DIVERSITY, DISTRIBUTION, MANAGEMENT, AND PRODUCTION CONSTRAINTS OF YAMS LANDRACES (*DIOSCOREA* SPP.): THE CASE OF BOLOSO SORE AND DAMOT GALE DISTRICTS OF WOLAITA ZONE, SOUTH ETHIOPIA REGION

M.Sc. THESIS

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M.Sc. THESIS

GEMEDA DESTA

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MAJOR ADVISOR: WENDAWEK ABEBE (PhD)

CO-ADVISOR: FIREW KEBEDE (PhD)

NOVEMBER, 2023

ADVISORS' APPROVAL SHEET

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY ADVISORS' APPROVAL SHEET

(Submission sheet-1)

This is to certify that the thesis entitled," **Diversity, Distribution, Management, and Production Constraints of Yams Landraces (*Dioscorea* spp.): The case of Boloso Sore and Damot Gale Districts of Wolaita Zone, South Ethiopia"** submitted in partial fulfillment of the requirements for the degree of Masters of Science with specialization in **Botanical Science** of the Graduate Program of Department of Biology, College of Natural and Computational Sciences, Hawassa University and has been carried out by **Gemeda Desta,** Id No **GPBotSR/0004/14** E.C under our supervisions. Therefore, we recommend that the student fulfilled the requirements and hence hereby can submit the thesis to the department.

Wendawek Abebe (PhD)	______________________	____________________
Name of major Advisor	Signature	Date
Firew Kebede (PhD)	______________________	____________________
Name of Co-advisor	Signature	Date

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We, the undersigned members of the board of the examiners of the final open defense by **Gemeda Desta** have read and evaluated his thesis entitled: **" Diversity, Distribution, Management, and Production Constraints of Yams Landraces (*Dioscorea* spp.): The case of Boloso Sore and Damot Gale Districts of Wolaita Zone, South Ethiopia"** and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of **Master of Science in Botanical Science.**

Wendawek Abebe (PhD)	____________________	______________________
Name of major Advisor	Signature	Date
______________________	____________________	______________________
Name of Internal Examiner-I	Signature	Date
______________________	____________________	______________________
Name of Internal Examiner-II	Signature	Date
______________________	____________________	______________________
Name of External Examiner	Signature	Date
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DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Gemeda Desta email address: **gemededesta98@gmail.com**

Signature: ________________________

This MSc Specialty or equivalent thesis has been submitted for examination with my approval as thesis advisor.

Name: Wendawek Abebe (PhD)

Signature: ________________________

Place and Date of Submission: ________

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ACRONYMS/ABBREVIATIONS

ANOVA- Analysis of variance

ARDO- Agricultural and Rural Development Office

CSA- Central Statistical Agency

DAO- District Agricultural Office

DAs- Developmental Agents

FAO- Food and Agriculture Organization of the United Nations

FAOSTAT- Food and Agriculture Organization Statistics

FGD- Focus group discussion

GDP- Gross Domestic Product

IITA- International Institute of Tropical Agriculture

Km- Kilo meter

M.a.s.l- Meter above sea level

MT- Metric Tons

NARs- National Agricultural Research Institutes

NBS- National Bureau of Statistics

NMSA- National Meteorological Services Agency of Ethiopia

SER- South Ethiopia Region

SPSS- Statistical Packages for Social Sciences

ABSTRACT

Yam is a resilient staple tuber crop with a long shelf life that offers food security and income generation. However, its distribution and diversity are limited, with synthetic fertilizer-demanding crops being a persistent challenge in the study area. In this regard, therefore, this study was conducted to assess diversity, distribution, management, and production constraints of yams in two districts of Wolaita Zone, South Ethiopia Region, namely Boloso Sore and Damot Gale Districts of which six, yam growing Kebeles (three from each district) were selected. A total of 366 households were selected from the six kebeles using systematic random sampling techniques. The major data collection tools used were, semi-structured interviews, direct field observation, key informants interviews and focus group discussion. Both qualitative and quantitative data were analyzed using SPSS software ver.25. A total of 19 named yam landraces were recorded, with a range from one to eight (mean 2.3) on individual farm land owned by a farmer. Richness of yam landraces ranged from 1 to 8 per farm and from 5 to 14 per Kebele with in the two Districts. Yukara Kebele had the highest diversity, while Zegere Kebele had the lowest diversity. Yukara Kebele showed the highest diversity, with a diversity index (H') of 2.18 and Zegere Kebele had the lowest diversity, with a diversity index of 1.43. On average, 73.7% of yam landraces found in one Kebele were also found in the other Kebeles within the two Districts whereas 10.5% of them were common to all Kebeles of the two districts. The distributions of landraces also varied across the surveyed Kebeles. A small number of highly abundant yam landraces were grown throughout the surveyed Kebeles whereas the greater numbers of the yam landraces had a narrow distribution and abundances. In addition, the study showed that farmers in the study area manage diverse yam landraces with respect to time of maturity, adaptation to environmental conditions, and cooking properties. The major constraints to yam production include: wild animal attack, lack of materials for staking, land shortage, drought or climate change, and scarcity of mother yam, which reported by 90.7%, 87.4%, 86.1%, 74.9% and 68.8% of respondents, respectively. Therefore, local communities' conservation, preservation, and utilization techniques for yam landraces can ensure their long-term viability.

Key words: *Constraint; Distribution; Diversity; Landrace; Management; Yam*

1 INTRODUCTION

1.1 Background of the study

Yam is a tuber crop that belongs to genus *Dioscorea* and family Dioscoreaceae which provides food and medicine to millions of people in the world, especially in the tropics and subtropics (Aighewi *et al*., 2021). It is a staple food crop and a source of income for millions of people in West Africa (Pouya *et al*., 2022). This genus consists of more than 600 species distributed from Africa, Asia, the Caribbean’s South America, and the South Pacific islands (Salehi *et al*., 2019). Ten yam species are grown to feed millions of people in the tropics as staple foods; each species is of tropical origin and is grown for its starchy, tasty tubers (Paterne *et al*., 2019). West Africa produces the vast majority of the world's yams (Muluneh Tamiru *et al*., 2007).

The conservation of crop species' genetic diversity has been a worldwide concern for many decades due to the fear that much of this diversity would disappear with agricultural and economic development, resulting in genetic erosion (van de Wouw *et al*., 2010). It is important not only as a staple food crop but also as an integral component of society and culture of the millions of people who depend on it. However, due to its regional importance, yam has long been regarded as an “orphan crop” lacking a due global attention (Sugihara *et al*., 2021). Knowledge on yam diversity comes from the West African yam belt, primarily through work at the National Agricultural Research Institutes (NARs) and International Institute of Tropical Agriculture (IITA) (Muluneh Tamiru *et al*., 2011).

Yam contributes about 10% of the total root and tuber production around the world. They provide pharmacologically active compounds in traditional medicine and for the pharmaceutical industry (Lebot and Dulloo, 2021). It is an orphan crop that is widely distributed globally and has made significant contributions to food security, particularly in Sub-Saharan Africa, due to its role in providing nutritional benefits and income (Obidiegwu *et al*., 2020). It is recognized as the fourth most important tuber crop after potatoes, cassava, and sweet potatoes and grown in approximately 50 tropical countries (Muluneh Tamiru *et al*., 2006; Padhan and Padan, 2020).

According to the available FAO statistics, the world's annual production is approximately 72 million metric tons of fresh tubers (Lebot, 2021). More than 98% of the world’s yam production is cultivated in Africa, with only four countries (Nigeria, Côte d’Ivoire, Ghana, and Benin) accounting for 93% of this output, or more than 67 million metric tons per year. Less than 1% of global production is produced by Asia and Oceania combined (FAOSTAT, 2020).

In Ethiopia, yams play a significant role in the country's economy, especially in the highly populated south, southwest, and western regions. It grows in a wide range of soils with an altitude range of 1140–2200 masl (Atnafua Bekele and Endashaw Bekele, 2020). In Ethiopia, a large pool of yams is largely distributed in complex cropping systems with a wide genetic base in different parts of the country (Wendawek Abebe *et al*., 2013). It is the third most important root crop in Ethiopia, after cassava (*Manihot esculenta* Crantz) and sweet potato (*Ipomoea batatas* (L.) Poir) (Muluneh Tamiru *et al*., 2007).

Production of yam in Ethiopia is dependent on unimproved landraces maintained by farmers. Smallholder farmers maintain considerable genetic diversity that remains to be further unexploited for sustainable utilization and conservation of yam genetic resources. It is widely grown in many parts of Ethiopia and plays a vital role in local subsistence. Nevertheless, its diversity has not been studied in detail (Muluneh Tamiru *et al*., 2008). Consequently, there is little information about the genetic diversity of yams (Muluneh Tamiru *et al*., 2011).

According to Belachew Garedew *et al.*, (2017), results showed that the edible yams (*Dioscorea alata, Dioscorea bulbifera,* and *Dioscorea cayenensis complex*) were important to agriculture and food security in the community of the Sheko district and even in other District of the "Bench Maji Zone." The yam (*Dioscorea cayenensis* complex) is one of the oldest varieties of yams from West Africa (Ogundiran, 2005), while *Dioscorea alata* originated in Southeast Asia, specifically in tropical Myanmar and Thailand (Muluneh Tamiru *et al*., 2006), and *Dioscorea bulbifera* is native to tropical Africa, Asia, the Pacific Islands, and northern Australia. It is now used in tropical America and the West Indies (Lim, 2016).

In Wolayita and Gamo-Gofa Zone, farmers are familiar with the diversity available in yams and the attributes of each landrace, which they utilize accordingly to meet their needs (Muluneh Tamiru *et al*., 2008). The study by Muluneh Tamiru *et al*. (2008) revealed that our study area is considered to be a hot spot for yam diversity. However, yam productions in Wolaita and Gamo Gofa Zoe were mainly based on a limited number of widespread landraces; the majority of landraces recorded have a rather limited distribution and abundance. In South Ethiopia, especially in these areas yam is a traditional crop that has long been cultivated as a staple alongside cereals and other root and tuber crops.

Weed pressure, a decrease in the quality of the soil, diseases and parasites carried by the soil, storage pests, the high labor costs associated with preparing and maintaining the land, staking, and barn construction, to name a few issues that impact yam production (Emmanuel and Bassey, 2017). Furthermore; the quality and fertility of the soil have a great effect on output, especially since the soil under which the farmers were farming was an undisturbed high forest area (Idumah and Owombo, 2019).

1.2 Statement of the problem

Ethiopia is an important center of origin and diversity of yam landraces (*Dioscorea* spp.) (Muluneh Tamiru *et al*., 2006). Yam has been cultivated in different major growing areas of the South and Southwest parts of the country for different purposes and product forms (Tewodros Mulualem, 2022). However, according to Demilew Deres (2022), Ethiopian yam production has declined year over year since 1993, from 200 thousand tons to 45 thousand tons in 2020, despite genetic variety, cropland availability, and the release of more varieties.

Yam crops are drought resistant because of their high food and water storage capacity. Therefore, they are an essential contribution to the fight against food insecurity, particularly in developing countries like Ethiopia. However, its diversity is still low and much focus was given to synthetic fertilizer demanding crops (Muluneh Tamiru *et al*., 2008). The crop is also attractive for food security because of its resilience to adverse weather, broad agro-ecological adaptation, significantly longer shelf life compared to other staple crops, and diverse options for value-added utilization (Adjei *et al*., 2022).

The genetic resources of neglected and underutilized crops like yam are being eroded as improved cultivars or cash crops (Tsegaye Babege *et al* 2021). There is a lack of knowledge regarding the genetic diversity of yams, which is primarily held by local farmers. Consequently, the status and selective implication of the yam individual varieties and their role to overall diversity are not identified (Amare Seifu and Daniel Fitamo, 2016). Genetic erosion of yam diversity has raised concerns, emphasizing the need for its conservation (van de Wouw *et al*., 2010).

There is a need for better post-harvest processing and marketing strategies. On the other hand, Yam production faces various constraints. Consequently, majority of yam landraces in Wolayita and Gamo-Gofa faced extinction, owing to their rarity and limited distribution (Muluneh Tamiru *et al*., 2008). Up-to-date data: existing information on the distribution, diversity, constraints, and management practices of yam production in Boloso Sore and Damot Gale Districts is outdated (there is a lack of up-to-date information). Current data is needed to assess the current status and identify any changes or trends in yam production. Conducting a comprehensive assessment can fill these knowledge gaps and contribute to the sustainable production of yams in the study area.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this study is to assess the diversity, distribution, management practices, and production constraints of yams landraces *(Dioscorea* spp.*)* in Boloso Sore and Damot Gale Districts of Wolaita Zone, South Ethiopia Region.

1.3.2 Specific objectives

The specific objectives of this study are:

- To determine the current diversity and distribution of yam landraces in the study area
- To explore the local farmers' management practices of yam landraces *(Dioscorea* spp.)
- To document the role of yam landraces in household food security and
- To investigate the production constraints of yam landraces (*Dioscorea* spp.) those are faced by farmers in the study area.

1.4 Research question

To achieve the stated objectives, the study was focused on the following questions.

What is the current diversity and distribution of yam landraces in the study area?

How do local farmers manage yam landraces (*Dioscorea* spp.) in the study area?

What role do yam landraces play in household food security in the study area?

What are the production constraints faced by farmers in the study area in cultivating yams (*Dioscorea* spp.)?

1.5 Significance of the study

Yams are essential in meeting farmers' livelihood and food security needs. It is also important because they meet local food preferences, providing an important part of the diet as they produce more edible energy per hectare per day than any other crop groups which play an important role in food security, nutrition and climate change adaptation. Yams are predominantly produced crop to meet food security needs (Belachew Garedew *et al*., 2017). The knowledge and understanding of local cultivars' diversity are essential for properly managing genetic resources, conservation, sustainable use and their improvement through breeding (Agre *et al*., 2021).

This study provides valuable insights into traditional knowledge used by farmers in implementing management practices for yams. It focuses on diversity, distribution, and production constraints, as well as their contribution to household food security. The findings are crucial for promoting the conservation of yam landraces and increasing production within the study area. Understanding the current status of yam genetic diversity is essential for developing strategies to preserve and enhance genetic resources. The study also helps identify major constraints to yam species and explores traditional management practices. It serves as a baseline for future research and generates significant baseline data for future research.

1.6 Scope of the study

The study was conducted in Damot Gale and Boloso Sore Districts, Wolaita Zone, South Ethiopia Region. The study covered two districts, namely Boloso Sore and Damot Gale Districts, from which six yam-growing Kebeles (three from each district): Yukara, Dubo, and Tadisa from Boloso Sore, and Zegere, Obejage, and Wandara Gale from Damot Gale District, were selected. The study also dealt with the diversity, distribution, and management practices of farmers and their associated constraints on yams.

1.7 Limitations of the study

The study did not include the whole area of Wolaita Zone. It was limited to only two Districts (Boloso Sore and Damot Gale) based on the yams growing and their diversity in the both Districts. It was also limited to a representative sample of kebeles of households from a selected District.

2 LITERATURE REVIEW

2.1 Botanical description of yam

Most *Dioscorea* species are perennial plants with simple leaves or compound leaves and reproduce sexually and/or asexually (Sugihara *et al*., 2021). The shape, size and color of the leaves vary from species to species and even from plants of the same species, tubers are formed by the actions of meristems in the ground and are anatomically more similar to stems than roots. Aerial nodules such as kidney or liver or horse's foot (Belachew Garedew *et al*., 2017). The straight stems of filaments are often long and curved, with alternate or opposite leaves, but they are rarely short and erect and have a single leaf around them (Caddick *et al*., 2002).

The flowers of most *Dioscorea* are dioecious, with male (staminate) and female (pistilate) flowers borne on separate plants. Female plants produce spike inflorescences with round trilocular capsules that contain two seeds per locule, and male plants produce spike inflorescences with small sessile flowers .Yam species are generally dioecious and present male and female flowers on different plants (Lebot and Dulloo, 2021). Flowers in *Dioscorea* are mostly dioecious with male and female flowers borne on separate individuals, and multiple sex-determination systems were reported in the genus (Sugihara *et al*., 2021).

In addition to sexual reproduction, *Dioscorea* species reproduce clonally through bulbs, rhizomes, or tubers. Bulbs are aerial tubers produced in the leaf axils or bracts of some *Dioscorea* species (Sugihara *et al*., 2021). Although it is mainly consumed as food, it is also used as traditional medicine in many cultures (Ikiriza *et al*., 2019). Rhizomes and tubers are morphologically diverse structures that serve as underground starch storage organs, and in some species, spiny roots prevent tubers from being buried or burrowed by animals and herbivores (Sugihara *et al*., 2021).

2.2 Origin and distribution of yam

People in West Africa, it is said that harvesting yams for domestic use began as early as 5000 BC. The family Dioscoreaceae has 350–400 species found in tropical and subtropical regions, particularly in West Africa, parts of Central America and the Caribbean, the Pacific Islands, and Southeast Asia (Caddick *et al*., 2002). There are 11 important species of edible yams (*Dioscorea alata*, *Dioscorea bulbifera*, *Dioscorea cayenensis*, *Dioscorea* *dumetorum*, *Dioscorea esculenta*, *Dioscorea japonica*, *Dioscorea nummularia*, *Dioscorea oppositifolia*, *Dioscorea pentaphylla*, *Dioscorea rotundata* and *Dioscorea trifida*, (five-leaved, round and three-lobed yams) (Lebot and Dulloo, 2021). The only species that has gained importance as a food crop in the American tropics is the alpine patch (*Dioscorea trifida*), but production is currently limited to the West Indies (Brücher, 1989). *Dioscorea bulbifera*, commonly known as aerial yam, is native to Africa and South Asia (Salehi *et al*., 2019).

Yams (*Dioscorea* spp.) occur in tropical, subtropical, and temperate regions of the world, particularly in West Africa, parts of Central America and the Caribbean, the Pacific Islands, and Southeast Asia (Maneenoon *et al*., 2008). Additionally, many wild species are important for food scarcity and medicinal purposes (Lebot and Dulloo, 2021). Martin and Ortiz (1963) described the geographical origin and habitat of the species, including its distribution, botanical classification, morphology, and cytology. Geographical origins of various yam species vary. On the other hand, the diversity found in the tropics comes from three different geographical regions: West Africa, Southeast Asia, and tropical America. Ethiopian yams are different from the types of yams found in West Africa. *Dioscorea abyssinica* is native to Ethiopia, but its cultivation is limited in this country (Muluneh Tamiru *et al*., 2007). *Dioscorea bulbifera* is a carbohydrate-rich species that grows in south Ethiopia (Muluneh Tamiru *et al*., 2007).

2.3 Yam production in the world

Yam is a globally important edible tuber and root plant (Cao *et al*., 2021). It is the fourth most important tuber crop in the world (IITA 2006). The West African yam belt region, which includes Benin, Ghana, Côte d'Ivoire, Nigeria, and Togo, produces almost 96% of the world's production (72.6 million tonnes) (FAOSTAT 2017). Nigeria is the world's leading yam producer, accounting for over 65% of global production (FAOSTAT 2017). In 2020, the world's top 10 yam producing countries (Table 1) produced 72.3 million tonnes of yams, of which Africa accounted for approximately 99%. Approximately 97% of global yam production comes from West Africa, with Nigeria alone producing approximately 69%, producing more than 50 million tonnes across an area of 6.3 million hectares (Wumbei *et al*., 2022).

The remaining decade's yam production trends in west Africa and in three leading yam-producing nations, Nigeria, Ghana, and Côte d'Ivoire, using the meals and agriculture enterprise company statistical database (FAOSTAT) information. A production increase of 1.72, 1.43, and 1.35 times resulted in an area harvest increase of 2.25, 1.23, and 1.59 times in Nigeria, Ghana, and Côte d'Ivoire, respectively. Nigeria and Côte d'Ivoire had the worst yam productivity across the decade by producing at an even in Ghana, wherein the productivity increased throughout the decade, the average productiveness turned into 33% of the expected capacity yield. For that reason, it is able to be discovered that the primary purpose for the increase in yam manufacturing throughout the globe and in West Africa is especially because of the increase in area below cultivation in the predominant yam-generating countries (Danquah *et al*., 2022).

Table 1: List of 10 top yam-producing countries in 2020 in the World

Rank	Country	Production (tons**)**	Production (ha)	Yield (tons/ha)
1	Nigeria	6,307,232	50,052,977	8
2	Ghana	468,433	8,532,731	18
3	Cote D'Ivoire	1,200,405	7,654,617	6
4	Benin	228,998	3,150,248	14
5	Togo	98,547	868,677	9
6	Cameroon	62,008	707,576	11
7	Central African Republic	58,533	491,960	8
8	Chad	47,784	458,054	9.6
9	Papua New Guinea	21,185	363,387	17
10	Haiti	9,983	63,358	6
	Total	8,503,108	72,343,585	

Source: Wumbei *et al*., 2022

Yam has the ability to grow in the presence of biotic and abiotic stress factors, which makes it suitable to many agro-ecologies. It is small wonder, then, that it can be found in over 50 nations, with Africa accounting for 96.5 % of its production, America for 2.4 %, Asia for 0.4 %, and Oceania for 0.7 % (FAO, 2021). Yam production has increased at an annual rate of 3.6 over the last three decades. Over 74 million tons of yams were produced in 2020 (Demilew Deres Andualem, 2022).

According to the National Bureau of Statistics, agriculture employed approximately 60% of Nigeria's labor force and contributed more than 40% of the country's annual average real gross domestic product (GDP) (National Bureau of Nigeria Statistics, 2012). Between 2009 and 2018, the annual production of yams in Africa increased by 55%. However, yield per hectare has decreased over the same time period. The decline in yam yield per hectare in Africa between 2009 and 2018 was estimated to be more than 21%.

2.4 Yam production in Ethiopia

Farmers in Ethiopia rely on unimproved landraces to sustain yam production. Smallholder farmers have significant genetic diversity that can be further exploited for sustainable yam genetic resource utilization and conservation (Muluneh Tamiru *et al*., 2008). Ethiopia is Africa's fifth largest yam producer, with an estimated annual production of 1,191,809 metric tons in 2014 (FAO, 2015).

The crop is critical to local livelihood, particularly in densely populated areas of the country's south, southwest, and west (Muluneh Tamiru *et al*., 2006). Nine different types of yam have been reported to grow in Ethiopia, demonstrating the country's species diversity. It grows at elevations ranging from 1140 to 2200 masl and in a variety of soil types, primarily clay, clay loam, sandy, and sandy loam. During the 2018 cropping season, Ethiopia's annual yam production was estimated to be over 1.35 million metric tons on 45,254 hectares of land, accounting for more than 90% of eastern Africa production (FAOSTAT, 2018). Despite the fact that Ethiopia has a large supply of fresh tubers, production is still far below what it is in some West African countries.

Yam (*Dioscorea* species) is one of the most significant staples tuber crops in Ethiopia (Fekadu Korsa *et al*., 2022). In Ethiopia, yam is widely distributed and grown by subsistence farmers in the country's south, southwestern, and western regions (Atnafua Bekele and Endashaw Bekele, 2020). In 2020, Ethiopia's total yam production was estimated to be 45,730 tons on 4874 hectares of land by 356,872 farmers (Wasihun Gizaw and Desu Assegid, 2021). The availability of a widely diverse landrace, large tracts of arable land, and newly released cultivars holds much promise for Ethiopia's yam production (Demilew Deres, 2022). There are eleven (11) *Dioscorea* spp. in Ethiopia.

