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Urban Crop Production and Natural Resource Management Practices, Challenges, and Intervention Options in Addis Ababa

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Abstract

The population of Addis Ababa is growing at rapid pace and currently reaches about 5 million. Food shortage, unemployment of youths and women, and increasing prices of major food items are critical constraints. In spite of the efforts to overcome the limitations, information is lacking on urban crop production and natural resource development and management practices to take informed decisions to enhance urban crop production and environmental sustainability. Therefore, this study was undertaken in Addis Ababa to identify and generate information on urban crop production and natural resource management practices, bottlenecks of the practices, and recommend possible intervention options to mitigate the challenges. Quantitative and qualitative secondary and primary data were collected through review of secondary sources and sample survey of urban producers and stakeholders using distinctive checklists. Data were collected through focus group discussions, key informant interviews, and matrix rankings by multidisciplinary research team. The collected data were analyzed using thematic and narrative analyses to achieve objectives of the study. Most of urban producers grow Swiss chard, lettuce, head cabbage, Ethiopian kale (gomen). These crops are selected due to their short life cycle (could be grown three to four times annually), ease of cultivation and low disease incidence. Carrots, beet roots, cauliflower, garlic, onion and potatoes were also grown by some producers. A few producers grew spices and high value crops such as leeks, chives, celery, zukuni, parsley, spinach and spices like coriander. Cereal crops and mushrooms were also produced by limited number of producers. Managing tree seedling nurseries, afforestation and reforestation, and agroforestry practices are carried out to develop and manage natural resources and keep ecological balance. However, shortage of improved technologies, land, and water supply were main constraints in the city. Environmental degradation, inadequate waste disposal and management, limited waste recycling and reuse, and food safety and quality were constraints in Addis Ababa. Overcoming the challenges need involvement of all stakeholders to jointly plan, formulate policy and strategy, and take coordinated and targeted actions.

Keywords: Addis Ababa, urban crop production, natural resource, food safety

Introduction

Addis Ababa is the capital city of Ethiopia and a home for many national and international institutions, with the current population size estimated to be more than 5 million (CSA, 2018; worldometers, 2022). The annual growth rate of city's population is 4.4 percent. It is estimated that 40 percent of Addis Ababa population lives under poverty (World Bank, 2023). In addition, there is inadequate food supply from various parts of the country to feed the growing population of Addis Ababa. In order to bridge the gap and address the growing food demand, urban agriculture has been initiated to ensure food security, create employment opportunities, and generate income for youths and women. The city administration supports and encourages urban dwellers to practice urban agriculture.

Vegetable production has been one of the important components of urban agriculture in Addis Ababa. About 248,536 producers and 1,478 institutions were involved in vegetable production in 2022 in Addis Ababa (Addis Ababa Urban Agri. Commission, unpublished report). Some producers grow different vegetables on a wider area of land greater than 1 ha while majority of the participants grow vegetables either on very small plots of land or on pots. Predominately Swiss chard, lettuce, head cabbage, Ethiopian kale (*gomen*) are grown by farmers. These crops are selected due to their short life cycle (could be grown three to four times annually), ease of cultivation and low disease incidence. In addition, carrot, beet root, cauliflower, garlic, onion and potatoes are also grown to the lesser scale. A few farms grow spices and high value crops such as leeks, chives, celery, zukuni, parsley, spinach and spices like coriander.

Even though, there are crop production activities, Addis Ababa has experienced rapid urbanization which resulted in the conversion of agricultural and natural land into built-up areas. This expansion has led to the loss of vital green spaces, agricultural land, and increased impervious surfaces. Land management in Addis Ababa is a complex task, given the dynamic urban growth and the need to balance development with environmental protection. The city has been working on urban planning and zoning regulations to guide development and prevent unplanned expansion. Sustainable land management practices aim to strike a balance between urban development and the preservation of green spaces and agricultural land.

The other urban agricultural practice is mushrooms production. Mushrooms are often appreciated for their substantial nutritional and medicinal qualities. They are important source of protein that is naturally high in Vitamin D, potassium, magnesium, and many other nutrients. Mushrooms also contain all the essential amino acids. Extracts from common mushrooms are among some of the most powerful medicines, supporting a healthy immune system, lowering cholesterol, and fighting cancer cell development, among a long list of other medical attributes (Mdachi et al., 2004; De Silva et al., 2012; Rathore et al., 2017). Mushroom cultivation, which can be done in small and repurposed spaces, offers great opportunities for urban individuals and communities to address food security issues.

Urban food production should take food safety and quality into consideration to ensure urban food security. It is believed that there is no food security without food safety. Food safety is an essential part of food security. Only when food is safe can it meet nutritional needs and help people to live an active and healthy life and children to grow and develop (FAO, 2023). Food safety can be affected at different stages of food production, processing, transporting, handling, and marketing. In urban areas especially in Addis Ababa, the first factor that affects food safety especial vegetable production is polluted water since most farms use untreated various streams water flowing in the city. When food safety standards are applied, consumers will be protected by the efforts that have been undertaken in making sure that the food they consume is safer. Food safety standards provide the common basis for understanding and, at the same time, the common basis for joint action to ensure that all of us can benefit from safe food (FAO, 2023).

The challenges facing the city has led Addis Ababa city administration to give due attention to urban agriculture and natural resource management activities. However, there is limited information on urban crop production and natural resource management efforts. Information is needed for urban crop production's and natural resource management's targeted extension activities, to revise existing policies and strategies, and design appropriate technologies and market linkages. Taking these views in to account, this study was carried out in Addis Ababa with the following specific objectives:

- Identify urban crop production and natural resource management practices.
- Identify the challenges in urban crop production and natural resource management endeavors.
- Assess perceptions of producers and consumers on urban waste disposal and food safety
- Suggest recommendations for development, research, extension and policy intervention options that help address the challenges of crop production and environmental sustainability.

Materials and Methods

Research Design

This study used qualitative research method to identify urban crop production and natural resource management practices, and to identify the challenges of the practices. The study was carried out by multidisciplinary research team. The team carried out survey on urban crop production and natural resource management practices and stakeholders to collected data. Data were collected using specifically designed checklists. Data were collected through focus group discussions and key informant interviews. Secondary data were also collected by reviewing secondary sources.

Location of the study

The study was conducted in all eleven sub cities of Addis Ababa. Addis Ababa is located in the central high lands of Ethiopia between 38° 39´2.76´´ and 38° 54´19.4´´ east longitude and 8° 50´13.06´´ to 9° 6´4.62´´ north latitude. The scope of the study was limited to assessing the existing status of urban crop production and natural resource management practices. The following figure shows location of Addis Ababa in Ethiopia, and the elven study sub cities.

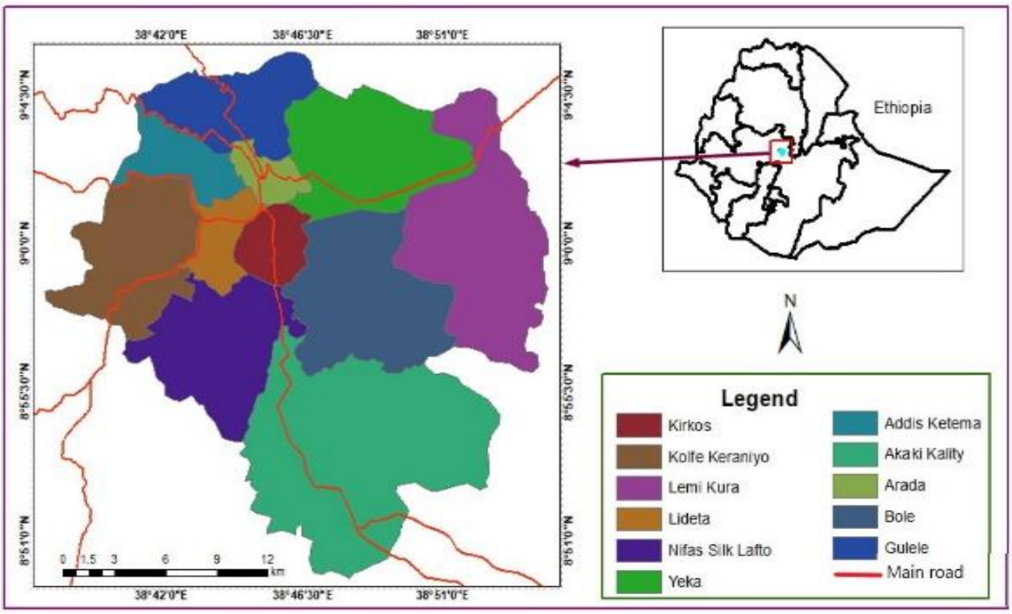

Figure 1. Study location sub cities of Addis Ababa.

Sampling procedure

The sampling frame of the study was the population of urban crop especially vegetable producers, participants in natural resource management and other actors that were engaged either fully or part time in certain types of urban farming and resource management activities. It was assumed that urban producer was the one who was either fully or partially participated in crop production and natural resource management activities for his/her livelihoods. Prior to sample selection, consultative meeting was carried out with city and sub cities' agricultural officers to have better understanding about the potential of districts (*weredas*) that were involved in urban crop production and resource management practices..

Multistage sampling procedure was used to select sample districts and respondents. The first stage was purposive sampling of potential districts that were engaged in urban crop production. The second stage was probability sampling of urban producers and stakeholders along crop and seedling production value chains. Accordingly, 16 districts purposively and 28 producers and other actors in the value chain were randomly selected. Besides, data were collected from 98 agricultural officers or experts found at various levels of urban agricultural office of Addis Ababa. The sample size was determined based on the concept of information saturation which was the point at which no new information was observed in the data from the completion of additional key informant interviews (KII) and focus group discussions (FGD).

Data collection approach

Two standard data collection techniques and approaches were employed. These were desk reviews and qualitative survey techniques. The first stage focused on gathering secondary information while the second stage targeted collecting primary information from target respondents. In the first stage of data collection, secondary information was collected from published and unpublished documents of Addis Ababa city Administrations, Ethiopian Statistical Service (ESS), MoA and other governmental, non-governmental and international institutions. Some of the major sources of published secondary information include journals, books, proceedings, manuals, ESS publications, and unpublished reports. Data were collected using specifically designed checklists by multidisciplinary research team.

In the second stage, qualitative survey methods such as focus group discussions (FGD), key informant interviews (KII) and matrix rankings were adopted to collect primary information from urban producers, offices of agriculture, urban agricultural experts, traders, and consumers. The data were collected from 98 agricultural experts, 25 focus groups discussions, each group with minimum of five members, and 3 traders (supermarkets, retailers and wholesalers). Specific checklist was designed for each of the target group to collect qualitative information by the multidisciplinary research team. Moreover, in this study, the dynamics of land use land cover (LULC) changes over the past three decades was examined using geospatial technologies. A training dataset for supervised image classification was established. To illustrate, urban farmland was identified by annotating it within the image. Subsequently, additional training locations representing the entire image were progressively included. This process was repeated for each land cover class until representative samples were obtained for all classes. As a result, a signature file containing spectrum data for each training sample was generated. The final step involved performing signature file classification using ERDAS (Earth Resource Data Analysis System) and ArcGIS software.

Data Analysis

Thematic and narrative analysis were used to analyze the collected data. Narrative analysis identifies the basic story which is being told, focusing on the way an account or narrative is constructed, the intention of the teller and the nature of the audience as well as the meaning of the story or 'plot' (Riessman, 1993). On the other hands, thematic analysis is mainly described as a method for identifying, analyzing and reporting patterns (themes) within data (Braun & Clarke, 2006). Thematic moves beyond counting explicit words or phrases and focuses on identifying and describing both implicit and explicit ideas. The analysis focused on investigating urban crop producers' and stakeholders' ideas, values, meanings, beliefs, thoughts, experiences, challenges, and feelings related to his/her crop production and natural resource management practices, technology needs and farm input utilizations, urban agricultural support and service mechanisms, and challenges for crop production and natural resource managements as well as urban vegetable food safety and quality. Preferences and priorities were assessed and prioritized using matrix and ranking tools. Technology and input preferences as well as production and management constraints were assessed and identified.

Results and Discussion

Crop production in Addis Ababa

Vegetables

Small scale vegetable production was carried out in Addis Ababa. Some farms grew different vegetables on a wider area of land greater than 1 ha while majority of the participants grew vegetables either on small plots of land or on pots. Growers accessed land either through inheritance from their parents or from the city administration or institutions which have unutilized land; those who accessed land from the latter were unemployed residents organized as small-scale enterprises. The Producers were of age from 27 to 62 years, educational background ranged from illiterate to college graduates (most have elementary and high school education). They have an average family size of six, ranging from 3-12 members. The purpose of establishing the farms was mainly to generate income, employment and/or house-hold food security.

Input was an indispensable prerequisite for production and lack of one or more of which renders production difficult and even impossible. Input includes land, source of water for irrigation, seed/plating material, organic and inorganic fertilizers, capital, and agro-chemicals. Owing to the scarcity of lad, most urban dwellers in Addis Ababa grow vegetables on small beds or in pots. Some growers who had own land or youth organized as small-scale enterprise who obtained land from the city government had wider area of land ranging from 0.05 - 3 ha or more. The small-scale enterprises obtained land that belong to friends or family, government (schools) or non-government organizations which own large unutilized marginal lands on river banks, garbage dumping sites or woodlands. Such lands involved high cost of initial land preparation to clear trees and rocks and construct terraces on sloppy river banks. The option of using vertical farming was seen mostly in the promises of sub-cities, not in individual farms. In addition to the scarcity of land, obtaining legal status for long term (sustainable) production was the major problem. The vegetable farms had only temporary permission letter that allows them use the land for unidentified period of time. Lack of long-term security, consequently, led the farms to limit investment on modern technologies (greenhouses, lath-houses, irrigation schemes, etc) and production of permanent fruit crops which intern reduced productivity of the farms and the tendency to remain in the business.

Availability and quality of vegetable seeds was the most important prerequisite for vegetable production. Most growers procure imported commercial vegetable seeds from agro-dealers in Piaza and Gojam Berenda. They complained that the germination quality and varietal purity of seeds procured from the agro-dealers was poor; however, some disagree and claim that the quality of the seeds from these sources was good. Selecting varieties and brands, and establishing reliable relations with the agro-dealers were the means to secure seed quality. A small amount of vegetable seeds was provided from woreda urban agricultural offices; nonetheless, the type and amount of vegetable seeds provided was not based on the needs of growers. A very few of the farmers obtained seed donations from relatives living abroad. Still a few farmers with better information procured seedlings of pepper and tomatoes from commercial vegetable nurseries such as JoyTech. In addition to the problem of quality, shortage of vegetable seeds, seed health that manifested itself during production (pod rotting in pepper) and high price of seeds driven by ever increasing inflation were the major bottlenecks of vegetable production.

Unlike in rural areas, urban vegetable production didn't receive much research attention. Most highland vegetable crops grown in Addis Ababa: Swiss chard, lettuce, head cabbage, Ethiopian kale, cucumber, and carrots were considered as low priority crops in the national research system until recently when Cool Season Vegetable Crops Research Program was established. Consequently, varieties of these crops recommended in the 1960s were commonly used for production. On the other hand, private seed companies introduce and register seeds of vegetable varieties in Ethiopia. These companies avail seeds of registered varieties of aforementioned crops (except for Ethiopia kale) to growers in the rural areas through their own marketing and extension systems. However, urban vegetable production could not benefit from the registered varieties. In addition to using unimproved varieties, agronomic practices and insect pest and disease management systems used in vegetable production in Addis Ababa were traditional. These practices were developed elsewhere and yet were not adapted to soil and environmental conditions of Addis Ababa. Therefore, adopting these varieties and adjusting their management practices with due consideration to intensive utilization of narrow spaces in urban settings is of paramount importance to intensify production and increase productivity.

Increasing production and productivity was the major objective of any farm and could be achieved only through use of appropriate production technologies and management practices. Despite the fact that farmers used traditional production practices, most of them perceived that productivity of their farms was good. They mostly attributed the productivity of their farm to multiple cycles (three cycles of vegetables or two cycles of vegetables followed by one cycle of cereal) production per year. However, most farmers reported that shortage of land, water, fertilizers, improved seeds, diseases, insects, finance and extension service were constraints in crop production in order of their importance. In addition, water logging, heavy rainfall and hail damage during rainy season (June - August) and frost damage in (October –January) were also reported to cause low productivity.

Vegetable production problem emanates from lack of recognition, commitment, and necessary support by responsible institutions. Although vegetable production usually needs relatively wider area of land as compared to other urban businesses, most farms had small plots ranging from 0.05-2 ha. All farms had only temporary permit to use the land. This caused insecurity and lack of enthusiasm prohibiting long term investment on constructing structures, establishing irrigation systems, etc. that could increase production and productivity. Some farms didn't have electricity supply so they were subjected to high cost of fuel for running water pumps and theft of during the night time.

There was urban extension service gap in vegetable production. Most farmers started vegetable production business traditionally as unemployed residents or inherited from their parents. They had no formal education or sufficient training on agronomy, protection and management of vegetable farms. They also lacked exposure to intensive horticultural farms that could serve as sources of new ideas. Thus, most farms lacked the knowledge and skills necessary to run the farms as profitable businesses leading them to low profitability and disappointment. In addition, the extension advisory service they get from urban agricultural office was inconsistent and some producers consider it as not helpful.

Urban agriculture in general and vegetable production in particular have shortage of land and modern technologies feasible for urban setting to undertake vegetable production. It was very difficult to get land for expansion or start a new farm. Most of the farms were found scattered all-over the city, some located side-by-side with residential areas or unsuitable (sloppy, rocky) sites. Coordinated provision of these resources, extension service, experience exchange, and marketing were difficult under these conditions. Therefore, allocation of land dedicated to clusters of vegetable farms could be important to ensure long term security and success of the farms through building the confidence of farmers to plan long term investment. It also creates suitable conditions to provide the necessary infrastructure, inputs and services. Moreover, modern technologies for urban oriented vegetable productions are lacking or limited, not promoted; and the potential urban vegetable production in Addis Ababa could also include school and institutional gardens, community gardens, vertical farming, rooftop gardening, container gardening, aquaponics and hydroponics, and agroforestry. Therefore, it is essential to develop a clear roadmap with achievable targets and robust extension system involving competent staff capable of designing and leading urban vegetable production.

Cereals

Cereal production in Addis Ababa is a vital component of urban agriculture, contributing significantly to the city's income and employment. Urban residents in Addis Ababa engage in cereal cultivation, primarily focusing on crops like teff, maize, barley, and wheat. Cereal urban farming activity provides income for many households, particularly low-income families, while creating employment opportunities. It was estimated that the total area currently under cereal crops cover was about 3,349 hectares in the city in 2023.

The production and productivity of cereals in Addis Ababa depend on factors like land availability and security, input accessibility, and the use of efficient farming techniques. In this regard, due to the lack of timely input supply and limited use of improved technologies and management practices, productivity of cereal was about 20 quintals per hectare. Urban cereal producers face significant challenges that include land ownership insecurity, which compels them to sell their land due to the fear of potential dispossession by the city administration or the need to construct family housing and meet basic family requirements. Furthermore, they contend with challenges like the shortage and delayed delivery of essential farm inputs like fertilizers and improved seeds. Moreover, the prices of crucial inputs such as fertilizers and herbicides are increasing from time to time.

Therefore, to enhance cereal production in Addis Ababa, there is a need for on time supply of farm inputs with affordable prices and required quality, technology transfer, training and extension services. Urban land planning should also establish secured land ownership for cereal producers to enhance productivity and sustainability.

Mushrooms

There were limited efforts that involve training on mushrooms production, technical support, and sometimes subsidies to encourage urban dwellers to take up mushroom cultivation as a livelihood option in Addis Ababa. The results of this study show that Addis Ababa's mushroom production has significantly decreased mainly due to limited supply of mycelium, low productivity of the varieties, limited access to training, limited supply and the high price of the substrate (cottonseed), and lack of credit service. For these reasons, only a tiny percentage of producers remain active in this market while a large majority have ceased production. Currently, there are only two active mushroom growers in the city. This report is therefore based on insights gleaned from these two functional farms.

Mushroom cultivation in the city is generally accomplished by both individuals and enterprises, often with a focus on commercial endeavors. However, the currently active growers lean more towards personal consumption rather than mass market distribution. Mushroom production necessitates the availability of both dark rooms for the initial growth phase and well-illuminated spaces to facilitate maturation. Individuals typically engage in this practice on their privately owned land, utilizing their personal finances and family labor. In contrast, enterprises operate on public land, relying on the labor of their members, and often secure loans from financial institutions to support their mushroom cultivation ventures.

Mycelium is the living fungal culture grown onto a substrate. It provides the backbone to any mushroom-growing operation. The producers obtain mycelium from the city’s urban agriculture commission and some private suppliers. The respondents revealed that mycelium from private sources is relatively expensive. Limited access, shortage and low quality of mycelium are challenges related to the input. Sometimes mycelium supplies are affected by bacteria and fungus which then affect the whole farm. Mushrooms also need a substrate to grow, just like plants require soil. The substrate supplies energy, nutrition, and structure needed by the mycelium, to develop and grow into beautiful mushrooms. The producers use cotton seed, sorghum, sawdust, hay, and straw (tef straw) as a substrate. However, cotton is given priority by producers due to its high nutrient content and reduced productivity from the use of other substrates. Limited access to the market and the high price of cotton is the major challenge in mushroom production. The current price of a quintal of cotton is 2,600 Birr.

Mushroom provides output two to three times in its lifespan. About 60kg of mycelium yields 180 to 300 kg of production based on the quality of the mycelium from the farm of the individual. Enterprises harvested only 20 kg from 100 boxes of production, which was extremely low. The market outlet for the product was hotels. The product reaches hotels through collectors as the producers have no receipt (TIN) to directly sell the product to hotels. Collectors assemble from farms and sell to international hotels. Enterprises sell the product to suppliers of inoculants. The market is not an issue for mushroom products due to high demand. The price of a kilogram of mushroom costs 120 to 150 Birr. They don't know the current market status since the farms are currently not producing for the market. Individuals produce for home consumption while the enterprise supplies the product to the market.

The challenges in mushrooms production included the limited supply of mycelium, low productivity of the varieties, limited access to training, limited supply and the high price of the substrate (cottonseed), and lack of credit service. High market demand for the product, having a relatively short growth cycle, and allowing for multiple harvests throughout the year are opportunities in mushroom production. It is recommended that development and dissemination of improved productive varieties, provision of adequate technical and business training, availing extension and credit services, and enhancing the mushroom value chain, especially input suppliers and producers are essential to enhance its production and productivity.

Natural Resource Management

Land management in Addis Ababa is a complex task, given the dynamic urban growth and the need to balance development with environmental protection. The city has been working on urban planning and zoning regulations to guide development and prevent unplanned expansion. Sustainable land management practices aim to strike a balance between urban development and the preservation of green spaces and agricultural land. These efforts include strategies to protect natural habitats and incorporate green infrastructure into the city's design to enhance its resilience to environmental challenges.

In response to pollution concerns, Addis Ababa has taken steps to manage and mitigate pollution sources. This includes addressing air and water pollution, waste management, and reducing industrial emissions. Additionally, the Green Legacy Initiative, introduced by the Prime Minister, aims to tackle pollution and environmental degradation by emphasizing afforestation and reforestation efforts across the country, including Addis Ababa. This initiative encourages the planting of millions of trees to combat deforestation, improve air quality, and enhance urban greenery. Many thriving youth and women groups and businesses are actively involved in seedling nurseries, and successfully multiplying millions of seedlings to support the city's afforestation and urban greening endeavors.

The *Green Legacy Initiative* has gained significant momentum in Addis Ababa. The program not only focuses on afforestation but also involves urban greening and the preservation of existing green spaces. Thousands of people in the city have been actively involved in tree planting campaigns, contributing to the re-greening of urban areas and the improvement of air quality. These efforts align with the broader goal of achieving a more sustainable and environmentally friendly future for Addis Ababa, while also inspiring environmental consciousness among its residents.

Accordingly, in 2023, the dominant land cover type was built-up land, encompassing a substantial area of 350.6 square kilometers, representing 66.5% of the total land coverage. Vegetation covered 95.9 square kilometers, accounting for 18.2% of the area, with a minor increase of only 0.6 square kilometers observed between 2013 and 2023. In contrast, there has been a significant decline in the area coverage of urban farming and bare land, now constituting 57.7 square kilometers (10.9%) and 21.4 square kilometers (4.1%), respectively. Additionally, 1.5 sq. km (0.3%), 1.6 sq. km (0.3%), and 1.6 sq. km (0.3%) are all included in the water land cover class. These results are supported by a similar study by Mitiku and Dessalegn (2021) who also examined the land use/land cover change of Addis Ababa over three decades.

In the context of urban agriculture, land-use change in Addis Ababa has emerged as a significant and intricate issue in recent years. The city has witnessed a significant transformation in its landscape as the demand for urban development collides with the need for sustainable food production. This conflict between urbanization and agriculture has led to the conversion of fertile agricultural land into residential and commercial areas, resulting in reduced agricultural productivity and raised potential food security concerns. This dramatic change in land use and vegetation cover in Addis Ababa is clearly indicated by the land use land cover change map (*Figure 2*).

