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# Optimization of Production and Postharvest Practices for Enhanced Yield, Quality and Shelf-Life of Onion (*Allium Cepa* L.) in Northwest Ethiopia

Yeshiwas, Yebirzaf

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**BAHIR DAR UNIVERSITY**  
**COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES**  
**DEPARTMENT OF HORTICULTURE**  
**Ph.D. PROGRAM IN HORTICULTURE**

**OPTIMIZATION OF PRODUCTION AND POSTHARVEST PRACTICES FOR  
ENHANCED YIELD, QUALITY AND SHELF-LIFE OF ONION (*Allium cepa* L.) in  
NORTHWEST ETHIOPIA**

**Ph.D. DISSERTATION**

**BY**

**YEBIRZAF YESHIWAS MELESE**

**JANUARY 2025  
BAHIRDAR, ETHIOPIA**



**OPTIMIZATION OF PRODUCTION AND POSTHARVEST PRACTICES FOR  
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NORTHWEST ETHIOPIA**

**Ph.D. Dissertation**

**By**

**Yebirzaf Yeshiwas Melese**

**Submitted in Partial Fulfilment of the Requirements for the Degree of  
Philosophy of Doctor (Ph.D.) in Horticulture**

**Advisory Board Members:**

**Major Supervisor: Prof. Melkamu Alemayehu**

**Co-Supervisor: Prof. Enyew Adgo**

**January 2025  
Bahir Dar, Ethiopia**

## DISSERTATION APPROVAL SHEET

As a member of the board of examiners of degree of Doctor of Philosophy (Ph.D.) in Horticulture open defence examination, we have read and evaluated this dissertation prepared by Mrs. Yebirzaf Yeshiwas Melese entitled "Optimization of Production and Postharvest Practices for Enhanced Yield, Quality and Shelf-Life of Onion (*Allium cepa* L.) in Northwest Ethiopia". We here by certified that the dissertation is accepted for fulfilling the requirements for the award of degree of Doctor of Philosophy (Ph.D.) in Horticulture.

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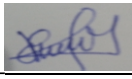


## DECLARATION

This is to certify that this Dissertation entitled “Optimization of Production and Postharvest Practices for Enhanced Yield, Quality and Shelf-Life of Onion (*Allium cepa* L.) in Northwest Ethiopia” submitted in partial fulfillment of the requirements for the award of the degree of Philosophy of Doctor in “Horticulture” to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mrs.Yebirzaf Yeshiwas Melese (ID. No. BDU1300529) is an authentic work conducted by her under our guidance. The matter embodied in this dissertation work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

### Name of PhD candidate

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Date: March 28, 2025

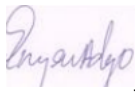
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## **DEDICATION**

I lost my son Nahom Esubalew (Biba), while I was busy with my research works. I am sorry my son Nahom, you did not get to see my completed dissertation. Nahom (Biba) was not only a beacon of joy but also a constant source of inspiration, reminding me of the enduring power of love, resilience, and the pursuit of knowledge. I'm not really sure what to say. I'm lost for words more than I dedicate this dissertation to the cherished memory of my beloved son Nahom who departed this world too soon (April 25/2009 E.C- Pagume 03/2014 E.C). In dedicating this work to his memory, I honour the indelible mark he left on my heart and the enduring influence he had on my academic journey.

## **ABBREVIATIONS AND ACRONYMS**

|         |                                                                    |
|---------|--------------------------------------------------------------------|
| ARARI   | Amhara Regional Agricultural Research Institute                    |
| ANOVA   | Analysis of variance                                               |
| CSA     | Central Statistical Agency                                         |
| CIMMYT  | Center for Improvement of Maize and Wheat                          |
| DLS     | Diffused light storage                                             |
| DMRT    | Duncan Multiple Range Test                                         |
| EIAR    | Ethiopian Institute of Agricultural Research                       |
| FAO     | Food and Agricultural Organization of the United Nations           |
| FAOSTAT | Food and Agriculture Organization of the United Nations Statistics |
| HFA     | Healthy Food Africa                                                |
| LSD     | Least significant difference                                       |
| MoARD   | Ministry of Agriculture and Rural Development                      |
| NGOs    | None governmental organization                                     |
| OEC     | Observatory of Economic Complexity                                 |
| RCBD    | Randomized complete block design                                   |
| SAS     | Statistical Analysis System                                        |
| SPSS    | Statistical Package for Social Sciences                            |
| SE      | Standard error                                                     |
| TSS     | Total soluble solid                                                |
| TSP     | Triple Super Phosphate                                             |

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# OPTIMIZATION OF PRODUCTION AND POSTHARVEST PRACTICES FOR ENHANCED YIELD, QUALITY AND SHELF-LIFE OF ONION (*Allium cepa* L.) IN NORTHWEST ETHIOPIA

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## GENERAL ABSTRACT

*Onion is an economically important cash crop in Ethiopia and the Amhara Region, which is widely produced under irrigation condition to meet year-round market demand. Despite its importance, however, onion production faces challenges such as low productivity due to a lack of improved varieties with extended shelf life, improper fertilization practices, suboptimal plant density. Studies were conducted in 2021–2023 in North Mecha (Koga), Bahir Dar Zuria (Woramit), and Fogera (Woreta) districts to assess farmers' knowledge and management practices, identify key supply chain constraints, and optimize nitrogen fertilizer rates and plant populations to enhance onion growth, yield, and quality. The study combined a field experiment and a survey. Field experiments were laid out in a factorial arrangement using a Randomized Complete Block Design (RCBD) with three replications. The survey result showed that onion production is dominated by adults households, but faces challenges of input shortages, high costs, and postharvest losses. Seven alternative marketing channels were identified, involving key actors such as farmers, local collectors, brokers, transporters, wholesalers, retailers, and consumers. The majority of the produce (66.15%) was sold to wholesalers. However, producers received only a small share of the final consumer price, while experiencing the highest*

average postharvest losses among all actors in the supply chain. Similarly, the experimental study indicate that onion growth and yield are significantly influenced by planting density, variety, and nitrogen fertilizer rate across growing location. Hybrid varieties (Russet and Jambar) consistently exhibited superior performance, achieving the highest bulb diameter, weight, harvest index, firmness, total yield, and marketable yield under the planting density of 666,666 plants ha<sup>-1</sup> across all locations. Russet and Jambar recorded the highest marketable yields of 28.54 t ha<sup>-1</sup> and 26.61 t ha<sup>-1</sup>, respectively. Planting at higher densities (666,666 plants ha<sup>-1</sup>) with a spacing of 40cm x 20cm x 5cm between double rows, rows, and plants respectively resulted in the highest marketable yield (28.42 t ha<sup>-1</sup>). Moreover, the application of 82 kg ha<sup>-1</sup> nitrogen fertilizer further enhanced growth and yield parameters, with Russet and Jambar achieving yields of 26.50 t ha<sup>-1</sup> and 24.57 t ha<sup>-1</sup>, respectively, across locations. The hybrid varieties (Russet and Jambar) and optimal nitrogen application rate (82 kg ha<sup>-1</sup>) also provided the highest net benefits. Postharvest quality was significantly influenced by packaging materials, nitrogen fertilizer, and variety. Proper handling allowed onions to be stored for up to one month without significant losses, regardless of the packaging materials used. Russet and Jambar varieties, when produced with optimum nitrogen fertilizer rate and stored on locally constructed shelves exhibited delayed sprouting, minimal decay, lower weight loss, and better firmness. In contrast, Bombay Red and Red Coach varieties showed higher storage losses. The study recommends for producers and traders in the study area, as well as similar to agro-ecologies adopt Russet and Jambar varieties, combined with higher planting densities and 82 kg ha<sup>-1</sup> nitrogen fertilizer for improved onion. Storing bulbs on shelves until market conditions improved can contribute to a sustainable onion supply chain. Furthermore, the study found that pre-harvest treatments, such as toppling at 90% neck fall, improved postharvest storage. Onions of Jambar and Russet varieties were able to be stored for up to four weeks without significant loss. The study underscores the need for further exploration, particularly to evaluate various hybrid onion varieties at high plant density levels. The investigation of phosphorus fertilizer is also recommended for

*future research, and since the study's limitation to a single season and location, further research is needed to test and to validate these findings across multiple locations and repeated years.*

**Keywords:** Constraint, market channel, nitrogen fertilizer, onion, packaging material, plant density, postharvest quality, shelf life, supply chain, yield

# Chapter 1: GENERAL INTRODUCTION

## 1.1. General Background and Justification

Onion (*Allium cepa* L.) is a bulb crop belonging to the genus *Allium* of the family *Alliaceae*. Onions are originating in southwestern Asia and have become ones of the most widely cultivated vegetables for bulb production over the past 4,000 years (Kumar *et al.*, 2007; Brewster, 2008).

Globally, onions rank as the second most cultivated vegetable, following tomatoes in terms of both cultivation area and economic significance (FAO, 2022). In 2018, total onion production, including green onions and shallots, reached 100 million tons, nearly doubling over two decades (FAOSTAT, 2020). This supports a global economy valued at \$6 billion annually, fulfilling both domestic and export demands. Onions are grown in over 130 countries, with China, India, and the United States as the top producers. Egypt leads Africa in onion production, yielding over 2.2 million metric tons annually, ranking fourth globally (World Atlas, 2024; FAO, 2022).

In Africa, Egypt's substantial production accounts for a significant share of the continent's contribution to global onion output. Ethiopia introduced onion cultivation in the 1970s and has become the third-largest producer of onions in Africa. Despite being the third-largest producer in Africa, Ethiopia's contribution to global production remains limited at 2.7% (FAOSTAT, 2020). The Amhara Region, particularly the northwestern areas, accounts for over half of the national production, demonstrating significant potential for expansion (Yebirzaf Yeshiwas *et al.*, 2023).

Onions are cultivated primarily for their characteristic pungency, adding flavor to a variety of dishes, including sauces, soups, sandwiches, and snacks like onion chips. Since it is rich in flavonoids, volatile oils, and allylprophl sulfides, onions serve as valuable condiments

and are a source of essential vitamins and minerals including vitamin C, vitamin B6, folate, potassium, and manganese. Both bulbs and green leaves can be consumed fresh, cooked, or in soups and salads. Onions are also recognized for their medicinal properties, offering potential health benefits, such as reducing the risk of high blood pressure, cancer, heart disease, and diabetes, along with exhibiting antibacterial, antiviral, antiallergenic, and anti-inflammatory effects (Renbomo and Biswas, 2017; Raemaekers, 2001). Additionally, onions play a crucial role in income generation and export, contributing significantly to the global economy (Lemma Dessalegn and Shimelis Aklilu, 2003).

In Ethiopia, onions were introduced in the 1970s and have since become an integral part to the country's agriculture (Lemma Dessalegn and Shimelis Aklilu, 2003). Onions, categorized as cool-season crops, are adaptable to various climatic conditions, thriving at altitudes ranging from 500 to 2400 m.a.s.l., with an optimal range of 700-2200 m.a.s.l. It prefers well-drained sandy loam soils rich in organic matter, with an ideal soil pH between 6.2 and 7.0 (MoARD, 2019). Onions are cultivated year-round by both smallholder farmers and commercial growers, utilizing irrigation and rain-fed systems to meet local demand and support export markets (MoARD, 2019; Sara Belay *et al.*, 2015; Nikus Olani and Mulugeta Fikre, 2010).

Despite being the third-largest onion producer after Egypt and South Africa, Ethiopia accounted for only 2.7% of global onion production between 2002 and 2021 (FAOSTAT, 2020). The Amhara Region is the primary producer, contributing 54% of the national yield, with an average yield of 16 t ha<sup>-1</sup> during the 2021/22 main season (Yebirzaf Yeshiwas *et al.*, 2024; FAOSTAT, 2020). Specifically, in the northwestern Ethiopia, which includes the Fogera, Dera, Mecha, and Bahir Dar Zuria districts, onion production is rapidly expanding, demonstrating a competitive advantage. In 2017/18, the Mecha district cultivated 943.75 hectares with an average yield of 18 t ha<sup>-1</sup>, while Fogera

cultivated 11,880.5 hectares with an average yield of 20.3 t ha<sup>-1</sup>, highlighting opportunities for higher profitability and expansion.

However, onion productivity in Ethiopia, at 11.7 t ha<sup>-1</sup>, remains below the global average of 21.1 t ha<sup>-1</sup> (FAOSTAT, 2022; CSA, 2020). Several factors contribute to this low productivity, including a lack of improved cultivars, inappropriate agronomic practices, weak extension services, pest and disease infestations, inadequate marketing systems, fluctuating climatic conditions, poor infrastructure, and high postharvest losses (Muluneh Bekele *et al.*, 2019a; Agidew Abebe, 2018; Almaz Giziew, 2018; Taye Melese *et al.*, 2018; Habtamu Gudisa, 2017; AgroBIG, 2016). Among these, major challenges include the absence of improved varieties, inappropriate agronomic/horticultural practices, nitrogen fertilizer rates, plant population issues, weak market linkage, poor product handling, and high postharvest losses (Muluneh Bekele *et al.*, 2019b; Kassa Getu and Ahmed Ibrahim, 2018; AgroBIG, 2016).

Feeding the growing global population, expected to reach 10 billion by 2050, requires a 70% increase in yield or the cultivation of two million hectares additional land that is the scarce resource (FAO, 2009). To address this, options including use of improved varieties, optimized agronomic practices such as nitrogen fertilization, plant population management, and reduction of postharvest losses are essential activities.

Regarding improved varieties, hybrid onions offer significant potential benefits, including higher yield, uniformity, and better storage life. Hybrid varieties can potentially double yields compared to open-pollinated varieties, making them key to improving productivity (Agnieszka *et al.*, 2017). In Ethiopia, efforts to improve onion production have led to the development of 28 improved open-pollinated and hybrid varieties (MoARD, 2019; Lemma Dessalegn and Shimelis Aklilu, 2003). However, complete production technologies remain inadequately addressed. Hybrid onion can be stored for up to five

months, depending on the storage conditions (MoARD, 2019). Hence focusing on the utilization of improved varieties with better storage characteristics is crucial to enhance production and productivity (Mondal, 1991).

Proper plant density in onion cultivation reduces competition for resources like water, nutrients, and light, ultimately improving yields and quality (Nehra *et al.*, 1988; Nichols and Heydecker, 1964). Optimizing plant population ensures efficient land use and maximizes yield. Lower plant density improves yield per plant, while Higher plant density boosts yield per unit area up to a certain point (Tsegaye *et al.*, 2022; Haile and Abate, 2020; Bhuiyan *et al.*, 2012; Abubaker, 2008). Nitrogen management is also critical and insufficient nitrogen reduces yields (Kahan *et al.*, 2021; Lee, 2014), while excessive nitrogen can harm plants and the environment (Geary *et al.*, 2015; Buckland, 2013). Careful optimization of plant density and nitrogen application are vital for maximizing onion yields sustainably. Compared with open-pollinated varieties, hybrid onion varieties, with rapid adaptability, uniformity, and double yield potential, require higher nutritive inputs to achieve their yield potential (Agnieszka *et al.*, 2017; Hyde, 2010; Singh and Bhonde., 2011; Meer, 1994).

Onion storage plays a crucial role in maintaining a steady supply for export and processing markets by quality, reducing postharvest losses and ensuring year-round availability (Ullah *et al.*, 2008; Adamicki, 2005). In Ethiopia, onion storage poses a significant challenge, with reported losses of up to 100%, primarily due to the cultivation of short-storage, open-pollinated varieties (Daniels and Fors, 2015). Overall, postharvest losses in horticultural crops in Ethiopia can range from 15–70%, with onion losses estimated at 13–36% in specific Regions (Daniels and Fors, 2015; Ko *et al.*, 2002).

Improving storage methods can help mitigate postharvest losses, which include physiological weight loss, sprouting, and rotting. Storage duration is influenced by bulb

characteristics such as dry matter content, and pungency (Ko *et al.*, 2002). The shelf life of onions is primarily determined by genetic traits, however it can also be influenced by effective crop management and appropriate storage conditions (Agnieszka *et al.*, 2017).

Addressing the production-to-market chain issues through improved market linkages and price stability can enhance smallholder farmers' incomes and boost national production efficiency (Agidew Abebe, 2018; AgroBIG, 2016). In Ethiopia, onion market supply is often surplus during peak production seasons due to poor storage capabilities. Farmers are not benefited a price advantage because of inconsistent supply and inadequate storage capacity, resulting in lower prices during main production season. Strategies to ensure a year-round supply include efficient pre-harvest treatments, improved storage methods, and better handling practices, which can reduce losses and stabilize the market (Yebirzaf Yeshiwas *et al.*, 2023; Adamicki, 2005).

Hence, studies on the performance of various hybrid onion varieties under different agronomic practices and postharvest handling methods are essential for realizing the crop's full potential in northwestern Ethiopia.

## **1.2. Statement of the Problem**

Onion plays a significant role in Ethiopia, serving as one of the primary cash crops grown by smallholder farmers across the country, including the Amhara Region. Despite its recent introduction, it is a popular vegetable crop, because of its high yield potential per unit area, and ease of propagation by seed (MoARD, 2019; EIAR, 2015).

In 2022, Ethiopia ranked as the world's 50<sup>th</sup> largest onion exporter, with exports valued at \$5.12 million, making onions the country's 61<sup>st</sup> most exported product. Major export markets included Djibouti (\$1.56M), Germany (\$1.24M), Switzerland (\$295K), and Kenya (\$250K). Between 2021 and 2022, Ethiopian onion exports experienced significant

growth in the Netherlands (+\$320K), Kenya (+\$93.5K), and Norway (+\$43.7K) (OEC, 2024). This growth highlights the potential of onion production to contribute significantly to improving farmers' incomes and livelihoods, as well as bolstering the national economy (Habtamu Mossie, 2020). However, this potential remains constrained by several challenges, including the lack of improved varieties, inappropriate agronomic practices, low soil fertility, improper fertilizer use, limited land availability, and environmental degradation. Additional issues such as a weak extension system, pest and disease infestations, inadequate storage facilities, poor market linkages, and high postharvest losses have further hindered onion production and productivity, particularly in the Amhara Region (Muluneh Bekele *et al.*, 2019a; Agidew Abebe, 2018; Almaz Giziew, 2018; Taye Melese *et al.*, 2018).

Farmers in Ethiopia traditionally use open-pollinated varieties, primarily Bombay Red and Adama Red. Recently, however, hybrid onion varieties with higher yield potential have been introduced into the farming system. Despite this advancement, farmers continue to apply agronomic practices recommended for open-pollinated varieties. On the other hand, the required agronomic practices like the fertilizer rate and plant density depend on the yielding potential of the crop, the soil fertility status and the environmental and edaphic conditions of the growing areas (Yebirzaf Yeshiwas *et al.*, 2023; Habtamu Gudisa, 2017). In this regard, identifying the optimum nitrogen fertilizer rate and plant population of hybrid onion varieties is necessary to enhance the productivity of onion in Amhara Region.

Postharvest loss is another critical challenge in Ethiopian onion production. Losses occur in the form of sprouting, weight loss, decay, and bulb rotting at various stages of the supply chain. Factors such as pre-harvest agronomic practices, mineral nutrition, choice of varieties, climatic conditions during the growing season, and packaging materials significantly influence onion storability (Ullah *et al.*, 2008; Adamicki, 2005). Smallholder

farmers in Ethiopia including Amhara Region are producing mainly Bombay Red and Adama Red varieties, which are suitable in most cases for fresh consumption. Storing of these varieties is mostly associated with high postharvest loss. Storage, however, is critical for ensuring a continuous market supply, avoiding price fluctuations, and stabilizing farmers' incomes. Introducing onion varieties with better storability and improved packaging materials to prolong shelf life is necessary to reduce postharvest losses and support a sustainable supply chain. The present studies were thus initiated to identify the major constraints along the onion value chain and optimize agronomic practices for hybrid onion varieties to enhance production, productivity, shelf life and postharvest quality of onion bulb in northwestern Ethiopia.

### **1.3. Objectives of the Study**

#### **1.3.1. General objective**

The overall objective of the study was contributing for the enhancement of production, productivity, and shelf life of onion through optimization of agronomic practices of hybrid onion varieties and reduction of postharvest losses by using pre-harvest treatments and proper packaging methods in northwestern Ethiopia.

#### **1.3.2 Specific objectives**

- To identify the management practices and constraints of onion production by smallholder farmers and analyze the supply chain of onion in northwestern Ethiopia;
- To investigate the effects of planting density and variety on the growth, yield, and quality of onion;
- To determine the influence of nitrogen fertilizer rate and onion variety on the growth, yield and shelf life of onion bulb;
- To assess the influence of packaging material and variety on the shelf life and quality of onion bulb; and

- To evaluate effectiveness of pre-harvest treatment and variety on the shelf life and postharvest quality of onion bulbs

The analytical framework that visualizes interconnection of these objectives and their contribution to each other is indicated in Figure 1.1.

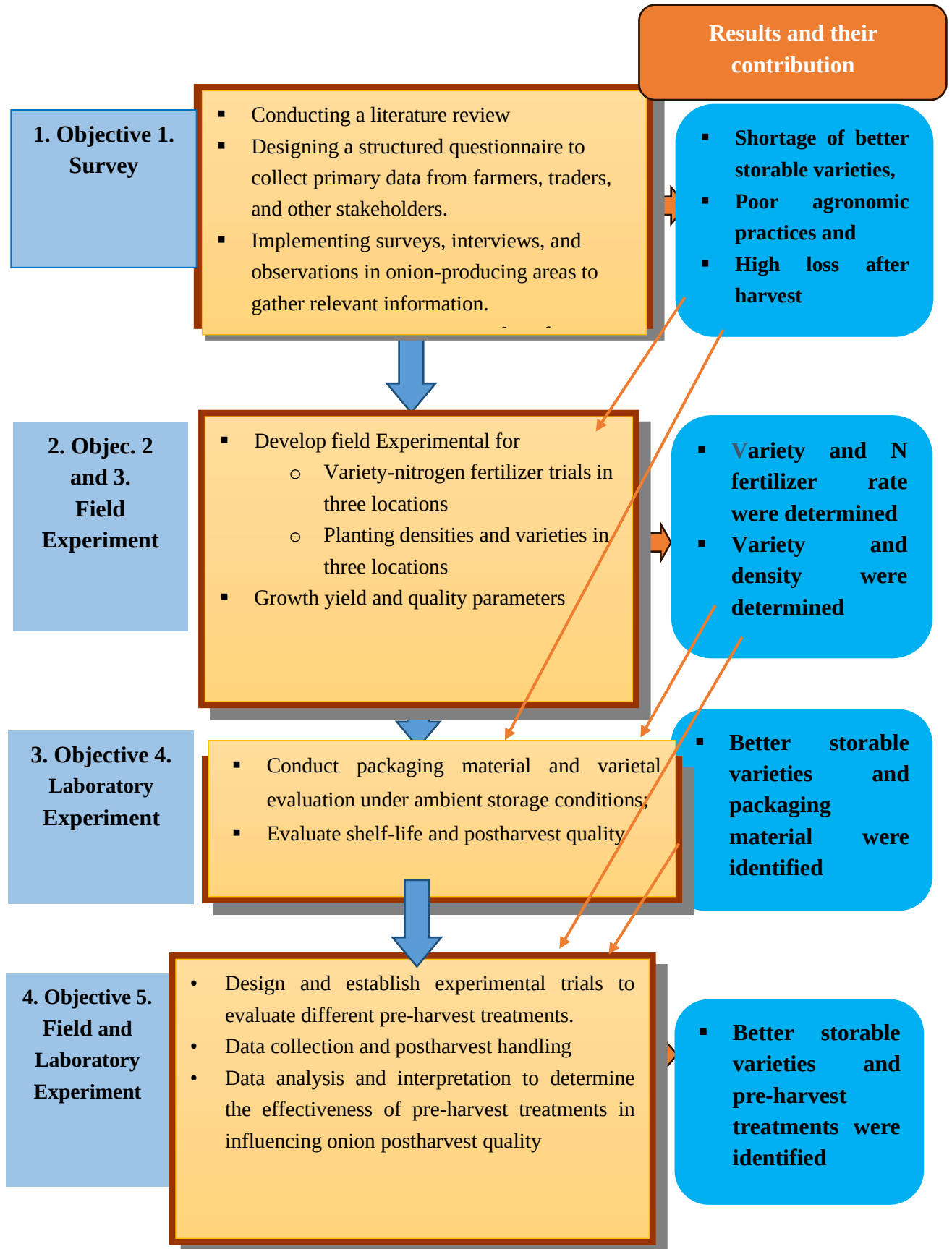


Figure 1.1. Analytical framework of the study

## 1.4. Organization of the Dissertation

The dissertation is structured into eight chapters.

**The first chapter:** is a general introduction, offering a comprehensive overview of the study. It provides background information on the global status of onion production, highlighting its importance as a widely cultivated and consumed vegetable. It also examines onion production in Ethiopia, underscoring its significance to smallholder farmers and the national economy. The chapter identifies key challenges contributing to low onion productivity, such as the lack of improved varieties, inappropriate agronomic practices, low soil fertility, and high postharvest losses. Additionally, it outlines the of inadequate storage facilities and weak market linkages.

**The second chapter** describes the general materials used and the methods followed, it includes area description, methods of data collection, and statistical methods for data analysis to achieve the study objectives.

**The third chapter** addresses a survey study that assesses the onion management practices applied by smallholder farmers, the constraints of production and postharvest management of onion along the supply chain in northwest Ethiopia. It also deals with the identification of major supply chain actors of onion and their role and the marketing channel of onion.

**The chapters four to seven** present the experimental studies, stating the theoretical background information that supported the necessity of conducting the particular experiment. Each chapter outlines the specific objectives and methods, planting materials, experimental design and treatments used, the collected data and their method of analysis and key findings.

**Chapter eight** states a general conclusion and recommendation based on the findings of the study. Additionally, it provides suggestions for future research areas.

## **Chapter 2: GENERAL MATERIALS AND METHODS**

### **2.1. Description of the Study Area**

#### **2.1.1. Survey study**

The study was conducted in three potential onion-producing districts and six *kebeles* (two *kebeles* in each district) of north-west Ethiopia. Major onion-producing districts and *kebeles* are namely: Mecha district (*Kudmi and Enguti kebeles*), Fogera district (*Shina and Kuhar Micael kebeles*), and Bahir Dar Zuria district (*Yigoma, and Sebatamit kebeles*) from August 2021–March 2022.

#### **2.1.1. Geographical location and climate of study sites**

Field experiments were conducted at three districts of Amhara Region namely North Mecha (Koga), Fogera (Woreta), and Bahir Dar Zuria (Woramt) districts (Fig. 2.1) during the 2021/2022 irrigation season.

The Fogera district is one of the 126 districts of the Amhara Regional State. The district is situated at 11°58' N latitude and 37°41' E longitude. Woreta is the capital city of the district and is located 625 km from Addis Ababa and 55 km from the Regional capital, Bahir Dar. The average annual rainfall is 1216.3 mm, with long and short cropping seasons. Its altitude ranges from 1774 to 2410 meters above sea level. The climate is almost medium highland with an average temperature ranging from 10.3 °C to 27.2 °C.

North Mecha district is one of the 14 districts found in Amhara National Regional State of West Gojjam Administrative Zone. It is located 515 km north of Addis Ababa, the country's capital, and 37 km southwest of Bahir Dar, capital city of the Amhara Regional State. Merawi, Woreda's capital city, is located on the main road connecting Addis Ababa and Bahir Dar. The district is located between 11°05' N to 11°38' N and 37°00' E to

37°23' E. The study area receives an annual mean rainfall of 1395.23 mm. The mean maximum and minimum temperature of the study area are 27 °C and 12.8 °C respectively.

Bahir Dar Zuria district is located around Bahir Dar town, within 37°10' East of longitude and 11°15' North of latitude. It is approximately 578 km northwest of Addis Ababa. The mean altitude of the district is 1,800 meter above sea level, and the temperature of the district ranges from 10 °C to 38 °C throughout the year, with a mean annual rainfall of 750 mm. The map of the experimental locations and specific trial sites represents distinct agroecologies conditions (Figure 2.1).

The geographical locations, altitudes, rainfall, and soil types of the districts are presented in Table 2.1. The average maximum and minimum temperatures of specific study areas, Woreta and Woramit during the experimental period were 29 °C and 17.8 °C and 28 °C and 12.4 °C, respectively. The Koga experimental site had mean maximum and minimum temperatures of 28.8 °C and 9.5 °C, respectively, as indicated in Figure 2.2 (Amhara Regional Meteorological Station, 2022).

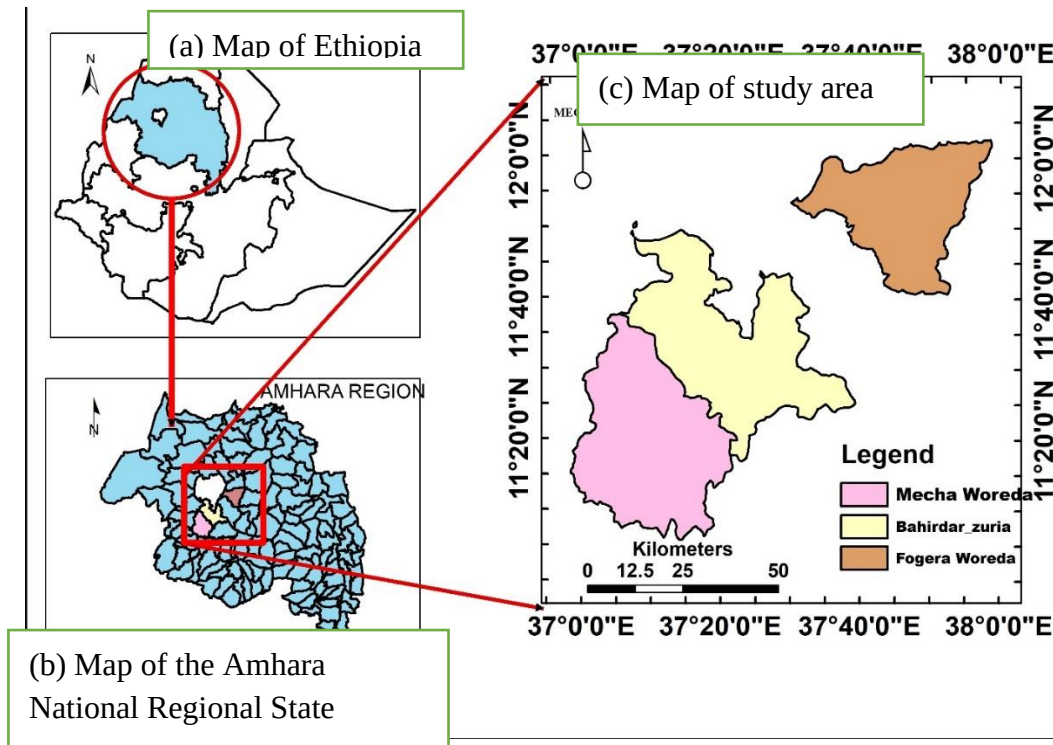


Figure 2.1. Map of the study sites: map of Ethiopia (a), map of the Amhara National Regional State where the study area is located (b), map that shows the study area with topographic information and the locations of the sites (c)

Table 2.1. Location coordination, altitudes, rainfall and soil types of experimental sites

| Location | Lat. (N) | Long.(E) | Altitude (masl) | Rainfall (mm) | Soil texture |
|----------|----------|----------|-----------------|---------------|--------------|
| Woramit  | 11°38′   | 37°10′   | 1800            | 1248.8        | Nitisoile    |
| Koga     | 11°20′   | 37°7′    | 1953            | 1300 -1380    | Nitisoile    |
| Woreta   | 11°55′   | 37°42′   | 1828            | 1250          | Vertisol     |

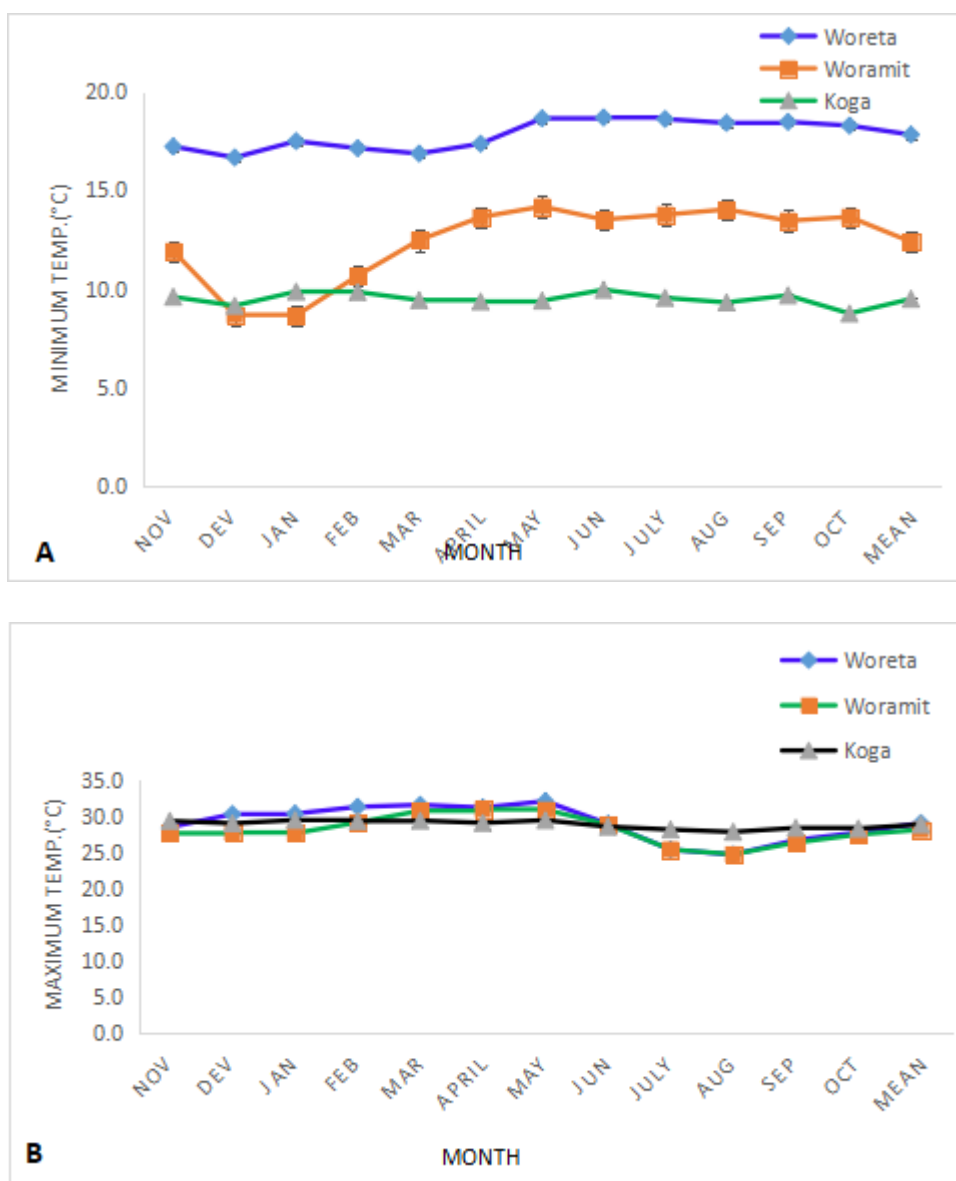


Figure 2.2. Minimum (A) and maximum (B) temperatures of the testing sites during the 2021/2022 cropping season

Source: Amhara Regional Meteorological Station (2022)

### 2.1.2. Selected properties of the soils of experimental sites

Soil samples from the experimental sites were collected following standard procedures prior to planting. Composite soil samples were taken before the experimental plots were plowed by mixing samples collected at eight different spots of each site along the two diagonal lines of the field at 0-20 cm depth using an auger. The physical and chemical properties of the composite soil samples of experimental sites were analyzed at the Soil and Plant Nutrition Laboratory of the College of Agricultural and Environmental Sciences, Bahir Dar University. The results of the soil analysis are presented in Table 2.2.

