POST-HARVEST LOSS FACTOR ASSESSMENT AND TUBER STORABILITY EVALUATION OF POTATO (*Solanum tuberosum L.*) VARIETIES UNDER DIFFERENT STORAGE STRUCTURES IN GUMMER DISTRICT, CENTRAL ETHIOPIA

MSc. THESIS

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Post-harvest Loss Factor Assessment and Tuber Storability Evaluation of Potato (*Solanum tuberosum* L.) Varieties under Different Storage Structures in Gummer District, Central Ethiopia

A Thesis Submitted to School of Graduate Studies, in Partial Fulfillment of the Requirements for the Degree of Master Science (MSc) in Horticulture

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We hereby certify that we have read and evaluated this Thesis entitled "**Post-harvest loss Factor Assessment and Tuber Storability Evaluation of Potato (*Solanum tuberosum* L.) Varieties under Different Storage Structures in Gummer District, Central Ethiopia**" prepared under our guidance by Mr. Sisay Sifir. We recommend that the Thesis shall be submitted as fulfilling the requirements for the award of a M.Sc. degree in Horticulture.

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By my signature below, I hereby declare and affirm that this thesis is my original work. I have followed all the requisite ethical principles from the proposal development, field layout of the experiment, data collection, data analysis, final writing up, and submission of the thesis. This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science (MSc.) from the School of Graduate Studies at Wolkite University. The thesis shall be deposited in the Wolkite University library and made available to users subject to its rules and regulations. I also solemnly declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born on the 21st of December 1993 in Gurage Zone, Central Ethiopia Regional State. He attended his elementary, Secondary, and preparatory education at Anbere Elementary School, Quante Secondary School and Arekit Secondary and Preparatory School, respectively. After successful completion of the EGSE, he joined Jigjiga University in 2011 and graduated with a B.Sc. degree in crop science on 28 July 2014. After graduation, he served in the Gummer Woreda Agriculture Office for about 6 years as a plant science expert. He joined Wolkite University, School of Graduate Studies in November 2022 to pursue his M.Sc. degree in Horticulture.

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ABBREVIATIONS AND ACRONYMS

CA	Controlled Atmosphere
CIP	International Potato Center
CSA	Central Statistical Agency
DA	Developmental Agent
DMC	Dry matter content
FAO	Food and Agriculture Organization of the United Nations
GDAO	Gummer District Agricultural Office
GDPEO	Gummer District Plan and Economy Office
HA	Hectare
HH	Household
M	Meter
Mt	Metric Ton
PHL	Post Harvest Lose
Qt	Quintal
RTC	Roots and Tuber Crops
WMC	World Market Center
LDCs	Least Developing Countries
WL	Weight loose
SMS	Subject Matter Specialist
SPSS	Statistical package for social science

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN THE APPENDIX

LIST OF FIGURES IN THE APPENDIX

ABSTRACT

In the study area,there is huge potato production with high post harvest loss . Therefore, the current study was initiated to assess the main factors responsible for postharvest losses of potatoes and to evaluate tuber storability using different storage structures. For the survey, a total of 120 farmers and 6 key informants were interviewed from four (4) kebeles which were selected purposively. A descriptive research design was employed and quantitative data were measured and analyzed by using SPSS software version 20. The results indicated that inadequate awareness, lack of appropriate harvesting materials inappropriate harvest maturity determination and storage facilities as well and market uncertainty were as the main factors that contribute to the prevailing high level of postharvest losses of potatoes in the area. The result indicated that 62% of the respondents have no awareness, 23% have medium awareness and 15% have low awareness of postharvest losses and postharvest handling methods for potato tubers. For harvesting, majority of the respondents (63.3%) use rake to dugout tubers. For the experiment, four storage structures (pit, bamboo baskets, floor, and loft) and two potato varieties (Gudene and 'Key dinch') were laid out in 4×2 Complete block Block design, and data were collected frequently in a time interval. The analysis of variance showed that the main effect of variety, storage structure, and time was significantly influenced all the postharvest parameters except variety and pH content of the tuber. The lowest weight loss (6.11 and 6.22) was recorded from pit storage and at 30 days of storage, respectively. The longest days to 50% sprouting were obtained from all treatment interactions except from the variety Gudene interacted with the floor (72 days) and with basket storage (72 days). None of the tubers were sprouted by the interaction of Gudene with the loft method and were stored for 30, 60, and 90 days after storage. The highest dry matter content (24.5%) was obtained from tubers stored in the pit after 90 days of storage whereas the lowest dry matter content (21.5%) was obtained from tubers stored on the floor for 90 days after storage. for better storage stability of potato tubers, loft storage method with Gudene variety were found to be more ideal for extending the storage or shelf-life of the tubers.

Key words: *Dry matter, pH, postharvest loss, potato, varieties, rotting, sprouting , storage structures, weight loss,*

1. INTRODUCTION

1.1. Background

Potato (*Solanum tuberosum* L.) originated in the central highlands of the Andes in South America and was brought to Europe in the 16th century (Dawit and Alemayehu, 2021). Currently, it can grow in 154 countries globally due to its resistance to drought, cold, barren with wide adaptability. The soil and climate conditions in most parts of the world can meet its growth conditions. Potato is the world's fourth most important crop after wheat, rice, and maize (Dawit and Alemayehu, 2021). However, it is first among root and tuber crops, followed by yams, cassava, and sweet potatoes (Komelgal *et al*., 2021).. Currently, Asia, Latin America, and Africa are high potato producers (FAO, 2022).The world's total production of potatoes was 359,071,403 metric tons in year 2020. China ranks 1st by 21.8% of total production while India and Ukraine rank 2nd and 3$^{rd.}$ by potato production respectively. The African continent, Nigeria is the leading country in high production of potato it contributes 58% of the total production (FAO STAT, 2023). The world average productivity of potatoes is 44 tons/ha (FAO, 2022).

Potato was first introduced to Ethiopia in 1858 by a German immigrant, Wilhelm Schimper, adoption by Ethiopian farmers occurred very gradually for several decades (Kidane, 1980). In Ethiopia, potatoes evolved over a century and a half from a garden crop grown in a few regions to a staple crop grown in many regions under various agro ecological conditions (Ashley *et al*., 2022). Ethiopia has the most potential for potato production because the highlands comprise 70% of the country and are home to a higher percentage of the population (Ejeta, 2019). Ethiopia is one of the major potato-producing countries in Africa and possibly displays a unique position for having the highest potential area for cultivating potatoes it is gifted with suitable climatic and edaphic conditions for the production of yield potatoes production (Shamil and Dereje, 2021).

Despite Ethiopia's favorable agro ecology for potatoes, growth in potato production and productivity was steady and very low for nearly a century (Zewdie, 2021). Shortage of good quality seed, disease, pest, inappropriate agronomic practices, poor storage, transport and marketing conditions, soil nutrient depletion, moisture stress, frost, and inadequate extension

services are the major limiting factors for expanding potato production in Ethiopia (Yebirzaf and Esubalew, 2021). It is the most important cash and food vegetable crop which plays a vital role in ensuring food security globally (Fikadu *et al*., 2013). Due to its large genetic diversity, current cultivation, and demand, potato research, and innovation can contribute to a sustainable Agri-food system and help to achieve zero hunger and sustainable development goals (FAO, 2022).

For nations like Ethiopia, where a lack of protein and calorie supplies are obvious nutritional problems, it is a very important crop(FAO,2018). Additionally, it offers job opportunities in the supply, value, and marketing chains (Leanne and Michael, 2021). Potato is considered to be one of the main staple crops for ensuring food security, providing more calories, vitamins, and nutrients per unit area than any other staple crop (Singh and Kaur,2016). Potatoes produce more nutritious food quickly, on small land, and in harsh climates than any other major crop (FAO, 2021). Potato is considered a food security crop that helps meet the growing food demand in the tropical highlands of sub-Saharan Africa (Kolech, *et al*., 2019).

Gummer Woreda is one of the districts located in the Western part of the Gurage Zone where potato farming is an important component of agricultural activity. In this district, potato is cultivated in almost all kebeles and gives a dependable yield even under adverse agro climate conditions. According to (GDAO, 2023) the area coverage of potatoes is increased gradually through time and in the 2023 production year , the area cultivated by vegetable crops was 3064 ha from which 2834 ha (92.5%) was potato that had produced 81,312-ton with average productivity of 32 tha^{-1} even more than this figure upto 40 tha^{-1} by model farmers (GDAO, 2023).

Post-harvest loss of perishable commodities including potatoes is one of the major problems in many countries including Ethiopia (Benyam *et al*. 2018). Postharvest loss (PHL) is defined as the measurable quantitative and qualitative loss of products at any point in the postharvest chain, from harvest to consumption (Kikulwe *et al*., 2018). With the reduction in postharvest losses by 50%, food availability would be increased by 20% without cultivating additional land to increase crop yield (Ayandiji *et al*., 2011). Until recently, knowledge of postharvest handling of fruits and vegetables such as improved storage, packaging, transport, and handling techniques is limited.

Postharvest loss (which is estimated at 20–25%) is one of the major problems in potato production (Benyam *et al*., 2018). Potato is very sensitive to quality loss because the risk of unacceptable moisture loss, disease spread, mold infections, and insect pest attacks is obvious (Shraddha and Kabindra, 2020). Potato productivity has increased by more than 24 tons per ha due to the adoption of new varieties. However, postharvest loss reduction efforts have not been tailored well (Vita, 2014). PHL is also the main problem of potato farming in the Gummer district. Postharvest losses are the limiting factor for this high productivity so, needs due attention to prevent significant amounts of qualitative and quantitative losses. The post-harvest loss of potatoes in the district has not quantified scientifically and there was no studies were conducted on postharvest loss assessment before. In the study area there is high level of produce is loss due to many problems but the problems that are responsible for postharvest loss of potato were not identified. Therefore, this study seeks to examine postharvest losses at different levels, identifying factors that contribute to the massive postharvest losses, taking into consideration postharvest handling practices and how they affect the food security of potato farmers in the Gummer district.

Moreover, farmers in the study area use traditional storage structures that have not been studied for their storage capacity for a long period with minimum losses and those methods result in reduced shelf life and increased deterioration of potato tuber (GDAO, 2022). Therefore, this study, it is aimed to select the best storage structure with minimum postharvest losses and recommend to the farmers to use the best storage structure.

1.2 Objectives of the Study

1.2.1 General Objective

- To assess factors responsible for postharvest losses of potatoes and evaluate tuber storability under different storage structures

1.2.2 Specific Objectives

- To identify the major factors that contribute for postharvest losses of potato
- To assess tuber storability of potato varieties under different storage structures
- To identify the best storage structure for prolonged shelf life of tuber

2. LITERATURE REVIEW

2.1. Botanical Description of Potato

Potato is a herbaceous plant that grows 0.4m to 1.4m either Erect or entirely prostrate (Spooner and Knapp, 2013). The Potato tuber is an enlarged part of an underground stem from which new shoots are produced. The tuber is morphologically a fleshy stem, carrying buds and eyes in the axil of small-scale-like leaves. Eyes are concerted near the apical end of the tuber, with a small number near the stolon or basal end. Eye number and distribution are characteristics of the variety. In the early stages, the stem is erect and later it becomes proliferates and the prostate(MoEFCC,2014). Potato is an annual crop, which mainly is reproduced vegetatively using its tubers; seldom by seeds mainly for breeding purposes (Padmanabhan, 2016).