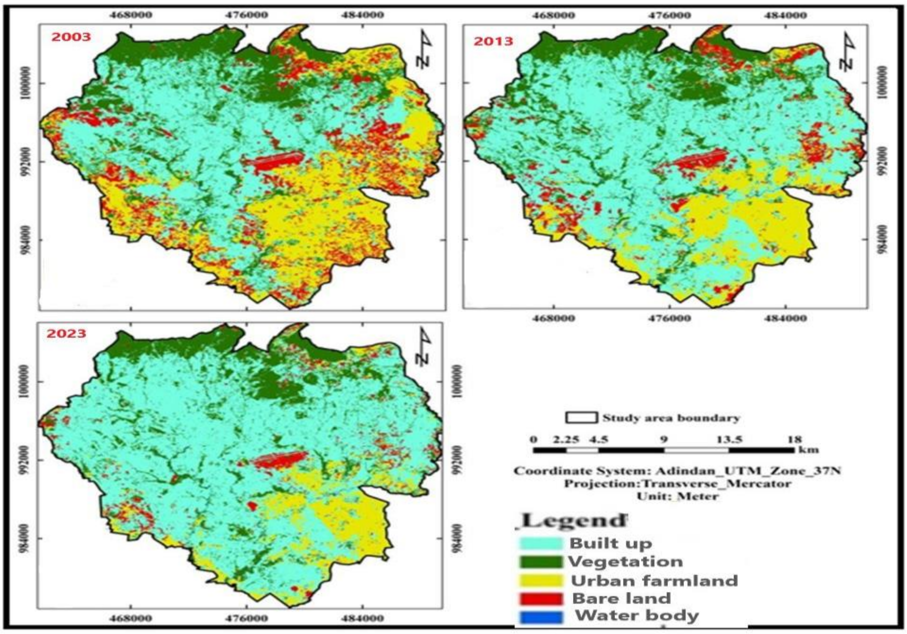

Figure 2. Land use land cover change of Addis Ababa over the last 20 years.

Maintaining the ecological balance of urban agricultural production and reducing environmental pollution need the use of eco-friendly waste disposal techniques like composting and recycling. To guarantee that urban agriculture remains a sustainable and ecologically conscious practice, cooperation among communities, local governments, and urban farmers is crucial. Local producers in the majority of Addis Ababa's sub-cities generally believe that urban agriculture does not present a serious environmental danger in terms of pollution. Some growers efficiently recycle organic resources by making compost out of vegetable and animal leftovers and other farm wastes. However, wastes from industries, households, institutions, and urban farms are contributors to environmental pollution in Addis Ababa.

In general, the use of compost and farm waste as organic fertilizers in urban vegetable and cereal crops production presents both challenges and opportunities for Addis Ababa. While issues such as sourcing quality organic material and managing composting processes require attention, the benefits of sustainable urban agriculture, improved soil health, and economic development make the investment in organic fertilizers a promising avenue for the city's future food security and environmental sustainability. Addressing these challenges and seizing the opportunities will be pivotal in ensuring the success of sustainable agricultural production in Addis Ababa.

Urban Food Safety and Quality

Studies show that discharge of untreated effluent from industries, solid wastes and wastewater from households and institutions are the major sources of pollution of the rivers flowing through Addis Ababa. We observed that most urban vegetable producers use polluted river and stream water for vegetable production. Vegetable productions using polluted water could be a factor affecting food safety and quality. Shortage of tap and ground water make producers use polluted rivers' water for production of various vegetable crops in the city. Different studies show that urban agricultural products produced using polluted or contaminated water are unsafe and do not meet safety and quality criteria. Water pollution is a critical challenge to food safety since most Addis Ababa urban producers use polluted and unsafe water for production activities. The urban food products produced using polluted water could not meet food safety and quality standards.

Potentially toxic elements or heavy metals and pesticides residues are major factors affecting food safety in urban food productions (Buscaroli et al., 2021). Heavy metals and pesticides residues affect human health. Vegetable producers in Addis Ababa mainly use river water and pesticides. This production practice is one of the main routes of heavy metals entry into human body. Agricultural products produced by polluted water could have toxic elements or heavy metals that can greatly affect human health. Vegetable outputs from Addis Ababa urban agriculture could not be free from contamination by heavy metals and pesticide residues since most urban producers use polluted water and pesticides in their vegetable productions.

Generally, unsafe food affects the realization of the right to adequate food in the context of national food security and reduces efforts to guarantee health and wellbeing. Safe food is also a prerequisite for achieving healthy diets, increasing market access and economic development. Unsafe food causes an estimated 600 million cases of food-borne diseases (FBDs) every year, as well as 420 000 annual deaths globally; and Children under the age of five account for 143 000 of those fatalities (WHO, 2015). Human illnesses due to unsafe food are estimated to cause yearly productivity losses equating to USD 95 billion for low- and middle-income countries (LMICs) (Jaffee et al., 2019).

The challenges in vegetable production include limited knowledge or lack of awareness among the majority of urban vegetable producers, supporters, consumers, and policy makers on food safety risks of urban agricultural products. The main objectives of urban agriculture are to ensure food security, generate income and employment opportunities. We perceived that most consumers did not know the source and production practices of vegetables bought from market; and focus on urban food safety was limited or non-existent.

There are several evidences of food safety hazards related to urban food production practices. Studies carried out in different parts of the world indicate that foodborne pathogens and micro-organisms, potentially toxic elements (PTEs), pesticides residues, nitrate and nitrite are common hazard categories for urban food production systems (Buscaroli et al., 2021). Producers in Addis Ababa use unsafe production practices, and food products could not be free from these problems. Further quantitative studies and laboratory analysis are needed to substantiate this fact.

Therefore, growing food to ensure food security in Addis Ababa requires responsibility for the safety of food products. Urban producers must have guidelines and recommendations to improve the safety and quality of agricultural products. The guidelines and recommendations on good urban agricultural practices enhance the safety and quality of agricultural products by preventing microbial contamination from soil, water, hands, and surfaces throughout production, processing, and marketing stages.

Conclusion and Recommendation

The assessment of crop production in Addis Ababa reveals that there are productions involving vegetables, cereal crops, mushrooms, and seedling nurseries. Vegetable and cereal productions have relatively higher income generations and employment opportunities. In addition to vegetable production, there are various urban agricultural practices that can be explored and implemented to enhance urban food security, promote sustainability, and contribute to the well-being of urban dwellers. The possible potential urban agricultural practices in Addis Ababa could also include school and institutional gardens, community gardens, vertical farming, rooftop gardening, container gardening, aquaponics and hydroponics, and agroforestry.

Even though urban crop production has huge potential to ensure food security and generate employment opportunities, however, it has been constrained by various challenges. The challenges affect production, productivity, and consumption of urban agricultural commodities. These challenges are related to availability or limited supply of infrastructures (land, water, and electricity), shortage of improved technologies (plant seeds, seedlings, production & management practices, tools and implements), limited availability of quality farm inputs with affordable prices (fertilizers, and agrochemicals), shortage or unavailability of basic services and supports (urban agricultural extension, training, credit, policy and regulatory frameworks), limited urban waste disposal and management mechanisms, and urban food safety and quality.

The challenges are diverse and interrelated. Solving the challenges require collaborative approach involving various stakeholders for strategic interventions. Some of the key strategic actions need to be taken to overcome the challenges and enhance urban crop production, natural resource management, and food safety and quality in Addis Ababa include:

- Establish and implement urban crop production and natural resource management policies related to land use planning, water management, infrastructure, waste disposal and environmental pollution, and food safety and quality.
- Implement policies that provide secure land tenure for urban producers that promotes long-term production and sustainability.
- Develop efficient irrigation systems, ground water and rainwater harvesting, and water recycling initiatives.
- Develop mechanisms to ensure reliable and affordable access to improved agricultural technologies and inputs, and financial support mechanisms.
- Implement training and awareness creation programs, workshops, and extension services.
- Develop and strengthen urban- rural input and output market linkages.
- Enhance research and research funding on urban crop production, natural resource management, and food safety and quality.

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Performance of Andinet Soybean [*Glycine max* (L.) Merrill] Variety

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Abstract

Several soybean genotypes that have been introduced in 2015 from the Institute of International Tropical Agriculture (IITA), Nigeria, by the Pawe Agricultural Research Center of the Ethiopian Institute of Agricultural Research were evaluated for yield and other desirable agronomic traits, aiming to identify genotypes that have better yields than the existing varieties cultivated in the country. The combined mean square of genotype plus genotype × environment interaction (GEI) analysis showed highly significant (P < 0.01) difference for grain yield among the tested genotypes. Genotype Tgx-1989-75F has showed best performance for grain yield, hundred seed weight, number of branches per plant and number of seed per pod based on the combined mean results. In addition, the genotype exceeded the standard check (Pawe-03) and local check (Gishama) varieties by 35.6% and 19.7%, respectively. And also, it has showed additional merits such as; resistance to frog eye leaf spot and tolerance to bacterial blight, brown leaf spot, red leaf blotch, and rust, and has been shown to be stable across test locations and seasons. Genotype Tgx-1989-75F has released as a variety with name "Andinet" and can be widely used for commercial farming in Pawe, Asosa, Bako, Sirinka, Areka, Jimma, Gonder, and similar areas, resulting in increased revenue for smallholder farmers.

Keywords: Andinet, Genotypes, Soybean, Stable, Standard check, Variety

Introduction

Soybean [*Glycine max* (L.) Merrill] is a multipurpose crop that can be used for a variety of purposes, including the preparation of different kinds of foods and animal feed, alleviating malnutrition, improving soil fertility status, and as a raw material for the processing industry. Ethiopia has a huge potential for soybean production and the crop has been found to be the best crop for intercropping with maize and sorghum, as well as rotational crops in irrigated production environments with cotton and wheat. In addition to its economic advantage, the crop has a significant contribution to sustainable crop production by replenishing soil fertility (Hailegiorgis, 2010; FAO, 2020).

In Ethiopia, soybean is well adapted to the lowland to mid-altitude agro-ecologies of the country (Fentahun, 2019). During the 2020-2021 cropping season, soybean was produced on 108,665.6 hectares of land, and the national average productivity was 2.5 tons ha^{-1} (Central Statistics Agency, 2021). Soybean is grown predominantly by smallholder farmers and has shown an increasing trend to be grown by medium-scale and commercial farmers because of the growing demand from the industry. In the past twelve years, the total area under soybean production has increased from 5,679 to 108,665.6 hectares of land, and the total volume of production during the same period has increased from 7205 to 208,676 tons, and productivity has increased from 1.3 to 2.5 tons ha-^{1} (Central Statistics Agency, 2021).

However, the average productivity of the crop is lower than the world average, which is greater than 3 tons ha^{-1} (USDA, 2020), due to biotic and abiotic stresses (Mulugeta Atnaf *et al*., 2015), lack of diversified soybean materials, and reduction of the genetic potential of released varieties (Mesfin Hailemariam and Abush Tesfaye, 2018). Therefore, the Pawe Agriculture Research Center has strived to develop varieties with higher yield, disease resistance, high seed oil content, and other desirable agronomic traits than the previously released varieties to increase crop production and productivity in the country. Though, several soybean genotypes have been introduced in 2015 from the Institute of International Tropical Agriculture (IITA), Nigeria, by the Pawe Agricultural Research Center of the Ethiopian Institute of Agricultural Research and tested for their disease rection, quality and yield performances through successive trial stages, about fourteen of them were selected and passed for further two consecutive years national variety trail with the aim of identifying genotypes that have better yields than the existing varieties and cultivars cultivated in the country. Therefore, genotype Tgx-1989-75F has showed superior performance in disease resistance, grain yield and quality traits than the checks (standard check variety Pawe-03 and the local check variety Gishama) (Table 5 & 6) and, hence, has released as a variety with name "Andinet" and it is under production in its suitable agro-ecological areas of Pawe, Asossa, Bako, Sirinka, Areka, Jimma, Gonder, and similar areas.

Materials and Methods

Experimental materials and test locations

Only fourteen soybean genotypes (Table 1) have advanced to variety verification trial based on their grain yield and other quality (oil and protein parameter) after two consecutive years (2016-2017) of national variety trial at five testing locations (Pawe, Asosa, Bako, Areka, and Sirinka) across the country.

Table 1. Number of tested Soybean genotypes and their code for graphical representation

No.	Genotype	Gen.code	No	Genotype	Gen.code
1	TGX 1989-11F	G1	10	TGX 1990-114F	G10
2	TGX 1989-42F	G2	11	TGX 1990-87F	G11
3	TGX 1989-45F	G3	12	TGX 1990-80F	G12
4	TGX 1989-53F	G4	13	TGX 1990-95F	G13
5	TGX 1989-75F	G5	14	TGX 1993-4F	G14
6	TGX 1990-106F	G6	15	Pawe-03 (st. check)	G15
7	TGX 1990-107F	G7	16	Gishama (loc. check)	G16
8	TGX 1990-110F	G8			
9	TGX 1990-111F	G9			

Where, No. = Number and Gen.code = Genotype code, st. check = standard check and loc. check = local check.

Data collection

Days to 50% flowering, days to 95% maturity, protein content (%), oil content (%), grain yield (kg) were recorded on plot bases. The grain yield per plot was measured from the middle two rows and converted to hectare bases. All other parameters were recorded on plant basis by taking ten plants randomly from each experimental plot according to Malek *et al*. (2014). However, main yield contributor traits (number of seed per plant, hundred seed weight) and grain yield data were considered for this paper analysis and interpretation.

Analysis of Variance

The mean squares for genotype and genotype × environment interaction (GEI) was highly significant ($P < 0.01$) in the analysis of variance for grain yield of the tested soybean genotypes (Table 2). This revealed that the GEI resulted in various yield ranks for the cultivars (Kang, 2002). In such cases, a cross-environment evaluation of varieties for mean yield and stability is required to select varieties that perform consistently well under all conditions or to identify particular varieties for each environment (Gauch, 2006).

Table 2. The analyses of variance of grain yield of 16 soybean genotypes tested at the five locations

Source	DF	Variance explained (%)	Mean squares
Environment	4	77.45	20610239.47
Genotype	15	7.03	2487140.5***
G*EI	63	15.47	208222.9**

Where, G*EI = Genotype by Environment Interaction and DF = Degrees of freedom.

Results and Discussion

Grain yield and yield related agronomic trait performances

The combined mean yield and agronomic traits performances of 16 Soybean genotypes tested in five environments are presented in Table 3. Genotype 5 (TGX 1989-75F) showed the highest grain yield and medium to late days to maturity comparable to genotype 8 (TGX 1990-110Fn), which showed medium grain size. This indicates that, the released variety, “Andinet”, showed best performance in terms of grain yield, hundred seed weight, number of branches and seed per pod based on the combined mean results.

Variety "Andinet" outperformed the local and standard checks of Gishama and Pawe-03 in both seasons, with grain yield of 2276.7, 1951.9, and 1698.3 kgha^{-1}, respectively (Table 4). The Andinet variety exceeded the standard and local checks by 35.6% and 19.7%, respectively (Table 5). The observed yield advantage of the new variety over the checks was quite high, indicating a successful attempt in the country's variety yield enhancement breeding program.

Table 3. The combined mean yield and agronomic traits performances of 16 Soybean (genotypes and checks) at 5 locations in 2016-2017

No.	Genotypes	DF 50%	DM 95%	NSPP	HSW (g)	AdjYld (kgha^{-1})
1	TGX 1989-11F	64.8	122.2	2.4	12.9	1741.8
2	TGX 1989-42F	63.6	122.3	2.3	12.7	1808.3
3	TGX 1989-45F	61.9	121.6	2.4	12.7	1686.9
4	TGX 1989-53F	63.7	121.9	2.4	12.6	1746.7
5	TGX 1989-75F	62.8	122.5	2.4	13	2276.7
6	TGX 1990-106F	64.7	122.2	2.3	12.7	1686.2
7	TGX 1990-107F	64.2	122.8	2.3	13.3	1801
8	TGX 1990-110Fn	61.4	121.8	2.4	12.9	2188.2
9	TGX 1990-111F	64.5	121.4	2.4	12.7	1811.5
10	TGX 1990-114F	65.1	122.2	2.3	13	1742.6
11	TGX 1990-87F	62.4	122.6	2.4	13.1	1910.5
12	TGX 1990-80F	64.9	156.4	2.2	13.4	1620.3
13	TGX 1990-95F	67	122.3	2.3	12.6	1689.8
14	TGX 1993-4F	63.9	122.9	2.4	12.8	1726.6
15	Pawe-3	65	123	2.4	12.7	1698.3
16	Gishama	64.4	121.9	2.3	12.5	1951.9
	Mean	64	124.3	2.4	12.9	1817.9
	CV (%)	8.2	2.2	16	10	24
	LSD	2.7**	1.6**	0.2**	0.64**	226.2**

Where, DF 50%=50% Days to flowering, DM95%=95% Days to maturity, NSPP=Number of seeds per pod, HSW= hundred-seed weight in grams, AdjYld(kgha^{-1}) = Adjusted Yield per hectare in kilogram, CV (%) = coefficient of variation in percent (%)., and LSD= Least Significance Difference at 5% probability level.

Table 4. Mean grain yield (kgha^{-1}) performance of Soybean genotypes evaluated in the National Variety Trial across locations and over years (2016-2017)

		2016						2017						
No.	**Genotypes**	**Bako**	**Areka**	**Asosa**	**Pawe**	**Sirinka**	**Mean**	**Bako**	**Areka**	**Asosa**	**Pawe**	**Sirinka**	**Mean**	**Over all mean**
1	TGX 1989-11F	1760.8	1262.7	1550.9	1337.4	1913.4	1565	1372.3	1491.7	1393.1	2563.8	2771.5	1918.5	1741.8
2	TGX 1989-42F	1969.4	1312.5	1105.9	1590	1753.8	1546.3	1994.1	1618.4	1676.1	2830	2233.3	2070.4	1808.3
3	TGX 1989-45F	1810.7	1454	927	1035.9	1782.7	1402.1	1696.9	1661.4	1512.3	2545.3	2442.7	1971.7	1686.9
4	TGX 1989-53F	2076.7	1567.5	1582.1	980.6	1771.1	1595.6	1437.3	1588.5	1860.6	1981.3	2621.8	1897.9	1746.7
5	TGX 1989-75F	2374	2275.4	1605.7	2473.9	2403	2226.4	1958.1	2184.4	2415	2570.5	2506.7	2326.9	2276.7
6	TGX 1990-106F	1545.5	1391.2	1449.9	963.6	1727.1	1415.5	1148.1	2283	1289	2479.5	2585.3	1957	1686.2
7	TGX 1990-107F	1778	1682	1411.6	1441	1870.4	1636.6	1395.6	1748	1902.3	2320.2	2460.9	1965.4	1801
8	TGX 1990-110Fn	2142.6	1743.6	1961.5	1966.7	2497.3	2062.3	1475.4	1984.4	2371	2665	3074.7	2314.1	2188.2
9	TGX 1990-111F	1474	1320.4	1600.8	1231.3	2432.5	1611.8	1859.9	1689.2	1531.8	2314.4	2660.7	2011.2	1811.5
10	TGX 1990-114F	2008.9	1246.8	1388.5	1385.3	2050.8	1616	1630.4	1466.5	1055.1	2461.8	2732	1869.2	1742.6
11	TGX 1990-87F	1921	1858.2	1517.5	1486.2	1861.1	1728.8	2258.2	1565.8	1829	2319.2	2489.3	2092.3	1910.5
12	TGX 1990-80F	1688.4	1220.2	1326.2	1297.5	1646.4	1435.7	1564	1711	1058.1	1674.9	3016.7	1804.9	1620.3
13	TGX 1990-95F	1707.9	1396.2	1338.5	1486.2	2051.6	1596.1	2006.5	1084.7	1394.8	1839.9	2591.9	1783.6	1689.8
14	TGX 1993-4F	2009.5	1129.2	1341.1	1353.8	1646.8	1496.1	1713.5	1695.2	1328.4	2392.3	2655.7	1957	1726.6
15	Pawe-03	1626.4	1184.8	1346	1551.3	1785.3	1498.8	1455.4	1518.4	1710.3	2195.7	2609.1	1897.8	1698.3
16	Gishama	1928.4	1918.7	1650.4	1556.5	1925.2	1795.9	2637.9	1752.4	1572.5	2051.3	2525.4	2107.9	1951.9
	Grand mean	**1858.1**	**1489**	**1432.4**	**1446.2**	**1932.9**	**1631.7**	**1833.2**	**1683.3**	**1632**	**2317.7**	**2621.2**	**1997.7**	**1814.7**
	LSD	620*	800*	700*	978**	557**		700*	988*	870*	600**	657**		
	CV (%)	16	20.3	19.7	15.7	19		11.8	13	14.2	18	10.6		

Grain yield stability performance

The yield performance and yield stability of the evaluated soybean genotypes were visually represented using a GGE biplot (Figure 1). The Average Environment Coordination (AEC) abscissa is a straight line passing through the AEC with a biplot origin, and the AEC ordinate is a straight line passing through the origin and perpendicular biplot (Yan, 2002; Yan and Kang, 2003). Based on the AEC coordinates, the genotypes were split into two groups: below and above the average overall yield. Figure 1 displays how the four high-yielding soybean genotypes (G16, G15, G8, and G5) outperform the average yield. Genotype 5 (Tgx-1989-75F) provided the maximum yield and was suited to the three test areas of Ethiopia that are, Pawe, Asosa, and Sirinka, which could be cultivated in places up to 1650 m above sea level.

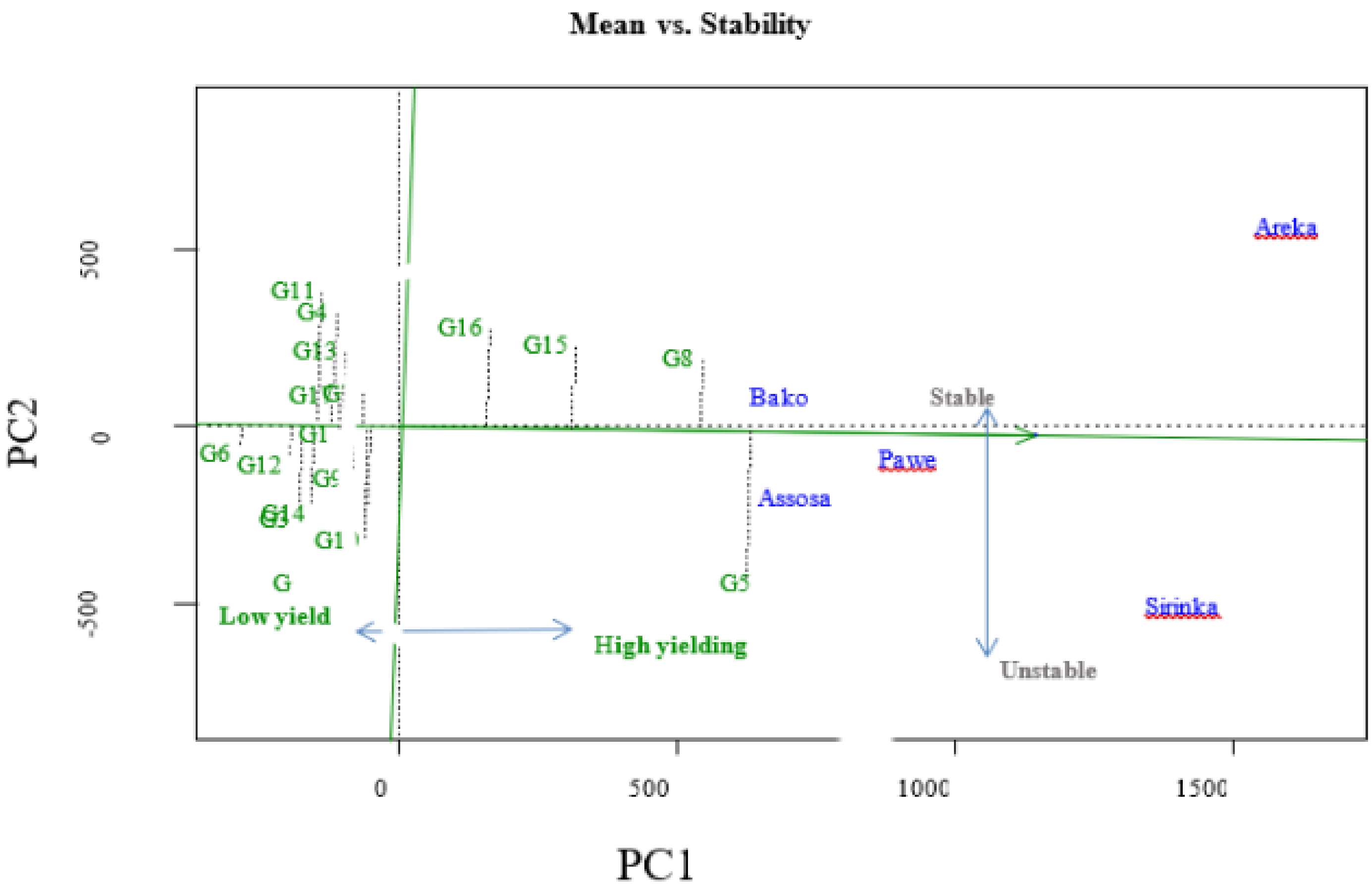

Figure 1: Average environment coordinate (AEC) of the GGE biplot. Where, GGE: Genotypes, Genotypes by Environment interaction, PC1: = the first Principal Components and PC2: = the second Principal components.