Off these, number of yam species produced in Sheko district reported by Belachew Garedew *et al*. (2017), were *Dioscorea cayenensis complex Dioscorea alata*, and *Dioscorea bulbifera*.

2.5 Farmer's folk taxonomy of yam

Morphological diversity research in crop plants is critical for defining morphological descriptors for genetic resource characterization and management (Beyerlein and Pereira, 2018). Similar to other forms of indigenous technical knowledge, folk taxonomy may have consistency issues. Therefore, the primary concern for validation was the name system's consistency (Firew Mekbib, 2007). The overall structure of morphological diversity corresponds to local classification systems. However, some landraces that farmers thought were distinct were classified together, and no clear morphological differences were found between them. A few landraces with the same vernacular names were morphologically distinct as well (Bizuayehu Tesfaye *et al*., 2021; Muluneh Tamiru *et al*., 2011). The morphological characteristics of folk species vary, and these variations are frequently used as phenotypic markers for folk taxonomy. Their differences included seed color, yield, and panicle type, and maturity period, resilience to biotic and abiotic stressors, feed, and food value. The most important morphological trait used in folk taxonomy is morphology (Firew Mekbib, 2007).

Qualitative morphological characterizations such as the presence or absence of spines on stems and roots, the number of male and female inflorescences, stem length, twining direction, and flesh color were used to characterize and identify *Dioscorea* species (Atnafua Bekele and Endashaw Bekele, 2020). Spines of various sizes are distributed all over the surface of the vine and tuber in wild type landraces. Landrace tuber shape ranged from irregular to oval to cylindrical. Tuber flesh color, white with purple followed by purple, purple with white and outer purple/inner white, with dominant light and dark brown tuber skin color, were used to identify yam landraces (Tewodros Mulualem *et al* 2021).

Qualitative and quantitative traits are important agronomic traits for distinguishing landraces from the population (Mulualem Tewodros *et al*., 2020).

2.6 Management practices of yam diversity

2.6.1 Trends of landrace maintenance

Study from Basketo and Dera Malo Districts reported a decreasing trend in maintaining high on-farm landrace diversity, which may be related to farmers' withdrawal from certain landraces for a variety of reasons (Tizazu Gebre, 2019). Results have been also reported from Gamo Gofa and Wolaita Zones over the last 20-30 years, with yam production and the number of landraces maintained on individual farms declining in most localities (Muluneh Tamiru *et al*., 2008).

2.6.2 Source of planting materials

Yams are traditionally grown from tubers or pieces of tuber from the previous crop. The planting component is referred to as a "mother tuber" or "sett." While 300 g is a reasonably normal quantity, the size of sett utilized varies, ranging from about 100 g to 500 g or more (Osullivan, 2010). Planting material is obtained from a variety of sources, including personal savings, exchange with neighbors or relatives, and, to a lesser extent, purchases from local markets (Yeshitila Mekbib and Temesgen Deressa, 2016). In the Wolaita and Gamo-Gofa Zones, there is no formal seed supply system for yam, nor do farmers specialize in the production of yam planting materials. Farmers rely primarily on planting materials saved from the previous cropping season (Muluneh Tamiru *et al*., 2008; Yeshitila Mekbib and Temesgen Deressa, 2016).

2.6.3 Staking materials

Yams are grown along stake rows, with the exception of wild yams, which are planted close to trees for support. Among the materials commonly utilized to support yam plants are young Eucalyptus trees, as well as maize and sorghum (*Sorghum bicolor*) stalks. Staking starts once the tubers have grown and formed sizable tendrils. Each plant is trained along a vertical stake that is provided. The only kind of staking that is used in Wolaita and Gamo Gofa Zone is individual staking. In South Ethiopia, most of farmers got their staking materials from trees planted on their farms and the neighboring forests and some purchasing from different sources (Muluneh Tamiru *et al*., 2008). Staking is an important practice and without staking no yams production possible practice, because yams are climber plant. Staking is supporting the yams vines so that they can grow upright (Belachew Garedew e*t al*., 2017).

2.6.4 Planting time of yam

The growing season of yam in Ethiopia varies from region to region. It is sown in October in most of south Ethiopia and in November to December at the beginning of the dry season in the southwestern and western part of the country, taking advantage of moisture reserves from previous rain. In Ethiopia, yam is seen as a supplementary crop for farmers in times of food scarcity, as it is usually grown in October at the beginning of the dry season and harvested from early-maturing local varieties in May and June. It is an important crop for food and security in the country (Muluneh Tamiru *et al*., 2008). According to Andres *et al*. (2016), yams are typically planted in Ghana's traditional areas between December and February, which is the heaviest part of the dry season. As a result, planting is often accompanied by mulching (mulching) of the group with some grass or leaves to prevent the plants from growing hot and dry. However, farmers who are not able to plant around this time would usually wait until the rain starts in April/May. Moreover, according to the survey in Sheko district, most of the farmers practice mixed farming and only a few farmers practice mono-cropping. Farmers intercrop the crop with other grains such as maize or vegetables such as cabbage (Belachew Garedew *et al*., 2017).

2.6.5 Nutrient requirements of yams

Yams have long been aware of the need for soil fertility because productivity drops rapidly when other crops are grown on the same land or during periods of decline. For yams production, nitrogen is the most crucial ingredient. However, it does not make sense to consider the need for fertilizer in this context. The needs of crops in a location depend on the ability of the soil to provide nutrients and the ability of the crops to utilize nutrients. The amount of nutrients removed from crops is often used as a preliminary estimate of crop fertilizer yield. Nutrients in terms of nitrogen, phosphorus and potassium are often depleted by replanting; this is an essential strategy for long-term preservation of fertility (Osullivan, 2010).

2.6.6 Storage of yams

The maturity, harvesting time, and storage location varied by location, as did the various types of root and tuber crops grown by local farmers. Most farmers use ground or field storage, which means they are left in the ground to grow for varying lengths of time until they are needed for eating or/and propagation purposes as planting material for the following propagation seasons or for sale purposes because deterioration is usually slow (Belachew Garedew *et al*., 2017). In order to partly ensure food security, yam storage is very important. In other words, yams are stored either for future consumption, higher market prices or for replantation (seeds yam) in another season (Verter and Becvarova, 2014).

Due to the difficulties in yam preservation, the majority of the yam farmers are compared to either consume or sell all their yam products at low prices before the new harvesting season. Consequently, before new harvesting period, they are bound to suffer food security crises (Verter and Becvarova, 2014).

2.6.7 Harvesting and post-harvest practices of yams

In terms of yam harvesting and storage, there are practices in place. At full senescence, late-maturing landraces are harvested only once, whereas early-maturing types are harvested twice (double harvested). The first harvest occurs in the East Wollega and Ilu Ababora Zones of western Ethiopia in July, followed by the second harvest in December (Yeshitila Mekbib and Temesgen Deressa, 2016).

The first harvesting occurs in August or September, when the vines are about to stop growing and some of the bottom leaves have turned yellow. This occurs when the plant has fully bloomed, which is normally six months after planting. The yam plant will recover and continue to grow after this initial harvest before eventually withering and drying up. This makes it possible to produce late yam types such *Discorea alata* as well as seed yam, which is harvested during the second harvest period (December to January) (Wumbei *et al*., 2022). According to Belachew Garedew *et al*., (2017), the majority of harvesting occurred in June after seven months of planting in Sheko District, Southwest Ethiopia. Similarly, farmers in the Gamo-Gofa and Wolaita Zones of south Ethiopia used both single and double harvest practices, with early maturing landraces planted in October and the first harvest beginning in May or June (Muluneh Tamiru *et al*., 2008).

2.7 Food security and yam cultivation

According to the World Food Summit of 1996, food security is achieved when all people have physical and financial access to enough safe, nutrient-dense food that satisfies their dietary needs and food preferences for an active and healthy life, regardless of their circumstances. When individuals always have access to enough food for a healthy and active life, food security is ensured. Thus, food security implies that the food must be available to the consumers. Food must also be able to meet acceptable nutritional levels in terms of calories, proteins and minerals that are needed by the body (Davies, 2009).

Yams are important food sources that can be boiled, baked, or fried. It provides food and nutritional security to 300 million people in Africa, Asia, parts of South America, the Caribbean, and the South Pacific Islands (Nanbol and Namo, 2019). Fresh yam tubers have a high nutritional content of protein, fiber, and important minerals such as calcium and iron, but a relatively low fat content (Atnafua Bekele and Endashaw Bekele, 2014). Yams are grown mainly for food and commercial purposes. Crops such as corn, wheat, taro, sweet potato, millet, and cassava are grown for food security, while tomatoes, potatoes, coffee, and cabbage are grown for cash (Tewodros Mulualem *et al*., 2022).

After a decades-long decline and five years of relative stability since 2014, the global level of the prevalence of undernourishment (PoU) has increased sharply between 2019 and 2020 and rose at a slower pace between 2020 and 2021, under the shadow of the COVID-19 pandemic. Nearly 10% of the world population suffered from hunger in 2021, compared with 9.3 percent in 2020 and 8 percent in 2019. The situation is most alarming in Africa, where the PoU is the highest among all regions and has increased the most between 2019 and 2021 by 2.8 %. In 2021, 20.2 percent of the populations in Africa were undernourished (FAOSTAT, 2022).

Because it can be stored, traded, and consumed during the dry, off-season, or "hungry months," when the production of other crops is unattainable, yam is a crop that promotes both food security and income development (Neina, 2021). In many of the countries where it is grown, yam cultivation is seen as a source of both food security and employment for a large number of people (FAO, 2020). Yams are considered food security crops and are widely consumed for nutritionally rich tubers, particularly in developing countries. In order to reduce hunger and ensure food security, especially for the poor rural residents who are more susceptible to bad luck, food production is a prerequisite (Bakayoko *et al*., 2021).

Yam is the main staple food consumption, source of income and employment generation. This implies that, yam production is a necessary condition in enhancing food security. Nevertheless, facing a food security crisis, in recent years, global attention has been focused on the need to eliminate food insecurity and hunger across the especially in the developing countries where chronic hunger and malnutrition still persist. Attaining food security is presently one of the major problems households are facing in as elsewhere in West Africa (Verter and Becvarova, 2014).

2.8 Importance of yams

2.8.1 Food importance of yams

Yams are the staple food for households (Degla and Sourokou, 2020; Pouya *et al*., 2022). It is a significant food crop in developing countries feeding over 150 million people (Frossard *et al*., 2017). It is also an important root crop that is widely used for food (Tewodros Mulualem *et al*., 2018). In terms of nutrition, yam is a major staple food consumed by millions of people in West Africa. It consumed in various forms, including fufu (also known as poundo yam and Amala in Nigeria), boiled, fried, and roasted (Aidoo, 2009). Yam is also high in vitamins A and C, as well as fiber and minerals. In many countries, yams are grown and consumed as edible tubers and regarded as a major root crop due to its importance (FAOSTAT, 2018; Kim *et al*., 2021).

2.8.2 Socio-cultural importance of yams

Aside from the nutritional composition, including carbohydrates, proteins, minerals, and vitamins, yams play a key role in social, cultural, and religious aspects of lifestyle in western Africa (Agre *et al*., 2021). Many beliefs made yam, in the past a unique crop used through offerings for transmission between the ancestors and the living and whose production was subject to special rites. From planting to harvesting the yam, customary rules were observed to ensure a better yield and avoid unhappiness. As a sacred crop, ceremonies and rites related to the yam were organized from the first harvest and remained a prerequisite for its consumption (Degla and Sourokou, 2020). Yams are important in social and cultural activities in Sub-Saharan African countries such as Nigeria and Ghana. Some households, for example, used it during marriage and fertility ceremonies. Furthermore, the festival is held yearly to commemorate its harvest and other social ceremonies (Bamire and Amujoyegbe, 2005; Aidoo, 2009).

2.8.3 Economic importance of yams

The average yearly production of yams worldwide is 60 million tons, with a gross value of $14 billion USD (Darkwa *et al*., 2020). It is a source of income for millions of people in West Africa (Pouya *et al*., 2022). If in the past, yam had only been a food and cultural crop; over time it has acquired a market importance which nowadays also makes it a popular cash crop, about 34% of the annual production intended for sale (Degla and Sourokou, 2020).

2.8.4 Medicinal (therapeutic) importance of yams

Both cultivated and wild yam tubers are high in nutrients, minerals, and bioactive metabolites, providing significant nutritional and therapeutic benefits (Obidiegwu *et al*., 2020). These health-promoting products can help to prevent cardiovascular disease, diabetes, and gut microbiome disorders (Epping and Laibach, 2020). Patients with a variety of health problems take yam processed food as medicine. Yams are grown primarily for their tubers, which are high in carbohydrates, proteins, lipids, fibers, and minerals; their foliage is used to make pharmaceutical products (Padhan *et al*., 2018).

2.9 Chemical composition of yams

Yam tubers have high moisture content, ranging from 60 to 85%, and low dry matter content, ranging from 7 to 40%. The observed high moisture content has a negative impact on tuber storage quality. In terms of protein and fat, yam tubers may not be considered a particularly high-protein or high-fat food source. Yam tubers are good sources of energy, and the energy is primarily derived from carbohydrate because the tubers are low in fat (Emmanuel and Bassey, 2017). Their organoleptic properties make them the most widely used carbohydrate food and dietary supplements. The underground and/or aerial tubers represent valuable sources of proteins, fats, and vitamins for millions of people in West Africa (Salehi *et al*., 2019).

2.10 Production constraints of yams

Productivity of yam was hampered by low soil fertility, a lack of improved yam varieties, poor road networks, high labor costs, and a lack of funds to carry out necessary farming activities. Pest-related problems have also been identified as significant constraints to yam production. These include parasitic nematodes, insects like leaf and tuber beetles, fungi like leaf spot and tuber rot, and viruses (Asante *et al*., 2007).

According to Yeshitila Mekbib (2007), Storage roots in yams are used as propagating material for next planting season, increasing genetic similarity among landraces. Farmers selected and preserved landraces based on phenotypic and agronomic traits

Traditional yam production methods include double harvesting and cutting large tubers into 150-1000g setts. Farmers have been introduced to the minsett technique, which uses 25-50g setts to produce seed yam, but adoption is generally low (IITA, 1985). Pests and diseases in both the field and storage are the most significant constraints in yam production; pests, particularly yam beetles, create holes in the tubers, reducing tuber quality and facilitating fungal infection, leading to tuber rots. Nematode attack also has an impact on tuber quality. Nematode infestations in yam-producing areas are increasing due to the shortening of fallow periods. It is also estimated that staking could double the cost of yam production, particularly in remote areas where live stakes or crop stakes are not present in the farm for trailing of the vines (Manyong and Oyewole, 1997).

When compared to older varieties and local types, the yam varieties in farmers' fields are no longer the heavy foliage type with high yielding, and this situation creates favorable conditions and open spaces for rapid weed growth. As a result, farmers perform three weddings before the final harvest, increasing the overhead cost of production and reducing yam farmers' profit margins (Manyong and Oyewole, 1997).

The decline in *Dioscorea rotundata* production in West Africa is attributed to a general lack of planting material (Alvarez and Hahn, 1983). Water yam (*Dioscorea alata*) production is primarily done with small, whole tubers or setts cut from larger tubers. Because these planting materials are edible and economically important components of the crop, the demand for yam tubers as a planting material competes with the demand for consumption (Akoroda and Hahn, 1995). Yam plants and harvested tubers are frequently attacked by a variety of fungi, insects, viruses, bacteria, and nematodes. Several pathogenic fungi have been discovered to be associated with yam, causing diseases such as anthracnose, leaf spots, and blight, as well as yam tuber rotting (IITA, 1975). Tubers that have been harmed by the yam beetle (*Heteroligus* spp.) or termites should not be stored. Insect attacks can result in the destruction of 50% of the harvest after several months of storage.

To increase women and youth participation in yam production, extension field officers will need to use communication strategies that are sensitive to people's age, educational level, primary occupation, and household size (Adam *et al*., 2014). Increased participation of women in agricultural production increases their decision-making power in pest and disease management, resulting in increased crop production and productivity (Okonya *et al*., 2021). Male farmers dominated yam production practices, with a lower percentage of female farmers. The lower percentage of female farmers could be attributed to the previous land ownership system, which discriminated against women in all of the areas surveyed (Tewodros Mulualem *et al*., 2022). Muluneh Tamiru *et al*., (2011) conducted a similar study and found that most farming activities are dominated by men.

Socioeconomic, biotic, and abiotic factors are threatening yam production in southwest Ethiopia (Tewodros Mulualem *et al*., 2022). It includes inadequate crop attention and crop dilution due to lack of improved crop technologies, drought, and wild animal attacks. Drought and wild animal attacks were the primary causes of yield loss. Moreover, from the Wolaita and Gamo Gofa Zone yam productions were hampered by a number of environmental and production factors such as agro-ecology, household resources, population pressure and cultural background (Muluneh Tamiru *et al*., 2008). This has resulted in a decrease in production and yam diversity in the majority of the surveyed areas (Muluneh Tamiru *et al*., 2005). According to Tewodros Mulualem *et al*., (2022), the majority of farmers were aware of the constraints affecting their crops. The main limiting factors in yam production were reported to be low crop attention, drought, animal attacks, poor management, and a lack of farm land, dilution of the crop by improved cereal technologies, labor shortage, low soil fertility, and poor extension service.

3 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location of the study area

Boloso Sore is located in Wolaita Zone in South Ethiopia Region. The district is one of the 16 districts of Wolaita Zone and 7 city administrations. It is located about 380 km south of Addis Ababa, 210 km from Hawassa, and 40 km from the town of Wolaita Sodo (Derese Balcha and Mathewos Chafa, 2022). Boloso Sore is situated between 7000" 00' and 7011"00' N Latitude and 370 00"00' and 37050"00' E longitude. Boloso Bombe District to the west, Damot Sore District to the south, Badawacho District of Hadiya Zone to the east, and Kambata Tambaro Zone to the north are the districts' borders., Areka is a major town of Boloso Sore District and it was established 1955 E.C changed from Boloso Sore to Areka at the time of empire Haile Sellasie. Moreover, this town is comparatively situated on the West Tadisa Kebele, the East Dubo Kebele, the North Wurimuma Kebele, and the South of Yukara Kebele (Figure 1).

Damot Gale is also a District in the Wolaita Zone of the South Region of Ethiopia. The District is also one of the 16 districts of Wolaita Zone and 7 city administrations, which is located in escapement of rift valley and lies between 6.89°-7.12° N and 37.75°-38° E longitude. The altitude ranges from 1900-3000 meters above sea level and its peak was Mount Damot and 370 km of South of Addis Ababa and is 150 km West of Sidama region (Haimanot Zewdu *et al*., 2021). Administratively, it is subdivided into 31 Kebeles (DGWMAO, 2014). From an astronomical perspective, the district lies between latitudes 6° 55' 00" and 7° 10' 00" N and longitudes 37° 45' 0" and 38° 0' 0" E. Its borders are as follows: Sodo Zuria to the southwest; Boloso Sore and Damot Pulasa to the northwest; Hadiya Zone to the north; Diguna Fango to the east; and Damot Weyde to the southeast. Boditi serves as Damot Gale's administrative center (Figure 1).

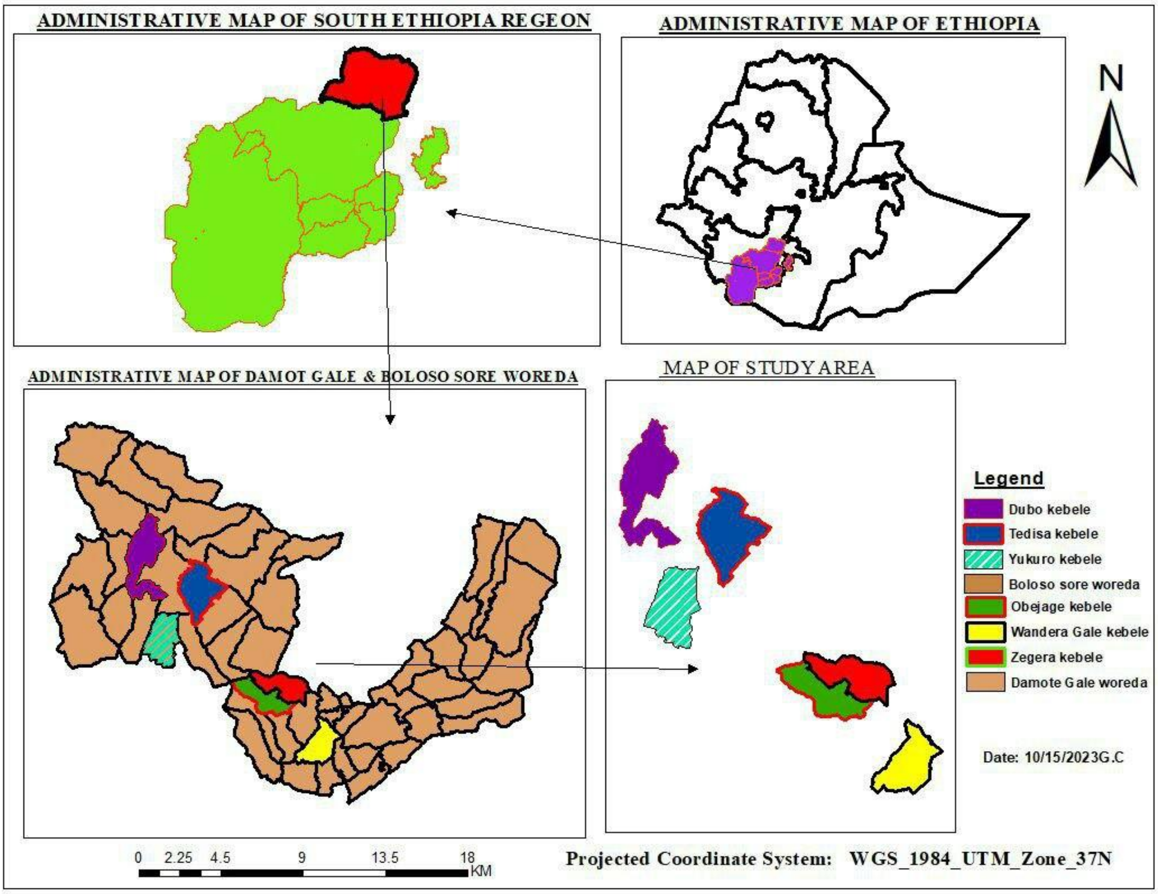

Figure 1: Administrative map of the study area; Source: ArcGIS, 2023

3.1.2 Population

Boloso Sore is one of the largest District of Wolaita zone with large population and land area. The area of the district is 28,800 hectare and further divided in to 29 rural kebeles (Mefekir Woldegebrel, 2017). According to the 2019 population projection conducted by the Central Statistical Agency (CSA), this District has a total population of 279,218, whom 144,236 are female and 134,982 are male. From the total population only 9.18% are urban dwellers and the rest were rural dwellers (Mefekir Woldegebrel, 2017). Based on the 2019 population projection conducted by the CSA, Damot Gale District has a total population of 213,245, of whom 104,006 are male and 76,852 are female; 24,133, or 15.97%, of its population are urban dwellers. The District has area coverage of 24,285.9 hectare and accommodates an estimated number of 145,741 human populations (Haimanot Zewdu *et al.*, 2021).