Potato is predominantly a self-pollinated plant and is occasionally cross-pollinated (Navjot *et al*.,2021). The peak time of pollination takes place in the early morning (Ashok *et al*., 2018).The terminal bud forms lateral flowers, inflorescence consisting of 1-30 (usually 7-15) flowers, depending on the maintenance and cultivation. The five petals form a star-shaped open flower. A flower of a pistil protrudes to form a cluster of five large bright yellow anthers. The corolla color varies from white to a complex range of red, blue, and purple. Flower opening begins nearest the base of the inflorescence and proceeds upward at the rate of about 2-3 every day. Flowers are open for only 2-4 days and the receptivity of the stigma and period of pollen production is about 2 days (Spooner and Knapp, 2013).

2.2. Status of Potato Production in Ethiopia

Ethiopia is one of the major potato producers in eastern Africa due to its suitable agro ecology (FAO, 2019). In Ethiopia, potatoes is grown in a wide range of agro-ecological zones, throughout the year using different growing practices and are considered a "hunger breaking crop" because they can be grown and harvested when cereals don't mature for consumption. (Shamil and Dereje, 2021). Two of the three known agro ecologies zones are: Woyina Dega (1500– 2300m) and Dega (above 2300m) exhibit the best out-grower potato production (Benyam *et al*.,). In Ethiopia, potatoes are among the list of major food crops that are consumed across the country (CSA, 2015). Potato is among the major root and tuber crops in

Ethiopia, it is grown by approximately 1.3 million smallholder farmers for both consumption and income generation. About 68 percent of the overall production is eaten at the household level, indicating that consumption predominates. The remaining 12 percent is kept as potato seed, while about 20 percent is sold in the market. Despite the rising market need, this pattern persisted over time. Along with the number of households producing potatoes and the area of land used for the crop has expanded dramatically in recent years (FAO, 2021).

Oromia and Amhara have a higher position in the production of potatoes in Ethiopia (Gedefaw *et al*., 2022). The southern part of the country is one of the potential potato growers in Ethiopia. The major potato-producing zones in southern area are Gurage, Gamo, Goffa, Hadiya, Wolaita, Kambata, Siltie, and Sidama and West Arsi zone in Oromiya. According to CSA (2015/16) potato in Ethiopia planted around 296,577.59 ha is planted and 3,657,638 ton of potato production annually. This implies the average yield of the country was 12.33 ton/ha. This data shows that there is a significant difference or there is progress in potato production both in productivity and production. But still, the productivity is lower compared with other countries even though it is lower than most potato-producing countries in Africa like South Africa and Egypt which produce 34 and 24.8 t/ha respectively (FAO, 2021).

According to Yohannes *et al*. (2022), the average potato productivity in Ethiopia is 13.62 tons/ha, which is far below the world average (44 t/ha). According to FAOSTAT (2020), many factors have been identified as the causes for low yield in most of the East African countries. Some of the production constraints that have contributed to the limited production or expansion of potatoes in Ethiopia include poor quality seed, poor agronomic practices, and poor pre and post-harvest handling, marketing, and transportation systems.

Table 1. Potato production in Ethiopia (2016-2020)

Potato	**2016**	**2017**	**2018**	**2019**	**2020**
Area harvested	66,923	67,591	66,635.00	70,362.00	76,677.64
Production	92,1403	932,701	933,109	924,528	1,141,872
Yield (t/ha)	13.7	13.7	14.00	13.14	13.62

Source: Yohannes *et al*., (2022), FAO (2020)

According to the above table, the potato cultivated area in Ethiopia increased within the past five years except for the production year of 2018. When the production of potatoes is increased from 2016 to 2020 but the yield in 2019 decreased because of the drought encountered in some areas of the country (Dawit and Alemayehu, 2021).

2.3. Postharvest Losses of Potato in Ethiopia

In Ethiopia, post-harvest losses of horticultural crops may be estimated to be 15 to 70% at various stages (Misrak *et al*., 2014). Potato is known as a semi-perishable commodity and storage of both seed and ware potatoes. According to (Benyam *et al*., 2018) in Ethiopia, postharvest loss of potatoes is estimated at 20 to 25% this implies that one-fourth of the total production is lost at different level from the initial harvest through assembly and distribution to the final consumer. Thus, to reduce postharvest losses, appropriate technologies should be developed and promoted. With the reduction in postharvest losses by 50%, food availability would be increased by 20% without cultivating an additional hectare of land to increase crop yield (Ayandiji A. *et al*, 2011).

2.3.1 Major Causes of Postharvest losses of Potato

Post-harvest loss is one of the biggest problems affecting economic growth globally. FAO (2019) estimates that $1/3^{rd}$ of loss in food products occur every year. The most important factors that are responsible for post-harvest losses are sprouting, the infestation of Potato Tuber Moth (PTM), weight loss, and awareness of post-harvest technologies in the farming communities (NPRP, 2018). In Ethiopia, potato tubers are harvested, stored, packaged, and transported with slight care to avoid physical damage to the tuber, most likely because of the low level of knowledge about the consequence of physical damage by all parties involved (Adane, 2013).

Appropriate and efficient post-harvest technology and marketing are critical to the entire production, and consumption system of potatoes because of their bulkiness and perishability (Alvarez *et al*., 2011). Reduction of post-harvest losses and quality deterioration are essential in increasing food availability from the existing production. Minimizing the loss has great significance for food security, economic growth, and the welfare of society (Mohhamed, 2016). The following are the major factors responsible for postharvest losses of potatoes.

2.3.1.1 Harvesting technique, time and method of Potato

The harvesting technique is the base for other factors or the first factor of post-harvest losses of potatoes. Harvesting technique, material, time, and methods could be the major factors for the post-harvest loses of potatoes. Inappropriate harvesting time is a major problem for the PHL of fruits and vegetables in Ethiopia (Etefa *et al*., 2022). Poor cultural practices are the major pre-harvesting causes of fruit and vegetable loss (Bantayehu *et al*., 2019). As the size of potato tuber is large, it is necessary to use the appropriate tool for harvesting, But the farmers are not using proper equipment results the tuber facing the problem of cutting, if it is cut negatively affects the quality of the tuber as well as an option for the development of other diseases, so it has a negative effect on loss of the product. Postharvest loss and quality deterioration of horticultural crops occurred due to lack of proper care, use of inappropriate harvesting equipment and materials, and lack of motivation and interest to improve and upgrade the harvesting and handling techniques from time to time (Mohhamed, 2016).

2.3.1.2 Crop Nature

Potatoes belong to the group of semi-perishable goods, that is, products with high natural moisture content (Kibar, 2012). Loss of moisture leads to quality loss and finally to non-marketable produces (Singh and Kaur, 2016). Potatoes comprise tremendously high moisture content large in size and soft texture when compared to cereals and legumes and selling fatly after harvest is more advantageous. Horticultural crops are enormous and perishable, which makes them challenging to maintain throughout the postharvest period in contrast to dry grains (Gebru and Derbew, 2015). They need cautious managing and in the absence of correct handling and suited environmental conditions their storability is affected and the chance of loss is enhanced. Proper and efficient postharvest technology and marketing are critical to the

entire production-to-consumption system of the potato because of its bulkiness and perishability (Mohamed *et al*., 2006).

2.3.1.3 Lack of Transportation

In developing countries, challenges like lack of recommended harvesting practices and tools, poor road and transportation access as well as absence of storage make it difficult to extend shelf life of products and maintain desired quality (Chala *et al.,* 2019). Postharvest loss of potato during transit rise as a result of the bad roads in rural areas, where most production takes place. Even in rainy times, the getting cars might get stuck in the mud leads to loss (Aysel , 2019). Poor transportation of potatoes causes significant loss (Misrak *et al*., 2014). Potato grown on rain feed or in belg season the harvesting will during the rainy season, so farmers find it difficult to supply the produce to the market as there is no road option in the most of the rural areas. To fence this problem they use other transport options like animal but it is not possible to deliver them to the market in the required quantity, quality and speed. So there is high possibility of the product being spoiled.

According to Hussen *et al*., (2013), transportation contributed to 5–20% of the total PHLs of potato, this indicate that improper transportation or lack of transportation leads to high post-harvest loose of potato. The common problems associated with transportation are Bad conditions of the vehicles tents/covers, Poor cushioning systems of the vehicles, Inappropriate systems of loading and unloading, Uncovered vehicles, expose the product to the negative effect of the environmental conditions, Inappropriate systems of packing. Commercially, a poor transport system could prevent a farmer from selling his produce within the necessary timeframes and result in significant postharvest loss of potato(Benjaw, 2017)

2.3.1.4 Lack of Storage Facilities

In Ethiopia, the storage methods and tools used are old-style and very poorly to maintain the required level of storage quality (Debela *et al*., 2011). Potatoes are mostly produced during the winter season from November to March, but are consumed year round. Therefore, storage plays an important role in the creation of time and place utilities (CIP, 1994). The lack of proper storage facilities in developing countries is seen as the main cause of post-harvest losses of potato (kibar, 2012). In Ethiopia potatoes is basically stored for two reasons: ware

and seed. Farmers use different traditional potato storage system depending on the use. However, these storage facilities are not proper to keep the quality of tuber for more than 1-2 months. As a result, farmers are forced to sell their potatoes at low prices during harvest (Abebe , 2020).

The lack of enough storage is due to two major reasons, one is due to lack of awareness and not trying to set up small storage as much as possible before the product is arrives to harvest, and the other is due to lack of economic capacity due to insufficient economic capacity to purchase some factory materials which are need for building potato storage (GDAO, 2022). The storages to build are not sufficient in terms of type and quality, so forced to sell the produce at lower price, and not easy for the farmer to drop the produce on the field. This is not only has negative impact on the food security and income of the farmers, but also has significant impact on the farmers not to produce in the future.

In agriculture, and especially in LDCs, supply often exceeds demand in the immediate post-harvest period. The glut reduces producer prices and wastage rates can be extremely high. The storage function is one of balancing supply and demand. Both growers and consumers gain from a marketing system that can make produce available when it is needed. A farmer, merchant, co-operative, marketing board or retailer who stores a product provides a service. That service costs money and there are risks in the form of wastage and slumps in market demand, prices, so the provider of storage is entitled to a reward in the form of profit (FAO, 2021). In Ethiopia the absence of storage technologies for ware and seed potato, farmers keep potato harvest in the ground for a long period this reduces tuber yield significantly. In a recent report, losses during postharvest storage of potato ranged from 15-20% (Bhattarai, 2018).

