *et al.*(2021) observed that application of 40 to 46 kg P ha^{-1}, significantly increased the number of branches. Hasan (2021) also reported that phosphorus at these levels optimizes cytokine synthesis, thereby enhancing branches and increasing the number of potential sites for flower and pod formation. The

highest number of branches was obtained with increasing phosphorus (P_2O_5) levels up to 50 kg ha^{-1} and Sulphur levels of 50 kg ha^{-1}. Akther (2022) observed the highest number of primary branches per plant with the application of 80 kg P_2O_5 ha^{-1}.

Table 6. Mean number of branches per plant of fenugreek as influenced by the interaction effect of Phosphorous rates and varieties

Varieties	P_2O_5 (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	3.87^{fg}	4.63^{cd}	5.83^{b}	7.30^{a}	5.26
Burqa	3.70^{fgh}	4.30^{de}	5.43^{b}	5.83^{b}	4.67
Jamma	3.40^{gh}	3.80^{ef}	5.23^{bc}	5.4^{b}	4.33
Local cultivar	3.10^{h}	3.30^{fg}	4.30^{de}	4.60^{cd}	3.68
Mean	3.52	4.01	5.20	5.80	4.48
	Varieties	P_2O_5 Rate	V*P		
LSD (5%)	0.221	0.68	0.422		
CV (%)	5.16				

Values followed by the different letters within the column and rows significant different at 0.05 probability level

4.3.3. Taproot length

The analysis of variance indicated that the main factor Phosphorus and Variety showed highly significant ($P<0.01$) effect on taproot length, while the main factor interaction was significant ($P<0.05$) (Table 8 and Appendix 3).

The longest taproot length (19.50 cm) obtained from the Bishoftu variety at 69 kg P_2O_5 ha^{-1} of fertilizer, which was statistically at par with the same variety at 46 P_2O_5 kg ha^{-1}; while the shortest taproot length (9.17 cm) obtained from Local variety at 0 kg P_2O_5 ha^{-1} of fertilizer (Table 9). This might be due to varietal genetic differences and increased phosphorus availability, which enhanced root length, nutrient uptake, and overall plant growth. This result agrees with Nahar *et al*. (2021), who found that higher fertilizer application rates linearly increased root length in fenugreek cultivars. Similarly, Buraka *et al.* (2016) reported superior response of the Jamma variety compared to the Local variety which might be due to enhanced physiological efficiency and genetic potential for root plasticity in improved genotypes. Furthermore, the deeper root penetration observed at high

(69 kg P_2O_5 ha-1). Nuru (2021) and Tesfaye *et al.* (2023) noted that certain varieties respond more effectively to phosphorus by extending their root systems. Also, Trindade and Araujo (2014) also reported as increasing phosphorus doses consistently promotes both the mass and total length of the taproot architecture.

Table 7. Interaction effects of Phosphorus fertilizers and Varieties on taproot length

Varieties	P_2O_5 (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	11.43^{ef}	14.50^{d}	18.50 ^{ab}	19.50^{a}	15.98
Burqa	10.60^{fg}	13.17^{de}	16.50 ^{c}	17.5^{bc}	14.44
Jamma	9.83 ^{fg}	11.50^{ef}	14.50 ^{d}	17.1^{bc}	13.25
Local cultivar	9.17 ^{g}	10.57 ^{fg}	13.63 ^{d}	13.90^{d}	11.82
Mean	10.26	12.43	15.78	17.02	13.87
	Varieties	P_2O_5 Rate	Varieties * P_2O_5		
LSD (5%)	0.68	0.68	1.86		
CV (%)			4.40		

Values followed by the different letters within the column and rows are significant different at a 0.05 probability level

4.4. Nodule Parameter of fenugreek

4.4.1. Total Number of Nodules per Plant

The analysis of variance revealed that number of nodules per plant was highly significantly ($P < 0.01$) affected due to the main effect of varieties and phosphorus, as well as their interaction (Table 9 and Appendix 2).

The highest (52) total number of nodules per plant was obtained from Bishoftu variety under application of 69 kg $P_2O_5ha^{-1}$, which was statistically at par with the same variety at 46 kg P_2O_5 ha^{-1} and Burqa variety received 69 kg P_2O_5 ha^{-1}. While the lowest total number of nodules per plant (9.00) was obtained local variety under the no phosphorus treatment level, which was statistically at par with Jamma variety received 0 kg P_2O_5 ha^{-1}. This might be due to that phosphorus enhances the root and microbial activities in the root zone of the plant and in turn increases the absorption and ultimately increases the number of nodules per plant. The present result is in line with Alemu (2009) who reported that the number of

nodules per plant increased with increase in the rate of Phosphorus fertilizer from 0 to 39 kg p ha^{-1}. Similarly, Li *et al*. (2022) found that the number nodule and nitrogenase activities increased with increase in phosphorus rates. This result is in agreement with Serbessa *et al*. (2019) who stated that increasing phosphorus application increased the total number of root nodules and dry weight. Similar, Nigatu (2017) has also reported increased nodulation due to application of 69kg P_2O_5 ha^{-1}.