Table 5. The yield advantage (%) of the Andinet variety over the standard and local checks

		Yield ($kgha^{-1}$)			Yield advantage (%) of candidate over checks	
Test year	No. of test loc	Candidate (Tgx -1989-75F)	St. check (Pawe-03)	Loc.check (Gishama)	St. check (Pawe-03)	Loc. check (Gishama)
2016	5	2226.4	1498.8	1795.9	48.55	23.97
2017	5	2326.9	1897.8	2014.9	22.61	15.48
Overall mean		2276.65	1698.3	1905.4	35.58	19.73

Table 6. Oil and protein contents of the Andinet variety and the checks

Oil content (%)			Protein content (%)		
Candidate (Tgx-1989-75F)	Standard check (Pawe-03)	Local check (Gishama)	Candidate (Tgx-1989-75F)	Standard check (Pawe-03)	Local check (Gishama)
23.5	23	20	35.4	-	31.4

Where, St. check= standard check and Loc. Check = local check

Table 7. Agronomical and Morphological characteristics

No.	Characteristics	Description	No.	Characteristics	Description
1	Adaptation area	Pawe, Asosa, Bako, Srinka, Areka, Jimma, Gonder and similar areas	19	Maturity group	Medium to late
			20	Branching ability (number)	High
2	Altitude (m.a.s.l.)	700-1860	21	Pod attachment(number)	High
3	Rainfall (mm)	500-1586	22	Oil content (%)	High
4	Seed rate ($kgha^{-1}$)	60-70	23	Yield ($kgha^{-1}$) at:	
5	Fertilizer rate($kgha^{-1}$) DAP	100		Research field	1960-2550
6	Spacing (cm) between:			Farmers field	1700-2300
	Row	60	24	Year of release	2019
	Plants	5	25	Maintainer	Pawe ARC
7	Date of Planting	3rd June-1st week of July			
8	Days to 50% flowering	62.8			
9	Days to 95% maturity	122			
10	Plant height(cm)	69.1			
11	Growth type	Semi-determinate			
12	Seed coat color	Yellow			
13	Helium color	Brown			
14	Pubescence color	Brown			
15	Flower color	Purple			
16	Hundred seed weight (g)	13			
17	Oil content (%)	23.5			
18	Protein content (%)	35.4			

Abbreviations: m.a.s. l = meter above sea level, mm= Mili meter, $kgha^{-1}$ = kilogram per hectare, DAP = Di ammonium phosphate, cm = cent meter, g = gram,

Other merits and reactions to major disease

The Andinet variety can produce a high number of branches and pod attachments. Moreover, the variety is resistance to frog eye leaf spot and tolerance to bacterial blight, brown leaf spot, red leaf blotch, and rust.

Conclusions

The findings of this study have shown that in terms of seed production and seed oil content, the released Andinet variety is superior to the standard check (Pawe-03) and local check and (Gishama) varieties. The new variety has additional advantageous characteristics such as, resistance to frog eye leaf spot and tolerance to bacterial blight, brown leaf spot, red leaf blotch, and rust, and has shown to be stable across test locations and seasons. Finally, the newly released Andinet variety can be widely used for commercial farming in Pawe, Asosa, Bako, Sirinka, Areka, Jimma, Gonder, and similar areas, resulting in increased revenue for smallholder farmers.

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Crossbred Cows Conformation Traits and Milk Yield Correlations in Central Ethiopia

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Abstract

We examined the effects of different genotypes and parities on linear conformation traits and assessed the phenotypic relationship between milk yield and linear conformation traits of crossbred dairy cows. We measured twelve linear conformation traits combined with body weight and body condition score of thirty-one 50% Friesian Boran and thirty-five 75% Friesian Boran crossbred cows from 2019 to 2022. Feeding management practices that are usually used for Holeta research station dairy farms consisting of natural grazing, hay and concentrate supplements at the rate of 4 kg per day/cow were the recommended feeding practices in the farm. The overall means of stature, wither height, heart girth, rump length, body length, body condition score and body weight of Friesian Borana crossbred cows were 134.20 cm, 133.31cm, 172.26 cm, 65.00 cm, 149.26 cm, 2.84 and 424.60 kg, respectively. Crossbred cows having 75% exotic gene inheritance had lower body condition score (2.6) than cows with 50% exotic gene inheritance (3.11). The 75% Friesian Borana crossbred cows had also wider udder circumference before and after milking (32.9 and 29.2 cm) than the 50% Friesian Borana crosses (30.4 and 28.4 cm), respectively. High phenotypic correlations (P<0.01) were observed between milk yield with rump length (r_p=0.91), body length (r_p=0.68), front udder height (r_p=0.92), rear udder height (r_p=0.66), and udder circumference (r_p=0.78). Hence, rump length, body length, front udder height and udder circumference can be taken as better predictors of milk yield of dairy cows and accounting for these traits in the dairy cattle breeding program aids in achieving additional information on selection of cows for milk production.

Keywords: *G*enetic group; milk yield; phenotypic *c*orrelation; udder conformation

Introduction

Udder conformation traits and other body linear measurements in dairy cattle are important in breed improvement programs. Various studies have been carried out to investigate the phenotypic and genetic relationship between dairy conformation and milk production traits in pure dairy cattle breeds (Ibrahim Tapki and Yusuf Ziya Guzey, 2013; Zink et al. 2014; Liu et al. 2014; Bohlouli et al. 2015). Dairy farmers usually judge the merit of dairy cows depending on different body and udder conformation traits (Addis Getu and Godadaw Misganaw, 2015). Conformation traits also help in the selection of the best milk-producing dairy cows to increase the profit of dairy farmers (Valencia et al. 2008).

Assessment of the relationship between linear conformation and production traits of Frisian X Boran (FB) crossbred cows will provide vital information that will help dairy farmers to adjust their breeding and management programs. Several attempts have been made to improve the productivity of some of the most economically important traits such as milk production, growth rate, and reproduction performances of crossbred cattle through crossbreeding. The results of these crossbreeding experiments in Ethiopia have been amply reported in numerous literature (Getahun et al. 2020; Tefera et al. 2020; Shumye et al. 2021; Getahun, 2022; Hunde et al. 2022; Fikadu, 2023). Evaluation of crossbred dairy cattle in tropical countries is exclusively based on data recorded on milk production, reproduction, and growth performances. However, data on confirmation or type traits is scarce. In effect, the relationship of these traits with other production traits such as daily milk and lactation milk yield has not been evaluated in the dairy cattle crossbreeding scheme in sub-Saharan or tropical countries.

Therefore, we aimed to evaluate linear confirmation traits and their relationship with milk yield in crossbred cows so as to assist visual selection of dairy cows under field conditions where performance records are not available.

Materials and Methods

Description of the study area:

The study was conducted at Holetta Research Center which is located 34 Km west of Addis Ababa. The area is located at an altitude of 2400 m above sea level (masl) and receives an annual average rainfall of 1100 mm and an average maximum temperature of 21.3^{o}C.

Animal management

The experimental cows were allowed to graze on pasture for 8 h/day and supplemented with hay and concentrate feeds. The concentrate feed supplement was a mixture of wheat middling (32%), wheat bran (32%), noug *(Guizocia abyssinica*) cake (34%), and salt (2%). Milking cows were supplemented with concentrate feed mixture at a rate of 4 kg per day/animal. The animals had free access to clean water all time.

Measurements of linear conformation traits

Twelve linear conformation traits, coupled with body weight (BW) and body condition score (BCS) were measured on thirty-one 50% FB and thirty-five 75% FB crossbred cows between 2019 and 2022. The linear conformation traits comprised five body conformation traits (linear body measurements): stature (ST), heart girth (HG), wither height (WH), body length (BL), rump length (RL), and seven udder conformation traits; front teat length (FTL), rear teat length (RTL), front teat diameter (FTD), rear teat diameter RTD), front udder height (FUH), rear udder height (RUH), and udder circumference (UC). The linear conformation traits were measured in centimeters (cm) using a graduated measuring stick and flexible tape while BW was measured in-kilogram using cattle weighing Bridge (scale). The body condition score (BCS) was evaluated based on a score of 1 to 5 (David Allen, 1990). Linear body measurements (body conformation traits) were recorded monthly on milking cows in the morning before feeding and watering. Udder measurements (udder conformation traits) were measured monthly pre- and post-milking times. Teat length and udder heights were measured with a flexible measuring tape (sewing 150 cm soft tailors). Teat diameters were measured with Vernier-type calipers before and after milking. The details of the measurements and definition of the traits are presented in Table 1

Statistical analysis

Crossbred genotype group and parity were considered as fixed effects in the model whereas – linear and udder conformation traits were dependent variables. Data were analyzed using the general linear model of SAS, (2008). The following model was used:

$Y_{ij} = \mu + G_i + P_j + e_{ij}$

Y_{ij} is the observation of measurement (udder and body linear measurements), μ is the overall mean, G_i is the effect of genetic group (i: 1, 2); P_j is the effect of parity (j: 1, 2, 3.4, and 5); e_{ij} is the random error.

Table 1 shows details of the udder and body conformation trait measurements

Traits	Abbreviation	Description of measurements	Instruments
Stature	ST	Measured from the top of the spine in between hips to the ground	Measuring stick
Heart girth	HG	Measured as a circumference of the body at a point immediately behind the forelegs, perpendicular to the body axis or simply as the smallest circumference.	Measuring stick
wither height	WH	The highest point over the scapulae vertically to the ground or measured from the highest point on the dorsum of the animal to the ground surface at the level of the front legs	Flexible tape
Body length	BL	Measured from the point of the shoulder to the ischium.	Flexible tape
Rump length	RL	Larger and more nearly level from hip to pin bone	Flexible tape
Front teat length	FTL	Length of front teats	Flexible tape
Rear teat length	RTL	Length of rear teats	Flexible tape
Front teat diameter	FTD	The diameter of the front teats	Calipers
Rear teat diameter	RTD	The diameter of the rear teats	Calipers
Front udder height	FUH	Measured perpendicularly from the point of attachment in the ventral abdomen to the lowest point of the front udder.	Flexible tape
Rear udder height	RUH	Measured straight upright from the highest mammary point at the cow's caudal body to the lowest point of the rear udder.	Flexible tape
Udder circumference	UC	Measured based on the largest UC between the two hind legs of the cow.	Flexible tape

Source (IHFA, 2006)

Results and Discussion

Effects of genotype and parity on body conformation traits

The least-square means for linear body measurements (body conformation traits) by genotype and parity are presented in Table 2. Only body condition scores significantly ($P < 0.01$) varied between genetic groups. Crossbred cows having 75% exotic blood level had lower body condition scores than those having 50% exotic blood level. This result indicated that the level of feeding management in the research dairy farm may not be adequate for 75% FB crosses to attain good body condition since the same level of management is applied to both genotypes regardless of the actual requirement for each. The mean values of ST, WH, BL, BCS, and BW in this study were higher than ST (129.83 cm), WH (126.12 cm), BL (123.52 cm), and BW (391.30 kg) reported by Alphonsus et al. (2012) for Nigerian Friesian X Bunaji crossbred cows. The difference could be ascribed to the genetic difference between experimental animals and the variation of feeding supplements offered to animals.

Parity (lactation number) had a significant ($P < 0.01$) effect on HG, RL, and BW, but not on other body conformation traits (Table 2). The HG, RL, and BW tend to increase with progressing lactation numbers.

Effects of genotype and parity on udder conformation traits

Means with the standard errors for front and RTL, TD, UH, and UC are given in Table 3. The genetic group had a significant ($P < 0.01$) effect on FTL and RTL before and after milking time. By contrast, FTD and RTD before and after milking did not significantly vary between genetic groups. Of the FB crosses, 75% had longer front and rear teats pre-and post-milking time than those of 50% FB crosses. This shows that 75% FB crosses have better teats (udder) conformations which indicate better dairy characteristics than 50% FB crosses. Moreover, 75% FB crosses have a higher proportion of Frisian gene inheritance.

Table 2. Least square means and standard errors for linear body measurements, body condition score and body weight of Friesian X Boran crossbred cows.

Variables	N	Stature (cm)	Wither height (cm)	Heart girth (cm)	Rump length (cm)	Body length (cm)	Body condition Score	Body weight (kg)
Overall mean	66	134.20	133.31	172.26	65.00	149.26	2.84	424.60
Genetic group								
50% FB	31	133.36±0.96	131.90±1.15	171.91±1.96	64.22±1.19	145.80±2.30	3.11±0.10[a]	420.17±15.20
75% FB	35	135.11±0.92	134.51±1.10	172.31±1.87	65.83±1.14	152.70±2.20	2.6±0.10[b]	431.59±14.50
LS		NS	NS	NS	NS	NS	**	NS
Parity								
1	11	131.31±1.36	130.72±1.64	163.15±2.78[c]	59.59±1.6[b]	141.1±3.29	2.65±0.1	342.02±21.5[c]
2	13	135.2±1.50	132.2± 1.80	168.37±3.1[bc]	63.73±1.9[ab]	145.8± 3.70	2.8±0.17	390.10±24.4[bc]
3	15	133.9±1.20	134.81±1.50	176.9±2.5 [ab]	65.7±1.5[a]	151.2±3.00	2.9± 0.1	454.3±19.7[ab]
4	14	134.6±1.80	134.15±2.38	174.1±3.8[ab]	66.6±2.3a	153.9±4.50	2.8±0.2	466.3±30.0[a]
5	13	136.00±1.30	134.13±1.50	178.13±2.7[a]	69.4±1.6[a]	154.1±3.19	3.0± 0.1	476.6±20.9[a]
LS		NS	NS	**	**	NS	NS	**

*Means with different superscripts within a column are significantly different (p<0.05) and p<0.01; LS= Level of significance; NS= Non Significant; *= p<0.05; **=p<0.01; 50% FB= Friesian Boran cross with 50% Exotic blood level, 75% FB= Friesian X Boran cross with 75% Exotic blood level; N = number of observations.*

Table 3. Least square means and standard error for udder conformation traits of Friesian X Boran crossbred cows.

Variables	N	FTL(mm)		RTL(mm)		FTD (mm)		RTD (mm)		FUH (cm)		RUH (cm)		UC (cm)	
		BM	AM	BM	AM	BM	AM	BM	AM	BM	AM	BM	AM	BM	AM
Overall Mean	66	49.4	51.6	43.4	44.0	19.2	18.0	18.2	17.1	13.1	11.2	36.6	33.4	31.4	29.5
Genetic group															
50% FB	31	45.5±1.4^{b}	46.4±1.2^{b}	39.1±1.2^{b}	40.4±1.0^{b}	18.7±0.4	17.8±0.3	17.6±0.3	16.9±0.3	12.6±0.4	10.7±0.3	35.5± 0.5	33.3±0.5	30.4±1.3	28.4±1.2^{b}
75% FB	35	52.1±1.3^{a}	54.3±1.2^{a}	46.6±1.2^{a}	46.1±0.9^{a}	19.3±0.4	17.5±0.3	18.1±0.3	16.6±0.3	13.1±0.4	10.9±0.3	36.9±0.5	33.6± 0.5	32.9± 1.5	29.2±1.2^{a}
LS		**	**	**	**	NS	NS	NS	NS	NS	NS	NS	NS	*	*
Parity															
1	11	46.6±2.0^{ab}	47.3±1.8^{b}	40.3±1.8^{b}	41.2±1.4^{bc}	18.2±0.6^{b}	17.4±0.5^{b}	17.6±0.4	16.6±0.4	11.9±0.5^{b}	10.6±0.5^{b}	35.2±0.8^{b}	32.9±0.7^{b}	30.2±1.5^{ab}	28.7± 1.4^{ab}
2	13	48.5±2.5^{ab}	49.2±2.2^{b}	41.9±2.2^{b}	43.0±1.8^{b}	18.6±0.8^{b}	16.5±0.6^{b}	17.4±0.5	15.4±0.5	11.1±0.6^{b}	8.9±0.6^{c}	33.3±0.9^{b}	30.1± 0.9^{c}	29.5±1.6^{b}	27.9±1.4^{b}
3	15	44.2±2.4^{b}	44.5±2.12^{c}	37.9±2.1^{c}	39.5±1.7^{c}	18.5±0.8^{b}	17.2±0.6^{b}	16.6±0.5	16.9±0.5	12.1±0.6^{b}	10.0±0.6^{c}	34.7±0.9^{b}	33.2± 0.8^{b}	30.5±1.5^{ab}	28.6±1.5^{ab}
4	14	50.2±1.9^{ab}	51.2±1.7^{b}	44.4±1.7^{b}	41.9±1.4^{bc}	18.7±0.6^{b}	17.1±0.5^{b}	18.2±0.4	16.8±0.4	14.3±0.5^{a}	12.1±0.5^{a}	38.5±0.8^{a}	34.7±0.6^{a}	30.9±1.4^{ab}	29.0±1.3^{ab}
5	13	54.5±1.6^{a}	59.6±1.4^{a}	49.5±1.4^{a}	50.5±1.2^{a}	21.0±0.5^{a}	20.5±0.4^{a}	19.5±0.4	18.0±0.3	14.6±0.4^{a}	12.5±0.4^{a}	39.4±0.6^{a}	36.4±0.5^{a}	32.1±1.4^{a}	30.0±1.5^{a}
LS		*	**	**	**	**	**	NS	NS	**	**	**	**	**	**

Means with different superscripts within a column are significantly different (p<0.05) and p<0.01; LS= Level of significance; NS= Non-Significant; *= p<0.05; **=p<0.01; 50% FB= Friesian Boran cross with 50% Exotic blood level; 75% FB= Friesian Boran cross with 75% Exotic blood level; FTL= Front teat length; RTL= Rear teat length; FTD= Front teat diameter; RTD= Rear teat diameter; FUH= Front udder height; RUH= Rear udder height; UC= Udder Circumference

Parity significantly ($P < 0.05$) affected FTL and RTL and front teat diameter before and after milking. FTL and RTL tend to increase pre- and post-milking with progressing parity. Similar to our current study, FTL and RTL increased with advanced parity (Rasmussen et al. 1998; Tilki et al. 2005). Measurements of FTD and RTD in pre-milking were higher than in post-milking. Teat diameters increased during pre- and post-milking time with advanced parity. Similar results have been demonstrated by reports of researchers (Lin et al. 1987; Tilki et al. 2005).

Higher teat measurement parameters estimates were reported by Tilki et al. (2005) in Brown Swiss cows whose FTL, RTL, FTD, and RTD during pre- and post-milking times were 59.45, 65.33, 49.72, 55.95, 22.14, 20.47, 21.53 and 20.01, respectively. The difference in teat measurement estimates between the present result and the previous reports may be associated with the breed of an animal and the rearing environment.

Except for the udder circumference at pre- and post-milking times, the genotype of crossbred cows had no significant effect on FUH and RUH. Effects of parity on FUH and RUH at pre- and post-milking were significant ($P < 0.01$). This study showed that the 75% FB crossbred cows had wider udder circumference at pre and post-milking than 50% FB crosses. The observed difference between cows in the two genetic groups could be attributed to their differences in exotic (Friesian) gene inheritance levels. Front and rear udder height and udder circumference measurements increased before and after milking times with increased parties. Discordance to this study, Soeharsono et al. (2020) describing higher front udder (37.81 cm) and rear udder (87.86 cm) circumference measurements for HF cows kept by smallholder farmers. This later study in particular utilized pure HF breed with larger body frame size than animals used in our experiment.

Correlation between linear conformations traits and daily milk yield

Phenotypic correlations between linear conformations traits and daily milk yield are presented in Table 4. The ST, WH, HG, FTL, RTL, FTD, and RTD were positively correlated with the daily milk yield of FB crossbred cows. There was also positive and highly significant ($P<0.01$) association of ST with WH; WH with HG and BL; RL with BL, FUH, and RUH; BL with FUH and RUH; FTL with RTL and RTD; FTD with RTD; FUH with RUH, and UC; RUH with UC. In addition, RL, BL, FUH, RUH, and UC were positively and highly significantly ($P<0.01$) correlated with daily milk yield. These findings were similar to the report of Mingoas et al. (2017) who confirmed that udder size was strong and positively correlated to milk yield in White Fulani and Red Mbororo cows.

Table 4. Phenotypic correlation (r_p) between linear conformation traits and daily milk yield of Friesian X Boran crossbred cows

	ST	WH	HG	RL	BL	FTL	RTL	FTD	RTD	FUH	RUH	UC	DMY
ST	1.00	0.84**	0.48*	0.25	0.51*	0.16	0.10	0.14	0.02	0.20	0.30	0.19	0.23
WH		1.00	0.62**	0.30	0.60**	0.06	0.07	0.06	0.06	0.32	0.44*	0.29	0.31
HG			1.00	0.26	0.47*	-0.24	-0.13	-0.01	-0.13	0.28	0.49*	0.22	0.17
RL				1.00	0.75**	0.25	0.29	0.32	0.27	0.89**	0.57**	0.46*	0.91**
BL					1.00	0.09	0.15	-0.04	-0.12	0.71**	0.59**	0.46*	0.68**
FTL						1.00	0.83**	0.56**	0.37	0.18	0.19	0.21	0.32
RTL							1.00	0.52*	0.41*	0.23	0.20	0.22	0.34
FTD								1.00	0.7**	0.34	0.35	0.30	0.39
RTD									1.00	0.33	0.35	0.32	0.31
FUH										1.00	0.68**	0.66**	0.92**
RUH											1.00	0.67**	0.66**
UC												1.00	0.78**
DMY													1.00

*= Significant ($p<0.05$); **= Highly significant ($p<0.01$); (ST)= stature; WH= wither height; HG= heart girth; RL= rump length; BL= body length; FTL= front teat length; RTL= rear teat length; FTD= front teat diameter; RTD= rear teat diameter; FUH= front udder height; RUH= rear udder height; UC= udder circumference; DMY=daily milk yield. The correlation coefficient of udder conformation traits was based on measurements before milking

This study is also in agreement with Soeharsono et al. (2020) who indicated that there was a significant correlation between BL, FUH, RUH, and UC with daily milk production in Holstein Friesian cows. However, teat measurement traits such as FTL, RTL, FTD, and RTD, did not show a significant association with daily milk yield in this study, which is in agreement with Bello *et al.* (2023), who demonstrated a similar result for White Fulani cows in Nigeria.

Conclusions

This study revealed that measurements on HG, RL, and BW tend to increase with advancing parity (lactation number). 75% FB crossbred cows had longer front and rear teats pre- and post-milking than those 50% FB crosses. 75% FB crossbred cows had wider udder circumferences in pre- and post-milking than 50% FB crosses. RL, BL, FUH, RUH, and UC were positively and highly significantly correlated with daily milk yield and they can be taken as better predictors of milk yield of dairy cows, and accounting for these traits in dairy cattle breeding program aids in achieving additional information on selection for milk production. It can also be recommended that further study should be conducted using pedigree records to estimate genetic parameters on confirmation traits for selection of crossbred dairy cattle for milk production.

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Contribution of Authors

Corresponding Author designed the experiment and coordinated the study, analyzed the data, and drafted the manuscript. **Second Author** supervised the experiment and took part in critically checking this manuscript. All authors read and approved the final manuscript

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Effects of Natural Pasture Hay and Concentrate-Based Total Mixed Ration on the Performance of Jersey Calves

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Abstract

The study aimed to compare the effect of natural pasture hay and concentrate-based total mixed ration (TMR) with separate feeding on dry matter and nutrient intakes, apparent digestibility, feed efficiency, body weight gain and reproductive performances of dairy calves. A total of eighteen post-weaned Jersey calves (age was 6.20 ± 1.61 months, and weighing was 90.4 ± 5.48 kg, mean ± S.D) were randomly assigned into a completely randomized design. Treatments were separate feedings of natural pasture hay and concentrate (T1) and TMR (T2). The feeding trial was carried out for 10.23 months. The calves in T2 group consumed more ($P<0.0$) dry matter (8.71kg vs.7.86 kg), crude protein (1.62 kg vs.1.32 kg), neutral detergent fiber (4.63 kg vs.4.11kg) and acid detergent fiber (3.54 kg vs.3.12 kg) compared to the calves fed T1. The calves in T2 showed higher ($P<0.05$) organic matter, neutral detergent fiber, and acid detergent fiber digestibility compared to the calves fed T1 but similar ($P<0.05$) in dry matter and crude protein digestibility. Calves in T2 group showed superior ($P<0.05$) daily weight gain (600.55 g vs. 335.18 g) and reached their first service at an average weight and age of 263.9 kg and 13.61 months, compared to 199.30 kg and 15.63 months, respectively, for T1 groups. Heifers in T2 required fewer inseminations per conception (1.12 vs. 1.75) and generated lower ($P<0.05$) total cost of production. Thus, the study recommends the TMR over separate feeding for weaned Jersey calves to increase the productive and reproductive efficiency at breeding.

Keywords: daily gain, digestibility, feed intake, *cost of production*

Introduction

In many farms, heifers often experience inadequate daily body weight gain and delayed first calving, exceeding 24 months. However, the primary goal of heifer rearing is to achieve optimal body weight at breeding age and ensure first calving by 24 months (London *et al*. 2012). Dairy heifers and dairy cows fed a balanced ration and maize stover silage based total mixed ration typically exhibit good health and productivity, feed efficiency, daily body weight gain , and with average blood protein levels of 17% and 13%, respectively (Ferlizza *et al*. 2020; Terefe *et al*. 2021b). Selection during separate feeding can significantly influence heifers' feed intake (Borland and Kesler, 1997; Khan *et al*. 2010).