Table 2.2. Selected properties of composite soil samples of experimental sites before planting in 2021/2022 irrigation season

| Soil properties                                | Experimental sites |           |        |
|------------------------------------------------|--------------------|-----------|--------|
|                                                | Koga               | Woramit   | Woreta |
| Texture                                        |                    |           |        |
| Sand (%)                                       | 56                 | 44        | 43     |
| Silt (%)                                       | 16                 | 24        | 15     |
| Clay (%)                                       | 28                 | 32        | 42     |
| Textural class                                 | Sandy Clay Loam    | Clay Loam | Clay   |
| pH with_H <sub>2</sub> O (1:2.5)               | 5.40               | 5.69      | 6.02   |
| EC (μS/cm)                                     | 161.30             | 89.10     | 74.00  |
| Organic Carbon (%)                             | 2.18               | 1.72      | 1.33   |
| Organic Matter (%)                             | 3.77               | 2.96      | 2.29   |
| CEC (cmol (+)kg <sup>-1</sup> )                | 27.60              | 26.00     | 41.40  |
| Total Nitrogen (%)                             | 0.42               | 0.17      | 0.18   |
| Available phosphorus (mg/kg)<br>[Olsen method] | 10.02              | 20.24     | 6.48   |

The textural classes of the experimental soils were found to be sandy clay loam, clay loam and clay at Koga, Woramit and Woreta experimental sites with pH values of 5.4, 5.69 and 6.06, respectively. The soil pH of Woreta site falls within the optimal range, whereas those of Koga and Woramit are slightly acidic and are within a preferred range for most crops. The electrical conductivity values of the experimental soils are within acceptable limits for

onions, indicating that the sites had low salinity levels. The organic matter content of the site is in the medium range (2-4%) for Ethiopian soils per the criteria developed by Murphy (1968). On the basis of the rating made by Tekalign Tadesse *et al.* (1991), the total nitrogen content of the experimental soils was found to be high in Koga and low in Woreta and Woramit. According to Landon (1991), the Olsen extractable available phosphorus (P) contents of the soils of Koga, Woramit and Woreta experimental sites were 10.02 mg kg<sup>-1</sup> (rated as medium), 20.24 mg kg<sup>-1</sup> (rated as medium), and 6.48 mg kg<sup>-1</sup> (rated as low), respectively. The cation exchange capacity (CEC) of the soil was 27, 26, and 41, respectively, ranging from medium to high according to the rating by Jackson (1975) (Table 2.2).

Koga is the suitable site for onion cultivation, due to its well-balanced soil texture, high organic carbon and nitrogen levels, and moderate electrical conductivity (EC). However, the slightly higher EC, though still within an acceptable range, should be monitored to avoid potential salinity issues. Woramit is also a suitable location, offering favorable phosphorus levels, but its lower nitrogen and organic matter content may require some soil amendments. Woreta, on the other hand, needs more attention, especially due to its clayey soil, low phosphorus, and organic carbon content. Adding compost, phosphorus fertilizers, and possibly improving drainage would help enhance its suitability for onion farming.

## **2.2. Experimental Planting Materials**

Three hybrid F<sub>1</sub> onion varieties, Russet, Red Coach, and Jambar, and one open-pollinated Bombay Red variety were used as control in this study. The seeds of the hybrid varieties were collected from commercial suppliers (Eshet Agricultural Input Supplier, Bahir Dar, Ethiopia), while the seeds of the Bombay Red variety were obtained from the Melkassa Agricultural Research Center (MARC). The onion varieties were selected on basis of the the results of the preliminary pilot survey in which the farmers preferred them on the basis

of their growth and yield performance. The general characteristics of the selected onion varieties are presented below.

Table 2.3. List of onion varieties used in the experiments and their descriptions

| Variety name             | Year of release/registration | Area of adaptation |               | Maturity days |
|--------------------------|------------------------------|--------------------|---------------|---------------|
|                          |                              | Altitude (m)       | Rainfall (mm) |               |
| Russet F <sub>I</sub>    | 2013                         | 1500-2200          | Irrigated     | 90-110        |
| Red Coach F <sub>I</sub> | 2015                         | 500-2200           | Irrigated     | 107-120       |
| Jambar F <sub>I</sub>    | 2011                         | 1000-2500          | Irrigated     | 90-110        |
| Bombay Red               | 1980                         | 700-2000           | Irrigated     | 110-120       |

Source: MoARD (2019, 2016, 2004).

## 2.3. Experimental Treatments and Design

The treatments and designs used for the experiments in the study are summarized below in Table 2.4.

Table 2.4. Summary of treatments and designs used in the study

| No | Title of the experiment                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Treatments                                                                                                        | Design                     | Rep             |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|----------------------------|-----------------|
| 1  | <p>Potential constraints and determinants: onion production and postharvest management in the northwest Ethiopian supply chain</p> <ul style="list-style-type: none"> <li>- The rise and fall of onion production; its multiple constraints on pre-harvest and postharvest management issues along the supply chain in northwest Ethiopia</li> <li>- Strategic mapping of onion supply chains: a comprehensive analysis of production and postharvest processes in Northwest</li> </ul> | Assess the major production and postharvest handling determinants: farm, wholesale, retailer and consumers levels | Semi structured questioner | 312 respondents |

|   | Ethiopia                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                               |      |   |  |
|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|---|--|
| 2 | Enhancing bulb yield through fertilization and the use of hybrid onion varieties in northwest Ethiopia                                                                    | 4*4 factorial combinations of four varieties and four levels of N fertilizer rate (0, 41, 82, and 123 kg ha <sup>-1</sup> ), in three locations                                                                                                                                                               | RCBD | 3 |  |
| 3 | Influence of variety and plant density on the growth, bulb yield of bulb and quality traits of onion ( <i>Allium cepa</i> L.)                                             | 4*3 factorial combinations of four varieties, and three levels of planting density, (666,666 ha <sup>-1</sup> , 333,333 ha <sup>-1</sup> and 222,222 ha <sup>-1</sup> ), in three locations                                                                                                                   | RCBD | 3 |  |
| 4 | Effect of packaging materials on the shelf life and quality of hybrid onion varieties in north-western Ethiopia                                                           | 4*4*3 factorial combinations of four varieties, four levels of N fertilizer, and three types of packaging materials (burlap sack, wooden/mesh shelves, and open floor),                                                                                                                                       | RCBD | 3 |  |
| 5 | Influence of pre-harvest treatments on shelf life and postharvest quality of hybrid onion ( <i>Allium cepa</i> L.) varieties in Bahir Dar zuria district of Amhara Region | 4*4*3 factorial combinations of three varieties, four levels of pre-harvest treatments (toppled at 70% neck fall and irrigated before 3 days of harvesting; toppled at 90% neck fall, toppled at 70% neck fall, Control: un-toppled, un-irrigated and three storage durations (4 weeks, 8 weeks and 12 weeks) | RCBD | 3 |  |

## 2.4. Experimental Procedures

Seeds of each variety were sown on well-prepared raised beds and mulched with straw. After germination the mulching material was removed. Watering was done using a fine watering cane where the frequency was determined based on the climatic conditions. The seedlings were maintained at the nursery for 55 days after sowing and hardened before being transplanted to the field. This was done by reducing the frequency of watering and making the soil with low moisture status when the seedlings were ready for field planting.

Healthy and vigorous 12-15 cm long seedlings were carefully selected for transplanting (Appendix Figure 2.1). The selected seedlings were transplanted in January 2022 with a recommended double row planting system: 40 cm between irrigation furrows, 20 cm spacing between rows, and 5 cm, 10 cm, and 15 cm intra-row spacing with plant populations of high, medium and low plants per hectare, respectively, for the plant density experiment, while spacings 40 cm × 20 cm × 10 cm were used for the nitrogen rate determination study (Appendix Figure 2.2) (MoARD, 2004). In each plot, there were three double rows.

All agronomic practices were applied according to the recommendations for onion (MoARD, 2004). On the basis of the rates of the treatments, nitrogen fertilizer was applied in the form of Urea (46% N) in two splits, where the first 50% of the nitrogen was applied 15 days after transplanting, while the remaining 50% was applied one month after transplanting. Triple superphosphate (46% P<sub>2</sub>O<sub>5</sub>) was used as a source of phosphorus and was applied uniformly for all plots at the rate of 92 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> at the time of transplanting (Nikus Olani and Mulugeta Fiker, 2010).

Irrigation water was applied at four-day interval using furrow irrigation for the first four weeks and then extended to seven-day interval until the physiological maturity stage for all experiments. The application of irrigation water was completely stopped 15 days before harvesting for curing purposes. Onion bulbs were harvested when approximately 70% of the plants in each plot displayed neck fall, although the specific timing varied depending on the nature of the experiment (MoARD, 2004; IPGRI, 2001).

To control powdery mildew, the fungicide Redomil Gold (Active Ingredient: 390 g/kg Copper + 50 g/kg Metalaxyl-M) was applied every two weeks, starting at the first sign of the disease and before spots appeared. A solution was prepared by dissolving 50 g of the fungicide in 15 liters of water, which was then applied uniformly using a knapsack

sprayer. For thrips management, Ajanta (Deltamethrin) was sprayed on a weekly basis, applied at a rate of 3 kg ha<sup>-1</sup>. The pesticides were diluted in 600 liters ha<sup>-1</sup> rate of water and uniformly sprayed using a knapsack sprayer.

## 2.5. Data Collection

Data on onion growth, yield, and quality parameters were recorded from the central four single rows of the net plot area at the physiological maturity stage and harvesting time (Appendix Figure 2.3 - Appendix Figure 2.8).

### **Growth parameters:**

**Plant height (cm):** Plant heights of ten randomly selected plants were measured from the ground level to the tip of the longest leaves by using measuring tape from the net plots at physiological maturity stage and the average was computed.

**Leaf number per plant:** The total numbers of leaves per plant were counted from ten randomly selected plants at physiological maturity stage and the average was computed.

**Leaf diameter (cm):** The maximum diameter of the longest leaf was measured from six plants at its widest point using a digital Vernier caliper (Mitutoyo's 500 series).

**Bulb neck diameter (cm):** The average neck widths of ten randomly selected matured bulbs were measured by using digital Vernier caliper and expressed in centimeter (Mitutoyo's 500 series).

**Days to physiological maturity:** was recorded by counting the number of days from the time of transplanting to the day at which more than 70% of the plants in a plot showed yellowing and dried leaves.

### **Yield and yield related parameters:**

**Bulb length (cm):** The vertical height of a cured bulb was measured from the base to the top using a digital Vernier caliper (Mitutoyo's 500 series) and the average diameters were computed and used for further analysis.

**Bulb diameter (cm):** was measured by using a digital Vernier caliper (Mitutoyo's 500 series) at the widest point in the middle portion of the mature bulb after curing and the average diameters were computed and used for further analysis.

**Harvest index:** this was the ratio of total fresh bulb yield to total fresh biomass yield which was recorded from ten randomly selected plants at harvest time and expressed as a percentage.

$$\text{Harvest index (HI)} = (\text{EY/BY}) * 100$$

Where EY = weight of fresh bulb (economic yield); BY = weight of biological yield (above and belowground dry weight).

**The average bulb weight (g):** It was the average weight of each ten randomly selected marketable bulbs harvested from the net plot area using digital sensitive balance.

**Marketable bulb yield (t ha<sup>-1</sup>):** Marketable bulbs are bulbs that are free of splitting, damages, rotting and discoloration and greater than 20 g (Lemma Dessalegn and Shimeles Aklilu, 2003). Marketable bulbs harvested from the net plot area were weighed by using digital sensitive weighing balance and converted into hectare basis.

**Unmarketable bulb yield (t ha<sup>-1</sup>):** Bulbs that fail to meet market standards due to being undersized (<20g), diseased, decayed, or showing physiological disorders, such as splitting were selected from net plot area harvest and weighed with digital balance and converted into hectare basis.

**Total bulb yield (t ha<sup>-1</sup>):** It was the summation of marketable and unmarketable bulb yields.

**Bulb size distribution (%):** Marketable bulb yield was categorized as small (20-50 g), medium (50–100 g), and large (>100 g) based on Lemma Dessalegn and Shimelis Aklilu (2003). Each category was weighed and expressed in t ha<sup>-1</sup>.

### **Bulb quality parameters:**

- 1. Total soluble solid (TSS) content (%)** was determined using the procedures described by Waskar *et al.* (1999). The juice of the four sample bulbs was extracted using a juice extractor and the extracted juice was filtered using sieve. The TSS was determined using a pocket refractometer (ATAGO CO., LTD; ATAGO® PR-32α) by placing one to two drops of clean juice on the prism at a monthly interval in the four months storage experiment. The refractometer was standardized using distilled water (0% TSS). The prism of the refractometer was washed with distilled water and dried before the next use.
- 2. Firmness (N):** It was determined with a portable fruit penetrometer (GY-4 model S/N G2001707622) using an 8 mm stainless steel punch. The bulb was penetrated on at the two opposite sides at its equatorial Region and the average of the two measurements in Newton (N) was taken in monthly interval in the storage experiment.
- 3. Pungency (μmol/ml):** Content of the pyruvic acid developed in homogenized 4 sample bulb tissue was used as a measure of pungency following the modified procedures of Anthon and Barrett (2003).
- 4. Days to the first sprouting:** Onions were monitored daily to detect visible sprouts on at least one bulb by visual inspection. The number of days elapsed from storage to the first sighting of sprouting was counted and used as days to the first sprouting.
- 5. The physiological weight loss (%) of onion bulbs:** It was determined according to the methods described by Waskar *et al.* (1999) using the formula below [2]. The difference between the initial weight and successive weights gave the weight loss and expressed in percentages.

$$\text{Weight loss of bulbs \%} = \left( \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \right) * 100 \dots\dots\dots[2]$$

- 6. Percentage of sprouted bulbs:** It was ascertained by counting the number of bulbs sprouted at the beginning and mid of each month until the storage period and divided

by the total initial number of bulbs, then multiplied by 100. After each inspection, sprouted bulbs were removed to prevent double counting. Bulbs that sprouted and rotten simultaneously were classified as sprouted.

7. **Percentage of decay/rotten bulbs:** It was determined by counting the number of decayed bulbs and expressing them as a percentage of the total initial number of bulbs [3]. The percentage of rotted bulbs was calculated cumulatively, which was calculated at the beginning and midpoint of each month during a five, and three-months storage period. Rotted bulbs were discarded after each count to avoid duplicate counting.

$$\text{Percentage decay (\%)} = \left( \frac{\text{Number of decayed bulbs}}{\text{Total number of initial bulbs}} \right) * 100 \dots\dots[3]$$

8. **Percentage of marketable bulbs:** It was assessed subjectively according to the methods described by Mohammed *et al.* (1999). It was evaluated by observing the level of visible rotting, mold, discoloration, sprouting and shriveling of stored bulbs. Percentage of marketable bulbs was determined as the proportion of number of bulbs free of above-mentioned parameters (marketable) to the total number of stored bulbs and expressed as a percentage. It was taken in monthly interval during the storage period [4].

$$\text{Marketable onion bulbs (\%)} = \left( \frac{\text{Number of marketable bulbs}}{\text{Total number of initially stored bulbs}} \right) * 100 \dots\dots[4]$$

## 2.6. Data Analysis

The collected data were initially checked for the fulfilment of all the ANOVA assumptions (normality and homogeneity) by using Shapiro-Wilk normality test and Leven's homogeneity test. The data was subjected to analysis of variance (ANOVA) using the PROC MIXED procedure of SAS computer software version 9.0 (SAS Institute Inc., 2008) as required. When ANOVA showed significant differences ( $P < 0.05$ ), the mean separation was carried out using the least significant difference (LSD) (Gomez and Gomez, 1984). In addition, a simple Pearson correlation analysis was performed to reveal

the magnitudes and directions of the relationships between the selected growths, yield and quality parameters of onion.

# **Chapter 3: POTENTIAL CONSTRAINTS OF ONION PRODUCTION AND POSTHARVEST MANAGEMENT IN THE NORTHWEST ETHIOPIAN SUPPLY CHAIN**

## **3.1. The Rise and Fall of Onion Production; its Multiple Constraints on Pre-Harvest and Postharvest Management Issues Along the Supply Chain in Northwest Ethiopia**

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### **Abstract**

*Food and nutrition security is not only addressed by increasing production alone, it should also be ensured by reducing food loss. Onion has a great contribution to both economic and health issues. However, its production and productivity in the country is low. Thus, the study was initiated to identify constraints on onion production and postharvest handling practices and to determine the extent of postharvest loss along the supply chain in northwest Ethiopia. Survey was conducted at farm, wholesale, retailer, and consumer's level. The multistage sampling procedure was employed. The results revealed that sex, age, educational level, production experience, land covered by onion, and household size have a significant influence on onion production. Sex, age, education level, active household size, selling experience, amount purchased, and storage duration have a significant association with onion production and postharvest loss. Major onion production and postharvest loss constraints were high perishable nature of the crop,*

*market linkage problem, low market price, lack of awareness of using postharvest technologies, absence of better storable varieties and access to fertilizer, and disease and insect pests. The whole purchased produce never reached the consumer's hands. The total postharvest loss of onion at the farmer, wholesale, retail, and consumer level was found to be 29.8%, of which the higher loss (35.5%) was observed at the farmer's level. Based on the findings of the present study, onion producers were challenged by timely and adequate supply and high cost of major production inputs and high postharvest loss. Therefore, producers and handlers in the supply chain need to be trained on affordable and applicable postharvest technologies. In addition, continuous capacity-building training, improving infrastructures, and access to input should be designed and implemented to improve better crop management and postharvest handling practices. Moreover, marketing cooperatives working on onion postharvest handling and marketing systems should be functional to absorb surplus production and ensure continuous supply to the market. Thus, it is essential to design meaningful interventions in the development and implementation of policy on sustainable production, handling practices, and supply of onion.*

**Keywords: Onion:** Postharvest loss, pre-harvest handling, supply chain, yield constraints

### **3.1.1. Introduction**

Feeding a global population of 10 billion by 2050 is expected to become one of the greatest challenges of this time, which will require a 70% increase in food production (FAO, 2009; Tilman *et al.*, 2001). Food and nutrition security continues to pose a challenge to African countries taking into consideration the fast-rising population growth coupled with decreasing natural resources such as land and the stress posed to water resources by climate change (Sowe *et al.*, 2020). An increase in malnutrition has occurred in different parts of the world. Food and nutrition security is not only addressed by increasing production alone but also by reducing food losses. At this time, the most urgent

need is to increase production with proper postharvest management of onion in a sustainable manner and improve farm income to insure household food and nutritional security.

Onion is one of the more intensively consumed and most important cash-generating crops for farmers around northwestern Ethiopia (Kassa Getu and Ibrahim Ahmed, 2018). Even though the crop has a great contribution to both economic and health issues, its production and productivity are not scaled to the required level. Its production trend is not consistent, rises over in a certain period of time and falls in another period of time. As a result, farmers have not been able to reap significant benefit from onion production. Several factors contribute to the low levels of onion production. These factors are improper agronomic practices, high cost of production inputs, lack of adequate storage facilities, limited access to improved seeds, high cost of transport, fluctuation of market price and lack of sufficient capital, and postharvest losses (Grema and Gashua, 2014).

Onion postharvest loss begins from production and it is inevitable after harvesting particularly during storage. Its postharvest losses are incurred at each channel in the supply chain where the produce passes through. Therefore, identifying the major constraints of onion is important to alleviate the existing problems along the supply chain and to design intervention strategies. Thus, detecting multiple factors that determine the rise and fall of the production and postharvest handling of onion from the farm to the consumers would give direction to farmers and concerned bodies to improve problems in the production and continuous supply. This study was therefore initiated:

1. To investigate the skills and knowledge of farmers in the management practices and postharvest handling of onion;
2. To identify major onion production and postharvest handling constraints in supply chains in northwestern Ethiopia; and
3. To determine the extent of postharvest loss of onion along the supply chain.

### 3.1.2. Hypothetical framework

Household size positively influences the production, supply, and postharvest loss reduction activities. Household heads with large-sized family members eases the operations of farm activities in the production and management of harvested onions through additional labor force (Debebe Sisay, 2022; Mukaila *et al.*, 2021; Achoja and Obodaya, 2019; Abedullah *et al.*, 2009). The experience of the household in the production and selling of onion also enhances the skills and knowledge in the production and postharvest management operations. As a result, it was possible to hypothesize that farmers and traders with more experiences are expected to have better skill in production and postharvest management. Experienced farmers have better administrative abilities towards production and handling (Koye, 2022). Accordingly, as the age of the farmers increased, their capability in managing of the farm increased that in turn increased the yield of onion. Similarly, education enhances the decision-making abilities of farmers, traders and consumers to accept and practice new ideas and technologies. Furthermore, formal education positively influences the willingness of farmers and traders to produce better and reduce the extent of postharvest loss (Obayelu *et al.*, 2021).

High production costs decrease the ability of farmers to cover more hectares of land with onion that in turn reduces the quantity produced and supply of the market (Agumas Yideg, 2019). As a result, we hypothesized that the cost of farm inputs like fertilizer, pesticides, and fuel negatively influences the production of onion. The use of seed of improved varieties contributes by about 5% to 30% to the crop yield (Baliyan, 2014). Thus, using hybrid varieties enhances the productivity of onion. According to Falola *et al.* (2023) an increase in harvested and purchased volume of onion increases the quantity of postharvest losses. According to Kader (2005), as the stay in the market increases the produce deterioration rate will be increased. Thus, the number of days required to finish the selling activities has a positive relation with the proportion of onion spoilage.

### **3.1.3. Methodology**

#### **3.1.3.1. Study area description**

The study was conducted in three potential onion-producing districts and six *kebeles* (two *kebeles* in each district) of north-west Ethiopia. Detail descriptions of the study areas are presented in 2.1. and 2.2.

#### **3.1.3.2. Data types, sources, and collection methods**

To achieve the study objectives, primary data were collected through face-to-face interviews with key informants and supply chain actors, direct field, and market observations. Data on socio-demographic and socio-economic characteristics, onion production practices, and constraints related to farmers' onion production, utilization, marketing, harvesting, postharvest handling practices, postharvest loss, and their interaction with the respective actors were collected from the respondents.

To collect primary data, a semi structured questionnaire was used following Elahi *et al.* (2022) through key informant interviews of farmers, wholesalers, retailers, consumers, direct field observations, and market assessment. The structure of the questionnaire was designed as both open-ended and close-ended. The close-ended questions were designed to list or select a suitable response and they were coded. The open-ended questions were prepared by letting the respondents freely explain any of their ideas (Appendix 1). Before the interviews, the respondents were informed and convinced about the purpose of the study and each respondent was asked for his/her agreement before the interview. In addition, respondents were given the right to skip the questions which are uncomfortable for them and replace them with other voluntary respondents and their responses were kept strictly confidential (Elahi *et al.* 2021).

Secondary data were collected by using document analysis techniques. Documents of Agricultural Offices at all levels and other relevant offices were used as sources of secondary data. Moreover, a systematic review of peer-reviewed journal articles, proceedings and books was done to collect the necessary information. The questionnaires for the interview that were prepared in the English language were translated into the local language of respondents, Amharic to avoid the language barrier. The questionnaires used for the interview consisted of socio-demographic and socio-economic characteristics of households, questions on farming knowledge and practices, and on access to production inputs, harvesting, and postharvest handling practices, and market information. During the field observation (physical observation), onion production and handling practice was observed to determine the type and causes of postharvest loss at the time of harvesting. In addition, onion production, agronomic management, major disease and insect pests, and harvesting and postharvest handling activities were also observed to have more reliable information about the existing onion handling practices in the supply chain.

#### ***3.1.3.3. Sampling technique and sample size determination***

A reconnaissance survey was carried out together with the district horticulture experts to get an overview of the status of onion production in the selected areas. The survey was conducted following the supply chains of onion production, marketing (wholesale, retail) and consumption to identify the major constraints in the production and postharvest handling processes.

Multistage sampling procedure was employed as indicated by Abbas *et al.* (2022) and (Elahi *et al.*, 2022). At the first stage two potential onion-producing Zones such as South Gonder, and West Gojjam were selected purposely. At the second stage, three potential onion-producing districts Fogera, North Mecha and Bahir Dar Zuria were selected purposely from two major onion-producing zones. At the third stage, two highly potential onion-producing *kebeles* were selected purposely from each major onion-producing

districts. The selected *kebeles* have high onion production capacity and have market-linkage with the major onion marketing centers of the country. In the fourth stage, onion-producing households were randomly selected from the selected *kebeles* for an interview purpose. In the fifth stage, wholesalers, retailers, and consumers at Bahir Dar, Woreta, and Merawi cities were purposely selected based on their purchasing capacities. The retailer's chain included the roadside sellers, town market displayers, and other small-scale traders. Yamane's (1967) sampling formula [1] with a 7% precision level was applied to draw the sample sizes of the households.

$$n = \frac{N}{1+N(e)^2} \quad [1]$$

Where; n is the required sample size, N is the target population size (total number of onion-producing households), and 'e' is the precision level (7%). The 7% precision level was used to minimize the sample size. Thereby, the representative proportional sample size was calculated.

Accordingly, a total of 312 respondents; 197 onion-producing farmers, 15 wholesalers, 50 retailers, and 50 consumers were selected and interviewed in the onion supply chain. Moreover, a key informant discussion was also conducted with agricultural office managers, development agents, and agricultural officers to augment the information supplied by respondents (Table 3.1.1). Respondents from the consumer chain were interviewed considering the market nearness and vicinity of the study area. They were interviewed about their daily experience with the quality and handling of the onion together. Key informant interviews with farmers, wholesalers, retailers, and development agents were conducted. To cross-check the information from key informant interviews, a focus group discussion was also conducted.

#### **3.1.3.4. Conceptual framework**

Based on the literature review and empirical evidences, the interrelationships of key variables including institutional, production, socioeconomics and demographic variables, farm and market related variables were considered in the present study (Figure 3.1.1). Sociodemographic variables were age, educational level, sex, and household size while production variables were access to improved onion varieties, fertilizer, and pesticides. Institutional factors like access to credit, participation in training, membership in cooperatives, farmer and farm-related variables (like land allocated to onions, onion farming experience), and market factors (like lagged onion market price, distance to nearest market, selling experience) influenced on market participation. Market participation leads to the level of participation (amount of onion sales) which in turn increased the household income.

#### **3.1.3.5. Data analysis**

The collected data were coded, entered and analysed using the SPSS (Statistical Package for Social Science) software 16.0 version. By excluding the personal information (name of respondents), the collected data were encoded in SPSS for further analysis. The data were checked for possible outliers before running for statistical analysis. Preliminary descriptive analysis was carried out to identify inconsistencies and irregularities in data entry, which were then corrected by crosschecking the questionnaires. Microsoft Excel computer program was also used to draw graphs and error bars. Descriptive statistics, including frequency, mean, percentage, and etc was used. Furthermore, inferential statistics (using the Chi-square test) was implemented to explore the significant association between socio-demographic, socio-economic aspects and onion production and postharvest management determinants. In addition, mean comparison techniques such as ANOVA and independent sample-t test were employed to compare the differences in onion production and postharvest management constraints among the supply chain actors or handling practices.

Table 3.1.1. Sample distribution in the selected districts and *kebeles*

| District        | Kebeles       | Total onion producing households | Number of proportional sampled (7%) |
|-----------------|---------------|----------------------------------|-------------------------------------|
| Mecha           | Kudmi         | 300                              | 12                                  |
|                 | Engutti       | 300                              | 12                                  |
| Fogera          | Shina         | 1058                             | 40                                  |
|                 | Quhar Michael | 850                              | 33                                  |
| Bahir Dar Zuria | Yigoma        | 1715                             | 65                                  |
|                 | Sebatamit     | 920                              | 35                                  |
|                 | Total         | 5143                             | 197                                 |

Source: District agricultural offices, (2021)

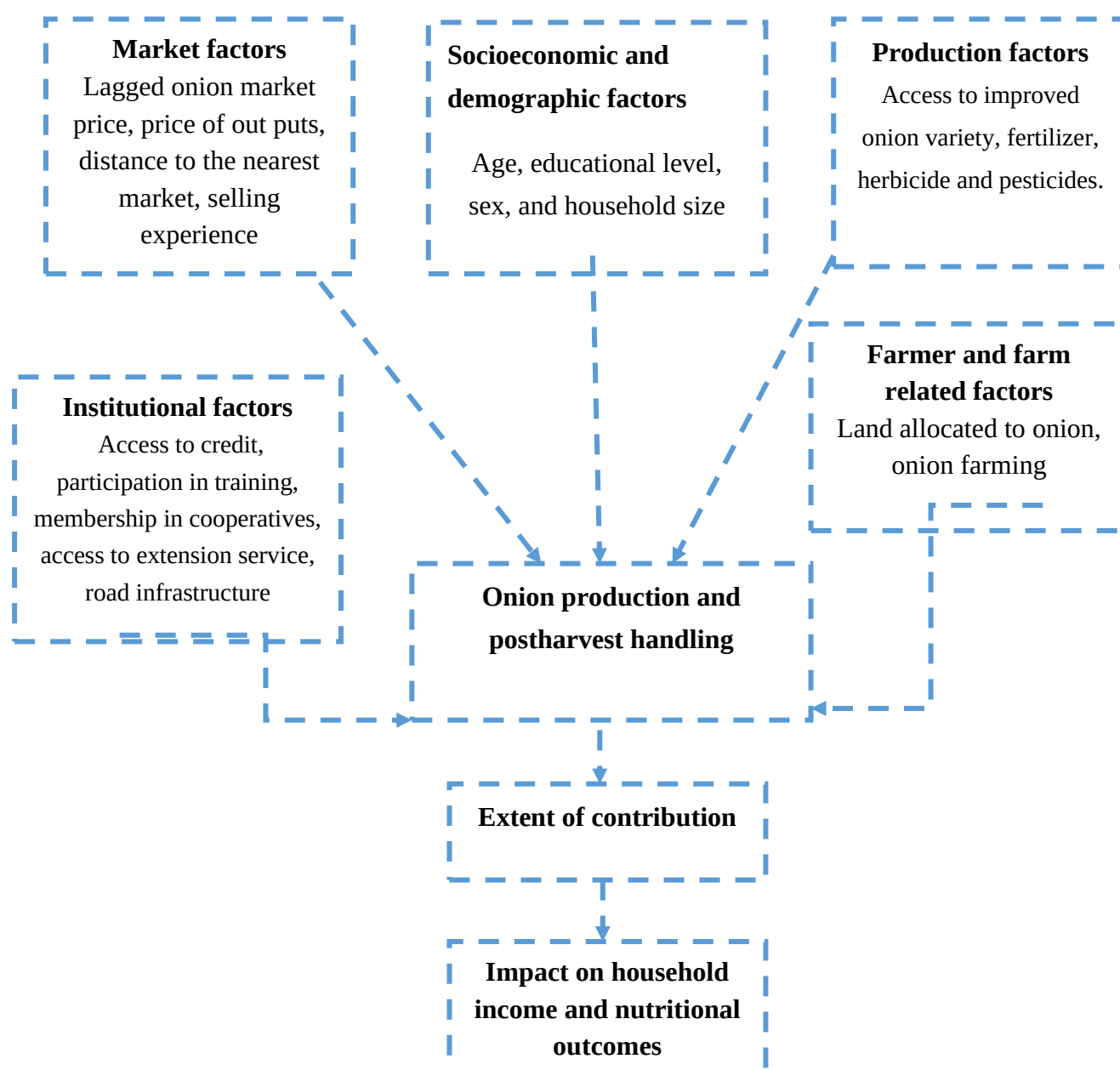


Figure 3.1.1. Conceptual framework of the onion supply chain (proposed by the author)

### **3.1.4. Results and discussion**

#### ***3.1.4.1. Socio-demographic characteristics***

The results showed that most onion producers (98.5%) and all wholesalers (100%) were male-headed households. In contrast, female-headed households were more involved in retail (75.8%) and as consumers (94%). The results implying that the majority of the onion-producing and wholesaling households in the study area are male-headed (Table 3.1.2). The present finding is in line with Samuel Gebrselassie (2013), who indicated that female farmers were discouraged to own their farms/enterprises due to time scarcity, price fluctuations, and lack of working capitals, difficulties in selling of onions and other high-value crops in Ethiopia. Similarly, based on the study conducted on the banana value chain in Uganda all wholesalers in the study area were male headed (Kikulwe, 2018). Yebirzaf Yeshiwas and Esubalew Tadele (2021) also reported that women headed households were the dominant retailers (85%) in the fruit and vegetable business in Debre Markos town, Ethiopia.