3.1.3 Climate of the study area

In terms of agro-climate, Boloso Sore is classified as *Wayna-Dega* (Central Land) accounting for 83% of the total area and the remaining 17% is classified as *Dega* (Highland) where the climate is good (BSWARD Office, 2014), for settlement. The average temperature is between 10°F and 20°F. It is rainy from June to August, and September is the transition period between the rainy season and the dry season. Annual rainfall in the region varies between 1201 mm and 1600 mm (Wolaita District Bureau of Meteorology, 2014). The altitude is approximately 1800 meters and the average rainfall is approximately 1538.44 mm. The mean minimum and maximum temperatures of the area are about 14.48 °C and 28.5 °C, respectively (Kebede Habtegiorgis *et al*., 2018). It is mainly midland agroecology with moderate temperature and better rainfall.

Damot Gale encloses three agro-climatic zones, high land (*Dega*), mid land (*woynadega*), and low land (*kola*). The Dega is above 1800masl, and Woina Dega 1500-1800masl. These climatic zones are highly degraded, over cultivated for long periods of time and densely populated with easily erodible landscape (Mathewos Agize *et al*., 2016). Two cropping seasons (called Gabbaa and Silla in the local language, or Belg (short rainy season) and Meher (main rainy season) in the national language, respectively) are known in the area. The Belg cropping season extends from March to May with medium amount of rainfall, whereas Meher extends from June to September with high amount of rainfall. Mean annual rainfall was 1328.4 mm with the highest record in August. Damot Gale District has Dega (22%), Woina Dega (49%) and Derek Woina Dega (29%) climatic condition. The mean annual minimum and maximum temperature of the area were 10.8°C to 28°C respectively.

3.1.4 Topography of the study area

Boloso Sore Woreda is known for its diverse topography, characterized by a combination of highlands, lowlands, and river valleys. The area is part of the Ethiopian Rift Valley, which contributes to its varied landscape. The region is situated at an altitude ranging from approximately 1,200 meters to 2,800 meters above sea level. In the highland areas, you can expect to find steep slopes, rugged terrain, and rolling hills. These areas may be more suitable for agriculture and are often utilized for farming purposes. On the other hand, the lowland areas tend to have a flatter topography, with plains and valleys. The presence of rivers and streams in the woreda creates fertile river valleys that support agricultural0 activities.

The topography of Damot Gale District is ranged from middle to steep slope. The mount Damota is rugged with deep gorges incised by river valleys. The slope gentle at its foot but becomes very steep at about altitude of 2000 m and above (Haimanot Zewdu *et al*., 2021). In the study area, agricultural land is the primary resource base that is used to create economic opportunities for rural households. Approximately 90% of the study area's economic activity is derived from agriculture (Awoke *et al*., 2019).

3.1.5 Crop cultivation in the study area

Boloso Sore is suitable to crop production; Enset, coffee, taro, potatoes, yam and fruits are the common crops grown (Kebede Habtegiorgis *et al*., 2018). However, the government focused on production of Teff, Maize, and wheat and haricot bean with high artificial fertilizers demand and with high market value. In addition, Taro, Ginger, Potatoes, Fruits mainly (mango and avocado) and yams are also produced. Crops such as maize, teff, sweet potato and enset are major cereals, roots and tuber crops grown and they occupy the largest proportion of cultivated land. Coffee, teff and Irish potatoes are grown as cash crops. Corn also plays an important role in cash generation. Farmers also raise animals such as, cows, goats, sheep, donkeys, horses and chickens. Agriculture meets the population's needs for milk, dairy products and meat. Livestock generates income, provides draught power, source of manure and means of transportation (Derese Balcha and Mathewos Chafa, 2022). The Boloso Sore District is known by its practicing predominantly agriculture (arable farming and animal husbandry). The main agriculture in the district is corn, teff, coffee, Enset, banana, etc. products (Mefekir Woldegebrel, 2017).

Damot Gale has an area of intensive agriculture; farming systems that combines annual and perennial crops; where cereals, root crops and cash crops grown. Cropping system in Damot Gale could be categorized into; intensive cereals, root crops and pulses. Major cereals crops growing in the area are like Wheat, Barley, Teff, Sorghum, and Maize, from cereals Wheat is mainly grown for market (Melese Data and Zegeye Paulos, 2017). Crops cultivated close to home sites or inside the home stead are such as *Daucus carota, Colocasia sculenta, Colocasia antiquorum, Yantothoma sagittifolium, Lactuca sativum, Brassia* spp., *Ipomoea batatas, Carica papaya, Cucurbita pepo, Dioscoria alata, Ph*aseolus *vulgaris, Pisum sativum, Plectranthus edulis, Ensete ventricosum, Musa paradisiacal, Saccharum officinarum, Malus sylvestris, Capicum* spp, *Lycopersicom esculenta, Zea mays, and Solanum tuberosum.* In Wolaita culture farmers plant coffee (locally called Tukkiyaa) more close to house in that they believe the smoke from the house and the frequent interaction of people stimulate the coffee to give more yield. In general, the home gardens in the study area are a mixed- farming system that is based on the enset and the coffee crops. These two crops are high economic return value so as high attention is given in cultivation of these crops. In Wolaita enset has special importance due to its massive use and the development of diverse local varieties (Mathewos Agize *et al*., 2016).

3.1.6 Geology and soil types

The soil types of Boloso Sore District are sandy clay loam (Kebede Habtegiorgis *et al*., 2018). Soil types in Damot Gale district are silt, clay and clay loam. In mount Damota area, the soil has reddish brown (Nitosols) color and derived from a multistory ignimbrite substratum the soil has high porosity and infiltration. These features gave the soil a good quality for cultivation. However, low levels of nitrogen and phosphorus (nutrient depletion) due to erosion and repeated cultivation significantly affect the production in the area (Haimanot Zewdu *et al*., 2021).

3.1.7 Agro-ecological conditions of the study area

The Figure 2 represents rainfall, maximum temperature, and minimum temperature for two districts, Damot Gale and Boloso Sore, over a period of 12 months. For Damot Gale, the rainfall varied from 442.1 mm to 3359.32 mm, with an average of 2106.85 mm. The maximum temperature ranged from 27.04°C to 32.72°C, with an average of 29.32°C. The minimum temperature varied from 12.85°C to 14.59°C, with an average of 13.72°C. For Boloso Sore, the rainfall varied from 555.1 mm to 4842.2 mm, with an average of 3097.98 mm. The maximum temperature ranged from 25.52°C to 30.28°C, with an average of 27.07°C. The minimum temperature varied from 13.36°C to 15.06°C, with an average of 14.5°C. From meteorological records of the National Meteorological Services Agency of Ethiopia (NMSA), Hawassa branch, the raw monthly data at the station, total monthly rainfall, average rainfall, and average maximum temperatures and average minimum temperatures of both districts were calculated to check climate variability. Both districts experienced varying levels of rainfall and temperature throughout the year, with Boloso Sore having higher rainfall and Damot Gale having slightly higher temperatures on average (Figure 2). These agro-ecological variations may result in the formation of different varieties of yams in the study area.

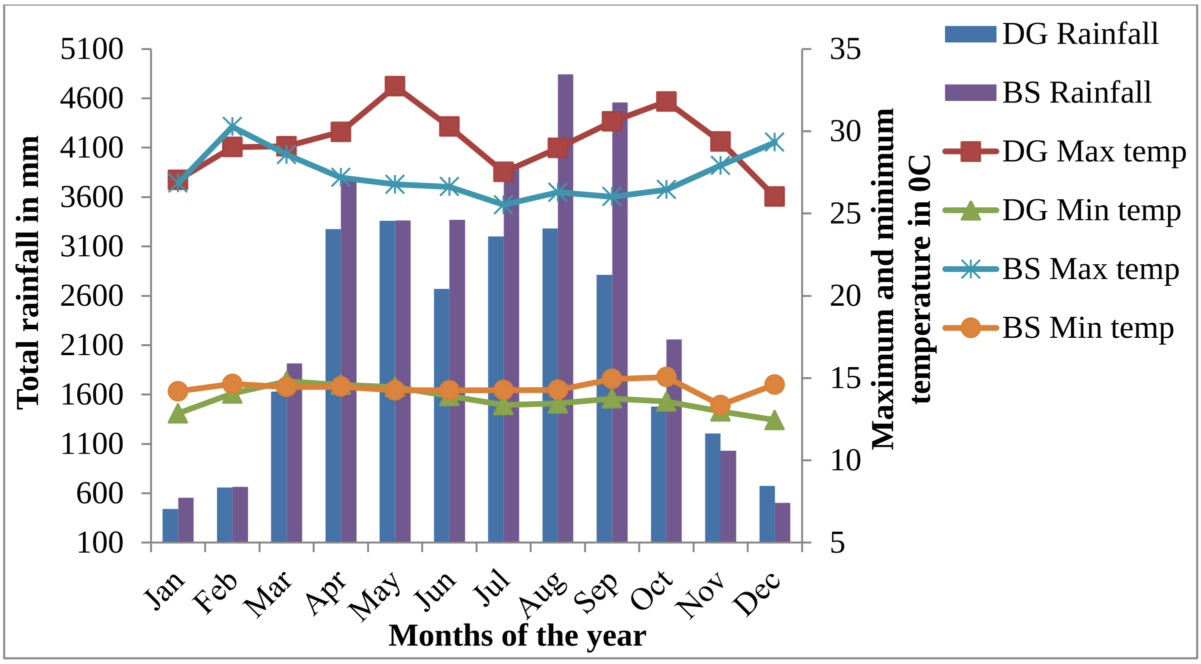

Figure 2: Maximum and minimum temperatures for Boloso Sore from 2015-2020, and for Damot Gale from 2000-2020, along with the rainfall data for the same period in both districts.

3.2 Sampling design

3.2.1 Sampling techniques

The preliminary survey was made at the beginning of February 2023 before the actual data collection for the determination of sample size, which mainly depends on the purpose of the study. In order to select the respondents a three-stage sampling approach were employed. First, the study area (Boloso Sore and Damot-Gale Districts) were purposively selected based on yam growing habits of the Districts. Accordingly, the six representative sampling kebeles namely Yukara, Dubo, Tadisa from Boloso Sore District; Zegere, Obejage and Wandara Gale from Damot Gale District were selected because of production popularity in yam production with the guidance of the Developmental Agents (DAs).

Second, households were selected from each of the six kebeles proportionally. The total farmer's house hold of six kebeles were 4,373 (N) from these samples of 366 (n) households were selected based on Yamane (1967) simplified formula (Eq. 1). Therefore, the total farmers of selected kebeles were 4,373 then arranged as P1, P2, P3, P4, P5 and P6 are 1068, 465, 626, 721, 562 and 931represents Yukara, Dubo, Tadisa, Zegere, Obejage and Wandara Gale respectively. So, ki = sample size (n) (Pi/total house hold of selected kebele), where ki is sample size of house hold in each kebele, Pi is the household number of each kebele. Finally, systematic random sampling methods used to select respondents from each kebeles. The use of this particular sampling method involved three steps. In first step, sample interval (n^{th}) was determined by dividing total households of six kebeles (4,373) by their respective sample sizes (366).

The second step involved a random sampling of respondents from six kebeles. To begin random process, first number was picked between 1 and n^{th} number using systematic random sampling through lottery method. At this time, first number to n^{th} number were written on pieces of papers and folded in a bowl. Then, a blindfolded person asked to pick first number from bowl, which served as basis for selecting rest of respondents using sample interval.

The data were collected from February 2023 to June 2023 from the selected households and key informants residing in the six kebeles and through phone contact. Consequently, primary information was collected through a sample household survey and key informant interviews.

3.2.2 Sample size determination

In fact, formulas can be used to determine sample size based on the size of the population, the amount of variability in the population, the estimated size of the effect, and the amount of sampling error. The larger the sample size, the more accurately it represent the population. Yamane (1967) provides a simplified formula to calculate sample sizes.

$$n = \frac{N}{1+N(e)2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. \dots \dots \dots \dots \dots \dots ... (Eq. 1)$$

Where “n” is the sample size, “N” is the population size, and “e” is the level of precision (sampling error) at 5% (0.05) with confidence level of 95%. “1” is probability of the event occurring. Then, the sample size (n) was calculated by using Equation 1.

n = targeted population / (1 + targeted population * (sampling error) ^{2}), in this case, targeted population = 4,373, sampling error = 0.05

Substituting the values into the formula:

$n = 4,373 / (1 + 4,373 * (0.05)^2)$

$n = 4,373 / (1 + 4,373 * 0.0025)$

n = 4,373 / (1 + 10.9325)

n = 4,373 / 11.9325, n ≈ 366, according to the calculation, a sample size of approximately 366 households would be selected from the targeted population of 4,373.

$$n = \frac{4{,}373}{1 + 4{,}373(0.05)2} = 366$$

Accordingly, 366 households were sampled from the total household population of the six selected kebeles (4,373) by using the proportions of the household population of the respective kebele (Eq. 2) below: Samples household of each kebele was expressed as:

$$ki = \frac{n * Pi}{N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eq. 2)$$

Where, “n” is the sample size was selected from the six sample kebeles, Pi is the number of household population of the respective kebeles, N represents the total households of the six kebeles and k is samples household of each kebele (Eq. 2). Accordingly, 90, 39, 52, 60, 47 and 78 households sample respondents were sampled from Yukara, Dubo, Tadisa, Zegere, Obejege and Wandara Gale respectively. The systematic random sampling technique was used to select households from each kebele. The population sizes of the six kebeles were obtained from both districts of Agricultural and Rural Development Office (ARDO) and the managers (DAs Office) of the respective kebeles. Total number of households, sample sizes and Elevation range of each kebele was summarized in (Table 2).

Table 2: Total numbers of households, Elevation range (masl) and sample sizes

Districts	Kebele	Elevation range (masl)	Total Households in Kebele	Sampled Households
Boloso Sore	Yukara	1,600-2,000	1068	90
	Dubo	1,700-1,900	465	39
	Tadisa	1,600-1,900	626	52
Damot Gale	Zegere	1,800-2,120	721	60
	Obejage	1,700-2,100	562	47
	Wandara Gale	1,700-2,220	931	78
Total	6		4,373	366

3.3 Instruments/tools used and source of data

Both primary and secondary data were collected by employing the following data collection methods/ instruments. Thus, Primary data were collected from yam producers through personal interviews and key informant interviews by using Kobo collect application tool. The respondents were knowledgeable local farmer household heads of different age, farming experience, wealth status and educational levels. Secondary data sources included relevant documents from various websites, as well as unpublished reports from the District Agricultural Offices (DAO) and the Libraries, as well as research articles.

3.3.1 Key informant interviews

The key informants were identified as individuals who are knowledgeable on the cultivation and managements of yams (*Dioscorea* spp.). The key informants were selected purposively from each study kebeles based on professional and educational background, leadership role and experience in traditional farming systems. Based on the above criteria, one kebele manager, four model farmers, and one developmental agent (1+4+1)*6 = 36 were selected from each kebele. Also, two agriculture experts were selected from each district of Agricultural Office for additional information. Totally thirty-eight (38) key informants were selected from six kebeles.

3.3.2 Field observation

Field observation was conducted to assess the essentiality of the study area with respect to diversity, distribution, management, and their constraints of yams (*Dioscorea* spp.). It includes transect walks (home gardens, cultivated fields), key informants, and informal dialogue with farmers in order to collect information from selected farmers. This survey was used to collect general information about the study area and identify representative sampling sites.

3.3.3 Semi-structured interviews

For this purpose, the respondent households were selected from the six kebeles based on the sizes in Table 2 using systematic random sampling method. A semi-structured interview was conducted with household heads on different aspects of yams (*Discorea* species). The main focuses of the interview were socio-demographic information, land ownership, ethno-botanical information, agronomic and socio-economic aspects, and input usage by farmers. The collected information was documented, saved, and sent to Kobo Collect application tool for data entry into Microsoft Excel for analysis.

3.3.4 Focus group discussion

Purposive Sampling method was used to select members for focus group discussion from targeted population: This method involves hand-picking participants based on relevant knowledge, experiences, or characteristics that can contribute to the discussion about yam production. Focus group discussion (FGD) helps to allow a small group of respondents to guide by a skilled moderator, to focus on key issue of the research topic. Two FGDs were held in each kebele, each FGD was composed of six individuals who were selected based on socially status within the society and are known to have better knowledge on the present and past yam status of the study area. The main purpose of FGD is to get insights and understand of smallholders about yams. During the focus group discussion, the perception of farmers about yams in the area, constraints of yam particularly wild animal attack and temperature variability (drought) and occurrence of extreme events were given an emphasis and also participants of FGDs have also discussed on management strategies.

3.4 Data management, analysis and presentation of findings

Data collected, both qualitative and quantitative, were analyzed by statistical software and summarized in tables and graphs as percentages. The qualitative data was analyzed partially during the process of data collection to be able to immediately identify gaps to be filled through subsequent data collection. The quantitative data was first summarized, tallied, coded, and processed, and analyzed by analysis of variance (ANOVA) and frequency distributions, descriptive statistics, correlations, and other relevant data analysis was carried out using SPSS version 25 statistical software.

3.5 Diversity measurement and yam landraces

i. Shannon diversity index (H')

ii. Evenness (E)

iii. Simpson's diversity index (D)

iv. Sorenson's similarity index = $\frac{2c}{a+b}$

The diversity of yam landraces was measured in terms of richness and evenness. "Richness" refers to the number of different kinds of landraces without indicating their frequencies. Evenness refers to measuring how similar the frequencies of the different variants are. Distribution, on the other hand refers to the number of surveyed locations occupied by a landrace. Yam landrace diversity was measured across sites, and the variation in richness and evenness across sites were also be compared. Shannon and Simpson diversity indices were used to measure the diversity of yam landraces across districts and kebeles.

i. Shannon diversity index (H'):

Shannon diversity index (*H')* combines both number and evenness of categories considered, and can be increased either by greater evenness or more unique species.

The index is described as:

Shannon diversity index (H') = $-\sum_{i=1}^{s} pi\ lnpi$ … … … … … … … … … … … … … … … … Eq 3

Where, "s" is number of landraces, and "pi" frequency of landrace i (ni/N). "ln" is natural logarithm.

ii. Evenness (E) :

Evenness (E) was also calculated separately as a measure of the ratio of the observed diversity to the maximum diversity. It is defined by the function:

$$\mathrm{E} = \frac{H'}{lns} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 4$$

Where, "*H*'" is Shannon index and "s" refers to the number of landraces recorded in each district (kebele). "*lns*" is a measure of landraces abundance. A value of evenness approaching zero reflects larger difference in abundance of landraces, whereas the higher evenness value means all landraces are equally abundant with high diversity (Magurran, 1988).

iii. Simpson's diversity index (D):

Simpson's diversity index (D) basically measures the probability that two individuals randomly selected from a sample belong to the same category (Simpson, 1949). Hence, as D increases, diversity decreases. The index has become, therefore, converted as 1 - d simply so more variety corresponds to higher values:

Simpson's diversity index (1-D) = $1 - \frac{\sum n(n-1)}{N(N-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 5$

where "n" represents number of farms where landrace i was found, and "N" sum of the number of farms where individual landraces was found.

iv. Sorenson's similarity index = $\frac{2c}{a+b}$

Using Sorenson's similarity index, the variance in landrace composition that happened between locations was examined. The index's calculation was:

Sorenson's similarity index = $\frac{2c}{a+b} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. 6$

Where, "a" represents number of landraces in site A; "b" represents number of landraces in site B; and "c" represents number of landraces common to both sites.

4 RESULTS AND DISCUSSION

4.1 Socio-demographic information of Households

According to the results of our study, about 83.9% of the respondents are male and 16.1% are female (Table 3). Similarly, Tizazu Gebre (2019) found that the majority (68.75% of households) were male-headed households, while 31.25% were female-headed households. Similarly, Tewodros Mulualem *et al*. (2020) reported that products were made by men (75.83%) in the Jimma (Manna, Shebesombo, Dedo, Sekachekorsa, and Kersa), Sheka (Yeki), and Bench-maji (Sheko) regions of Western Ethiopia.

Table 3: Socio-demographic information of respondents

Variable	Categories of variable	Frequency	Percentage (%)	Mean (m)
Gender	Male	307	83.9	
	Female	59	16.1	
	Total	**366**	**100.0**	
Household size	1-3	16	4.37	
	4-6	200	54.64	6
	7-9	138	37.71	
	10 and above	12	3.28	
	Total	**366**	**100.0**	
Age	21-30	31	8.47	
	31-40	138	37.70	
	41-50	129	35.25	43
	51-60	48	13.11	
	61 and above	20	5.47	
	Total	**366**	**100.0**	

Marital status	Married	303	82.8
	Widowed	39	5.7
	Divorced	2	0.5
	Single	1	0.3
	Polygamy	21	10.7
	Total	**366**	**100.0**
Religion	Protestant	245	66.9
	Orthodox	115	31.4
	Catholic	6	1.6
	Total	**366**	**100.0**
Educational level	Illiterate	135	36.9
	Grade 1- 4	95	26.0
	Grade 5- 8	80	21.9
	Grade 9 12	40	10.9
	Degree (diploma, bachelor, MSc)	16	4.4
	Total	**366**	**100.0**

As per the findings of this study, household size indicates that households with 1-3, 4-6, 7-9, and 10 and above members contain 16 (4.37%), 200 (54.64%), 138 (37.71%), and 12 (3.28%) of the respondents, respectively (Table 3). The minimum household size was 2 and the maximum was 14, with an average household size of 3.28% and a mean of 6 household sizes, and the family size of most households was 4-6 (54.64%), with 37.71% of respondents belonging to households with 7-9 members, and 3.27% belonging to households with 10 members and above.

Based on our study, the majority of the respondents were between the age groups of 31–40 and 41–50 years, with 138 (37.70%) and 129 (35.25%), respectively (Table 3). The age of the household of all respondents ranged between 24 and 85, with an average age of about 43. The higher representation of respondents within the 31-40 and 41-50 age groups indicates a mature and potentially stable workforce engaged in yam production. This understanding can guide labor planning, resource allocation, and support systems within farming societies. This result is supported by the finding of Boadu *et al*. (2019), from a major yam-producing district in Ghana, who reported that the majority of the respondents were between the ages of 30 and 49.

According to our study about 303 (82.8%), 39 (5.7%), 2 (0.5%), 1 (0.3%), and 21 (10.7%) were married, widowed, divorced, single, or polygamous, respectively. Married individuals often have access to additional labor resources within their households, which can positively impact the cultivation, maintenance, and harvesting of yam crops. This indicates the importance of recognizing and involving the entire household in agricultural activities to maximize productivity. widowed can lead to decreased household labor, reduced access to resources, and limited social support systems, which might have implications for yam production. About 245 (66.9%) of the sampled respondents are protestant religion followers, 115 (31.4%) are Orthodox religion followers, and the remaining are Catholic religion followers in the study area (Table 3). Religious preferences can influence dietary choices and food consumption patterns. Considering the dominant religious group's dietary preferences, such as yam consumption, can help in aligning production and distribution strategies to meet the local demand effectively.