Table 8. Interaction effects of Phosphorus fertilizer and Varieties on total number of nodules per plant

Varieties	Phosphorus (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	18.00^{gh}	32.33^{cd}	48.00^{ab}	52.00^{a}	37.58
Burqa	14.67^{hi}	28.33^{de}	42.33^{b}	46.00^{ab}	32.83
Jamma	11.00^{ij}	22.00^{fg}	32.00^{cd}	35.00^{c}	25
Local	9.00^{j}	15.33^{hi}	23.33^{efg}	26.00^{ef}	18.42
Mean	12.92	24.25	36.17	39.5	28.21
	Varieties	P_2O_5 Rate	V *P		
LSD (5%)	2.31	2.31	6.33		
CV(%)			7.37		

Values followed by the different letters within the column and rows are significant different at 0.05 probability level

4.4.2. Number of Effective Nodules per Plant

The result revealed that there was a highly significant (P<0.01) difference in the number of effective nodules due to the main effect of varieties, phosphorus rates, and the interaction effect of varieties and phosphorus fertilizer rates (Table 10 and Appendix 2.).

Bishoftu variety with application of 69 kg P_2O_5 ha^{-1} produced the highest (44.00) number of effective nodules, which was statistically at par with Burqa variety received 69 kg P_2O_5 ha^{-1} and Bishoftu variety received 46 kg P_2O_5 ha^{-1}. While the local variety with no fertilizer application produced the lowest (5.00) number of effective nodules per plant which was statistically at par with Jamma and Burqa variety received 0 kg P_2O_5 ha^{-1}. This increment in the number of effective nodules at the highest rate of phosphorus could be due to the effect of phosphorus on better root development and fixation that depends on the fenugreek

varieties. In agreement with this study, Debela and Wogi (2020) reported that ported that the stage of effective nodule development in fenugreek is significantly affected by time and growth stage. Effective nodules, which are pink or reddish inside due to leghemoglobin, are generally most active during the vegetative growth and flowering stages.

Likewise, Wondimu (2017) reported there was a highly significant difference in the number of effective nodules due to the interaction effect of variety and Phosphorus rates. Ahmed *et al.*(2020) also reported that the highest number of effective nodules (79.50 per plant) was obtained from the application of 150 phosphorus kg ha^{-1}.

Table 9. Interaction effects of Phosphorus fertilizer and Varieties on Effective Nodules per Plant

Varieties	Phosphorus rate (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	14.00^{ghi}	26.33^{de}	40.00^{ab}	44.00^{a}	31.08
Burqa	10.67^{hij}	22.33^{ef}	35.00^{bc}	39.00^{ab}	26.75
Jamma	8.00^{ij}	18.00^{fg}	26.00^{de}	29.00^{cd}	20.25
Local cultivar	5.00^{j}	10.33^{hij}	16.33^{fgh}	19.00^{fg}	12.67
Mean	9.42	19.25	29.33	32.75	22.69
	Varieties	P_2O_5 Rate	V *P		
LSD (5%)	2.35	2.35	6.43		
CV(%)			7.37		

Values followed by the different letters within the column are significant different at 0.05 probability level

4.4.3. Nodule Fresh Weight

Nodules fresh weight was highly significantly ($P<0.01$) affected by the main effect of phosphorus fertilizer rate, varieties and their interaction (Table 11 and Appendix 2).

The application of a higher phosphorus fertilizer rate (69 kg P ha -1) under Bishoftu Variety produced the maximum nodule fresh weight (1.15mg per plant). while the minimum nodule fresh weight (0.12mg per plant) was obtained from the local cultivar under the control treatment (0kg P_2O_5 ha-1), which was statistically at par with Jamma and Burqa variety received 0 kg P_2O_5 ha^{-1}. The increased nodule weight might be attributed to phosphorus application, which enhanced plant growth, root development, and carbohydrate supply to

nodules, resulting in greater nutrient accumulation and heavier nodules. These results align with Tolera (2021) and Gadisa *et al*. (2024) who reported that the biomass of nodules in legumes is heavily dependent on the amount of phosphorus and the plant's overall vigor. Similarly, Singh (2018) also reported that the heavier nodules result from an enhanced carbohydrate supply provided by vigorous plants grown with adequate phosphorus.

Table 10. Mean nodule fresh weight per plant (mg) of fenugreek as influenced by interaction of Phosphorous rates fertilizer and verities

Varieties	Phosphorus rate (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	0.30^{hij}	0.60^{def}	0.96^{b}	1.15^{a}	0.75
Burqa	0.25^{jk}	0.53^{efg}	0.85^{bc}	0.95^{b}	0.64
Jamma	0.18^{jk}	0.42^{ghi}	0.65^{de}	0.75^{cd}	0.5
Local cultivar	0.12^{k}	0.28^{ij}	0.45^{fgh}	0.55^{efg}	0.35
Mean	0.21	0.46	0.73	0.85	0.56
	Varieties	P_2O_5 Rate	V * P_2O_5		
LSD (5%)	0.057	0.057	0.156		
CV (%)			9.12		

Values followed by the different letters within the column and rows are significant different at 0.05 probability level

4.4.4. Nodule Dry Weight

The nodule dry weight of fenugreek was strongly affected by the rate of phosphorus fertilizer, fenugreek varieties and their interaction (P<0.01) (Table 12 and Appendix 2).