2.3.1.5 Insufficient Market Access

An efficient marketing system that minimizes transport costs and particularly wastage will significantly lower retail prices. According to Gildeacher *et al*., (2009) In Ethiopia, 88 percent of the potatoes are sold in the village market. It is the challenging task of the extension officer to accelerate the introduction of more efficient marketing processes which will lead to the lowering of consumer prices. As a result of lower prices, consumption will increase, which will offer the potential for expanded production. The market price of the product and marketing systems are very problematic (Tewodros *et al*., 2014). Due to a lack of appropriate

storage and handling equipment, a substantial amount of potato is believed to go to waste before they reach for consumption or are sold at a low price.

The market plays a great role in increasing agricultural products and productivity by increasing the initiation of farmers and increasing their income which leads to increased productivity. Horticultural products in Ethiopia are mainly produced by smallholder farms and most of the farmers sell their products in the neighboring market and a few sell both on the farm and in the nearby market such that the marketing condition is insufficient and gloomy (Seid and Yitbarek 2013). The reasons for unsatisfactory market conditions indicated that higher supply of the produce at a time, middle men condition and products sold on farms and the nearby market. When supplies become excessive, farmers in more remote locations facing high transport costs might be forced to dump their potatoes (Benjaw, 2017).

2.3.1.6 Lack of Resistance Varieties

This is related to making appropriate decisions in selecting resistance varieties. Potato varieties have different potential for tolerating postharvest lose. Some varieties are very sensitive to postharvest loss and others have tolerance capacity and which have high stability potential. The major conditions that are postharvest loss of potato varieties are short post-harvest life, early sprouting; tuber rot, shrinkage, and weight loss (Upadhyay *et al*., 2018). Varieties differ in their sprouting behavior (Kalika *et al*. 2021). Similarly, John *et al*., (2017) stated that rotting incidence and rate of rotting differ in potato varieties. So, potato varieties have different potential to expose postharvest losses in different level.

2.4. Effect of Storage Structure and Condition on Shelf Life of Potato Tuber

During storage, postharvest losses of potatoes occur due to weight loss, sprouting and rotting which are directly affected by storage conditions (Shraddha and Kabindra, 2020). The quality of potato and its storage life is reduced by the loss of moisture, decay, and physiological breakdown. These deteriorations are directly related to storage temperature, relative humidity, air circulation, and gas composition. Potatoes, being living organisms, require effective management for storage. The quality of the potatoes deteriorates gradually during storage.

Bruise prevention, minimum weight loss, and storage disease prevention are the main parts that are to be looked after during storage (Anjali and Ajeet , 2010).

2.4.1. Effect of Different Storage Structures on Shelf Life of Potato Tubers

The other factor for postharvest loss is the faulty selection of storage structures. After harvest, tubers are stored for several months. Therefore, optional storage conditions play a key role in postharvest quality management (Mansour, 2023). Storage method and storage duration can modify several qualitative and physiological parameters of tubers due to the physiological aging of the tuber (Helis *et al*,.2022). These storage facilities are inadequate to maintain the quality of the tuber for longer than a couple of months (Endale *et al*., 2008). Farmers used a variety of conventional methods to store potatoes, either for consumption or as seed. Farmers cannot store potatoes for more than three and a half months in these conventional storage facilities without them deteriorating (Tewodros *et al*., 2014). The major objectives of storage are for the future consumption, future processing, and maintenance of seed reserves. Also, it allows better use of processing capacity, better tuning of production and consumption, and better quality of seed potatoes. To guarantee a top-quality product, storage conditions must be well controlled (Pringle *et al*., 2009). Low-temperature storage, CA storage, storage in diffused sunlight, in situ storage, traditional clamp storage, storage in pits, and storage in bamboo baskets are the major storage techniques practiced all over the world (Mohamed *et al*., 2006).

2.4.2. The Role of Environmental Factors on Shelf Life of Potato Tuber

Temperature, light, humidity, and air movement are the most important environmental factors affecting storability (Tashome and Ibsa , 2021). Throughout the period between harvest and consumption, temperature control is one of the most important factors in maintaining product quality. The two critical environmental factors involved in properly storing potatoes are temperature and humidity. Adequate and unrestricted air movement is also necessary to maintain constant temperature and humidity throughout the storage pile and to prevent excessive shrinkage from moisture loss and decay. The health of potato tubers in storage does not improve over time but can be maintained by ensuring a proper storage environment, A Proper storage environment in combination with the use of postharvest fungicides and

disinfectants is important for managing losses during the storage period (Knowles and Plissey 2008).

2.4.3. Effect of Postharvest Diseases and Pests

Careful harvesting and handling techniques to minimize bruising, skinning, and cutting are the most important mechanisms for incidences of diseases of stored potatoes . The most important postharvest disease of potato are *Phytophthora infestants* (late blight), *Fusarium species* (dry rot), *P.erythroseptica* (pink rot), *Pythium ultimum* (Pythium leak), *Macrophomina phaseolina* (charcoal rot) and bacteria such as *Ralstoni solacearum* (brown rot), *Erwinia carotovora subsp. Carotovora*, soft rot and black leg (Rajesh *et al*., 2021). Fusarium dry rot caused by several species of Fusarium, is one of the most important postharvest disease in potato(Noureddine,2012). Potato tuber moth, cutworms termites, white grubs, mole crickets and red ants are pests which damages the tuber in the feed and in storage (Man deep *et al*., 2013).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted in Gummer woreda, Gurage zone, Central Ethiopia. Gummer is located 219 km from Addis Ababa, and 68 km from the Wolkite which is the administrative center of the Gurage zone. The district is bordered on the southeast by the Silte zone, south-west by the Geta, on the northwest by Cheha, and the north by Ehza. According to (GDPDO, 2022). It has a total population of 122,860 from this 57,506 are male and 65,354 are females. The agro-climatic condition of the district is Dega. The soil type of the district is loam an average temperature of 10-15^{0}C with an annual rainfall pattern of 2100-2400 mm. It is located at an elevation of 2700-3169 meters above sea level (GDAO, 2022).

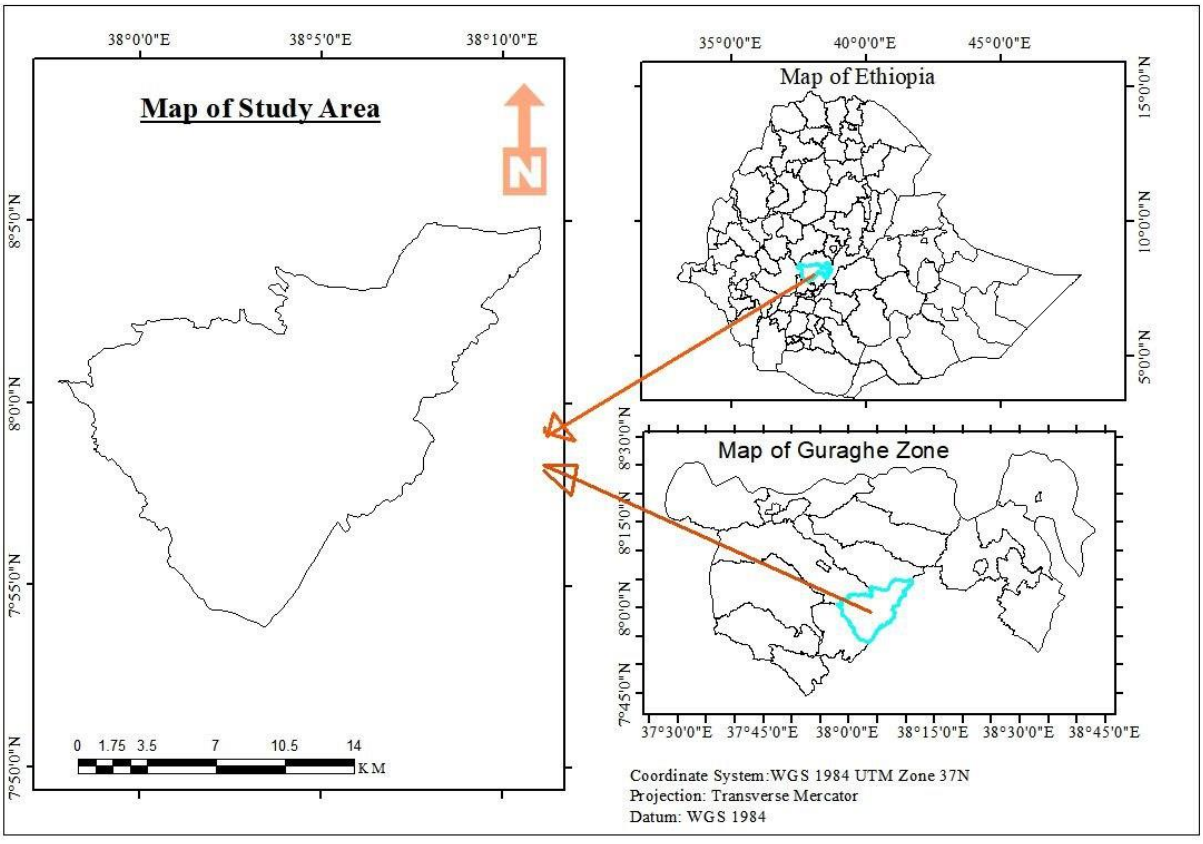


Figure 1. Map of the Study Area

Part_1. Survey Work

3.2.1 Research Design

A descriptive research design was employed for survey work. The main purpose of descriptive research design is the description of the objectives of the study (Kothari, 2004). A descriptive research design was employed for the study to describe and interpret the key factors of postharvest loss of potatoes in the Gummer district.

3.2.2 Sources of Data

Both primary and secondary data were collected. Primary data were designed to gather information by interview through questionnaires prepared for farmers involved in potato production, extension workers, and experts. Secondary data (information) were gathered from published and unpublished documents which are available from journals, books, NGOs, gov`t reports.

3.2.3 Method of Data Collection

The data for the study were collected from multiple sources. Prepared Semi-structured questionaries' and primary data were collected by questionnaire and interview. For recording primary data Four (4) *kebele*s were purposively selected from the district. These are *Essen*, *B/Denber*; *Ziznecho* and *Arekit Shelko*. A total of 120 farmers and 6 key informant respondents participated during the interview. The questionnaire was first prepared in English language but later translated into the Amharic language this is for easy understanding by the local farmers and the respondents.

3.2.4 Target Population

The target population of the study was potato-producing farmers. The sample proportion is described in Table 2.

Table 2. Target Population and Sample Size of the Study Area

No	Kebele	Target population	Sample proportion
1	Burdana Denber	941	24%
2	Essen	1200	30.6%
3	Arekit Sheleko	829	21.14
4	Zizecho	951	24.26%
	Total	3921	100%

3.2.5 Sample Size Determination

The sample size was determined using Yamane (1967) which is a simplified formula for the total number of potato producers at tolerable precision error of 0.09.

$$n = \frac{\mathrm{N}}{1+\mathrm{N}(e^2)}$$

Where: n= Number of samples taken

N= Population size

e = sampling error /level of precision. Accordingly the target population results, the following samples.

$$n = \frac{3921}{1+3921(0.09^2)} = 120$$

3.2.6. Sampling Technique

From a total of 120 sample households, 37 households from *Essen*, 29 households from *Burdana dneber*, 29 households from *Ziznch*o, and 25 households from *Arekit shelko* kebeles were selected based on probability proportional to the population size of the selected kebeles. Finally, farmers are selected by using a systematic sampling technique to minimize biasedness.