Education is important to the improvement of agricultural productivity; formal education opens the mind of a farmer to knowledge; non-formal education gives a farmer hands-on training and better methods of farming; and informal education keeps a farmer well-informed with changing innovations and ideas and allows a farmer to share experience gained (Oduro-Ofori Eric *et al*., 2014). Regarding the results of this study, the majority of 135 (36.9%) were illiterate, while Grades 1–4 were 95 (26.0%), Grades 5–8 were 80 (21.9%), and Grades 9–12 were 40 (10.9%). Moreover, the respondents who had degrees (Diploma, bachelor, and MSc) were only 16 (4.4%) of the respondents. This result implied that the sample respondents with different educational backgrounds participated in the interview. However, the most of the households were illiterate. The relatively higher proportion of respondents in Grades 5-8 (21.9%) and Grades 9-12 (10.9%) suggests a range of educational backgrounds and skill levels. This diversity may lead to differing levels of productivity and efficiency in yam production. The results indicate that a significant portion of the yam farming households lacks formal education and advanced degrees. This could have implications on the economic aspects of yam production, such as access to markets, value addition, and income generation. It is a similar result to that reported by Tizazu Gebre (2019) from Basketo and Deramalo Districts, Southwest Ethiopia: out of 248 sample respondents, about 46.7% were illiterate. Similarly, Tewodros Mulualem *et al*. (2020) reported that 102 (42.5%) were illiterate and had never attended formal school; 116 (48.33%) had completed primary school, and 22 (9.17%) had completed secondary school.

4.1.1 Farmland holding size

According to our results, the size of farms allocated to yam production ranged from 0.01 to 0.12 hectares, with an average farm size of 0.03 hectares. In comparison, the overall agricultural farm size ranged from 0.06 to 2.13 hectares, with an average of 0.5 hectares. The farm sizes for other crop production fell within a similar range, varying from 0.05 to 2.10 hectares, with an average size of 0.47 hectares (Table 4). Similarly, Tizazu Gebre (2019) reported that few households cultivate yam accessions share a small land area and invest less capital in the Basketo and Dera Malo Districts of south Ethiopia Region. Relatively, a similar result was also reported by Tinsae Abrham *et al*. (2020) on sweet potato from Misrak Badawacho District, Hadiya Zone, Central Ethiopia Region, which indicated that farmers are producing sweet potato on a maximum of 0.25 hectares of their total land size. Similarly, in the two main cassava-producing areas of Offa and Amaro in south Ethiopia, Shiferaw Bogale et al. (2022) showed that the average land holding was 0.6 hectares with a maximum land holding of 1.25 hectares.

Table 4: Farms of yam producers in the study area

Kebele	" Mean total farm size" (ha)	"Mean yam farm size" (ha)	"Mean farm size of other crops" (ha)
Yukara	0.65 (0.13-1.50)	0.04 (0.01-0.12)	0.62 (0.10-1.48)
Dubo	0.57 (0.13-1.5)	0.03 (0.01-0.11)	0.54 (0.12-1.47)
Tadisa	0.57 (0.25-2.0)	0.04 (0.01-0.12)	0.52 (0.21-1.88)
Zegere	0.33 (0.06-2.13)	0.02 (0.01-0.08)	0.37 (0.11-2.10)
Obejage	0.40 (0.06-1.50)	0.02 (0.01-0.03)	0.42 (0.05-1.47)
Wandara Gale	0.39 (0.06-1.0)	0.01(0.01-0.03)	0.34 (0.05-1.98)

Numbers in parenthesis refer to minimum and maximum values of farm sizes in each Kebele

Yared Dagne and Tewodros Mulualem (2014) reported that land holdings per household in the study villages of the Dalbo Watershed in the Wolaita Zone of South Ethiopia on taro are typically small, rarely reaching one hectare, and the average size of a land holding per home was 0.771 hectare. 0.25 hectares and 2.5 hectares, respectively, were the minimum and maximum land holding sizes. There was no significant correlation between farm size for agriculture with land size allocated for yam (r = 0.072). On the other hand, the farm land size for other crop production with land size allocated for yam (r = 0.095); accordingly, there was a significant correlation between farm size for agriculture with farm land size for other crop production (r = 0.648**) at the 0.01 level of significance (Appendix 3). The result indicates that even those farmers with smaller landholdings allocate a considerable share of their land for yam cultivation in order to get a reasonable production and meet family needs. However, they allocate an equitable share of their land for other crop production.

According to the results of this study, the majority of households (109, or 29.8%) farm between 0.01 and 0.02 hectares. The average yam farm sizes of 0.04, 0.03, 0.04, 0.02, 0.02, and 0.01 were recorded in the Yukara, Dubo, Tadisa, Zegere, Obejage, and Wandara Gale

Kebele, respectively (Table 4). Also, the highest average yam farm size of 0.04 hectare was recorded among farmers in the Yukara and Tadisa Kebele. This is about 0.03 hectares bigger than that operated by farmers in the Wandara Gale kebele. Similarly, Kutoya Kusse (2021) reported that the production and productivity of the major root and tuber crops have been decreasing due to a dramatic decline in the area of land under root and tuber crop cultivation in the South Omo Zone, South Ethiopia. Also, Kuwornu *et al*. (2010) state that the larger the farmland owned by the household, the higher the expected level of food production and the more likely the household is to be food secure.

4.1.2 Elevation ranges and conservation status of yam landraces

According to the results of this study, in Tadisa, were all households selected produce yam were located at intermediate elevations (1,750–2,000 masl) (Table 5). On the other hand, in Dubo, Yukara, Zegere, and Obejage, most of the farms surveyed were also found at intermediate elevations. However, in Wandara Gale Kebele, the majority, approximately 79.5% of the surveyed farms, were living at high elevations (2,000–2,225 masl) (Table 5). The study findings indicate the importance of considering elevation as a factor in understanding the geographic distribution and conservation of yam landraces in the surveyed districts (Boloso Sore and Damot Gale).

Table 5: Number of yam landrace growing farms surveyed at three different altitude ranges and conservation status of yam landraces in Boloso Sore and Damot Gale district

Districts	Kebele	Number of farms according to elevation			The conservation status of yam landraces		
		High	Intermediate	Low	Conserved	Threatened	Very rare
Boloso Sore	Yukara	0	87	3	14 (15.6)	76 (84.4)	0 (0.0)
	Dubo	0	37	2	1 (2.6)	33 (84.6)	5 (12.8)
Damot Gale	Tadisa	0	52	0	5 (9.6)	47 (90.4)	0 (0.0)
	Zegere	8	52	0	4 (13.3)	48 (80.0)	8 (6.7)
	Obejage	6	40	1	8 (17.0)	27(57.4)	12 (25.5)
	Wandara Gale	62	16	0	1 (1.3)	59 (75.6)	18 (23.1)

Altitude range: High (2,000–2,225 masl), intermediate (1,750–2,000 masl) and Low (1,550–1,750 masl) according to Muluneh Tamiru *et al*. 2008 (Numbers in parenthesis refer to percentage values based on the number of farmers interviewed in each Kebele)

The current study result was in line with results reported by Muluneh Tamiru *et al*. (2008) from the Wolayita and Gamo-Gofa zones of South Ethiopia Region, reported that the elevation ranges where yam farmers were interviewed varied among districts. Similarly, Nuru Endris (2018, unpublished) in Basketo Special Districts reported that the number of landraces recorded in each Kebele by concerning elevation range. Also, concerning the enset landraces in the Amaro Special District, South Ethiopia, Tizazu Gebre and Aschenaki Lemma (2019) reported on the agro-ecologies highland (2001 – 3000 masl), midland (1400 – 2000 masl), and lowland (<1400 masl). In other reports, contrasting this study finding, yam grows well in an open canopy at lower altitudes compared to high altitudes, according to Subba *et al*. (2023).

The classification of yam landraces as "Conserved," "Threatened," or "Very rare" typically depends on certain criteria, Concerning population size and geographic distribution. Conserved landraces generally have a large and stable population, while threatened landraces have a declining population, and very rare landraces have a critically small population. Concerning geographic rage, conserved landraces are usually widely distributed across different regions, while threatened landraces may be limited to specific areas, and very rare landraces may be restricted to just a few locations.

Accordingly, the results of this study reveal that only 15.6% of yam landraces were conserved, with a significant majority of 84.4% being threatened in Yukara Kebele. About 2.6% of yam landraces were conserved, 84.6% faces threats in Dubo Kebele, and 12.8% were considered very rare. 9.6% of landraces were conserved, but about 90.4% were threatened in Tadisa Kebele. In Zegere Kebele, 13.3% were conserved, 80.0% were threatened, and 6.7% were very rare. Also, in Obejage Kebele, about 17.0% were conserved, but 57.4% remained threatened, and 25.5% were reported as very rare. Only 1.3% was conserved, with a significant majority of 75.6% threatened and 23.1% very rare reported in Wandara Kebele (Table 5). These findings indicate the urgent need for targeted conservation initiatives to address the considerable threat and rarity levels observed in each kebele.

In contrast to other crops like maize, cassava, and sweet potatoes, the status of yam in the Democratic Republic of the Congo was reported as threatened, according to Adejumobi *et al*. (2023). Similarly, Tinsae Abrham *et al*. (2020) found on sweet potatoes from Misrak Badawacho District, Hadiya Zone, Central Ethiopia Region that the status of sweet potato production is very rare under farmer conditions. Tizazu Gebre and Aschenaki Lemma (2019) also reported the conserved status of Enset in the Amaro District of the South Ethiopia Region, and every farming household cultivates Enset in their home gardens.

4.2 Diversity of yam landraces across in the two districts

In this study, a total of 19 yam landraces were identified, with 12 classified as early landraces and 7 as late landraces (Table 6). Among the late landraces, Unkurubo was identified as a particularly distinct type, belonging to the *Dioscorea bulbifera* species, characterized by its tuber resembling a horse's foot. This classification was based on variations in the shape and size of the aerial tubers, known as bulbils. The yam landraces in the study area exhibited variations in maturity time, tuber flesh color, and desirability for consumption.

Table 6: Yam landraces described in Boloso Sore and Damot Gale districts of their Kebele

Yam landraces (*Dioscorea* spp.)	Number of farms per Kebele								
	Y	D	T	Z	O	WG	TNS	TNF	RF
Bota boye (Dolka) [d]	48	13	24	0	21	19	5	125	34.2
Arkiyia [d]	0	0	0	37	3	41	3	81	22.1
Gajela [s]	18	0	2	18	39	28	5	105	28.7
Attuma-Ayina [s]	53	32	43	29	17	16	6	190	51.9
Macha-Ayina [d]	28	3	3	2	6	1	6	43	11.7
Oha [d]	0	0	0	25	0	6	2	31	8.5
Wayicha [s]	30	1	16	0	0	0	3	47	12.8
Unkurubo [a]	12	13	14	0	0	2	4	41	11.2
Wolabua/Wolabo boye [s]	16	1	8	0	0	7	3	32	8.7
Hatiye [d]	6	1	1	0	4	4	5	16	4.4
Genna [d]	14	3	8	0	0	0	3	25	6.8
Moratabua/Mortabo [s]	2	17	15	0	0	0	3	34	9.3
Gassa [d]	4	1	0	0	1	0	3	6	1.6
Fara [d]	3	0	0	0	1	0	2	4	1.1
Macha boye [d]	0	1	0	0	0	0	1	1	0.3
Wodala [s]	1	0	0	0	0	2	2	3	0.8
Welawa [d]	0	2	0	0	0	0	1	2	0.5
Zo'o-macha boye [d]	1	0	0	0	1	0	2	2	0.5
Suyitiyia [d]	0	0	0	0	0	2	1	2	0.5

Y – Yukara, D – Dubo, T – Tadisa, Z – Zegere, O – Obejage, WG – Wandara Gale; TNS – Total number of sites, TNF – Total number of farms, RF – Relative frequency; "a" aerial yam, "d" double-harvested, "s" single-harvested; (0)-"not reported to be present".

Similar findings regarding yam landraces have been reported in other studies by Atnafua Bekele and Endashaw Bekele (2020), Muluneh Tamiru *et al*. (2008), Belachew Garedew *et al*. (2017), and Itefa Degefa and Baressa Anbessa (2017), emphasizing the diversity and characteristics of different yam types. Tewodros Mulualem *et al*. (2022) also stated that farmers preferred yam attributes such as high yield, suitable market, early maturity, powdery texture after boiling, and disease resistance. This aligns with the findings of Tewodros Mulualem *et al.* (2020) in Jimma, Sheka (Yeki) and Bench-maji (Sheko) Zones of Southwestern Ethiopia. Also, in line with Shiferaw Bogale *et al*. (2022) for selecting cassava varieties for production in south Ethiopia, indicating the importance of specific traits for cassava selection and production. On the other hand, the classification of yams into "male" and "female" categories, such as Macha Boye (early maturity) and Attuma Boye (late maturity) in the Gamo-Gofa and Wolaita Zone of South Ethiopia Region, was found to be independent of their reproductive biology, according to Tamiru Muluneh *et al*. (2011). However, Sugihara *et al*. (2021) reported that various sex-determination systems exist within *Dioscorea* species, based on both cytological observations and molecular analyses.

On the other hand, Tizazu Gebre (2019) in the districts of Basketo and Deramalo and Tsegaye Babege *et al*. (2021) in Bench-Sheko and Sheka Zones of southwestern Ethiopia reported higher number of yam landraces. Similar studies on landraces of other crops, such as sweet potatoes in Northern Benin by Adjatin *et al*. (2018), have reported variations in early and late landraces. The diversity of enset landraces in the Sidama Region, as indicated by Bizuayehu Tesfaye and Peter Ludders (2003) further exemplifies the richness of traditional crop varieties in different regions. The number of yam landraces recorded in this study is smaller compared to other reports in South and southwestern Regions of Ethiopia. The variation could be attributed to factors such as different surveyed areas, diverse ethnic groups, and the use of traditional identification methods by farmers. This study emphasizes the diversity of yam landraces based on various attributes and indicates the preferences of farmers in selecting specific traits for yam cultivation. The study uncovers previously undocumented varieties or landraces of yams grown in the study area. This contributes to the overall knowledge of yam diversity in the study area and potentially highlights the importance of conserving rare or endangered yam varieties. Also, it is essential for maintaining yam landraces diversity.

4.3 Diversity of yam landraces among study Kebeles within districts

According to the results of this study, the total number of recorded yam landraces in Zegere and Yukara Kebele varied from 5 in Zegere to 14 in Yukara. The mean number of landraces across the two districts was 10.2, ±3.1 (Table 7). Similarly, Tsegaye Babege *et al*. (2021) reported that the numbers of landraces recorded (richness) per Kebele varied from 5 to 13 in Bench-Sheko and Sheko Zones of Southwest Ethiopia. The findings are consistent, indicating a similar pattern of landrace richness across the regions. Also, Muluneh Tamiru *et al*. (2008) considered into the diversity of landraces in the districts of Gamo Gofa and Wolaita Zone of South Ethiopia Region in a similar manner. These studies focused on assessing the diversity of landraces in specific districts or zones. The current study reported variations in landrace diversity across two districts and Kebeles, as reported Muluneh Tamiru *et al*. (2008) in Gamo Gofa and Wolaita Zone. These studies provide evidence of wide-ranging diversity within specific regions, emphasizing the importance of preserving genetic resources.

Table 7: Yam landrace diversity in Boloso Sore and Damot Gale District and their respective Kebeles

Districts	Kebele	Richness	No of unique landrace	H'	1-D	Evenness
Boloso Sore	Yukara	14	0	2.18	0.86	0.83
	Dubo	12	2	1.82	0.79	0.73
	Tadisa	10	0	1.91	0.83	0.83
Damot Gale	Zegere	5	0	1.43	0.74	0.89
	Obejage	9	0	1.58	0.75	0.72
	Wandara Gale	11	1	1.92	0.83	0.80

The number of landraces recorded in this study was also so much lower than reported by Nuru Endris (2018, unpublished) in Basketo Special Districts, who reported that the number of landraces recorded in each Kebele varied from 16 to 27. The current study's recorded number of landraces (5 to 14 per Kebele) was lower compared to Nuru Endris's findings (16 to 27 landraces per Kebele) in Basketo Special Districts. This suggests regional differences in landrace richness, possibly due to geographic, cultural, or ecological factors. The lower number of recorded landraces in the present study highlights the need for conservation and management efforts to prevent the loss of genetic diversity. Moreover, According to Tewodros Mulualem *et al*. (2020) reported higher numbers of landraces per district and Kebele in Bench-Sheko and Sheko Zones of Southwest Ethiopia compared to the current study. The wider range (30 to 42) and higher means (34.28 district level; 10.90 Kebele level) observed in their study indicate greater landrace richness. The discrepancy may be attributed to different study locations or specific local (agro-ecology) variations in landrace diversity. The variations in landrace richness and diversity imply the importance of localized conservation and management strategies.

According to our results, Yukara Kebele had the highest diversity, while Zegere Kebele had the lowest diversity. Yukara Kebele showed the highest diversity, with a diversity index (H') of 2.18, indicating a rich variety of yam landraces. Zegere Kebele had the lowest diversity, with a diversity index of 1.43, suggesting a limited range of yam landraces. The Simpson diversity index further confirmed the high diversity in Yukara and Wandara Gale, while Dubo and Zegere had the lowest diversity.

The richness of landraces among Kebeles showed a significant correlation with Shannon's diversity index (r = 0.916*) and Simpson's diversity index (r = 0.814*), as indicated in (Appendix 5). The positive correlation between landrace richness and diversity suggests that promoting landrace richness can contribute to overall diversity conservation. These results align with previous studies that found wide-ranging diversity in Bolosso-Sore and Damot-Gale districts in the Wolayita Zone (Muluneh Tamiru *et al.*, 2008).

According to this study, the evenness of landraces per Kebele ranged from 0.72 to 0.89 (Table 7). Lower evenness of landraces was observed in Dubo, Boloso Sore district, with richness of 12, and in Obejage, Damot Gale district, with a richness of 9. On the other hand, high evenness of landraces was observed in Yukara, Boloso Sore district, with a higher richness of 14. This suggests that there is a more even distribution of a large number of landraces in Yukara and this also indicates the diversity of yam landraces. Furthermore, there were differences in the evenness of landraces among the surveyed Kebeles, as presented in Table 7. However, the evenness of landraces among Kebeles showed a negative and insignificant relationship with richness (r = -0.391) (Appendix 5). The insignificant relationship (negative correlation) between evenness and richness indicates the need for further investigation into the factors influencing landrace distribution patterns. The evenness of landraces varied among kebeles, with Zegere demonstrating high evenness and Dubo and Obejage showing lower evenness. However, there was a negative and insignificant relationship between evenness and richness across the kebeles. Therefore, the results of the study indicate significant variations in yam landrace diversity, richness, and evenness among two districts and kebeles.

4.4 Diversity of yam landrace at Household level

According to the results of this study, there is variation among Kebeles with respect to the number of landraces maintained per farm. Majority of farmers on average grew single landraces per farm, about 126 farms cultivated only one landrace (Table 8). This means that in these farms, farmers focused on growing a single type of landrace. The range of landrace richness at the household level was largest in Yukara, where it varied from 1 to 8 landraces, while the smallest range was observed in Dubo Kebele, ranging from 1 to 4 landraces. At the individual farm level, the number of landraces ranged from 1 to 8, with an average of 2.3 landraces per farm. This diversity in farming practices was reflected in the proportions of farms growing different numbers of landraces across the Kebeles.

Also, 114 farms grew two landraces, 69 farms grew three landraces, 33 farms grew four landraces, 16 farms grew five landraces, 4 farms grew six landraces, 3 farms grew seven landraces, and 1 farm grew eight landraces (Table 8). These imply that the majority of farmers focused on growing a single landrace per farm, indicating a preference for mono-cropping. However, there was still variation among Kebeles, with some households cultivating multiple landraces.

The majority of these households had less than three cultivars per farm, with the most frequent category being those who grew one to two landraces. Furthermore, the mean number of farms per Kebeles was higher in Boloso Sore compared to Damot Gale District, with averages of 2.6 and 1.9 farms per Kebele, respectively.

Table 8: Variation in the number of landraces planted per farm across the Kebele within both districts

No of landraces per farm	Number of farms per Kebele						
	Yukara	Dubo	Tadisa	Zegere	Obejage	Wandara Gale	**Total**
1	23	10	15	22	17	39	**126**
2	19	13	13	25	14	30	**114**
3	23	9	12	9	9	7	**69**
4	10	5	9	4	5	0	**33**
5	9	2	2	0	1	2	**16**
6	3	0	0	0	1	0	**4**
7	2	0	1	0	0	0	**3**
8	1	0	0	0	0	0	**1**
Total	**90**	**39**	**52**	**60**	**47**	**78**	**366**
Mean	**2.8**	**2.4**	**2.5**	**1.9**	**2.2**	**1.7**	**2.3**

Comparing the findings of our study with previous studies, there are significant similarities and differences in the number of landraces maintained per farm in different regions. Muluneh Tamiru *et al*. (2008) reported 1 to 6 different landraces in Wolaita and Gamo-Gofa Zones; our study reported a higher number of landraces per individual farm. Similarly, Tsegaye Babege *et al*. (2021) reported a lower range of 1 to 6 landraces in Bench-Sheko and Sheko Zones. Nuru Endris (2018, unpublished) reported a range of 1 to 7 landraces in Basketo Special Districts, while Tizazu Gebre (2019) found a wider range of 4 to 25 landraces per household in Basketo and Dara Malo District. These variations in landrace numbers can be attributed to factors such as local agro-ecological conditions, farmer preferences, cultural practices, and accessibility to diverse germplasm sources. It emphasizes the need for researchers to consider these variations when managing yam landrace diversity.

Furthermore, when comparing the number of landraces in yam cultivation to other crops, our study found a higher number of landraces per individual farm compared to sweet potato farming in Northern Benin (2 to 6 landraces per village) (Adjatin *et al*., 2018) and a lower number of landraces per individual farm compared to potato farming in Ethiopia (where at least 70% of farmers grew two or more potato varieties) (Semagn Asredie *et al*. 2015). The implications of these findings suggest that yam farmers in the study area exhibit a relatively higher level of landrace diversity compared to previous studies and some other crops.

4.5 Variation in yam landrace composition similarity that occurred between Kebeles

As in the method mentioned, a Sorenson similarity index was used to measure the similarity between pairs of Kebele in terms of named landraces. As per the findings of this study, the similarity values ranged from 0.24 to 0.83 (Table 9). This indicates a range of similarities among the Kebele pairs and the similarity and dissimilarity between all possible pairs of Kebele with respect to named landraces. The similarity or dissimilarity between Kebele can vary based on different factors, such as the genetic diversity of landraces and their environmental distance. The most similar Kebele pairs were Tadisa and Yukara, followed by Tadisa and Dubo, Dubo and Yukara, and Dubo and Obejage. These Kebele pairs exhibited higher similarity values, suggesting a closer genetic relationship in terms of landraces. On the other hand, the most dissimilar Kebele pairs were Dubo and Zegere, Yukara and Zegere, Tadisa and Zegere, Dubo and Wandara Gale, Tadisa and Obejage, and Zegere and Obejage (Table 9). These pairs showed lower similarity values, indicating greater genetic distance in terms of landraces.