The application of a higher phosphorus fertilizer rate (69 kg P ha-1) was produced the maximum nodule dry weight (0.183 mg per plant) with Bishoftu Variety, which was statistically at par with all variety received 46 and 69 kg P_2O_5 ha^{-1}. While the minimum nodule dry weight (0.017mg per plant was obtained from control (0 kg P ha^{-1}), which was statistically at par with all variety received 0 kg P_2O_5 ha^{-1} (Table 12). Higher nodulation due to increased phosphorus rates might be due to symbiotic nitrogen fixation requires higher phosphorus for the maximum activity in reduction of atmospheric nitrogen by nitrogenase system. This result agrees with Serbessa *et al.*(2019) who reported that the notable increase in nodule dry weight as a result of phosphorus application and varietal

differences, as these factors improve atmospheric nitrogen fixation. Similarly, Abdallah identified nodule dry weight as a key marker for the interaction between fertilization and nitrogen fixation efficiency. Mehari *et al.* (2023) also highlighted nodule dry weight accumulation as a key marker for nitrogen fixation efficiency. Arebu (2019), observed the highest nodule dry weight (0.27 g/plant) from 46 kg P_2O_5 ha -1 and the lowest (0.08 g/plant) from the control.

Table 11. Interaction effects of Phosphorus fertilizer and Varieties on nodule dry weight of fenugreek

Varieties	Phosphorus rate (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	0.050^{efg}	0.120^{cd}	0.170^{ab}	0.183^{ab}	0.131
Burqa	0.040^{fg}	0.087^{de}	0.160^{abc}	0.177^{ab}	0.116
Jamma	0.027^{fg}	0.063^{ef}	0.163^{ab}	0.173^{a}	0.109
Local cultivar	0.017^{g}	0.140^{bc}	0.167^{ab}	0.173^{ab}	0.124
Mean	0.033	0.103	0.165	0.177	0.119
	Varieties	P_2O_5 Rate	V *P		
LSD (5%)	0.015	0.015	0.042		
CV (%)			11.53		

Values followed by the different letters within the column and row are significant different at 0.05 probability level

4.5. Yield and Yield Components of fenugreek

4.5.1. Number of Pod per plant

The analysis of variance indicated that the main effect of Phosphorus fertilizer rates and fenugreek varieties highly significantly ($P<0.01$) influenced the number of pods per plant. Further, the interaction of Phosphorus fertilizer rates and varieties showed a significant ($P<0.05$) effect on the numbers of pods per plant (Table 13 and Appendix 4).

The highest number of pods per plant (37.83 and 36.50) were recorded from the Bishoftu variety at the phosphorus rate of 69 and 46 kg P_2O_5 ha^{-1} respectively, which was statistically similar with the Burqa variety at 69 kg P_2O_5 ha^{-1}. While the lowest number of pods per plant (12.60) was obtained from the local cultivar under the control treatment (0 kg P_2O_5

ha⁻¹), which was statistically similar with the Jamma variety at 0 kg P_2O_5 ha⁻¹ (Table 13). This increased number of pod per plant might be attributed due to the adequate availability of phosphorus, which likely enhanced vegetative growth by promoting branch development and plant height, ultimately resulting in higher pod formation and due to genetically potential variety to produce pods. This finding agrees with Erman *et al*. (2025), who reported an increase in pods per plant in fenugreek with increasing phosphorus rates. Abdi. *et al*. (2021) reported that phosphorus plays a key role in increasing pods per plant and seed weight in fenugreek, which explains the yield improvement at higher phosphorus levels. In addition, Bekele *et al*. (2020) noted that the Bishoftu variety has higher nutrient use efficiency, which contributes to its superior performance under fertilized conditions. Similarly, Dhakal *et al*. (2015) found that the combination of improved genotype and phosphorus fertilization significantly enhances reproductive growth

Table 12. Interaction Effect of Variety and Phosphorus Rate on number of pod Plant per plant

Varieties	Phosphorus rate(kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	20.50^{gh}	28.50^{cd}	36.50^{a}	37.83^{a}	30.83
Burqa	18.50^{hi}	25.50^{de}	32.50^{b}	34.50^{ab}	27.75
Jammer	15.57^{ij}	21.60^{fgh}	28.50^{cd}	31.50^{bc}	24.29
Local cultivar	12.60^{j}	16.57^{i}	22.57^{efg}	24.50^{ef}	19.06
Mean	16.79	23.04	30.02	32.08	
	V	P_2O_5	V*P_2O_5		
LSD (5%)	1.238	1.238	3.395		
CV (%)			4.38		

Values followed by the different letters within the columns and rows are significantly different at 0.05 probability level

4.5.2. Number of Seeds per pod

The analysis of variance indicated that the main effect of Phosphorus fertilizer rates and varieties had a highly significant effect ($P<0.01$) on the number of seeds per pod but there was no significant effect ($P>0.05$) from the interaction of phosphorus fertilizer rates and varieties (Table.14 and Appendix.4).