3.2.7 Method Data Analysis

For the survey data, primary and secondary data were collected, and the collected data were coded and entered into Excel sheets. The respondent's data were summarized from the sheet and made ready for analysis. Descriptive statistics (mean, present, frequency, and standard deviations) were used to summarize the survey data. All the quantitative data measured were analyzed using SPSS software version 20. The interview questions were analyzed using descriptive statistics and narrations.

Part_2. Field Experiment

3.3.1. Experimental Set-Up, Treatments and Design

To evaluate the storage of potato varieties, four storage structures, namely: (1) storage in bamboo baskets; (2) storage on the floor (3) loft (locally called ‘‘Kot”), and (4) pit storage. Thus, treatments consisted of four storage types and two varieties (Gudene and key dinch) in 4×2 factorial arrangements using Complete Randomized Design (CRD). An equal amount of ware potato tuber (6kg per treatment) of each variety which was harvested from the same plot of land and managed uniformly was used as experimental material. Equal amounts of harvested tubers were placed in each storage structure simultaneously according to the treatments and randomization.

3.3.2 Experimental Procedure

The two potato varieties were planted in the second week of January and harvested in the last week of June 2023 after reaching full harvesting. All the required agronomic practices were done uniformly from planting to harvesting. Carefully harvested tubers were graded based on their size to get the required uniform sized tuber for storage. Thus, disease-free, mechanically undamaged, and uniform medium to large-sized tubers were selected. The uniform weight of tubers (6kg per treatment) of each variety was placed on each storage structure as per the treatment. Treatment placement (storage) began on June 21^{st,} 2023, and was completed on September 18, 2023, in which storage duration was 90 days. Storage of potato tubers was done on the same day and at once to avoid variation and tubers were not subjected to any other postharvest treatments including curing.

3.3.3 Data Collection and Measurement

Data were collected on every 30 days interval after storage. The initial weight of tubers and the number of tubers were recorded first, just at the time of tuber storage. The following postharvest parameters were collected and recorded at frequent time intervals.

Physiological Weight Loss (%):

The difference between initial weight and final weight gives weight loss. Weight loss was measured by digital electronic balance, and calculated by subtracting periodic weights of tubers from the initial weight at the time of storage every 30 days interval and expressed in % using the following formula.

$$\mathrm{WL}(\%) = \frac{\mathrm{wi}-\mathrm{wf}}{wf} \times 100$$

Rotted Tubers (%):

The rotted tubers were detected by visual observation counted and discarded to remove double counting. The number of rotted tubers was counted on every 30 day interval and expressed in percent.

$$\text{rotten tuber}\ (\%) = \frac{\text{number of rotten tubers}}{total\ number\ of\ tuber} \times 100$$

Days to 50% Sprouted:

This is recorded by counting the date from storage to when 50% of the stored tubers in each storage structure become sprouted.

pH:

The sample tubers were washed using clean water, and crushed to extract juice. Then after, the pH of the extracted juice was measured using a pH meter. The pH was measured twice before and after storage.

Dry Matter Content (%):

To measure the dry matter content, six tubers were selected randomly from randomly taken plants and chopped to take a 200gm sample which was measured and dried under the sun at first and then dried using oven dry. The dry material content was calculated by using the following formula:

$$\text{dry matter}\ (\%) = \frac{\text{weight of the sample after drying}}{initial\ wieght\ of\ sample} \times 100$$

3.3.4 Method of Data Analysis

Data were recorded on potato postharvest parameters. The collected data were subjected to analysis of variance (ANOVA) using the general linear model of SAS statistical package software (version 9.3). Means were compared at a 5% probability level using least significant difference (LSD) mean separation method.

4. RESULTS AND DISCUSSIONS

Part1. Survey result

4.1. General Information of the Respondents

4.1.1. Sex of Respondents

The study finding in Table 3 showed that 80.8 % of the respondents were male and the remained 19.2% were female-headed households (Table 3). This showed that from the total respondents, the number of males exceeds the number of females by 76.29%. In the study area, the majority of potato production and other farming responsibilities are taken by men rather than women. This finding is in line with the finding of Basavaraji (2018) who stated that in rural areas, agricultural activities are done largely by male households. Similarly, in their study, Gebru *et al*., (2017) stated that most of the interviewed heads of households (88.8%) were men while the rest (11.2%) were female household heads who were widows or divorced. The same authors mentioned that household resource leaders are mostly males as is the case in other African countries.

4.1.2 Age of the Respondents

From the total of 120 respondents, the mean age of the respondents was 43.09. The age category of the respondents was 30-40 (27.5 %), 41-50 (48.3 %), 51-60 (16.7%) and greater than 61 (7.5%). Thus, from the total respondents, the majority were in the age category of 41-50 years this was followed by the age category of 30-40 years. However, the lowest proportion of respondents lies in the age group of equal to and greater than 61 years. The finding indicates that farmers are enough mature and experienced in potato production. This is in line with the report of Gebru *et al*.,(2017) stated about 63.5% of respondent households were within the range of working age (15–65 years old), whereas 36.5% of them were older (>65 years old). This might be related to the fact that effective and independent workers who are known to possess the physical strength required for crop production are found in this age category. Some reports showed that mature farmers are estimated to use their agricultural skills to choose suitable postharvest handling practices and later an overall reduction in postharvest losses (Maremera, 2014).

Table 3. Age and Sex Distribution of the Respondent Farmers

Variables	**Frequency**	**Percent (%)**
Sex category		
Male	97	80.8
Female	23	19.2
Total	120	100
Age		
30-40	33	27.5
41-50	58	48.3
51-60	20	16.7
>61	9	7.5
Mean	**43.09**	
SD	**0.86**	

4.1.3 Educational Status of Respondents

The majority of the respondents (46%) can read and write whereas 23% and 22% of the respondents attended elementary education and are illiterate, respectively. However, the lowest (9%) proportion of the respondents have attended secondary education and above. This showed that 78% of the respondents have taken formal and informal education at different educational levels (Figure 2). Education had a great impact on potato farming and associated postharvest handling practices, the more the farmer is educated the more adoption of improved farming practices and technologies. Tiruneh *et al*. (2017) reported that improving the technical efficiency of smallholder farmers can improve the productivity of potatoes. According to the report of Beriso (2018) sex of household heads, land allocated for potato production, access to input supply, potato farming experience and households' participation in non/off-farm income activities positively and significantly affect potato production.

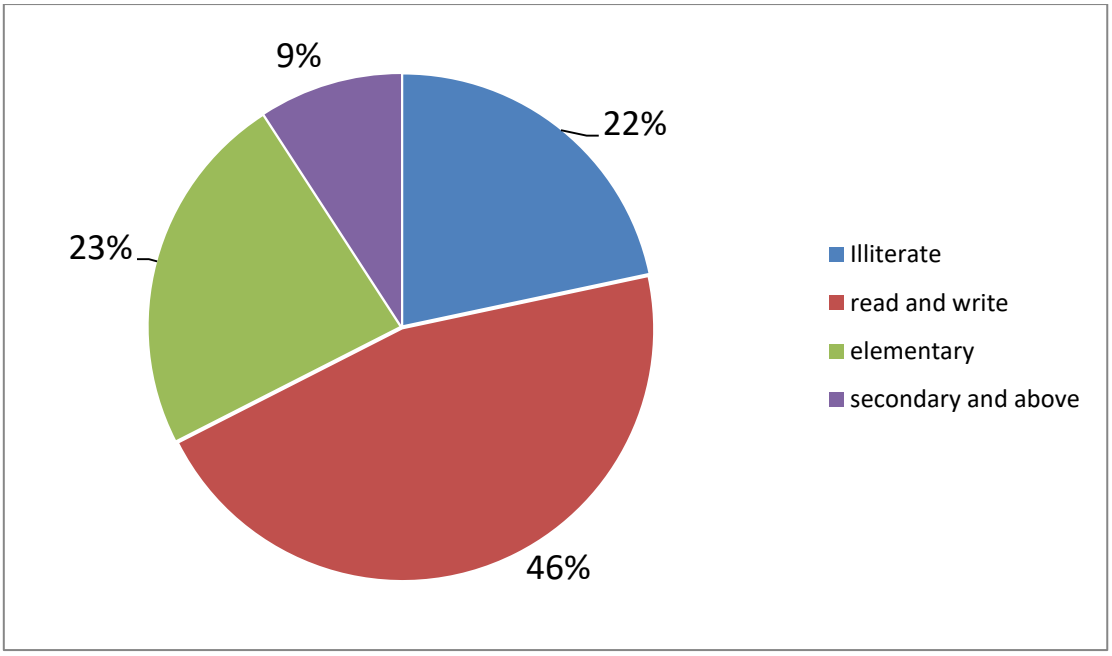


Figure 2. Educational Background of the Respondents

4.1.4. Potato Farming Experience by the Respondent Farmers

The majority of the respondent farmers (41.5%) have 11-20 years of experience in potato farming, however, the lowest proportion of respondents (7.5%) have 31-40 years of experience (Table 4). The mean experience of farmers in potato farming was 19.45, the maximum was 38 and the minimum was 5 years of experience in potato production. This showed that the respondent farmers have enough experience in potato production. This has huge potential for minimizing postharvest losses of potatoes. According to the report of Mamerma (2014) stated that experienced farmers are expected to have more knowledge on the adoption of postharvest handling technologies than non-experienced farmers. This result implies that in the study area farmers have enough experience on potato production from their Indigenous knowledge. However, there is lack knowledge on postharvest handling methods.

Table 4. Years of experience by potato farmers in percent

Variables	**Frequency**	**Percent (%)**
Experience		
1-10	25	21
11-20	50	41.5
21-30	36	30
31-40	9	7.5
Mean	**19.45**	
SD	**1.01**	

4.2 The Main Income Sources of the Respondents

According to the survey result from 120 respondents, 99 respondents stated that their main income source was potato production whereas the remaining 13 and 8 respondents' income source was enset and cabbage production, respectively (Appendix table 1). This survey result indicates that 82.5% of the respondents were engaged in potato production as the main means of income generation but only 10.8% and 6.7 relied on enset and cabbage production as the main means of income respectively.

4.3 Percent share of Potato from Other Root and Tuber Crops

As indicated from above (means of income) potato is dominantly grown in the study area greater than any type of RTCs. The study declared that in the study area the majority (44.1%) of the respondents, 70-80% of their farm is covered by potato. However, the smaller (16.6%) proportion of the respondents, 80-90% of their farm is covered by potato. This result is in line with GDAO, (2022) Annual report which, out of 2921 hectares of land 2541(86.9%) hectares are covered by potatoes.

4.4 Factors Contributing to Postharvest Losses of Potato in the Study Area

Minimizing PHL is crucial to alleviating food security in developing countries. Potato tubers belong to the semi-perishable goods, *i.e*., produce with high natural moisture content. In the study area, the postharvest handling of Potatoes is affected by different factors that challenge farmers indicated as follows. The main contributing factors to the post-harvest loss of potatoes are presented in Figure 4.