Table 9: Sorenson similarity evaluations of yam landrace diversity among study Kebele, on the basis of presence and absence of landraces

Districts	Kebele	Yukara	Dubo	Tadisa	Zegere	Obejage	Wandara Gale
Boloso Sore	Yukara	1.00					
	Dubo	0.77	1.00				
	Tadisa	0.83	0.82	1.00			
Damot Gale	Zegere	0.32	0.24	0.40	1.00		
	Obejage	0.70	0.76	0.53	0.57	1.00	
	Wandara Gale	0.64	0.52	0.67	0.63	0.60	1.00

In our study, the Sorenson similarity indices were used to measure the similarity between Kebele pairs, and the values ranged from 0.24 to 0.83, indicating a range of similarities among the pairs. The most similar Kebele pairs were generally located within the same district, suggesting that geographical proximity and shared environmental conditions contribute to the genetic relationship in terms of landraces. On the other hand, the most dissimilar Kebele pairs were found between two districts, indicating greater genetic distance in terms of landraces.

These findings are consistent with previous research conducted by Tsegaye Babege *et al*. (2021) in Bench-Sheko and Sheko Zones, where the most dissimilar Kebele pairs were located in different districts. Similarly, the study by Muluneh Tamiru *et al*. (2008) in Wolaita and Gamo-Gofa Zones found that the most dissimilar pairs of districts were those located relatively far apart. Tizazu Gebre (2019) also reported variations in the composition of yam landraces between pairs of sites in Deramalo and Basketo districts. Also, Nuru Indris (2018, unpublished) reported similar findings in Basketo district

The implications of these findings suggest that geographical factors, such as proximity and environmental conditions, play a role in the similarity and dissimilarity of landraces between Kebele pairs. This implies that cultivar exchange and genetic flow are more prevalent within districts, where Kebeles share a closer genetic relationship. Understanding these patterns of similarity and dissimilarity can inform strategies for germplasm conservation, cultivar exchange programs, and the management of landrace diversity at the local and regional levels. On other crop, Pawan *et al*. (2020) found similar results in their study on genotypes of sweet potatoes in India, with genotype clusters and variable similarity coefficients indicating diverse amounts of genetic relatedness.

4.6 Distribution and abundance of yam landraces

4.6.1 Distribution of yam landraces across Kebeles

According to our findings, out of the 19 landraces, three landraces (Macha Boye, Welawa, and Suyitiyia) were specific to one kebele, meaning they were only found in that particular kebele and accounted for 15.8% of the total landraces surveyed. Four landraces (which make up 21.1% of the total) were distributed in two Kebeles, indicating a slightly wider range compared to the specific landraces mentioned earlier. The majority of landraces (63.1%) were recorded in more than two Kebeles (Figure 3), suggesting a relatively broader distribution. Among these, one landrace (Unkurubo) was found in four Kebeles, while three landraces (Bota Boye/Dolka, Gajela, and Hatiye) were distributed in five Kebeles each. The remaining landraces were recorded in three Kebeles, indicating a moderate level of distribution. However, there were two landraces (Attuma-Ayina and Macha-Ayina) that were grown in all the Kebeles surveyed, making them the most widespread among the landraces studied.

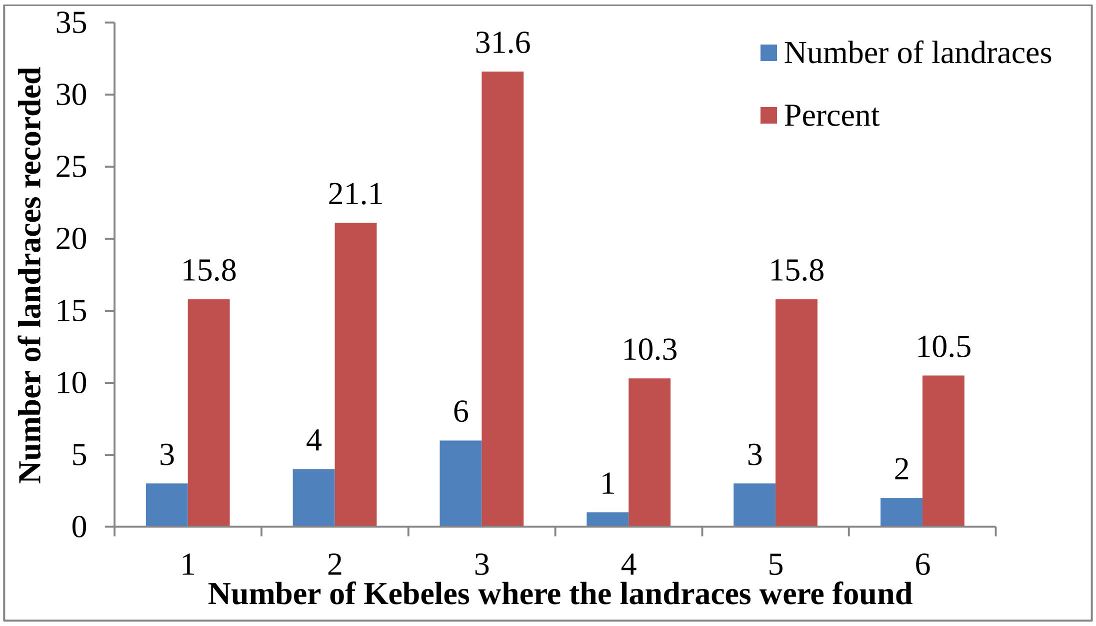

Figure 3: Distribution ranges of yam landraces across the surveyed Kebeles

Of the 19 landraces, on the other hand, 3 (15.8%) had a narrow distribution and were specific to one Kebele, whereas 16 (84.2%) were recorded at more than one Kebele. This result was similar with the previous report of Muluneh Tamiru *et al*. (2008) in district level, who reported from the Wolaita and Gamo-Gofa zones of South Ethiopia that of the 37 recorded landraces, only two (5%) were ubiquitous, being found in all districts surveyed and the others had variable range of distribution. Similarly, Tsegaye Babege *et al*. (2021) from the Bench-Sheko and Sheko Zones found that cultivar distribution differed across the Kebeles studied. 11 (32%) of the 34 landraces had a limited distribution and were found only in one Kebele, whereas 23 (68%) were found in various Kebele. Similarly, Tizazu Gebre and Aschenaki Lemma (2019) in Amaro Special District, South Ethiopia reported uneven distribution of enset landrace varieties. The implication of these findings is that there is variability in the distribution of landraces across different regions in Ethiopia, with some being widely dispersed and others being localized to specific regions. This suggested that certain landraces have adapted to specific local conditions, which could be due to factors such as environmental variations, farmer preferences, or historical factors.

The distribution of current landraces was positively and significantly correlated (r = 0.720**) with abundance (Appendix 4), indicating that more widespread landraces were typically more abundant. Similarly, Tsegaye Babege *et al*. (2021) reported that landraces distribution was found to be positively and very strongly correlated (r = 0.76***) with local abundance, implying that more widespread landraces were typically more abundant.

It is also important to recognize and preserve the genetic diversity of landraces, particularly those with limited distribution. Additionally, understanding the distribution patterns of landraces can help inform strategies for their management and utilization, such as promoting the exchange of germplasm between regions or prioritizing conservation efforts for rare or endangered landraces. Moreover, these studies show the importance of documenting and studying the distribution of landraces and learn about it in order to understand their diversity and conservation requirements. The results can help make well-informed decisions about sustainable development, conservation, and agricultural practices. Concerning the distribution of yams, the study revealed new information on the study districts- Boloso Sore and Damot Gale Districts-where yam production is low. This help in identifying potential areas for expansion or targeting interventions to increase yam production.

4.6.2 Number of distribution ranges of yam landraces across Kebeles within two districts

As per our results, in the Yukara Kebele, out of the total 19 landraces, 14 were recorded, accounting for 73.7% of the total. Similarly, in Dubo, Tadisa, Obejage, and Wandara Gale, the percentages of recorded landraces were 63.2%, 52.6%, 47.4%, and 57.9%, respectively (Table 10). In Zegere, however, only 26.3% of the landraces were recorded. The mean values recorded for the different study kebeles were as follows: 16.9 in Yukara, 7.3 in Dubo, 13.4 in Tadisa, 22.2 in Zegere, 10.3 in Obejage, and 11.6 in Wandara Gale. These mean values represent the average characteristics or measurements associated with the respective landraces in each Kebele.

Table 10: Number of yam landraces, mean, standard Deviation, number of local landraces, and landraces recorded on a single farm identified across Kebele in Boloso Sore and Damot Gale District

Districts	Kebele	Mean	Standard Deviation	No of local landraces	Landraces recorded on single farm
Boloso Sore	Yukara	16.9	17.1	0	0
	Dubo	7.3	9.7	2(10.5%)	1(0.3%)
	Tadisa	13.4	12.7	0	0
Damot Gale	Zegere	22.2	13.2	0	0
	Obejage	10.3	13	0	0
	Wandara Gale	11.6	13.1	1(5.3%)	0

According to the results of this study, two landraces, Macha Boye and Welawa, were exclusively recorded in the Dubo Kebele, accounting for 10.5% of the total landraces; one landrace, Suyitiyia, was recorded solely in Wandara Gale Kebele, representing 5.3% of the total landraces as indicated in Table 6 above. In a similar manner, Macha Boye was found on a single farm within the Dubo Kebele. These findings demonstrate variations in the distribution and occurrence of yam landraces across the Kebeles in the study area, along with differences in mean values and the presence of specific landraces in certain locations.

The results of current study showed variations in the distribution and occurrence of yam landraces. Different percentages of recorded landraces were observed in each Kebele, ranging from 26.3% in Zegere to 73.7% in Yukara. The mean values, representing the average characteristics of the landraces, also differed among the kebeles. In a similar study conducted by Tsegaye Babege *et al*. (2021) in the Bench-Sheko and Sheka Zones of Southwestern Ethiopia, rare landraces and both localized and widespread landraces were reported at the district and kebele levels. This suggests that the distribution of yam landraces can vary across different regions. Another study by Tizazu Gebre (2019) in Basketo and Dera Malo Districts of Southwest Ethiopia found significant variations in the occurrences of different yam landraces along the sampled kebeles. This further emphasizes the fact that the presence and distribution of specific landraces can differ depending on the location.

4.6.3 Abundance of yam landraces

As per the results of this study, three landraces, namely Attuma-Ayina, Bota Boye (Dolka), and Gajela, were found to be the most predominant among the recorded landraces. They were present on 51.9%, 34.2%, and 28.7% of the surveyed farms, respectively (Figure 4). Attuma-Ayina (51.9%) and Macha-Ayina (11.7%) were found in all Kebeles within two districts, indicating their widespread occurrence throughout the study area. This suggests that the yam production in the study area primarily relies on a limited number of widely distributed landraces. On the other hand, some landraces had a narrow distribution and low local abundance in a specific Kebele, being absent from the remaining areas. For example, Oha (8.4%), Fara (1.1%), Wodala (0.8%), and Zo'o-macha boye (0.5%) were found in two Kebele and they are called sporadic yam landraces, while Welawa (0.5%), Suyitiyia (0.5%), and Macha boye (0.3%) were found in only one Kebele (as shown in Table 6 above).

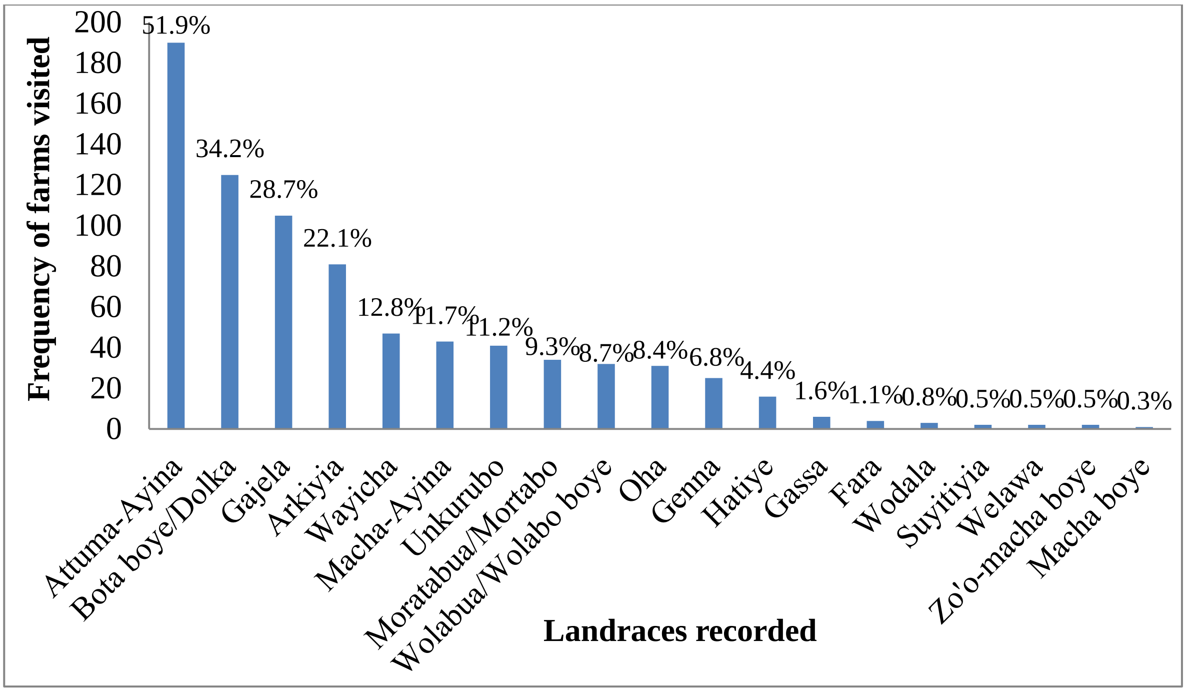

Figure 4: The relative abundance of 19 yam landraces (on the bases of n = 366)

According to the results described above, three landraces, namely Attuma-Ayina, Bota Boye (Dolka), and Gajela, were found to be the most predominant among the recorded landraces. They were present on a significant percentage of the surveyed farms, indicating their widespread occurrence in the study area. This suggests that yam production in the area heavily relies on these few widely distributed landraces. Similarly, the study conducted by Tsegaye Babege *et al*. (2021) in Bench-Sheko and Sheka Zones of Southwestern Ethiopia also reported the presence of a small number of more abundant landraces distributed across the districts, while some narrowly distributed landraces had high local abundance in specific sites but were virtually absent elsewhere. This pattern indicates the dominance of certain landraces and the potential vulnerability of narrowly distributed ones. On the other hand, our study and the study by Tsegaye Babege *et al*. (2021) reported the presence of narrowly distributed landraces with low local abundance. This indicates the risk of extinction for these landraces across their entire range, emphasizing the importance of conservation efforts to safeguard their genetic diversity.

Moreover, Tewodros Mulualem *et al*. (2022) observed a comparable trend in Jimma, Sheka, and Bench-maji Zones of Southwest Ethiopia, where a small number of highly abundant landraces were found to be widely distributed. In the case of sweet potato, Tinsae Abrham *et al*. (2020) reported a similar finding, where a small number of highly abundant landraces were widely distributed throughout a specific district in Misrak Badawacho District of Hadiya Zone of Central Ethiopia. This shows the occurrence of certain dominant landraces in sweet potato cultivation. Also the report on enset by Bizuayehu Tesfaye and Peter Ludders (2003) in Sidama Region about enset landraces indicated that the landraces had a limited distribution range and low abundance. The comparative analysis of these findings implies that there is a common pattern of a small number of highly abundant landraces dominating the agricultural lands in various regions. This concentration of specific landraces poses a potential risk in terms of genetic vulnerability and potential loss of diversity.

Therefore, it is crucial to recognize and conserve both the highly abundant landraces and the narrowly distributed ones. Conservation efforts should focus on safeguarding the genetic resources of these rare landraces to ensure their long-term persistence and contribute to the sustainable use. Understanding the distribution patterns and abundance of different landraces can inform targeted conservation strategies, promote sustainable agricultural practices, and enhance food security by preserving the diverse genetic pool available in local farming systems. The implications of these findings emphasize the need for comprehensive and proactive measures to protect and sustainably manage the range of landrace diversity, from the widely distributed dominant ones to the narrowly distributed and endangered ones.

Regarding the results of this study, the top three yam landraces cultivated by farmers in Boloso Sore District were Attuma-Ayina, Bota boye (Dolka), and Wayicha. Attuma-Ayina was cultivated by 70.7% of farmers, Bota boye (Dolka) by 47.0% of farmers, and Wayicha by 26.0% of farmers (Figure 5). On the other hand, in the Damot Gale district, the top three yam landraces cultivated by farmers were Gajela, Arkiyia, and Attuma-Ayina. Gajela was cultivated by 45.9% of farmers, Arkiyia by 43.8% of farmers, and Attuma-Ayina by 33.5% of farmers. Bota boye (Dolka) and Oha were also cultivated, but by a smaller percentage of farmers 21.6% and 16.8% respectively (Figure 6). The results suggest that the abundance and preference for specific yam landraces or varieties can vary across two districts; these may be influenced by factors such as local agricultural practices, local preferences landraces, and environmental conditions. These findings are consistent with a study conducted by Boadu *et al*. (2019) in major yam-producing districts in Ghana.

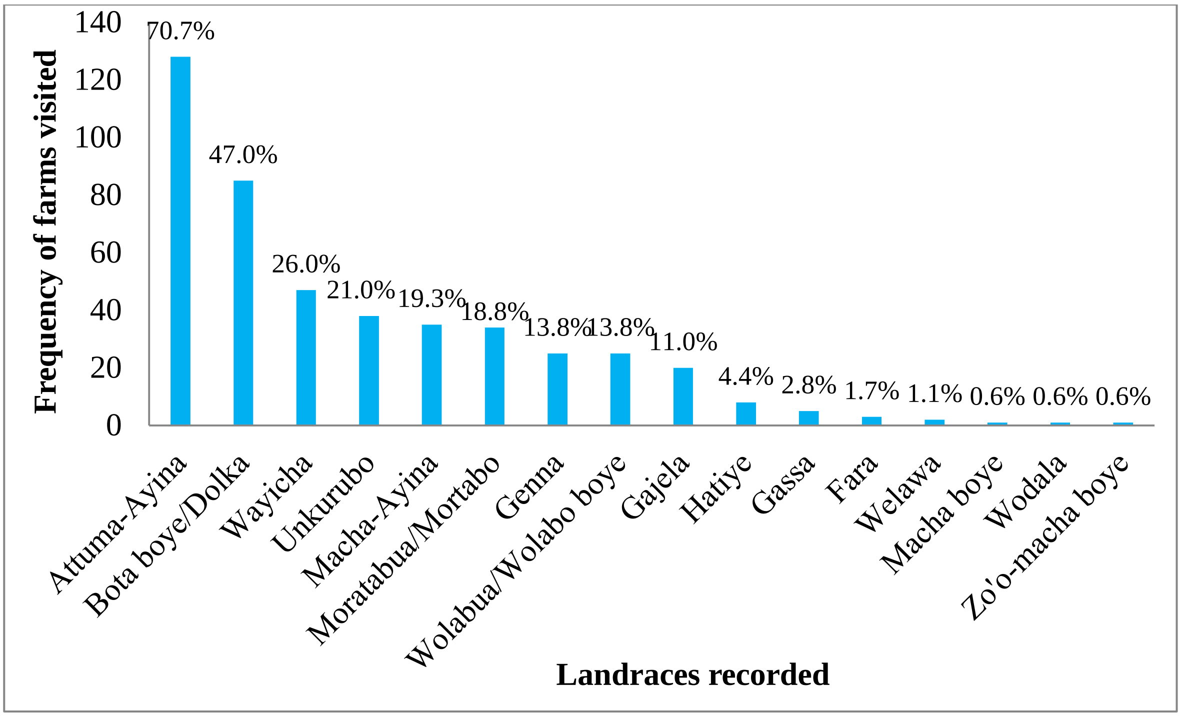

Figure 5: The relative abundance of yam landraces in Boloso Sore districts (on the bases of n = 181)

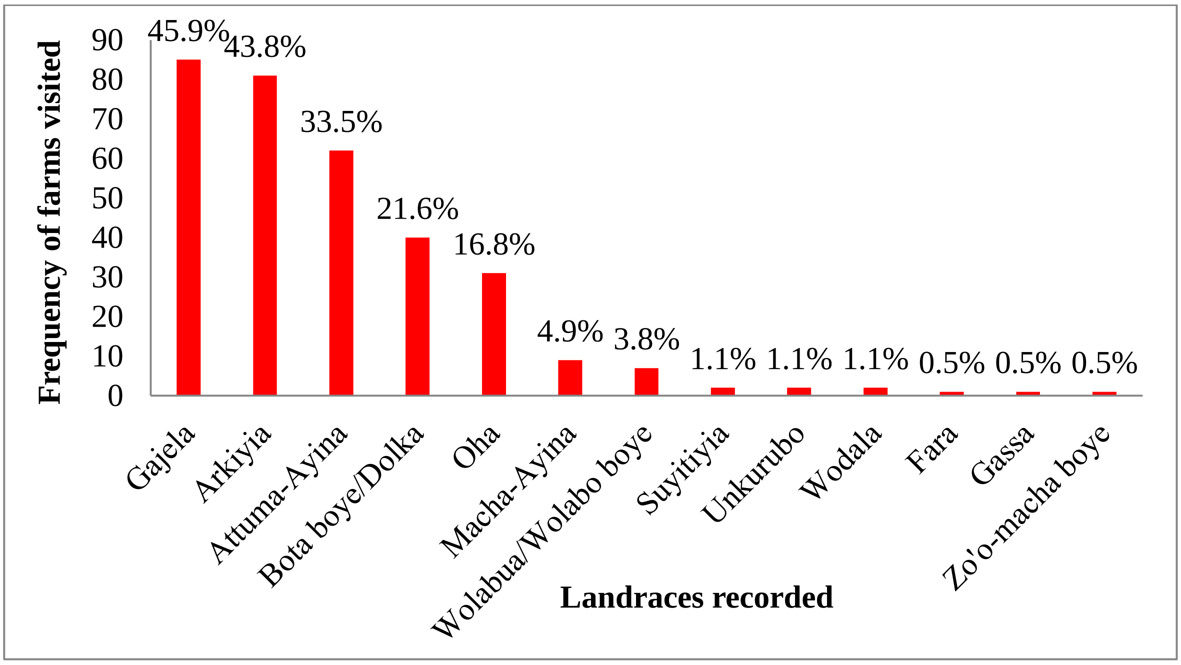

Figure 6: The relative abundance of yam landraces in Damot Gale districts (on the bases of n = 185)

4.7 Management of yams

4.7.1 Trends and preference of yam production

Regarding the results of this study, farmers perceived a decreasing trend in yam production over time in Yukara, Dubo, and Obejage, accounting for 87.8%, 94.9%, and 97.9%, of the households, respectively, even those Kebele where overall (100%) yam production has been decreasing over time (Tadisa, Zegere, and Wandara Gale). About 97.3%, 59.0%, 59.6%, 90.0%, 83.0%, and 79.8% of farmers reported high preferences for yam production in Yukara, Dubo, Tadisa, Zegere, Obejage, and Wandara Gale, respectively (Table 11). Despite the high preference for yam crop production in all surveyed Kebeles, the trends of yam production have been decreasing. It suggests that the agricultural practices employed by farmers in the study areas may not be effectively supporting yam production. Muluneh Tamiru *et al*. (2008) reported a similar decreasing trend in yam production in the Gamo-Gofa and Wolaita Zones of south Ethiopia. Tsegaye Babege *et al*. (2021) also reported a decreasing trend of 79% in yam production in Bench-Sheko and Sheko Zones. On the other hand, Wumbei *et al*. (2022) indicated a positive growth in yam production within Nigeria.