Regarding the educational status of producers, five respondents (3.6%) had attended higher education and 18 (9.1%) had attended the grades 10 to 12, while 37 (18.8%) respondents were illiterate, and 83 (18.8 %) were able to read and write. On the other hand, the dominant supply chain actors at the wholesaler, retailer, and consumer level had completed their secondary school (grade 10-12) as indicated in Table 3.1.2. Among the supply-chain actors, wholesalers and retailers had the better level of education, indicating that more educated youths prefer and compete for marketing of onion.

The survey results also showed that the average ages of the household-heads participated in production, wholesaler, retailer, and consumer were 44, 43, 37, and 38 years, respectively (Table 3.1.3). These indicate that the production and marketing of onion in the study area is dominated by adult and educated persons. Age is the primary

demographic feature used to characterize the working capabilities of the respondents. Similar results were reported by Habtamu Mossie *et al.* (2020) and Teklebrhan Abrha *et al.* (2020) who reported the average age of onion producers is around 44 years. Previous studies, for instance, confirmed that the average household size in the East Shewa Zone of Ethiopia was ranged from 5.4 to 5.5 (~6) family members (Gezai Abera *et al.*, 2020; CSA, 2011). Having a family with high household size has a positive effect on the production and handling of onions, and it also helps to reduce the cost of production and marketing as they use family labor during the production and marketing activities.

Table 3.1.2. Socio-demographic characteristics of onion supply chain actors in Mecha, Fogera, and Bahir Dar Zuria districts

| Questions          | Status              | Producer<br>(N=197) |      | Wholesaler<br>N=(15) |      | Retailer<br>N=(30) |      | Consumer<br>N=(50) |     |
|--------------------|---------------------|---------------------|------|----------------------|------|--------------------|------|--------------------|-----|
|                    |                     | Freq                | %    | Freq                 | %    | Freq               | %    | Freq               | %   |
| Sex                | Male                | 194                 | 98.5 | 15                   | 100  | 5                  | 15.2 | 3                  | 6   |
|                    | Female              | 3                   | 1.5  | -                    | -    | 25                 | 75.8 | 47                 | 94  |
| Marital status     | Married             | 187                 | 94.9 | 12                   | 80.0 | 18                 | 60.0 | 34                 | 68  |
|                    | Single              | 7                   | 3.6  | 3                    | 20.0 | 8                  | 26.7 | 8                  | 16  |
|                    | Widowed             | 3                   | 1.5  | 0                    | 0    | 2                  | 6.7  | 4                  | 8   |
|                    | Divorced            | 0                   | 0    | 0                    | 0    | 2                  | 6.7  | 4                  | 8   |
| Educational status | Illiterate          | 37                  | 18.8 | 0                    | 0    | 0                  | 0    | 7                  | 14  |
|                    | Read and write only | 83                  | 42.1 | 0                    | 0    | 0                  | 26.7 | 7                  | 14  |
|                    | 1-6                 | 31                  | 15.7 | 1                    | 6.7  | 0                  | 10   | 4                  | 8   |
|                    | 7-9                 | 20                  | 10.2 | 7                    | 46.7 | 0                  | 33.4 | 3                  | 6.0 |
|                    | 10-12               | 18                  | 9.1  | 7                    | 46.7 | 0                  | 20   | 16                 | 32  |
|                    | College level       | 1                   | 0.5  | 0                    | 0    | 0                  | 10   | 8                  | 16  |
|                    | Higher education    | 7                   | 3.6  | 0                    | 0    | 0                  | 0    | 5                  | 10  |

Table 3.1.3. Household age and size of major actors of onion value chain in the study area

| Indicators                      | Producer<br>N=197 | Wholesaler<br>N=15 | Retailer<br>N=30 | Consumer<br>N=50 |
|---------------------------------|-------------------|--------------------|------------------|------------------|
|                                 | Mean SD           | Mean SD            | Mean SD          | Mean SD          |
| Age of the household head(year) | 44.7±8.728        | 43.33±8.812        | 37.56±6.806      | 38±9.88          |
| Total household size(number)    | 5.7±1.704         | 4.67±1.63          | 4.93±1.617       | 4.8±1.89         |

#### 3.1.4.2. Socio-demographic characteristics and their association with onion production

The Chi-Square analysis was used to determine the significance of certain variables on onion production. The present study indicated that sex ( $X^2 = 89.125$  and  $p = 0.009^{**}$ ), age ( $X^2 = 2957.97$  and  $p = 0.000^{***}$ ) and educational level ( $X^2 = 406.61$  and  $p = 0.04^*$ ) had a significant influence on onion production. Household size ( $X^2 = 622.6$  and  $p = 0.000^{**}$ ), production experience ( $X^2 = 1212.57$  and  $p = 0.000^{**}$ ), and land covered by onion ( $X^2 = 894.4$  and  $p = 0.000^{**}$ ) also had significant effect on the production of onion (Table 3.1.4). Likewise, independent variables such as sex, education level, household size, production experience, and land covered by onion ( $X^2 = 1101.73$  and  $p = 0.000^{**}$ ) were found to be very highly significantly associated with the dependent variable onion yield. However, marital status ( $X^2=112$  and  $p = 0.686$ ) was not significantly associated with the dependent variable onion yield. As expected, educational level, household size and production experience positively influence onion production.

Table 3.1.4. Chi-square test results for the association between socio-demographic/economic factors and onion production among producers

| Variable                     | Chi-square value( $X^2$ ) | d.f  | P value   |
|------------------------------|---------------------------|------|-----------|
| Sex                          | 89.125                    | 60   | 0.009**   |
| Age                          | 2957.97                   | 2520 | 0.000**** |
| Educational level            | 406.61                    | 360  | 0.04*     |
| Marital status               | 112.026                   | 120  | 0.686ns   |
| Household size (number)      | 622.6                     | 413  | 0.000**** |
| Production experience (year) | 1212.57                   | 960  | 0.000**** |
| Land covered by onion(ha)    | 1101.73                   | 480  | 0.000**** |

Where, NS=non-significant, \*, \*\*and\*\*\*\* significance difference at 5%, and 1% probability levels, respectively. ha=hectare

Chi-square test on postharvest loss indicated that the independent variables such as sex, age, education level, active household size, selling experience, amount purchased and storage duration have significant associations with postharvest loss at producers and consumers levels. At the retailer's level, selling experience and storage duration are significantly associated (Table 3.1.5). As expected, age, educational level, household size,

production experience, and amount of onion bulbs harvested/purchased positively influenced the postharvest loss along the supply chain. The present findings are in line with the results of other scholars who reported the increase of the spoilage percentage as the waiting time for selling increases, due to the longer exposure of the commodity to the fluctuating environmental condition (Kereth *et al.*, 2013; Adugna Debela *et al.*, 2011; Yebirzaf Yeshiwas and Esubalew Tadele, 2021). Similar results were reported as the age and sex of traders did not significantly influence the postharvest loss of fruits and vegetables at wholesalers, as also reported by Masood (2011); Yebirzaf Yeshiwas and Esubalew Tadele (2021). In contrast to the present findings, Gezai Abera *et al.* (2020) reported that gender has a significant contribution to the postharvest loss of tomatoes. At the wholesaler's level, independent variables did not significantly associate with the postharvest loss. At the consumer level, age and total household size influenced the likelihood of onion postharvest loss, while the amount purchased and storage duration significantly affected the extent of the loss. However, educational level and marital status had no significant effect (Table 3.1.5), which is probably associated with relatively high level of education of the consumers.

Table 3.1.5. Chi-square results for postharvest loss of onion and socio-demographic factors in the supply chains

| Variable                       | Producer       |      |          | Wholesalers                                                              |     |         | Retailers      |     |         | Consumers      |     |         |
|--------------------------------|----------------|------|----------|--------------------------------------------------------------------------|-----|---------|----------------|-----|---------|----------------|-----|---------|
|                                | X <sup>2</sup> | d.f  | Pvalue   | X <sup>2</sup>                                                           | d.f | Pvalue  | X <sup>2</sup> | d.f | Pvalue  | X <sup>2</sup> | d.f | Pvalue  |
| Sex                            | 99.87          | 66   | 0.005**  | No statistics are computed because sex of the respondents is a constant. |     |         | 16.000 a       | 15  | 0.709ns | 4.331          | 11  | 0.959   |
| Age                            | 3561.55        | 2772 | 0.000*** | 138.7499                                                                 | 130 | 0.284   | 2.586E2a       | 240 | 0.195ns | 3305.60        | 220 | 0.000** |
| Educational status             | 406.6          | 354  | 0.028**  | 38.750a                                                                  | 30  | 0.131   | 81.944a        | 90  | 0.715ns | 70.694a        | 66  | 0.324ns |
| Marital status                 | 122.11         | 132  | 0.72ns   | 11.875                                                                   | 10  | 0.294ns | 40.602a        | 45  | 45.487a | 45.487a        | 33  | 0.072ns |
| Total household size           | 554.48         | 462  | 0.002**  | 63.54a                                                                   | 60  | 0.353ns | 107.22         | 90  | 0.104ns | 157.35         | 88  | 0.000** |
| Producing/Selling experience   | 1212.32        | 1056 | 0.001**  | 75.417a                                                                  | 70  | 0.308   | 175.41a        | 135 | 0.011*  |                |     |         |
| Amount harvested/<br>purchased | 10743.73       | 3960 | 0.000**  | 1.238E2a                                                                 | 100 | 0.05*   | 71.825         | 60  | 0.141ns | 22.312E2a      | 132 | 0.000** |
| Storage duration               |                |      |          | 55.417a                                                                  | 50  | 0.278ns | 48.018a        | 32  | 0.034*  | 2.654E2a       | 156 | 0.000** |

NS=Non-significant, \*, \*\*and\*\*\* significance difference at 5%, and 1%, probability levels respectively

#### ***3.1.4.3 Farmers' knowledge on onion production practices in the study areas***

The present result indicated that households in the study districts have diversified income sources. A mixed type of farming including the production of cereal, and vegetable crops, and rearing animals was the major source of income of the farmers (Table 3.1.6).

Among the vegetable crops, onion was the primary source of income and shared 86.6% of household's income followed by tomato (8.1%), potato (4.1%), head cabbage (0.5%), pepper (0.5%), and papaya (Table 3.1.6 and Appendix Figure 3.1.1).

Approximately 64% of respondents cultivated onions on their own land, while 22.8% grew onions on family-owned land (Table 3.1.6). Relatively, farmers who produce their onions on rental land tend to cultivate a larger area compared to those who use their own land.

The study results also indicated that the majority of onion producers 172 (87.3%) produced onion once per year, while 25 (12.7%) of the respondents produced twice per year using irrigation in the study area. Onion producing households in the study area owned a total average of  $1.09 \pm 0.47$  ha cultivated land. Of which about  $0.49 \pm 0.297$  ha of land was covered with onion. While the minimum land allocated for onion was 0.125 ha and the maximum was two ha (Table 3.1.6). This implies that onion farming becomes a promising venture. Mixed farming provides resilience to farmers against climatic and market shocks, and its predominance in Ethiopia supports the role of onion production in complementing other farming practices to enhance food security and income (Gebru Yohannes *et al.*, 2020). Onions, as a high-value cash crop, generate substantial income even on small plots of land, playing a significant role in improving rural livelihoods (Mohammed Ali *et al.*, 2019).

Despite Ethiopia's small average farm size, typically less than one hectare, onion production remains profitable due to its high yield potential and suitability for double cropping during the irrigation season (Alemayehu Gebre *et al.*, 2018). This practice not only boosts annual yields but also stabilizes income, as onions thrive under irrigation systems (Bekele Tadesse and Kebede Abebe, 2021).

Table 3.1.6. Income sources and annual onion production cycle using irrigation

| Questioners                                |                      | Frequency | Percentage |
|--------------------------------------------|----------------------|-----------|------------|
| Main income sources                        | Vegetable production | 43        | 21.8       |
|                                            | Cereals production   | 2         | 1.0        |
| Comparative income source from vegetables  | Mixed                | 152       | 77.2       |
|                                            | Onion                | 171       | 86.8       |
|                                            | Tomato               | 16        | 8.1        |
|                                            | Potato               | 8         | 4.1        |
|                                            | Cabbage              | 1         | 0.5        |
|                                            | Pepper               | 1         | 0.5        |
| Means of land acquisitions                 | Owned                | 126       | 64.0       |
|                                            | Gift                 | 17        | 8.6        |
|                                            | Family               | 45        | 22.8       |
|                                            | Rented               | 3         | 1.5        |
|                                            | Inherited            | 6         | 3.0        |
| Onion production per year using irrigation | Once                 | 172       | 87.3       |
|                                            | Twice                | 25        | 12.7       |
| Land covered by onion in ha                | Mean                 | Minimum   | Maximum    |
|                                            | 0.49                 | 0.125     | 2.000      |

#### *Onion seedling management and transplanting practices*

The result revealed that all respondents in the study area produced onions by transplanting. More than 80% (158) of the respondents transplanted onion seedlings at the age ranging from 40-50 days after seed sowing. Transplanting onion seedlings within this age range allows for the development of robust root systems and reduces transplanting shock, which are crucial for better field establishment. Younger seedlings (less than 40 days) are often too fragile to withstand transplanting stress, while older seedlings (beyond 50 days) may exhibit reduced vigor and adaptability to field conditions. The observed practice demonstrates the farmers' understanding of the critical timing needed to balance seedling vigor and ease of handling during transplanting.

In the study area, 63.5% of onion producers implemented the practice of trimming seedlings to half their height either 3–4 days before or during transplanting. On the other hand, 72 respondents (36.5%) did not trim the tops of seedlings (Table 3.1.7). According to the farmers, trimming of longer leaves is useful for ease of transplanting, uniformity of seedling and avoiding seedling lodging. It also enhances field establishment and initiation of new growth. From a scientific perspective, trimming the seedlings serves to reduce transplanting stress by minimizing the amount of leaf area, which in turn reduces water loss through transpiration. The reduction in leaf area also helps the seedlings diverting energy/assimilates to root development and adaptation to the new field conditions, eventually fostering quicker establishment (Ali Mohammed *et al.*, 2019). Additionally, trimming promotes uniformity, which ensures all seedlings having similar size and structure that is in turn essential for efficient spacing and growth. Studies conducted by Gebru Yohannes *et al.* (2020) have shown that uniform seedling size leads to better crop performance, as it reduces competition among plants for resources.

The present survey results also indicated that the planting distance between irrigation furrows, rows, and plants varies from one farmer to another. About 36 of the respondents (18.6%) transplanted onion seedlings through non-uniform/irregular transplanting which is mostly practiced in Fogera district. While this method may reduce labor requirements, it often requires a greater amount of planting material. The minimum planting distances implemented by farmers were 10 cm, 10 cm, and 3 cm between the irrigation furrow, row, and plants, respectively while the maximum were 60 cm, 40 cm, and 7 cm between furrows, rows, and plants, respectively. The majority of farmers transplanted the onion seedlings using 5 cm intra row. The three (3) cm intra-row spacing is very narrow for onions, which results in increasing the number of unmarketable small bulbs. A similar result was observed by Nikus Olani, and Mulugeta Fikre (2010) and Habtamu Tegen *et al.*

(2016) who reported 6 cm as optimum intra-row spacing to obtain the highest marketable bulb yield of onion with the maximum number of medium-sized bulbs.

Table 3.1.7. Transplanting stage and trimming practices of onion seedlings in the study districts

| Questioners                    | Status  | Producer (N=197) |            |
|--------------------------------|---------|------------------|------------|
|                                |         | Frequency        | Percentage |
| Stage of transplanting         | 30 Days | 8                | 4.1        |
|                                | 35 Days | 12               | 6.1        |
|                                | 40 Days | 48               | 24.4       |
|                                | 45 Days | 56               | 28.4       |
|                                | 50 Days | 54               | 27.4       |
|                                | 55 Days | 13               | 6.6        |
|                                | 60 Days | 6                | 3.0        |
| Practice of trimming seedlings | Yes     | 125              | 63.5       |
|                                | No      | 72               | 36.5       |

#### ***3.1.4.5. Irrigation access, sources and associated problems***

In the study area, onion production was carried out during the off-season using irrigation (Table 3.1.8). However, the access to irrigation varied from one farmer to another. Of the total respondents, 77 (77%) were in the Bahir Dar Zuria district, and 4 (16.7%) were in Mecha district, they had access to sufficient irrigation water. They apply irrigation water in 7–14 days and 7–16 days intervals at Bahir Dar Zuria and Mecha districts, respectively. However, in the Fogera district, all respondents did not get sufficient irrigation water. They apply irrigation water every 15 days at an early stage (up to one month of transplanting) and every 7–10 days one month after transplanting. The longer irrigation interval at Fogera district was due to the Vertisol nature of the soil, which has a better capacity to hold water and supplies better moisture for plant growth (Table 3.1.8).. Agumas Yideg (2019) reported that onion producers in the Fogera district consistently face irrigation water shortages driven by limited infrastructure and growing competition for water.

As illustrated in Fig. 3.1.2, the major irrigation water sources for the production of onion in the study areas are rivers, dams, and groundwater. In Bahir Dar Zuria district, Andassa, Abay, Tikurit, Yeshmet, and Yizana Rivers are the major irrigation sources. In the Mecha district, the only irrigation source for the production of onion was the Koga Irrigation Dam. Whereas in Fogera district, Gumara and Guanta Rivers and groundwater are the major irrigation water sources. There is sufficient irrigation water in the Andassa *kebele*, and the area experiences flooding due to an excess available water and surface irrigation. The primary sources of irrigation water in Andassa are the Abay and Tikurit Rivers (Figure 3.1.2). Generally, onion production in Fogera and Mecha districts frequently encountered shortage of irrigation water, especially during the months of March and April in relation to the use of irrigation. The major reason for shortage of irrigation water in Fogera district is the poor infrastructure in the irrigation scheme where no primary and secondary channels are constructed. Farmers are using pumps to deliver water to their farms, which increases the cost of production due to high price of fuel and labor. Mekonen et al. (2020) point out that the lack of irrigation channels and the use of fuel-powered pumps in Fogera increase production costs, especially when fuel prices rise. Moreover, water resource competition is the other problem in Fogera district. Currently more farmers are producing tef and wheat using irrigation water due to government policy, which contribute the scarcity of water for onion production. The main cause of irrigation water scarcity in North Mecha district is the delayed release of water from the dam.

Table 3.1.8. Irrigation practices in the study districts

| Questioners                              |     | B/Dar Zuria<br>(N=100) |      | Mecha<br>(N=24) |      | Fogera<br>(N=73) |      |
|------------------------------------------|-----|------------------------|------|-----------------|------|------------------|------|
|                                          |     | Freq                   | %    | Freq            | %    | Freq             | %    |
| Access to sufficient<br>irrigation water | Yes | 77                     | 77.0 | 4               | 16.7 | 0                | 0    |
|                                          | No  | 23                     | 23.0 | 20              | 83.3 | 100              | 100  |
|                                          |     | 7                      | 49   | 10              | 41.7 |                  |      |
| Irrigation frequency<br>(days)           | 8   | 17                     | 17.0 |                 |      |                  |      |
|                                          | 10  | 13                     | 13.0 | 9               | 37.5 | 25               | 34.2 |
|                                          | 12  | 12                     | 12.0 | 3               | 12.5 | 1                | 1.4  |
|                                          | 13  | 6                      | 6.0  |                 |      | 1                | 1.4  |
|                                          | 14  | 3                      | 3.0  |                 |      |                  |      |
|                                          | 15  |                        |      | 1               | 4.2  | 10               | 13.7 |
|                                          | 16  |                        |      | 1               | 4.2  |                  |      |

|                                                                                  |    |      |
|----------------------------------------------------------------------------------|----|------|
| Applied every 15 days during the early transplanting stage and every 10 days MAT | 14 | 19.2 |
| Applied every 15 days during the early transplanting stage and 7 days MAT        | 14 | 19.2 |
| Applied every 15 days early and 8 days MAT                                       | 8  | 11.0 |

Where, Freq= frequency; % = percentage; MAT= months after transplanting

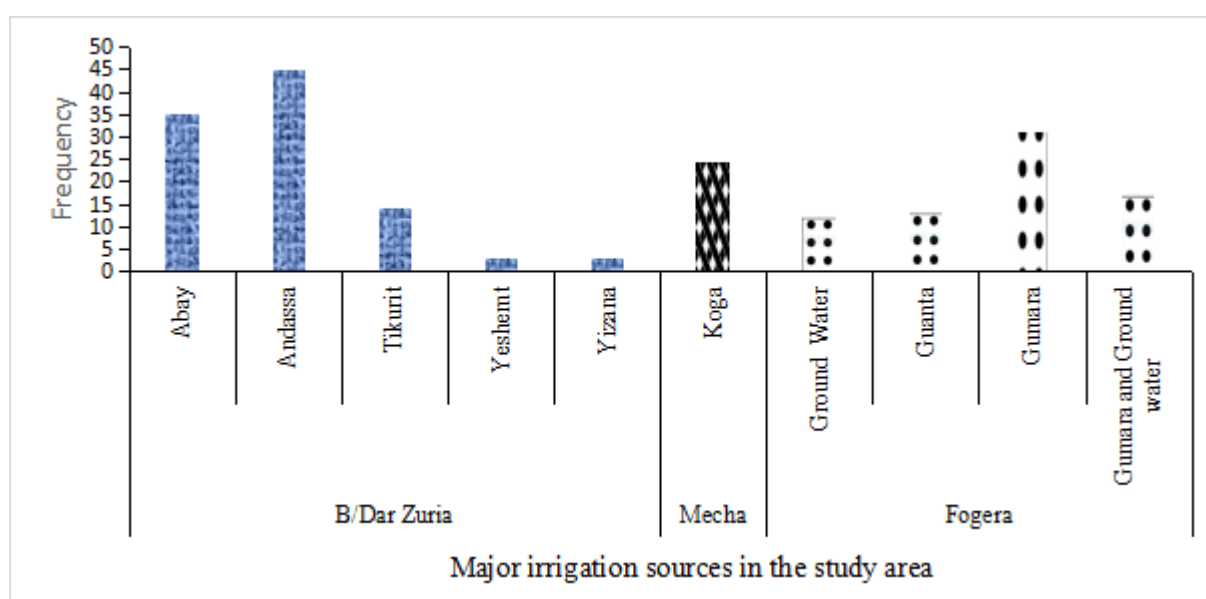


Figure 3.1.2. Major irrigation water sources and frequency for irrigated onion production in the study area

#### 3.1.4.6. Use of hybrid onion varieties and access to their seeds

The use of varieties with better quality is a basic input and foundation for enhanced productivity and longer storage period. Hybrid crops including onion with high yielding capacity play an important role in supporting global food security. They produce higher yields and are often more resistant than open-pollinated varieties to disease and climate stress. In the study area, farmers have experience in using hybrid onion varieties. About 26 (13.2%) of the respondents are producing hybrid onion varieties such as Jambar, Russet and Red Coach. The varieties are produced in large areas as well as in the demonstration plots (Table 3.1.9 and Appendix Figure 3.2.2). This aligns with findings of Fikre et al.

(2018), who reported that farmers' exposure to demonstration plots and training programs significantly increases the adoption of improved crop varieties. On the other hand, 86.8% of the respondents (171) did not produce hybrid onion varieties, which is associated with the high cost of seeds, lack of extension advice, and lack of awareness (Table 3.1.9). According to Abate *et al.* (2017), access to information and affordability are critical drivers of technology adoption in smallholder farming systems in Ethiopia. Since the start of hybrid onion production, for the last three years, the proportion of farmers producing hybrid onion is in increasing trend. Among the hybrid onion producing farmers, about 7.69% of the respondents started in 2018 production season and 11.55% of the respondents started in 2019, while 80.76% of the respondents started during the 2020 production season (Figure 3.1.3a). The trend indicates that with better awareness and improved extension advice, more farmers are likely to adopt the production of hybrid onion varieties in the future. Due to their higher yield potential, high market demand, and prolonged shelf life (Figure 3.1.3b), the production of hybrid onion varieties will continue in the near future. Among the onion producers, 34.61 % of the respondents preferred the Jambar variety, followed by 30.78% who favored the Russet variety. Additionally, 34.61% of respondents preferred a combination of Jambar, Russet and Red Coach varieties.

Access to quality seed for onion producers is essential to increase crop productivity. In the study area, 34 (17.3%) respondents have sufficient access to seeds of hybrid onion varieties. However, 163 (82.7%) respondents have no information about the accessibility or inaccessibility of seeds. This is consistent with the findings of Spielman and Kennedy (2016), who emphasize that weak seed distribution systems and limited involvement of the private sector often hinder the spread of improved varieties in Ethiopia. According to the respondents, local market and non-governmental organizations (NGOs) were the main seed/seedling sources of hybrid onion varieties where SNV project was the major seed/seedling supplier as explained by the District Agriculture Offices (Table 3.1.10).

Table 3.1.9. Hybrid onion varieties grown by onion producers in the study areas and their constraints

| Questioners                                  | Options                   | Frequency | Percentage |
|----------------------------------------------|---------------------------|-----------|------------|
| Growing hybrid onion varieties               | Yes                       | 26        | 13.2       |
|                                              | No                        | 171       | 86.8       |
| Name of varieties                            | Jambar                    | 9         |            |
|                                              | Red Coach                 | 7         |            |
| Extent of production                         | Russet                    | 17        |            |
|                                              | Production in large areas | 26        |            |
| Reasons for not using hybrid onion varieties | At demonstration plot     | 4         |            |
|                                              | High cost of the seeds    | 55        | 27.9       |
|                                              | Lack of extension advice  | 53        | 26.9       |
|                                              | Lack of awareness         | 63        | 32.0       |

Table 3.1.10. Access for hybrid onion varieties and sources of seeds

| Questioners                            |          | Frequency<br>(N=197) | Percentage |
|----------------------------------------|----------|----------------------|------------|
| Sufficient access for hybrid varieties | Yes      | 34                   | 17.3       |
|                                        | No/DHI   | 163                  | 82.7       |
| Sources of hybrid onion seeds          | Market   | 10                   | 5.1        |
|                                        | NGOs     | 16                   | 8.1        |
| Way of getting seeds                   | Purchase | 11                   | 5.6        |
|                                        | Gift     | 15                   | 7.6        |

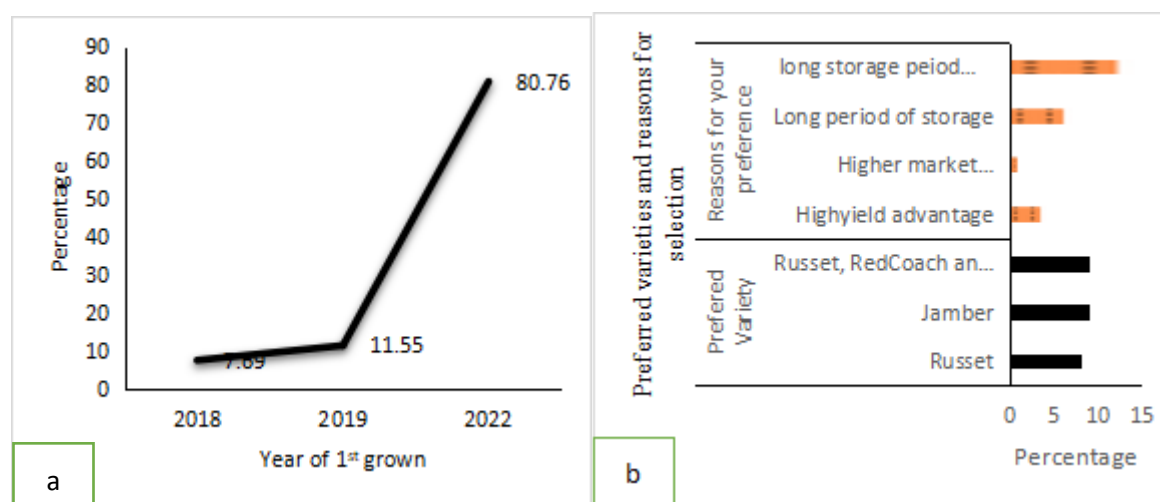


Figure 3.1.3. (a) Percentage of farmers started using hybrid onion production and (b) farmer's preference for hybrid variety and associated reasons

#### 3.1.4.7. Access and supply of fertilizer, pesticides and credit

The present study indicated that farmers could not promptly and adequately access fertilizers from formal suppliers such as cooperatives. About 6.1% of the respondents

obtained fertilizers from cooperatives, while 93.9% purchased from the local markets at high prices due to the inadequate supply of fertilizers by the cooperatives. The farmers also purchased pesticides from suppliers at the nearby markets (Table 3.1.11).

The reasons for inadequate access to fertilizers are mostly supply shortages at country or regional level, which are determined by the price and availability in the international markets. Delayed supply and uneven distribution within the country and region may also create problems with the accessibility of the fertilizers. Most farmers purchased fertilizers from local traders at the highest price to solve the accessibility problem (Table 3.1.11). Similarly, Spielman *et al.* (2013) reported that Ethiopia's cooperative-based input distribution system is inefficient and slow, which forces farmers to look for alternatives in informal marketplaces, which are usually significantly more expensive. Some farmers applied the quantity of fertilizers they got from cooperatives and additionally used organic fertilizers like compost to compensate for the deficient amount of inorganic fertilizers. Others used the fertilizers they saved from the previous cropping season and/or purchased them in advance before the onion growing season began.

Credit provision enhances the financial capacity of onion producers, enabling them to purchase the required production inputs such as improved varieties of seed, chemical fertilizers, pesticides, insecticides, fuel, etc. As a result, access to credit in the study area was not well practiced, and hence, the study areas purchased all farm inputs in cash. Access to credit serves as a catalyst for agricultural development by easing cash flow constraints and enabling farmers to invest in high-quality inputs (Khandker and Koolwal, 2016).

Table 3.1.11. Fertilizer and pesticide access in the study area

| Questioners                                         | Frequency<br>(N=197) |     |            |
|-----------------------------------------------------|----------------------|-----|------------|
|                                                     |                      |     | Percentage |
| Access for fertilizer in terms of time and adequacy | Yes                  | 2   | 1.0        |
|                                                     | No                   | 192 | 97.5       |
| Sources of fertilizer                               | Cooperatives         | 12  | 6.1        |

|                                                                     |                                                            |     |      |
|---------------------------------------------------------------------|------------------------------------------------------------|-----|------|
|                                                                     | Local market and Cooperatives                              | 185 | 93.9 |
| Source of pesticide                                                 | Local market                                               | 197 | 100  |
| Reasons for inadequate access                                       | Supply shortage, high-cost Urea                            | 197 | 100  |
| Measures taken by farmers to solve the accessibility of fertilizers | Addressing the amount, we get and using organic fertilizer | 30  | 15.1 |
|                                                                     | Purchasing at high prices from merchants                   | 179 | 90.5 |
|                                                                     | Early purchasing and storage                               | 31  | 15.7 |
|                                                                     | Purchasing form local market and use of organic fertilizer | 9   | 4.6  |
|                                                                     | Use of organic fertilizers alone                           | 14  | 7.1  |

#### **3.1.4.8. Fertilizer and pesticide application rate**

High and better yields can only be achieved with the application of optimum rates of fertilizers and the proper use of pesticides. An optimum nitrogen rate also increases the total yield and average bulb size and reduces the bolting percentage (Aklilu Nigussie *et al.*, 2015). In the study area, all respondents applied chemical fertilizer/synthetic fertilizers (NPS or NPSB and Urea) and organic fertilizers such as compost and animal manure for onion production. The quantity of fertilizers and chemicals applied varied among respondents. Most respondents (77.7%) used a combination of NPS or NPSB and Urea fertilizers for onion production, while 14.2% used only NPS or NPSB, and 7.1% applied a mixture of Urea, NPS or NPSB, and organic fertilizers (Table 3.1.12).

In the study area, NPS/B is the primary source of nutrients for onion production. However, most respondents (193 or 98%) applied it improper amount. They also noted that soil fertility decreases annually, requiring increasing fertilizer. Without applying higher rates of fertilizer, they do not expect to achieve better yields. Farmers in the study area used Urea and NPS/NPSB at the ranges of 25-350 kg ha<sup>-1</sup> and 25-500 kg ha<sup>-1</sup>, respectively, for the production of onion with the mean values of 105 kg ha<sup>-1</sup> and 143 kg ha<sup>-1</sup> in the same

order (Figure 3.1.4b). Accordingly, farmers in the study area applied about 5.04% more Urea, and only 72.5% of the national blanket recommended NPS/NPSB fertilizer rates, which would be 100 kg ha<sup>-1</sup> Urea and 200 kg ha<sup>-1</sup> NPSB.

Figure 3.1.4a illustrates the variation in organic fertilizer application rates (in quintals per hectare) used by respondents. The most frequent application rate is 20 quintals per hectare, while some respondents apply between 10 and 50 quintals per hectare. This indicates that onion farmers use a moderate range of organic fertilizers.

The primary reasons for applying slightly more Urea but less NPS or NPSB and agrochemicals than the recommended rates are declining soil fertility, limited awareness among farmers, and reduced effectiveness of agro-chemicals. Farmers emphasized that declining soil fertility has led to increase reliance on Urea to maintain yields, while limited accessibility to fertilizers has resulted in the underutilization of NPS or NPSB.

The results indicate that the majority of respondents (71.06%) identified low productivity/yield as the main limitation of the recommended fertilizer rate. This is followed by issues related to fertilizer availability despite supply problems (27.9%). A smaller proportion of farmers expressed concerns regarding reduced chemical effectiveness (5.58%), frequent changes in pesticide types (4.56%) and limited access to pesticides (2.53%). These findings suggest that while fertilizer availability and supply inconsistencies are notable, the major concern remains farmers' inability to achieve optimal yields.