4.4.1 Level of awareness by the respondents

Knowledge of postharvest handling is a very important instrument for minimizing postharvest loss of potatoes at different post-harvest handling stages. The current findings indicate that 62% of the respondents have no awareness, 23% have medium awareness and 15% have low awareness of postharvest loss and postharvest handling methods of potatoes. In the current study, respondent farmers were allowed to rate lack of awareness towards post-harvest loss of potatoes as low, medium, high, and very high; and most of the respondents (58%) rated this attribute to very highly affect the post-harvest loss of potato tuber. However, the remaining 22%, 15%, and 5% of respondents rated this as high, medium and low (Figure 4). But they have their background knowledge so it is well base to provide scientific knowledge for the farmers. This finding is also supported by (Yebirzaf and Esubalew, 2021) stated that local farmers do not have enough awareness of postharvest management. The current result agrees with the report of Gebru *et al* (2017) who stated that about 65% of the respondents have an awareness of potato storage. One of the major problems in potato production and marketing in Ethiopia is high postharvest loss (Bezabih and Mengistu, 2011).

4.4.2 Harvesting Material and Time

4.4.2.1 Harvesting Materials and method of harvesting

In the survey area potato is harvested manually or using simple agricultural tools. Majority of the respondents 76 (63.3%) use Rake which is locally called *Cheke*. The remaining 17%, 15%, and 5% used sickles, plows, and hand pick respectively (Figure 3). Harvesting materials could greatly affect post-harvest handling of tubers as some may cause mechanical bruises to tubers making them liable to post-harvest loss. Because there is no other optional materials that are good for harvesting by protecting from tuber poke and cut. The current result is also supported

by Emana *et al*., (2015) who indicated that farmers don't have adequate knowledge about how and when to harvest and don't select appropriate time and materials, farmers commonly use sticks, sickles, spades, hoes, and axes used to harvest but cannot keep the produce's proper quality. Generally all postharvest losses are directly and indirectly related with loses at harvesting. This is supported Benyam *et al*., (2018) who argued that postharvest lose at time of harvesting is very high due to inappropriate use of harvesting materials.

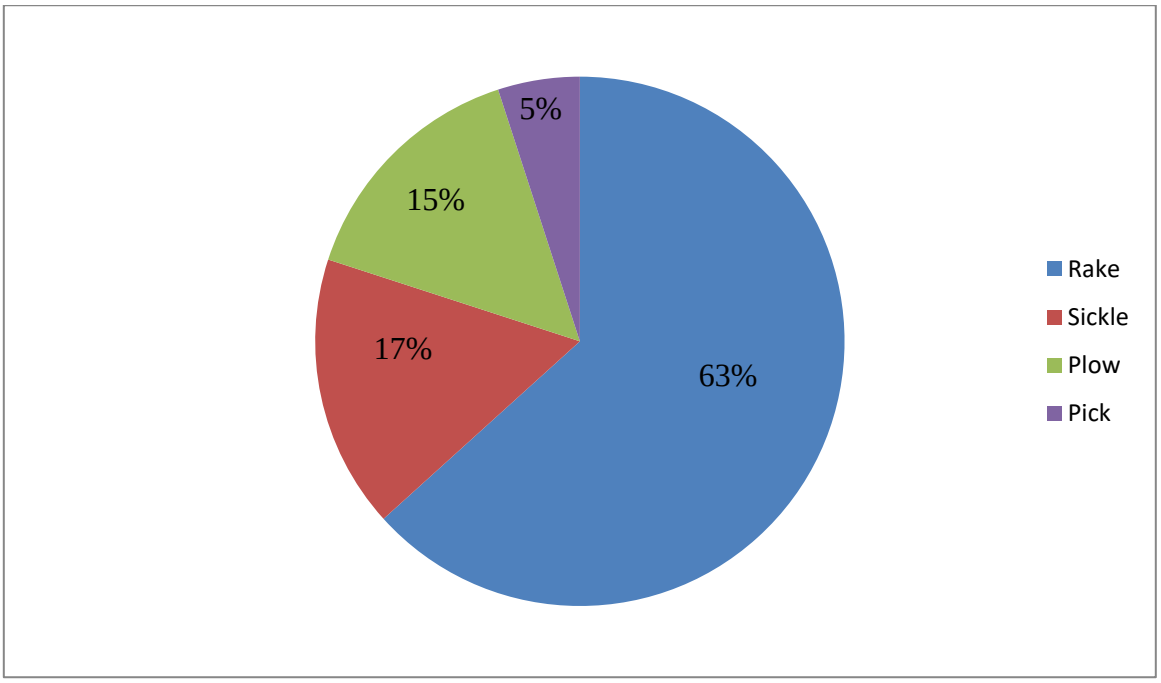


Figure 3. Harvesting material of potato used by potato producing farmers at Gummer district in 2023.

4.4.2.2 Harvesting Time

Selecting the appropriate time for harvesting potatoes plays an irreplaceable role in minimizing postharvest loses of potatoes. In the study area unfortunately potatoes are ready to harvest during the rainy season. Out of 120 respondents 70(58.4%) of the respondents harvest their produce even there is rain. Whereas, 41.6% of the respondents harvest potato when there is no rainfall. The survey result declared that the majority (58.4%) of the respondents harvest potatoes at rainy times due to different problems. This causes important postharvest losses, the rain drops on harvested potatoes cause the skin of the potato to peel and hold unwanted moisture causes further deterioration and finally affecting the shelf life of potato tubers. the idea is in line with some (4) interviewers; which an appropriate time selection is one factor for

postharvest loose of potato. However farmers don't consider selecting the right time for potato harvesting.

4.4.3 Potato variety

Potato variety might differ in their tolerance to post-harvest loss factors. In the study area farmers were grown and improved and local potato variety *i.e*. Gudene, Jalene, Belete, and local. From a total of 120 respondents; 58%, 28%, 10%, and 4 % the respondents said that varieties have a very high, high, medium, and low contribution to postharvest losses, respectively (Figure 4). This might be due to differences in the genetic makeup of potato cultivars to respond variably to postharvest loss factors. The result is in line with the finding of (Upadhyay, 2018) who stated that potato variety is the main cause of short life, quick sprouting, tuber rot, shrinkage, and infestation of potato tuber moth. Of the total respondents 50(41.7%), 27(22.5%), 18(15%), and 25(20.8%) have used improved Gudene, Jalene, Belete, and local varieties respectively (Appendix table 1). Similarly, in their survey result, Gebru *et al*., (2017) stated that Gudene (53.0%) was the most storable variety while Wachacha (5.3%) was the least one out of the varieties commonly cultivated in the study area.

4.4.4 Storage condition

Storage plays a key role in maintaining the quality of agricultural products and preventing them from deterioration for a specified period, beyond their normal shelf life (Kiaya, 2014).

Farmers explained (rated) the importance of storage to reduce losses of potatoes. Thus, the majority (61%) responded that lack of storage very highly and negatively affects post-harvest handling of potatoes, and the remained 26% and 13% of the respondents showed high and medium effects (Figure 4). Considering the type of storage structure to use, the majority (58.75) of the respondents have used a loft (built by wood) followed by floor of which 19.8% of respondents used putting tubers. However, a small proportion of the respondents (14% and 6.6% used a barn and bamboo basket (Appendix table 1). This showed that farmers did not have appropriate storage facilities for prolonged storage of potato tubers by maintaining tuber quality. In that case, they are forced to sell their harvested potato immediately to the market without looking for a better market option in the future. This finding is also supported by the work of (Hajong and Moniruzzaman, 2014) and (Abebe, 2019) who stated that the farmers

were forced to sell immediately after harvesting at a very low price because of a lack of storage facilities. This finding is also in line with the study of Endale *et al*., (2008) who stated that farmers use diverse traditional potato storage methods depending on the use. However, these storage facilities are not appropriate to preserve the quality of tubers for more than 1-2 months. From the current study, the reason why they didn't construct warehouse storage independently is due to low product, economic problems, and lack of awareness. These storage structures are not well for keeping the desired quality of tuber.

According to survey results farmers store the tuber based on storage type and varieties. The idea is in line with some (5) interviews; which storage is the crucial instrument in minimizing postharvest loose of potatoes but the farmers do not have an independent and standard warehouse that can store the produce for a long time with minimum losses. The finding is supported by Debela *et al*., (2011) who stated that in Ethiopia the storage practices , the storage techniques and tools used are traditional and very poorly to sustain the required level of storage. A postharvest loss of 30–50% of the produce was reported , and lack of adequate storage is the major reason for the postharvest loss (Endale *et al*. 2008). Moreover, Bezabih and Mengistu (2011) quantified that 62–63% of the producers in Ethiopia faced a shortage of warehouses as the major problem resulting in postharvest losses of potatoes.

4.4.5 Lack of Market Access

The market plays a great role in increasing agricultural products and productivity by increasing farmers' income which leads to increased agriculture productivity. In the current survey, 77.5%, 16.6%, and 6.6% of the respondents sold their potato tuber in local markets, at distant and at both local and distant markets, respectively. This is because farmers can reduce transportation costs by selling their potatoes to the local market. Moreover, tubers will be liable to less damage by transporting potatoes to local markets than to distant markets. This argument is supported by Seid and Yitbarek (2013) who stated that the horticultural products in Ethiopia are mainly produced by smallholder farms and most of the farmers sell their products to neighboring markets and a few sell both on farms and in nearby markets such that the marketing condition is insufficient and gloomy. The mean kilometer of the nearest market by the respondents is 3.02 kilometers far from the farm. This affects the marketing process of the product and difficult for farmers to access the product for the market. This finding is also

supported by Dawit and Alemayehu (2021) who suggested that the marketed surplus of potatoes was affected by distance to the market.

In the current study, the majority of the respondents (69.1%) sold their harvested potatoes directly to consumers, 17.5% sold for retailers, and 13.3% sold for whole sellers (Appendix table 1). This forced the farmers to sell their product by low price. Benjaw, (2017) reported that factors responsible for losses at the marketing stage are rain, poor handling during loading and unloading, and price versatility due to excess product in the market. This finding was also supported by Misrak *et al*., (2014) who stated that farmers sell their products at peak times at low prices due to a lack of suitable storage structure. The finding is also in line with the finding of Benyam *et al.,* (2018) stated that lack of market access stayed the product for several days at a farm or home under poor handling goes to be wasted.

4.4.6 Lack of Transport Access

Transport plays an irreplaceable role by facilitating agricultural products from the point of production to the point of consumption. In the study area, potatoes are harvested in the rainy season so there is a huge problem for farmers to supply their product for market. Means of transportation and road problems are the main problems in the study area. From 120 respondents 40 (33.33%) use Animals, 54 (45%) use donkey carts, 11 (9.17%) use vehicles and 15 (12.5%) use manpower for transportation of tuber to the market (Appendix table 1). The study result indicates that majority of farmers use animal transportation this leads to the farmers uncompetitive and to see other market alternatives. This finding is in line with the study of Bezabih and Mengistu, (2011) stated that one factor that greatly affects the effectiveness of the potato value chain is the lack of safe transportation and equipments. The common problems associated with transportation in the study are poor arrangement of packaging, breakdowns of vehicles, loading-unloading problems, rainfall, and lack of road access.