Neina and Agyarko-Mintah (2023) stated that current yam yield declines in the face of increasing cultivated areas, land scarcity, and population growth. Expanding the cultivated area, employing more family labor, and investing additional capital are identified as potential strategies to increase yam production, according to Degla and Sourokou (2020). Similarly, Danquah *et al*. (2022) indicated the contribution of increased area under cultivation to the rise in yam production. Moreover, Pouya *et al*. (2022) found that with the rapid population growth in West Africa and the limited availability of land, there is a pressing need to develop sustainable cropping methods to enhance yam productivity in rotational cropping.

Table 11: Trends of yam production and preference by farmers in Boloso Sore and Damot Gale district

Districts	Kebele	Trend of yam production		Rate of preference of yam crop production compared to other crops		
		Increase over time	Decrease over time	High	Medium	Low
Boloso Sore	Yukara	11 (12.2)	79 (87.8)	66 (97.3)	18 (6.7)	6 (20.0)
	Dubo	2 (5.1)	37 (94.9)	23 (59.0)	13 (33.3)	3 (7.7)
	Tadisa	0	52 (100)	31 (59.6)	18 (34.6)	3 (5.8)
Damot Gale	Zegere	0	60 (100)	54 (90.0)	2 (3.3)	4 (6.7)
	Obejage	1 (2.1)	46 (97.9)	39 (83.0)	8 (17.0)	0 (0.0)
	Wandara Gale	0	78 (100)	56 (79.8)	15 (19.2)	7 (9.0)

Numbers in parenthesis refer to percentage values based on the number of farmers interviewed in each Kebele

The implications of these findings suggest that the decreasing trends in yam production reported in multiple studies emphasize a need for urgent interventions to address the challenges faced by farmers. It is crucial to improve agricultural practices and provide support in areas such as land availability and fertility to enhance yam production. Strategies like expanding cultivated areas, employing more labor, and investing capital can potentially contribute to increasing yam production.

4.7.2 Source of planting materials

According to this study, the main source of planting materials that the farmers used to cultivate yams were from home or previous year's harvest (50.8%), followed by home or previous year's harvest and market (18.8%), market (13.1%), home or previous year's harvest and neighbors (12.0%), and neighbors (5.7%) (Figure 7). This indicates the importance of preserving traditional landraces and promoting crop diversity for sustainable agriculture. The reliance on neighbors for planting materials (5.7% and 12.0% in different situations) indicates the importance of knowledge sharing and support within the farming community.

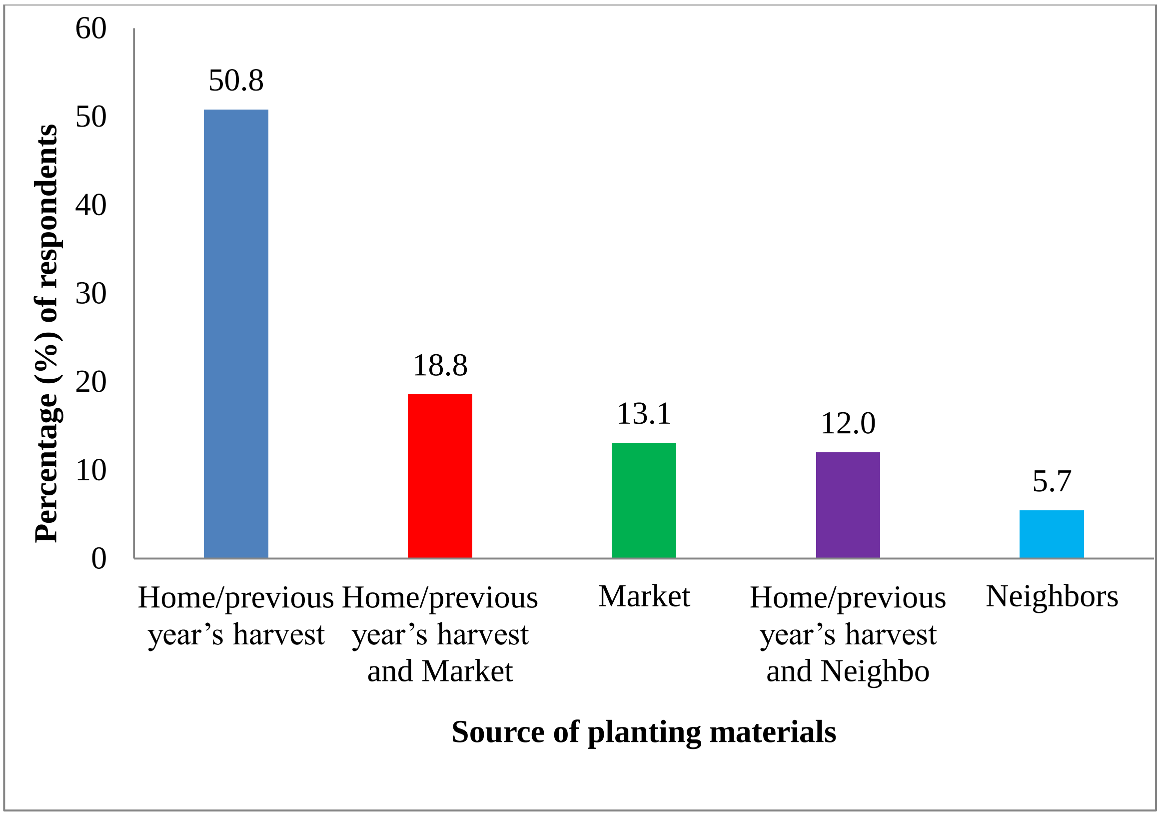

Figure 7: The source of planting materials in the study area

The study does not provide information on the quality of planting materials obtained from different sources. However, it is crucial to consider the implications for planting materials quality and disease control. Farmers using their own harvest should ensure that the yam materials are healthy and free from diseases to maintain crop productivity. Hence, there is no formal seed supply system for yam production in the study area.

Aighewi *et al*. (2014), Tsegaye Babege *et al*. (2021), Muluneh Tamiru *et al*. (2008), these studies support the finding that there is no formal seed yam production or marketing system. Farmers primarily obtain planting materials from their own preserved stock or previous year's harvest. Seed tubers may also be sourced from friends, neighbors, and sometimes purchased from the market. Similarly, Belachew Garedew *et al*. (2017) found similar patterns in Sheko Zone, Southwest Ethiopia. Farmers in this district primarily obtained planting materials from previously harvested crops, friends or neighbors, and the market. Moreover, according to Yeshitila Mekbib and Temesgen Deressa (2016), farmers in the East Wollega and Ilu Ababora Zones primarily rely on their own planting supplies that they have preserved from the previous cropping season. Also, Boadu *et al*. (2019) stated that their own production was the source of yam seed for 84.7% of yam farmers in major yam-producing districts in Ghana. Aighewi *et al*. (2014) state that yam seeds are either purchased, given as gifts; instead, or inherited by a large number of Nigerian farmers.

4.7.3 Storage of yam products

The current study found that the most common known practices for yam storage in the study area were storing yam products in the soil (76.5%), burred them (18.9%), and storing them at home (local storage) (4.6%) (Figure 8). The majority of households storing yam products in the soil or leave in the soil (76.5%) indicate the reliance on traditional storage methods in the study area. This suggests that farmers have been using this practice for generations, emphasizing its effectiveness and suitability for preserving yam products. Storing yam products in the soil and burying them are likely to provide favorable conditions for maintaining the quality of yams. These methods can help regulate temperature and humidity levels, preventing spoilage and extending the shelf life of yam products. The use of traditional storage methods reflects the cultural significance of yam in the study area. Preserving yams using traditional methods helps maintain cultural practices and traditions associated with yam cultivation and consumption. These findings can inform farmers, researchers, and policymakers about the importance of preserving and promoting traditional storage practices, leading to improved yam storage techniques and reduced post-harvest losses.

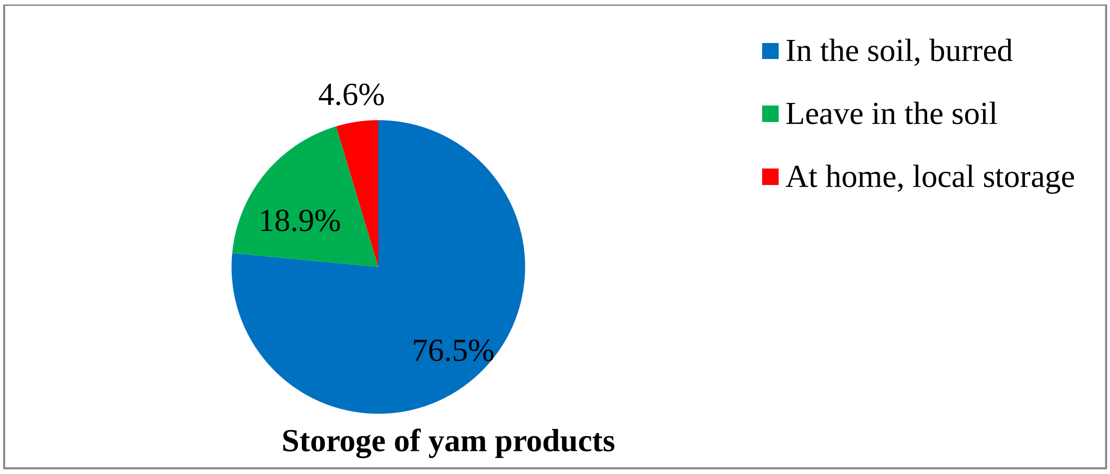

Figure 8: Storage of yam products in the study area

This aligns with Belachew Garedew *et al*. (2017), who reported similar findings, where leaving yams in the ground until the following planting season (30.74%) and storing them in a sack at home (27.14%) were common practices. Aighewi *et al*. (2014) stated that a suitable storage facility for seed yam should possess proper ventilation, sufficient shade, and effective security measures against theft, rodents, and pests. Since seed yams are living organisms, they require oxygen, making adequate airflow within the stored tubers crucial. Inadequate air circulation can cause delays in wound healing and promote tuber decay, whereas excessive airflow can lead to dehydration and decrease the weight of the seed tubers. Nteranya and IITA (2015) reported that in-ground storage capability permit flexible harvesting periods which aids sustained food availability.

The study by Semagn Asredie *et al*. (2015) identified storability as a crucial characteristic for potatoes in the main potato-growing regions. This is consistent with the importance of improving yam storage indicated in the current study. Developing adequate storage facilities and promoting good storage practices for potatoes and yams can contribute to sustaining food availability and reducing losses. Shiferaw Bogale *et al*. (2022) found that the majority (63%) of cassava producers in south Ethiopia do not have long-term cassava storage because of the optimum harvesting age. In contrast, yam and potato storage practices focus on preserving the crops for extended periods. Unlike yam and potato storage, for cassava, the emphasis should be on optimizing harvesting time to avoid yield losses. Providing guidance to farmers regarding timing and promoting appropriate handling practices can help minimize post-harvest losses.

4.7.4 Planting methods of yam landraces

The findings of the current study show that majority of (93.4%) farmers in the study area planted yam alone and 6.6% practiced intercropping (Figure 9). This indicates that the majority of farmers in the study area (93.4%) practiced mono-cropping of yam alone; believing that intercropping reduces yam yield and makes cultivation and weeding activities more challenging. This aligns with the findings of Yeshitila Mekbib and Temesgen Deressa (2016) and Muluneh Tamiru *et al*. (2008) in the East Wollega and Ilu Ababora Zones and Wolaita and Gamo-Gofa Zones of south Ethiopia respectively. However, it contradicts the report of Belachew Garedew *et al*. (2017), which stated that a majority of farmers (96.8%) practiced intercropping with yam. Similar studies from Brazil by Siqueira *et al*. (2014) reported that yams are planted alone for commercial and other purposes. Also, Tinsae Abrham *et al*. (2020) reported on sweet potato from Misrak Badawacho District, Hadiya Zone of Central Ethiopia, and also reported mono-cropping as a common practice among farmers. There seems to be regional variation and differing beliefs among farmers regarding intercropping with yam. Providing farmers with information on the benefits and drawbacks of intercropping can help them make informed decisions based on their specific context.

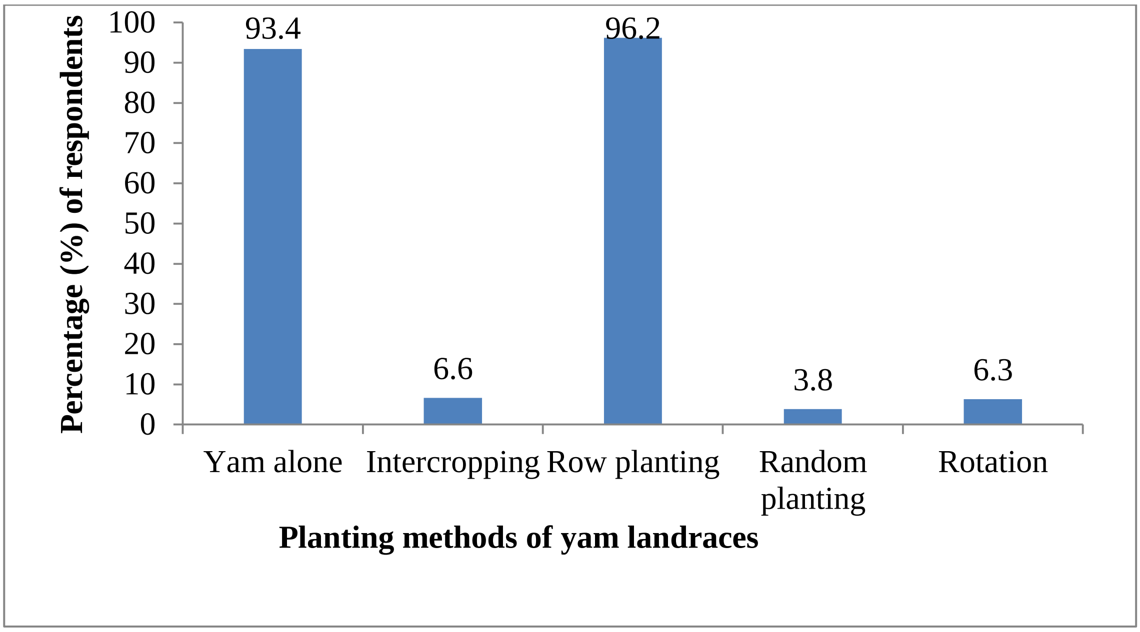

Figure 9: Planting methods of yam landraces in the study area

As per the results of this study the crops planted with yams included maize (*Zea mays*), sweet potato (*Ipomoea batatas*), cabbage (*Brassica* spp.), chat (*Chata edulis*), enset (*Ensete ventricosum),* and coffee (*Coffea arabica*) in Appendix 8. Similarly, Muluneh Tamiru *et al*. (2008) reported a similar finding that the crops planted with yams included maize (*Zea mays*), sweet potato (*Ipomoea batatas*), cabbage (*Brassica* spp.), beans (*Phaseolus* spp.), and, to a lesser quantity, coffee (*Coffea arabica*). Similarly, Aighewi *et al*. (2014) also reported that seed yam was intercropped with maize, cocoyam and cassava for household livelihood in Ibadan, Nigeria. Parallel to this, Siqueira *et al*. (2014) found that, among Brazilian farmers they visited, the majority planted yam intercropped with other crops (59%), a practice more common among small-scale farmers who depend on the crop for livelihood. The current study and previous studies mentioned identified various crops that are commonly planted with yams, including maize, sweet potato, cabbage, beans, and coffee. This indicates the practice of mixed cropping to maximize land use and diversify agricultural production. Encouraging appropriate crop pairings and educating farmers about planting together can improve soil fertility, production, and overall farm resilience.

The majority of farmers in the current study 352 (96.2%) planted yam in rows; while a small percentage 14 (3.8%) used random planting methods (Figure 9). As information gathered from households, key informants and focus group discussion row planting method have more yield advantageous than random planting. This practice was also reported in the previous study by Tamiru Muluneh *et al*. (2008) and Itefa Degefa and Baressa Anbessa (2017) in Gamo-Gofa (Abaya District) and Wolaita Zone of South Ethiopia. The use of rows may facilitate management practices and improve soil structure and fertility. Encouraging farmers to adopt row planting methods can help optimize crop management and increase yields. Educating farmers about the benefits of proper land use and management can reduce the use of random planting, which may result from a lack of awareness.

The rotation of yam plots with other crops at intervals of one to four years was practiced by a small percentage 23 (6.3%) of farmers in the current study (Figure 9). Similarly, Brooker *et al.* (2017) described crop rotation as a key principle of management because it improves soil structure and fertility. Crop rotation is recognized as a valuable practice for improving soil health and fertility. Promoting the benefits of crop rotation and providing farmers with knowledge on suitable rotating crops can contribute to sustainable yam production and soil conservation. The current study revealed an interesting traditional practice used by farmers in the study area to overcome the problem of yam tubers growing deep in the soil. Inserting a piece of clay below the root of each plant inhibits downward tuber growth and promotes horizontal tuber development. This practice was also reported in the previous study by Yeshitila Mekbib and Temesgen Deressa (2016). The implications of these findings were that exploring and documenting local traditional practices can provide valuable perceptions for improving cultivation techniques and addressing specific crop management challenges.

4.7.5 Farm inputs

According to our results, farmers manage soil fertility by applying only animal manure 320 (87.4%), animal manure and compost 41 (11.2%), and animal manure and chemical fertilizer 5 (1.4%) (Table 12). This shows that most of the farmers in the study area used only animal manure, indicating a strong preference for organic fertilizer. A very few farmers used inorganic fertilizers to increase crop yields. According to information gathered from key informants, households used only animal manure for yam production commonly, nearest to homesteads. As per this study, about 41 (11.2%) of the households used animal manure and compost, indicating an interest in enhancing soil fertility through organic materials. Manure is applied in two methods: before planting and after planting. According to information gathered from key informants, households used compost during planting and animal manure after planting and before planting the crop. According to farmers in the study area, applying manure above the ground after planting used for three purposes, to keep the plant from the sun during dry season, soil moisture and to increase the soil fertility for future time and burying manure in the soil before planting the crop (Appendix 7H). This result implied that households in the study area used animal manure and compost together. Only 5 (1.4%) farmers used animal manure and chemical fertilizer (Table 12), possibly due to limited purchasing power. According to information gathered from some local farmers, they have a want to use chemical fertilizers, but due to a lack of purchasing power, the majority of farmers use animal manure for yam production.

Table 12: Cultivation and management of yam landraces in the study area

Input of yam fields	**Frequency**	**Percentage (%)**
Animal manure	320	87.4
Animal manure and compost	41	11.2
Animal manure and chemical fertilizer	5	1.4
Total	366	100.0

The yam crop in the study area was grown in animal manure by the majority of farmers (87.4%); as reported on other crops such as sweet potatoes, most of the surveyed farmers (85.56%) don’t use agricultural inputs (fertilizers or pesticides) for the growth, development, and protection of their crop (Adjatin *et al*., 2018). Similarly, according to Itefa Degefa and Baressa Anbessa (2017) study based on farmer answers, the majority of farmers in Abaya District use organic fertilizers 34 (56.7%) and 2 (3.3%) use inorganic fertilizers for yam production to increase agricultural yields. Furthermore, according to Gebeyanesh Zerssa *et al*. (2021), using organic and inorganic fertilizers together reduces yearly fertilizer costs while increasing agricultural yield. In a similar manner, Deriba Kifle (2020) found that applying 50% compost and 50% prescribed NP together produced a 5% higher yield than applying inorganic NP fertilizers alone. Additionally, Bekele Abdisa *et al.* (2018) verified that integrated use of organic matter and chemical fertilizers is beneficial in sustainability by improving crop production and maintaining soil PH. Overall, the results indicates the predominant use of animal manure and the potential benefits of incorporating organic and inorganic fertilizer to enhance soil fertility and agricultural yields

4.7.6 Ways of using and consuming yams in the study area

According to the results of this study, out of the total sample households, 264 (72.1%), 73 (19.9%), and 29 (7.9%) of households consume yam as seasonal and emergency food, staple food, and supplementary food, respectively (Table 13). These results reveal the significance of yam as a food source among surveyed households. The majority of households consume yam as a seasonal and emergency food, indicating its importance in times of scarcity or need. Additionally, a significant portion of households consume yam as a staple food, showing its role in their daily diet. However, the smaller proportion of households using yam as a supplementary food suggests that it may not be as commonly utilized for that purpose.

Table 13: Used or consumed way of yams in the study area

Ways to use or consume yams	Frequency	Percentage (%)
Seasonal and emergency food	264	72.1
Staple food	73	19.9
Supplementary food	29	7.9
Total	366	100.0

The consumption of yam as a seasonal and emergency food emphasizes its contribution to food security among surveyed households. In times of limited food availability, yam serves as a reliable source of sustenance. This finding align with previous reports of Muluneh

Tamiru *et al*. (2006; 2008), who reported that the yam crop is used to fill a seasonal gap in food supply in the Gamo-Gofa and Wolaita Zones of the South Ethiopia Region. Similarly, in the Bench-Sheko and Sheko Zones, wild yam is a popular food source; more than 30% of farmers eat it during their short journeys in the forest for hunting, according to Tsegaye Babege *et al*. (2021). Moreover, according to Pouya *et al*. (2022), yams are a staple crop and a significant source of income for millions of people in West Africa. The study's results underline the importance of yam as both a food source and a potential income generator. Understanding its role within the surveyed households can aid in agricultural planning and promoting sustainable farming practices to enhance food security and livelihoods.

4.7.7 Crop preferences in the study area

As per this study, about (49.2%), (42.1%), and (8.7%) of households used taro, yam, and sweet potato respectively (Figure 10). The results indicate that taro is the main crop chosen by the majority of households, followed by yam and sweet potato. This implies that taro products serve as the primary source of food for the producers and meet their family's needs for an extended period. Additionally, yam is identified as the main staple food, particularly during the harvesting season. Taro products being available for a long period of time means a stable food supply for the households, contributing to food security. During focus group discussion, all of respondent reported that yam was a highly preferred crop previously in the study area, the shift in preference from yam to taro and other crops due to production difficulties suggests the agricultural challenges faced in the study area. These findings have implications for food security, cultural practices, agricultural sustainability, and economic considerations. Understanding and addressing the factors affecting crop preferences and production can contribute to improved livelihoods and better agricultural outcomes.