The maximum number of seeds per pod (16.85) was recorded from Bishoftu variety and the minimum number of seeds per pod (12.60) was recorded from Local cultivar. This increased number of seeds per plant with the under Bishoftu variety could be due to the variety's embryo survival capacity. Similarly, Kebede *et al*. (2023) and Shiferaw *et al*. (2024) also found that seed setting in pods is maximized relates to the specific genetic potential of the plant.

The maximum numbers of seed per pod (17.02) was recorded at a rate of 69 kg P_2O_5 ha^{-1} while the minimum seed per pod (12.01) at 0 kg P_2O_5 ha^{-1}. The highest number of seeds per pod recorded at the highest phosphorus rates might be because of the availability of major nutrients increased at highest phosphorus rates due to the concentration of carbohydrates in the seed, which serves as a reservoir of carbohydrates, resulting in an increased number of seeds in each pod. Similarly, Kebede *et al*. (2023) and Shiferaw *et al*. (2024) also reported that seed setting in pods is maximized when phosphorus availability increased. Tunçtürk (2011) also showed that the seeds per pod increased significantly with increasing dose of Phosphorus fertilizer

4.5.3. Thousand Seed Weight

The analysis of variance indicated that the main effect of Phosphorus fertilizer rates and varieties had a highly significant effect ($P<0.01$) on thousand seed weight but their interaction effects was non-significant ($P>0.05$) (Table 15 and Appendix 4).

The maximum 1000-seed weight (18.56g) was recorded from the Bishoftu variety, while the lowest 1000-seed weight (15.30g) was recorded from the local cultivar. The reason for variation in thousand seed weight might be due to genetic variability of the varieties for this trait. This result is in agreement with the findings Yaldiz and Camlica, (2022) who reported that fenugreek cultivars are different in thousand seed weight. Similar result was reported by Serbessa *et al.*, (2019) that Variety Bishoftu produced the highest 1000 seed weight over all genotype tested in their experiment.

Similarly, the highest thousand seeds weight (18.33 g) was recorded from 69 kg P_2O_5 ha^{-1} while the lowest thousand seed weight (15.76g) was recorded from control treatment fertilizer. This might be due to phosphorous fertilizer application contributed to increased efficiency of major nutrients and thus, led to higher seed weight and yield. Moreover, this could be due to the application of phosphorus-aided carbohydrate synthesis that resulted for better seed filling, resulting in higher weight. This confirms the results of Balcha (2021);

Zebede*e al.* (2023), who reported that thousand-grain weight increased significantly when phosphorus application rate increased. Also, Eswaran *et al.* (2016) reported that phosphorus application enhances seed weight and quality in legumes.

Table 13. The main effect of phosphorus rate and varieties on seed per pod plant and 1000 seed weight of fenugreek

Varieties	Number of seed pod^{-1}	Thousand seed weight (g)
Bishoftu	16.85^{a}	18.56^{a}
Burqa	15.27^{b}	17.91^{b}
Jamma	14.28^{c}	16.83^{c}
Local cultivar	12.60^{d}	15.30^{d}
LSD (5%)	0.56	0.35
P_2O_5 Rates kg ha^{-1}		
0	12.01^{d}	15.76^{d}
23	13.94^{c}	16.75^{c}
46	16.02^{b}	17.76^{b}
69	17.02^{a}	18.33^{a}
LSD (5%)	0.56	0.35
CV (%)	3.41	1.83

Values followed by the different letters within the column are significant different at 0.05 probability level

4.5.4. Dry Biomass Yield

The analysis of variance indicated that the main effect of Phosphorus fertilizer rates and varieties, and their interaction had a highly significant effect ($P<0.01$) on the dry biomass yield of fenugreek (Table 16 and Appendix 4).

The highest (5677 kg ha^{-1}) dry biomass yield of fenugreek was recorded from the Bishoftu variety at 69 kg P_2O_5 ha^{-1}, while the local cultivar under control conditions produced the lowest (3100 kg ha^{-1}), which was statistically at par with Jamma and Bishoftu varieties received of 0 kg P_2O_5 ha^{-1}. The increased in biomass yield at maximum rate of P_2O_5 fertilizer under Bishoftu variety might be due to high Phosphorus rates combined with high-potential varieties lead to more robust vegetative growth that resulted in higher total dry matter yield. These findings align with Abdi *et al*. (2021) who reported that Bishoftu superior Phosphorus uptake and biomass response up to 26 kg P ha^{-1} across genotypes. Getu *et al*. (2022) also reported that improved varieties like Bishoftu outperform locals by 25 to 35% under higher Phosphorus fertilization. Singh *et al.* (2019) found phosphorus up

to 40 kg ha⁻¹, linearly improved dry matter accumulation, aligning with our interaction effects, where Bishoftu showed maximum response at higher rates.