Separate feeding of forage and concentrates often leads to dairy cattle consuming a higher proportion of concentrates, elevating the risk of ruminal acidosis (Maekawa *et al*. 2002). However, research by Coppock *et al*. (1981), Bargo *et al*. (2002), and DeVries (2011) suggests that total mixed ration (TMR) improves rumen conditions by minimizing pH fluctuations and creating a more favourable environment for rumen microbes. Utilizing TMR for dairy cows and heifers ensures a balanced intake of feed and a nutrient by circumventing individual preferences for forage and concentrates, thereby enhancing productivity (Lailer *et al*. 2010; Khan *et al*. 2010; Dejene *et al*. 2017). Maize stover and hay-based TMRs have been found to positively impact the growth and feed intake of Boran-Friesian and Holstein-Friesian dairy calves (Terefe *et al*. 2021c; Cavallini *et al*. 2023). However, despite the confirmed benefits of feeding TMR to dairy calves and heifers, there is limited evidence regarding fiber sources and inclusion levels (Terefe *et al*. 2021a; Toledo *et al*. 2023).

Effective feed management significantly influences dairy cattle performance. However, there has been minimal research conducted on TMR feeding for dairy cattle in Ethiopia, where dairy heifers often exhibit low productivity. Incorporating water and molasses into feed preparation aimed to streamline blending procedures, especially with dry hay and concentrates. This addressed challenges in effectively mixing these components due to dry hay's low moisture content. Adding water and molasses in total mixed ration feed facilitated uniform nutrient distribution and improved palatability, encouraging higher consumption. This approach managed feed consistency, aligned with cost-effective practices, and optimized nutrient delivery, enhancing overall feed quality and livestock nutrition. Therefore, this study hypothesized that TMR would enhance feed intake and digestibility, promote body weight gain, improve feed and economical efficient as well as key reproductive parameters in post-weaned female Jersey calves.

Materials and Methods

Description of the study area

The study was conducted at the Adea Berga dairy farm. The farm is located in the central highlands of Ethiopia at 9^{o} 16’28.85” N latitude and 38^{o} 23’14.59” E longitude, 70 km west of Addis Ababa. It lies at an altitude of 2500 meters above sea level. It is characterized by a cool subtropical climate with a mean annual temperature and rainfall of 18 °C and 1225 mm, respectively.

Experimental feed preparation and management

Natural pasture hay was harvested at 50% blooming stage, following the typical agronomic practice at the farm. The dominant species in the natural pasture hay included *Andropogon virginicus, Pennisetum setacium grasses,* and *Trifolium* *hybridum* legumes. Following harvesting, the natural pasture hay was dried and stored in a ventilated facility.

The concentrate feeds for the preparation of total mixed ration (TMR) were sourced from food processing industries in Addis Ababa city and Mojo town, Ethiopia. These ingredients included wheat bran, cotton seed cake, Noug (*Guizotia abyssinica*) seed cake, urea, molasses, and salt. Various steps were involved in producing the TMR. Initially, the natural pasture hay was chopped into pieces of 3-5 cm. Subsequently, different proportions of wheat bran, cottonseed cake, Noug seed cake, salt, and urea were weighed (dry matter basis) and mixed together (Table 1). Different suggestions are available concerning the optimal water-to-molasses ratio for dilution. The primary focus is to ensure that the resulting solution allows for efficient mixing with hay, chopped materials, raw feeds, and other components (Senthilkumar *et al*. 2016; Dejene *et al*. 2017). Molasses and water (in a ratio of three parts water to one part molasses) were then weighed and thoroughly mixed. This mixture of molasses and water was subsequently sprayed and uniformly mixed with the concentrate and chopped natural pasture. Water and molasses improved feed blending for dry hay and concentrates, ensuring even nutrient distribution and enhancing palatability, boosting consumption. Finally, the TMR was packed into bags which are important to protect moisture lose in TMR and this enables to keep uniformity by compacting concentrate and roughage feeds and then offered to the heifers. For the preparation of 100 kg of TMR, 50% natural pasture hay and 50% concentrate mixture, including urea and salt, was used.

Table 1: Proportions of the natural pasture hay and concentrate feeds for different experimental animals (%, dry matter basis)

	Feeds						
Animals age	NPH	WB	CSC	NSC	M	Urea	Salt
4-6 months	50	14	8	14	11	1	2
6-12 months	50	12	10	12	13	1	2
12-18 months	50	10	10	9	18	1	2

NPH=natural pasture hay, WB=Wheat bran, CSC=Cotton seed cake, NSC=Noug seed cake

Before beginning the experiment, the calves received treatment with a broad-spectrum anti-helminthic (Albendazole 2500 mg), following the manufacturer's guidelines. Dosage for medications in calves is usually determined by their body weight. This approach ensures a more precise dosage, maximizing therapeutic effectiveness while reducing the risk of side effects or inadequate dosing. Calves were housed individually in well-ventilated barns with concrete floors, one-sided walls, and corrugated iron roofs to shield them from rain. The pens were equipped with appropriate drainage systems and gutters. Water was freely available to the calves. A preliminary period of fifteen days was allocated for the calves to acclimatize to the treatment diets. Additionally, the calves were allowed to exercise outside the barn from 8:00 p.m. to 8:30 p.m.

Experimental animal selection, design and treatments

In this study, eighteen post-weaned Jersey female calves (age = 6.20 ± 1.61 months, and weight =90.4 ± 5.48 kg, mean ± S.D, respectively) were selected from the farm and completely randomized design was implemented. The calves were grouped in to two treatment groups containing nine calves in each group based on their body weight. The treatments consisted of two feeding treatments: separate feeding of natural pasture hay and concentrate (T1), and their total mixed ration (T2). The diets were offered and formulated based on the nutritional requirements of post-weaned Jersey calves (NRC, 2001).

Feeding trial

The calves' initial body weights were assessed using a fixed cattle weighing balance at the onset of the experiment and continued throughout the experimental period fortnightly just before providing the morning diet. The feeding trial spanned on 10.23 months. Natural pasture hay for the separate feeding group (T1), and total mixed ration for T2 group calves were provided at 8:00 a.m., 12:00 a.m., and 6:00 p.m., while the daily requirement of concentrate portion for T1 group was divided in to two and administered twice daily at 8:00 a.m. and 6:00 p.m. Feed offer per each dietary treatment was periodically subjected to revision with changes in live body weight. The amount of the feed consumed and refused per each calves was recorded to calculate feed and nutrient intake of the calves throughout the experiment. The average daily body weight gain was computed by dividing the difference between the final and initial live weights of the calves by the total number of feeding trial periods. The feed and protein conversion efficiency of the calves were determined using the

$$\text{Feed conversion efficiency} = \frac{\text{daily body weight gain}}{\text{daily dry matter intake}}; \text{ protein conversion efficiency} = \frac{\text{daily body weight gain}}{\text{daily crude protein intake}}.$$

Apparent digestibility

In this study, a total faecal collection method was employed for each calf. Faecal samples were collected over a period of 7 consecutive days at the end of the experiment. To prevent faecal-urine cross-contamination, farm personnel were assigned to clean the pens by promptly removing fresh faeces and washing the floor with high-pressure tap water dispensed through a plastic hose. Representative faecal samples, comprising 1% of the daily faecal output by weight were collected in the morning prior to offering fresh feed to the animals. These samples were then stored in a deep freezer at -20 °C until they were ready for subsequent laboratory analysis. The apparent digestibility of feed and nutrients was determined using the formula outlined by McDonald *et al*. (2002).

$$\text{Apparent DM/nutrient digestibility (\%)} = \frac{\text{DM/nutrient intake - Faecal DM/nutrient excreted}}{\text{DM/nutrient intake}} * 100$$

Reproductive performances evaluation

The evaluation of key reproductive parameters was conducted with careful attention to detail, employing a comprehensive approach to ensure thorough assessment. Age at first service, representing the pivotal moment when reproductive maturity initiates, was carefully noted. This innovative was complemented by monitoring the weight at the onset of the first oestrus or insemination, as it provides insights into the physiological readiness for breeding.

Furthermore, the age at first conception, a crucial metric indicative of reproductive efficiency, was precisely determined. This parameter sheds light on the ability of the heifers to conceive at an optimal age, thereby influencing overall herd productivity. Additionally, the number of inseminations per conception was scrutinized, offering valuable insights into breeding success rates and efficiency of reproductive management practices. The assessment methodology encompassed a combination of visual observation techniques and rectal palpation, ensuring a comprehensive understanding of reproductive health and performance. Through visual observation, subtle cues such as behavioural changes and physical indicators were noted, providing supplementary information to the palpation findings.

Rectal palpation, a fundamental tool in reproductive assessment, allowed for direct examination of the reproductive tract, enabling the identification of physiological changes indicative of breeding status and pregnancy. Moreover, a rectal examination conducted 60 days post-insemination served as a pivotal checkpoint to confirm pregnancy status and monitor early embryonic development. Following the confirmation of pregnancy, the pregnant heifers were subjected to routine husbandry practices essential for ensuring their well-being and optimizing reproductive outcomes.

Chemical analysis

The total mixed ration and faecal samples were dried in a forced-air oven at 60 ºC for 72 hours. The samples were ground to 1 mm sieve size. All samples of feeds offered, refusals, and faeces were analysed for DM, ash and N according to AOAC (1990). Crude protein content was calculated as Nx6.25. Neutral detergent fiber, acid detergent fiber, and acid detergent lignin was determined using the method developed by Van Soest and Robertson (1985). Additionally, *in vitro* dry matter digestibility of the feed was assessed using the two-stage procedure outlined by Tilley and Terry (1963). The metabolizable energy (ME) content of the feeds was estimated from *in vitro* organic matter digestibility (IVOMD) using the equation described by McDonald *et al*. (2002), where ME (MJ/kgDM) = 0.16× IVOMD.

Cost-benefit analysis

Cost-benefit assessments were conducted by calculating the expenses, including feed costs (concentrate and native pasture hay), labour, initial animal costs, and other incurred expenses. This was compared with revenues generated from manure and lives animal sales over the course of the entire experiment. Market prices for concentrate, native pasture hay, and all other components were obtained from prevailing market rates in Holeta, Ethiopia.

The cost-benefit analysis aimed to determine the total production cost per heifer per day. The benefit-cost ratios were calculated using the following formulas:

NM=TR-TC......................... (1)
Where, NM = Net Margin; TR= Total Return; TC = Total Cost;
TC=TVC+TFC.. (2)
Where, TVC = Total Variable Cost, TFC = Total Fixed Cost

The following variables were calculated, where;

A) Gross margin (GM) is the difference between the total revenue earned and the total variable cost incurred, GM = TR-TVC.
B). Variable cost (VC) is the cost that varies with changes in output; it is a function of output level. The variable cost includes transportation, labour cost and cost of live cattle
C) Fixed Cost is the cost that does not vary with respect to output (tools and equipment).
D) Total cost is the total expenditure for the farm including addition of both variable and fixed costs TC= TFC+TVC.
E) Total revenue (TR) is the total income realized on output produced that is, quantity sold multiplied by price per unit.
F). Net Revenue is the difference between the total revenue and the total cost.
G). Cost-benefit cost ratio (BCR) is the total revenue divided by the total cost, BCR=TR/TC. When BCR is greater than 1, the business is profitable (Sarma *et al.* 2014).

Statistical analysis

The data was subjected to analysis using a single factor ANOVA using the SAS procedure (SAS, 2002). The Tukey mean separation test at the 5% level of significance was used. The following statistical model was used for the analysis.

$Y_{ij} = \mu + X_i + E_{ij}$,

Where,

Y_{ij} = is the response variable, μ = over all mean, X_i = the treatment effect and E_{ij} = random error.

Results and Discussion

Chemical composition of feeds

The chemical composition of the experimental feeds is presented in Table 2. Molasses and natural pasture hay exhibited lower crude protein (CP) contents compared to Noug seed cake and wheat bran. Natural pasture hay has numerically higher neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents than other feeds and it has numerically lowest *in vitro* dry matter digestibility (IVOMD) and metabolizable energy (ME). Conversely, wheat bran demonstrated higher IVOMD and ME compared to other feeds. The crude protein (CP) level of natural pasture hay ranged from 4.5% to 6%, consistent with reports by Getu *et al*. (2012), Dawit *et al*. (2013), Dereje *et al*. (2017), and Terefe *et al*. (2021a). However, an earlier report by Tesfaye (2017) indicated a higher CP value (8%) in natural pasture hay, possibly influenced by agronomic practices and environmental factors. Comparable levels of acid detergent fiber (ADF) and ME were reported by Seyoum *et al*. (2007) and Getu *et al*. (2012) for natural pasture hay. The concentration of CP in molasses in our study aligns with Dawit *et al*. (2013), who reported a CP value of 3–4%. However, our findings contrast with previous research by Sani *et al*. (2016), which indicated a lower CP value (2%) in molasses. This disparity could be attributed to variations in molasses sources, processing methods, or analytical techniques employed between studies. The neutral detergent fiber (NDF) and *in vitro* organic matter digestibility (IVOMD) values of wheat bran observed in the current study are comparable with previous findings by Fekede *et al*. (2015), Ajebu *et al*. (2016), Dereje *et al*. (2017), and Terefe *et al*. (2021a).However, in the current study, higher dry matter (DM) and ash contents of wheat bran were observed compared to previous reports by Getu *et al*. (2012), Dawit *et al*. (2013), and Terefe *et al*. (2021b). Similarly, cotton seed cake (CSC) exhibited higher DM, ADF, and NDF contents compared to values reported by Dereje *et al*. (2017) and Terefe *et al*. (2021b). These differences could be attributed to variations in the sources of wheat bran and cotton seed cake, differences in processing techniques, or variations in the regions where the samples were obtained from. However, Geberemariyam *et al*. (2024) reported lower IVOMD and ME values in CSC. Additionally, Kasahun *et al*. (2012) and Ajebu *et al*. (2016) reported lower dry matter (DM), ash, and crude protein (CP) values in Noug seed cake compared to the current findings. This discrepancy suggests potential variability in the composition of Noug seed cake across different studies. Several factors could contribute to this variation, including differences in the geographical origin of the Noug seeds, variations in soil composition and environmental conditions affecting seed growth, differences in processing methods utilized to extract the seed cake, and variations in analytical techniques employed for nutrient analysis. Moreover, differences in the genetic makeup of the Noug plant varieties used for seed production could also influence the nutrient composition of the resulting seed cake. Thus, the observed differences underscore the importance of considering multiple factors when interpreting and comparing research findings across studies. Earlier studies have reported comparable proportions of DM and CP in the total mixed ration (TMR) which is consistent with the current finding (Shiriyan *et al*. 2011; Muhammad *et al*. 2012; Raja *et al*. 2013). However, Lailer *et al*. (2010), Pachauri *et al*. (2010), and Arto *et al*. (2014) reported lower fiber fractions in TMR, which could be attributed to variations in feed types and proportions used in TMR preparation.

Table 2: Experimental feed chemical composition

Heifers age		Hay	WB	CSC	NSC	M	Urea	Salt	TMRO	TMRR
4-6 Months	DM	93.5	92.1	94.2	93.2	74.5	-	-	92.1	89.9
	Ash	8.2	6.8	5.6	11.5	5.1	-	-	9.2	10
	CP	5.2	17	24	36.8	5	247	0	15.8	14.9
	NDF	65.6	49.6	42.7	37.8	-	-	-	46.6	63.2
	ADF	45.6	26.7	24.9	27.7	-	-	-	32.8	37.8
	ADL	9.4	3.9	6.3	4.4	-	-	-	6.5	7.2
	IVOMD	47.5	78.3	62.9	70.2	-	-		62.3	55.2
	ME	7.6	12.5	10.1	11.2	-	-	-	9.97	8.83
6-12 months	DM	94	93	93.5	92.9	75	-		93	91
	Ash	7.9	7.2	6.5	10.5	6	-	-	8.2	7.5
	CP	4.3	15	22	33	3	247	0	13	11.7
	NDF	54.3	50.6	39.6	39.4	-	-	-	45.2	52.1
	ADF	33.6	28	25	29.8	-	-	-	36.5	32.3
	ADL	8.7	3.5	5.7	4.1	-	-	-	5.5	6.4
	IVOMD	47.1	74.3	61.8	70.4	-	-	-	62.4	53.8
	ME	7.5	11.9	9.9	11.3	-	-	-	9.96	8.6
12-18 months	DM	93	93	92.1	92.9	74.8	-	-	88.9	90.2
	Ash	8	6.9	7	9.7	6	-	-	9.8	7.2
	CP	5.1	16.2	22.2	32.6	3.6	247	0	12.2	10.1
	NDF	61.3	47.8	41.7	34.8	-	-	-	52.3	48.7
	ADF	39.2	28.4	22	30.2	-	-	-	40.1	39.1
	ADL	10	4	6.2	5	-	-	-	4.4	5.7
	IVOMD	45.2	75	63	69.8	-	-	-	60.8	47.3
	ME	7.3	12	10.1		-	-	-	9.72	7.56

Except dry matter (DM), all values are represented on DM basis, CP=Crude protein;, NDF= Nutrient detergent fiber; ADF=Acid detergent fiber; ADL=Acid detergent lignin; IVOMD= Invitro organic matter digestibility; ME=Metabolizable energy; WB=Wheat bran; CSC=Cotton seed cake; NSC=Noug seed cake; M=molasses, TMRO =offered total mixed ration, TMRR=Refusal total mixed ration

Dry matter and nutrient intake

The dry matter and nutrient intake data are presented in Table 3. In the total mixed ration group (T2), intake levels of dry matter, organic matter, crude protein, and fiber fractions were notably higher ($P<0.05$) compared to separate feeding (T1). However, there was a significantly higher rate of feed refusal ($P<0.01$) in T1 compared to T2. The observed enhanced dry matter and crude protein intake in dairy calves fed on total mixed ration (TMR) is in line with the report by Shiriyan *et al*. (2011), DeVries and Gill (2012), and Dejene *et al*. (2017). However, the current result contradict those of Jalil *et al*. (2017) and Naik *et al.* (2009), who found no significant difference in feed consumption between TMR and separate feeding systems. According to observations by Miller and DeVries (2009), Maekawa *et al*. (2002), and Felton *et al*. (2010), the addition of water to TMR can deter intake and contribute to increased feed refusal in TMR. Restricting TMR availability to five hours per day altered the eating and rumination behaviours of lactating dairy cows, with *ad libitum* hay significantly affecting dry matter intake patterns, as noted by Heinrichs *et al*. (2021).

Table 3: Feed and nutrient intake in the experimental heifers

Intake (kg/calf/day)	T1	T2	SEM	SL
TDM	7.86	8.71	0.21	*
OM	7.36	8.32	0.13	*
CP	1.35	1.62	0.06	*
NDF	4.11	4.63	0.15	**
ADF	3.12	3.54	0.07	*
Refusal	2.05	1.32	0.40	**

.*=p<0.05; **= p<0.01, DM=Dry matter, TDMI= Total dry matter, CP= Crude protein, OM= Organic matter, NDF=Neutral detergent fiber, ADF=Acid detergent fiber, T1=Separate feeding; T2= Total mixed ration, SEM=Standard error of mean and SL=Significance level

Feed DM and nutrient digestibility

The apparent digestibility values for dry matter, organic matter, acid detergent fiber, neutral detergent fiber, and crude protein is presented in Table 4. Heifers fed total mixed ration (T2) showed significantly higher (P<0.05) digestibility of organic matter, neutral detergent fiber, and acid detergent fiber compared to heifers fed natural pasture hay and concentrate mixture separately (T1).The current finding is consistent with previous studies by Hundal *et al*. (2004), Khan *et al*. (2010), Raja *et al*. (2013), Jalil *et al*. (2017) and Terefe *et al*. (2021b) who reported that total mixed ration (TMR) has a significant effect on the nutrient digestibility in dairy cows, calves, and buffalo. However, there was no significant difference (P>0.05) in dry matter and crude protein digestibility between T1 and T2. However, studies by Bargo *et al*. (2002) and Dey *et al.* (2022) reported no significant variation in dry matter and crude protein digestibility between total mixed ration (TMR) and separate feeding in dairy cattle. Thorough mixing in a TMR promotes uniform microbial colonization, enhancing microbial action in the rumen and facilitating breakdown and fermentation of fibrous materials. Additionally, it maximizes surface area for enzymatic and microbial activity, enhancing access to substrates in NDF and ADF. Synergistic effects in a TMR promote efficient fiber digestion, aided by readily fermentable carbohydrates from concentrate.

Table 4: Apparent dry matter and nutrient digestibility in the heifers fed with total mixed ration and separate feeding

Parameters (%)	T1	T2	SEM	SL
DM	67.18	64.42	2.11	NS
OM	70.67	73.67	3.1	*
CP	73.64	71.99	2.16	NS
NDF	63.99	68.78	1.7	**
ADF	60.74	65.08	1.65	**

*p<0.05; ** p<0.01; NS= Non significance; DM=Dry matter, CP= Crude protein, OM= Organic matter, NDF=Neutral detergent fiber, ADF=Acid detergent fiber, T1=Separate feeding; T2= total mixed ration, SEM =standard error of mean, and SL=significance level

Daily weight gain and feed conversion efficiency

Heifers fed total mixed rations (TMR) (T2) demonstrated significantly higher (P<0.01) average daily weight gain, feed conversion efficiency, and protein conversion efficiency compared to those on separate feeding (T1). Throughout the growth period, heifers in T2 group exhibited greater weight gain than those on T1. The feed conversion efficiency of heifers in T2 was also significantly higher (P<0.001) than in T1 (Table 5). Calves on a TMR-based diet experienced enhanced daily weight gain due to higher nutrient intake and digestibility. Despite the absence of a significant difference (P > 0.05) in dry matter and crude protein digestibility between T1 and T2, the elevated daily body weight gain observed in TMR feed (T2) can be attributed to several factors. Firstly, the higher crude protein intake in T2 groups may have contributed to improved growth rates, as protein is essential for muscle development and overall growth. Additionally, enhanced digestibility of energy source nutrients such as acid detergent fiber (ADF) and neutral detergent fiber (NDF) in the diets could have provided a more efficient energy supply, supporting increased body weight gain. A higher intake and improved utilization of these fibrous components may have facilitated better rumen function and microbial activity, leading to enhanced nutrient absorption and utilization for growth. This finding is supported by Cavallini *et al*. (2023), who reported that higher daily body weight gain (618 g/day) in calves on a natural pasture based total TMR. Additionally, our results align with those of Nissanka *et al*. (2010), O'Neill *et al*. (2011), Shiriyan *et al*. (2011), and Cavallini *et al*. (2023), indicating that TMR positively impacts growth rate, rumen development, and nutrient intake balance in dairy calves and heifers. Similarly, Iqbal *et al*. (2019) and Terefe *et al*. (2021a) reported as dairy calves fed on a TMR diet improved daily body weight gain and feed efficiency. Offering TMR *ad libitum* to Holstein calves resulted in robust growth levels without compromising health effect (Spina *et al*. 2023) but Mitchell et al. (2020) stated that the transition of component feeds to TMR resulted in higher hay consumption, consequently lowering the intake of starter and overall dry matter. This, in turn, led to diminished weight gain and structural development. The observed greater feed and protein conversion efficiency in the case of TMR diet is consistent with findings of DeVries (2011), Muhammad *et al*. (2012), and Dejene *et al*. (2017).

Table 5: Feed efficiency and daily body weight gain of heifers under total mixed ration and separate feeding

Growth Parameters	T1	T2	SEM	SL
Initial live weights	90.4	90.4	0.0	NS
Final live weight(kg)	199.3	263.9	5.45	*
Mean of live weight gain(kg)	108.9	173.50	4.24	**
Average daily body weight gain(gram)	335.18	600.55	44.23	***
Feed conversion efficiency(DBWG:DDMI)	0.04	0.07	0.01	***
Protein conversion efficiency (DBWG:DCPI)	0.25	0.37	0.01	**

*=p<0.05; ** =p<0.01, ***=p<0.001; NS= Non significance, SL=significance level; T1=Separate feeding; T2= total mixed ration, DBWG=Daily body weight gain, DCPI=Daily crude protein intake, DDMY=Daily dry matter intake, SEM =standard error of mean and kg=kilogram

Reproductive performance

Heifers provided with a total mixed ration (TMR) (T2) showed significantly higher (p<0.001) weight at first service compared to heifers raised on separate feeding of natural pasture and concentrate (T1). Moreover, heifers in T2 group had shorter (P<0.01) ages at first service and first conception than those in T1. Additionally, heifers under T2 groups required fewer services per conception compared to T1 (Table 6). This result aligns with earlier studies by Coppock *et al*. (1981), Hamed *et al*. (2011), and Soren *et al*. (2013), which demonstrated that total mixed ration (TMR) is highly effective in enhancing nutrient consumption and improving reproductive and productive performance in dairy heifers. Feeding concentrate and fodder separately, as highlighted by Maekawa *et al*. (2002), increases the risk of ruminal acidosis due to inadequate nutrient supply, negatively impacting dairy cattle's reproductive and productive capabilities, and making them more susceptible to disease. Previous research by Muller *et al*. (2011), Hamed *et al*. (2011), and Siatka *et al*. (2017) also supports the positive effects of TMR on service per conception, age at first service and first conception in dairy heifers and cows. However, contrary findings were reported by Muller and Botha (2013), who found no effect of either TMR or separate feeding on inseminations per conception in dairy cows.

Table 6: Reproductive performance of heifers' fed total mixed ration and natural pasture hay and concentrate separately.