Table 3.1.12. Type of fertilizers used by respondents in the study area

| Questioners             |                      | Frequency<br>(N=197) | Percentage |
|-------------------------|----------------------|----------------------|------------|
| Use of fertilizer       | Yes                  | 197                  | 100.0      |
| Type of fertilizer used | NPS or NPSB          | 28                   | 14.2       |
|                         | NPS or NPSB and Urea | 153                  | 77.7       |
|                         | NPS or NPSB, Urea    | 14                   | 7.1        |
|                         | Organic              |                      |            |

|                                                                |                            |     |      |
|----------------------------------------------------------------|----------------------------|-----|------|
| Proper application of recommended fertilizer and chemical rate | NPS and organic fertilizer | 2   | 1.0  |
|                                                                | Yes                        | 4   | 2.0  |
|                                                                | No (higher and lower)      | 193 | 98.0 |

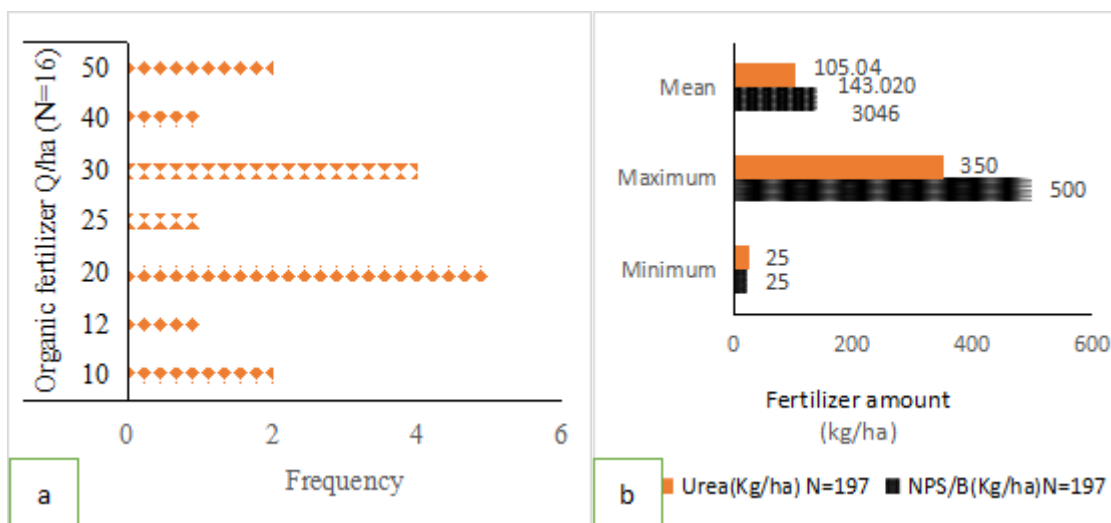


Figure 3.1.4. Rates of organic (a) and inorganic (b) Fertilizers applied by onion growing farmers

#### 3.1.4.9. Major constraints of onion production

The current survey result indicated that the average yield of onion in the study area was 16 t ha<sup>-1</sup>, which is better than the average onion yield in Amhara National Regional State (11.67 t ha<sup>-1</sup>) as reported by CSA (2017). Despite the relatively better yield in the study area, onion productivity is below the world average of 21.1 t ha<sup>-1</sup> (FAO, 2022). Data from the Central Statistical Authority indicate that the land area allocated for the production of onion in Ethiopia has shown an increasing trend from 1995 EC/2001 to 2015 EC/2021, while productivity has decreased over the same period (Figure 3.1.5). In this regard, onion growers identified several production challenges, including of the lack of better storable onion varieties leading to high postharvest losses, as well as the shortage and high cost of fertilizers and other agricultural inputs. Additionally, inadequate infrastructure, including roads and storage facilities further hampers production (Figure 3.1.6). The rising costs of key farm inputs, like fertilizer, pesticides and fuel, have had a negative influence on both onion production and market supply .

The results of the present study are in line with the findings of Kassa Getu and Ahmed Ibrahim (2018) who indicated that high cost of inputs, and weak market linkage are the major constraints that hinder onion productivity. The results are also in agreement with the study conducted by Almaz Giziaw (2014) who reported that the onion and tomato value chain is complicatedly associated with lack of production and marketing skills.

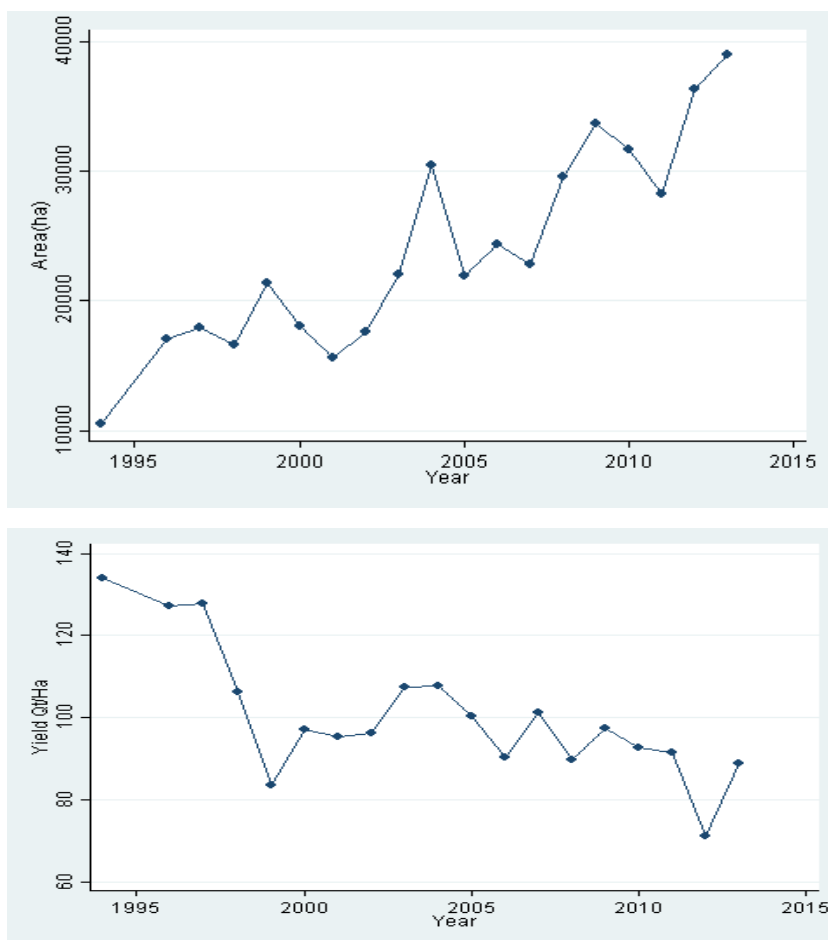


Figure 3.1.5. Onion production trend in Ethiopia (1995EC/2001 to 2015EC/2021)

Source; CSA (2020)

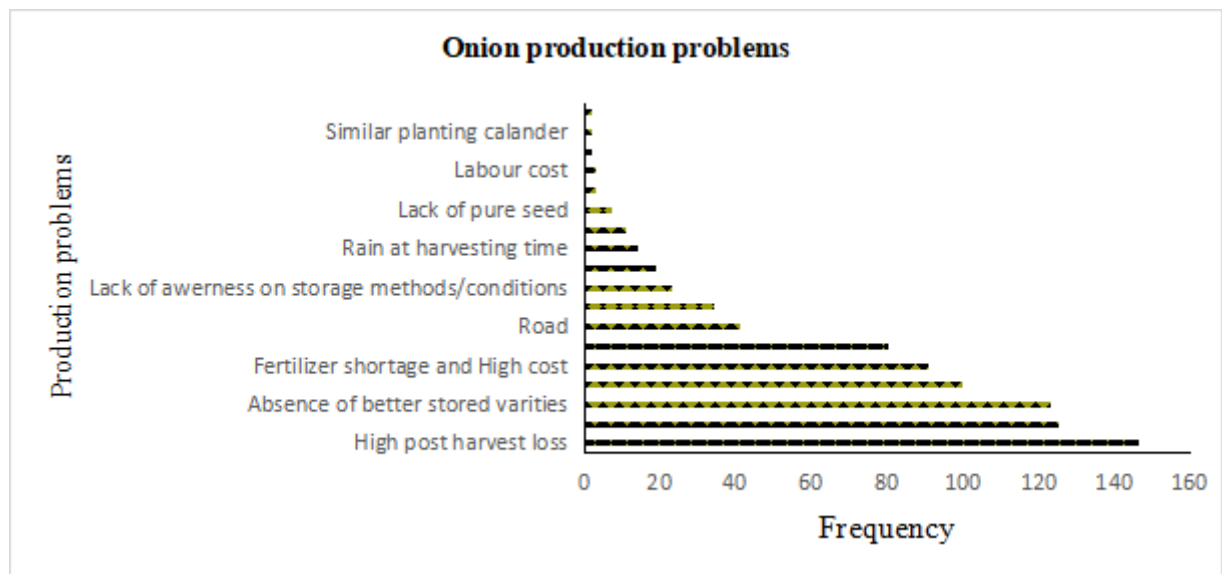


Figure 3.1.6. Major onion production constraints in the study area

#### 3.1.4.10. Disease and insect pests

In the study areas, disease and insect pest infestation were very high. Powdery mildew (*Leveillula taurica*), Downy mildew (*Peronospora destructor*) (Mech) and Black fungus and Thrips (*Thrips tabaci*) were the major diseases and insect pest of onion identified by the farmers and district extension officers. These findings are consistent with previous studies that have reported similar pest and disease pressures in onion-growing regions of Ethiopia and elsewhere. Mekonnen *et al.* (2021) documented that Downy mildew and Thrips are among the most damaging pathogens and pests in onion production, particularly in areas with poor pest management practices. Farmers used different kinds of chemicals for the management of onion pests including Omaxis as preventive chemical for disease, the fungicide Redomil Gold for the control of powdery mildew, Ajanta (Deltamethrin) and Prostar 70 WP for the management of Thrips. During chemical application, the farmers were not wearing protective clothing (Table 3.1.13). This practice poses serious health risks, as exposure to pesticides without proper protection can lead to short-term or long-lasting health problems.

Table 3.1.13. Major diseases in the study area

| Questioners        |                                                                  | Frequency<br>(N=197) | %     |
|--------------------|------------------------------------------------------------------|----------------------|-------|
| Major diseases     | Downy mildew ( <i>Peronospora destructor</i> ) Mech (local name) | 44                   | 22.3  |
|                    | Powdery Mildew ( <i>Leveillula taurica</i> )                     | 151                  | 76.6  |
|                    | Black fungus (Mold)                                              | 30                   | 15.2  |
| Major insect pests | Thrips ( <i>Thrips tabaci</i> )                                  | 197                  | 100.0 |

#### 3.1.4.11. Market price

Farmers primarily grow onion for market supply to get cash, with only a small portion reserved for household consumption. Yet, the perishable nature of the crop introduces a level of vulnerability to price fluctuations that occur from season to season and year to year. The present findings highlight this volatility: during peak harvest periods, the minimum lagged price dropped as low as one Birr per kilogram, whereas, in the off-season, it rose significantly to 13 Birr per kilogram. The big difference in onion prices between seasons raises important questions about how the market functions and whether farmers can benefit from higher prices. Although off-season prices increase sharply, most farmers fail to take advantage of the opportunity because they lack proper storage facilities and storable onion varieties (Table 3.1.14). As a result, they miss out on potential income. Almaz Giziew *et al.* (2014) also observed similar challenges, noting that frequent price changes and unfair market practices often put onion farmers at a disadvantage. These findings emphasize the need for farmers to improve storage and postharvest handling to secure better prices and achieve more stable incomes.

Table 3.1.14. Prices of onion bulb in nearby markets of the study area

| Indicators                                                                      | Producer N=(197)  |         |               |
|---------------------------------------------------------------------------------|-------------------|---------|---------------|
|                                                                                 | Minimum           | Maximum | Mean _ SD     |
| The market price of onion at its pick harvesting season in 2020 Birr/quintal    | 0.1               | 7       | 1.9±1.009     |
| The market price of onions per kilogram during the off-season (summer) in 2020. | 13                | 32      | 21.62±5.59574 |
|                                                                                 | Frequency (N=197) |         | %             |

|                                                   |            |     |      |
|---------------------------------------------------|------------|-----|------|
| Trend of onion price                              | Increasing | 197 | 100  |
| Benefit of farmers from the increased onion price | Yes        | 4   | 2.0  |
|                                                   | No         | 193 | 98.0 |

#### **3.1.4.12. Role of Brokers in marketing of onions**

In the study area, middlemen (brokers) facilitate the marketing process and provide information in the chain, mainly between farmers and wholesalers. The brokers also check the quality of the onion bulbs and supervise the onion harvesting process. They are a major actor in determining onion prices between the farmers and wholesalers. According to the respondents, the brokers, in most cases, determined the price in favour of the wholesaler and underestimated the selling price of onion. Due to the perishable nature of the crop, brokers put pressure on producers to sell their onions at low prices. Gebremedhin and Jaleta (2010) also found that because produce spoils quickly, farmers are often forced to sell it fast, even at low prices, leading to losses. In some cases, they created problems in the payment of the money when they took the onions on a credit basis. According to the information of the respondents, farmers did not store onion for a long period of time (Table 3.1.15). Brokers play a key role in agricultural marketing by linking farmers to buyers, facilitating price negotiations and managing logistics such as transportation and distribution. They reduce market uncertainties by providing market information and sometimes offering credit to farmers. However, brokers may exploit farmers through unfair pricing, high commissions and price manipulation, which limit farmers' bargaining power. According to Poulton *et al.* (2010), this challenge is common among farmers in many African countries, who often have limited choices for selling their crops/produces and significantly less access to market information than buyers.

Table 3.1.15. The role of brokers/ middle man in onion marketing and prices

| Questioners                  |                   | Frequency (N=197) | %    |
|------------------------------|-------------------|-------------------|------|
| Availability of brokers      | Yes               | 197               | 100  |
| Who decide the selling price | Yourself          | 1                 | 0.5  |
|                              | Brokers           | 179               | 90.9 |
|                              | Market demand and | 9                 | 4.6  |

|                                                         |                                                                                |     |       |
|---------------------------------------------------------|--------------------------------------------------------------------------------|-----|-------|
|                                                         | supply                                                                         |     |       |
| Involvement of brokers with regard to selling price     | By negotiation                                                                 | 8   | 4.1   |
|                                                         | Negotiating the market                                                         | 32  |       |
|                                                         | Contacting sellers and buyers                                                  | 2   |       |
|                                                         | Underestimation of the price                                                   | 180 |       |
|                                                         | Provision of credit                                                            | 17  |       |
|                                                         | Disrupt the link b/n farmers and merchant                                      | 15  |       |
| Problems created by brokers with regard to onion market | Took to limited client, incorrect weighing of product, wrong price information | 197 | 100.0 |

### ***3.1.4.13. Harvesting and postharvest handling practices in the onion supply chains***

#### ***Postharvest handling practices at farm level***

##### *Harvesting*

The stage of onion maturity is one of the most important factors determining crop quality and storability/shelf life. Harvesting immature onion bulbs can lead to bruising, hastened sprouting time, and the highest weight loss. Wilcox et al. (2001) found that onions harvested before reaching full maturity are more susceptible to physical damage and disease, which can affect their quality and storage life. Onions are usually harvested when the neck of onion bulbs falls down to the ground. Manual harvesting is the most common practice in the study area. The majority of onion producers, 120 (60.9%), responded that onion harvesting is done based on bulb maturity when the leaf's color changed from deep green to light green or yellowish. This is consistent with findings from Dossa et al. (2017), who showed that many farmers rely on simple, observable maturity signs to determine optimal harvest time. However, manual harvesting, as the study points out, often leads to bulb damage, which can increase spoilage rates and reduce overall market quality (Wang et al., 2015). In the study area, almost all onion producers harvested their produce at any time of the day by digging with human power using a hoe (*Mekoferia/gesso*, *Mekotkocha*), which damaged bulbs during digging and hastens the spoilage rate of bulbs.

Onion bulbs are susceptible to high storage losses as they contain a high amount of water. Once harvested, their internally stored food and water decline over time. As a result, bulbs are subject to sprouting, rotting, and shrinkage losses during storage. Curing techniques help to improve the shelf life (storage quality) of onion, increasing the return from onion production and stabilizing the market situation. In the present study, most farmers follow traditional rather than standardized curing methods. After harvesting, the bulbs are typically left in the field for several days, often in a shaded, well-ventilated area, to dry and allow the outer layers of the onion skins to become papery and the necks of the bulbs to tighten. However, in the study area only 7% of the respondents cured the harvested onion bulbs for five days in the production field, while the remaining respondents did not practice curing (Table 3.1.16).

Different types of maturity indices were used by the farmers to determine the maturity stage of onion in the study area. Leaf drying, leaf color change, neck failure, days after transplanting (90–120), market demand, bolting, the high pungency of leaves during leaf cutting, and crack of the soil around the bulb are some of the indices used by farmers (Figure 3.1.7). Farmers in the study area use some scientifically valid maturity indicators, such as leaf color change and neck failure, to determine onion readiness for harvest. However, their manual harvesting methods often damage the bulbs, which eventually lead to spoilage. The inappropriate implementation of curing reflects a gap in awareness about its importance for improving storage quality. Educating farmers on proper postharvest handling, including curing, could improve onion quality and market stability.

Table 3.1.16. Harvesting practices of onion in the study area

| Questioners                                      |                           | Frequency (N=197) | %     |
|--------------------------------------------------|---------------------------|-------------------|-------|
| Criterion for determining the date of harvesting | Maturity                  | 120               | 60.9  |
|                                                  | Market price              | 8                 | 4.1   |
|                                                  | Maturity and market price | 69                | 35.0  |
| Harvesting time                                  | Anytime/the whole day     | 197               | 100.0 |
| Method of harvesting                             | Pulling by hand           | 9                 | 4.6   |

|                     |                              |     |      |
|---------------------|------------------------------|-----|------|
| Time of top removal | Digging by hoe/ <i>gesso</i> | 176 | 89.3 |
|                     | Digging and hand pulling     | 12  | 6.1  |
|                     | 5 days after harvesting      | 7   | 3.6  |
|                     | At the point of sell         | 66  | 33.5 |
|                     | Immediately after harvest    | 124 | 62.9 |

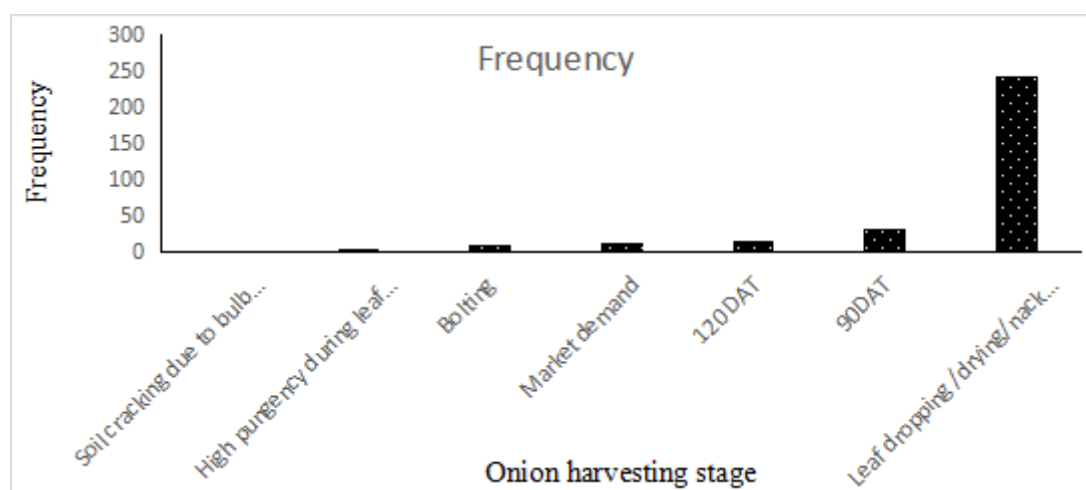


Figure 3.1.7. Methods used for harvesting stage determination of onion practiced by farmers

Various cultural practices were applied before harvesting, including toppling, irrigating fields a few days prior to harvest, stopping irrigation, and reducing irrigation frequencies (Figure 3.1.8). Toppling was used to enhance bulb quality and filling and increase bulb weight by translocating food from the leaf part to the bulb and stopping further vegetative growth. Farmers demonstrate a practical understanding of how irrigation affects onion quality, recognizing that pre-harvest irrigation improves bulb weight, color, and yield. They also understand that reducing or stopping irrigation helps prevent rotting, sprouting and strengthens bulb skin. These practices reflect a solid grasp of water management for better onion production. However, there may be room for improvement in optimizing the timing and application of these techniques. Further education could enhance their knowledge and overall productivity.



Figure 3.1.8. Cultural practices applied by farmers before onion harvesting

### ***Transportation***

According to the survey, the open truck was mostly used by wholesalers, local collectors and retailers for the transportation of onion. On the other hand, farmers used animal-driven carts and human labour to deliver onion to the market. All onion producers in the study area faced significant market challenges, as highlighted in Table 3.1.17. These issues included price fluctuations, lack of organized markets, and limited bargaining power due to dependence on middlemen. The absence of proper storage facilities exacerbated the problem, forcing farmers to sell immediately after harvest at low prices. Moreover, poor market information hindered their ability to make informed decisions about when and where to sell, resulting in reduced profitability. These challenges emphasize the need for improved marketing strategies, such as cooperative marketing, better storage solutions, and access to reliable market data, to enhance producers' incomes and market stability. Aemro Worku and Ali Ulku (2022) reported similar practices as the primary mode of transportation to deliver the harvested onions to the nearest market place where animal-driven carts (62.8%) followed by trucks (19.7%) and labor (17.5%) were the major once. According to the observations made during the survey, road access in the study area is poor and not suitable, which causes bruising and mechanical damage through vibration leading to high of postharvest losses of onion bulbs. In this regard, Idah *et al.* (2007)

reported that vibration due to roughness of roads is one of the major causes of postharvest losses of fruits and vegetables.

Table 3.1.17. Challenges in onion marketing and storage practices

| Questioners                                            |                                  | Frequency | %     |
|--------------------------------------------------------|----------------------------------|-----------|-------|
| Type of transport used                                 | Animal driven cart               | 59        |       |
|                                                        | Human labor                      | 24        |       |
|                                                        | Open Truck                       | 127       |       |
| Presence of market problems with regard to onion price | Yes                              | 197       | 100.0 |
| Storing onion bulbs for late selling                   | Yes                              | 35        | 17.8  |
|                                                        | No                               | 162       | 82.2  |
| Storage duration (N =35)                               | 5 days                           | 7         | 3.6   |
|                                                        | 6 days                           | 12        | 6.1   |
|                                                        | 1 week                           | 10        | 5     |
|                                                        | 2 weeks                          | 3         | 1.5   |
|                                                        | 2 months by renting storage room | 2         | 1     |

### ***Marketing and storage problem of onion at farm level***

The production of onion in the study area during the irrigation season leads to over-saturation of the market and reduction of the prices in the production season. On the other hand, only 17.8% respondents were able to store the onion bulbs for five days to two months for late selling at a better price. Most of the farmers (82.2%) prefer to sell their produce immediately after harvest, with the current market prices, which are of mostly unsatisfactory and low. These situations significantly reduce the income of the farmers and their motivation towards the production of onion in the next production season. The possible reasons for not storing onion by farmers could be poor storability of onion varieties, lack of affordable storage technologies and high postharvest losses due to inappropriate curing and handling practices. Emana Bezabih (2017) reported that over 30% of postharvest losses of vegetables in Ethiopia were attributed mainly to inadequate handling practices, inefficient marketing systems, insufficient storage facilities and substandard transportation infrastructure.

### ***Postharvest handling practices and losses***

Inadequate postharvest management of onions in the study area led to significant losses. Poor agronomic practices, improper sorting, packaging, transportation and lack of storage facilities contributed to mechanical damage, sprouting and rotting. During the 2020 cropping season, unsuitable bulbs accounted for 2–100% of harvested produce, particularly when harvesting was delayed due to low market prices (Figure 3.1.9). Sukhvinder *et al.* (2020) reported that the longer onions are left in the field (delayed harvesting), the higher the chances of damage from weather conditions, pests, and disease, reducing both the shelf life and marketability of the bulbs. Onions were packed in poorly ventilated burlap sacks, exposed to harsh sunlight and overloaded during transport, increasing damage and losses (Table 3.1.18). This finding is consistent with Sharma *et al.* (2018), who found that postharvest losses in vegetables like onions are critical in many developing regions, particularly where storage and handling practices are suboptimal.

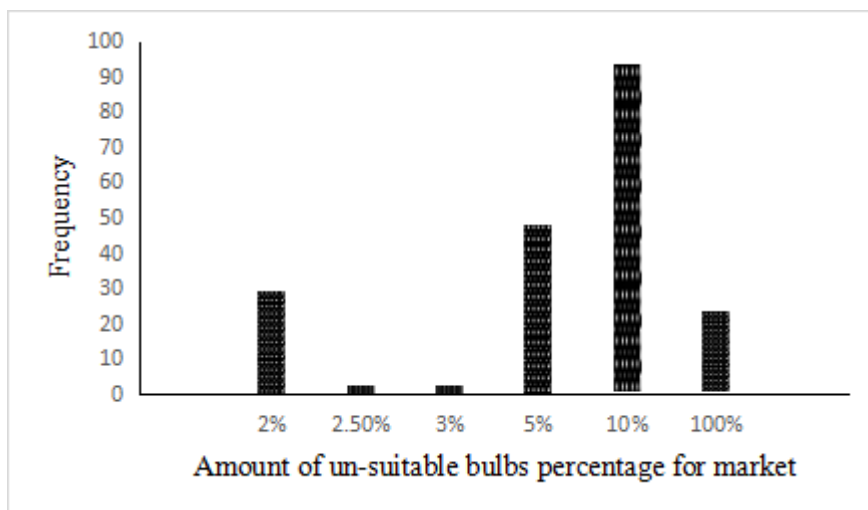


Figure 3.1.9. Percentage of onion bulbs deemed unsuitable for market due to postharvest losses

Table 3.1.18. Postharvest handling practice of onion at farm level

| Questions                      | Response | Frequency(N=197) | %     |
|--------------------------------|----------|------------------|-------|
| Is there any postharvest loss? | Yes      | 197              | 100.0 |

|                                                                   |                                                                 |     |       |
|-------------------------------------------------------------------|-----------------------------------------------------------------|-----|-------|
| What type of container do you use for marketing onions?           | Burlap sack (100 kg)                                            | 197 | 100.0 |
| What storage method or material do you use at home?               | Jute/burlap bag                                                 | 87  | 44.2  |
|                                                                   | Spread on ground                                                | 88  | 44.7  |
|                                                                   | Shelf                                                           | 10  | 5.1   |
|                                                                   | Field                                                           | 11  | 6.1   |
| Who are your main customers for selling onions?                   | Cooperatives                                                    | 6   | 3.0   |
|                                                                   | Wholesalers                                                     | 177 | 94.3  |
|                                                                   | Local collectors                                                | 11  | 5.6   |
|                                                                   | Retailers                                                       | 3   | 1.5   |
|                                                                   | Consumers                                                       | 2   | 1.0   |
|                                                                   | Better price                                                    | 2   | 1.0   |
| Why do you prefer selling to these buyers?                        | Large volume of purchase                                        | 166 | 84.3  |
|                                                                   | No option                                                       | 29  | 14.7  |
| Are marketing cooperatives available to collect harvested onions? | Yes                                                             | 62  | 31.5  |
|                                                                   | No                                                              | 135 | 68.5  |
| Are you interested in selling your onions through cooperatives?   | Yes                                                             | 188 | 95.4  |
|                                                                   | No                                                              | 9   | 4.6   |
| Do you think onion farming is profitable?                         | Yes, except market problem and poor storage period of varieties | 197 | 100   |
| How do you get information about buyers/transporters?             | Through brokers                                                 | 197 | 100.0 |

#### *Selling experience and marketing practices of wholesaler and retailer of onion*

Producers and local collectors were the sole suppliers of onions to the wholesalers, while retailers bought the onion bulbs from wholesalers and producers. Both wholesalers (73.3%) and retailers (100%) received sample onion bulbs before the buying contract. However, the buyers observed often quality differences between the sampled and delivered onion bulbs (Table 3.1.19). Furthermore, all the wholesalers and retailers reported experiencing losses during the selling and storing of onions, including spoilage, shrinkage, and physical damage to the bulbs. On average, 4.5% of onion bulbs at wholesalers and 13.93% at retailers are deemed unsuitable for sale (Table 3.1.20; Appendix Figure 3.1.3. and Appendix Figure 3.1.4).

The widespread use of burlap sacks as primary packaging materials is attributed to their affordability and accessibility (Table 3.1.21). However, these sacks lack adequate ventilation, leading to issues like sprouting and rotting of onion bulbs. Kader and Rolle (2004) highlighted that sack containers for fruits and vegetables can trap heat generated by metabolic reactions, accelerating mechanical damage and increasing susceptibility to microbial attacks.

Table 3.1.19. Onion handling information of wholesalers and retailers

| Questioners                                            |                                | Wholesalers(N=15) |       | Retailers(N=30) |       |
|--------------------------------------------------------|--------------------------------|-------------------|-------|-----------------|-------|
|                                                        |                                | Frequency         | %     | Frequency       | %     |
| Sources of onion bulbs                                 | Producers and local collectors | 15                | 100   |                 |       |
|                                                        | Wholesalers                    |                   |       | 15              | 50    |
|                                                        | Wholesalers + producers        |                   |       | 15              | 50    |
| Presence of quality problem                            | Yes                            | 15                | 100.0 | 30              | 100.0 |
| Type of problems/issues                                | Damaged                        | 4                 | 39.9  | 19              | 63.3  |
|                                                        | Size (under sized)             | 4                 | 26.7  | 19              | 63.3  |
|                                                        | Disease                        | 4                 | 26.6  | 10              | 33.3  |
|                                                        | Sprouting                      | 4                 | 26.7  | 9               | 30    |
|                                                        | Decay                          | 3                 | 20    | 28              | 93.3  |
|                                                        | Immature bulbs                 | 6                 | 40    | 7               | 23.3  |
|                                                        | Shriveling                     |                   |       | 2               | 6.7   |
| Evaluation of samples of the onions before buying them | Yes                            | 11                | 73.3  | 30              | 100   |
|                                                        | No                             | 4                 | 26.7  |                 |       |

Table 3.1.20. Percentage of bulbs unfit for sale at wholesaler and retailer levels

|               | Minimum | Maximum | Mean  | Standard deviation |
|---------------|---------|---------|-------|--------------------|
| Whole sellers | 2%      | 7%      | 4.5   | 1.43               |
| Retailers     | 5%      | 25%     | 13.93 | 7.65               |

Table 3.1.21. Marketing and storage practices of onion wholesalers and retailers

| Questioners                                                   |     | Wholesalers(N=15) |       | Retailers(N=30) |       |
|---------------------------------------------------------------|-----|-------------------|-------|-----------------|-------|
|                                                               |     | Freq              | %     | Freq            | %     |
| Do you sell all the bought onions                             | No  | 15                | 100.0 | 30              | 100   |
| Are there any storage possibilities for onions at the market? | Yes | 15                | 100.0 | 30              | 100.0 |
| How many days are required to                                 | 4   |                   |       | 6               | 20.0  |

|                                                                               |                          |    |       |    |      |
|-------------------------------------------------------------------------------|--------------------------|----|-------|----|------|
| finish selling of your onion bulbs? _____ days                                | 5                        | 2  | 13.3  | 12 | 40.0 |
|                                                                               | 6                        | 3  | 20.0  | 7  | 23.3 |
|                                                                               | 7                        | 7  | 46.7  | 4  | 13.3 |
|                                                                               | 8                        | 3  | 20.0  | 1  | 3.3  |
| What do you do with unmarketable onions?                                      | Throwing                 | 15 | 100.0 | 30 | 100  |
| What do you do to reduce postharvest losses?                                  | Sorting, ventilation     | 15 | 100   | 25 | 83.3 |
|                                                                               | Spreading during night   |    |       | 2  | 6.7  |
|                                                                               | Nothing                  |    |       | 3  | 10.0 |
| How often do you purchase new onions from suppliers? _____ days.              | 4 days                   |    |       | 1  | 3.3  |
|                                                                               | 5 days                   |    |       | 3  | 10.0 |
|                                                                               | 6 days                   |    |       | 18 | 60.0 |
|                                                                               | Every week               | 3  | 20    | 8  | 26.7 |
|                                                                               | Depends on market demand | 11 | 73.3  |    |      |
|                                                                               | Up on finishing          | 1  | 6.7   |    |      |
| How do you store onions?                                                      | Using Jute bag           | 6  | 40.0  | 30 | 100  |
|                                                                               | Heaping on the floor     | 6  | 40.0  |    |      |
|                                                                               | Using wooden box         | 3  | 20.0  |    |      |
| What type of packaging material do you use to transport onions to the market? | Jute/Burlap sack         | 15 | 100.0 | 30 | 100  |

Where, Freq = frequency

### ***Causes of postharvest loss and strategies for minimizing losses at wholesaler and retailer chain***

At the retailer level, all respondents indicated that there is postharvest loss. The major causes for loss are bruising, sprouting, damage during harvesting and transport, decay, disease, mechanical damage, damage during harvesting, transportation, perishability nature, rotting, mechanical damage and shrivelling (Figure 3.1.10). Ademe *et al.* (2020) also found that in Ethiopia, more than 30% of onions are lost after harvest due to these poor practices and weak infrastructure. Market problems are associated with delayed sales, improper sorting practices, rotting due to inadequate drying, pest infestations, and lack of awareness of proper postharvest practices. Gebrehiwot *et al.* (2023) highlight that the lack

of cold storage, coordinated market scheduling, and adequate transport infrastructure are key factors driving onion losses in Ethiopia's value chain. Addressing these challenges requires improved infrastructure, such as ventilated and moisture-controlled storage facilities, training on handling and sorting techniques, and better market access. Scheduling harvests during dry periods and reducing dependency on brokers can also mitigate losses. Coordinated efforts across the value chain are essential to reduce these losses and ensure sustainable production.