Table 14 . Main effect of phosphorus fertilizer rates and varieties on dry biomass yield of fenugreek

Varieties	P_2O_5 Rate (kg ha^{-1})				
	0	23	46	69	Mean
Bishoftu	3323.3^{ij}	4183.3^{g}	4933.3^{d}	5676.7^{a}	4529.2
Burqa	3443.3^{i}	4150.0^{g}	4856.7^{de}	5433.3^{b}	4470.8
Jamma	3266.7^{ij}	4000.0^{gh}	4676.7^{ef}	5250.0^{bc}	4298.3
Local cultivar	3100.0^{j}	3856.0^{h}	4623.3^{f}	5183.3^{c}	4190.8
Mean	3283.3	4047.5	4772.5	5385.8	4372.3
	Varieties	P_2O_5 Rate	V × P_2O_5		
LSD (5%)	83.67	83.67	229.19		
CV (%)			1.73		

Values followed by the different letters within the columns and rows are significantly different at 0.05 probability level.

4.5.5. Stand Count

The analysis of variance indicated that the main effect of Phosphorus fertilizer rates and varieties as well as the interaction effect of varieties and phosphorus fertilizer rates had significant effect ($P<0.05$) on the stand count of the plant (Table 17 and Appendix 4).

The highest stand count (232,778 plants ha⁻¹) was recorded from the local variety at the phosphorus rate of 69 kg P_2O_5 ha⁻¹, which was statistically at par with Local variety received of 46 kg P_2O_5 ha^{-1}. While the lowest stand count (167,222.2 and 171,111.23 plants ha⁻¹) were recorded form the Bishoftu and Burqa varieties from the control treatment (0 kg P_2O_5 ha⁻¹). This might be due to superior seedling vigor or better adaptation of local cultivar to the environmental conditions and adequate fertilization to reduced competitive mortality that resulted in the highest final stand count under local cultivar. This is consistent with Gezagn *et al.*,(2021) who reported that phosphorus application significantly improves the stand count of legumes by promoting vigorous root systems that can withstand early-season environmental stress and mortality. Similarly, Abayneha (2018) observed that the highest final stand count under local cultivar that might be due to superior seedling vigor or better

adaptation to the specific environmental conditions and adequate fertilization to reduced competitive mortality.

Table 15. The main effect of phosphorus fertilizer rates and varieties on Stand Count of fenugreek

Varieties	Phosphorus rate (kgha^{-1})				
	0	23	46	69	Mean
Bishoftu	167,222.13^{k}	198,889.00^{ghi}	206,111.20^{efg}	215,000.0^{bcd}	196,805.60
Burqa	171,111.23^{k}	195,555.70^{i}	203,889.10^{efgh}	216,666.07^{bc}	196,805.70
Jamma	181,666.17^{j}	200,000.00^{fghi}	210,555.07^{cde}	218,889.50^{b}	202,777.80
Local	196,667.1^{hi}	207,778.00^{def}	227,777.70^{a}	232,777.70^{a}	216,250.10
Mean	179,166.80	200,555.70	212,083.30	220,833.30	203,159.18
LSD (5%)	Varieties 3,027.65	P_2O_5 Rate 3,027.65	V * P_2O_5 8,293.80		
CV (%)			1.345		

Values followed by the different letters within the column and rows are significantly different at 0.05 probability level

4.5.6. Seed Yield

Analysis of variance showed that fenugreek seed yield was highly significantly affected ($P<0.01$) by phosphorus fertilizer rates, varieties, and their interaction (Table 18 and Appendix 4).

The highest seed yield (2.047 t ha^{-1}) obtained from Bishoftu at the maximum phosphorus rate (69 kg P_2O_5 ha^{-1}), while the lowest seed yield 0.993 t ha^{-1} obtained from Local cultivar at the minimum phosphorus rate (0 kg P_2O_5 ha^{-1}). The yield increase with increased rate of P_2O_5 fertilizer rates might be due to cumulative effect of more number of seeds per pod due to the increased nutrient uptake by the plants, which might have stimulated the rate of various physiological processes like growth and assimilation of nutrients. In line with this study Serbessa *et al.* (2019) reported the highest seed yield (1.22 kg t ha^{-1}) in Bishoftu variety by application of 26 kg P_2O_5 ha^{-1}. Similarly, Nahar. (2021). reported that the highest seed yield was obtained with 60 kg P_2O_5 ha^{-1}, though this was statistically at par with 45 kg P_2O_5 ha^{-1}. Likewise, Alemu *et al.* (2018) found that seed yield in fenugreek can be

doubled with the application of 46 to 69 kg P_2O_5 ha^{-1}. Furthermore, Dejene *et al*. (2020) noted that released varieties like Bishoftu demonstrate greater phenotypic stability and nutrient-use efficiency compared to traditional landraces, which often lack the physiological capacity to translate high soil fertility into grain yield.

Table16. Interaction Effect of Varieties and Phosphorus Rate on Seed Yield (ton/ha) of Fenugreek

Varieties	Phosphorus rates (t/ha)				
	0	23	46	69	Mean
Bishoftu	1.055^{hi}	1.407d^{ef}	1.711^{c}	2.047^{a}	1.555
Burqa	1.115^{hi}	1.394^{ef}	1.684^{c}	1.885^{b}	1.52
Jamma	1.015^{i}	1.289^{fg}	1.534^{d}	1.761^{bc}	1.4
Local cultivar	0.993^{j}	1.173^{gh}	1.484^{de}	1.695^{c}	1.286
Mean	1.053	1.316	1.603	1.847	1.44
	Varieties	P_2O_5 Rate	V × P		
LSD(5%)	0.048	0.048	0.131		
CV (%)			2.99		

Values followed by the different letters within the column and rows are significantly different at 0.05 probability level

4.5.7. Harvest Index

The harvest index of Fenugreek was highly significantly (P<0.01) influenced by the main effect of Phosphorus fertilizer rates and main effect of varieties, as well as by their interaction (Table 18 and Appendix 4).