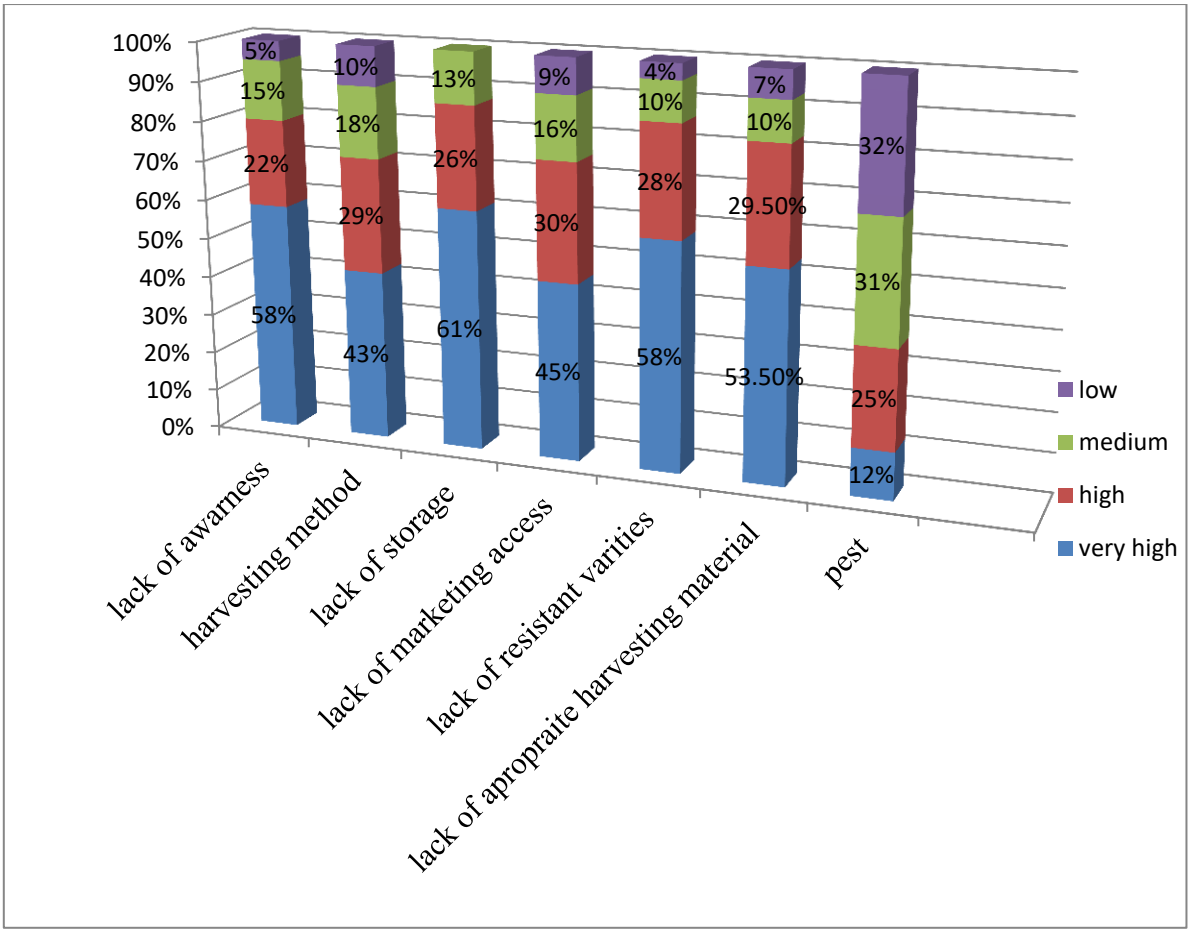


Figure 4. Contributing factors and their magnitude for postharvest losses of potato at Gummer district in 2023 cropping period.

Part_2. Experimental result

This part of the study was conducted in order to examine tuber storability performance under different storage method on two potato varieties (Gudane and key dinich). Hence, the effect of different storage method and potato varieties was analyzed for storability parameters of potato. The analyzed storability parameters of the tuber was Physiological weight loss, Tuber dry matter content, Tuber rotting, Days to 50% sprouting and pH content of the tuber.

4.5 Physiological Weight Lose

The analysis of variance revealed that weight loss was highly significantly ($P < 0.001$) influenced by the main effect of storage time and storage structure. However, none of these were interacted to significantly influence this parameter (Appendix table 2).

The highest weight loss (11.07%) of potato tuber was recorded from tubers that were placed on the floor whereas the lowest weight loss (6.1%) was obtained from tubers placed in pit storage. Regarding the storage time, the highest tuber weight loss (11.85%) was recorded from tubers stored for 90 days whereas the lowest tuber weight loss (6.22%) was recorded from tubers stored for the shortest storage duration (30 days) (table 4.). The lowest weight loss for the shortest storage duration might be due to less moisture lost for the shortest duration than tubers stored for the longest period. This is because time plays a key role in the postharvest biochemical changes. Moreover, tubers stored in closed and less ventilated conditions lose less weight than tubers stored in open conditions. Khanal and Bhattarai (2020) reported that total loss was lowest (4.38%) for cold stored potatoes and the highest (13.04%) for in-house stored potatoes. in line with this, John *et al*., (2017) reported that weight loss was very high in 9 weeks when compared to three and six weeks in storage.

Table 5. The main effects of the storage structure and storage time on physiological weight loss of potatoes in the Gummer district in the 2023 cropping season

Storage structures	**Weight loss (%)**
Pit	6.11[d]
Loft	9.20[c]
Floor	11.07[a]
Basket	10.10[b]
LSD (5%)	**0.40**
CV (%)	**6.6**
Storage time (DAS)	
30	6.22[c]
60	9.32[b]
90	11.85[a]
LSD (5%)	**0.35**
CV (%)	**6.6**

Where; DAS= Days after storage, LSD= Least significant difference, CV= Coefficient of variation. Means followed by the same letter are not significantly different at 5% level of significance

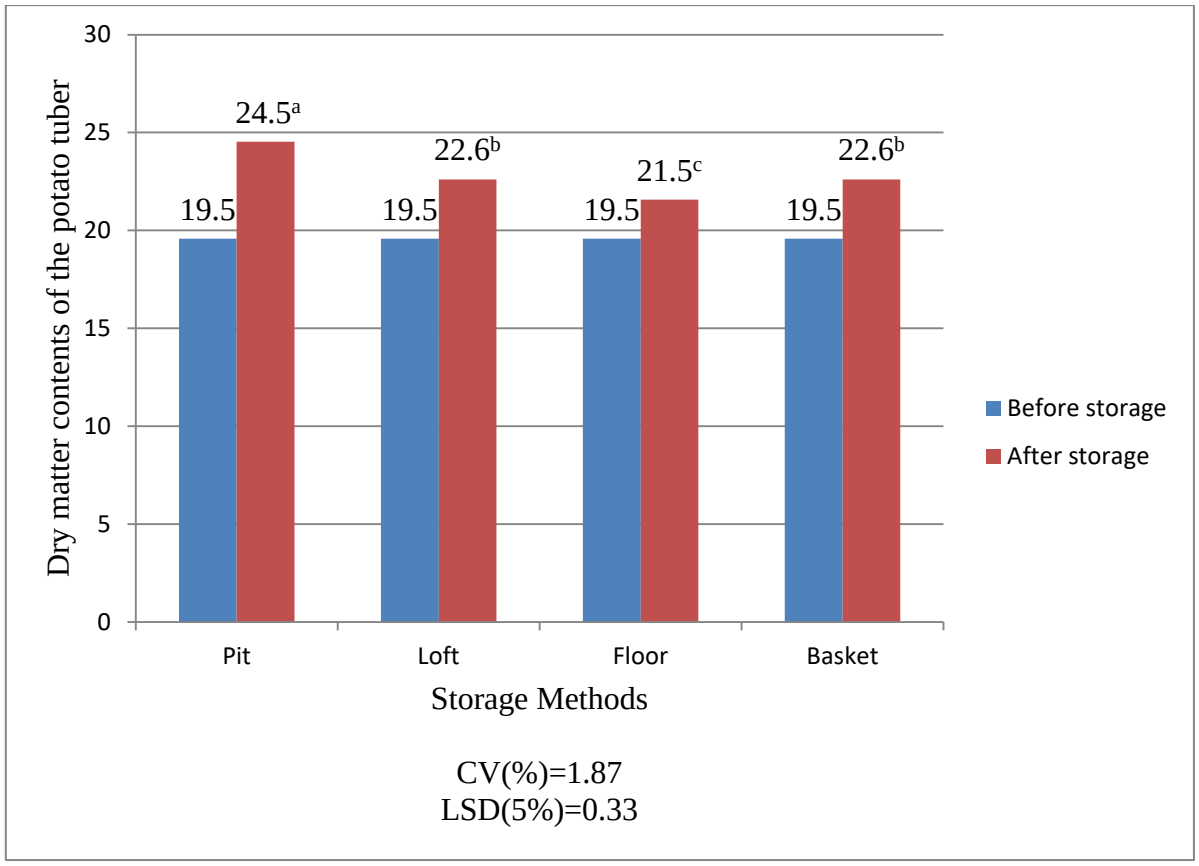
4.6 Tuber Dry Matter Content

The analysis of variance showed that storage method and storage time interacted to highly significantly (P<0.001) influence the dry matter content of tuber (Appendix table 2). the main effects of variety, storage method, and storage time also highly significantly (P<0.001) influenced tuber dry matter content.

Tuber dry matter content is considered the main determinant of processed potato tuber quality. The highest dry matter content (24.5%) was obtained from tubers stored in the pit after 90 days of storage whereas the lowest dry matter content (21.5%) was obtained from tubers stored on the floor for 90 days after storage. The dry matter content of tubers increased after 90 days of storage than dry matter before storage (Figure 5**)**. This is in line with the finding of Kumar *et al*., (2006) stated that dry matter content is increased when storage time is increased.

This result is supported by Ustun, *et al*., (2006) reported that the dry matter was high as storage was longer. A similar finding is stated by Sengul and Keles (2005) suggested that dry matter content increases when the potato on storage. At the start of the storage, the dry matter content of Gudene was 22% and key Dinich 17.16%. In terms of variety Gudene has a higher

dry matter content than Key dinich may be due to genetic differences. The finding also supported by Birhanu (2018) stated that varieties are different in their dry matter content.



Where; LSD= Least significant difference at 5%, CV= Coefficient of variation. Means with the same letter are not significantly different at a 5% level of significance

Figure 5. Interaction effect of storage method and storage time on DMC of potato tuber in Gummer district in 2023

4.7 Sprouting

The analysis of variance revealed that interaction effect of variety and storage method highly significantly influenced tuber sprouting. However, all the rest two-way and three-way interactions did not significantly ($P>0.05$) affect the sprouting of potato tuber (Appendix table 2). Tuber sprouting was highly significantly ($P < 0.0001$) influenced by the main effects of variety, storage time, and storage.