Parameters	T1	T2	SEM	SL
Weight at first service (kg)	199.3	263.9	10.48	***
Age at first service (months)	15.63	13.61	0.55	**
Age at first conception (months)	17.03	15.83	0.65	***
Number of services per conception	1.75	1.12	0.29	**

** =p<0.01; ***=p<0.001, SL=Significance level; SEM =Standard error of mean, kg=kilogram; T1=Separate feeding; T2= Total mixed ration

Partial budget analysis

The cost-benefit analysis of separate feeding and total mixed-ration feeding is presented in Table 7. In the total mixed ration (T2), significantly higher ($P<0.05$) total fixed cost, total revenue, gross margin, net margin, and marginal rate of return were observed compared to separate feeding (T1). Conversely, total variable cost was higher ($P<0.05$) in T1 than in T2. Total mixed ration (TMR) feeding showed a lower total cost of production for the calves. Similarly, previous studies by Soder and Rotz, (2003), Yi Zheng, (2013), and Soren *et al*. (2013) have highlighted that heifers and dairy cows fed a TMR can reduce production costs by enhancing daily feed conversion efficiency and generating higher profits. Research by Iqbal *et al*. (2019) demonstrated that feeding pelleted TMR containing 15% oat hay could reduce weaning age by five days and feed cost per unit gain by 14% without compromising growth performance and feed efficiency in crossbred calves under heat stress conditions. Similarly, Jahani-Moghadam *et al*. (2015) found that including alfalfa hay (10%) in the TMR diet could reduce the cost of production for Holstein calves

Table 7: Cost-benefit analysis of the heifers' fed total mixed ration and natural pasture hay and concentrate feed separately.

Variable cost ($)	T1	T2
Initial cost of calf	55.56	55.56
Feed cost	412.42	320.96
Labour (Transport &house cleaning)	33.83	33.82
Medication/Veterinary cost	5.33	3.11
Ropes	0.44	0.44
Plastics	0.22	0.89
Miscellaneous	11.11	11.11
TVC ($)	518.93	425.91
Total fixed cost ($)		
Local Chopper (Pole)	0.00	4.44
Feed trough	2.22	2.22
Water trough	2.22	2.22
Bucket/ '*joneya*'	1.33	1.33
Spade	1.11	1.11
Rakes	2.22	2.22
TFC ($)	9.11	13.56
TC=TVC+TFC	528.05	439.47
Return ($)		
Manure/ Dung Selling	58.00	63.22
Selling price of heifer after the experiment	560.67	623.89
TR ($)	618.67	687.12
GM	99.74	261.21
NM	90.62	247.65
MRR or CBR (TR:TC)	1.17	1.56

CBR= Cost-benefit; TVC=Total variable cost; TFC=Total fixed cost; GM=Gross margin; NM=Net margin; TR=Total revenue; TC=Total cost and MRR=Marginal rate of return, T1=Separate feeding; T2= Total mixed ration.

Conclusions

Feeding heifers a total mixed ration led to elevated dry matter intake, enhanced nutrient digestibility, improved feed efficiency, and increased weight gain. Consequently, employing a total mixed-ration feeding approach proves profitable and holds practical significance for dairy farming. However, additional research is warranted to thoroughly understand its long-term impacts on the health and reproductive performances of dairy heifers.

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Author Contributions

Geberemariyam Terefe and Getu Kitaw: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools, or data; Wrote and edit the paper. Ajebu Nurfeta, Getnet Assefa, Mesfin Dejene, and Mulugeta Walelegne: Analysed and interpreted the data; Contributed materials, analysis tools; Wrote and review the paper.

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Effects of Lime and NPSB Fertilizer Rates on Yield Attributes and Yield of Wheat, and Soil Properties in Harbagona District of Sidama Region, Ethiopia

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Abstract

Wheat is a crucial global cereal crop, particularly vital for Ethiopian highlanders. However, its production is often influenced by various environmental factors, notably soil acidity. This field experiment was carried out in Harbagona, Sidama Region of Ethiopia, during the main cropping season of 2022, aimed to evaluate the effects of combined lime and NPSB fertilizer applications on wheat yield and soil properties. The experiment was designed in a randomized complete block with ten factorial combinations involving five rates of NPSB fertilizer (0, 50, 100, 150, and 200 kg ha^{-1}) and two lime levels (with and without) replicated thrice. Results showed that combining lime with NPSB fertilizer significantly increased wheat grain and biomass yields, with the highest yields achieved at 150 kg ha^{-1} NPSB application rate. Furthermore, the integrated application of lime and NPSB improved soil pH, reduced exchangeable acidity, and increased cation exchange capacity, thereby enhanced nutrient availability. Economic analysis revealed that lime integrated with 100 kg ha^{-1} NPSB fertilizer provided the highest net benefit and marginal rate of return. Additionally, lime application extended days to heading, but accelerated days to maturity, while NPSB fertilization reduced both heading and maturity durations. Moreover, the combined application of lime and NPSB fertilizer enhanced various yield attributes of wheat, including tiller count, plant height, spike length, seed weight, and harvest index. In conclusion, the application of 100–150 kg ha^{-1} NPSB fertilizer combined with lime not only enhanced soil properties, but also optimized yield and economic benefits. These findings emphasize the importance of nutrient management and soil amelioration practices in optimizing wheat yield and soil health in acidic soil conditions.

Keywords: lime application, NPSB fertilizer, Soil acidity, Wheat, yield attributes and yield

Introduction

For nearly one-third of the world's population, wheat (*Triticum aestivum* L.) stands as a vital staple food source (Cakmak, 2009). With an estimated 2.1 million hacultivated under both rain-fed and irrigated systems, Ethiopia emerges as the second-largest producer of wheat in sub-Saharan Africa(Hei, Shimelis, & Laing, 2017). In comparison to the genetic potential of wheat varieties released by the research system, the national average wheat productivity, recorded at 3.1 t ha^{-1}, is notably very low (Agegnehu et al., 2021). Contributing factors to low yield include the use of unimproved cultivars, inadequate weed control techniques, the prevalence of aggressive crop diseases, depletion of soil minerals, limited chemical fertilizers usage, and the absence of contemporary crop management practices.(Belachew, Maina, Dersseh, Zeleke, & Stoddard, 2022)

The degradation of soil quality is hastened by diverse factors such as soil types, geography, climatic conditions, and land use patterns, resulting in wheat yields falling below the potential of more than 6.0 t ha^{-1}. Numerous studies including Klink (2014) highlight the role of improper land use in exacerbating the deterioration of soil properties, including physical, chemical, and biological aspects. Land use profoundly impacts essential processes such as erosion, soil structure, nutrient cycling, leaching, carbon sequestration, and other related physical and biological processes (Tully et al., 2015).

Soil acidity poses a significant challenge to achieving profitable and sustainable agricultural productivity across various regions worldwide. This issue is exacerbated by a growing trend in soil acidity and exchangeable aluminum in both arable and abandoned lands, largely attributed to intensive agricultural practices and persistent application of inorganic fertilizers, which contribute to acidification (Behera & Shukla, 2015). The complexity of soil acidity stems from a combination of factors, including nutrient/element toxicities, insufficient activity of beneficial microorganisms, and restricted plant root growth, thereby limiting nutrient and water absorption (Agegnehu & Amede, 2017).

The predominant soil factor influencing plant development, crop productivity, and profitability is the soil pH, a concern prevalent across regions with sufficient precipitation to leach exchangeable bases from the soil surface (Yirga, Erkossa, & Agegnehu, 2019). Numerous studies have shown that soil pH levels below 5.5, exacerbated by high levels of aluminum and manganese and deficiencies in essential nutrients such as phosphorus, nitrogen, and sulfur, significantly impede crop growth(Havlin, 2020).

Liming stands as a widely adopted and effective practice for boosting crop productivity in acidic soils while enhancing their physical, chemical, and biological attributes (Zingore, Mutegi, Agesa, Tamene, & Kihara, 2015). The acidic nature of the soil contributes to low yields of main cereal crops, notably wheat, often reaching as low as 0.5 Mg ha^{-1}. Studies indicate a tripling of yields upon ameliorating soil pH through lime, nitrogen, and phosphorus additions (Dereje, Tamene, & Anbesa, 2019). When coupled with other advantageous agricultural methodologies or inputs, lime application exhibits significant yield improvements. Yield enhancements ranging from 34% to over 252% have been documented in wheat, barley, and tef under moderate to severe acidic soil conditions(Desalegn, Alemu, Adella, & Debele, 2017), 111–182% in maize (Opala, Odendo, & Muyekho, 2018), and 45–103% in Mucunain Kenya (Agba et al., 2017). To realize substantial yield increments, the combined application of nitrogen and phosphorus, and fertilizers with lime and other improved management techniques is recommended.

This research was conducted to assess the effectiveness of lime application, in combination with nitrogen and phosphorus containing fertilizers, in mitigating soil acidity and augmenting wheat productivity. By targeting soil acidity, a pivotal factor influencing soil pH levels and nutrient accessibility, the study aims to overcome a significant obstacle to wheat production. The primary objective of this study was to comprehensively dissect the multifaceted challenges impeding wheat productivity in the study area, with a specific emphasis on soil acidity and its consequences on wheat yield. Additionally, this work endeavored to uncover the promise of lime application, in tandem with nitrogen and phosphorus containing fertilizers, as a feasible approach for mitigating soil acidity and increasing wheat yields. By scrutinizing results obtained from field experiments, the aim was to evaluate the effectiveness of combined applications of lime with NPSB and urea fertilizers in enhancing soil quality, nutrient availability, and ultimately, wheat productivity.

Materials and Methods

Description of study site

This study was conducted in Harbagona district, southern Ethiopia, during the main cropping season of 2022. The geographical coordinates of the study site are06°26'59" N latitude and 38°27'44" E longitudes, situated at an altitude of 2648 meters above sea level. Harbagona experiences a sub-humid climate characterized by a bi-modal pattern of rainfall, with a mean annual precipitation ranging from 1000 to 1300 mm. The major rainy season lasts from June to September, typical of the highland regions in Ethiopian agro-ecological categorization. The main cereal crops produced in the area include wheat and barley. The prevailing soil type of the study area is Nitiosls (IUSS Working Group WRB, 2014).

Treatments and experimental design

The experiment was designed in a randomized complete block (RCB) with three replications. The experiment evaluated ten factorial combinations involving two lime levels (with and without)with five NPSB fertilizers levels (0, 50, 100, 150, and 200 kgha^{-1}).The experimental field was prepared using a native plough (Maresha), and plots were randomly assigned within the layout according to the experimental design specifications. Each plot measured 1.6 m in length and 1.5 m in breadth, totaling2.4 m^2. The full doses of NPSB fertilizers, as per the treatment setup, were applied in rows as a basal placement immediately before sowing. The wheat seeds were manually drilled with in a row spaced at 0.20 m intervals between each row, encompassing all eight rows of wheat that were sown. Urea was applied at the recommended rate of 100 kg ha^{-1}, 45 days after the sowing.

According to Nelson and Su (2010), the exchangeable acidity of the soil (Al^{3+}+ H^{1+}) was used as the basis to determine the required amount of lime as shown in equation

$$LR, CaCO_3 (kg\ ha^{-1}) = \frac{EA * 0.15\ m * 10^4 m^2 * BD * 1000}{2000}$$

Where:

LR is the lime requirement in kg ha^{-1}

EA is the exchangeable acidity of the soil in $cmolekg^{-1}$

BD is the bulk density of the soil Mgm^3

The lime requirement (LR) was calculated based on the acidity level of the experimental field, which exceeded the critical level for wheat production. Thus, employing equation 1, the total amount of lime required to neutralize the acidity of the experimental soil was found to be 4.8 t ha^{-1}.High-grade agricultural limes ($CaCO_3$) with a neutralizing value of 98% was utilized. A month before the sowing of wheat, lime was evenly distributed by hand across plots based on the treatments setup, and thoroughly incorporated into the soil using oxen plows. All other agronomic practices, including weeding, cultivation, and pest control, were carried out in accordance to the established guidelines for wheat production in Ethiopia.

Data collection

Soil physico-chemical properties

Initial composite surface soil samples were collected from five randomly selected locations diagonally across the experimental field using an auger sampler at a depth of 0–20 cm, aiming to characterize the soil. Subsequently, these collected soil samples were combined to create one composite sample. Furthermore, post-harvest soil samples were also collected from the 20 treatment-based locations within the experimental field to assess the impact of treatment application on soil properties. The collected soil samples were air-dried and ground using a mortar and pestle, then sieved through a 2 mm mesh. The prepared soil samples were analyzed to organic carbon (OC), total nitrogen (N), pH, available phosphorous (P), exchangeable acidity, cation exchange capacity (CEC), calcium and magnesium in Hawassa University of Agriculture College. Particle size distribution was determined using the hydrometric Bouyoucos method, following the accepted approach. The available soil P was determined following the procedure set by (Olsen, 1954). Soil pH was measured using a glass electrode connected to a digital pH meter, with a soil-to-water dilution ratio of 1:2.5. Total N was determined using Kjeldahl method (Bremner, 1961). OC content of the soil was determined through wet chemistry, following the procedure outlined in the

Walkley method (Walkley, A., Black, I. A. 1931.), exchangeable acidity was determined with buffer pH method (Mehlich, 1976). Cation exchange capacity was determined with ammonium acetate method (Schollenberger & Simon, 1945) and calcium and magnesium was determined with simple titrimetric method (El Mahi, Ibrahim, Abdel Magid, & Eltilib, 1987).

Phonological data

The days to emergence were determined by counting the number of days between sowing and the point when 50% of the plants displayed visible emergence. Similarly, the days to heading were calculated based on visual observation by calculating the duration from seeding to the moment the plants attained heading stage. Additionally, the days to maturity were assessed through ocular observation, marking the interval from sowing to the plant's full maturity. Senescence of the leaves and the ability to threshing grain from the glumes by pressing them in between the forefinger and thumb were relied upon as indicator of physiological maturity.

Growth and yield attributes data

At physiological maturity, the height of each plant from the ground surface up to the tip of the panicle was measured for ten randomly chosen plants from each plot. The spike length was determined by averaging measurements taken from five randomly chosen plants per plot, measuring the distance between the node where the first spike branches appear and the spike's tip. The number of seed per spike was calculated by averaging three chosen spikes from each plot. The number of tillers per square meter was determined by placing a 1 m^2 quadrant in the center of each plot, and tallying the total number of tillers within the designated area. Just before harvest, five randomly selected ears from each plot were selected, and kernel number per spike was measured.

To determine the total above-ground biomass yield, harvesting was conducted from three central rows to minimize border effects. The harvested samples were air-dried and weighed using a digital balance. Manual threshing was performed to separate seeds from straw, followed by cleaning and measurement for grain yield determination. Both the above-ground total biomass yield and grain yield were converted to tons per hectare for statistical analysis. Prior to statistical analysis, grain yield was adjusted to a standard moisture content of 12.5%.Harvest index was calculated by dividing grain yield by the total above-ground air-dry biomass yield. Grains were carefully counted and weighed using a digital balance to determine the weight of 1000 seeds.

Data analysis

The data collected were subjected to an analysis of variance (ANOVA) using SAS software version 9.0 as described by (Littell, Stroup, & Freund, 2002). Means separation was performed following the guidelines by (Gomez & Gomez, 1984) using the least significant difference (LSD) test at either a 5% or 1% probability level depending upon the results of the ANOVA.

Economic analysis

The partial budget analysis was conducted according to the procedure outlined in (Alimi, 2000) to evaluate the economic viability of the tested treatments. Total variable costs (TVC) in this study comprised expenses for procuring NPSB and urea fertilizers, as well as lime, and labor costs for lime application at the experimental site. Lime and fertilizers application labor costs were computed based on the required number of days, expressed in Ethiopian Birr (ETB).Urea and NPSB fertilizers were priced at 13.38 and 12.30 ETB kg^{-1}, respectively, while lime and its application cost amounted to 12,500.00 ETB kg^{-1}.Total benefits (TB) considered the revenue generated by the farmer, calculated by multiplying the farm gate selling price of wheat grain by the total harvested yield. The farm gate price of wheat grain stood at 17.25 ETB kg^{-1}.The net benefit was determined by subtracting the TVC from the TB. Grain yields obtained in this study was downscaled by 10% to represent the actual harvestable yield according to local farming practices. Treatments were then arranged based on their increasing TVC. Treatments with marginal costs exceeding marginal benefits were excluded from further analysis as they were deemed dominated. The acceptable marginal rate of return (MRR) considered in this study was equal to or greater than 100%.

Results and Discussion

Physico-chemical properties of the experimental soil before sowing

The initial characteristics of the experimental soil are presented in Table 1. The soil texture revealed that the experimental area primarily consisted of clay-based soil, with composition of31% sand, 32% silt, and 37% clay, indicative of a clay loam texture. These textural characteristics influence various soil properties such as water holding capacity, aeration, and root penetration. The initial pH of the soil was measured at 4.47, indicating a very strong acidic soil reaction according to (Chimdi, 2015).The cation exchange capacity (CEC) of the soil was determined to be 19.76 cmol $_{(+)}$ kg^{-1}, categorizing it as medium fertility soil based on Landon's classification(Landon, 2014). The organic carbon (OC) and total nitrogen (N) contents of the experimental soil, measured at 2.36% and 0.14% respectively, indicate medium statuses for both OC and total N content according to Murphy (1968) classification. The soil also exhibited a very low level of available phosphorus (P; 3.53 mg kg^{-1}) according to (Olsen, 1954)Olsen et al. (1954) classification (Table 1).

Table 1: Selected physico-chemical properties of the experimental site soil before sowing

Soil properties	Unit	Value
Sand	%	31
Silt	%	32
Clay	%	37
Texture class		Clay loam
Soil reaction (pH)		4.47
Organic carbon	%	2.36
Total nitrogen	%	0.14
Available phosphorous	mg kg^{-1}	3.53
Boron	mg kg^{-1}	0.46
Cationexchange capacity	$Cmole_{(+)}$ kg^{-1}	19.76
Exchangeable acidy	$Cmole_{(+)}$ kg^{-1}	0.91
Calcium	$Cmole_{(+)}$ kg^{-1}	1.54
Magnesium	$Cmole_{(+)}$ kg^{-1}	2.24
Potassium	$Cmole_{(+)}$ kg^{-1}	1.91
Bulk density	g cm^{-3}	1.14

Effects of lime combined with NPSB fertilizer on selected soil properties

The results indicated that the combined application of lime and NPSB fertilizer significantly improved the chemical properties of the soil, as evidenced in Table 2.The combined application of lime with NPSB fertilizer notably raised the pH levels of the experimental soil from 4.48 (without lime or other external inputs) to 4.76, 4.79, 4.82, 4.81, and 4.65 with increasing doses of NPSB (ranging from 50 to 200 kg ha^{-1}), indicating a pH increment of 0.14–0.29 units. Additionally, this combined treatment effectively reduced the exchangeable acidity of the soil from 0.93 $cmo_{l(+)}$ kg^{-1} to 0.65, 0.51, 0.47, 0.57, and 0.62 $cmol_{(+)}$ kg^{-1} with corresponding NPSB doses, showcasing a reduction of 0.09–0.28 $cmol_{(+)}$ kg^{-1} (Table 2).

The rise in pH and subsequent decline in exchangeable acidity resulted in an enhanced CEC of the soil and increased availability of P, Ca, and Mg as outlined in Table 2. The combined application of lime and NPSB fertilizer increased the CEC and available P levels from 21.55 cmol (+) kg^{-1} and 3.51 mg kg^{-1} (without lime and other external inputs) to 22.2–24.63 cmol(+) kg^{-1} and 9.5–10.5 mg kg^{-1}, respectively, across the range of NPSB doses. These changes represented increments of 0.64–2.37 cmol (+) kg^{-1} and 5.09–6.1 mg kg^{-1} due to the effects of the combined treatment. Furthermore, the integration of lime with NPSB fertilizer led to a notable increase of 0.05–5.44 cmol(+) kg^{-1} in Ca content and 0.07–0.36 cmol(+) kg^{-1} in Mg content of the soil. The results also indicated a rise in total nitrogen (N) content from negligible levels to 0.02%, accompanied by a reduction in soil OC content ranging from 0.51% to 0.089% (Table 2).

The incorporation of lime to acidic soil exerts a neutralizing effect, which is responsible for these changes in soil chemical properties, a phenomenon well-documented by (Yang, Mitchell, & Howe, 2018). This process elevates the soil pH while concurrently reducing its exchangeable acidity, as evidenced in our study. The reduction in exchangeable acidity can be attributed to the enhanced displacement of Al^{3+} ions by Ca^{2+} ions at exchange sites, leading to the subsequent precipitation of Al^{3+} as $Al(OH)_3$ upon liming (Alemu, Selassie, & Yitaferu, 2022). Moreover, the increase in soil pH prompts the precipitation of exchangeable and soluble Al^{3+} ions as insoluble Al hydroxides, thereby diminishing the concentration of Al^{3+} in the soil solution. This pH adjustment facilitates the release of phosphate ions previously complexed with Al^{3+} and Fe^{2+} ions, rendering P more accessible for plant uptake (Ghosh & Devi, 2019). By encouraging the mineralization of soil organic phosphorus, liming can raise the availability of phosphate (Dereje et al., 2019). The shift in pH and the release of the variable charged minerals and functional groups within humus compounds by Ca^{2+}ions likely underlie the observed rise in CEC following liming. This elevation in CEC stems from the augmented availability of negative charges on mineral surfaces. Consistent with our findings, (Frank, Zimmermann, & Horn, 2020) reported similar changes in soil CEC up on application of 3.75 t ha^{-1}, preceding the sowing of common beans by 60 days.

Similarly, in agreement with our results, (Mkhonza, Buthelezi-Dube, & Muchaonyerwa, 2020)observed heightened total N levels upon treating acidic soils with lime. Moreover, applications of N and P fertilizers resulted in higher N contents in both light and heavy fractions compared to unbalanced applications, particularly in barley production on acidic soils (Hameso, Worku, & Ayalew, 2022).The decline in OC contents of the experimental soil after harvest may be attributed to soil tillage, which enhances aeration, thereby, stimulating microbial activity and accelerating the decomposition rate of soil OC(Kibet, Blanco-Canqui, & Jasa, 2016).

Table 2: Effects of lime combined with various rates of NPSB fertilizer on selected chemical properties of acidic soils of Harbagona

Lime	NPSB rate (kg ha^{-1})	pH	OC%	TN%	Av. P (mg kg^{-1})	CEC ($cmol_{(+)}$ kg^{-1})	EA ($cmol_{(+)}$ kg^{-1})	Ca ($cmol_{(+)}$ kg^{-1})	Mg ($cmol_{(+)}$ kg^{-1})
Without	0	4.48	2.37	0.13	3.51	21.55	0.93	1.57	2.37
	50	4.51	2.36	0.16	3.62	22.43	0.78	1.61	2.53
	100	4.53	2.37	0.19	4.46	23.15	0.56	1.68	2.57
	150	4.52	2.35	0.18	4.46	23.63	0.67	1.65	2.55
	200	4.51	2.36	0.16	4.42	22.56	0.83	1.62	2.52
With lime	0	4.76	1.86	0.14	9.49	22.19	0.65	6.55	2.73
	50	4.79	1.57	0.18	9.56	24.66	0.51	6.68	2.82
	100	4.82	1.48	0.21	10.54	25.52	0.47	7.12	2.86
	150	4.81	1.51	0.18	10.56	25.17	0.57	7.08	2.83
	200	4.65	1.53	0.16	9.51	24.63	0.62	1.67	2.59

The effects of lime and NPSB fertilizer on phenology of wheat

The effects of lime on phenology of wheat

The application of lime and NPSB fertilizer had a significant ($p < 0.0001$) influence on both the days to heading and maturity. Nevertheless, the interaction effects between lime and NPSB fertilizer applications did not prove to be statistically significant, as illustrated in Table 3.The application of lime resulted in an extension of the days to heading, with a mean value of 73 compared to 71 in the unlimed treatments. Conversely, liming the soil accelerated the days to maturity, with a mean value of 116 compared to 118 in the treatment without lime, as depicted in Table 3.

Our findings indicated the profound impact of acidic soils amendment using lime on wheat phenology and growth, as demonstrated in Table 3. The application of lime mitigated the detrimental effects of soil acidity, leading to improved wheat performance. Specifically, lime-treated crops generally attained physiological maturity earlier compared to untreated plots. These results align with previous findings suggesting that wheat's vegetative growth is hindered in the presence of aluminum in nutrient solutions (Asresach, 2021). Acidic soils often contain high levels of aluminum, which can be toxic to plants and inhibit root development. Lime neutralizes soil acidity, reduces the availability of toxic aluminum ions and allows roots to function more effectively. As a result, plants may reach maturity sooner due to improved nutrient uptake and healthier root systems (Asresach, 2021). Lime application also raises the pH of acidic soils, making essential nutrients more available to plants. This enhanced nutrient availability can promote faster growth and development, leading to earlier maturity. Overall, lime application to acidic soils can positively influence various factors contributing to plant growth and development, ultimately resulting in faster days to maturity.