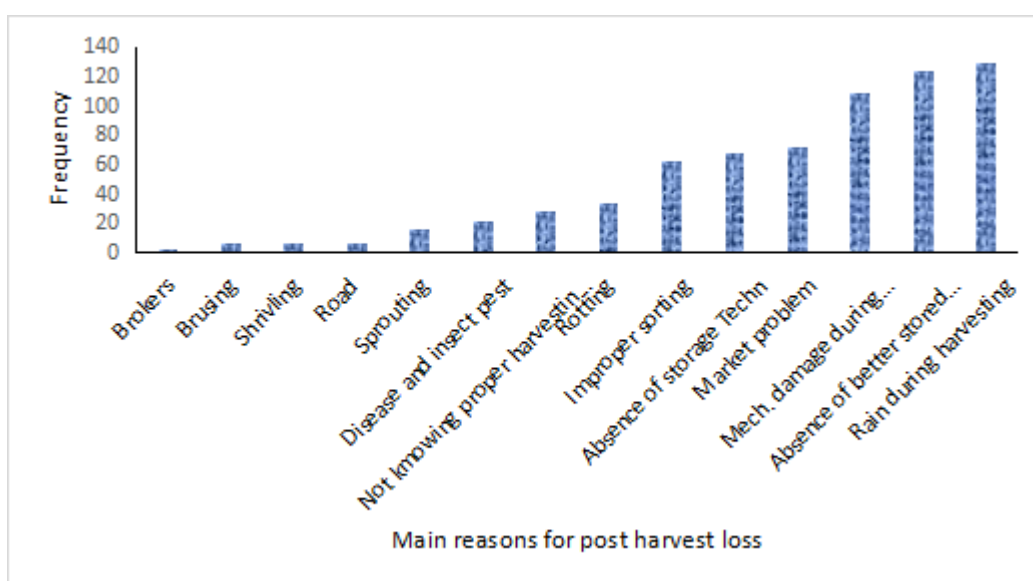


Figure 3.1.10. Main reasons for the postharvest loss of onion

To minimize losses, farmers adopted strategies such as immediate sales, delaying top removal, adjusting planting times, adjusting planting time and constructing storage rooms (Figure 3.1.11). Despite these efforts, 100% of respondents used burlap sacks for marketing. For home storage, 44.7% of respondents spread bulbs on the ground, 44.2% used jute sacks, and 6.1% and 5.1% utilized on-field and shelf storage, respectively (Table 3.1.18).

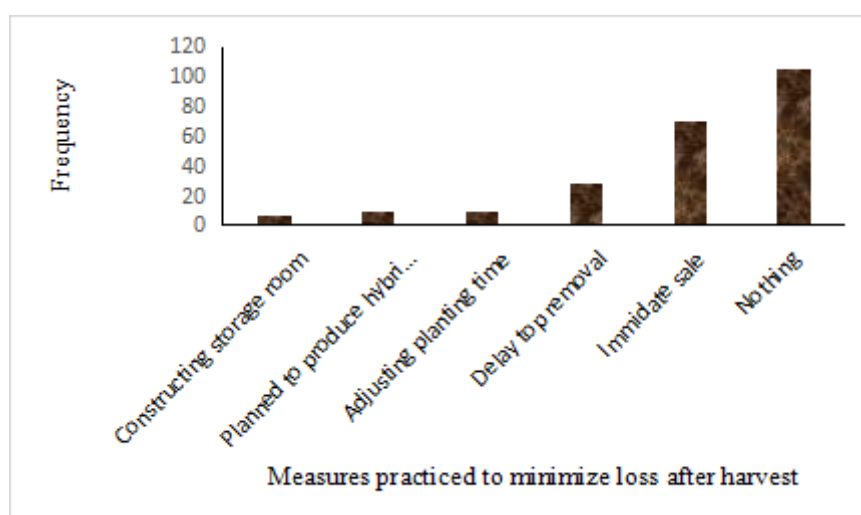
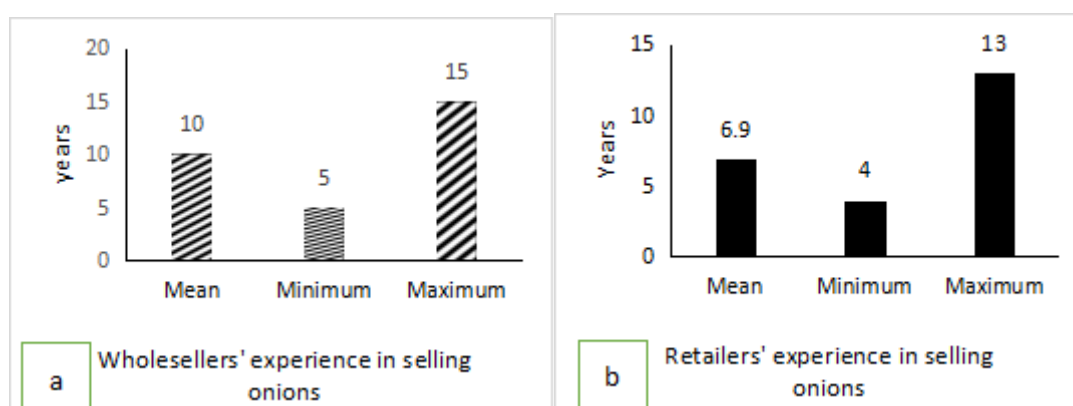


Figure 3.1.11. Measures practiced by farmers in minimizing loss after harvest

The survey results indicated that wholesaler and retailer respondents had 5 to 15 and 4 to 13 years of experience in buying and selling of onions, respectively (Figures 3.1.12a and b). Despite their extensive experience, survey observations revealed that wholesalers and retailers lack adequate knowledge of postharvest handling practices.



Figure

e 3.1.12. Experience in selling at the wholesaler (a) and at the retailers (b)

### ***Quantity of onions purchased and duration of storage***

The survey results indicated that wholesalers bought 10-70.2 quintals of onion at a time while retailers had 0.25-1.0 quintals. This pattern reflects broader trends observed in developing countries, where wholesalers often dominate the bulk market, while retailers handle distribution in smaller, local markets (Gebrehiwot *et al.*, 2023). Traders stored the onion bulbs by spreading or heaping them on the ground floor and using wooden boxes

(Figures 3.1.13a, b and c). The traders also indicate that the demand for onion is year-round. Still, they faced onion supply shortage from May to October because there was no practice of storing bulbs for late selling and no production during these months. During these seasons, the price of onion increases more than 3-fold compared with pick harvesting seasons in the months of February and March. The price falls during the pick harvesting season because of the large supply over the demand, as all farmers plant at similar planting times. These findings are supported by Hailu et al. (2021), who noted that seasonal production and lack of cold storage systems result in a sharp supply-demand mismatch, creating volatility in onion prices.

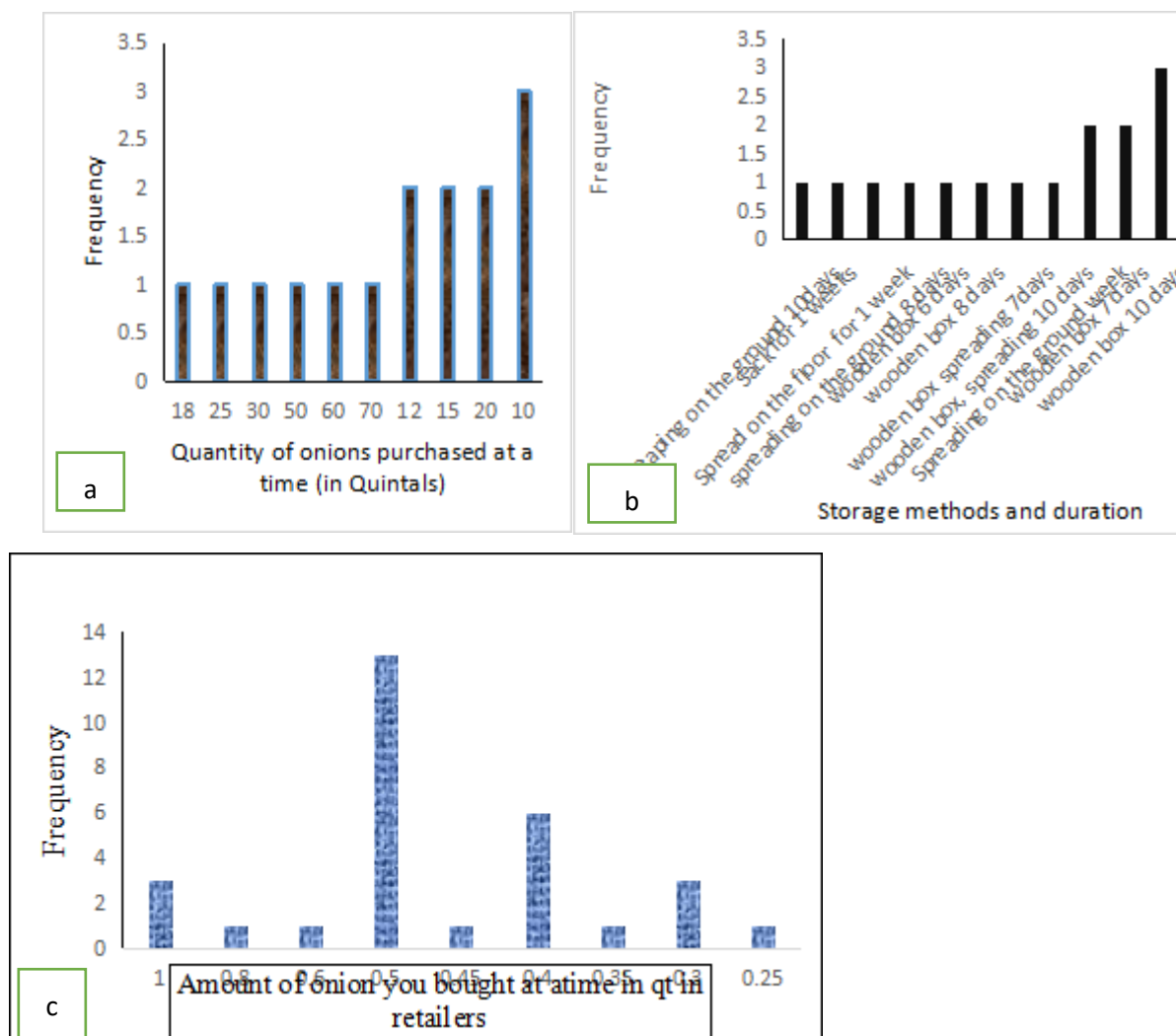


Figure 3.1.13. Amount of onion (qt) bought by retailers (a) and method of storage at wholesaler level (b) and quantity of onions purchased at a time by retailers (c)  
Where, qt=quintal.

### ***Mode of transportation of onions at wholesaler and retailer levels***

In this study, the onion traders used different modes of transportation, from farm to marketing chain. Most onion wholesalers (86.7%) transport their produce from the farm to the local markets by using an open FSR truck. While 13.3% of wholesalers used open ISUZU trucks. The difference transportation methods relates their loading capacity; FSR trucks can carry 50-80 quintals of fresh onions, while ISUZU trucks hold 40-60 quintals. Among retailers, 36.7% transported onions by using vehicle-driven goods carrier (*careta*), 30% used *hand carts*, 23.3% relied on *animal-driven carts*, and 13.3% used motorcycles. Rehman *et al.* (2007) explained the need for careful handling during transportation to prevent mechanical injury and deterioration of the produce. For wholesalers, postharvest losses occur during loading due to bruising, crushing, mechanical damage, and heat buildup in the bulbs. Retailers did not record any loss of bulbs during transportation because of short transport distance and small volume of produce (Table 3.1.23). In addition, retailers were frequently ventilated during storage, sorted them, discarded the rotten bulbs, and sold them at relatively discounted prices. About 80% of wholesalers indicated they have no contact with farmers; instead they contact brokers. Indeed, the remaining 20% of wholesalers have direct contact with farmers. The wholesalers do not have any information about the onion varieties they bought. They also got information about transportation trucks through brokers (Table 3.1.24).

Table 3.1.22. Methods of transportation at wholesalers and retailers chain

| Questioners                                                      | Options          | Wholesalers(N=15) |        | Retailers(N=30) |      |
|------------------------------------------------------------------|------------------|-------------------|--------|-----------------|------|
|                                                                  |                  | Freq(N=197)       | %      | Freq(N=197)     | %    |
| What type of transportation you are using?                       | Open FSR truck   | 13                | 86.7   |                 |      |
|                                                                  | Open Isuzu truck | 2                 | 13.3   |                 |      |
|                                                                  | Animal driven    |                   |        | 7               | 23.3 |
|                                                                  | Gari             |                   |        |                 |      |
|                                                                  | <i>Hand Gari</i> |                   |        | 8               | 30   |
|                                                                  | <i>Careta</i>    |                   |        | 11              | 36.7 |
| At what time you transport onion from the farm to your location? | Motor            |                   |        | 4               | 13.3 |
|                                                                  | Any time         | 15                | 100.00 | 30              | 100  |

|                                                      |                                   |    |        |    |     |
|------------------------------------------------------|-----------------------------------|----|--------|----|-----|
| Is there any loss during transportation?             | Yes                               | 15 | 100.00 |    |     |
|                                                      | No                                |    |        | 30 | 100 |
| If yes common causes for loss during transportation? | Bruising                          | 11 | 73.4   |    |     |
|                                                      | Crushing/<br>Mechanical<br>Damage | 3  | 20.1   |    |     |
|                                                      | High heat                         | 1  | 6.7    |    |     |
|                                                      |                                   |    |        |    |     |

Table 3.1.23. Communication of wholesalers

| Questioners                                                 | Response                         | Frequency (N=15) | %     |
|-------------------------------------------------------------|----------------------------------|------------------|-------|
| Do you have contact with farmers?                           | Yes, have direct contact         | 3                | 20.0  |
|                                                             | All contact goes through brokers | 12               | 80.00 |
| What onion-varieties you bought?                            | Don't have information           | 15               | 100.0 |
| How do the wholesaler find trucks for onion transportation? | Drivers                          | 1                | 6.7   |
|                                                             | Through brokers                  | 14               | 93.3  |

#### 3.1.4.14. Consumer-level postharvest management practices

Consumers stand at the final stage of the onion value chain. They are affected financially as well as in terms of the availability of quality and quantity produces. The survey results revealed that approximately 31.1% consumers face quality issues, such as sprouting, undersized bulbs, bruising and decay, particularly during the rainy season after purchase (Figures 3.1.14a and b). These challenges are consistent with findings by Tadesse *et al.* (2022), who noted that high humidity and poor storage practices during the rainy season accelerate onion deterioration. During rainy season, it is generally challenging to find quality onion bulbs. On average, consumers purchase between 1 kg and 50 kg of onions at a time, though not all of the purchased bulbs are used for one day consumption. Depending on the storage method and initial quality, consumers experience issues such as shriveling, sprouting, bruising and rotting. Consumers store onion bulbs for periods ranging from 5 days to 3 months, with the majority using methods such as spreading the bulbs on the ground or storing them in polyester plastic bags. Other packaging materials consumers use include *Hode/Zenbil*, baskets, plastic rakes, shelves, storing under beds, and drying in the sunlight (Table 3.1.25). These methods are generally inadequate for

maintaining onion quality, as they provide little protection from moisture and temperature fluctuations. Gajbhiye *et al.* (2019) observed that poor household-level storage significantly contributes to sprouting, weight loss, and decay, especially in tropical and subtropical climates.

The survey also indicated that consumers purchasing larger quantities of onions tend to buy from wholesalers, while those buying smaller quantities typically purchase from retailers. About 40% of respondents buy from retailers, 26% from wholesalers, 12% from producers, and 22% from both wholesalers and retailers. Price discounts for bulk purchases from wholesalers and the ability to select specific bulbs from retailers influence consumer preferences. Consumers seeking fresh and unmixed bulbs prefer to buy from producers and retailers. Proximity is another important factor in selecting when and where to purchase onions. Many consumers purchase larger quantities during periods of low prices and surplus supply (usually in the dry season) so they can store them for future use and avoid paying higher prices during the rainy season (Tables 3.1.22 and 26). This behavior aligns with the seasonal supply-demand pattern documented by Tefera *et al.* (2022).

Table 3.1.24. Onion handling practices at consumer's level

| Questioners                                                  | Options                                | Frequency | Percent |
|--------------------------------------------------------------|----------------------------------------|-----------|---------|
| Causes of postharvest losses                                 | Bruising                               | 8         | 16      |
|                                                              | Rotting                                | 26        | 52      |
|                                                              | Sprouting                              | 28        | 56      |
|                                                              | Shrivelling                            | 8         | 16      |
| What methods are used to minimize onion loss during storage? | Applying cold charcoal ash             | 4         | 8       |
|                                                              | Ventilating by spreading on the ground | 34        | 68      |
|                                                              | Sorting                                | 10        | 20      |
|                                                              | Nothing                                | 10        | 20      |
|                                                              | Sun drying                             | 3         | 6       |
| How long you store onion bulbs?                              | 5 days - 2 weeks                       | 2         | 4.0     |
|                                                              | 1 week                                 | 16        | 32      |
|                                                              | 2 week                                 | 21        | 42      |
|                                                              | 1 month                                | 3         | 6       |
|                                                              | 2 month                                | 7         | 14      |
|                                                              | 3 months                               | 1         | 2.0     |

|                                         |                              |    |      |
|-----------------------------------------|------------------------------|----|------|
| How do you store bulbs for consumption? | Basket                       | 3  | 6    |
|                                         | Drying on the sun            | 2  | 4.0  |
|                                         | Ground /spread on the ground | 14 | 28   |
|                                         | Hod/ <i>Zenbil</i>           | 8  | 16.0 |
|                                         | Plastic rake                 | 5  | 10   |
|                                         | Polyester plastic bag        | 12 | 24   |
|                                         | Spreading on shelf           | 3  | 6.0  |
|                                         | Spreading under bed          | 2  | 4.0  |

Table 3.1.25. Market information

| Questioners                                                                     | Options                                                                             | Frequency | Percent |
|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------|---------|
| From where do you buy onions and why do you buy onions from that certain place? | Wholesalers and retailers                                                           | 11        | 22      |
|                                                                                 | Producers/ farmers                                                                  | 6         | 12      |
|                                                                                 | Retailers                                                                           | 20        | 40      |
|                                                                                 | Wholesaler's                                                                        | 13        | 26      |
| Do you sometimes buy more or fewer onions than you need?                        | No                                                                                  | 14        | 28      |
|                                                                                 | Yes, too little during supply shortage too much during low price and during surplus | 36        | 72      |

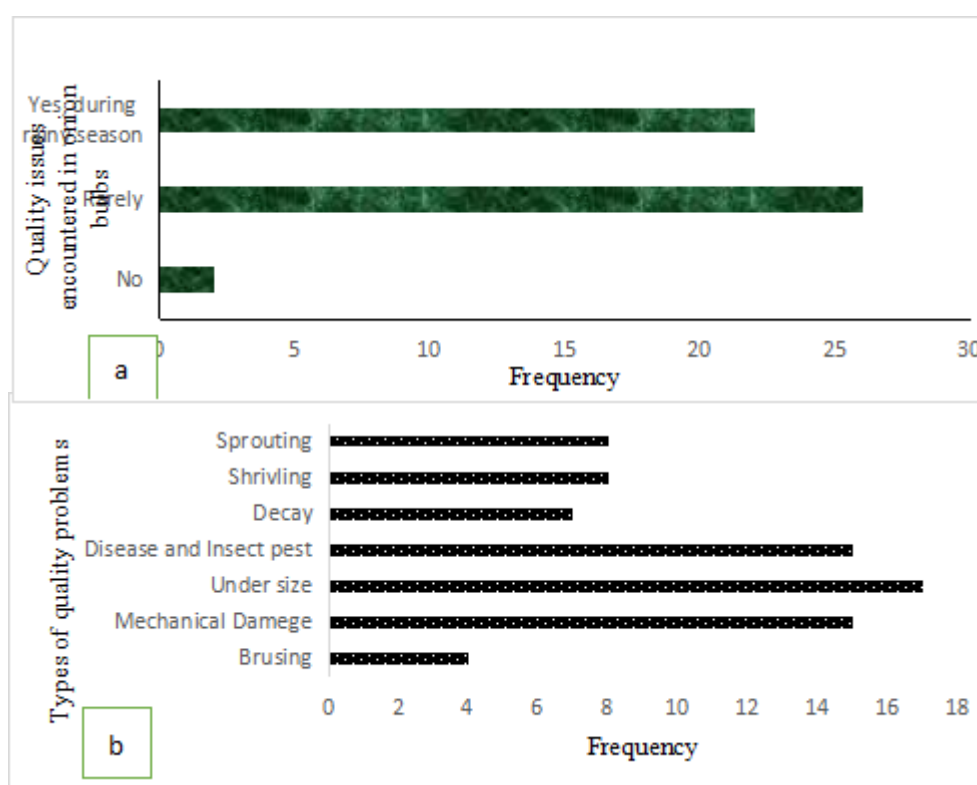


Figure 3.1.5. Presence of onion bulb quality problems (a), specific types of quality problems (b)

### ***Role of vegetable marketing cooperatives in the study areas***

In the study areas (Andassa, Kudmi and Fogera), fruit and vegetable marketing cooperatives were established, but, except the cooperative in Fogera, cooperatives in Andassa and Kudmi *kebeles* are not functional. The fruit and vegetable marketing cooperative in Fogera district is found in *Kuahir mical kebele*. The name of the cooperative is *Lomidir* and it has 240 members, of which 221 are male and 19 are female. The cooperative operates have their own established working guidelines and they have a strong capacity during peak harvesting seasons, often receiving more onions than they can handle. However, they face challenges with a lack of inputs during the off-season. The cooperative prioritizes attractive and marketable size bulbs, which are received and ranked first. Each week, they handle up to 12 tons of onions, which are delivered to wholesalers, hotels, and markets in Addis Ababa. Regarding their storage, they use methods such as spreading onions on beds or shelves and storing them in burlap sacks. The cooperative buys produce from its members twice a week, typically on rest days. Despite their success, they struggle with inadequate storage space and the lack of proper storage infrastructure, particularly shelves to maintain the quality of the onion produce.

### ***Extent of losses in supply chain of onion***

As shown in Table 3.1.27, the total postharvest loss of onions across the farmer, wholesale, retail and consumer levels was found to be 29.775%. The highest proportion of losses (35.5 %) occurred at the farmer level, followed by the retail level. At the wholesaler level, losses accounted for 27.77%, while 19.81% loss accounted at the consumer level. The findings highlight those postharvest losses along the supply chain primarily affect farmers and retailers, emphasizing the need for targeted interventions at these stages. The lowest loss (16.87%) was observed at the consumers' level.

The highest level of postharvest loss at the farm level could be due to the improper pre- and postharvesting factors such as pest, mechanical damages and the rain during harvesting. On the other hand, the observed high percentage of postharvest loss at the retailers level can be attributed to the cumulative effects of improper handling, packaging and transportation at the wholesaler and the retail levels. Wholesalers sold onion to the retailers in mass without sorting the damaged, diseased and under-sized bulbs, which also contribute to the high level of postharvest losses at the retailer level. On the other hand, retailers practiced sorting and sold quality bulbs to consumers that increases the proportion of unsold bulbs and thus increases the postharvest losses. Generally, postharvest loss is a serious challenge in the value chain of onion production, which is about 29.8% observed in the present study. In this regard, Calica and Cabanayan (2018) also reported about 31.49% postharvest losses of onions in the Philippines. The present results are in line with the findings of Emanu Bezabih (2017) who reported that producers (farmers) and retailers are mostly affected by postharvest losses along the supply chain of onion. Similarly, Falola *et al.* (2023) also reported that onion farmers experienced a 23.9% postharvest loss in Nigeria.

Table 3.1.26. Average postharvest losses of onion along the value chain

| Supply chain | Average loss (%)* | Share to the total losses (%) |
|--------------|-------------------|-------------------------------|
| Producers    | 10.58             | 35.5                          |
| Wholesaler   | 5.9               | 19.81                         |
| Retailer     | 8.27              | 27.77                         |
| Consumer     | 5.025             | 16.87                         |
| Total        | 29.775            | 100                           |

*\*Losses were estimated as the difference between the quantity harvested/purchased and quantity sold in relation to the total quantity harvested/ purchased.*

### 3.1.5. Conclusion and recommendations

The salient findings of the present study indicated that sex, age, educational level, production experience, land covered by onion, and household size have a significant influence on the production of onion. Sex, age, education level, active household size,

selling experience, amount purchased and storage duration have significant associations with the production and postharvest losses of onion. Improper postharvest handling practices, poor market linkage, poor storability of varieties, fertilizer shortage, disease, and insect pests were the major constraints of onion production. There are a significant quality differences between the sampled and delivered onion bulbs to traders in the marketing process, which were expressed in terms of damaged, undersized, sprouted and immature bulbs. The estimated postharvest loss at the whole value chain of onion was about 29.8%. Of which the higher proportion of losses (35.5%) was observed at the farmer's level (production chain). The existing problems and perishability nature of the crop aggravate the onion postharvest loss. Therefore, producers and handlers in the supply chain need to be trained on affordable and applicable postharvest handling methods. Continuous capacity-building trainings, improvement of the infrastructures and access to inputs should be designed and implemented along the supply chain to improve crop management and postharvest handling practices. Moreover, marketing cooperatives working on the marketing system should be active and functional. The information from the current study can be used as baseline for policymakers and researchers to improve the production and productivity and to minimize the postharvest losses of onion. In this regard, meaningful interventions in the development and implementation of policy on sustainable production, handling practices and supply of onion should be designed to improve the livelihood of farmers.

### 3.2. Strategic Mapping of Onion Supply Chains: A Comprehensive Analysis of Production and Postharvest Processes in Northwest Ethiopia

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#### **Abstract**

*Onion is a significant vegetable crop in Ethiopia and serves as a source of income for smallholder farmers. However, various production and postharvest handling challenges impede a consistent supply and marketing of the crop. This study focused on a comprehensive analysis of the onion supply chain, ranging from production to postharvest handling, to address the existing production and marketing processes. The research initiative was undertaken to map the onion supply chain from farmers to consumers, intending to establish an improved marketing system in northwest Ethiopia. The study area covered three onion-producing districts of the Amhara Region. Data collection involved interviews, observations, and market assessments using a semi-structured questionnaire. Sampling followed a multistage sampling technique. The analysis included descriptive statistics and food system analysis to map the supply chain and estimate marketing margins. According to the results, postharvest loss presents a major obstacle in the production of onion and negatively affects its growth. The study identified seven alternative channels of onion marketing where different actors are involved throughout the supply chain. Key stakeholders include farmers, local collectors, brokers, transporters, wholesalers, retailers, and consumers. Packaging and sorting activities are implemented at different supply chain stages to minimize postharvest losses. Farm-level activities, including curing, sorting, grading, and ventilating, were crucial for reducing losses. The perishable nature of onion bulbs and the existing production and handling challenges aggravate postharvest losses. Efforts to address this challenge demand a*

*comprehensive approach, integrating interventions across the value chain, from improved varieties and storage infrastructure to enhanced market access strategies. Hence, stakeholders and governmental organizations are urged to promote onion value-addition technologies. Such endeavors promote collaborative efforts across the onion supply chain, ensuring sustainable benefits for producers and traders.*

**Keywords:** Mapping, market channel, market prices, onion supply chain, postharvest handling, postharvest losses, production challenges, smallholder farmers

### **3.2.1. Introduction**

Ethiopia's diverse agro-climatic conditions are highly suitable for producing a wide range of vegetable crops, including onions, which serve as both a vital food source and a cash crop (Lemma Dessalegn *et al.*, 2006; Dawit Alemu *et al.*, 2004). Onion (*Allium cepa*) is the second most important vegetable in the country, cultivated on small and large-scale farms for domestic consumption and export (Lemma Dessalegn and Shimelis Aklilu, 2003). Despite its profitability and increasing production area, the sector faces significant challenges, including limited access to quality inputs, inadequate agronomic practices, poor extension services, and ineffective disease and pest management (Agidew Abebe, 2018; AgroBIG, 2016). Postharvest losses due to high moisture content, mechanical damage, diseases, pests, bruising, and shriveling further hinder supply chain efficiency, while seasonal production cycles complicate year-round market demand (Pessu *et al.*, 2011; Kitinoja and Kader, 2002).

The onion supply chain in Ethiopia also suffers from inadequate storage facilities, inefficient handling and transportation networks, pricing inconsistencies, and weak market coordination (Agidew Abebe, 2018; AgroBIG, 2016; Carvalho *et al.*, 2012). Beyond meeting domestic demands, in 2023 onions contribute to the national economy, with about 3.87 million kilograms of onion bulbs and cut flowers exported worldwide (Fresh Onion Market in Ethiopia, 2023). Farmers in northwestern Ethiopia also produce onions as a cash

crop, influenced by year-round consumer demand and dynamic market forces (CSA, 2018; Kassa Getu and Ahmed Ibrahim, 2018). Addressing these multifaceted challenges is crucial to improving productivity, livelihoods, and economic resilience, , and evaluating the supply chain remains vital for sustainable onion production (MoA, 2020; Masamha *et al.*, 2018).

This study, focusing on Northwest Ethiopia, seeks to address gaps by analyzing production and postharvest processes and mapping supply chain actors. Therefore, this study aimed to investigate the onion supply chain, map actors, understanding their roles, and explore linkages in Northwest Ethiopia.

### **3.2.2. Review of related literature**

#### *3.2.2.1. Food supply chain*

According to FAO (2007) and Van der Vorst *et al.* (2007), a supply chain encompasses the end-to-end processes from production to consumption, involving multiple organizations to fulfill customer demands. It manages the flow of materials, information, funds, and products, covering product development, marketing, operations, sales, and customer service. Supply chain mapping visually represents its structure to comprehend functionality and complexity. The food supply chain analyses production, storage, transportation, trading, processing, and retailing. It is influenced by external factors like transportation and regulatory bodies. Business services that provide inputs and assistance interact with the food supply system, shaping its dynamics (Van Berkum *et al.*, 2018). Understanding these details is essential for effective management and optimization of supply chain processes.

Mila *et al.* (2022) stated that supply chain analysis systematically elucidates the movement of goods and services from origin to destination, facilitating effective production

management for quality control and enhanced year-round market access. The importance of supply chains has steadily increased as companies in various industries realize the benefits of establishing collaborative relationships both within and outside their organizations (Gallo *et al.*, 2019).

#### *3.2.2.2. Supply chain actors and their roles*

Stakeholders in supply chain management play a crucial role for various reasons, including sharing information, collecting, packing, distributing, selling, processing, buying and consuming produces (Adamashvili *et al.*, 2021; Minnens *et al.*, 2019). Their involvement is integral for enhancing sustainability performance (Tsoulfas *et al.*, 2019). For impactful interventions, it is necessary to prioritize and understand the stakeholders, their interactions and interrelations (WCDI, 2021). In the case of onion, various chain actors directly or indirectly contribute to the overall supply chain dynamics.

#### ***Supply chain actors and dynamics in onion production***

- **Input Suppliers:** Provide agricultural inputs (seeds, compost, fertilizer, pesticides) from various sources, including government, individuals, and growers (Wudineh Getahun *et al.*, 2018; Addisu Hailu *et al.*, 2017).
- **Producers/Farmers:** Undertake field operations, from field preparation to postharvest handling of the crop. They are the major value chain contributors. They apply inputs, manage the cultivation of crops, and participate in marketing processes (Agidew Abebe, 2018).
- **Local Collectors:** Middlemen/wholesalers facilitating onion distribution for specific wholesalers and retailers (Kassa Getu and Ahmed Ibrahim, 2018).
- **Brokers/Middlemen:** Intermediaries between farmers and wholesalers and providing market information (Daniels and Fors, 2015).
- **Wholesalers:** Purchase and supply large volumes of locally produced or imported onions to retailers and consumers (Wudineh Getahun *et al.*, 2018).

- Retailers: Sell onions and other items in public markets, acting as the final link between producers and consumers (Daniels and Fors, 2015).
- Consumers: Households, cafes, restaurants, and hotels purchase onions directly from producers, retailers, or wholesalers.
- Chain Supporters: Organizations providing diverse support, funds, and research collaboration, including research institutes, universities, credit unions, governmental and non-governmental organizations (i.e., SNV), infrastructure, and private companies.
- Influencer Actors (Enabling Environment): Policies, regulatory frameworks, financial sectors, trade and market development offices, business support services, land administration, and environmental protection offices shape the overall onion supply chain (WCDI, 2021).
- Extension Services: Extension workers and research centers provide technical advice and improved onion varieties (WCDI, 2021).

### **3.2.2.3. Constraints of onion production**

Onion production in the Amhara Region, Ethiopia, faces challenges despite a labour-intensive approach, with over 50% of the population capable of engaging in cultivation (BoFED, 2003). Sustainable strategies encompass good management, cultural practices, new variety development, and improved production input access. However, obstacles like low soil fertility, inadequate postharvest technologies, improper agronomic practices, inappropriate fertilizer use, pests, diseases, and costly production inputs contribute to Ethiopia's low and unstable onion yields (Kumilachew Alamerie *et al.*, 2014; Lemma Dessalegn and Shimelis Aklilu, 2003), preventing farmers from maximizing the benefits of onion cultivation. Mila *et al.* (2022) highlighted a lack of research and market information, while Berhanu Gebremedhin *et al.* (2009) observed that insufficient access to improved inputs and limited land holdings resulted in inadequate production to meet household consumption needs. Getu and Ibrahim (2018) noted the crucial role of fertilizers

and pesticides in boosting onion productivity in the Amhara Region. However, they also noted that high input costs and poor accessibility lead to suboptimal fertilizer use among most farmers, negatively affecting crop yield.

Bewuketu Haile *et al.* (2016) found that the lack of pesticides is the primary constraint in onion production in the Masha district. Melkamu Alemayehu *et al.* (2015) noted that fertilizer availability mainly for main-season crops, is insufficient for irrigated onion production. Diseases and insect pests are significant challenges to onion production in the Amhara Region. Agumas Yideg (2019) identified constraints in the Fogera district, highlighting suboptimal fertilizer application rates due to untimely supply and insufficient capital for purchasing the recommended amount.

Ethiopian agricultural cooperatives historically focused on input marketing, but recently, they have shifted their involvement into imports since the 1970's. These cooperatives serve as crucial foundations, supporting smallholder farmers with necessary inputs and mitigating market risks (Thomas Woldu *et al.*, 2013). Despite smallholders contributing 95% of Ethiopia's agricultural output, they face challenges such as restricted market access and low productivity (Gebremedhin *et al.*, 2009; Musa Hasen and Hiwot Mekonnen, 2017), underscoring the need for improved support structures and market integration for enhanced agricultural sustainability and productivity.