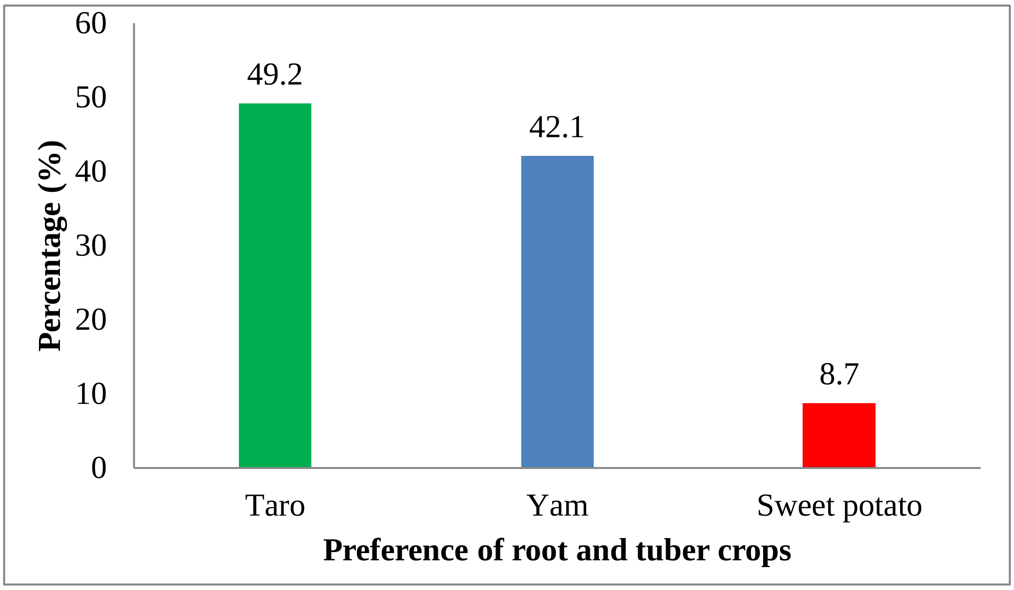

Figure 10: Crop preferences in the study area

This result was similar to the finding of Belachew Garedew *et al*. (2017), who state that there was minor variation in the distribution and abundance of yams (*Dioscorea* spp.) along the kebeles due to the cultivation of comparable taro as a stable food, which was highly distributed and practiced by Sheko people. Also, on other crops in Kenya, sweet potatoes (*Ipomoea batatas* L. Lam.) ranked second with a preference level of 61%, while Irish potatoes (*Solanum tuberosum* L.) had the highest level at 70%, according to Fredrick *et al*. (2022). 42% of respondents preferred arrowroot (*Maranta arundinacea* L.). The least favored crops were cassava (*Manihot esculenta* Crantz) and yams (*Dioscorea alata* L.), with 22% each.

The aggregate value of yam, cassava, potato, and sweet potato exceeds all other African staple crops and is much higher than the value of cereal crops, according to the Nteranya and IITA (2015) reports. In other ways, leaf shape, vine color, tuber shape, size and color, spine or not on stem and taste were used for naming landraces in the study area.

Similarly, Barlagne *et al*. (2016) reported that the most frequently used criteria for the preference of yam were the taste, texture, and color of the fish after cooking. Taste was considered more important than the other criteria for the preference for yams. Furthermore, gender-based preferences for yams in Ghana were found by Effah-Manu *et al*. (2022), who found that sweet taste are preferred by both females and males. Moderately hard-boiled yams and shelf-stable food products are liked by males, whereas aroma is highly rated by females. Comparing with other studies, such as the preference for Irish potatoes and sweet potatoes in Kenya, and arrowroot, cassava, and yams in the study area, the findings shed light on regional variations in crop preferences. This information can be valuable for crop selection, planning, and promoting agricultural diversity.

4.7.8 Purpose of produce yam crop in the study area

Regarding the results of this study, about (92.9%) consume yam tubers. Followed by market or income generation (7.1%) (Figure 11). The findings indicate the significance of yam as an important tuber crop in the study area, particularly white yams, which are preferred for consumption and highly demanded in the market due to their sweetness. The consumption patterns and utilization of yams for preparing cultural foods, such as Fichata **(**in Wolaytato Kalan)**,** indicate their cultural and dietary importance in the local community. The preference for white yams for preparing Fichata, a popular traditional dish made from boiled and pounded yam mixed with fermented milk and butter, highlights the cultural significance of yam in the study area. The preparation and consumption of this traditional food contribute to the culinary heritage and local food practices. According to this study, some households reported that regular yam tuber eating can result in anemia, which is significant for raising awareness among consumers and healthcare providers. This information can guide measures to promote balanced diets and mitigate any potential health risks associated with excessive yam consumption.

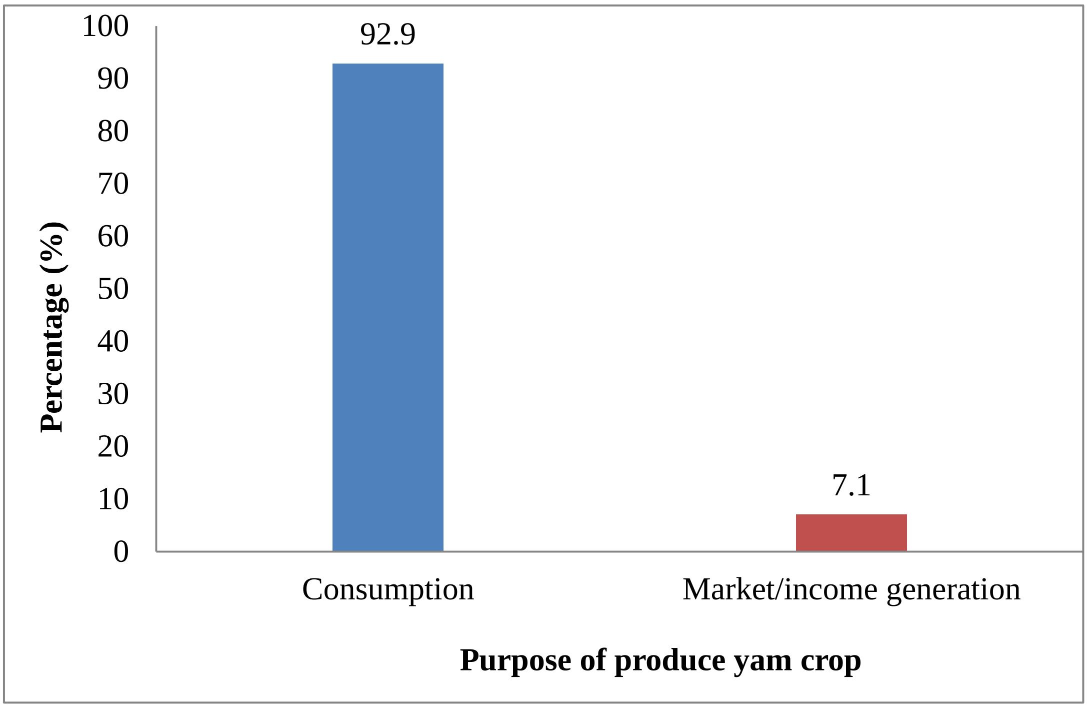

Figure 11: Purpose of yam landraces in the study area

Similarly, Muluneh Tamiru *et al*. (2008) state that yam is highly valued for preparing a cultural food called Fichata and managed accordingly to meet their needs. Moreover, Baressa Anbessa and Itefa Degefa (2019) from Abaya District reported that edible parts of *Dioscorea* species are only consumed after boiling. Boiling may be important to make these plants suitable for eating and reduce their toxicity. On the other hand, dioscorin from *Dioscorea* might aid in controlling high blood pressure, according to Ryan *et al*. (2009). As they reported, yams are a good source of nutrition. It might provide numerous health advantages, such as reducing blood cholesterol and menopausal symptoms. Similarly, Waad *et al*. (2022) reported that the consumption of yam or its extracts can be beneficial for improving blood glucose. These findings emphasize the cultural significance of yam, its role in food security and household consumption, as well as its potential medicinal applications. The results also highlight the need for proper food management practices, income generation opportunities, and awareness regarding potential health risks associated with yam consumption. Understanding these implications is essential for promoting sustainable agricultural practices and improved well-being within the community.

4.8 Constraints of yam production in the study area

The sample household, key informants and during focus group discussion were asked to mention the major constraints of yam production included wild animal attack (90.7%), lack of materials for staking (87.4%), land shortage (86.1%), drought or climate change (74.9%), and scarcity of mother yam (68.8%) (Table 14). These results implied that the production of yam in the study area was highly constrained by wild animal attacks. The main animals reported by farmers were porcupines, deer, rodents (such as rats), and some birds. Deer and some birds that ate the growing shoot part (the emerging shoot) of the plant were called Zukia kafo (the name of birds) in Wolaytato Kalan. However, some yam landraces have spines in their tubers and defend against porcupine attacks, such as Gajela. This result was supported by Sugihara *et al*. (2021), who found that some species have roots with spines to protect tubers from burrowing or digging animals or herbivores. However, the white yam landraces and spineless were highly preferred by porcupines. Similarly, Tewodros Mulualem *et al.* (2022) reported that yam production was highly constrained by wild animal attacks such as porcupine (13.93%) and mole rat (9.29%) from Jimma, Sheka, and Bench-maji zones of Southwest Ethiopia. Yeshitila Mekbib and Temesgen Deressa (2016) also reported from East Wollega and Ilu Ababora Zones that yam is very susceptible to damage by wild animals. Similarly, Tinsae Abrham *et al*. (2020) reported on sweet potato that about 28% rodents were the dominant factors in sweet potato production in Misrak Badawacho District, Hadiya Zone of Central Ethiopia Region.

As per the findings of this study, about 87.4% reported that a lack of materials for staking affects yam production; without staking, yams cannot give a good yield in production. Due to a lack of access to staking materials in the study area, yams were highly constrained by staking materials. This result was supported by Adejumobi *et al*. (2023) and Belachew Garedew *et al*. (2017), who reported that staking is an important practice and that without staking; no yam production is possible because yams are climber plants. Also, a similar result was reported by Tewodros Mulualem *et al.* (2022), who reported that about 7.59% of stake shortage was considered a yield-limiting factor for yam in Manna and Dedo districts of Jimma Zone. Muluneh Tamiru *et al*. (2008) also reported that staking is the only method encountered by farmers in the Wolayita and Gamo-Gofa Zones of South Ethiopia Region.

Table 14: Constraints to yam production in the study area

Constraints	Frequency	Percentage (%)	Rank
Drought/climate change	251	74.9	4
Lack of materials for staking	315	87.4	2
Wild animal attack	332	90.7	1
Financial shortage/production cost	162	44.3	7
Land shortage	320	86.1	3
Tediousness of the practice	125	34.2	9
Scarcity of mother yam	274	68.8	5
Labor cost	140	38.3	8
Post-harvest loss	52	14.2	10
Pre-harvest loss	217	59.3	6

Percentage greater than 100 due to multiple responses from the respondents

The third major constraint to yam production faced by farmers was a shortage of land. As previously mentioned, the average farmland holding size by the sample households in the study area was 0.48ha (Table 4), and this indicates that there is a shortage of farmland in the study area, and they cultivated yams within a small plot (0.01ha) of land. As per this study, high population density is the main cause of land shortages. Similarly, Derese Balcha and Mathewos Chafa (2022) reported that in the Wolaita Zone, land shortages were a serious problem due to the high population growth. Similarly, Tewodros Mulualem *et al.* (2022) reported that a shortage of farm land (11.46%) was the main limiting factor in yam production due to high population pressure and city expansion in the Jimma, Sheka, and Bench-maji Zones of Southwest Ethiopia. Following planting, when the crop is still in the soil and at an early stage of growth and until harvest season, entirely key informants mentioned drought or climate change (74.9%) and wild animal attack (90.7%) as the primary factors limiting yam production. Similarly, Tewodros Mulualem *et al.* (2022) stated that drought at an early stage (14.4%) was the main yam production constraint in the Jimma, Sheka, and Bench-maji Zones of Southwest Ethiopia.

According to the findings of this study, scarcity of mother yam (68.8%), pre-harvest loss (59.3%), financial shortage/production cost (44.3%), labor cost (38.3%), tediousness of the practice (34.2%), and post-harvest loss (14.2%) were also ranked as 5th, 6th, 7th, 8th, 9th, and 10th, respectively (Table 14). Similarly, Boadu *et al.* (2019) reported that yam producers faced a scarcity of mother yam in major yam-producing districts in Ghana. As per Boadu *et al.* (2019) also reported that pre-harvest losses occur before the process of harvesting begins, due to several environmental (biotic and abiotic) and production factors. Based on our study, about 44.3% of financial shortages or production costs was considered a yield-limiting factor for yam and highly associated with the cost of the yam seed and staking materials in the study area. According to the results of this study, about (38.3%) of Labor cost and (34.2%) of tediousness of the practice were also other constraints in the study area. Muluneh Tamiru *et al*. (2008) found that the production system for yam is labor-intensive, which indicates the need for effort and manual labor in cultivating yams.

As per this study, about (14.2%) of post-harvest loss (Table 14), this might be because farmers have problems with post-harvest training and storage, which causes considerable product losses and parasite infestations, which resulting in poor-quality products. According to this study reports, post-harvest loss occurs due to poor management practices such as injury to yam tubers during weeding and harvesting and over storage. The injury around yam tubers, called Boyea shiha in Wolaitato kalan, is the main case of post-harvest loss in storage in the study area. These findings agree with those of Rashid *et al*. (2015), reported from Ekiti State, Nigeria, where over storage (98.0%), ineffective postharvest handling (96.8%), and injury to yam tubers (80.0%) were also responsible for losses among the farmers. Similarly, Tinsae Abrham *et al*. (2020) also reported on sweet potatoes that lack of suitable storage (22%) was the major problem in Misrak Badawacho District, Hadiya Zone of Central Ethiopia Region. The study revealed several factors described above that are limiting yam production in the study area.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study presented the diversity, distribution, management practices, and production constraints of yams (*Dioscorea* spp.) in Boloso Sore and Damot Gale Districts. The result showed that there was a total of 19 named yam landraces from 366 households that were selected from the six Kebeles in the study area. An average of 10.2 yam landraces was grown in each farm. The result from this study also showed that richness and diversity of yam landraces were different between the two districts and among the study Kebeles. A small number of highly abundant yam landraces are growing throughout the surveyed Kebeles whereas the greater numbers of landraces had a narrow and unequal distribution and rare abundances.

There was also variation in the composition of yam landraces among the two districts and between kebeles. There is a general trend that farmers abandon the cultivation of some yam landraces. The study found that some Kebeles, such as Yukara Kebele in Boloso Sore District and Wandara Gale in Damot Gale District, exhibited higher richness and diversity of landraces compared to others. Similarly, the evenness of landraces varied among the surveyed kebeles. On the other hand, the majority of farmers in the study areas practices yam alone cropping method and store their yam products in the soil, with burying being the most commonly known practice. Results showed that there were several constraints to yam production in the study area. The major constraints identified include wild animal attacks, lack of materials for staking, land shortage, and drought or climate change.

5.2 Recommendations

Conservation efforts are vital to prioritize the preservation of yam landraces in both areas with lower richness and diversity, as well as in areas with higher richness and diversity. This can involve, promoting the use of traditional farming practices, and raising awareness among local farmers about the importance of preserving their landrace varieties. Encouraging the exchange and sharing of yam landraces between different districts and kebeles can help enhance diversity and further research and documentation on yam landraces is needed to better understand their characteristics, adaptability, and potential uses. This information can contribute to designing effective conservation and utilization strategies.

Providing training and capacity building programs for farmers, extension workers, and local communities on yam landraces conservation, preservation, and utilization techniques can help ensure the long-term viability of these yam varieties. Extension services and agricultural programs should provide training sessions or workshops to educate farmers about improved storage methods.

Farmers should explore effective measures to protect their yam crops from wild animal attacks and drought. Efforts should be made to ensure farmers have access to materials for staking yam vines. Farmers should be provided with information and support on climate-smart agricultural practices. Further research should be conducted on the development of yam varieties that are resistant to wild animal attacks, drought, and other constraints. Additionally, research on innovative cultivation techniques, biotic and abiotic constraints management strategies, and value-added processing of yam products can contribute to improving yam production and profitability.

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7 APPENDICES

Appendix 1: Semi-structure interview questions from Kobo's collection application tool were administered to sample households.

Hawassa University

School of Graduate Studies

College of Natural and Computational Sciences

Department of Biology

Specialization Botanical science

General instructions

Dear Enumerator, please note that each question must be answered/field. Please save the data by the name of the respondent/your name at the end. For data collector/Enumerators

OK, please continue.

Dear respondent, the overriding objective of this questionnaire survey is to collect data for an MSc study entitled **Diversity, Distribution, Management and Production Constraints of Yam landraces (*Dioscorea* spp.): The Case of Boloso Sore and Damot Gale Districts of Wolaita Zone, South Ethiopia**. Therefore, your responses to the questions are valuable and will be held in the utmost confidentiality to be used only for the analysis of this research. If you accept to participate in this research, you will be doing so voluntarily, and there will not be any monetary returns. You are also free to refuse to respond to any questions you do not feel comfortable answering or to withdraw from the research altogether. This interview will take about an hour of your time to respond to the questions. For respondent

OK, please continue.

Are respondents willing to participate in the study (or willing to respond the following questions)? Yes/No: - (If No, drop him/her. Consent of the respondent

(a) Yes

(b) No

Data collector/Enumerator name and phone number

____

Date of data collection:

Date___________________________

Time___________________________

A. Socio-demographic information of the respondents

1. Name of respondent and phone number

____

2. District of the respondents

(a) Boloso sore (b) Damot Gale

3. Kebele of the respondent____

4. Gender of the respondent

(a) Male (b) Female

5. Household size (write in numerical value) ________________________________

6. Age of respondent (write in numerical value) in year________________________

6. Religion of the respondent

(a) Muslim (b) Protestant (c) Orthodox

(e) Catholic (f) Has no religion

(g) Other specify____________________________________

7. The education level of the respondent

(a) Illiterate (b) Grade 1- 4 (c) Grade 9- 12

(d) Grade 5- 8 (e) Degree (diploma, bachelor, MSc)

8. GPS location (lat/long)

____

B. Land ownership

1. Do you have land? If the farmers don’t have land, drop him/her

(a) Yes (b) No

2. Total farm size for agriculture/crops production (write in hectare)___________________

3. Land size allocated for Yam production out of your total farm size__________________

4. Land size allocated for other crops production out of your total farm size_____________

C. Ethno- botanical information (IK of farmers)

1. Mention numbers of yam landraces at your home-garden/yam farm land. Hint: in number and local name

____

____

2. Which Yam variety/landrace is more produced in your area (list most important first) and why?

____

____

____

3. Which yam landraces require high nutrition (fertilizer) and strict farm management practices for its production? Order from higher to lower

____

____

____

4. Which yam landraces is more accessible in local market and why?

____

____

____

5. Which yam landraces have high local preference and high demand in market?

____

____

____

6. Order yam landraces in your area in terms of nutrition and taste quality? Hint: local preference

____

____

____

7. Which yam landraces forms big size tuber with high quantity and help to feed your house hold? Hint: order it from higher to lower tuber size

____

____

____

8. Which yam landrace is widely cultivated across your locality and provide higher yield? Why?

____

____

____

9. Which yam landrace is more susceptible to diseases and moisture stresses in your area?

____

____

10. Which yam landrace have high market preference/market availability is low and known to be very expensive? Why?

____

____

____

11. Which yam landrace is easy to cook and consume?

____

____

12. Mention the yam landrace which consumed when other types are not available in the market?

____

____

____

13. Which yam landrace is harvested (or produced) two times per year?

____

____

14. Mention the kind of dish's (food) prepared from yam products in your locality?

____

____

15. Source of yam seeds: from where do you get yam seeds?

(a) Market (b) Government (c) Neighbors (d) Wild

(e) Home/previous year's harvest

16. Type of Yam landraces that you have currently.

(a) Improved (b) Local/cultivated Wild (c) Both (improved and local)

(e) Others ____

17. For what purpose you produce Yam crops

(a) Consumption (b) Market/income generation (c) Cultural use Animal feed

(d) Others ____

18. Which parts of yam is used (or consumed)?

(a) Tubers (b) Leaves (c) Green pod

(d) Others ____

19. Who engaged mainly in yam production? Men refers to father while Women refers to wife

(a) Daily labourer (b) Whole family (c) Men

(d) Young children (e) Both Men and Women

(f) Others ____

____

20. Is there any wild relative? What is it called?

____

____

21. What are the uses and values of the yam crop other than food?

(a) Income generation (b) Improving soil fertility (c) Forage, medicinal

(d) Alcoholic beverage (e) Ritual, Myths and beliefs associated with the crop

22. How do you cultivate and manage your yam field to improve productivity of the yam crop?

(a) Using chemical fertilizer only (b) Using compost only

(c) Using animal manure only (d) Just grow without any treatment

e) Others ____

23. What is your planting method for your Yam landraces?

(a) Row planting (b) Randomly (c) Rotation

(d) Intercropped (e) Yam alone

(f) Others ____

24. What is the conservation status of yam landraces at your area?

(a) Well conserved (b) Threatened (c) Very rare

(d) Others specify ____

25. Rate your preference of Yam crops production compared to other crops in your area.

(a) High (b) Low (c) Medium (d) No preference

26. How do you store yam products?

(a) At home, local storage (b) In the soil, burred (c) Modern storage

(d) Leave in the soil (e) Not stored at all

(e) Other way of storing ____

28. How do you use/consume yam?

(a) As staple food (b) As supplementary food

(c) Poor household food (d) Seasonal and emergency foods

D. The production constraints of yams faced by farmers in the study area.

1. What are the main constraints of yam landrace production at your area?

(a) Drought/climate change (f) Lack of materials for staking

(b) Wild animal attack (g) Financial shortage/production cost

(c) Land shortage (h) Tediousness of the practice

(d) Scarcity of mother yam (i) Labor cost

(e) Post-harvest loss (j) Pre-harvest loss

E. General questions

1. Which of the following root and tuber crops would you prefer to produce?

(a) Taro (b) Yam (c) Sweet potato

(d) Other specify ____

2. How do you evaluate trends of in yam yield/production?

(a) Constant over time (b) Increase over time

(c) Decrease over time (d) Fluctuates over time

3. If it increase or decrease over time, what are the major reason?

____

____

____

4. What economic return do you get from yam production compared to other crops?

(a) Better (b) Less (c) Equal

5. What are the advantages of yam production compared to other crops?

(a) Drought resistance (b) Require low fertilizer input

(c) Available at any season (d) Used in the absence of staple food

(e) Grow fast and has high yield

6. Which yam landraces is more productive?

(a) Wild (b) Cultivated (c) Improved

7. How do you apply chemical or organic fertilizer for yam production?

(a) Using indigenous knowledge (b) Fixed rate

(c) Not apply at all (d) Guided by DA's

8. What is happing to the trend of annual rainfall in the area as per your observation?

(a) Increasing (b) Decreasing

(c) Constant (e) Don’t know

End time ____

F. Checklist question for focus group discussion Key informant interview

a) Which management practice is more effective for sustainable production of yam?
b) What are the major constraints of yam production in your area currently?
c) Which indigenous knowledge is more effective to control production constraints?
d) Do experience sharing takes place among the Kebeles farmer?
e) Are the formal seed supply systems in your area?
f) How do you see the present status of yam in comparison to the past?