The effects of NPSB on phenology of wheat

Our results also revealed a notable trend where the days to heading and maturity decreased as the rates of NPSB increased, as illustrated in Table 3. The longest periods to heading (75 days) and maturity (120 days) were observed in the treatment with no NPSB input. As the NPSB rate increased to 50, 100, 150, and 200 kg ha^{-1} the days to heading decreased by 3, 4, 4, and 5 days, respectively. Similarly, except for the 200 kg ha^{-1} NPSB treatment, the same trend was observed for the days to maturity. This may be increased N prolongs the vegetative growth period, delays maturity(Anas et al., 2020). With NPSB rates of 50, 100, and 150 kg ha^{-1}, the days to maturity decreased by 6, 11, and 16 days, respectively, as depicted in Table 3. The unusually longer period required for maturity with the 200 kg ha^{-1} NPSB treatment could not be justified.

The application of various rates of NPSB greatly impacted wheat phenology, likely due to balanced nutrition and the physiological actions of N and P.N promotes vegetative growth, but delays maturity, whereas P hastens maturity. This balance is reflected in our findings and supported by (Abdeta, Tulu, & Berecha, 2022) and (Dugassa, Belete, & Shimbir, 2019), who noted that NPSB applications accelerated heading and maturity by enhancing nutrient availability and photosynthesis. NPSB provides readily available N and P, stimulating photosynthesis and carbohydrate production, which fuels growth and development. Adequate nutrient availability reduces stress on plants, such as nutrient deficiencies, soil acidity, and aluminum toxicity, enabling efficient progression through growth stages. In summary, NPSB applications promote faster heading and maturity by ensuring nutrient availability, reducing stress, enhancing photosynthesis, and improving overall plant health. Hameso et al. 2022.

Table 3: Effects of lime and NPSB fertilizer treatments on days to heading and physiological maturity under acidic soil condition

Treatments	Day to heading (No)	Day to maturity (No)
	Lime	
Without lime	70.8[b]	118.3[b]
With lime	72.7[a]	116.3[a]
LSD	1.36	1.67
	NPSB (kg ha^{-1})	
0	74.7[a]	119.8[a]
50	72.0[b]	113.5[b]
100	71.2[bc]	108.8[c]
150	71.2[bc]	103.8[d]
200	69.8[bc]	114.3[b]
CV (%)	**2.48**	**1.94**
LSD (0.05)	**2.16**	**2.64**

Notes: Means within a column followed by the same letter are not significantly different at 5% probability level

The effects of lime and NPSB fertilizer on yield attributes of wheat

The effects of lime on yield attributes of wheat

The analysis of variance revealed that the applications of lime and NPSB fertilizer significantly ($p < 0.0001$) impacted all measured yield attributes of wheat, including tiller count, plant height, spike length, seeds per spike, seed weight, and harvest index. However, the results indicated that the interaction effects between lime and NPSB fertilizer were not significant for any of the measured variables (Table 4).

Applications of NPSB fertilizer at various rates notably enhanced the yield attributes of wheat as described in Table 4. The highest rate of NPSB fertilizer application, at 200 kg ha^{-1}, yielded the maximum total tillers plant^{-1} (5.9), effective tillers plant^{-1} (5.6), plant height (78.8 cm), spike length (8.5 cm), grains spike^{-1}

(49.8), seed weight (63.5 mg), and harvest index (40.8%; Table 4). Similarly, applying 150 kg ha^{-1} of NPSB fertilizer resulted in comparable total tillers plant^{-1} (5.9), effective tillers plant^{-1} (5.5), plant height (77.8 cm), spike length (8.5 cm), grains spike^{-1} (49.8), seed weight (63.3 mg), and harvest index (38.1%). Moreover, statistically equivalent effective tillers plant^{-1} (5.2), spike length (8.2 cm), grains spike^{-1} (47.4), seed weight (62.8 mg), and harvest index (39%) were observed with the application of 100 kg ha^{-1} of NPSB fertilizer (Table 4).

The improved yield attributes observed with the addition of lime can be attributed to changes in soil properties subsequent to lime application. As described in Table 3 and corroborated by the findings of (Ejigu, Selassie, & Elias, 2023),lime application, led to the neutralization of soil acidity, resulting in an increase of soil pH and reductions in exchangeable acidity and exchangeable Al^{3+}.These changes fostered enhanced soil fertility and created favorable conditions for agricultural production, thereby supporting increased yield attributes such as tillers, plant height and spike length.

Consistent with our findings, (Wubayehu, 2021)similarly documented that the application of lime significantly influenced the quantity of productive tillers plant^{-1}. Moreover, (Victoria, Ping, Yang, & Eneji, 2019) noted a significant impact of nitrogen and lime application on plant height throughout the growth stages, with the tallest plants observed when lime and N were applied at a rate of 180 kg N ha^{-1}. In accordance with our findings, (Dabesa & Tana, 2021) reported that lime application at a rate of 3.12 t ha^{-1}resulted in a significantly higher harvest index (41%) of soybean compared to no lime application (39%).This outcome may be attributed to the role of lime in neutralizing soil acidity, which in turn enhancing the availability of P. This increased phosphorus availability is crucial for initiating flowering and seed formation, thus contributing to the observed improvement in harvest index (Dabesa and Tana, 2021).(Victoria et al., 2019) further emphasized that in addition to raising soil pH and mitigating acidity's adverse effects on crop performance, the combined application of NPS fertilizer along with lime amendment plays a significant role in enhancing the availability of applied P. Likewise, according to (Megersa, 2022), the largest mean plant height, spike length, number of seeds plant^{-1}, biomass production, and thousand seed weight showed a progressive increase with higher quantities of lime application. This suggests that lime application positively influences various aspects of plant growth and development, ultimately contributing to improved crop productivity. In agreement to our current findings, (Y. Tesfaye, Alemu, Asefa, Teshome, & Chimdesa, 2020) and (Hameso, Worku, & Ayalew, 2021) also observed that barley genotypes treated with the recommended NPSB and NPS rates produced more effective tillers on average per square meter compared to NP, with no significant differences between the two. They further noted that effective tillers were strongly influenced by the application of P. Similarly, (Ameyu & Asfaw, 2020) found that the plant height of soybeans significantly increased with combined application of lime and phosphorus to the soil. In line with our results, (Tilahun Abera, Lemma, Hundesa, Husen, & Firomsa, 2021)stated that spike length increased as the rates of both NPS and N increased from zero to the highest levels. They reported that the highest and lowest spike lengths were measured in response to combined applications of 100 kg NPS ha^{-1} with 92 kg N ha^{-1} and control treatments, respectively. In line with our results, (Kuma Megersa, 2019) also reported the largest number of grains per bread wheat spike (50.6) in acidic soil conditions with the In agreement to our current findings, (Y. Tesfaye et al., 2020) and (Hameso et al., 2021)also observed combined applications of NPS fertilizers at a rate of 150 $kgha^{-1}$ with 50 $kgha^{-1}$KCl, while the lowest number of grains per spike (16.33) was observed in the unfertilized treatments.

Additionally, (Mamo & Erkeno, 2022) reported the maximum kernel count per spike (76.78) with the application of blended fertilizers. Our results further corroborated with the findings of (Ishete & Tana, 2019), who noted a significant difference in the thousand kernel weight between the control mean and the NPS-treated mean in their study on durum wheat. The harvest index represents the coefficient of efficacy between the aboveground biomass yield to grain yield ratio. The balance between the plant's productive portion and its reserve, which together make up the economic yield, is represented by the harvest index. Greater photo assimilate production and its subsequent partitioning into grain yield may be responsible for the increase in harvest index with higher rates of NPSB fertilizer. In accordance with our current result, Tagesse and Adinew(Tagesse Abera & Adinew, 2020) reported the highest value of harvest index (43.96%) with the application of 200 kg NPS ha^{-1}.

Table 4. The integrated effects of lime and NPSB fertilizer on yield attributes and harvest index of wheat under acidic soil condition

Treatments	Total tillers (No)	Effective tillers (No)	Plant height (cm)	Spike length (cm)	Seeds spike^{-1} (No)	Seed weight (mg)	Harvest index (%)
Lime							
Without lime	4.2^{b}	3.6^{b}	65.1^{b}	6.9^{b}	41.1^{b}	58.1^{b}	35.3^{b}
With lime	5.7^{a}	5.5^{a}	74.4^{a}	8.0^{a}	47.9^{a}	62.9^{a}	36.5^{a}
LSD	0.24	0.26	3.79	0.29	3.54	0.61	0.01
NPSB rates (kg ha^{-1})							
0	3.2^{d}	2.8^{c}	53.3^{c}	5.2^{c}	33.7^{c}	53.9^{c}	28.7^{c}
50	4.3^{c}	3.7^{b}	67.5^{b}	6.8^{b}	41.7^{b}	58.9^{b}	32.9^{b}
100	5.5^{b}	5.2^{a}	71.4^{b}	8.2^{a}	47.4^{a}	62.8^{a}	39.0^{a}
150	5.9^{a}	5.5^{a}	77.8^{a}	8.5^{a}	49.8^{a}	63.3^{a}	38.1^{a}
200	5.9^{a}	5.6^{a}	78.8^{a}	8.5^{a}	49.8^{a}	63.5^{a}	40.8^{a}
CV	**6.46**	**7.64**	**7.08**	**5.13**	**10.38**	**1.31**	**20.69**
LSD	**0.38**	**0.42**	**5.99**	**0.46**	**5.6**	**0.96**	**0.9**

The combined effects of lime and NPSB fertilizer on yield of wheat

The analysis of variance showed a significant (p<0.001) difference in grain and biomass yields due to the interaction between lime and NPSB fertilizer rates (Table 5).Combining lime with NPSB fertilizers increased wheat grain and biomass yields. Combined applications of lime and NPSB fertilizer at a rate of 150 kg ha^{-1} resulted in the highest grain (5.38 t ha^{-1}) and biomass (14.72 t ha^{-1}) yields of wheat. Likewise, combining lime with 200 kg ha^{-1}NPSB and 100 kg ha^{-1}NPSB also yielded comparable grain (5.36 and 5.35 t ha^{-1}, respectively) and biomass (14.57 and 14.44 t ha^{-1}, respectively) yields (Table 5). Furthermore, statistically equivalent grain yields were attained with the application of 200 kg ha^{-1}NPSB (4.11 t ha^{-1}) and 150 kg ha^{-1}NPSB (3.78 t ha^{-1}) without lime. However, the biomass yields at these rates without lime were significantly lower compared to the same rates with lime, underscoring the positive impact of lime in ameliorating soil acidity and consequently enhancing yield. Reducing the NPSB rates to 50 and 100 kg ha^{-1}, with or without lime, resulted in significantly lower grain and biomass yields compared to higher NPSB fertilizer rates (Table 5). The lowest grain yields were observed with the treatments receiving no inputs, whether without lime (0.99 t ha^{-1}) or with lime (1.31 t ha^{-1}), which were statistically indistinguishable from each other. Similarly, the lowest biomass yields were also observed in the treatments without inputs, whether without lime (3.91 t ha^{-1}) or with lime (4.12 t ha^{-1}; Table 5). Overall, the results highlighted that the application of lime with any level of NPSB led to higher grain and biomass yields compared to the same rates without lime (Table 5). For instance, the application of lime with 150 kg ha^{-1}NPSB resulted in 42% and 54% increases in grain and biomass yields, respectively, compared to the same rate without lime. This underscores the beneficial effects of lime in enhancing nutrient availability, improving soil health, and boosting wheat yield (Table 5).

The comparable wheat yield obtained with higher NPSB rates at 150 and 200 kg ha^{-1} without lime may be attributed to the surplus availability P and N for plant nutrition, surpassing soil fixation capacities. The rapid dissolution of N and P from the NPSB fertilizer in the soil yields readily absorbable phosphate and ammonium for plants. Consequently, the application of higher NPSB rates at 150 and 200 kg ha^{-1} enhances soil P levels, facilitating nutrient uptake and root growth, thereby ultimately enhancing grain and biomass yields. In agreement to our findings, (Ejigu, Selassie, Elias, & Molla, 2023) reported that applying 150 kg ha^{-1}NPSB without lime and 200 kg ha^{-1}NPSB without lime equivalently enhanced grain yield compared to applying 200 kg ha^{-1}NPSB with lime, 150 kg ha^{-1}NPSB with lime, and 100 kg ha^{-1}NPSB with lime. The inclusion of N, P, and S in blends at higher rates appears to have improved the yield without significant deviation from the results observed in limed treatments. Similar results were also found when comparing the mean grain yield of wheat across different NPS rates. The maximum grain yield of wheat (7.28 tha^{-1}) was recorded from a balanced application, whereas the control treatment yielded lower grain yield (2.24 tha^{-1}) (Jemal, Ahmad, & Hassen, 2022). The significant increase in grain and total biomass observed with combined applications of lime with 100, 150, or 200 kg ha^{-1}NPBS, compared to the 50kg ha^{-1}NPSB and control treatment, may be attributed to the significant increase in yield components such as the number of effective tillers, spike length, number of seeds per spike, and grain weight. Our findings, indicating increased wheat yield with the combined application of lime and NPSB fertilizers, align closely with the previous studies reported in the literature. Specifically, our results are consistent with those of (Ejigu, Selassie, Elias, et al., 2023), who demonstrated that adding 2 t ha^{-1} lime to acidic soil treatments resulted in a 24.2 t when compared to the control. Our findings are also consistent with those of (Ejigu, Selassie, Elias, et al., 2023),who reported that increasing lime application rates significantly enhanced wheat growth and yield characteristics compared to unlimed plots. Additionally, (T. Tesfaye, Laekemariam, & Habte, 2021)also observed similar trends, reporting that as the rates of NPS and KCl application rose from 0 to 50 kg ha^{-1} and 0 to 150 kg ha^{-1}, the total above-ground biomass yield of wheat demonstrated an increase of 49% and 279%, respectively.

Table 5. The integrated effects of lime and NPSB fertilizer on grain and above-ground biomass yields of wheat under acidic soil condition

Treatments	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})
No input with no lime	0.99^{c}	3.91^{d}
No input with lime	1.31^{c}	4.12^{d}
50 kg NPSB ha^{-1} with no lime	1.39^{c}	5.22^{cd}
50 kg NPSB ha^{-1} with lime	2.52^{bc}	6.32^{c}
100 kg NPSB ha^{-1} with no lime	3.58^{b}	8.77^{b}
100 kg NPSB ha^{-1} with lime	5.35^{a}	14.44^{a}
150 kg NPSB ha^{-1} with no lime	3.78^{ab}	9.53^{b}
150 kg NPSB ha^{-1} with lime	5.38^{a}	14.72^{a}
200 kg NPSB ha^{-1} with no lime	4.11^{ab}	9.19^{b}
200 kg NPSB ha^{-1} with lime	5.36^{a}	14.57^{a}
CV (%)	12.78	11.03
LSD (0.05)	1.59	1.67

Note: Means within a column followed by the same letter are not significantly different at 5% probability level

Effects of lime and NPSB fertilizer on economic benefits of wheat production

The results of the partial budget analyses for the combined use of lime with various rates of NPSB fertilizers are presented in Tables 6.The combined applications of lime with 100 kg ha^{-1} NPSB fertilizer yielded the highest net benefit of 75,494.50 ETB ha^{-1}, accompanied by an impressive marginal rate of return (MRR) of 7838%, as demonstrated in Table 6. This suggests that farmers could potentially earn 7,838.00 ETB ha^{-1} for each unit of investment on lime and NPSB fertilizer. Similarly, employing lime integrated with 150 kg ha^{-1} NPSB or 200 kg ha^{-1} NPSB also resulted in substantial net benefits of 75,397.00 and 74,437.00 ETB ha^{-1}, respectively. However, despite these higher returns, the marginal benefit of these treatments was outweighed by their marginal costs, rendering them less feasible options for farmers.

In contrast, the application of 100 kg ha^{-1} NPSB without lime still generated a considerable net benefit of 57,462.00 ETB ha^{-1}, with appreciable MRR of 6043%. Likewise, employing 50 kg ha^{-1} NPSB with or without lime yielded net benefits of 27,292.00 and 20,299.50 ETB ha^{-1}, respectively, with corresponding MRRs of 3294% and 1022%. Furthermore, the application of 200 kg ha^{-1} NPSB and 150 kg ha^{-1} NPSB without lime also resulted in net benefits of 65,374.50 and ETB ha^{-1}, respectively, accompanied by MRRs of 826% and 461%, respectively (Table 6).

Our findings demonstrate the economic viability of combining lime with NPSB fertilizers, especially at a rate of 100 kgha^{-1} for wheat production barley in the acidic soils of Harbagona. This application package yielded the highest net benefit and a significant MRR. While higher doses of NPSB in conjunction with lime exhibited significant net gains, they were constrained by escalating marginal costs. Applying NPSB without lime still resulted in considerable net benefits, highlighting the importance of appropriate fertilization approach. These findings emphasize the need to consider both economic and agronomic factors in fertilizer management decisions in agriculture.

Table 6. Economic evaluation for testing the feasibility of combined application of lime and NPSB fertilizer for enhancing wheat production in the acidic soils of Harbagona

Treatments	Adjusted grain yield (t ha^{-1})	Adjusted straw yield (t ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefits (ETB ha^{-1})	Marginal rate of return (%)
100 kg ha^{-1} NPSB with lime	4.82	13.00	15,068.00	75,494.50	7838
150 kg ha^{-1} NPSB with lime	4.84	13.25	15,683.00	75,397.00	-
200 kg ha^{-1} NPSB with lime	4.82	13.11	16,298.00	74,437.00	-
200 kg ha^{-1} NPSB without lime	3.70	8.27	3,798.00	65,374.50	826
150 kg ha^{-1} NPSB without lime	3.40	8.58	3,183.00	60,297.00	461
100 kg ha^{-1} NPSB without lime	3.22	7.89	2,568.00	57,462.00	6043
50 kg ha^{-1} NPSB with lime	2.27	5.69	14,453.00	27,292.00	3294
50 kg ha^{-1} NPSB with no lime	1.25	4.70	1,953.00	20,299.50	1022
0 NPSB with no lime	0.89	3.52	1,338.00	14,014.50	-
0 kg ha^{-1} NPSB with lime	1.18	3.71	13,838.00	7,034.50	-

Conclusions

Our findings from this study underscore the significant positive impact of integrating lime with NPSB fertilizers on enhancing grain and biomass yields, soil health, and economic returns for farmers. Our results underscore the pivotal role of lime in ameliorating soil acidity, thereby improving nutrient availability and fostering optimal conditions for crop growth. The synergistic effect of lime with varying levels of NPSB fertilizer demonstrated remarkable improvements in grain and biomass yields, with the highest yields achieved at a combined application rate of 150 kg ha^{-1} NPSB fertilizer and lime. Notably, the beneficial effects of lime were evident across all levels of NPSB application, emphasizing its role in ameliorating soil acidity and enhancing nutrient availability. This synergy was further highlighted by the notable improvements in soil pH, reduced exchangeable acidity, and enhanced cation exchange capacity and nutrient availability, particularly phosphorus, calcium, and magnesium by the combined treatment. Economic analysis revealed substantial net benefits and impressive marginal rates of return, particularly with the application of 100 kg ha^{-1} NPSB fertilizer integrated with lime, indicating its viability and profitability for farmers. Furthermore, the application of lime contributed to the improvement of various yield attributes of wheat including tiller count, plant height, spike length, seeds per spike, seed weight, and harvest index, emphasizing its role in optimizing crop development and quality. These findings underscore the importance of nutrient management and soil amelioration strategies in maximizing wheat productivity. Overall, our study highlights the importance of combined application of lime and NPSB fertilizer, in addressing soil acidity issues, enhancing nutrient availability, and ultimately maximizing wheat yield and farmer profitability. These findings offer valuable insights for sustainable agricultural practices aimed at ensuring food security and livelihood improvement in farming communities.

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Availability of data and materials

The data used to support the findings of this study are available from the author upon request.

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Evaluation of Productive and Reproductive Performances of Gumuz, Felata and Agew Goat Breeds in Metekel Zone, Benishangul Gumuz Ethiopia

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Abstract

Goat production is one of the key practices of livestock farming mainly in the lowland of the country. This study was undertaken to evaluate the production and reproduction potential of the Agew, Felata and Gumuz goat breeds in Metekel zone of Benishangul-Gumuz Regional State. Thirty goats from each of the three breeds making a total flock size of 90 were purchased from the local markets and kept on-station under uniform management conditions for performance evaluation during the period of 2016 to 2022. The appropriate flock management and health care were employed throughout the study period. Growth and reproductive performance data were collected for six consecutive years and the data were subjected to analysis using the General Linear Model Procedures of the Statistical Analysis System (SAS). Average birth weights recorded for Felata, Gumuz and Agew were 2.22±0.03, 2.01±0.02 and 2.03±0.02kg, respectively. Breed, birth year, season of birth, birth type, and sex had significant effect (P<0.001) on birth weight of kids. The overall least square means of birth weights of single, twins and triplets were 2.18±0.02, 2.01±0.02, and 1.78±0.05 kg, respectively. Breed, birth year, and season had significant effect on litter size of goats. The highest average weaning weight was attained by Felata goats (7.38±0.25 kg) and the lowest being for Agew goats (6.27±0.13 kg). The average yearling weight reached at 18.01±0.57 kg for Felata goats, 17.01±0.32 kg for Gumuz goats and 16.77±0.31 kg for Agew goats. The average age at first service for Felata, Gumuz, and Agew goats were 258.36±3.82, 231.05±2.11 and 240.20±2.70 days respectively. Similarly, the average age at first kidding was 413.84±10.63 days for Felata, 378.89±7.04 kg for Gumuz and 394.47±7.44 days for Agew goats. Thus, it can be concluded that under the same management condition in most performance parameters of Gumuz goat breeds was higher than Agew and Felata Goats. Therefore, Gumuz goats should be improved by establishing a community-based breeding program.

Keywords*:* Gumuz goat, Felata goat, Agew goat, body weight, reproductive performance

Introduction

Ethiopia has about 52.2 million goats (CSA, 2021), and they play an important role in sustaining the livelihoods of resource poor farmers (Solomon et al., 2014). Ethiopia is endowed with varied ecological zones and possesses diverse goat genetic resources. Research studies that evaluate the performance of goats, such as their growth and prolificacy, are typically carried out on farms that have different management conditions. However, to obtain accurate results, these traits should be measured under similar management conditions on a research station. In the Metekel zone, goats have a considerable impact on the livelihoods of households as they serve as a source of income and are used in festivals. On average, each household in the area owns 11.37 goats.

Indigenous goats make valuable socioeconomic contributions especially to the poor in the rural areas. They are important sources of meat, milk, manure, skin, and satisfy various cultural and religious functions (Tesfaye, 2004; Aziz, 2010). The importance of this valuable genetic resource is, however, underestimated and the contribution to the livelihood of the poor is inadequately understood (Kosgey and Okeyo, 2007; Aziz, 2010).

In Ethiopia, there are 14 different goat breeds that are characterized using their physical features and some have been reasonably documented (FARM-Africa, 1996). According to Getinet (2001), in the Benishangul Gumuz region, five goat breeds were identified based on the multivariate analytical technique and farmers' identification criteria, namely the Arab, Gumuz, Felata, Agew, and Oromo of which two of them are found to be dominant (Arab and Gumuz). The three goat breeds namely Agew, Gumuz and Felata are thought to be abundant in Metekel. However; the on-station performance of these goat breeds has not been studied under similar management conditions. It is, therefore important to evaluate the production and reproduction potential of the Agaw, Felata, and Gumuz goat breeds at on-station and to point out future strategies for further exploitation of the breeds.

Materials and Methods

Description of the study area

The experiment was conducted at Pawe Agricultural Research Centre (PARC), Metekel Zone, Benishangul Gumuz Region, and Ethiopia from 2016 to 2022. PARC is located at a latitude of 11° 19’ North and a longitude of 36° 24’ East at an altitude of 1120 m above sea level. It is found 572 km west of Addis Ababa. The mean minimum and maximum temperatures of the study area are 17.2 and

32.8 °C, respectively. The mean annual rainfall is 1574.7 mm with the main wet season from June to September, which can sometimes extend to November (National Meteorology Agency weather data base, 2009-2019).

Animal management

On-station performance evaluation study was carried out on goats of three breeds viz. Felata, Agew and Gumuz for a period of 6 successive years from 2016 to 2022. A total of 90 goats were purchased from the nearby local markets with each breed represented by 30 goats. All goats were vaccinated for common disease occurred in the area and treated against internal parasites, drenched and ear tag was given. Natural mating system was practiced and herding was based on breed groups. The buck was herded together at daytime and isolated at night, while one male assigned to 25 does. A raised bed housing type was used to for avoid the contamination of urine and faeces. The flocks were allowed to graze outdoor at on-station for 5 h a day and they had free access to drinking water. Pregnant does at late gestation and lactating does in early lactation were supplemented with concentrate mixture prepared from maize and soybean grain. All the other flocks were also supplemented with concentrate mixture on return from grazing. Newly born kids were kept together with their does during the first 3-5 days of parturition. Following these days of duration they were isolated and allowed to suckle three times per day in the morning, midday, and evening until weaning age (3month). After weaning, all the kids were kept together with the flock. Routine culling was practiced in the flocks for different culling reasons.

Felata Gumuz Agew

Figure1. Three goat breeds

Data collection

Data collection were made growth data like birth weight (BW), weaning weight (WW) at 90 days, six month weight (SMW), and yearling weight (YW). Reproductive data like age at first service (the number of days counted when the female goat showed the first sign of heat in her life for received male), age at first kidding (the age at which a doe gives birth for the first time: It can be explained as a function of first pubertal age, age at first mating and conception, and successful completeness of pregnancy), kidding interval (number of days counted the time interval between successive parturitions of the same doe), litter size (the number of kids per birth) and gestation length (the period of time a foetus develops inside the womb before birth).