The highest harvest index (36.06%) was obtained from Bishoftu variety with application of 69 kg P_2O_5 ha^{-1}, which was statistically equal to the Bishoftu variety with application 46 kg P_2O_5 ha^{-1} and Burqa Variety from application 69 and 46 kg P_2O_5 ha^{-1}. While the lowest harvest index (25.5) was obtained from Local Variety under application of 0 kg P_2O_5 ha^{-1}. The higher harvest index was attributed to increased P_2O_5 application and the superior nutrient translocation efficiency of the Bishoftu variety, which significantly improved seed yield and yield components, leading to greater partitioning of biomass to seed.In line with this result, Gutema *et al.* (2018) found that the increased harvest index with the application of Phosphorus on fenugreek. Additionally, Kassaye, (2019) found that Harvest Index in

legumes typically varies between 25 and 40% depending on nutrient translocation efficiency.

Table 17.Main Effect of varieties and phosphorus fertilizer rates on harvesting index of fenugreek

Varieties	Phosphorus rates (t /ha)				
	0	23	46	69	Mean
Bishoftu	31.71^{efg}	33.64^{bcd}	34.67^{abc}	36.06^{a}	34.02
Burqa	32.36^{def}	33.60^{bcd}	34.67^{abc}	34.70^{ab}	33.83
Jamma	31.08^{fg}	32.24^{defg}	32.80^{cdef}	33.53^{bcde}	32.41
Local cultivar	25.57^{h}	30.40^{g}	32.10^{defg}	32.70^{def}	30.19
Mean	30.18	32.47	33.56	34.25	32.61
	Varieties	P_2O_5 Rate	V * P_2O_5		
LSD(5%)	0.68	0.68	1.87		
CV(%)			1.88		

Values followed by the different letters within the column and rows are significantly different at 0.05 probability level

4.6. Pearson Correlation Between Phenological, Growth, Yield and Yield Components of Fenugreek

The correlation coefficients among phenological, growth, yield, and yield-component parameters of fenugreek are presented in Table 19. Correlation analysis showed that seed yield was positively and highly significantly correlated with numbers branches per plant, tap root length, total and effective nodules, nodule fresh and dry weights, pods per plant, seeds per pod, thousand seed weight, aboveground biomass yield, and harvest index. Among these traits, aboveground biomass yield (0.99), primary branches per plant (0.95), nodule fresh weight (0.94), and tap root length (0.93), exhibited the strongest positive associations with seed yield, indicating their important contribution to yield improvement in fenugreek. The results of the association between seed yield and yield-related traits in this study agree with the findings of Gurjar *et al.* (2016), who reported highly significant positive correlations between fenugreek seed yield, biomass, pods per plant, and seeds per pod under varying agronomic conditions. The strong correlation between seed yield and aboveground biomass yield (0.99) observed in this study is consistent with the findings of Gurjar *et al*. (2016), confirming biomass as a major determinant of seed yield in

phosphorus-responsive fenugreek genotypes. Overall, the results indicate that growth, nodulation, and yield-component traits were the major determinants of seed yield in fenugreek.

Table 18. Correlation coefficient among parameters of phenological, growth, yield, and Yield Components of fenugreek

	ED	FD	MD	PBP	PH	TR	TN	EN	NFW	NDW	PSC	PPP	SPP	THSW	SY	AGB	HI
ED	-																
FD	0.67**	-															
MD	0.55**	0.85**	-														
PBP	0.31*	0.19	0.11	-													
PH	0.19	0.14	-0.27	0.58**	-												
TR	0.28	0.19	0.14	0.97**	0.52**	-											
TN	0.37**	0.30*	0.22	0.97**	0.54**	0.97**	-										
EN	0.39**	0.32*	0.24	0.97**	0.55**	0.97**	1.00**	-									
NFW	0.32*	0.22	0.15	0.98**	0.55**	0.98**	0.99**	0.99**	-								
NDW	-0.04	-0.24	-0.28	0.82**	0.50**	0.81**	0.74**	0.72**	0.77**	-							
PSC1	-	-	-	0.55**	0.37**	0.53**	0.44**	0.42**	0.51**	0.80**	-						
PPP	0.38**	0.31*	0.23	0.98**	0.56**	0.98**	0.99**	0.99**	0.98**	0.76**	0.45**	-					
SPP	0.39**	0.33*	0.29*	0.97**	0.49**	0.97**	0.98**	0.98**	0.98**	0.73**	0.42**	0.99**	-				
THSW	0.55**	0.50**	0.29*	0.88**	0.65**	0.85**	0.90**	0.91**	0.88**	0.56**	0.20	0.91**	0.90**	-			
SY	0.16	0.04	0.07	0.95**	0.58**	0.93**	0.91**	0.90**	0.94**	0.87**	0.68**	0.92**	0.91**	0.81**	-		
AGB	0.06	-0.10	-0.20	0.92**	0.59**	0.90**	0.86**	0.85**	0.90**	0.90**	0.78**	0.87**	0.86**	0.73**	0.99**	-	
HI	0.40**	0.45**	0.28	0.85**	0.47**	0.80**	0.83**	0.83**	0.82**	0.63**	0.27	0.86**	0.86**	0.88**	0.84**	0.75**	-