The longest days (101) for 50% tuber sprouting was recorded from Gudene stored in the Loft method of storage which was statistically different from when the same variety was stored at the pit (78) on the floor (72), basket (72) and also when variety key dinich was stored in the pit (71), floor(65) and loft (81) (Table 6). Gudene variety on loft storage significantly differs from other storage and variety. The result indicates that varieties differ in days to sprouting when they interact with different storage methods. The finding is in line with the finding of Kalika *et al*. (2021) who reported that varieties differ in their sprouting behavior. The finding agrees with the findings of Shraddha and Kabindra (2020) stated that dormancy and extent of sprouting are influenced by variety. The study declared that the Gudene variety on loft storage can be stored for more than three months without any treatment. This finding agrees with the finding of Magno (2001) stated that varieties differences in their resistance characteristics to dormancy time length and sprouting.

Table 6.The interaction effect of variety and storage structure on 50% sprouting DAS of potato tuber in Gummer district in 2023 cropping season

Treatments		**Day to 50% Sprouting**
Variety	**Storage methods**	
Gudene	Pit	78[c]
	Loft	101[a]
	Floor	72[d]
	Basket	72[d]
Key dinich	Pit	71[d]
	Loft	81[b]
	Floor	65[e]
	Basket	67[e]
LSD (5%)		1.3409
CV (%)		1.43

Where; LSD= Least significant difference at 5%, CV= Coefficient of variation. Means with the same letter are not significantly different at 5% level of significance

4.8 Tuber Rotting

The analysis of variance showed that all the two-way and three-way interactions showed highly significant ($p<0.0001$) influences tuber rotting of potatoes. Similarly, all three main effects of variety, storage structure, and storage time were highly significantly ($p<0.0001$) influenced tuber rotting (Appendix table 2).

The highest tuber rotting (11.33% and 14.66 %) was obtained when key dinch was stored on the floor at 60 DAS and 90 DAS, respectively, which was statistically difference when Key dinich has interacted with pit, basket, and loft storage at 60 DAS and 90 DAS. Similarly, the Gudene variety stored on the floor at 60 DAS and 90 DAS gave the highest tuber rotting (9.33 and 11.66, respectively), which was statically different when the tuber was stored on the pit and basket (Table 7). However, no rotting was recorded when tubers of the potato varieties were stored for 30 days in all the storage methods. Similarly, no tuber rotting occurred throughout the storage times (30 DAS, 60 DAS, and 90 DAS) when the Gudene variety was stored in the loft.

At the end of the experiment, the highest (14.66%) rotting was occurred on key dinich stored on the floor but there was no rotting incidence in the Gudene variety which was stored in the loft, this may due to the genetic potential of the varieties in response to storage method and storage time. This finding is in line with John *et al*., (2017) stated that rotting incidence and rate of rotting differ in potato varieties. According to the finding, the rooting percentage is low it is due to taking care of storing the tuber by selecting a medium-sized tuber, disease-free and non-bruised tuber and the time also suitable to store the tuber. The storage environment was also very suitable and varieties were spread in a single layer without creating heaps so that adequate aeration among tubers was provided.

Table 7. The interaction effect of variety, storage method and storage time on rotting incidence of potato tuber in Gummer district in 2023 cropping season.

		Tuber rotting (%)		
Variety	**Storage methods**	**Time of storage**		
		30 DAS	**60 DAS**	**90 DAS**
Gudene	Pit	0	4.00^{k}	5.00^{f}
	Loft	0	0.00^{h}	0.00^{h}
	Floor	0	9.33^{cd}	11.66^{b}
	Basket	0	7.00^{e}	9.00^{cd}
Key dinich	Pit	0	4.66^{fg}	5.33^{f}
	Loft	0	7.35^{e}	8.65^{d}
	Floor	0	11.33^{b}	14.66^{a}
	Basket	0	7.66^{de}	9.66^{c}
LSD (5%)		-	0.38	0.53
CV (%)		-	5.70	8.5

Where; DAS= Days after storage, LSD= Least significant difference, CV= Coefficient of variation. Means followed by the same letter are not significantly different at 5% level of significance

4.9 pH

According to the analysis of variance, storage method and storage times interacted to highly significantly ($P<0.001$) influence the pH of potato. the main effects of storage method and storage time were highly significantly ($P<0.001$) affected the pH of potato tubers. However, the main effect of variety and the other two-way or three-way interactions were not significantly different ($P>0.05$) (Appendix table 2).

The largest pH value (6.7) was recorded on the floor method after 90 days of tuber storage. All the remained interactions of storage method and storage period after 90 DAS showed the lowest pH (Figure 6). John *et al*., (2017) reported that pH increases when the storage time increases. The finding is also agreed with the finding of Ustun, *et al*., (2006) who reported that the storage period increases pH significantly.

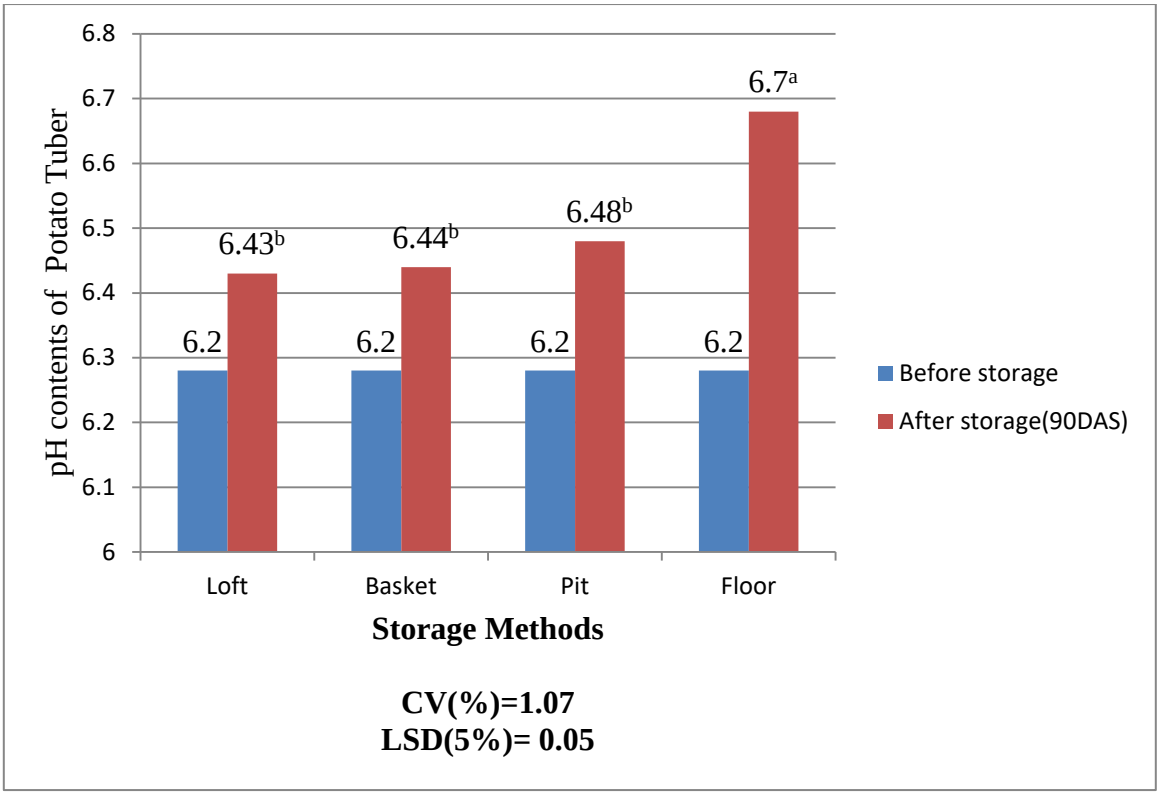


Figure 6. Interaction effect of storage method and time on pH content of potato tuber in Gummer district in 2023 cropping season

Where; LSD= Least significant difference, CV= Coefficient of variation. DAS= Days after Storage

Means followed by the same letter(s) are not significantly different at 5% level of significance

5. CONCLUSIONS AND RECOMMENDATIONS

The survey results showed that potato production in the study area is dominated by male-headed households (80.8 %). The share of female-headed households (FHHs) was shown to be only 19.2%. Potato is the main source of income for the local farming communities, as substantiated by about 82.5% of the respondents. Similarly, it is the major crop grown in the area as compared to other root and tuber crops, including enset. However, the prevailing high level of post-harvest loss is hindering the benefits of local farmers and discouraging their interest in further expansion. According to the study results, lack of appropriate harvesting materials is the major factor that causes the bulk of the postharvest losses followed by market uncertainty, inappropriate transportation facilities, and as well as rudimentary traditional storage structures and facilities. The majority of respondent farmers (63.3) use Rakes for harvesting, which is not ideal for maintaining the quality as it inflicts lots of mechanical damage, especially on the bigger-sized tubers. The survey results declared that farmers in the area generally a lack awareness of determining the correct stage of harvest maturity, which is critical for subsequent handling and maintaining the shelf life of the tubers. The majority of the respondents used the nearby local markets (77.5%), in which they are obligated to sell their produce at much lower prices because of excess supply or market glut. In the absence of transport vehicles, especially during the rainy season, farmers in the area predominantly used draft animals and manpower of their household members. As this is so cumbersome, it takes excessive time for the farmers to get the produce to the household and deliver it to the markets. This often results in high levels of postharvest losses with subsequent low prices and income.

In the laboratory-based tuber storability study, Dry Matter Content (DMC (%),Tuber rotting (%), and sprouting were significantly ($P<0.001$) affected by storage structure, storage duration, and variety. pH and physiological weight loss(PWL%), were also significantly ($P<0.001$) affected by storage structure and storage duration. The highest Dry Matter Content (26.86%) was recorded on the storage structure of the pit with the Gudene variety while the floor-based storage structure resulted in the lowest DMC (19.74%).

On the other hand, the highest physiological weight loss (11.07% and 11.85%) was recorded from floor storage and 90 days after storage, respectively. However, the lowest was recorded from loft storage (9.2%) and 30 days of storage after harvesting (6.22%). Early sprouting was recorded on floor storage with a variety Key Dinich (65 days). The most delayed sprouting was found when tubers were stored under the loft-based storage structure. The highest pH (6.7) was recorded under the floor and pit-based storage structures while the lowest (6.4) was recorded when tubers were stored under the loft and basket-based storage structure.

Since farmers in the study area have a longstanding experience of production, which is well associated with their indigenous knowledge of enset, another staple food crop to the local communities, it is worthwhile to recognize this potential as an opportunity for future research and development endeavors, including in the area of post-harvest loss minimization. This necessitates further strengthening and/or upgrading the capacity of farmers by way of assisting them through continuous training as well as provision of the basic infrastructure and facilities to enable them to minimize postharvest losses.

In addition to post-harvest loss minimization, other improved pre-harvest interventions such as the introduction of improved varieties and agronomic practices need to be given due attention through the existing research and extension institutions in the area. In so doing, attention should also be given to strengthening the capacity of such institutions in the area in all aspects (i.e. budget, skilled manpower, infrastructure, facilities, etc.). Since the road infrastructure within the major potato-producing localities is so rudimentary, due attention should be given both by the local and national administrative bodies to minimize the prevailing high level of postharvest losses. This would help to get the produce safe and faster to the destination markets and subsequently maximize the income of farmers from potato production.