Statistical analysis

The data on growth and reproductive performances were analysed using general linear model procedures of the Statistical Analysis System (SAS. 1999). The effect of fixed factors considered in the model on growth and reproductive traits were analysed. The least-squares mean separation was done using Duncan's multiple range tests.

The following model was used for statistical analysis

$$Y_{ijklmn} = \mu + B_i + Y_j + S_k + S_l + LS_m + eijklmn$$

Where: Y_{ijklmn} = the response variable

μ = Overall mean

B_i = Effect of the ith breed type

Y_j = Effect of the jth year of birth

S_k = Effect of the kth season of birth

S_l = Effect of the lth sex

LS_m = Effect of the mth birth type

e_{ijklmn} = Residual error

Results and Discussion

Birth season

Kidding has taken place across all the three seasons (dry, short rain, and main rain). The majority of the kidding seemed to occur in dry season for Felata goats, in main rain season for Gumuz goats and in short rain season for Agew goats (Table 1). The lowest number of kids recorded at short rain season in Felata and Gumuz goats, while dry and main rain season for Agew goat breed. High number of kidding is likely the result of adequate feed resources, and minimum environmental stress. The lower kidding percentage recorded during the main rain season for Felata and Agew breeds could be due to the presence of high rainfall that might affect duration of grazing period.

Table 1: Proportion of kids born from each breed across seasons

Birth Season	Felata		Gumuz		Agew		Overall	
	N	%	N	%	N	%	N	%
Dry	68	47.88	113	32.10	109	29.38	290	32.77
Short rain	36	25.35	99	28.12	153	41.24	288	32.54
Main rain	38	26.76	140	39.77	109	29.38	287	32.43
Total	142	100	352	100	371	100	885	100

N=number of record, Dry=October-January, Short rain=February-May, Main rain= June-September

Birth type

All the three breeds of goats have given multiple births although varied in birth rate (Table 2). Twining ability of Agew and Gumuz goats appeared to be higher relative to the Felata breed particularly in triple birth. This showed that Gumuz and Agew goat breeds are promising breeds to be considered in goat improvement program.

Table 2: Twining ability of Felata, Gumuz and Agew goat breeds

Birth type	Felata		Gumuz		Agew	
	N	%	N	%	N	%
Single	63	44.37	127	36.1	119	32.07
Twins	76	53.52	200	56.82	226	60.91
Triplets	3	2.11	25	7.1	26	7.01
Total	142	100	352	100	371	100

Growth performance

Birth weight

The overall least squares mean birth weight of goats was 2.05±0.01kg (Table 3). The birth weight of Felata goats was significantly higher than that of Gumuz and Agew goats. This could perhaps be associated with birth type where the Felata goats gave more single birth that had heavier birth weight. Breed, birth year, season of birth, birth type, and sex had shown significant effect ($p<0.01$) on birth weight of kids. Kids born in main rain and dry seasons exhibited heavier birth weight. The overall least squares mean birth weights (BW) of single, twin, and triple birth type were 2.18±0.02, 2.01±0.02 and 1.78±0.05 kg, respectively. At birth males kids were significantly ($p<0.05$) than females regardless of breed type. Our present finding is in agreement with the previous reports Netsanet et al., (2016) describing the weight of kids at birth were 2.03kg for Woyto-Guji.

Weaning weight

The average weaning weight for Felata, Gumuz, and Agew goat breeds were 7.38±0.25, 6.52±0.12, and 6.27±0.13kg respectively (Table 3).). The effect of breed, birth year, and birth type was significant ($P<0.01$) on weaning weight while season of birth and sex did not affect weaning weight of kids. This is in agreement with Bedhane et al., (2013) and Derbie and Taye, (2013) who reported that the early stage of growth performance of kids is largely influenced by genotype and the milk yield of the does. The higher weaning weight was recorded in Felata and Gumuz breeds, whereas the lower weaning weight was recorded in Agew breeds. On the other hand the current result on weaning weight was slightly lower than that reported by Temesgen et al. (2019) describing the weights of kids at three months were 7.44, 10.96 and 9.38 kg for Abergelle, Central Highland and Woyto-Guji breeds of goats, respectively.

Six Month and Yearling Body Weight

Birth year, and sex had significant effect ($p<0.001$) on the six-month and yearling body weight of goats whereas birth type affected only six-month weight (Table 3). Body weight of male kids increased from 6.6 kg at weaning to 17.6 kg at yearling age while the female kids reached to 16.5 kg of yearling weight from similar weaning weight of 6.4 kg (Table 3). The effect of birth type on body weight of kids lasted only until six months of age in this experiment. However, kids of single birth continued to have higher body weight even after six months of age though not statistically significant. Goats born in the year 2017 had higher YW while lower YW was observed in 2020 this variation could be attributed to differences feed resource availability over the year.

Table 3: Least squares mean and standard error of growth trait measurements for Felata, Gumuz and Agew goat breeds

Classes	N	LS	N	BW(kg) LSM±SE	N	WW(kg) LSM±SE	N	SMW(kg) LSM±SE	N	YW(kg) LSM±SE
Overall	865	1.71±0.02	864	2.05±0.01	330	6.51±0.08	237	10.38±0.12	131	17.03±0.21
Breed										
Felata	142	1.58^{b}±0.05	141	2.22^{a}±0.03	38	7.38^{a}±0.25	21	11.51±0.40	17	18.01±0.57
Gumuz	352	1.71^{ab}±0.03	352	2.01^{b}±0.02	150	6.52^{a}±0.12	111	10.13±0.17	56	17.01±0.32
Agew	371	1.75^{a}±0.03	371	2.03^{b}±0.02	142	6.27^{b}±0.13	105	10.43±0.18	58	16.77±0.31
p-value		<0.005		<.0003		0.0027		0.0555		0.1036
Birth year										
2017	60	1.73^{a}±0.07	60	2.12^{ab}±0.05	5	6.98^{ab}±0.68	4	10.50^{ab}±0.91	3	18.67^{a}±1.37
2018	188	1.7^{a}±0.04	188	2.23^{a}±0.03	76	7.63^{a}±0.17	70	11.55^{a}±0.22	53	17.94^{ab}±0.33
2019	232	1.78^{a}±0.04	232	2.05^{bc}±0.03	88	6.32^{ab}±0.16	45	9.98^{ab}±0.27	3	17.33^{bc}±1.37
2020	218	1.67^{b}±0.04	218	1.98^{c}±0.03	121	5.98^{b}±0.14	94	9.88^{ab}±0.19	72	16.29^{c}±0.28
2021	167	1.62^{b}±0.04	166	1.94^{c}±0.03	40	6.36^{ab}±0.24	24	9.69^{b}±0.37	-	-
p-value		0.0424		<.0001		<.0001		<.0001		0.0025
Season										
Dry	290	1.77^{a}±0.03	289	2.12^{a}±0.02	113	6.6±0.14	83	9.93±0.20	36	16.57±0.39
Short rain	288	1.72^{ab}±0.03	288	1.91^{b}±0.02	132	6.58±0.13	89	10.82±0.19	58	16.93±0.31
Main rain	287	1.63^{b}±0.03	287	2.14^{a}±0.02	85	6.83±0.16	65	10.38±0.23	37	17.65±0.39
p-value		0.0065		<.0001		0.9507		0.4481		0.1633
Birth type	-	-								
Single	-	-	309	2.18^{a}±0.02	122	6.8^{a}±0.14	92	11.14^{a}±0.19	53	17.32±0.33
Twine	-	-	501	2.01^{b}±0.02	185	6.39^{ab}±0.11	127	10.05^{b}±0.16	70	16.83±0.28
Triple	-	-	54	1.78^{c}±0.05	23	5.93^{b}±0.00	18	8.87^{c}±0.43	8	16.94±0.84
p-value				<.0001		0.0154		<.0001		0.3293
Sex	-	-								
Male	-	-	470	2.11^{a}±0.02	171	6.58±0.12	120	10.71^{a}±0.17	61	17.59^{a}±0.30
Female			394	1.99^{b}±0.02	159	6.44±0.12	117	10.05^{b}±0.17	70	16.55^{b}±0.28
p-value	-	-		<.0001		0.3337		0.0087		0.0039

***: p<001, **: p<0.01, *: p p<0.05, ns: Not significant, LS: Liter size, BW: Birth weight, WW: Weaning weight, SMW: six month weight, YW: yearling weight, LSM: Least square mean and SE: Standard error

Reproductive performance

Litter size

The overall least squares mean litter size (LS) of three goat breeds obtained in the current study is presented in (Table 3). The average litter sizes for Felata, Gumuz, and Agew were 1.58±0.05, 1.71±0.03, and 1.75±0.03 per doe per parturition, respectively. LS was significantly different ($p<0.05$) between breed, birth year, and season of birth. The higher litter size was recorded in Agew and followed by Gumuz goat breeds. The litter size of the Agew and Gumuz goats was not significantly ($P>0.05$) different. On the other hand, there was a significant ($P<0.05$) difference between Felata and Agew goat breeds. The current result was higher than the report for Arsi Bale goats (Tatek et al., 2004), and for Central Highland goats (Tesfaye et al., 2006; Mengistie et al., 2013). In line with our findings, Belete (2009) reported similar results who found that the average litter size of goats was 1.74 in the Goma District of Jimma Zone, Western Ethiopia. Dadi et al., (2008) also reported closer litter size of 1.6 kids per doe per parturition and the current result was in the range of 1-2(ESGIP, 2010). By contrast, Endeshaw (2007) and Bainesagne et al., (2021) reported a higher litter size for Woito-Guji goat (2.07) and Gumuz goat (2.34) breeds from a survey work in Metekel Zone, Benishangul Region. However, Temesgen et al., (2019) reported small number of kids (1.03, 1.40 and 1.09) per doe per parturition for Abergelle, Central Highland and Woyto-Guji goat breeds, respectively.

Age at first service

The overall age at first service was 238.31±1.52 days (Table 4). There was significant difference between breeds in age at first service. The longest age at first service (258.4±3.8 days) was recorded for Felata goats while the shortest (231.1±2.1 days) was for Gumuz goat breed. The shorter age at first service observed in Gumuz goats, in particular is a desired trait for further breed improvement.

The current results of age at first service for Gumuz and Agew goats fall in the range of 5-8 months as reported by ESGIP (2010) for most tropical breeds, while Felata breed had longer age at first service exceeding this range. The present result for Felata goats is also similar to the reports of Tesfaye (2009) indicating age at first service was 8.2 ± 1.64 months for goats of Metema district.

Gestation Length

The average gestation lenght for Felata, Gumuz, and Agew goat breeds was 150.33±0.39, 147.89±0.26, and 148.65±0.24 days respectively (Table 4). Gestation legth was longer for Felata goats whereas it was slightly shorter for Gumuz and Agew goat breeds. The gestation length was significantly different ($p<0.05$) among breeds.

Age at first kidding

The overall age at first kidding was 391.86±4.61days (Table 4). The reproductive parameter of age at first kidding was significantly (P<005) different between breeds. Goat breed that came to first service at earlier age would naturally give birth at earlier age, too. Gumuz goats gave first kids at earlier age of 378.89±7.04 days and followed by Agew goats with age at first kidding of 394.47±7.44 days. Felata goats had longer age at first kidding (413.84±10.63 days) compared to the other two breeds.

The current result on age at first kidding is similar to that of most tropical breeds ranging between 12 and 15 months (ESGIP, 2010). It also concurs with the results of Bainesagne et al., (2021) reporting 12.39 months and Mengistie et al., (2013) reporting 13.59 months for the Central Highland goats. The average age at first kidding (13.06 months) obtained in this study is lower than the 16.8 months reported for indigenous goats in Bati, Meta, and Kebri-Beyah districts (Dereje et al., 2014) but similar to the average value of 13 months reported for indigenous goats in Oromya Region (Workneh and Rowlands, 2004).

Kidding Interval

The average kidding interval obtained in this study was 287.12±3.97 days and significant difference was observed between breeds. The longest kidding interval was recorded with Felata goats (316.2 months) and Agew goats (295.6 months). The shorter kidding interval (266.7 months) seen in Gumuz goats is one of the desirable selection traits for improving the breed.

The current result on kidding interval is higher than the reported value of 8 months for most tropical breeds (ESGIP, 2010). However, the value of kidding interval obtained from the present study is similar to the results of previous studies reported by Bainesagne et al. (2021) and Tilahun et al. (2019). On the other hand, the present value of kidding interval was lower as compared to the values of 11.31 and 10.3 months for Abergele and Central Highland goats, respectively (Belay, 2008). Temesgen et al. (2019) reported kidding interval values of 12.06, 8.93 and 10.3 months for Abergelle, Central Highland and Woyto-Guji goats, respectively.

Table 4: Least squares mean and standard error of reproductive data for the Felata, Gumuz and Agew goat breeds

Classes	N	AFS(days) LSM±SE	N	GL(days) LSM±SE	N	AFK(days) LSM±SE	N	KI(days) LSM±SE
Overall	157	238.31±1.52	476	148.64±0.16	133	391.86±4.61	133	287.12±3.97
Breed								
Felata	25	258.36ª±3.82	82	150.33ª±0.39	25	413.84ª±10.63	25	316.24ª±9.16
Gumuz	82	231.05ᵇ±2.11	188	147.89ᵇ±0.26	57	378.89ᵇ±7.04	57	266.75ᵇ±6.07
Agew	50	240.20ᵇ±2.70	206	148.65ᵇ±0.24	51	394.47ᵃᵇ±7.44	51	295.61ª±6.41
p-value		<.0001		<.0001		0.0288		0.0001

***: p<001, **: p<0.01, *: p p<0.05, ns: Not significant, AFS: Age at first service, GL: Gestation length, AFK: Age at first kidding, KI: Kidding interval, LSM: Least square mean and SE: Standard error

Conclusions and Recommendations

In the current study, the productive and reproductive performances were evaluated for Felata, Gumuz and Agew goat breeds. They have shown promising performance on most of the traits considered for evaluation, but the effect of breed was significant for most of the traits. In this study, the growth and reproductive performance of Gumuz goat is observed to be higher than the other two breeds on the desired traits like age at first service, age at first birth, shorter kidding interval and higher litter size. Agew and Felata breeds are also the second and the third better performing goats in the study area. Since goat production is the most important farming practices in the study area, the Benishangul-Gumuz regional state authorities should give much emphasis to promote improved goat production practices in order to benefit the local community. Thus, it can be concluded that under the same management condition in most performances parameters of Gumuz goat breeds was higher than Agew and Felata Goats. Therefore, Gumuz goats should be improved as first priority by establishing a community-based breeding program.

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Determinants of Participation and Extent of Participation in Contract Farming Among Smallholder Malt Barley Farmers in Oromia Region, Ethiopia: A Double Hurdle Approach

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Abstract

The study examined contract farming participation intensity determinants among small-scale malt barley farmers in the Arsi Highlands, Oromia Region, Ethiopia. Data was gathered from 384 sample respondents using a multistage sampling procedure. Age, livestock ownership, crop output, price, advice service, cooperative membership, and credit were found to be major determinants of probability of contract farming participation. However, total land size and farming experience negatively determined the likelihood of participation in contract farming. The contract participation intensity was defined by educational level, landholding size, production selling price, amount of fertilizer applied, and off-farm income. It is discovered that smallholder producers of malt barley are increasingly drawn to contract farming. It is anticipated that the trend will continue, bringing about more awareness of the advantages of contract farming as well as better access to and utilization of agricultural input supplies.

Keywords: Contract farming, participation, intensity, Oromia, Ethiopia

Introduction

Poverty alleviation and economic growth drive transformation of subsistence agriculture in Ethiopia (Admassie *et al.*, 2016; Atakilte, 2018). Agriculture development flagship programs that include agricultural commercialization clusters; irrigated wheat production; ten in ten; ye lemat tirufat; the green legacy; and integrated soil fertility management practices put in place to achieve food system transformation.

Initiatives for the commercial transformation of subsistence agriculture attract the involvement of private companies in diverse sectors, including multinational beer companies, including Heineken, Diageo, Bavaria, and Soufflet in Ethiopia (Holtland, 2017; Tefera and Bijman, 2021). These multinational breweries renovated and upgraded old breweries, which led to soaring malt demand in the country. To bridge the gaps in malt demand, actors in the upstream (malt barley farmers) and midstream (malt factories and breweries) and downstream (retailers) began collaborating more closely through contractual agreements to create a local malt barley supply chain in Ethiopia. The malt barley supply focuses on organizing farmers in such a way as to provide technology like seeds of improved varieties for malt barley production, training, and other support so that farmers, in return, are expected to supply quality products deemed necessary for malting on a contractual basis.

The barley subsector in Ethiopia employs 3,630,719 barley farm holders who manage 799,127.84 hectares of land as one of their primary sources of income (CSA, 2022). Nevertheless, the barley sub-sector has been characterized by a number of intricate production, marketing, and financial limitations, such as high transaction costs associated with gaining access to markets, new technology, information, and inputs (Shiferaw et al., 2022; Dagnew et al., 2024). On account of these, the barley sub-sector is defined by strong demand and limited supply of the malt raw material and the grain as a whole. The upgrading of breweries and malt mills, along with a shift in consumer behavior toward higher beer consumption, is driving up demand for malted barley. Breweries and malt makers must consequently expand the scope of their malt procurement programs to fulfill the increased demand for malted barley. Despite widespread promotion of malt barley contract farming in major barley producing regions, farmers' engagement as net sellers in the output market remains relatively low (Gebru et al., 2019; Dagnew et al., 2024). In light of this, the study set out to look into the variables that affect farmers' involvement in contract farming in the research areas, as well as the extent of participation towards the national plan of import substitution and saving foreign currency expenditures.

Research Methodology

Descriptions of the Study Area

The study was carried out in the Oromia Region of Ethiopia in the Tiyyo and Limu Bilbilo districts of the Arsi zone and the Kofele and Shashemene districts of the west Arsi zone. From an astronomical perspective, the zones are located between 7°08'58" N and 8°49'00" N latitude and 38°41'55" E and 40°43'56" E longitude. The research areas experience an annual mean rainfall ranging from 1020 mm to 1300 mm. The research region offers ideal edaphic and climatic conditions for agricultural output. Wheat, barley (food and malt), beans, peas, maize, teff, sorghum, oats, chickpeas, noug, linseed millet, potatoes, and other vegetables are among the principal annual crops farmed in the two zones (Oromia Finance and Economic Development Bureau (OFEDB), 2019).

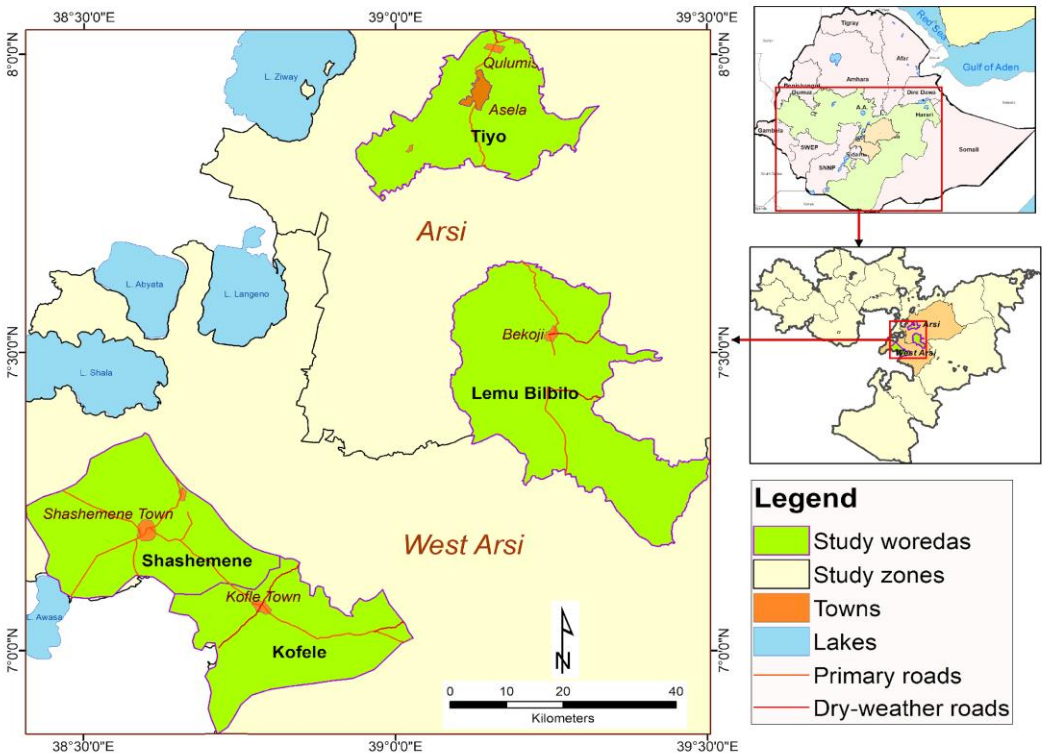

Figure 1. Map of the study area (Arsi and West Arsi zones)

Sampling Methods and Sample Size

The potential for malt barley production, the existence of contract farming practices, and the scheme's potential for scaling up were the factors taken into account while selecting the sample. Thus, the Arsi and West Arsi zones were purposively selected owing to their current potential for producing malt barley and presence of contract farming. Additionally, from each zone two districts, Lemu-Bilbilo and Tiyyo as well as Kofele and Shashemene were selected at random, respectively. The number of kebeles producing malt barley and their marketing profiles were used for randomly selecting two kebeles from each district. Then lists of malt barley producer households obtained from the respective kebeles and a simple random sampling technique was employed to determine the appropriate number of respondents in each kebele.

Accordingly, a representative sample size for the study was determined using the population size of malt barley producers obtained from district agricultural offices. A representative sample size was determined employing the formula provided by Kothari (2004):

$$n = \frac{Z^2 pqN}{e^2(N-1) + Z^2 pq} \quad (1)$$

$$n = \frac{(1.96)^2\ (0.5)\ (0.5)\ (92{,}286)}{(0.05)^2\ (92{,}286)\ +\ (1.96)^2\ (0.5)\ (0.5)} \approx 384$$

Where n is the required sample size, e is the desired level of precision, Z is the inverse of the standard cumulative distribution that corresponds to the confidence level, p is the estimated proportion of an attribute that is present in the population, and q = 1-p. The statistical Table, which includes the area under the normal curve at a 95% confidence level and p = 0.5, given by Kothari (2004), is where the value of Z can be determined. On the basis of this, 384 homes in total were chosen for the study from four districts; q = 1-p; N is the size of the whole population from which the sample was obtained; and a 95% confidence level and ± 5% precision were assumed. Finally, a sample of 384 (190 contract and 194 non-contract) household heads was drawn from eight Kebeles using simple random sampling with probability proportionate to size (see Table 1).

Table 1. Selected study districts, [1]Kebele and household sizes

District	Sampled *Kebele*	Household size	Sample households	Contract farming	
				CF	NCF
Limu Bilbilo	Chiba Michael	1323	90	23	23
	Limu Dima	1261		21	21
Tiyyo	Haro Bilalo	1,233	84	19	19
	Dosha	1,358		23	23
Kofele	Gurmicho	1,203	92	22	22
	Alkaso	1,249		24	24
Shashemene	Hursa Simbo	1037	118	31	32
	Gonde Karso	946		28	29
Total		9,610	384	190	194

CF = contract farming participants, while NCF is the farmers' producer for open market
Source: Agriculture Office

Sources and Methods of Data Collection

Both primary and secondary data were utilized for this study. A total of 384 malt barley farmers were contacted as the primary data source through face-to-face personal interviews. The respondents to the household survey were 190 contract participants. For comparison purposes, 194 non-contract malt barley farmers were

[1] Kebele is the smallest administrative division in Ethiopia.

randomly selected from the study area based on households' lists available at the respective study *Kebeles*. The interview schedule consisted of both open and closed-ended types of questions so as to collect information pertinent to the purposes of the study. Detailed household and plot-level data were gathered accordingly to allow statistical analysis of the quantitative data, given the available time and resources.

Methods of Data Analysis

In this study, descriptive and inferential statistical methods were utilized where deemed appropriate for the data attribute. Analytical methods that address each study objective are presented below.

Descriptive Analysis

Statistical inference and descriptive analysis were used in this research data analysis. Inferential statistical techniques, including the $\chi 2$-test and t-test were employed to compare household and farm characteristics between contract farming participants and non-participants. The household and farm profiles of the research areas are characterized using descriptive statistical methods such as averages, ratios, percentages, and frequencies.

Model specification for determinants of contract farming participation

In empirical studies on the determinants of farmers' participation in contract farming, diverse econometric models have been employed. The Probit, Tobit, Heckman, and double hurdle models have all been alternatively used to test determinants of involvement in contract farming (Komarek, 2010; Wang *et al.,* 2011; Abebe *et al.,* 2013; Ochieng *et al.,* 2016). The econometric approach to be used depends on the nature of the response variable. Participation in contract farming is a dependent variable that was analyzed in this study. Where contract farming participation status was denoted by 1 if the household head participated in contract farming in previous cropping period and 0 otherwise.

But the biggest issue with utilizing survey data to evaluate participation decisions is the sizable fraction of households reporting no adoption or participation. Traditionally, zero observations have been handled using the Tobit model, which was first developed by Tobin in 1958. However, it has limitations because the same variables and parameters that influence the probability of participation also control the levels of involvement. This assumption implies that the direction (sign) of a particular determinant's marginal effect is the same for smallholder farmers' involvement as well as the intensity of their engagement when they make the decision to participate (Burke, 2009). When modeling smallholder farmers' involvement in contract farming, this isn't a reasonable assumption to make.