Appendix 2: About yam preference in the study area

Characteristics of yam landraces as described by farmers in the study area

1. **Order of yam landraces in terms of nutrition and taste quality**

Bota boye (Dolka), Hatiye, Oha, Arkiyia, Fara, Suyitia, Macha boye, Zo'o-macha boye, Macha-Ayina, Gassa, and Welawa

2. **Order of am landraces require high nutrition (fertilizer) and strict farm management practices**

Bota boye (Dolka), Hatiye, Oha, Arkiyia, Fara, Suyitia, Zo'o-macha boye, and Welawa because they have less water content and small tuber size

3. **Order from higher to lower tuber size of yam landraces and forms big size tuber with high quantity and help to feed your house hold**

Wolabo boye, Gajela, Genna, Attuma-Ayina, Wayicha, Macha-Ayina,

4. **More produced and most important**

Bota boye (Dolka) due to its sweet tuber taste, white tuber flesh color, good for tuber consumption due to its palatability, high quality in production under favorable condition, high demand in market, best for cultural food (Fichata) preparation. It is the most expensive yam landraces in Boloso Sore district while Oha in Damot Gale district.

5. **More accessible in market**

Wayicha in Boloso Sore while Gajela in Damot Gale district due to their less sweet taste and market demand

6. **High local preference and high demand in market**

All Macha boye due to their sweet taste

7. **Widely cultivated across locality and provide higher yield**

Attuma and Macha-Ayina in Boloso Sore district while Gajela in Damot Gale district due to their resistance of drought and re grow fast after incidence and produce higher yield in production.

8. **More susceptible to disease and moisture stress**

All Macha Boye because they have less water content than Attuma Boye

9. **High market preference/market availability is low and known to be very expensive**

Bota boye (Dolka) in Boloso Sore and Oha in Damot Gale district

10. **Easy to cook and consume**

All Macha Boye

Appendix 3: Pearson correlation coefficients of farm size for agriculture, land size allocated for yam, and land size allocated for other crops

Correlations

		Total farm size for agriculture	Land size allocated for yam	Land size allocated for other crops
Total farm size for agriculture	Pearson Correlation	1	.072	.648**
	Sig. (2-tailed)		.068	.000
	N	366	366	366
Land size allocated for yam	Pearson Correlation	.072	1	.095
	Sig. (2-tailed)	.068		.170
	N	366	366	366
Land size allocated for other crops	Pearson Correlation	.648**	.095	1
	Sig. (2-tailed)	.000	.170	
	N	366	366	366

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix 4: Pearson Correlation coefficients between distribution and abundance of landraces between Kebeles within both districts

Correlations

		Abundance	Distribution
Abundance	Pearson Correlation	1	.720**
	Sig. (2-tailed)		.001
	N	19	19
Distribution	Pearson Correlation	.720**	1
	Sig. (2-tailed)	.001	

N	19	19

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix 5: Pearson Correlation coefficients, mean, standard deviation, sum of square and cross products, and covariance between Kebeles among the various diversity indices

Descriptive Statistics

	Mean	Std. Deviation	N
Correlation between Kebeles	3.50	1.871	6
Richness	10.17	3.061	6
Shannon diversity	1.8067	.26696	6
Simpson's diversity	.8000	.04817	6
Evenness	.8000	.06512	6

Correlations

		Richness	Shannon diversity	Simpson's diversity	Evenness
Richness	Pearson Correlation	1	.916*	.814*	-.391
	Sig. (2-tailed)		.010	.049	.443
	Sum of Squares and Cross-products	46.833	3.743	.600	-.390
	Covariance	9.367	.749	.120	-.078
	N	6	6	6	6
Shannon diversity	Pearson Correlation	.916*	1	.975**	-.028
	Sig. (2-tailed)	.010		.001	.959
	Sum of Squares and Cross-products	3.743	.356	.063	-.002
	Covariance	.749	.071	.013	.000
	N	6	6	6	6
Simpson's diversity	Pearson Correlation	.814*	.975**	1	.128
	Sig. (2-tailed)	.049	.001		.810

	Sum of Squares and	.600	.063	.012	
	Cross-products				.002
	Covariance	.120	.013	.002	.000
	N	6	6	6	6
Evenness	Pearson Correlation	-.391	-.028	.128	1
	Sig. (2-tailed)	.443	.959	.810	
	Sum of Squares and Cross-products	-.390	-.002	.002	.021
	Covariance	-.078	.000	.000	.004
	N	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

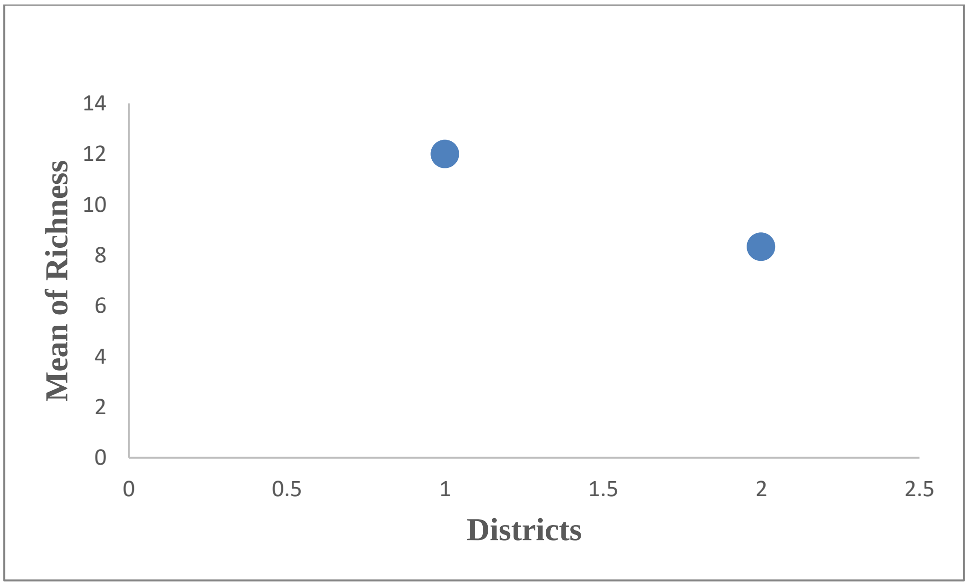
Appendix 6: ANOVA for richness and Shannon diversity of landraces between two districts

ANOVA

		Sum of Squares	Df	Mean Square	F	Sig.
Richness	Between Groups	20.167	1	20.167	3.025	.157
	Within Groups	26.667	4	6.667		
	Total	46.833	5			
Shannon diversity	Between Groups	.160	1	.160	3.262	.145
	Within Groups	.196	4	.049		
	Total	.356	5			

Based on the given information above, for both richness and Shannon diversity of yam landraces, the p-values (Sig.) are greater than .05, indicating that they are not statistically significant. Therefore, we fail to reject the null hypothesis and conclude that there is no significant variation between the richness and diversity of yam landraces.

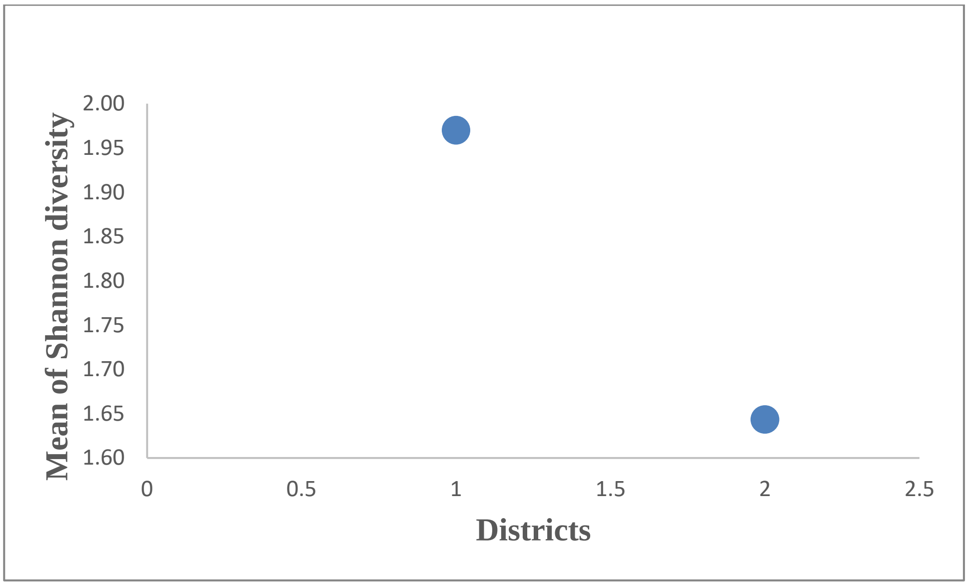
Mean plots of yam landraces richness between two districts



Mean plot showing variations in mean yam landrace richness between Boloso Sore (left) and Damot Gale (right)

The Figure result indicates that the mean landrace richness of Boloso Sore district was higher than Damot Gale.

Mean pots of yam landraces Shannon diversity



Mean plot showing variations in mean yam landrace Shannon diversity index between Boloso Sore (top) and Damot Gale (bottom)

Appendix 7: Figures on farmer's management practices of yam land races

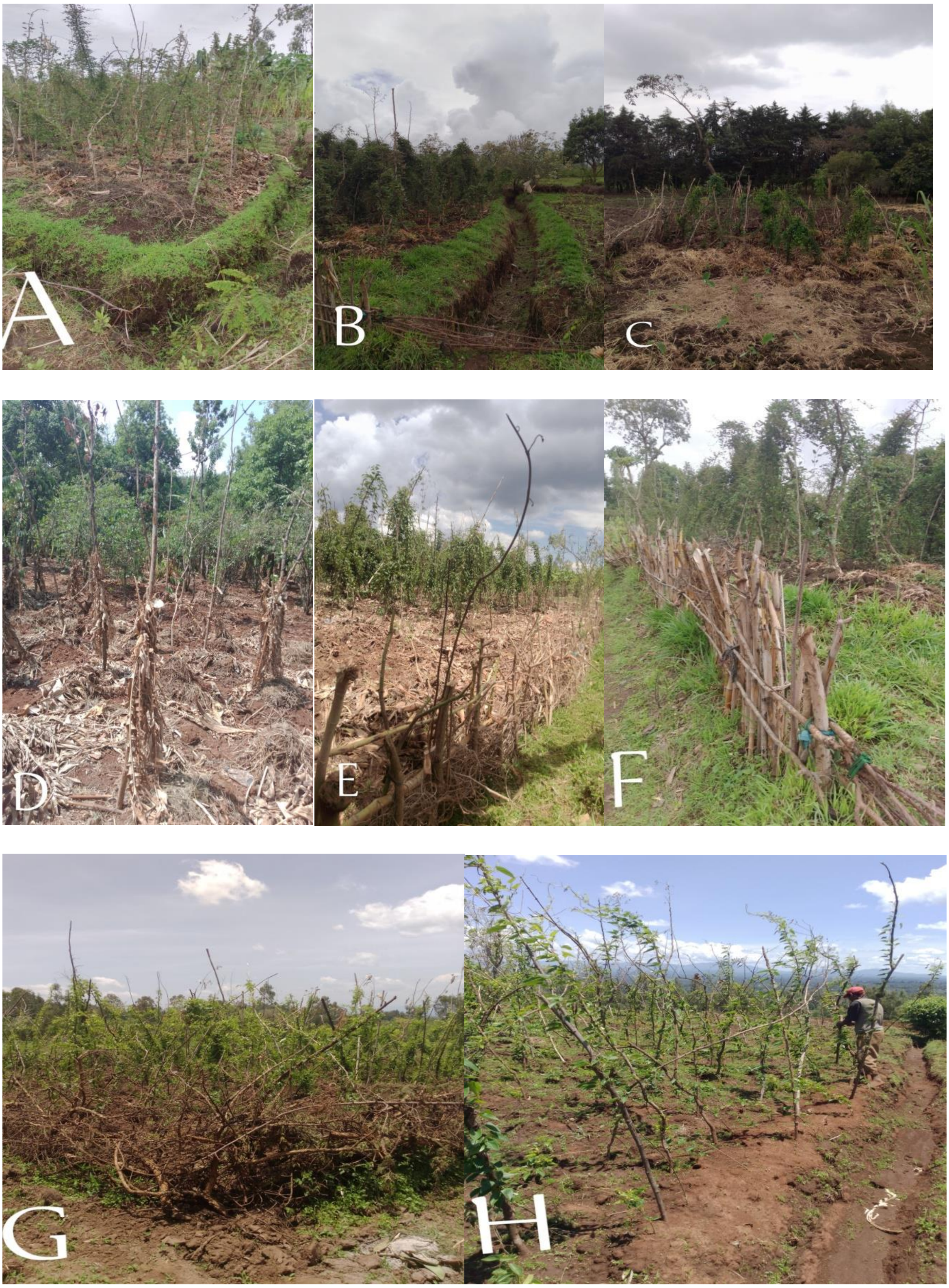


Figure 10: Photographs showing farmers management practices of yams in the study area: A and B: Ditching; E, F, and G: Fencing (farmers demarking field boundaries for yams and protecting yams from damage by animals like Porcupine); C: Mulching (Mulching yam

fields keeps soil moisture and improves soil organic matter content); D: Crop cover; H: Yam planted in manure-burred farms.

Appendix 8: Cropping system of Yam landraces in the study area

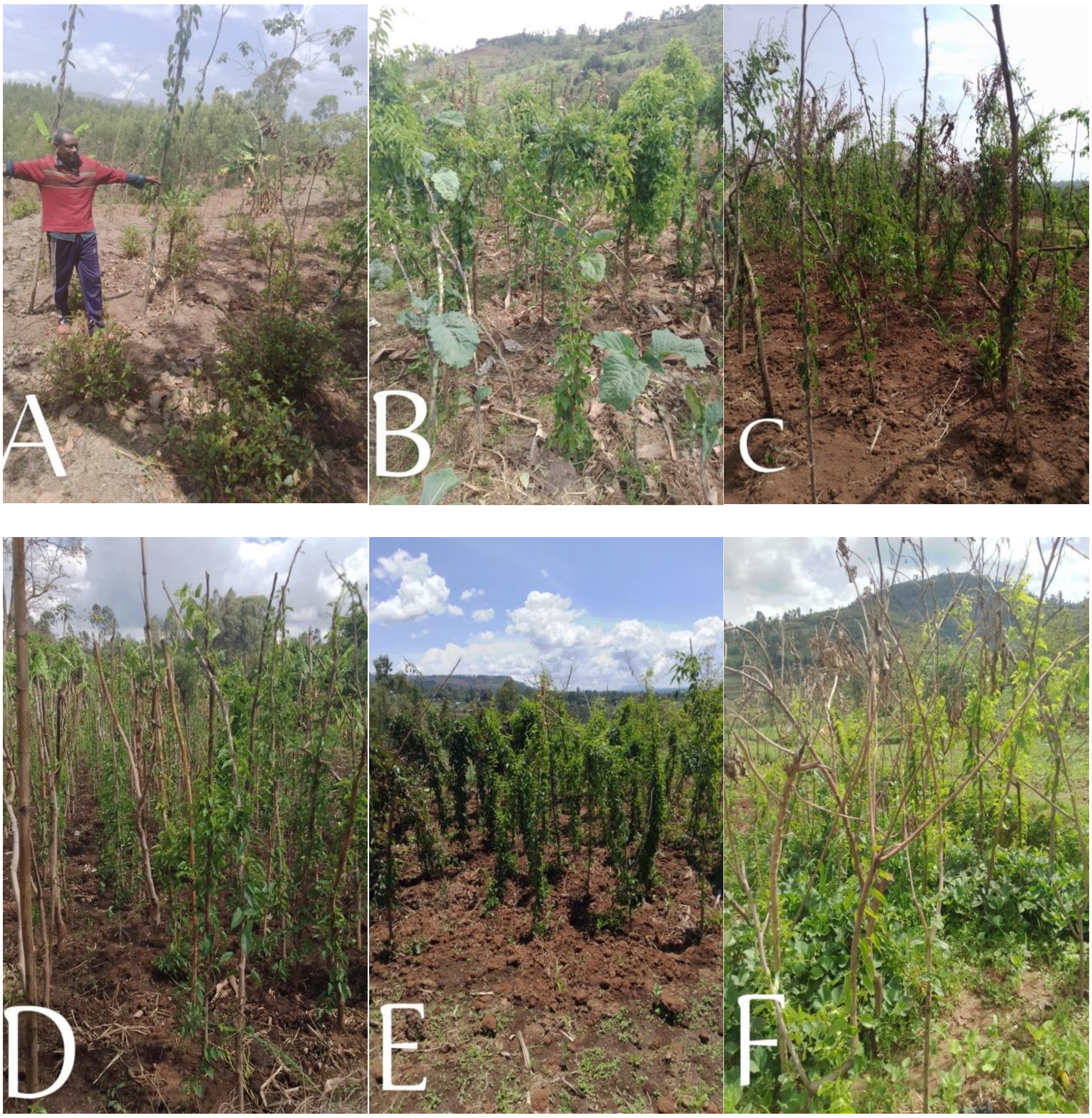


Figure 11: Photographs showing farmers cropping practices: A: Yam intercropped with chat; B: Yam intercropped with cabbage; C: Yam cropped with maize; D and E: Yam cropped alone in rows; F: Yam intercropped with Sweet potato.

Appendix 9: Constraints to yam production

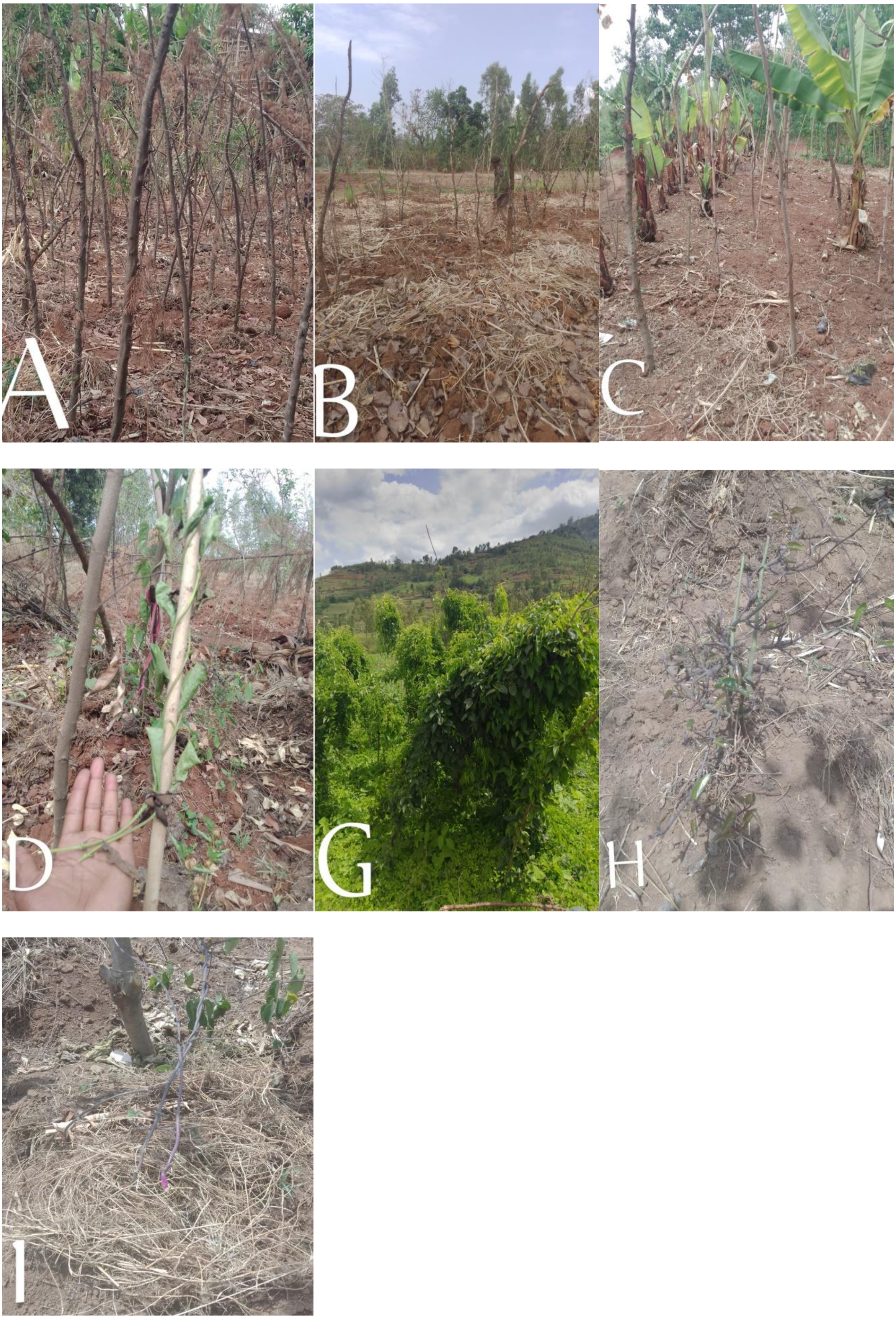


Figure 12: Photographs showing constraints to yam production in the study area: A, B, and C: Showing yam constrained by drought; D: Showing yam constrained by rodents such as rats; G: Showing yam constrained by weed; H: Showing yam constrained by Deer (locally called genissa); I: Showing yam constrained by Porcupine (locally called kutarssa).

Appendix 10: Morphological features of yam landraces from personal observation during a field survey


G
H
I
J
K
L
M
N

Figure 13: Photographs showing morphological features of yam landraces: A: Woman showing above-ground vegetative parts of Attuma-Ayina; B: Tuber with root morphology of Attuma-Ayina; C: Young stage above-ground morphology of Attuma-Ayina; D: Stem with prickle morphology of Gajela; E and F: Tuber with root morphology of Gajela; G: Tuber with root morphology of Oha (bears 6–12 new tubers after first harvest); H: Tubers (bulbils) of Unkurubo (aerial yam); I: Showing stem morphology of Wolabo boye; J: Showing leaf morphology of Hatiye; K: Showing leaf morphology of Suyitia; L: Showing young leaf morphology of Unkurubo (aerial yam); M and N: showing the leaf morphology of Oha; O: showing an aerial shoot climbing a long tree (*Cordia Africana*) with a close-up view of the stem (10m) of Wolabo boye; P: Showing new Wolabo boye sprouting from a previous harvest place.

AOUTHOR BIOGRAPHICAL SKETCH

I was born in Danema, Hadiya Zone of Central Ethiopia Region, on September 7, 1991 E.C. I attended primary school at Danema 01 Elementary School in West Bedawacho Woreda, and I attended high school at Danema Primary and Secondary High Schools in West Bedawacho Woreda. Then I joined Wolaita Sodo University in 2010 and graduated with a Bachelor of Science degree in Applied Biology in 2013. I was employed there in February 2013 and served as a graduate assistant (GA-1). After 6 months of service, I joined Hawassa University in September 2014 for MSc study.