Overall, the loft-based storage method and Gudene variety were found to be more ideal for extending the storage or shelf-life of the tubers than the pit, basket and floor-based storages and it is relatively found to be more effective in bringing about better storage stability of potato tubers, the extension system in the area needs to focus its training and awareness creation on promoting those techniques at least up until other modern and standard-storage structures are introduced and implemented in the area.

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7. APPENDIX

Appendix Table1. General information of respondents

Age Categories	**Frequency**	**Percent (%)**
30-40	33	27.5
41-50	58	48.3
51-60	20	16.7
>61	9	7.5
Total	120	100
Mean		43.09
SD		0.86
Sex categories		
Male	97	80.8
Female	23	19.2
Total	120	100
Sources of income(Crop)		
Potato	99	82.5
Cabbage	8	6.7
Enset	13	10.8
Total	120	100
Storage structures		
Loft made by wood and other	71	59.2
Floor	24	20
Bamboo Basket	8	6.6
Barn	17	14.2
Total	120	100
Potato Varieties		
Gudene	43	35.8
Jalene	26	21.7
Belete	18	15
Local	33	27.5
Total	120	100
Transporting system		
Animal	40	33.3
Donkey cart	54	45
Vehicles	11	9.2
Manpower	15	12.5
Total	120	100

Appendix table 2. MS of variance (ANOVA) For 5 Potato Quality attributes.

Parameter	Source of variation	DF	TSS	MS	F value
Dry matter content	Variety (V)	1	233.8184083	233.8184083	1486.10***
	Storage method (S)	3	14.3183583	4.7727861	30.33***
	Storage Time (T)	1	126.1656750	126.1656750	801.88***
	V x S	3	1.7932917	0.5977639	3.80ns
	S x T	3	14.3183583	4.7727861	30.33***
	V x S x T	3	1.7932917	0.5977639	3.80ns
	Error	17	4.7200958	0.1573365	
Physiological weight loss	Variety	1	116.1034014	116.1034014	315.03ns
	Storage method (S)	3	246.4282486	82.1427495	222.88***
	Storage Time (T)	2	381.6890861	190.8445431	517.83***
	V x S	3	3.8468597	1.2822866	3.48ns
	V x T	2	9.3545194	4.6772597	12.69ns
	S x T	6	2.7997472	0.4666245	1.27ns
	V x S x T	6	3.5322694	0.5887116	1.60ns
	Error	17	16.9531139	0.3685460	
pH	Variety	1	0.00500208	0.00500208	1.47ns
	Storage	3	0.12430625	0.04143542	12.15***
	Time	1	0.61880208	0.61880208	181.46***
	V x S	3	0.02267292	0.00755764	2.22ns
	V x T	1	0.05950208	0.05950208	17.45ns
	S x T	3	0.12430625	0.04143542	12.15***
	V x S x T	3	0.02267292	0.00755764	2.22ns
	Error	17	0.10230417	0.00341014	
Sprouting	Variety	1	495.041667	495.041667	422.17***
	Storage	3	1661.458333	553.819444	472.29***
	Time	2	81.89861	40.949	34.9***
	V x S	3	132.458333	44.152778	37.65***
	V x T	2	64.28932	32.1446	27.412ns
	S x T	6	24.546464	4.091077	3.4888ns
	V x S x T	6	22.543438	3.75723	3.204ns
	Error	17	16.416667	1.172619	
Rotting	Variety	1	64.2222222	64.2222222	743.72***
	Storage	3	587.3888889	195.7962963	2267.40***
	Time	2	435.3611111	217.6805556	2520.83***
	V x S	3	87.6666667	29.2222222	338.41***
	V x T	2	32.1944444	16.0972222	186.41***
	S x T	6	308.5277778	51.4212963	595.48***
	V x S x T	6	44.5833333	7.4305556	86.05***

Appendix Figures

Appendix Figure 1. Sample preparation for laboratory analysis to test Dmc and Ph content of tuber

Appendix Figure 2. Samples ready to test Dmc in oven-dry

Appendix Figure 3. Tuber in Oven Dry

Appendix Figure 4. Extracted potato juice ready to test the pH content of the tuber

Appendix Figure 5. Testing the pH content of the tuber by using a pH meter

APPENDIX 3. Research questioner filled by farmers

WOLKITE UNIVERSITY

College of agriculture and natural resource management

Department of Horticulture (Msc) program

The purpose of this questionnaire is to collect information for on the study entitled “postharvest loss assessment and tuber storability evaluation of Potato (*Solanum tuberosum* L.) Varieties under Different Storage Structures in Gummer District, Southern Ethiopia For partial fulfillment of Bsc degree in horticulture at **wolkite** University. The study is purely for academic purpose only. The research has significant effect for the understanding and handling of postharvest of potato to minimize the loss. Therefore your genuine information obtained from the questionnaire is necessary. The researcher would like to assure you that your response will be kept confidential. Truthfully, feel free and try to answer the questions honestly and accurately. You are not required to write your name. Thank you in advance for your kind cooperation and dedicating your time.

Part one: - Producers and traders Interview

1 demographic and other interview

1. Zone: _____Woreda:_____ Kebele: _____ Village: _____

2. Age of the respondent: _____years

3. Sex of the respondent: A. Male B. Female

4. Education level of the respondent A. educated B. uneducated

5. What is your major means of income generation? A. Potato production B. Cabbage production D. Fruit production, D. Enset E. other vegetable production

6. What are the major factors for postharvest loose of potato (multiple answer is possible)

A. harvesting method B. harvesting materials C. marketing D, lack of transport E. lack of storage F. lack of manpower G. pest H. other (please specify)

7. Method of harvesting potato? A. manually by hand B. using animals

8. What is your harvesting tool? A. plow B. fork C. shovel D. other (specify) why you select this material? ……

9. Total cultivated area use to grow vegetable for the production year? _____h/r

10. From the entire vegetable production how much is total potato production? _____h/r

11. How long have you been in produce potato (Experience)? _____Years

12. Which variety uses for planting materials an .improved B.? Local (specify) is the dominant in your area

13. Why you select this variety

14 which markets have you use A. local (neighboring market) B. far market

15. Distance of your home from the nearest market center: _____KM

16. How much did you produce per quintal in main seasons? , _____Quintal.

17. Is there rain at harvesting time? A. Yes B. No

18. is there loss at harvesting stage? A. Yes B. No

19. What is the cause of loss at harvesting stages?

A. Injury due to careless handling B. Rain during harvest C. Insects and Pests D. Strong Sunlight E. varieties F. harvesting materials F. other

20 is there adequate storage facility A. Yes B. No

21. If the answer for Q20 yes is what type storage is it? A. Roof Built by wood B. floor in the house C. bamboo basket D. Storage in plastic shed E. storage in barns F. other (specify)

22. If the answer for Q20 no Why? A. economic issue B due to low product C low land access D other (specify)

23. Duration of stored potato after harvest? A.1 month B. 2 month's C. three months D. more

24. Which factor is responsible for storage loss?(multiple choice is possible) A. High relative humidity B. Temperature C. Improper packaging D. Insect infestation and rodents. D. condensed atmosphere F. Too much time spent on the store

25. What type of transport does use? A. manpower B. animals C. handcart D. donkey cart E. vehicles F. other (specify)

26. Is their transportation loss in your produce? A. yes B. no

27. Which factor is responsible to loss during transporting of potato? A. Poor arrangement of packaging B. Breakdowns of vehicles C. Overloading D. Loading unloading problem E. Temperature F. Rainfall G. Lack of road access

28. For whom do you sell your product? A. Directly to consumers B. Local collector C. Wholesalers D. Retailers E. Others

29. Is there marketing loss? A. Yes B. No

30. If the answer for Q29 is yes, why? _____

31. Which factor is responsible to loss during marketing of potato? A. High temperature B. rain C. poor handling of loading unloading D. price versatility E. due to excess product

32. Which postharvest treatment do you apply _____

32. Which stage do you expect more loss? (Multiple choices is possible) A. Harvesting B. Storage C. Transportation D. Marketing stage

33. Which variety is more sensitive to post harvest loose A Gudene B Belete C Jalene D local E other (specify)

34. Totally how much potato do you expect loss in different stage (in quintal)……..

2 : factors of postharvest loose of potato

The major Factors those are responsible for postharvest loose of potato.

4=very high 3=high 2=medium 1=low 0= no loose

No	**Major factors of postharvest loose of potato**	**Rank**				
		4	**3**	**2**	**1**	**0**
1	Lack of awareness on harvesting(time, method,…etc)					
2	Varieties					
3	Lack of storage					
4	Access to market					

5	Lack of storage					
7	Harvesting material					
7	Method of harvesting					
8	Lack of excess land					
9	Harvesting time					
10	Pest					

APPENDIX 4. Key informant interview question

WOLKITE UNIVERSITY

COLLEGE OF AGRICULTURE DEPARTMENT OF HORTICULTURE

The purpose of this interview is to collect information for on the study entitled "postharvest loss assessment and tuber storability evaluation of Potato (*Solanum tuberosum* L.) varieties under Different Storage Structures in Gummer District, Southern Ethiopia For partial fulfillment of BSC degree in horticulture at **wolkite** University. The study is purely for academic purpose only. The research has significant effect for the understanding and handling of postharvest of potato to minimize the loss. Therefore your genuine information obtained from the questionnaire is necessary. The researcher would like to assure you that your response will be kept confidential. Truthfully, feel free and try to answer the questions honestly and accurately. You are not required to write your name. Thank you in advance for your kind cooperation and dedicating your time.

1. Is postharvest loss is the issue for potato production in your werda
   A. yes B. no
2. Do you have any awareness about postharvest lose
   A. yes B. no
3. Do you think Farmers use appropriate material for harvesting of potato
   A. yes B. no
4. If the answer is no why?
5. Do you think farmers have good awareness on how to handle post-harvest loss of potato?
6. What are the main factors responsible for postharvest loss of potato

A. harvesting method B. harvesting materials C. marketing D, lack of transport E. lack of storage F. lack of manpower G. pest

7. Which factor is the most important factor in your district

A. harvesting method B. harvesting materials C. marketing D, lack of transport E. lack of storage F. lack of manpower G. pest

8. Do you think post-harvest is differ from variety to variety
   A. yes B. no
9. Which cultivar dominantly use for planting materials. Why?
10. Is there enough market access for farmers to sell their products
11. More of the time farmers do not have storage what is the problem behind?
12. Is there enough transport access to deliver the product to market?
13. Which market type use farmers to sell their products A. far B. local
14. What do you think about how these problems handle? ……Who take the responsibility……

No	**Major factors of postharvest loose of potato**	**Rank**				
		4	**3**	**2**	**1**	**0**
1	Lack of awareness on harvesting(time, method,…etc)					
2	Varieties					
3	Lack of storage					
4	Access to market					
5	Lack of storage					
7	Harvesting material					
7	Method of harvesting					
8	Lack of excess land					
9	Harvesting time					
10	Pest					