Therefore, more adaptable models are needed to enable distinct procedures for identifying the variables that influence farmers' decisions on involvement as well as the degree of involvement. A binary variable is used to denote contract farming participation. Participants could not, however, get all of their barley sales through the program. The double-hurdle (DH) model (Cragg, 1971) that we employed suggests that the choice of whether to sell through the contract and the choice of how much to sell are independent choices. These choices are selected one after the other and may go through two distinct decision-making processes (Bellamare and Barrett, 2006). Therefore, the double hurdle model combines a zero-truncated continuous distribution to forecast non-zero values with a binary model to predict zero values. The amount of barley sold through contract farming is used for the second obstacle. According to Green (2003), a generalization of the Tobit model, the double-hurdle model features two independent stochastic processes that decide whether to participate and how intensely. For example, Hailemariam et al. (2006) found that a variety of factors affect the choice and rate of adoption of poultry technology. Further studies employing the model include the fertilizer adoption in Ethiopia study by Gebregziabher and Holden (2011), Kehinde and Adeyemo (2017), and Shiferaw (2008), which determined the reasons behind farmers' reluctance to adopt suggested technologies in the production systems of cocoa and pigeon pea in Nigeria and Tanzania, respectively.

While there are some similarities between the Heckman procedure and the double-hurdle model's parameterization in that both methods yield two distinct sets of parameters, the double-hurdle model is thought to be less constrictive. This is so because non-participants in the Heckman model will never, ever participate. On the other hand, non-participants in the double-hurdle model are viewed as a cornerstone solution in a utility-maximizing model (Yami et al., 2013). The double-hurdle model for contract participation assumes that smallholder farmers who voluntarily choose not to engage in contract farming are the source of the zero values reported in the first hurdle, while smallholder farmers who voluntarily choose to sell malt barley through contractual arrangements are the source of the values reported in the second hurdle.

The double-hurdle model, which assumes that the decision to engage in contract farming and the level of participation were controlled by two distinct stochastic processes, calls for the combined use of the Probit and the truncated regression models. A normal Probit model is used to estimate the formal model of the first hurdle, which is the participation choice given below:

$$D_i^* = \alpha' Z_i + \mu_i \qquad (2)$$
$$D_i = 1, if\ D_i^* > 0\ and\ 0\ if\ D_i^* \leq 0$$

D_i^* is a latent variable that takes the value 1 if the farmer sells malt barley via contractual arrangements and zero otherwise; and α is a vector of parameters. Z is a vector of explanatory variables that include demographic, socio-economic, and governance-related factors, while μ is a vector of error terms. The formal model of the second hurdle or intensity of participation equation is presented as:

$$Y_i^* = \beta' X_i + \mu_i \quad (3)$$

$$Y_i = Y_i^*, if\ Y_i^* > 0\ and\ if\ D_i^* > 0,$$

$$Y_i = 0, otherwise$$

Y_i^* *and* Y_i are the observable and hidden involvement levels in contractual agreements, respectively. The percentage of malted barley sold to each contracting partner was used to evaluate the level of involvement in the agreements. β is a vector of parameters to be estimated and X_i is a vector of variables impacting the household intensity of participation in contractual arrangements, including governance-related, socioeconomic, and demographic aspects, while μ is a vector of error terms.

Table 2. Summary of explanatory variables

Dependent variables			**Measure**	
First hurdle: Contract farming participation status			Dummy: Yes = 1, otherwise =0	
Second hurdle: Extent of contract farming participation			Continuous variable denoted by quantity of malt barley sold in quintals	
Explanatory variables			Hypothetical sign of influence on dependent variables	
Code	Descriptions	Measurement (unit)	Participation decision making in CF	Extent of contract farming participation
GENDER	Sex of the respondent	1 for male respondents married, and 0 for female respondent	Positive or negative	Positive or negative
RESPAGE	Respondent's age	Year	+/ -	+/ -
EDUCS	Educational level of the household head	Number of school years completed	+/ -	+/ -
MASTS	Marital status	1 married, 0 otherwise	+	+
HHSIZ	Number of family members	Number	+	+/ -
FASIZ	Cultivated farm size	Hectare	+	+
LIVES	Livestock ownership	TLU	+	+
COPMEM	Cooperative membership	Yes = 1, otherwise =0	+	+
CRACS	Credit access	Yes = 1, otherwise =0	-	+/ -
ADVIS	Access to advisory service	Yes = 1, otherwise =0	+	+
OFINC	Off/non-farm income	Birr/year	+/ -	+
MBFEX	Barley farming experience	Year	+	+
YIELD	Yield	Q/ha	+	+
DMKT	Distance to market	Number of minutes	+	-
PRICE	Price for 1 quintal barley	Birr/Qt	+	+
ACSIV	Access to imp. varieties	Yes = 1, otherwise =0	+	+
ACSTR	Access to training	Yes = 1, otherwise =0	+	+
NUMCC	Number of crops cultivated	Number	-	+
CFP	Contract participation	Yes = 1, otherwise =0	+	+
LEVCOM	Level of commercialization	Number	+	+/ -

Source: Literature review

Results and Discussion

Descriptive Statistics

The study comprises a sample of 384 farm household heads. From the sample, about half, i.e., 49.50%, were contract farmers, while 50.50% were non-contract malt barley farmers. The average age of the total sample household heads is 45 years old, which indicates that farm household heads were at their productive ages. The average schooling level of the total sample household heads is 6th grade. Only 20.05% of the respondents have completed secondary education. Generally, the level of education among malt barley farmers is basically considered to be low. The average family size of the total sample household heads is 7 persons, which is higher than the national average family size of 4.6 members. A larger family size guarantees that family labor is available when needed for agricultural tasks and lowers the expense of hiring labor, which could be one cause.

Analysis of socio-economic status of the households' indicated that the average landholding size for sampled household heads was 1.84 hectares. The livestock holding size in Tropical Livestock Unit was 7.26 for sample households. Distance travel to get various inputs and services determine information access and adoption decisions, accordingly the average travel time taken to reach the main road for the total sampled of household heads is 26.74 minutes. Mekonnen and Alamirew (2017) found that farmers near all-weather roads had a 19% commercialization index, while their remotely located counterparts recorded a 16% commercialization index. On average the farm size allocated for malt barley production by the total sample household heads was 0.74 hectares. Also, the average farm size allocated for malt barley production by contract and non-contract farmers was 0.83 ha and 0.66 ha, respectively. The t-test mean comparison indicated a significant difference: farmers with larger malt barley farm sizes are more involved in contract farming. Research indicates that the size of a land holding affects both the amount and the participation in contract farming, as demonstrated by studies conducted on rice and maize contract farming in Ghana and Benin, respectively, by Olounlade et al. (2020) and Ragasa et al. (2018).

Of the total sample household heads, 94.79% were male, while 93.68% and 6.32% were male and female-headed farm households that participated in malt barley contract farming, respectively. Descriptive statistics show that a household headed by male is in a better position to participate in contract farming than a household headed by female. The majority, or 83.59%, participated in improved crop production and protection technique trainings at least once in the previous cropping period. Participation in agro-industrial supply chains such as breweries or malt factories heavily requires production of quality, volume, and timely supply of products, which can be realized through getting training to be knowledgeable to that end. Access to and use of quality inputs such as improved varieties have been one of the most blamed constraints to realizing the maximum crop production potential in general and barley production in particular. About 86% of contract farmers utilized high-yielding improved malt barley seeds as compared with 79.38% of non-contract farmers. Literature documents the positive role of cooperative membership for farmers in information access, input and output markets, technology, etc. Out of the sampled households, only 53% were cooperative members. Access to credit and other extension services are expected to attract and link farmers with coordinated market chains and ease liquidity and input supply. Only 25% of the sample households had a chance of using financial services. Comparing malt barley farmers in terms of their access to and use of financial services, significant differences were observed: farmers selling their malt barley production through formal agreements were in a better position in terms of access to and use of financial services. It was found that farmers selling their malt barley production through formal agreements were 37 percent, while their counterparts were only 12 percent.

Table 3. Summary of demographic and socioeconomic variables

Item		Non-contract farmers		Contract farmers		T-Test
		Average	SD	Average	SD	
Respondent age		43.40	11.10	46.00	11.10	-2.02**
Family members		6.88	3.00	7.77	3.02	-2.90***
Educational level of the household head (grade completed)		6.07	3.37	6.13	3.59	-0.18
Landholding (ha)		1.70	1.66	1.98	1.46	-1.77*
Malt barley farm size (ha)		0.66	0.60	0.83	0.52	-2.88***
Household income (Birr/year)		48045	51292	86203	58317	-6.80***
Distance to main road (Min.)		30.03	18.17	23.53	18.76	3.44***
Livestock size (TLU)		6.84	4.28	7.69	4.31	-1.94*
Amount of credit used (Birr)		179.28	472.79	707.96	946.92	-6.90***
Variable	Item	NCF	Percent	CF	Percent	$\chi^2 - test$
Gender	Female	8	4.12	12	6.32	
	Male	186	95.88	178	93.68	0.93
	Total	194	100	190	100	
Marital status	Unmarried	9	4.64	12	6.32	
	Married	185	95.36	178	93.68	0.52
	Total	194	100	190	100	
Participation of training	Yes	140	72.16	181	95.26	
	No	54	27.84	9	4.74	37.34***
	Total	194	100	190	100	
Association in cooperative	Yes	57	29.38	146	76.84	
	No	137	70.62	44	23.16	86.77***
	Total	194	100	190	100	
Getting to credit	Yes	24	12.37	70	36.84	
	No	170	87.63	120	63.16	31.09***
	Total	194	100	190	100	
Having improved seeds	Yes	154	79.38	164	86.32	
	No	40	20.62	26	13.68	3.24*
	Total	194	100	190	100	

Note: NCF: Non-contract farming; CF: Contract farming; ***, **, and * represent significant t-test results at 1%, 5%, and 10% levels, respectively.
Source: Estimated from survey data

Table 4. Demographic and social networks

Item	List	Number of respondents		Non-contract farmers		Contract farmers		$\chi^2 - test$
		No.	Percent	No.	Percent	No.	Percent	
Gender	Female	20	5.21	8	4.12	12	6.32	
	Male	360	94.79	186	95.88	178	93.68	0.93
	Total	384	100	194	100	190	100	
Marital status	Unmarried	21	5.47	9	4.64	12	6.32	
	Married	363	94.53	185	95.36	178	93.68	0.52
	Total	384	100	194	100	190	100	
Participation of training	Yes	321	83.59	140	72.16	181	95.26	
	No	63	16.41	54	27.84	9	4.74	37.34***
	Total	384	100	194	100	190	100	
Association in cooperative	Yes	203	53	57	29.38	146	76.84	
	No	181	47	137	70.62	44	23.16	86.77***
	Total	384	100	194	100	190	100	
Getting to credit	Yes	94	24.48	24	12.37	70	36.84	
	No	290	75.52	170	87.63	120	63.16	31.09***
	Total	384	100	194	100	190	100	
Having improved seeds	Yes	318	82.81	154	79.38	164	86.32	
	No	66	17.19	40	20.62	26	13.68	3.24*
	Total	384	100	194	100	190	100	

Note: *** and ** represent significant t-test results at 1%, 5%, and 10% levels respectively.
Source: Estimated from survey data

Results of Econometric Analysis

Determinants of contract farming participation and its intensity

Factors that affect smallholder farmers' participation decision and intensity of participation in malt barley contract farming were examined using a double hurdle model. The first hurdle (Probit model) results on the determinants of malt barley contract participation decision, the Likelihood ratio (LR) of 107.94 is significant at p<1%. This suggests the combined importance of the explanatory factors contained in the model. Similarly, outcomes of the reduced regression models that were computed and displayed in Table 5 below shows that LR of 356.14 of the fitting models for information produced by malt barley contract farming was significant at p<1%. This indicates the joint significance of the explanatory variables in influencing the intensity of participation in contract farming. Yet, the results expose that there is some variation in the outcomes of the Probit and truncated regression models, and the factors that determined the variables that affected the farmers' choice to engage in contract barley farming were not quite the same as those that affected their level of involvement. This explains why the double-hurdle model is appropriate for analyzing farmers' involvement in malt barley contract farming. Below are brief discussions of the significant focal points.

Table 5. Determinants of contract farming participation and its intensity

Variables	Probit Regression (1^{st} Hurdle)			Truncated Regression (2^{nd} Hurdle)			
	Coef.	RStd. Err	dy/dx	Variables	Coef.	RStd.Err	dy/dx
Sex	0.145	0.399	0.056	Sex	-2.878	1.958	1.96
Age	0.020*	0.010	0.008	Age	0.046	0.063	0.06
Educational	0.011	0.030	0.004	Educational	0.322**	0.161	0.16
Household size	0.008	0.033	0.003	Household size	-0.485**	0.200	0.20
Land holding size	-0.173**	0.076	-0.067	Land holding size	24.810***	2.407	2.41
Livestock ownership (TLU)	0.061**	0.026	0.024	Livestock ownership (TLU)	-0.444*	0.245	0.25
Malt barley farming experience	-0.044**	0.019	-0.017	Malt barley price	0.012***	0.003	0.00
Distance to market	0.012**	0.005	0.005	Access to advisory service	-2.545*	1.556	1.56
Access to advisory service	0.981***	0.282	0.329	Access to chemical fertilizers	0.135***	0.034	0.03
Access to chemical fertilizers	0.005	0.004	0.002	Cooperative membership	3.327**	1.103	1.10
Cooperative membership	1.097***	0.175	0.408	Access to credit	-3.532***	1.283	1.28
Access to credit	0.889***	0.208	0.343	Off/non-farm income	0.000**	0.000	0.00
Off/non-farm income	0.000	0.000	0.000	_cons	-14.184	4.326	
Constant	-3.116	0.738		/sigma	9.674	0.731	
Number of obs = 303 Log pseudo-likelihood = -147.02137 Wald $chi^2(15)$ = 83.75 Prob > chi^2 = 0.000 Pseudo R^2 = 0.2932				Number of obs = = 303 Log pseudolikelihood = -1117.5661 Wald chi2(12) = 363.20 Prob > chi2 = 0.0000			

Significance: *** p<0.01, ** p<0.05, * p<0.1
Source: Analysis of survey data

Age of the household head: Age was statistically significant and positively influenced farmer's contract farming participation decision but was insignificant in influencing intensity of contract farming participation. The implication is that as the age of a farmer increases, he/she is more likely to participate in contract farming. This result is found to be inconsistent with the study of Alene *et al.* (2008), which revealed that as one grows older, risk-taking decreases, which could also decrease chances of contract farming participation. This could be because older farmers would have developed greater experience, networks, and trust that would allow them to participate in contract farming.

Educational level of the household head: Education had a significant and positive coefficient at p<5% in influencing farmer's malt barley contract farming participation intensity but was insignificant in determining participation decision. The implication is that farmers with higher levels of education were more likely to raise the volume of malt barley sales in contract farming. This result is in line with findings of Awotide *et al.* (2016) and Nhan (2019), who found that education positively determines the rice market's participation intensity in Nigeria and Vietnam, respectively.

Landholding size: The estimated coefficient of total land size significantly determined both contract farming participation and its intensity negatively and positively at $p<1\%$, respectively. This shows an inverse relationship between farm size and the likelihood of a decision to participate in contract farming. But once a farmer made the choice to engage in contract farming, the intensity of sales volume relied on farm size. This contradicts the theory and the findings of a prior study conducted by Khan et al. (2019), which indicated that farmers allocated their land for crops that responded to market signals in proportion to their land ownership. However, Rao *et al.* (2017) could not find a significant difference in farm size between contracted and decision-contracted farmers in India.

Livestock holding size (TLU): The livestock holding size (TLU) of a household has shown a significant influence on contract farming participation decisions positively, but the extent of participation negatively, at $p<5\%$ and $p<10\%$, respectively. The size of the livestock holding had a positive and significant coefficient, at less than five percent, influencing the farmer's contract farming participation decision. A large herd of animals demonstrates status and serves a variety of social and economic purposes. Farmers may find it easier to finance the investment necessary to enter contract farming if they have enough cattle. Studies show the mixed influence of livestock holdings on contract farming participation. For instance, Khan *et al.* (2019) did not find any significant relationship between livestock holding and farmers' maize and potato contract farming participation decisions in Pakistan. In contrast, Muroiwa et al. (2018) found a favorable correlation between farmers' decisions to engage in contract farming in Zimbabwe and their ownership of cattle.

Malt barley farming experience: Malt barley farming experience was statistically significant but negatively determined both contract farming participation decision at <5%. That is a 1 year increase after 6 years of average malt barley farming experience; the probability of participation decision decreases, keeping other covariates unchanged. But studies present mixed results; for instance, Maertens and Velde (2017) observe that farmers with previous experience in cotton farming are more likely to participate in contracts; Ruml *et al.* (2022) find no significant influence of experience on participation and its intensity between rice contract and non-contract farmers. Azumah *et al.* (2016) revealed that rice farming experience negatively affects farmers' contract farming participation and intensity.

Access to advisory service: The variable access to agricultural advice was statistically significant and exerted a positive influence on contract farming participation decisions at <5% and but with significant negative influence on intensity of participation at <10%. The implication is that with improved access to advisory services, so does contract farming participation inclination but not the intensity. In line with this study, Abebe *et al.* (2013) attested that farmers participate in contract farming as they seek various supports that enhance farmers' knowledge about improved production systems.

Access to chemical fertilizers: The variable quantity of fertilizer applied showed strong insignificant influence on intensity of contract farming participation at <1%. This implies that quantity of fertilizer applied is directly associated with quantity of malt barley sales, as marketable surplus production is a function of input use, including improved varieties and chemical fertilizers. Consistent with the finding, Shiferaw *et al.* (2014) underline the importance of adoption of improved varieties, fertilizers, and pesticides to increase quantity and quality of product sales.

Cooperative membership: Both the decision to participate in contract farming and the extent of participation were statistically significantly influenced by the cooperative membership variable. The marginal effect indicates that, as a farmer who is a member of an effective cooperative, the probability of participation in malt barley contract farming increases by 41%. The results are in line with those of Mishra et al. (2018), who discovered that cooperatives function as a middleman to facilitate transactions between farmers and major food processors. This is because these associations are adept at mediating conflicts of power between smallholder farmers and big enterprises. Moreover, farmer cooperatives are believed to facilitate agricultural service delivery, raise productivity, and link farmers to better markets (Ahmed and Mesfin, 2017).

Access to credit: Access to credit positively and significantly determined contract farming participation decisions, but against the expected signs and influence on intensity of participation. The study indicated that, if one changes from no credit access to credit access, the predicted probability of contract farming participation increases by 41%. As expected, farmers with access to credit, either in monetary terms or in kind, are likely to be motivated to participate in contract farming. Also, Mishra et al. (2018) support that contract farming offers incentives to boost a commodity's output through improved seeds, technical support, credit availability, and input access. It also improves the coordination of activities along value chains, the perceived favorability of transactions, dependability, and capacity to deliver on commitments.

Off/non-farm income: Off/non-farm income positively and significantly influenced intensity of contract participation at $p<1\%$. Studies show mixed effects on contract farming participation. It is considered that high- and low-income earners can easily mobilize productive resources, devise more diversified enterprises and likely exit from farming (Randela *et al.*, 2008). Bellemare and Bloem (2018) provide further evidence that off-farm income alleviates financial limitations, especially for resource-poor farmers, allowing them to buy items that increase production. Farmers who earn more income from off-farm or non-farm activities could seek to maximize that income, giving less attention to their farm activities, including malt barley production. Although this finding is inconsistent with many studies, a study by Osmani and Hossain (2015) found that they had reported similar findings.

Conclusions and Policy Implications

Participation in contract farming has been found to be determined by demographic characteristics, including age, gender, and household size. In addition to institutional factors like access to extension services, market information, cooperative membership, credit availability, and price and off-farm income, households' decisions to participate in contract farming have also been influenced by socioeconomic factors like educational attainment, the size of their landholding, and the number of livestock they own.

The following policy implications are emphasized for wider contract farming participation based on the evidence presented in this study:

- Farmers who engage in contract farming reveal that contract farming is as a platform that enables them to secure equitable marketing price for their production and boost sales volume that sustain malt industry and producer relationships.
- Landholding size strongly affects the extent of contract farming performance, so formulation of policies that encourage efficient land use and right transfer that ensure efficiency in allocation of factors of production, which is landholding.
- By encouraging farmers to share knowledge and experiences in their their cooperatives, malt barley farmers shall be able to increase their prospects of contract farming participation and extent of participation by selling their production in the scheme.
- Enhance access to rural financial services to motivate farmers' investment and participation in coordinated agri-food supply chains further.
- Access to inputs, including chemical fertilizers, is positively correlated with contract farming participation and involvement level. This shows that contract farming should be promoted by providing chances for input access. As a result, there will be more people involved in contract farming.
- Contract farming participation decision and its extent of participation will also be enhanced by efforts to devise off-income-generating interventions in the areas.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

Data will be made available on request.

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Contributions

The corresponding author contributed to survey design, data collection, cleaned the data, analyzed the data, and wrote the first draft of the manuscript. The other authors contributed to reading, editing, and structuring the manuscript. All authors read and approved the final version of the manuscript.

Availability of data and materials

Data used for the analyses in this article are available from the corresponding author upon request.

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The Ethiopian Journal of Agricultural Sciences (EJAS) publishes papers of original scientific work related to strategic, applied and interdisciplinary studies in all aspects of agricultural science as well as reviews of scientific topics of current agricultural relevance. Specific topics of interest may include all aspects of crop and animal production; farm animal welfare and behavior; soil science and soil health; plant and animal product quality; agricultural engineering solutions; decision support systems; land use; environmental impacts of agriculture; agroforestry systems relates to agriculture; impacts of climate change; climate change adaptation and mitigation; climate-smart agriculture; carbon sequestration; rural biodiversity; experimental design and statistical analysis; and the application of new analytical and study methods, including genetic diversity and molecular biology approaches. All manuscripts submitted will be judged from the standpoint of scientific originality and subject matter.

Manuscripts should not have been published in other professional journals or simultaneously submitted to another such journal with the exception of theses and research and development project reports.

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These papers treat both basic, applied, and action research findings related to Ethiopian agriculture. Articles from regional and international sources covering tropical and sub-tropical agriculture may also be considered for publication.

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The title should clearly reflect the content of the manuscript. It should be concise, specific, and descriptive enough to contain keywords or phrases the contents of the article. Maximum 100 characters without space, or 120 characters including spaces.

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3. **Abstract.** An abstract reflecting significant findings of the study is required. The abstract should not exceed 200 words and must be an informative type that includes the rationale, objectives, methods used, results, and conclusion. The abstract should be *italicized*. Abbreviations should be avoided in the abstract. Not more than five keywords, each word or phrase separated by semi-colon, should be included with the abstract.

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8. **Acknowledgments**. Acknowledgments given in a separate section immediately following the results and discussion. The donors should be properly acknowledged and the grant numbers (or project codes) should be included in the acknowledgement.

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3. References and citation

1. **Inline citation**

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More than two authors: (Akpo *et al*. 2021)

2. **Reference**

Journal Article

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Abdul Rahman, S., and R. Ellis. 2019. Seed quality in rice is most sensitive to drought and high temperature in early seed development. Seed Sci. Res. **29(4):238–249. (include "doi" if any)**

Book

Akpo, E., C. O. Ojiewo, I. Kapran, L. O. Omoigui, A. Diama, and R. K. Varshney (eds.). 2021. Enhancing Smallholder Farmers ' Access to Seed of Improved Legume Varieties Through Multi-Stakeholder Platforms. Springer Nature Singapore Pte Ltd, Singapore.

Chapter in a book

Bernanke, J., and H. Köhler. 2008. The Impact of Environmental Chemicals on Wildlife Vertebrates. Pages 1–47. *In :* D. M. Whitacre(ed.) *Reviews of Environmental Contamination and Toxicology*. Springer Science + Business Media, LLC 2008.

Paper in a proceeding

Abebe, M. 2019. An investigation into the cause of wilt in cotton. p. 129-139. *In: Proceedings of Symposium on Cotton Production under Irrigation in Ethiopia*. Melka Werer, Ethiopia, 21-22 October 2019. Ethiopian Institute of Agricultural Research, Addis Abeba.

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Tables should facilitate comparisons, reveal relationships, and save space. Do not repeat information in the text presented in the tables or in charts or graphs. Tables should be numbered consecutively as Table 1, Table 2, etc., in the order in which they are first cited in the text. Each table, with its heading, should be typed on a word processing. Only plain tables (not Table Grids) are acceptable. Tables should be presented next to their first citations.

8. Units

All measurements are to be reported in SI units. For example, do not use quintal (q) but kg or t instead.

9. Thesis based papers

Papers based on the thesis should be presented with the thesis adviser as coauthor and should indicate the institution, the year the work was done, and the full title of the thesis.

3. Submission

Your submission should include a cover letter signed by the corresponding author and all co-authors. A submission that does not include the consent of all the co-authors shall not be considered for further processing. Your cover letter should clearly state that the manuscript is previously not published or being considered for publication in any academic journal.

Submit a single document in Microsoft word format, with all illustrations placed at their appropriate positions.

4. Mailing Address

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