Where:TR:Tap root, PSC:Plant Stand Count ,SY:Seed yield, PH: Plant height, NB: Number of branch, TNN: Total nodules number, EN: Effective nodules numbder,NFW: nodule fresh weight ,NDW:Nodule dry weight, PPP: Number of pods/plant, NSP: Number of seeds /pod AGB:Above ground dry biomass,THSW: Hundred (1000) seed weight,:Correlation significant at 0.05 level, and **: Correlation highly significant at 0.01 level*

4.7. Effects of Phosphorous fertilizer rates on the economic feasibility of fenugreek production

The highest net benefit of ETB 627722 $ha^{-1}$was recorded at 69 kg P_2O_5 ha^{-1}, followed by 46 kg P_2O_5 ha^{-1} ETB 539463.4 ha^{-1}) and 23 kg P_2O_5 ha^{-1} ETB 442357 ETB ha^{-1} (Table 18). The highest marginal rate of return (2158%) was obtained with application at 46 kg P_2O_5 ha^{-1}, followed by 23 and 69 kg P_2O_5 ha^{-1}, with marginal rate of return 2025 and 1961% (Table 20). The value-to-cost ratio ranged from 20.50 to 20.68, showing that all phosphorus treatments were profitable. Based on these results, 69 kg P_2O_5 ha^{-1}, was the most economically efficient and suitable rate for fenugreek production in the study area.

Higher rates reduced efficiency because the extra cost was not matched by higher returns. According to CIMMYT(1988) ,fertilizer recommendations should be based on both net benefit and marginal rate of return. This also agrees with previous studies that show profitability depends on correct fertilizer use, improved varieties, and input costs (Gigaw *et al*., 2014; Wendimu *et al*., 2020).

Overall, the study confirms that phosphorus fertilization enhances both productivity and profitability of fenugreek production. However, the results also indicate that economic efficiency declines at higher application rates. Therefore, 69 kg P_2O_5 ha^{-1} is recommended as the most economically viable rate for fenugreek production under the agro-ecological conditions of Cheliya district.

Table 19.Effects of Phosphorous fertilizer rates on the economic feasibility of fenugreek production

Phosphorus rate (kg ha^{-1})	Grain yield(kg ha^{-1})	Adjusted yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Gross field benefit (ETB	TVC (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Value-to-cost ratio	MRR (%)
0	1044	939.6	1879.2	368323	17075.2	351248	20.57	D
23	1315	1183.5	2367	463932	21575	442357	20.50	2025
46	1603	1442.7	2885.4	565538.4	26075	539463.4	20.68	2158
69	1847	1662.3	3324.6	658297	30575	627722	20.53	1961

Where: Fenugreek seed cost =varieties 390ETB kg^{-1} and Local 360 ETB kg^{-1}. Urea = 6000 Birr 100 kg^{-1}, TSP = 9000 Birr 100 kg-^{1}, Labor cost = 4 person days' ha^{-1} at 300 ETB day^{-1}, Straw price = 2 ETB kg^{-1} (revenue), Grain selling price = 390Birr kg^{-1}; TVC = Total Variable Cost. MRR = Marginal Rate of Return. ETB = Ethiopian Birr per hectare. D = Dominated.

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1. Summary and Conclusions

The majority of tropical soils, including those in Ethiopia, have limited capacity to support high crop productivity due to nutrient deficiencies, particularly phosphorus deficiency. Consequently, crop yields often remain below their genetic potential. Fenugreek is one of the widely cultivated pulse crops in the Cheliya District; however, its productivity is still lower than both regional and national averages. This low productivity is mainly attributed to several constraints, including the limited use of improved varieties, declining soil fertility, inadequate fertilizer application, severe nutrient depletion, disease pressure, and poor agronomic practices. Among these factors, low soil phosphorus availability is a major constraint on fenugreek production in the study area. Therefore, a field experiment was conducted to evaluate the effects of different phosphorus fertilizer rates on the growth, yield components, and seed yield of fenugreek varieties. The treatments consisted of a factorial combination of three fenugreek varieties (Burqa, Bishoftu, and Jamma) and four phosphorus application rates (0, 23, 46, and 69 kg P_2O_5 ha^{-1}), arranged in a randomized complete block design with three replications.

The main effects of varieties and phosphorus fertilizer rates were highly significant ($P < 0.01$) for days to 50% flowering, days to 90% physiological maturity, number of branches per plant, number of seeds per pod, and thousand-seed weight. In addition, the interaction effects of variety and phosphorus rates were significant ($P < 0.05$) for the total number of nodules, number of effective nodules, nodule fresh weight, taproot length, number of pods per plant, dry biomass, and seed yield. The maximum seed yield (2.047 t ha^{-1}) was obtained from the Bishoftu variety at 69 kg P_2O_5 ha^{-1}. Seed yield showed a positive and highly significant association with most yield-related parameters. Economic analysis indicated that the application of 46 and 69 kg P_2O_5 ha^{-1} resulted in marginal rates of return of 2158 and 1961%, respectively, both of which are far above the minimum acceptable rate of return. This confirms that phosphorus fertilizer application is economically viable for fenugreek production under the study conditions.