Ethiopian cooperatives initially played a crucial role in fertilizer distribution, supplying 56% in 2010 (Matsumoto and Yamano, 2010). By 2008, cooperative unions dominated imports, reaching a 75% market share in 2007/2008 (IFPRI, 2012). However, to achieve economies of scale, the government centralized fertilizer imports through a single entity in 2008, annually selecting the importer that limited cooperatives' role in fertilizer distribution (World Bank, 2011; Degnet Abebaw and Mekbib Haile, 2013).

The demand for chemical fertilizer, and pesticide in Ethiopia is met only by importation. In addition, high cost, long lead time, little involvement of farmers in demand estimation, and the mismatch between quantity supplied and demand are the major factors in the accessibility of fertilizers. Due to this, farmers do not have timely access to the required amount. As illustrated in Fig.3.2.1 (From 1993 to 2022), the farmer fertilizer consumption trend in kilograms per hectare of arable land increased significantly. In 1993, 7.6 kg of fertilizers were applied to a hectare of crop-land. In 2022, however, 36.2 kg of fertilizer was required per hectare (World Bank, 2022). The increase in the amount of fertilizer applied might be due to the decreasing rate of soil fertility. Moreover, recently, the significant rise in the price of fertilizers and pesticides has posed a great challenge for farmers.

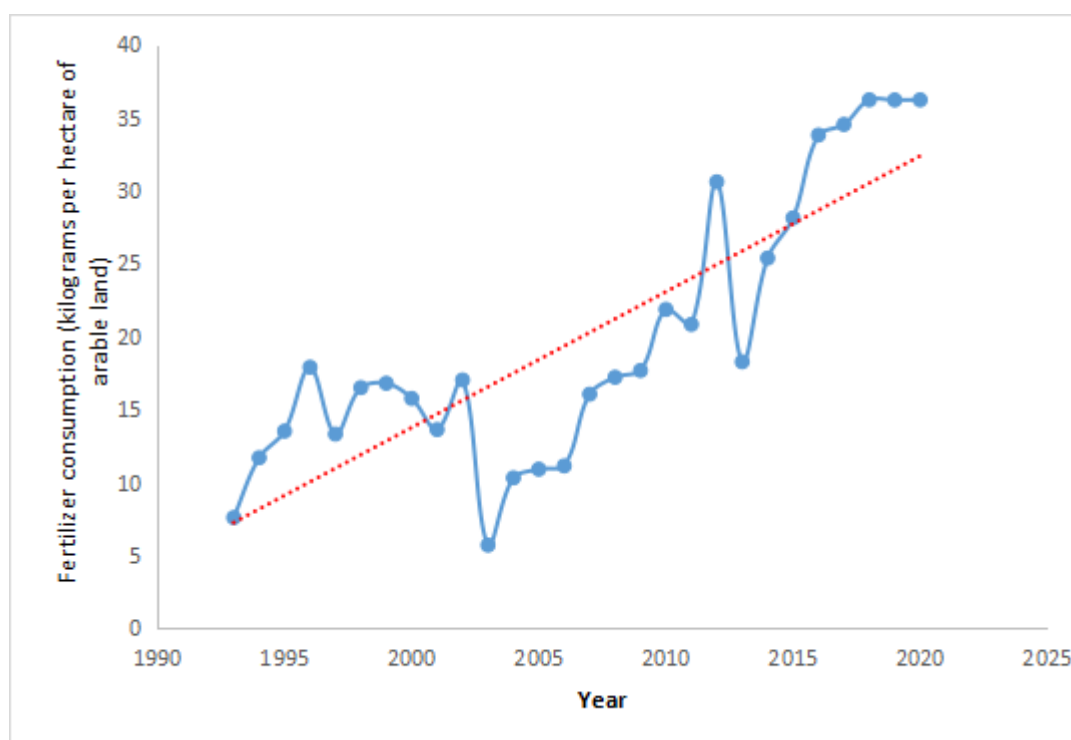


Figure 3.2.1. Fertilizer consumption trend in kilograms per hectare of arable land in Ethiopia (1993–2022)  
Source; World Bank (2022)

#### 3.2.2.4. Marketing channels

Marketing channels are routes through which agricultural products move from producer to consumer. The length of the channel varies from commodity to commodity, depending on the quantity to be moved, consumer demand, and the degree of regional specialization in production (Adnan, 2014; Kohls and Uhl, 1985). According to Kohls and Uhl (1985), the marketing channels start at the farmgate and end at the consumer's front door. Some of the products are processed on their way to the end users, while other products reach them without undergoing any form of change. According to Emana Bezabih *et al.* (2017), a significant proportion of onion harvest is meant for sale in various towns within Ethiopia, implying that production of the crop is commercially driven and access to the market is crucial to improve household income. In Ethiopia, there are increasing numbers of onion marketing channels where farmers are selling their products directly to consumers or through a middleman.

Kassa Getu and Ahmed Ibrahim (2018) identified six types of onion marketing channels in the Amhara region in Ethiopia. The first channel involves direct sales from the producer to the consumer. The second follows a sequence from the producer to the retailer and then to the consumer. The third channel progresses from the producer to the collector, then to the wholesaler, followed by the retailer, and finally to the consumer. In the fourth channel, transactions occur through brokers, where the producer or broker sells to the collector or broker, who then supplies wholesalers, retailers, and consumers. The fifth channel includes the producer selling to a processor, who then supplies retailers before reaching consumers. Lastly, the sixth channel involves the producer selling to a collector, who then supplies wholesalers, leading to exports. They also indicated that of the total onion produced, 10–15% of the produce was sold by farmers directly to consumers, whereby farmers are getting better profit margins.

Emana Bezabih *et al.* (2017) identified five marketing channels for onion in the Bora and Dugda districts of Oromia Regional State, Ethiopia. Farmers can sell the product to village

collectors, wholesalers, retailers, and cooperatives. Producers sell their onions to wholesalers, who serve as the main market channel, accounting for 95% of total sales. In contrast, village collectors and cooperatives buy very small proportions (1–2%) of the produce. Some farmers, especially women, also sell small quantities of onion on the open market to consumers. Six market channels of onion were also identified by Addisu Hailu *et al.* (2017) in the Ejere district, Oromia National Regional State of Ethiopia. They are (1) Producer–Consumer, (2) Producer–Rural Collector–Wholesaler–Central Retailer–Consumer, (3) Producer–District Retailers–Consumer, (4) Producer–Wholesaler–Central Retailer–Consumer, (5) Producer–Wholesaler–Processor–Consumer, and (6) Producer–Wholesaler–District Retailer–Consumer.

#### 3.2.2.5. Hypothetical framework

Elevated onion production costs, as discussed by Agumas Yideg (2019), diminish the likelihood of farmers bringing more products to the market. Our principal hypothesis indicates that production costs, encompassing agricultural inputs like fertilizers, pesticides, and fuel costs, negatively influence onion production.

Alemayehu Derege (2010) highlights the effect of fertilizer usage on crop yields, emphasizing the potential for diminished yields or crop failure with improper application. It is suggested that the appropriate use of chemical fertilizers can positively influence onion production, thereby enhancing farmer efficiency. Additionally, our hypothesis suggests a positive correlation between household size and onion production, as family members contribute valuable labor to onion cultivation activities (Abedullah *et al.*, 2009).

Yebirzaf Yeshiwas *et al.* (2023) argued that experienced farmers exhibit enhanced management skills, likely contributing to improved production processes. Therefore, it can be inferred that as farming experience, their proficiency in farming and yield enhancement may increase. Furthermore, factors such as transportation methods, market access, and

price information are anticipated to exert positive or negative influences on onion production decisions. The study hypothesizes that longer transportation distances may adversely affect onion production, as extended transport distance can reduce returns to producers.

### **3.2.3. Methodology**

#### ***3.2.3.1. Study area description***

The study encompassed three pivotal onion-producing districts in northwest Amhara: Mecha, Fogera, and Bahir Dar Zuria. Detail descriptions of the study districts are written in 2.1.

#### ***3.2.3.2. Sampling method and sample size determination***

This study employed a semi-structured questionnaire for key informant interviews, direct field observations and market assessments, following the methodology outlined by Elahi *et al.* (2022). Detailed sampling methods and sample size determination are written in 3.1.3.3.

The value chain mapping process began with discussions with various stakeholders during the first survey. The final version of the map was then refined and improved using insights gathered from key informant interviews and group discussions. Interlinkages among various activities of the actors in the onion supply chain were observed.

#### ***3.2.3.3. Data analysis and supply chain mapping***

Collected data were analyzed using SPSS 16.0 and Microsoft Excel. Descriptive statistics, including frequency, mean and percentage, were employed. Additionally, a food system analysis, Van Berkum (2018), was used to map the actual supply chain and its

linkages/interactions. This analysis provided a clear visualization of how different components of the food system are linked, from production to consumption.

Gross marketing, and net marketing margins of the main market actors were estimated using the following equations (Amikuzuno and Donkoh, 2012).

**Gross marketing margin = Sales price – Purchase price(consumer)**

**GroProducer share (%) = Farm price/Retail price \* 100**

### **3.2.4. Results and discussion**

#### **3.2.4.1. Production and marketing of onions**

The survey findings indicate an average onion yield of 16 t ha<sup>-1</sup> in the study area, surpassing the average productivity of onion (11.7 t ha<sup>-1</sup>) in Amhara National Regional State, as reported by CSA (2018). However, the productivity of onion recorded in this study falls short of the global average of 21.1 t ha<sup>-1</sup> (FAO, 2022).

Figure 3.2.2 depicts the trend in area coverage and productivity of onions in the last 20 years (2002-2022). The area under onion cultivation has shown an increasing trend since 2020, but onion productivity is declining. Factors limiting productivity include fluctuations in cultivation area and inappropriate agronomic practices, using low productive varieties, lack of fertilizers, and inadequate storage facilities, leading to significant postharvest losses. The surge in onion cultivation since 2020 highlights the production potential and the robust consumer demand for onion.

Despite a surplus of onions in the country for two to three months during peak harvesting time, prices of onions in these harvesting months remain low. This is attributed to the same harvesting time of onion across the region, increasing the supply and decreasing the price (1-3 Birr kg<sup>-1</sup>). On the other hand, during the rainy season, a shortage of supply increases the price (30-55 Birr kg<sup>-1</sup>) (Yebirzaf Yeshiwas *et al.*, 2023). Promoting the use of climate-resilient and high-yielding onion varieties can enable farmers to produce during

unfavorable seasons, mitigating supply shortages during the rainy season. Additionally, enhancing market linkages through digital platforms and farmer cooperatives can connect producers to larger markets, improving their bargaining power and reducing reliance on local traders. Real-time market information systems can further support informed decision-making. Lastly, encouraging value-addition through processing methods, such as drying, packaging, or pickling can help reduce postharvest losses and create new income opportunities for farmers. Implementing these solutions in an integrated and coordinated manner can stabilize prices, reduce losses, and enhance farmer incomes.

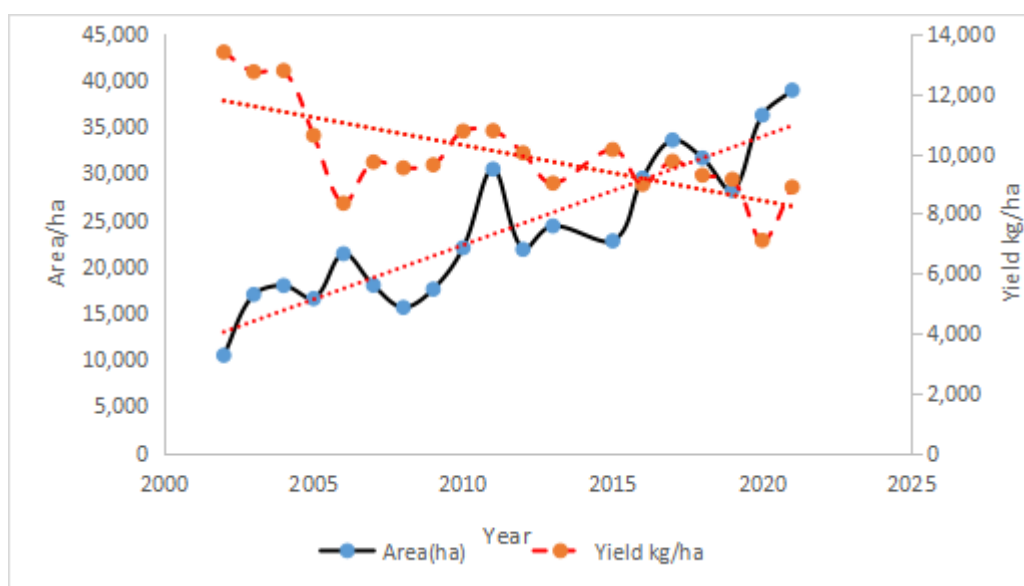


Figure 3.2.2. Onion production trend (2002–2021). Source; CSA (2022)

#### 3.2.4.2. Value-addition activities at the value chain of onion

The perishable nature of onions leads to postharvest losses due to mechanical damages, rotting, sprouting, and weight loss in the supply chain. Therefore, the supply chain actors practice different postharvest handling practices, including value-addition activities to reduce postharvest losses of onion (Appendix Figure 3.2.1). A limited proportion of the respondent farmers practiced curing, while most of the retailers practiced sorting and grading as value-addition activities. Wholesalers exhibited value-addition activities like sorting and grading (Table 3.2.1). Timely harvesting, curing, sorting, grading, and

packaging are necessary to enhance the value and storage life of onion bulbs. Moreover, it helps reducing the postharvest losses and maintaining the postharvest quality of onion bulbs. In this regard, Gizachew Wosene and Wubalem Gobie (2022) reported that value-addition activities on tomatoes boost shelf life and income returns.

Table 3.2.1. Value-addition activities in onion supply chain

| Variable       |     | Producers (%)<br>(N = 197) | Wholesalers (%)<br>(N = 15) | Retailers (%)<br>(N = 30) |
|----------------|-----|----------------------------|-----------------------------|---------------------------|
| Timely Weeding | Yes | 74.5                       |                             |                           |
| Toppling       | Yes | 50.3                       |                             |                           |
| Curing         | Yes | 3.6                        |                             |                           |
| Sorting        | Yes | 15                         | 44                          | 100                       |
| Grading        | Yes | 30                         | 2.5                         | 69                        |
| Packaging      | Yes | 100                        | 100                         | 100                       |
| Ventilating    | Yes | 8.7                        | 100                         | 83.3                      |

#### 3.2.4.3. Onion marketing channel in the study areas

Marketing channels of onion were sketched based on the direction of flow and volume of onion yield transacted. The present study identified seven alternative channels for onion marketing in the study areas as indicated below.

Channel I: Producers →consumers

Channel II: Producer →local collector →wholesaler-consumer

Channel III: Producer →wholesaler →consumer

Channel IV: Producer →wholesaler →retailer →consumer

Channel V: Producers →cooperative →wholesalers →transfer to Central Market AA

Channel VI: Producers →wholesalers →retailer →consumers and Producer→Retailer-consumer

Channel VII: Producers →retailers →consumers

These multiple marketing routes indicate the fragmented nature of onion distribution, where both direct and indirect linkages exist between producers and end-users. The presence of intermediaries such as local collectors, cooperatives, and wholesalers

significantly influences market efficiency, price transmission, and producer margins (Shiferaw *et al.*, 2017).

The estimated quantity of onion supplied to the market by the sampled households in the 2022 production season was about 253.6 quintals. However, the amount of onion transacted in these market channels was not the same. The results indicated that the producers sold most of their produce (66.15%) to wholesalers and about 11.81% to marketing cooperatives. The remaining producers sold to local collectors (9.85%), retailers (7.9%), and consumers (4.29%) (Figure 3.2.3).

#### **Channel I: Producers–consumers**

The producers sell their onions directly to the consumer at the nearest market and farmgate. In this channel, onion producers benefit more from better prices, and consumers can get fresh onions. However, a small volume of onion is transacted through this channel (Figure 3.2.3). The market size for such a shorter channel is small (4.29%) and cannot absorb all onions produced. Similarly, retailing in the local market is time-consuming for producers, especially for those who have more produce.

#### **Channel II: Producers–local collectors–wholesalers**

In this channel, the producers sold their onions to the local collectors (9.85%), who then sold them to wholesalers.

#### **Channel III: Producers–wholesalers–consumers**

The producers sold 66.15% of their onion to wholesalers. The wholesalers, in turn, sold 20.7% to consumers such as households, cafes, and restaurants that have the capacity to purchase five kilograms of onions or more. Producers sold their produce to wholesalers without the involvement of brokers. This is the most important channel where the largest volume of farmer`s onion was transacted in the study area.

**Channel IV: Producers–wholesalers–retailers**

The producers sold 66.15% of the onions to the wholesalers, who further sold 71.26 % of the onions to the retailer.

**Channel V: Producers–cooperatives–wholesalers–transfer (Central Market AA)**

The producers sold 11.81% of the onions to the marketing cooperatives. Of this quantity, 75% was sold to wholesalers in different parts of the country, while 25% was transferred to the central market in Addis Ababa.

**Channel VI: Producers–wholesalers–retailers–consumers**

In this channel, the producers sold their produce to the wholesalers, who sold further to retailers. The retailers sold the produces further to the consumers. It is the longest chain in terms of market participants (Figure 3.2.3). As the number of actors between producers and consumers increases, the profit margin of the producers will decrease.

**Channel VII: producers-retailers-consumers**

The producers directly sold 7.9% of the onions to retailers, who in turn sold all (100 %) to consumers (Figure 3.2.3).

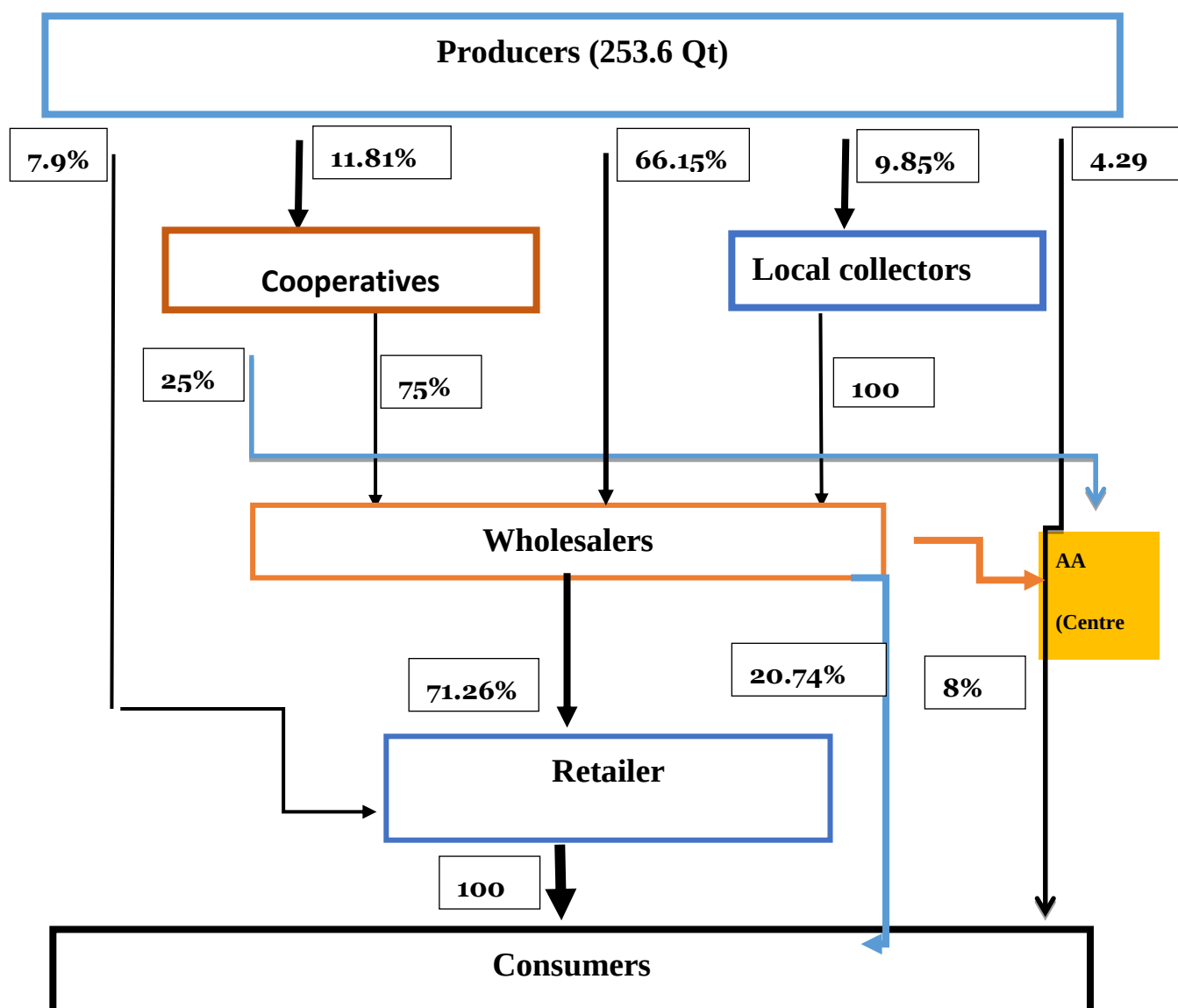


Figure 3.2.3. Onion supply chain and volume share of the flows

From the farmers' perspective, the marketing channels reveal opportunities and challenges. The dominant channel through brokers (66.15%) is convenient but often results in lower prices due to intermediary profit margins. Selling directly to cooperatives (11.81%) offers structured market access and potentially fairer prices, but cooperatives may still lack the capacity to handle large volumes efficiently. Accessing wholesalers directly (7.9%) could provide better returns, but logistical barriers, transportation costs, and market competition pose significant challenges. Overall, the existing channels highlight a need for

interventions to minimize intermediary dominance, enhance cooperative efficiency, and improve farmer access to profitable markets.

### ***Profit margins***

The findings showed that the highest profit margin was obtained by producers and collectors, followed by retailers and wholesalers. However, as producers received the largest share of the profit margin (38.38%), this share remains unsatisfactory when compared to the high production costs they incur. Ideally, their share should exceed 70% to reflect their pivotal contribution to the supply chain. The distribution of profit margins in the onion supply chain reveals that producers received the highest share (38.38%), followed by collectors (25.79%) and retailers (18.11%). Additionally, a notable portion of the margin (17.72%) was allocated to the wholesalers in the chain. This breakdown underscores the significant contribution of producers to the profitability of the supply chain, highlighting their pivotal role in onion marketing (Table 3.2.3). However, the current profit margins suggest a need for interventions to enhance producers' earnings. Strategies such as reducing the number of intermediaries, improving access to market information, and strengthening producer cooperatives could achieve a more equitable profit distribution (Hailegiorgis, 2017).

Table 3.2.2. Margin analysis for the main market actors (N=292) in the value chain of onion (Birr per quintal)

| Items                                     | Market actors (N=292) |                   |                     |                   |
|-------------------------------------------|-----------------------|-------------------|---------------------|-------------------|
|                                           | Producers<br>N=197    | Collector<br>N=30 | Wholesalers<br>N=15 | Retailers<br>N=50 |
| Purchase/Production Cost<br>(A) (Birr/qt) | 340                   | 1400              | 2150                | 2700              |
| Sell Price (B) birr/Q                     | 1400                  | 2150              | 2700                | 3200              |
| Gross Margin C= (B-A)                     | 1060                  | 750               | 550                 | 500               |
| Marketing Cost. (D) birr/Q                | 85                    | 95                | 100                 | 40                |
| Net Margin (Net Profit Margin)<br>(C-D)   | 975                   | 655               | 450                 | 460               |
| Share of MMP (%)                          | 38.38%                | 25.79%            | 17.72%              | 18.11%            |

(1 Birr = 0.02 USD, as of January 2021/22). Where; Q= Quintal, MMP (Marketing Margin Percentage). Onion marketing margin for different channels (Birr/qt); in small unit analysis Sell price: at producer level 14 Birr kg<sup>-1</sup>, at collector level 21.50 Birr kg<sup>-1</sup>, at wholesalers' level 27 Birr kg<sup>-1</sup> and at retailers' level 32 Birr kg<sup>-1</sup>.

#### **3.2.4.5. Mapping the onion supply chain and role of actors in the chain**

The supply chain is a complex network of organizations, activities and resources facilitating the movement of products from suppliers to customers (Chopra and Meindl, 2010; Felea and Albăstroiu, 2013). In the context of onion production, the supply chain encompasses key chain actors such as producers/farmers, local collectors, brokers, transporters, cooperatives, wholesalers, and consumers, with each stage playing a vital role in ensuring the smooth flow of products to the market (Figure 3.2.4). The current map's significance lies in designing a research framework and identifying barriers across the supply chain. Highlighting inefficiencies and challenges at various stages enables targeted interventions to enhance efficiency, reduce postharvest losses and ensure fair pricing for farmers. A meticulous two-stage process was employed to develop the final value chain map of the onion production. This approach is pivotal for comprehensively addressing challenges and optimizing the onion supply chain from farmers to consumers.

Different input suppliers were directly or indirectly involved in the onion supply chain in the study area. Input suppliers provided chemical fertilizers (Urea and NPS/B), onion seeds, herbicides, pesticides and fuel. The majority of fertilizers, accounting for 93.9%, are sourced from a combination of local markets and cooperatives, highlighting their critical role in providing essential agricultural inputs to farmers.

All respondent farmers purchased herbicides and pesticides from the local market. The present findings also indicated problems associated with timely and adequate supply inputs. High prices of fertilizers and fuel, as well as low quality of pesticides (sometimes farmers had the possibility to purchase expired pesticides) were also reported by respondent farmers.

**Producers/farmers:** Smallholder farmers are the major producers of onion in the study areas. The major functions performed by farmers are land preparation, raising seedlings, transplanting, irrigation, fertilizer application, weeding, cultivation, disease (Powdery mildew) and insect pest (onion thrips) management, harvesting, implementing postharvest handling activities, and marketing. The major value-addition activities performed by the onion producers are illustrated in Table 3.2.2.

**Local collectors:** A type of middlemen or wholesalers, plays a significant role in the distribution of onions. They are well-informed about areas with surplus onion production, purchasing directly from farmers at the farmgate and primarily reselling to wholesalers and retailers, with direct sales to consumers occurring only in rare cases.

**Brokers/middlemen:** They act between farmers and wholesalers, provide market and price information, identify potential producers, link the producers to wholesalers, and facilitate the transaction of onion marketing. They collect sample bulbs from the farms for quality evaluation and convince the purchase of onions by the wholesalers. In addition, they also mediate wholesalers to purchase onions. As explained by producers (farmers), brokers sometimes go beyond facilitation and tend to control the selling power of the producers and fix the selling prices of onions.

**Wholesalers:** They are individuals who purchase onions in large volumes that are either produced by farmers or collected by local collectors. In most cases, wholesalers supply onions to retailers and consumers. They mostly have storage facilities, better financial capacities, and communication access. Wholesalers stored onions usually for a maximum of seven days where the storage facilities were below the standard for onion storage. Moreover, wholesalers performed value-addition activities, including sorting, grading, and packaging (Table 3.2.2.). In the study area, major onion wholesalers are located in Merawi town, Bahir Dar city, Woreta town, Kudmi rural town, Andassa, and Sabatamit town.

About 66.15% (Figure 3.2.4) of the onions produced by the producers in the study area were handled by wholesalers in these towns.

**Retailers:** They are supply chain actors who buy and sell onions in small quantities compared to the wholesalers. They mostly supply onion to the consumers. The value-addition activities performed by retailers are buying onions, transporting, sorting, grading, displaying and selling to consumers (Table 3.3.2).

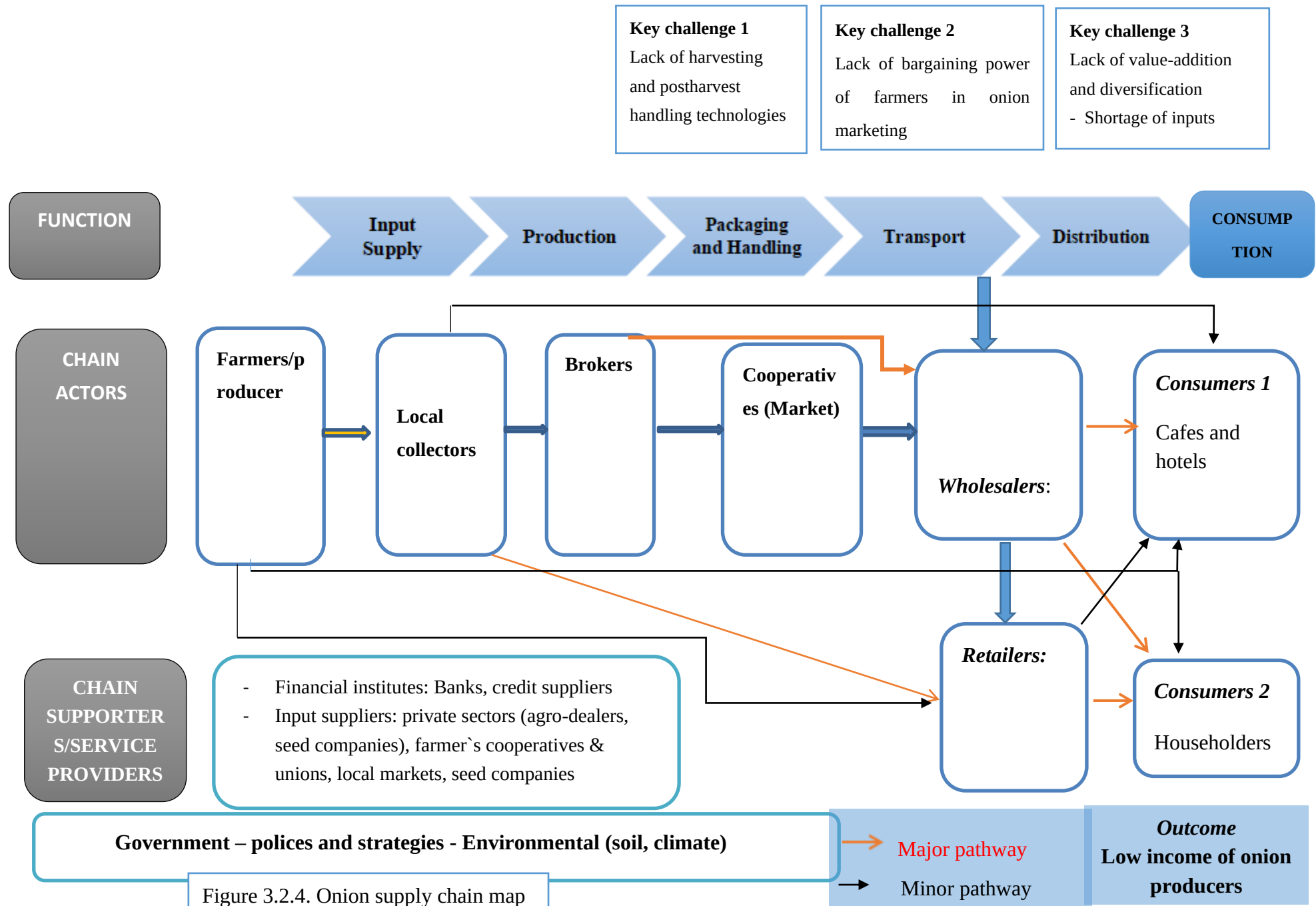
**Marketing cooperatives:** They are legal organizations established by vegetable and fruit producing farmers. The main purpose of these cooperatives is to collect vegetables and fruits, including onions from member farmers and supply them to wholesalers and institutions like hotels. They have the capacity to transport onions to the central market in Addis Ababa for better prices. They have strict quality requirements like attractive colour, marketable size, and sorted onion bulbs while purchasing onions from their members. They apply value-addition practices spread on the bed, packaging and storage (Figure 3.2.2.). As indicated in Figure 3.2.4, about 11.81% of the onions produced by farmers were handled by the farmer`s marketing cooperatives.

**Consumers:** They are end-users of onion in the supply chain. Most consumers purchase onions from retailers, although some buy onions from producers and wholesalers. The rural and urban households, cafes, restaurants, and hotels were identified as onion consumers in the study area.

**Chain supporters:** They are directly or indirectly involved in the onion supply chain. They provide different services, including financial services, access to technologies, infrastructure development, and market information. District agricultural offices provide extension services and facilitate the accessibility of inputs and technologies. The research centers provide improved production technologies for onion production, while non-

governmental organizations (NGOs) provide capacity-building training and support inputs, like onion seeds, to the producers (Figure 3.2.4).

***Chain influencers (enabling environment):*** They encompass the policies, institutions, and regulatory frameworks that shape and facilitate the functioning of a supply chain. In the study area, the chain influencers are regulatory frameworks and policymakers, revenue authority, trade and industry office, land administration, environmental protection office, and irrigation development office to intervene in onion marketing (Figure 3.2.4).



### **3.2.5. Conclusion and recommendations**

The onion supply chain, from production to consumer delivery, faces critical challenges that hinder its efficiency and productivity. Mapping the supply chain reveals key points impeding proper information flow and highlights inconsistencies in value-addition practices, particularly at the producer and intermediary levels. Although they are applied, packaging and sorting activities remain inadequate, especially among wholesalers and retailers. Transportation constraints, price volatility, and inefficient use of marketing channels further aggravate the situation, while poor storage facilities contribute to substantial postharvest losses. Producers mainly sell their yield to wholesalers, followed by cooperatives, with minimal direct consumer transactions .

Despite increasing cultivated area after 2020, productivity has been negatively affected due to fluctuating cultivation patterns, insufficient postharvest technologies, and challenges such as soil fertility issues, improper fertilizer application, pest infestations, and suboptimal agronomic practices. These factors contribute to low and inconsistent yields, limiting the overall potential of onion production in the region.

Based on the findings, considering the perishable nature of the crop and the existing challenges that aggravate onion loss after harvest, it is recommended to prioritize interventions that enhance onion value-addition, including establishing processing industries to mitigate postharvest losses. Stakeholders and governmental organizations should support onion producers and traders with continuous capacity building, improved extension services, infrastructure enhancement, and better input access for sustainable benefits. Meaningful policy interventions, informed by the identified supply chain dynamics, should be developed and implemented. Additionally, incorporating spatial and temporal data in future studies can provide a more comprehensive understanding for informed decision-making in onion production and handling.

# Chapter 4: ENHANCING BULB YIELD THROUGH NITROGEN FERTILIZATION AND THE USE OF HYBRID ONION VARIETIES IN NORTHWEST ETHIOPIA

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## Abstract

*Onions are among the most important cash crops in developing countries, including Ethiopia. However, their production and productivity in Ethiopia are very low, mainly due to inappropriate fertilization practices and the use of low-yielding varieties. Therefore, the present study was conducted to assess the effects of nitrogen fertilizer rate on the growth, yield, and quality of hybrid onion varieties in northwest Ethiopia. The experiment was conducted at three locations (Koga, Woreta, and Woramit) during the 2021/2022 cropping season under irrigated conditions. Factorial combinations of three hybrid onion varieties (Russet, Jambar, Red Coach) and one open-pollinated onion variety (Bombay Red) and four nitrogen rates (0, 41, 82, and 123 kg ha<sup>-1</sup>) were laid out in a randomized complete block design (RCBD) with three replications. Results of the present study revealed that onion growth, yield, and quality were influenced by the nitrogen fertilizer rate and onion variety across all locations. Compared with the open-pollinated Bombay Red variety, the hybrid varieties (Russet and Jambar) performed well in terms of bulb diameter, bulb weight, total yield, marketable bulb yield, and pungency. Nitrogen fertilizer applied at a rate of 82 kg ha<sup>-1</sup> resulted in the highest growth and yield parameters of onion. The Russet and Jambar varieties recorded the highest marketable bulb yields of 26.50 t ha<sup>-1</sup> and 24.57 t ha<sup>-1</sup>, respectively. Onion varieties treated with the highest nitrogen fertilizer dosage of 123 kg ha<sup>-1</sup>, particularly the Bombay Red variety, exhibited the longest duration to reach maturity. Onion plants supplied with 82 kg ha<sup>-1</sup> nitrogen showed the highest marketable bulb yields, with a*

value of 26.77 t ha<sup>-1</sup>. Excessive nitrogen application above 82 kg ha<sup>-1</sup> leads to decreased yield; hence, excess nitrogen might be lost to the environment. Furthermore, the Jambar and Russet hybrid varieties and the application of 82 kg ha<sup>-1</sup> nitrogen fertilizers provided the highest net benefit. The hybrid varieties Jambar and Russet and the application of 82 kg ha<sup>-1</sup> nitrogen fertilizer can be recommended for onion production in the study area and similar agro-ecosystems. Since this study is the first to evaluate hybrid onion varieties in the region, considering other hybrid onion varieties and optimizing agronomic practices such as spacing and phosphorus fertilizer, along with repeating the experiment in another season, are also recommended in future research to validate and expand upon the current findings.

Keywords: Growth, hybrid varieties, nitrogen fertilizer, net benefit, onion, quality, yield

#### **4.1. Introduction**

Onion in Ethiopia is mostly produced by smallholder farmers as a cash crop. Despite the presence of suitable climate conditions, the production and productivity of onions in the country are very low. According to the CSA (2020), the annual production and productivity of onion in Ethiopia were 346048.1 tons and 8.88 t ha<sup>-1</sup>, respectively. This productivity was significantly lower than the potential yield of 40 t ha<sup>-1</sup> achieved under research station conditions (CSA, 2020). Farmers in Ethiopia use open-pollinated varieties with low yields (Bombay Red and Adama Red). They also practice improper agronomic practices, including inappropriate soil fertility management (Yebirzaf Yeshiwas *et al.*, 2023; Yideg Agumas, 2019). These similar unimproved practices contribute to low level of onion productivity and bulb qualities, such as total soluble solids (Brix) and pungency that may affect onion market potential and consumer preference in the country.

Successful onion production depends on several factors, including the selection of adaptable high yielder varieties suited to local conditions, the implementation of proper agronomic practices, and the reduction of postharvest losses (Yebirzaf Yeshiwas *et al.*, 2023; Habtamu Gudisa, 2017). Compared with open-pollinated varieties, hybrid onion varieties generally boast greater yield potential, offering uniform bulb sizes and enhanced storability, extending onions' shelf-life (Singh and Bhonde, 2011; Hyde, 2010). In order to improve onion

production in northwest Amhara Ethiopia, a few hybrid varieties such as Russet, Red Coach and Jambar have been introduced into the local farming system. These varieties were selected due to their high yield potential and better storability compared to open-pollinated varieties. Preliminary trials and research conducted in similar agro-climatic regions have shown that these varieties adapted and performed well under local conditions of northwest Amhara, Ethiopia (Yebirzaf Yeshiwas *et al.*, 2023). Despite their introduction, however, the full production technologies, particularly regarding their specific nitrogen fertilizer requirements, have not been comprehensively studied and require research interventions.

Fertilization should aim to improve onion productivity and quality concerning nutrient requirements related to optimal yield at a minimum cost and high efficiency of fertilizer use (Lee, 2014). Compared with most other crops, onion plants have shallow and unbranched roots, which increase their vulnerability to nutritional deficiencies (Brewster, 1994). Consequently, onions require a relatively high level of nitrogen and respond well to supplemental nitrogen fertilizer (Brewster, 1994; Brewster, 2008). The rate of fertilizer application depends on various factors, such as the crop type, environmental conditions, soil fertility status, method of fertilization, and yield potential of the crop (Agnieszka *et al.*, 2017; Yoldas *et al.*, 2011). Dinega *et al.* (2023) reported that intensifying nitrogen fertilizer management can improve yield and bulb quality in onion.

Although exogenous nitrogen application is known to increase onion yield, many researchers have reported that the application of high levels of nitrogen fertilizer leads to a reduction in the storage life of onion bulbs (Khokhar, 2019). Excessively high doses of nitrogen also cause a delay in bulb maturity and encourage bolting, which is an undesirable characteristic (Aliyu *et al.*, 2008). On the other hand, according to Khan *et al.* (2021), a low rate of nitrogen causes a low yield of onions due to a shortage of nitrogen required for the chlorophyll pigment responsible for photosynthesis. Excessive nitrogen is hazardous to the environment, weakens foliage and predisposes plants to pathogenic diseases (Geary *et al.*, 2015). Therefore, applying the optimal nitrogen fertilizer rate is essential in onion production (Dinega *et al.*, 2023; Buckland *et al.*, 2013). Therefore, this study aimed to optimize nitrogen fertilizer rates for the economical production of hybrid onion varieties in northwestern Ethiopia.

## **4.2. Materials and Methods**

### **4.2.1. Description of the study area**

A field experiment was conducted at three locations, namely, the North Mecha (Koga), Fogera (Woreta) and Bahir Dar Zuria (Woramt) districts of the Amhara region (Figure 2.1) during the 2021/2022 irrigation season. The geographical locations, altitudes, average, minimum and maximum temperatures, rainfall, and soil types of the districts are presented in 2.1.

### **4.2.2. Experimental treatments and design**

Factorial combinations of four onion varieties (Russet, Red Coach, Jambar and Bombay Red) and four rates of nitrogen fertilizer ( $0 \text{ kg ha}^{-1}$ ,  $41 \text{ kg ha}^{-1}$ ,  $82 \text{ kg ha}^{-1}$ , and  $123 \text{ kg ha}^{-1} \text{ N}$ ) were laid out in a randomized complete block design (RCBD) with three replications. Treatment combinations (16) were randomly assigned to the experimental plots within a block at each location. The gross plot size of the experiment was  $1.6 \text{ m} \times 1.6 \text{ m}$  ( $2.56 \text{ m}^2$ ), while the net plot size was  $1.5 \text{ m}$  length  $\times$   $1.4 \text{ m}$  width ( $2.1 \text{ m}^2$ ). The blocks were separated with one meter wide path, while the space between plots within a block was 0.5 meter wide.

### **4.2.3. Treatments and experimental design**

The treatments consisted of four onion varieties, and four levels of nitrogen fertilizer ( $0 \text{ kg ha}^{-1}$ ,  $41 \text{ kg ha}^{-1}$ ,  $82 \text{ kg ha}^{-1}$ , and  $123 \text{ kg ha}^{-1}$ ), at three locations. The treatments were laid out in a randomized complete block design (RCBD) in a  $4 \times 4$  factorial arrangement with three replications. In total, 16 treatments were used in the experiment. The total plot size of the experiment was  $1.6 \text{ m} \times 1.6 \text{ m}$  ( $2.56 \text{ m}^2$ ), while the net plot size was  $2.1 \text{ m}^2$ . The blocks were separated by one meter, and the space between each plot within a block was 0.5 meter.

### **4.2.4. Experimental procedures**

Seeds of each onion variety were sown on well-prepared raised nursery beds and mulched with straw. After emergence, the mulching material was removed. Watering was done using a

fine watering can where the frequency was determined on the basis of climatic conditions. The seedlings were maintained for 55 days after sowing and hardened before being transplanted to the field. This was done by reducing the frequency of watering and making the soil to have a low moisture content when the seedlings were ready for field planting.

Healthy and vigorous 12–15 cm tall seedlings were carefully uprooted with their soil for transplanting. The selected seedlings were transplanted in January 2022 with a recommended double row spacing of 40 cm × 20 cm × 10 cm (MoARD., 2004).

All agronomic practices were applied according to the recommendation made for onion production (MoARD, 2004). The nitrogen fertilizer rates mentioned above as the treatments were applied in the form of Urea (46% N) in two equal splits, where the first 50% was applied 15 days after transplanting, while the remaining 50% was applied one month after transplanting. Triple superphosphate (46% P<sub>2</sub>O<sub>5</sub>) was used as a source of phosphorus and was applied at the rate of 92 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> during transplanting (Nikus Olani and Fekir Mulugeta, 2010).

Experimental plots were irrigated along furrow at four-day intervals for the first four weeks and then extended to seven-day intervals until the physiological maturity stage. Irrigation was completely stopped 15 days before harvesting for curing purposes. Onion bulbs were harvested when 70% of the plants in each plot showed neck fall (MoARD, 2004; IPGRI, 2001).

#### **4.2.5. Data collection**

Data on onion growth, yield, and quality parameters were recorded from the central four rows of the net plot area at the physiological maturity stage and harvesting time. Plant height, leaf number per plant, and leaf diameter were measured from ten randomly selected plants after exclusion of border rows and border plants, whereas days to physiological maturity, bulb diameter, average bulb weight, total, marketable, and unmarketable bulb yields were collected in the whole net plot area. Detail measurements of these parameters are described in 2.5.

#### **4.2.6. Data analysis**

The collected data were first checked to ensure that all ANOVA assumptions (normality) were met using the Shapiro-Wilk test. Data were subjected to analysis of variance (ANOVA) using the PROC GLM model of SAS computer software version 9.0 (SAS Institute Inc., 2008).

Following the Levens homogeneity test, a combined analysis of variance over location was performed using the SAS PROC MIXED procedure. The nitrogen fertilizer rate and variety were considered as fixed effects, whereas locations were considered as a random effect. Whenever ANOVA was significant ( $P < 0.05$ ), mean separation was carried out using least significant difference (LSD) tests (Gomez and Gomez., 1984). A simple regression analysis was conducted to determine nitrogen coefficients to develop the model using the PROC REG procedure for marketable bulb yield. The quadratic fit model was used to estimate the optimum values of nitrogen above which no additional net returns were predicted.

#### **4.2.7. Partial budget analysis**

Partial budget analysis following the procedures described by CIMMYT (1988) was performed to evaluate the economics of the treatments. The marketable yield was downscaled by 10% since the experimental yields are usually higher than those of farmers. The gross benefits of the treatments were estimated by multiplying the adjusted marketable bulb yield with the farm-gate price (20.00 Birr kg<sup>-1</sup>) of onion bulbs prevailing in the study area during harvest. The price of Urea fertilizer in local marketplaces was 32.50 ETB kg<sup>-1</sup>. Furthermore, the prices of onion seeds of Russet and Jambar are 16,000 ETB kg<sup>-1</sup>, Red Coach 13,000 kg<sup>-1</sup> Bombay Red 2,500 ETB kg<sup>-1</sup>, and labor costs 150.00 ETB day<sup>-1</sup>. The interactions of varieties and N-fertilizer rates were used to calculate gross incomes and variable costs. Seed, labor and Urea fertilizer costs were considered variable costs that changed with the treatments. The sum of these costs was considered as the total variable cost of the treatment. Net benefits from treatments were obtained by deducting total variable costs from gross benefit on a hectare basis, as indicated by CIMMYT (1988).

### 4.3. Results and Discussion

#### 4.3.4. Economic analysis of onion as influenced by the interaction of variety and nitrogen fertilizer rate

The partial budget analysis indicated that the application of 82 kg ha<sup>-1</sup> nitrogen fertilizer on Jambar (472,424.8 ETB ha<sup>-1</sup>) and Russet (447,164.80 ETB ha<sup>-1</sup>) varieties combined over the three locations recorded relatively the highest net benefits (Table 4.6). As indicated in Figure 4.1, the application of 82 kg ha<sup>-1</sup> nitrogen recorded the highest bulb yield, as well as the highest net return (Figure 4.3) across the three locations. An additional increase in the nitrogen rate beyond 82 kg ha<sup>-1</sup> reduced the net return of onion (Figure 4.3), and hence 82 kg ha<sup>-1</sup> N could be considered optimal for onion production in the study area.

Table 4.6. Partial budget analysis for onion production as influenced by variety and nitrogen fertilizer level across the three locations

| TC               | AMY             | ADJMY         | GB            | TVC            | Net benefit     | Dominance analysis | MRR%     |
|------------------|-----------------|---------------|---------------|----------------|-----------------|--------------------|----------|
| Bombay×0         | 16.65           | 14.985        | 299700        | 18000          | 281700          |                    |          |
| Bombay×41        | 19.03333        | 17.13         | 342600        | 22557.6        | 321042.4        |                    | 863.2263 |
| Bombay×82        | 20.95           | 18.855        | 377100        | 25115.2        | 351984.8        |                    | 1209.822 |
| Bombay×123       | 20.78667        | 18.708        | 374160        | 28672.8        | 345487.2        | D                  |          |
| Redcoach×0       | 17.53333        | 15.78         | 315600        | 52000          | 263600          | D                  |          |
| Redcoach×41      | 21.32333        | 19.191        | 383820        | 55557.6        | 328262.4        | D                  |          |
| Redcoach×82      | 23.14           | 20.826        | 416520        | 59115.2        | 357404.8        |                    | 15.94118 |
| Redcoach×123     | 23.36667        | 21.03         | 420600        | 62672.8        | 357927.2        |                    | 36.58824 |
| Russet×0         | 21.85           | 19.665        | 393300        | 64000          | 329300          | D                  |          |
| Jambar×0         | 20.34           | 18.306        | 366120        | 64000          | 302120          | D                  |          |
| Russet×41        | 25.14333        | 22.629        | 452580        | 67557.6        | 385022.4        |                    | 554.6839 |
| Jambar×41        | 24.07333        | 21.666        | 433320        | 67557.6        | 365762.4        | D                  |          |
| <b>Russet×82</b> | <b>30.19667</b> | <b>27.177</b> | <b>543540</b> | <b>71115.2</b> | <b>472424.8</b> |                    | 2456.78  |
| Jambar×82        | 28.79333        | 25.914        | 518280        | 71115.2        | 447164.8        | D                  |          |
| Russet×123       | 28.80333        | 25.923        | 518460        | 74672.8        | 443787.2        | D                  |          |
| Jambar×123       | 25.06333        | 22.557        | 451140        | 74672.8        | 376467.2        | D                  |          |

Note: MY = marketable yield; AMY = adjusted marketable yield; GB = gross benefit, TVC=total variable cost, NB = net benefit; D = dominated and MRR = marginal rate of return.

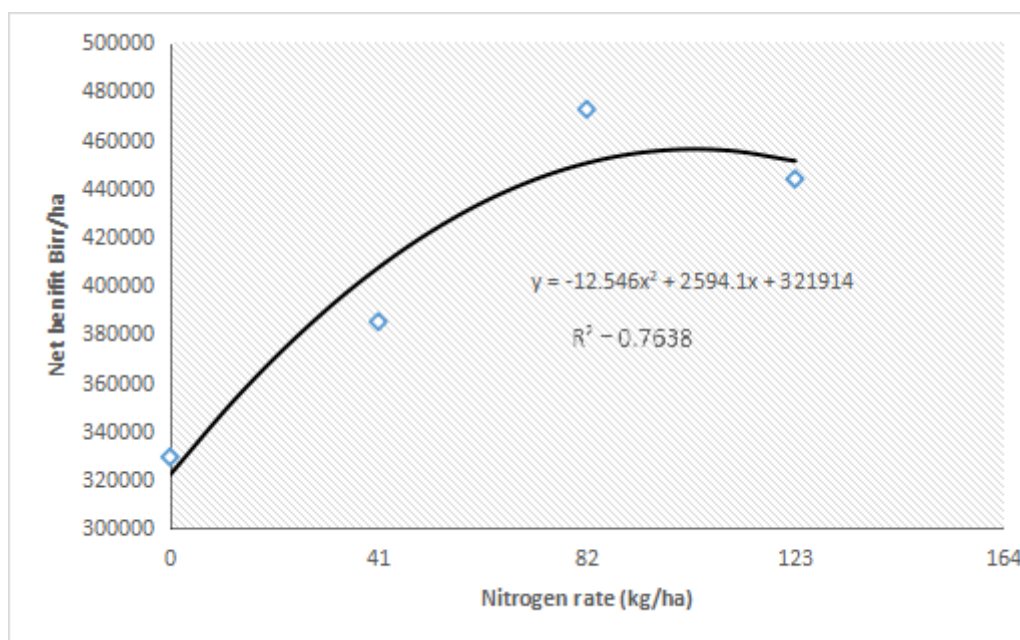


Figure 4.3. Polynomial curve fit and regression equation illustrating the relationship between nitrogen rate ( $\text{kg ha}^{-1}$ ) and net benefit ( $\text{Birr ha}^{-1}$ )

#### 4.4. Conclusion and Recommendations

The onion growth and yield parameters were influenced by the nitrogen fertilizer rate and variety across the three locations. Compared with the open-pollinated Bombay Red variety, the hybrid varieties (Russet and Jambar) performed well in terms of bulb diameter, bulb weight, total yield, and marketable bulb yield parameters. In general, the highest growth and yield parameters of onion were recorded when nitrogen fertilizer was supplied at a rate of  $82 \text{ kg ha}^{-1}$ . The onion plants supplied with  $82 \text{ kg ha}^{-1}$  nitrogen recorded the highest marketable bulb yield of 26.77. The experiment indicated that excessive N (above  $82 \text{ kg ha}^{-1}$ ) leads to decreased yield; hence, excess N is lost to the environment apart from economic loss.

The Russet and Jambar varieties recorded the highest marketable bulb yields, with values of  $26.50 \text{ t ha}^{-1}$  and  $24.57 \text{ t ha}^{-1}$ , respectively. The Russet and Jambar varieties and the  $82 \text{ kg ha}^{-1}$  nitrogen rate also recorded the greatest net benefit across all three locations. Given the significant economic benefits associated with their higher marketable yields, Russet and Jambar with  $82 \text{ kg ha}^{-1}$  nitrogen are recommended for production, particularly in northwest Amhara, where yield is prioritized. Therefore, Jambar and Russet varieties, and the application of  $82 \text{ kg ha}^{-1}$  nitrogen fertilizer are recommended for the economical production of

onions in the study areas, and other areas with similar agro-ecology. Future studies should consider other hybrid onion varieties and agronomic practices, such as spacing and phosphorous fertilizer along with repeating the experiment in another season. In addition, further research is required to enhance the quality characteristics of the high-yielding varieties.

## Chapter 5: INFLUENCE OF VARIETY AND PLANT DENSITY ON THE GROWTH, YIELD AND QUALITY OF ONION (*Allium cepa*)

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### Abstract

Onion is the most important and widely cultivated cash-generating crop in Ethiopia. Onion production is limited due to several factors, including low production and productivity. Among the many contributing factors, a lack of improved varieties and improper plant density are the major limiting factors. This study focused on assessing the effect of planting density and onion varieties on growth, bulb yield and quality of onion. Three hybrid and one open-pollinated onion varieties and three plant density (5cm, 10cm, and 15cm intra-plant spacing) were evaluated at three testing sites (Koga, Woramit, and Woreta) under irrigation conditions in 2021/2022 laid out in a randomized complete block design with three replications. The results of the present study revealed that the growth and yield of onion plants were influenced by the main effects of plant density and onion variety across locations. The Russet and Jambar hybrid varieties with a relatively high plant density exhibited superior performance across all locations. They consistently gave the highest values of bulb diameter, average bulb weight, harvest index, firmness, total bulb yield, and marketable bulb yield across all locations. The marketable bulb yield was positively correlated with the bulb weight and bulb diameter of the onion. The Russet (28.09 t ha<sup>-1</sup>) and Jambar (26.61 t ha<sup>-1</sup>) varieties yielded the highest marketable bulb yields and were generally superior in most growth, yield and quality parameters. The highest marketable bulb yield (28.42 t ha<sup>-1</sup>) was recorded from

*hybrid onion varieties and high plant population (666,666 plants ha<sup>-1</sup>), where the spacing between plants was 40cm x 20cm x 5cm spaced rows and double rows. Accordingly, hybrid onion varieties (Russet and Jambar) and higher plant populations (5 cm between plants) are recommended in the study area, as well as similar agro-ecology. It is advisable to consider other hybrid onion varieties with relatively high plant densities and repeat the experiment in another season.*

Keywords: Hybrid onion variety, marketable bulb yield, plant density, russet variety

## **5.1. Introduction**

Agricultural research institutes in Ethiopia have introduced 28 onion varieties, including 10 improved open-pollinated varieties and 18 hybrid types, aiming to increase onion production (MoARD, 2019; Lemma Dessalegn and Shimelis Aklilu, 2003). Despite these achievements, additional research is needed to optimize the agronomic practices and complete the production packages, particularly for hybrid onion varieties.

Evaluating and using high-yielding onion varieties is the best strategy for improving productivity (Ahmed *et al.*, 2013). In Ethiopia, many farmers, especially in the Amhara Region, traditionally use open-pollinated varieties, such as Bombay Red and Adama Red with narrow intra-row spacing. However, in recent years, hybrid onion varieties with different practices of spacing have been introduced. Some adhere to outdated recommendations used for open-pollinated varieties (10 cm between plants and 20 cm between rows), while others use –inconsistent/unspecified spacing (Yebirzaf Yeshiwas *et al.*, 2023; Gebremedhn Gebretsadkan *et al.*, 2018).

Plant spacing is a critical factor influenced by variety, the growing environment, and the production system (Lemma Dessalegn and Shimelis Aklilu, 2003). Optimization of the plant population, considering variety, environmental conditions, and soil fertility, significantly affects onion bulb characteristics, yield, and quality (Alemu Direbsa, 2022; Chang *et al.*, 2015; Brewster, 1994). Wider spacing enhances yield per plant, whereas closer spacing

increases yield per unit area up to a certain spacing point (Alemu Direbsa *et al.*, 2022; Bhuiyan *et al.*, 2012; Abubaker, 2008).

Proper spacing minimizes competition among plants for essential growth factors, optimizing light, water, and nutrient utilization (Candian *et al.*, 2017). Efficient land use without wastage is achieved through optimal plant populations per unit area, which is of a crucial factor in enhancing onion productivity (Geremew Awas *et al.*, 2010; Zobelidza and Gases, 1977). Ongoing and future researches should be focused on improving agronomic practices to fully realize the potential of hybrid onion varieties and improve overall onion productivity in Ethiopia. Therefore, the present study aimed to investigate the effect of plant density and variety on the productivity and quality of onions in northwestern Amhara, Ethiopia.

### **Hypotheses testing**

The hypotheses in the present study were as follows:

**Null Hypothesis (H<sub>0</sub>)** There is no significant difference among plant density and onion varieties in growth, yield, and quality traits.

## **5.2. Materials and Methods**

### **5.2.1. Description of the study area**

Field experiments were carried out at three potential onion-producing locations in northwestern Amhara Region, Ethiopia. detailed descriptions of the study areas are presented in 2.1.

### **5.2.2. Experimental planting materials**

Three onion hybrids, namely (Russet, Red Coach and Jambar) and one open-pollinated (Bombay Red) onion varieties, were used in this study. Seeds of the hybrid onion varieties were purchased from a commercial supplier, Eshet Agricultural Input Supplier), located in Bahir Dar, Ethiopia, while seeds of the Bombay Red variety were sourced from the Melkassa Agricultural Research Center (MARC), Ethiopia. These onion varieties were selected based on findings from a preliminary pilot survey, where farmers preferred them for their growth

and yield performance (Yebirzaf Yeshiwas *et al.*, 2023). The general characteristics of the selected onion varieties are presented in Table 2.3.

### **5.2.3 Experimental treatments and design**

The experiments consisted of four onion varieties and three levels of intra-row spacing (5, 10, 15 cm), with plant populations of high (666,666), medium (333,333), and low (222,222) plants ha<sup>-1</sup>. The treatments were laid out in the randomized complete block design (RCBD) with 4 × 3 factorial arrangements and three replications. Each treatment combination was randomly assigned to experimental units within a block at each location.

### **5.2.4. Experimental procedures and agronomic management**

The seeds of each variety were seeded on well-prepared raised beds and mulched with straw. After germination, the mulching material was removed. Watering was carried out using a fine watering cane, and the frequency of watering was determined according to the climatic conditions. The seedlings were maintained for 55 days after sowing and hardened before being transplanted to the field. Hardening was done by reducing the frequency of watering and leaving the soil at a low moisture level when the seedlings were ready to be planted in the field.

Healthy and vigorous seedlings 55 days after sowing were carefully uprooted with their soil and transplanted into the experimental plots with a gross plot size of 1.6 m × 1.6 m (2.56 m<sup>2</sup>). The blocks were separated by one meter, while the space between each plot within a block was 0.5 meter and with the recommended double row planting system: 40 cm between irrigation furrows, 20 cm spacing between rows, and 5 cm, 10 cm, and 15 cm intra-row spacing with a population of high, medium and low plants per hectare, respectively. Each plot had three double rows (MoARD., 2019).

All other agronomic practices were applied uniformly for all the treatments according to the recommendation used for onions (MoARD., 2004). Nitrogen fertilizer was applied at a rate of 82 kg ha<sup>-1</sup> using Urea (which contains 46% nitrogen) (Yebirzaf Yeshiwas *et al.*, 2024b). This was applied in split into two equal parts: the first half was applied 15 days after transplanting,

when the seedlings had fully established, and the second half was applied during the vegetative growth stage. Phosphorus fertilizer, in the form of triple superphosphate (46%  $P_2O_5$ ), was applied at a rate of 92 kg ha<sup>-1</sup>. The entire quantity of phosphorus fertilizer was incorporated into the soil at the time of transplanting (Nikus Olani and Fekir Mulugeta, 2010).

Irrigation water was applied using a furrow irrigation system at four-day intervals for the first four weeks and then extended to seven-day intervals until the crops reached the physiological maturity stage. Irrigation was stopped 15 days before harvest to harden the plants, allowing the bulbs to fully mature and their outer skins to dry, thereby enhancing storage quality (IPGRI, 2001; MoARD., 2004).

#### **5.2.5. Data collection**

The growth, yield, and quality parameters of the onion were collected from net plot areas of 1.86 m<sup>2</sup>, 1.8 m<sup>2</sup>, and 1.74 m<sup>2</sup> at 5, 10, and 15 cm intra-row spacing, respectively. Parameters were collected using the standard procedures described in section 2.5. Onion bulbs were harvested when 70% of the plants in each plot showed neck fall (MoARD, 2016; MoARD, 2004).

#### **5.2.6. Data analysis**

The collected data were initially checked to meet all ANOVA assumptions (normality, homogeneity, and residual) after Levene's homogeneity test. The data were subjected to analysis of variance (ANOVA) using the PROC MIXED procedure of SAS computer software version 9.0. Plant density and onion varieties were considered fixed effects, and location was considered as a random effect. When ANOVA revealed significant differences ( $P < 0.05$ ), the mean separation was carried out using Tukey's Honestly significant difference (THSD) test.

### **5.3. Results and Discussion**

#### **5.3.1. Effects of plant density on the phenology and vegetative growth of onion varieties**

### ***Days to physiological maturity***

The number of days required to reach physiological maturity was significantly ( $P<0.05$ ) influenced by the main effects of onion variety and plant density. The interaction of variety and density did not influence the physiological maturity of onion (Appendix Table 5.1).

The Russet onion variety reached maturity earlier than the Bomby Red variety, with differences of 13 days (Table 5.1). Previous studies have shown differences in maturity among onion varieties (Awoke Ali *et al.*, 2021; Hannachi *et al.*, 2014). Variations in physiological maturity also reflect genotypic differences in onion varieties in the length of growth period and maturity, which affects the transfer of photosynthetic materials from leaves to bulbs and the improvement of the growth rate that results in early bulb initiation and maturity (Pardeshi and Waskar, 2012).

The physiological maturity of the hybrid varieties is generally earlier than that of the open-pollinated varieties due to the heterosis genetic effect. These plants also exhibit increased photosynthetic efficiency, and the breeding is targeted for early maturity, ensuring timely harvests and multiple cropping cycles (Labro *et al.*, 2021). Similar results were reported where significant variations in days to maturity among onion varieties were observed (Alemu Diribsa *et al.*, 2022; Fikre and Mensa, 2021).

Furthermore, the Russet onion variety showed early physiological maturity due to its ideal number of leaves per plant (9). These findings are in line with the findings of Birhanu Lencha and Tilahun Bergen (2023), Kebede Woldetsadik (2003), and Cramer (2001), who claimed that hybrid onion varieties matured earlier than open-pollinated ones. With respect to plant density, a significant delay in maturity was observed as the plant population decreased. Early maturity was recorded at the highest plant density, while onion plants planted at low plant populations required an extended period to reach maturity across the three locations (Table 5.1). The early maturity of a high-density plant population may be caused by an inadequate supply of water and nutrients to prolong growth and metabolic processes. Plant density also influences physiological maturity by intensifying competition for abiotic factors such as light,

water, and nutrients, which ultimately accelerate maturity as plants allocate more resources to reproduction (Zhang *et al.*, 2021; Chapepa *et al.*, 2020). These results are consistent with the findings of Hidayatullah and Jillani (2018), who reported that plants grown at greater density matured in the shortest duration. Similar findings have been reported that plants grown at the lowest density took more time to reach maturity while those at the highest density matured early (Dasash Atalay *et al.*, 2022; Habtamu Tegen *et al.*, 2016;).

Table 5.1. Effects of variety and plant density on the number of days to physiological maturity of onion plants

| Onion varieties           | Days to physiological maturity |
|---------------------------|--------------------------------|
| Russet                    | 93.7 <sup>c</sup>              |
| Red Coach                 | 99.4 <sup>b</sup>              |
| Jambar                    | 98.8 <sup>b</sup>              |
| Bombay Red                | 105.2 <sup>a</sup>             |
| THSD <sub>0.05</sub>      | 4.3                            |
| SE±                       | 1.24                           |
| P values                  | ***                            |
| <b>Plant density</b>      |                                |
| Low (222,222 plants/ha)   | 99.7 <sup>a</sup>              |
| Medium (333,333 plant/ha) | 99.2 <sup>a</sup>              |
| High (666,666 plants'ha)  | 96.2 <sup>b</sup>              |
| THSD <sub>0.05</sub>      | 3.4                            |
| SE±                       | 1.23                           |
| P values                  | ***                            |
| CV (%)                    | 6.09                           |

where; \*\*\* = very highly significant at  $P < 0.001$ . means followed by the same letter (s) within a column are not significantly different; THSD<sub>0.05</sub> = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation.

### **Plant height**

The combined analysis across locations revealed that onion plant height was influenced ( $P < 0.001$ ) by variety and density. However, the interactions between variety and density did not influence onion plant height (Appendix Table 5.1).

The highest plant height (52.98 cm) was recorded for the Bombay Red cultivar, which was not significantly different from that of Red Coach (51.8 cm) and Jambar (51.51cm), while the lowest plant height (48.14 cm) was recorded for Russet cultivar. Onion seedlings transplanted at the lowest density of 222,222 and 333,333 plants ha<sup>-1</sup> showed the longest plants with a height of 52.56 cm and 51.8 cm, respectively, while high-density plants had the shortest (48.97cm) plant height (Figure 5.1).

Various scholars have also observed significant differences in plant height between onion varieties (Wubetie Adnew *et al.*, 2022; Gebretsadkan Gebremedhn *et al.*, 2018; Geremew Awas, 2010). Plant height is directly influenced by the availability of growth factors and their capacity to compete for these factors within a plant population. In densely populated plantings, intense competition for water, nutrients, and light results in shorter plant growth. However, in less populated plants, plants can fulfill their requirements for growth and development, promoting taller growth and overall better development. These findings are in line with the results of Alemu Diribsa *et al.* (2022) and Wubetie Adinew *et al.* (2022), who observed the tallest onion plants at the lowest plant densities.