Based on both agronomic performance and economic evaluation, the application of 69 kg P_2O_5 ha^{-1} is considered optimal, as it provides a balanced combination of high seed yield and strong economic return.

5.2 Recommendations

Based on the findings of this study, the application of 69 kg P_2O_5 ha^{-1} is recommended for fenugreek production in the Cheliya District. This phosphorus rate was found to be the most economically viable, providing the highest yield, net benefit and an acceptable marginal rate of return. The results of the study further demonstrated that phosphorus fertilization highly significant improved seed yield and profitability. Therefore, the application of 69 kg P_2O_5 ha^{-1} is recommended to maximize economic returns and promote the efficient use of fertilizer resources in the study area.

Furthermore, agricultural extension services should enhance farmers' knowledge of efficient fertilizer use through training, field demonstrations, and economic analysis to promote informed decision-making and the adoption of profitable and sustainable nutrient management practices. Future research should focus on conducting multi-location and multi-season studies to evaluate different varieties with different sources of phosphate and application rates to improve productivity and farm-level profitability.

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6. APPENDICES

Appendix 1. Mean Square of Anova for Phenological and Growth Parameters

		Mean Square		
Source of Variation	DF	50 % DE	50% DF	90%DPhM
Replication	2	0.3958 ns	4.50ns	0.68ns
Phosphorus	3	0.0208 ns	19.87***	76.06 ***
Variety	3	3.1875 ***	279.34***	522.26 ***
Interaction (PxV)	9	0.0764 ns	1.086 **	0.58 ns
Error	30	0.2625	0.266	0.63
LSD (5%)		NS	1.19	0.97
CV (%)		0.569	2.05	0.81

*Where: - *, **, ***: Significant at 0.05, 0.01, and .001respectively, DF: Degree of freedom, DE: Days of 50% emergency, Days to 50% flowering, DPHM: Days to 90% physiological maturity*

Appendix 2. Mean Square of Anova for Nodule Parameter of fenugreek

		Mean Square			
Source of Variation	DF	TN	EN	NFW	NDW
Replication	2	5.15	5.69	0.00491	0.000394
Phosphorus	3	1761.36	1333.41	0.97665	0.052208
Variety	3	944.14	773.41	0.36674	0.000880
Interaction (PxV)	9	37.94	35.39	0.02044	0.001128
Error	30	4.32	4.47		0.000189
LSD (5%)		6.33	6.43	0.156	0.042
CV (%)		7.37	9.31	9.12	11.53

*Where: - *, **, ***: Significant at 0.05, 0.01 and .001respectively, EN=Effective nodule; TN=Total numbers of nodule, NFW= Nodule fresh weight, NDW=Nodule dry weight*

Appendix 3. Mean Square of Anova for Growth Parameters

		Mean square		
Source of Variation	DF	PH	NBP	TR
Replication	2	0.57 ns	0.0194 ns	0.440 ns
Phosphorus	3	337.79 **	19.7091***	114.682 **
Variety	3	458.62 **	5.2508***	37.574 **
Interaction	9	35.97 **	0.3941***	1.587 **
Error	30	1.14	0.0534	0.373
LSD (5%)		3.25	0.422	1.86
CV (%)		3.25	5.16	4.40

*Where: - *, **, ***: Significant at 0.05, 0.01 and .001respectively, NBP= number of branch per plant;* PH=plant height; TR=taproot

Appendix 4.Mean Square of Anova for yield, and yield components of fenugreek

		Mean squares					
Source of variation	DF	NPPP	NSPP	SY	THSW	DBM	HI
Replication	2	1.05	0.028	312	0.0127	4050	0.00008
Phosphorus (P)	3	582.47 **	59.703 **	193623 **	15.442 **	9915013**	0.00090 **
Variety (V)	3	305.84 **	37.926 **	1610901**	24.159 **	290869**	0.00179 **
Interaction (PxV)	9	4.16 **	0.400 ns	7308 **	0.086 ns	600024 **	0.00021 **
Error	30	1.24	0.253	1177	0.0987	5702	0.00006
LSD (5%)		3.395	0.56	0.131	0.35	229.19	1.87
CV (%)		3.8	3.41	2.99	1.83	1.73	1.88

*Where, Where: - *, **, ***: Significant at 0.05, 0.01 and .001respectively, NPPP: Number of pods per plant, NSPP: Number of seeds per pod, DBMY: Dry Biomass yield, THSW: Thousand seed weight, SY= seed yield; HI: Harvest index,*

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Figure 2. Field layout and blocking of the experiment



Figure 3.Time of sowing the experiment



Figure 4. Weeding and crop management practices



Figure 5. data collection during flower initiation, and nodulation stages.



Figure 6. Time of parameter measurement and physiologically mature plants ready for harvesting