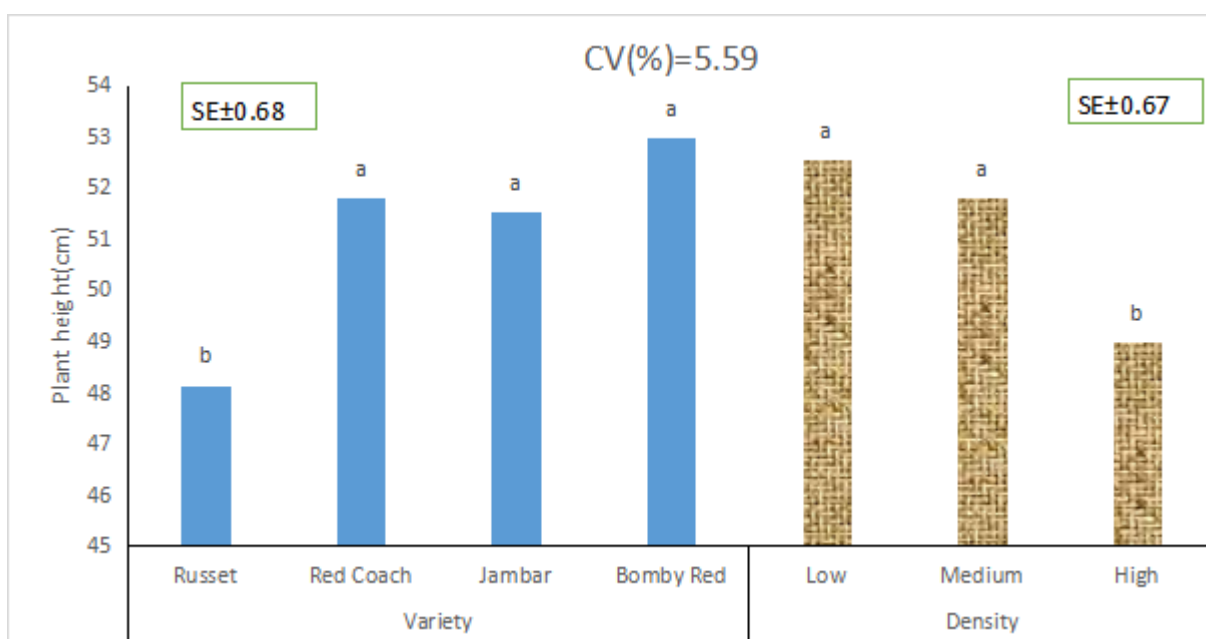


Figure 5.1. Effects of variety and density on the diameter of the plant height across the three locations

### ***Leaf number per plant***

The number of leaves per onion plant was highly significantly ( $P<0.001$ ) influenced by variety and plant density. However, the two-way interaction of variety and density did not influence the number of onion leaves per plant (Appendix Table 5.1). Consequently, the highest mean number of leaves was obtained for the Bombay Red variety, which was significantly statistically similar to that of the Jambar variety. The densest onion plants produced the lowest number of leaves per plant (8.27), while the less populated plants produced the highest number of plants (Table 5.2).

These results are in agreement with the findings of other scholars who reported significant differences in number of leaves between onion varieties (Kokobe W/Yohannes and Hirut Tsegaye, 2021; Bindu and Podikunju, 2015; Ayam *et al.*, 2014). In this regard, Steer (1980) reported that Bombay Red bulbs produced more splitter bulbs/shoots from multiple growing points, facilitating the production of more leaves per plant, as indicated in the present study.

The present study revealed that the planting density and the number of leaves are inversely related. As the plant population increased, the number of leaves per onion plant decreased. The lowest number of leaves observed at the highest plant density was probably attributed to the increased competition between plants for light, nutrients, and moisture. Brewster (2008) suggested that onion plants with approximately 6 to 8 fully expanded leaves can sustain optimal photosynthetic activity. Other researchers also reported similar results: more leaves per plant were recorded at the lowest plant density, while fewer leaves were produced on highly populated onion plants (Nasir *et al.*, 2007; Mekdes Atakelt, 2012; Alemu Deribsa *et al.*, 2022). Akoun (2005) also observed that the plant population significantly influenced different onion parameters, including the number of leaves produced per plant, leaf area, bulb diameter, and yield.

### ***Leaf diameter (cm)***

The combined analysis of variance showed that the main effects highly significantly ( $P<0.001$ ) influenced the diameter of the onion leaf. On the other hand, the interactions

between variety and density did not influence onion leaf diameter ( $P>0.05$ ) (Appendix Table 5.1).

The greatest mean leaf diameter was recorded from the Russet and Jambar varieties. Similarly, plants grown at the lowest plant density had the widest leaf diameter, while the smallest leaf diameter was recorded from plants grown at the highest plant density (Table 5.2). Generally, the leaves of hybrid onion varieties (Russet and Jambar) were wider than those of the open-pollinated Bombay Red variety. Chen and Chen (2013) and Cramer (2001) reported that hybrid onion cultivars tend to produce wider leaves than open-pollinated varieties. Breeders intentionally select wider leaf traits from parental lines to develop hybrids with enhanced qualities, yield, disease resistance, and adaptability to diverse environmental conditions.

The wider leaf diameter recorded at the lowest plant density might be due to sufficient light in the wider-spaced plants, which is essential for photosynthesis and nutrient uptake compared to those of the closely spaced plants. These results agree with those of many authors who also reported significant variation in leaf diameter due to differences in plant density (Demisie and Tolessa, 2018; Guesh Tekle, 2015; Seid and Fikirte, 2014; Yemane Kahsay, 2011).

Table 5.2. Effects of onion variety and plant density on leaf number and diameter across three locations

| <b>Onion varieties</b>                    | <b>Leaf number per plant</b> | <b>Leaf diameter</b> |
|-------------------------------------------|------------------------------|----------------------|
| Russet                                    | 8.5 <sup>c</sup>             | 8.7 <sup>a</sup>     |
| Red Coach                                 | 9.1 <sup>bc</sup>            | 7.4 <sup>b</sup>     |
| Jambar                                    | 9.0 <sup>b</sup>             | 9.1 <sup>a</sup>     |
| Bombay Red                                | 10.0 <sup>a</sup>            | 7.2 <sup>b</sup>     |
| THSD <sub>0.05</sub>                      | 0.57                         | 0.9                  |
| SE±                                       | 0.14                         | 0.22                 |
| P values                                  | ***                          | ***                  |
| <b>Plant density</b>                      |                              |                      |
| Low (222,222 plants ha <sup>-1</sup> )    | 10.0 <sup>a</sup>            | 8.6 <sup>a</sup>     |
| Medium (333,333 plants ha <sup>-1</sup> ) | 9.1 <sup>b</sup>             | 8.2 <sup>ab</sup>    |
| High (666,666 plants ha <sup>-1</sup> )   | 8.2 <sup>c</sup>             | 7.6 <sup>b</sup>     |
| THSD <sub>0.05</sub>                      | 0.4                          | 0.7                  |
| SE±                                       | 0.16                         | 0.22                 |
| P values                                  | ***                          | ***                  |
| CV (%)                                    | 8.81                         | 15.05                |

Where; \*\*\* = very highly significant at  $p < 0.001$ . means followed by the same letter (s) within a column are not significantly different; THSD<sub>0.05</sub> = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation.

### **5.3.2. Effects of variety and plant population on bulb yield and yield-related traits**

#### ***Bulb neck diameter (cm)***

The results of the analysis of variance indicate that the diameter of the onion bulb neck was significantly ( $P < 0.01$ ) influenced by the main effects of density and variety. However, the interaction of variety and density did not significantly influence onion bulb neck diameter ( $P > 0.05$ ) (Appendix Table 5.1).

The Bombay Red variety had the widest neck diameter, which was statistically similar to that of the Red Coach, while the lowest bulb neck diameter was obtained from Russet, which was statistically similar to that of the Jambar variety. On the other hand, the highest bulb neck diameter was recorded from the lowest (222,222 ha<sup>-1</sup> plants) plant density, while the highest plant density (666,666 plant ha<sup>-1</sup>) resulted in the thinnest bulb neck diameter (Figure 5.2).

The genetic composition and inherent traits of onion varieties contribute to the differences in bulb neck diameters as reported by Fery and Eissa (2002), which could also be true in the present study. The findings by Gautam *et al.* (2019) also indicated varying bulb neck diameters in different onion genotypes.

The wider bulb neck diameter observed in plants grown with a wider plant spacing (lowest plant density) is associated with less competition among plants for growth factors. Under these circumstances, the vegetative growth of the plants is enhanced, which in turn leads to wider bulb neck diameter as observed in the present study. On the other hand, high plant populations may have exerted pressure on the scarcity of growth factors such as light, space, moisture, and nutrients, leading to reduced vegetative growth and narrow bulb neck diameter (Khan *et al.*, 2003). According to Wubetie Adnew (2022), planting onions at higher densities can lead to smaller bulbs and reduced neck diameters, as plants compete for growth resources,

while lower planting densities can promote better bulb growth and potentially result in larger neck diameters.

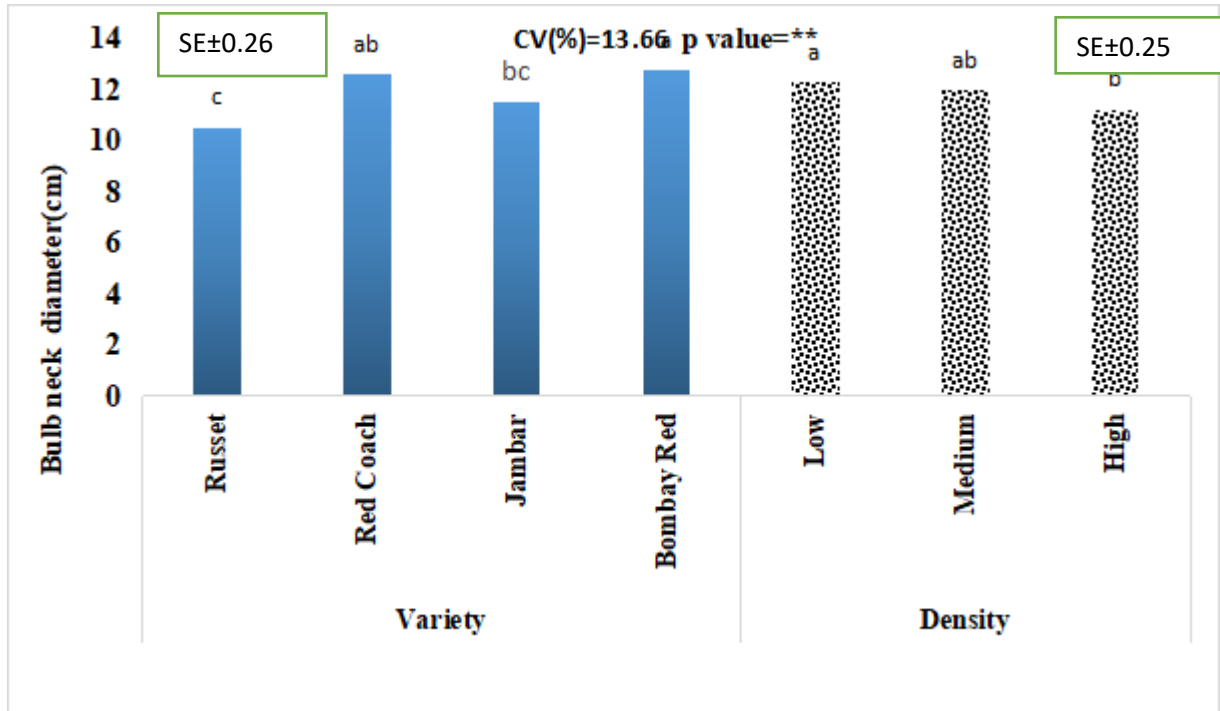


Figure 5.2. Effects of variety and density on the diameter of the onion bulb neck at the three locations

#### ***Average bulb diameter (cm) and bulb weight (g)***

Analysis results of variance indicated a highly significant difference ( $P < 0.01$ ) among the varieties and plant densities for the diameter of the onion bulb. However, the effects of the variety-density interaction did not influence the diameter of the onion bulb (Appendix Table 5.1). The average bulb weight of onions was highly influenced ( $P < 0.001$ ) by the main effects of variety and density. The interactions of variety and density did not significantly affect onion bulb weight ( $P > 0.05$ ) as shown in Appendix Table 5.1.

Hybrid onion varieties produced bulbs with the largest diameter and weight, which were statistically comparable to each other. In contrast, the Bombay Red variety exhibited the smallest diameter and weight. The higher plant density resulted in smaller bulb diameters and lighter weights than lower plant density (Table 5.3).

An increase of diameter and weight of onion bulb signify the potential for onion yield. These hybrid varieties excel compared to the local open-pollinated Bombay Red variety due to inherent differences. This finding aligns with the findings of Kokobe W/Yohannes and Hirut Tsegaye (2021), who noted significant variations in onion cultivar for length, diameter and weight.

Intense competition for resources negatively affects overall onion plant performance and reduces bulb diameter and weight. Densely populated onion plants are subjected to restricted nutrient availability, limited sunlight interception, decreased photosynthetic activity, and water stress, which in turn hinder bulb expansion. Previous research conducted by Alemu Direbsa *et al.* (2022), Yldrm and Ciftci (2011), and Brewster (2008) support the findings of the present study. Furthermore, studies conducted by Sikder *et al.* (2010), Muhammad *et al.* (2011), and Jilani *et al.* (2009) confirmed that decreasing plant density results in increased weight and size of individual onion bulbs.

Table 5.3. The main effects of variety and density on onion average bulb diameter and bulb weight across the three locations

| <b>Onion varieties</b>                    | <b>Bulb diameter (cm)</b> | <b>Bulb weight (g)</b> | <b>Harvest index</b> |
|-------------------------------------------|---------------------------|------------------------|----------------------|
| Russet                                    | 67.2 <sup>a</sup>         | 102.2 <sup>a</sup>     | 87.3 <sup>a</sup>    |
| Red Coach                                 | 65.8 <sup>ab</sup>        | 102.2 <sup>a</sup>     | 83.5 <sup>b</sup>    |
| Jambar                                    | 68.3 <sup>a</sup>         | 100.9 <sup>a</sup>     | 86.2 <sup>ab</sup>   |
| Bombay Red                                | 62.6 <sup>b</sup>         | 84.9 <sup>b</sup>      | 80.1 <sup>c</sup>    |
| THSD <sub>0.05</sub>                      | 4.4                       | 9.0                    | 34.29                |
| SE±                                       | 1.46                      | 2.07                   | 1.03                 |
| P values                                  | **                        | ***                    | **                   |
| <b>Density</b>                            |                           |                        |                      |
| Low (222,222 plants ha <sup>-1</sup> )    | 68.5 <sup>a</sup>         | 104.7 <sup>a</sup>     | 83.6                 |
| Medium (333,333 plants ha <sup>-1</sup> ) | 66.1 <sup>ab</sup>        | 99.8 <sup>a</sup>      | 85.7                 |
| High (666,666 plants ha <sup>-1</sup> )   | 63.3 <sup>b</sup>         | 88.2 <sup>b</sup>      | 83.6                 |
| THSD <sub>0.05</sub>                      | 3.4                       | 7.1                    | 3.4                  |
| SE±                                       | 1.43                      | 2.02                   | 1.04                 |
| P values                                  | **                        | ***                    | ns                   |
| CV (%)                                    | 9.36                      | 12.91                  | 7.11                 |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \*\* = highly significant at  $P < 0.01$ ; ns = non-significance means followed by the same letter (s) within a column are not significantly different; THSD<sub>0.05</sub> = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation

### **Total bulb yield (t ha<sup>-1</sup>)**

The combined analysis of variance showed that variety and plant density highly significantly influenced the total bulb yield ( $p < 0.0001$ ). However, the interaction of variety and density did not affect total bulb yield (Appendix Table 5.1). Russet had the highest bulb yield, statistically similar to that of Jambar, while Bombay Red had the lowest yield. Increasing the plant density to 666,666 plants ha<sup>-1</sup> increased the total bulb yield (Table 5.4). The different plant densities contributed to the yield variation by 42.43%. This reveals the importance of variety and planting density in optimizing the onion yield.

The yield of onions depends on variety, environmental conditions, and agronomic practices, and it is influenced by the genetic makeup and the interaction of the genotype and environment (Jilani and Ghaffoor, 2003; Yemane Kahsay *et al.*, 2014; Bindu and Bindu, 2015; Das *et al.*, 2015; Tegbew Walle *et al.*, 2018; Gautam, *et al.*, 2019). Hybrid onion varieties consistently outperformed the open-pollinated Bombay Red variety. These results also align with the findings on tomato cultivation (Devkota *et al.*, 2018; Islam *et al.*, 2012). An increase in plant density also correlates with the increase in garlic bulb yield as reported by Fikreyohannes Gedamu (2005), and Hemla and Hosmani (2003). This highlights the effect of genetic factors and planting density on improving onion and garlic productivity.

The plant population directly affects the yield of onion bulbs. Similar to the results of the present study, Geremew Awas (2010), Kantona *et al.* (2003), AVRDC (2004), Sara Belay (2015), and Yohannes Gebremichael *et al.* (2019) reported that increasing the plant population from 222,222 to 666,666 plants ha<sup>-1</sup> led to an increase of total bulb yield by 42.4%. Kantona *et al.* (2003) also observed an increase in onion yield from 17.4 to 39.5 t ha<sup>-1</sup> with an increase in plant population from 50 to 150 plants per square meter. However, the higher plant density reduced the diameter and weight of individual onion bulbs (Table 5.3), which is consistent with the findings of other researchers (Sikder *et al.*, 2010). According to

Zubelidia and Gases (1977), optimizing plant populations minimizes intense competition between plants for growth factors and helps the efficient utilization of available cropland. He *et al.* (2022) and AL-Naggar *et al.* (2021) reported that high plant density resulted in the highest grain yield for hybrid maize cultivars, which reflects that hybrids exhibit greater density tolerance, contributing to their superior performance in terms of grain yield.

### **Marketable bulb yield ( $t\ ha^{-1}$ )**

Analysis of variance revealed that variety and plant density highly influenced ( $P<0.001$ ) the marketable bulb yield of onion, while their interaction did not influence the marketable bulb yield of onion (Appendix Table 5.1).

The highest marketable bulb yield across the three locations was obtained from the Russet and Jambar varieties, whose yields were statistically similar. However, the lowest marketable bulb yield was recorded from the variety of Bombay Red. Onion plants grown at the highest plant density produced the highest marketable bulb yield, followed by those grown at the medium plant density. The plants grown in the lowest plant population produced the lowest marketable bulb yield, as shown in Table 5.4.

The trend of marketable yield of onion generally increased and reached a plateau at higher densities, which was optimal for onion production across all locations. However, a further increase in the plant population reduced the marketable bulb yield, as shown in Figure 5.3. The marketable yield increased with increasing plant density due to the accommodation of more plants per unit area, increasing the bulb yield per unit area. However, this increase in bulb yield depends on the availability of enough nutrients and other growth factors. In this regard, Yemane Kahsay *et al.* (2013) and Khan *et al.* (2003) indicated that as the plant density decreased from 666,666 plants  $ha^{-1}$  to 333,333 plants  $ha^{-1}$ , the marketable bulb yield decreased from 34.49  $t\ ha^{-1}$  to 28.10  $t\ ha^{-1}$ . Similarly, Kantona *et al.* (2003) reported increased marketable bulb yields with the increased onion plant density. Therefore, plant density determines marketable yield at varying locations (Kim and Park, 2023).

As shown in Fig. 5.4a and 5.4b, the marketable yield of onion has a positive relationship with the diameter and weight of onion bulbs. On the other hand, bulb weight has a negative relationship with days to physiological maturity (Figure. 5.4c).

The highest marketable yields observed by Russet and Jambar varieties in the present study were attributed to the increase in the diameter and weight of onion bulbs (Table 5.3). The difference in yield potential of onion varieties is associated with the genetic variation of the varieties as reported by various researchers (Alemu *et al.*, 2022; Gebremedhn Gebretsadkan *et al.*, 2018; Hailu Dinka *et al.*, 2015; Geremew Awas *et al.*, 2010). In recent meta-analyses by Garcia and Nguyen (2023), the onion variety significant affected marketable bulb yield. The analysis revealed that specific varieties consistently outperformed others, regardless of the planting density or specific environmental conditions

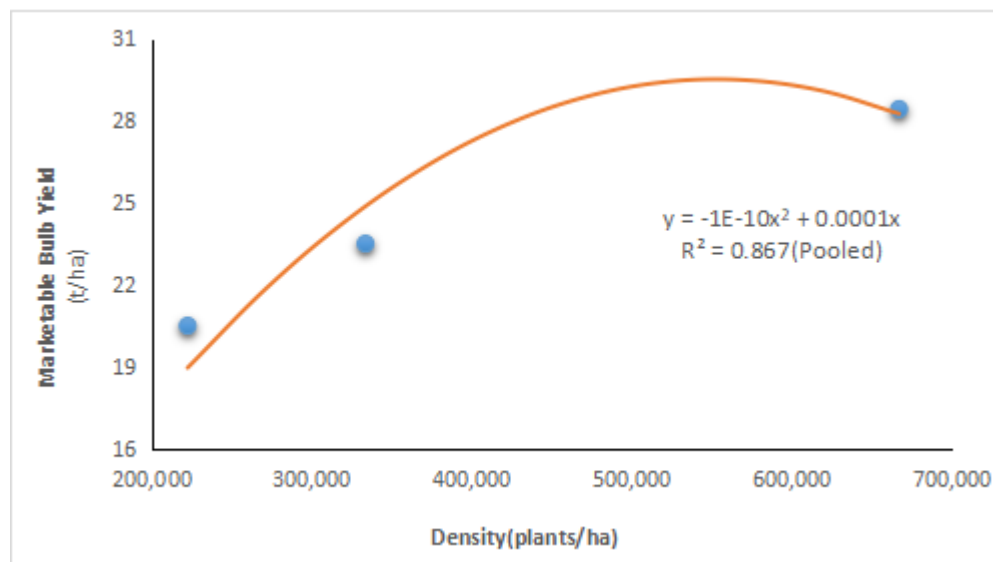


Figure 5.3. Trends of marketable onion bulb yield as influenced by plant density across three study locations

#### *Unmarketable bulb yield (%)*

The analysis of variance indicated that the variety influenced ( $P < 0.0001$ ) the unmarketable bulb yield of onion, while the plant density and the interaction did not influence the unmarketable bulb yield (Appendix Table 5.1).

The highest percentage of unmarketable bulb yield was obtained from the Bombay Red and Red Coach varieties, while the lowest percentage of unmarketable bulb yield was recorded from the Russet and Jambar varieties (Table 5.4). The difference in unmarketable yield between onion varieties could be attributed to the genetic variation of the onion varieties. Fikre and Mensa (2021) reported similar results, as variations in unmarketable bulb yield were observed between different onion varieties. Wubetie Adnew *et al.* (2022) indicated that the unmarketable bulb yield of onion cultivars was not significantly affected by plant density and the interaction of varieties and density.

Table 5.4. Responses of onion bulb yield to variety and plant population across the three locations

| <b>Varieties</b>                          | Marketable yield (t ha <sup>-1</sup> ) | Unmarketable yield (%) | Total yield (t ha <sup>-1</sup> ) |
|-------------------------------------------|----------------------------------------|------------------------|-----------------------------------|
| Russet                                    | 28.1 <sup>a</sup>                      | 0.9 <sup>b</sup>       | 28.5 <sup>a</sup>                 |
| Red Coach                                 | 23.1 <sup>b</sup>                      | 1.8 <sup>a</sup>       | 24.5 <sup>b</sup>                 |
| Jambar                                    | 26.6 <sup>a</sup>                      | 0.9 <sup>b</sup>       | 27.2 <sup>ab</sup>                |
| Bombay Red                                | 18.8 <sup>c</sup>                      | 1.9 <sup>a</sup>       | 19.4 <sup>c</sup>                 |
| THSD <sub>0.05</sub>                      | 4.4                                    | 0.2                    | 4.4                               |
| SE $\pm$                                  | 1.01                                   | 0.06                   | 1.02                              |
| P values                                  | ***                                    | ***                    | ***                               |
| <b>Density</b>                            |                                        |                        |                                   |
| Low (222,222 plants ha <sup>-1</sup> )    | 20.5 <sup>c</sup>                      | 1.3                    | 20.9 <sup>c</sup>                 |
| Medium (333,333 plants ha <sup>-1</sup> ) | 23.5 <sup>b</sup>                      | 1.4                    | 23.8 <sup>b</sup>                 |
| High (666,666 plants ha <sup>-1</sup> )   | 28.4 <sup>a</sup>                      | 1.3                    | 29.8 <sup>a</sup>                 |
| THSD <sub>0.05</sub>                      | 3.4                                    | 0.2                    | 3.4                               |
| SE $\pm$                                  | 0.98                                   | 0.97                   | 0.98                              |
| P values                                  | ***                                    | ns                     | ***                               |
| CV (%)                                    | 25.86                                  | 30.85                  | 28.81                             |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; ns = non-significant means followed by the same letter (s) within a column are not significantly different; THSD<sub>0.05</sub> = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation

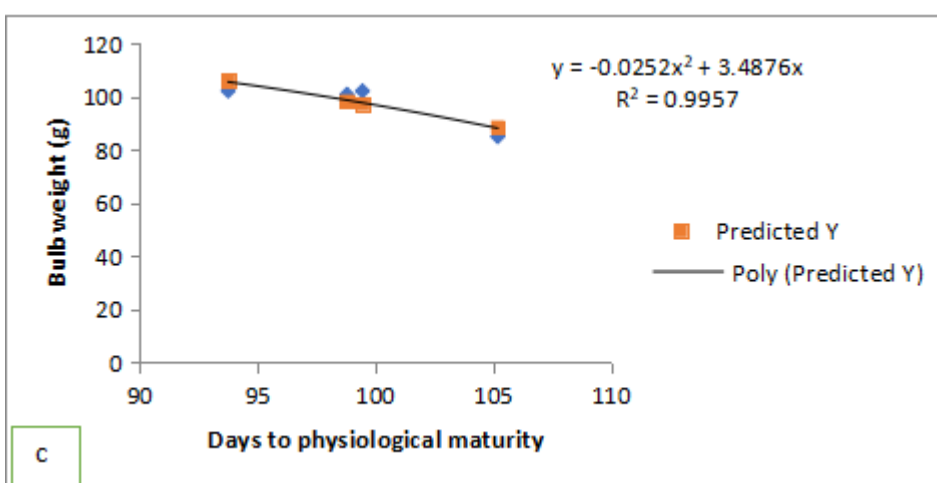
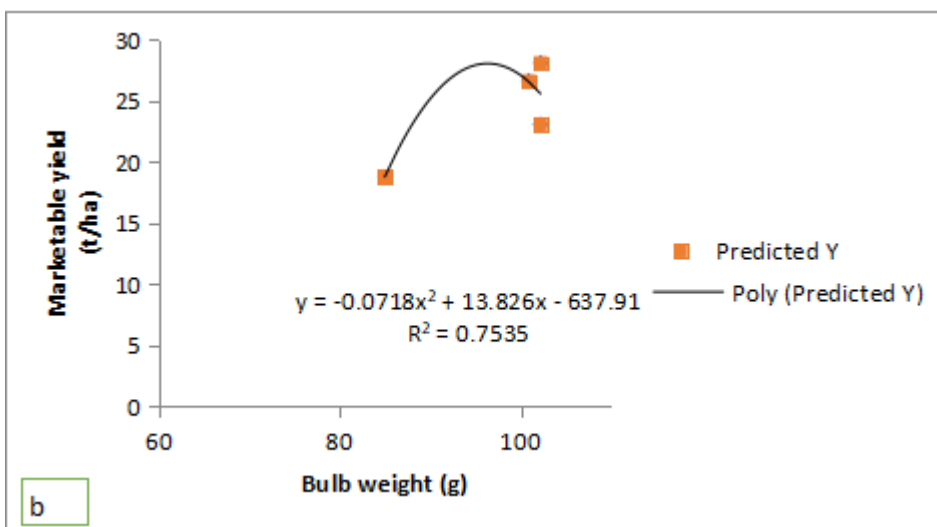
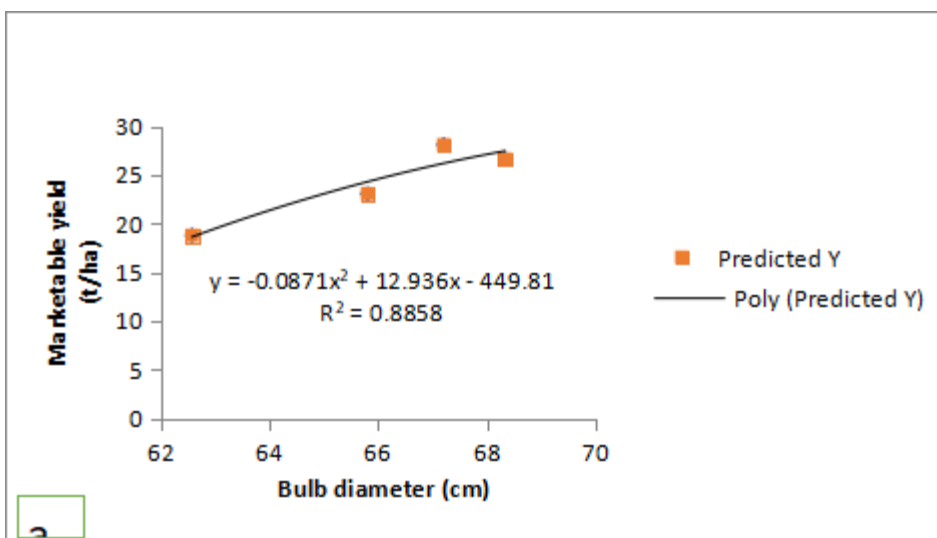


Figure 5.4. Trends of marketable bulb yield as influenced by bulb diameter (a), bulb weight (b); and of bulb weight as influenced by days to physiological maturity (c) across three locations

### ***Harvest index***

Analysis of variance revealed that variety influenced ( $P<0.001$ ) the onion harvest index, while plant density as well as an interaction of variety and density did not influence the onion harvest index (Appendix Table 5.1).

The highest mean harvest index was recorded from the Russet variety, which was statistically similar to that of the Jambar variety, while the lowest harvest index was recorded from the Bombay Red variety (Table 5.3). The harvest index is a measure of the success of the partitioning of photosynthetic assimilates. The harvest index is variable and calculated to reflect the crop yield performance (Gemechu Asefa, 2019). The greater harvest index of the Russet and Jambar onion varieties observed in the present study could be attributed to the higher average bulb weight of the varieties (5.3). These results agree with the findings of Tegbew Walle *et al.* (2018), who reported significant variations in the harvest index between onion varieties.

### **5.3.3. Marketable bulb yield distribution**

The combined analysis of variance revealed that variety and plant population/density influenced ( $P<0.001$ ) the percentage of small, medium, and large bulbs of onion. The density and variety interaction significantly ( $P<0.001$ ) influenced the percentages of medium and large bulbs (Appendix Table 5.1).

Increasing the plant density significantly increased the percentage of small bulb yield. The highest small bulb percentages were recorded from the Bombay Red variety and the highest planting density (Table 5.5). In the interaction effect, the highest percentage of medium-sized bulbs was recorded by the treatment combination of Russet x high plant density, Jamber x high plant density and Bombay Red x medium plant density, which were statistically similar to one to another. Similarly, Russet and Jamber, combined with high plant density, recorded the lowest percentage of large-sized bulbs (Table 5.6).

Increasing the plant density significantly increased the percentage of small bulbs, but decreased the percentage of large bulbs of onion (Figure 5.5). This could be due to resource constraints at high densities that encourage the growth of smaller bulbs to ensure survival and reproduction even in the face of scarce supplies. According to Uddin *et al.* (2012), a high plant population causes a larger proportion of small bulbs in the total output. Several scholars have reported similar results, in which increasing the plant density decreased onion bulb sizes (Yemane Kahsay *et al.*, 2013; Jilani *et al.*, 2009). According to Yemane *et al.* (2013), decreasing the plant population from 666,666 plants ha<sup>-1</sup> to 333,333 plants ha<sup>-1</sup> increased the percentage of large bulbs from 9.3 to 20.3%. On the other hand, planting onion plants at higher densities results in the formation of smaller bulbs (Yohannes Gelaye *et al.*, 2024).

All onion varieties grown at a medium planting density produced the highest percentage of medium-sized bulb yield (Table 5.6). Onion bulbs of Russet and Jambar grown at the highest plant density produced a significantly higher percentage of medium-sized bulbs than bulbs grown at a lower plant density. This might be due to the proper utilization of resources for all onions compared to lower densities (Uddin *et al.*, 2012).

These results agree with the findings of Rumpel *et al.* (2000), who reported that the yield of medium bulbs increased with increased density while the yield of large bulbs decreased. Similarly, Rumpel *et al.* (2000) and Nasir *et al.* (2007) reported that maximum weights of medium-sized bulbs were obtained at higher planting densities.

Table 5.5. Effects of variety and density on percentage of small bulbs across the three locations

| <b>Varieties</b>                          | Small-sized bulb (%) |
|-------------------------------------------|----------------------|
| Russet                                    | 24.4 <sup>b</sup>    |
| Red Coach                                 | 28.9 <sup>b</sup>    |
| Jambar                                    | 25.9 <sup>b</sup>    |
| Bombay Red                                | 40.5 <sup>a</sup>    |
| THSD <sub>0.05</sub>                      | 8.5                  |
| P values                                  | **                   |
| <b>Density</b>                            |                      |
| Low (222,222 plants ha <sup>-1</sup> )    | 23.9 <sup>b</sup>    |
| Medium (333,333 plants ha <sup>-1</sup> ) | 25.4 <sup>b</sup>    |
| High (666,666 plants ha <sup>-1</sup> )   | 40.4 <sup>a</sup>    |
| THSD <sub>0.05</sub>                      | 6.5                  |
| P values                                  | **                   |
| CV (%)                                    | 29.92                |

Where; \*\* = highly significant at  $P < 0.01$ . means followed by the same letter (s) within a column are not significantly different; THSD<sub>0.05</sub> = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation

Table 5.6. Onion size distribution affected by variety-density interaction across the three locations

| <b>Varieties</b>     | Density          | Medium bulb (%)      | Large bulb (%)       |
|----------------------|------------------|----------------------|----------------------|
| Russet               | Low (222,222)    | 35.3 <sup>c</sup>    | 44.2 <sup>ab</sup>   |
|                      | Medium (333,333) | 49.1 <sup>ab</sup>   | 28.0 <sup>abcd</sup> |
|                      | High (666,666)   | 51.5 <sup>a</sup>    | 18.7 <sup>cd</sup>   |
| Red Coach            | Low (222,222)    | 38.5 <sup>bc</sup>   | 25.9 <sup>abcd</sup> |
|                      | Medium (333,333) | 43.8 <sup>abc</sup>  | 29.3 <sup>abc</sup>  |
|                      | High (666,666)   | 39.1 <sup>bc</sup>   | 36.7 <sup>abc</sup>  |
| Jambar               | Low (222,222)    | 34.2 <sup>c</sup>    | 49.0 <sup>a</sup>    |
|                      | Medium (333,333) | 42.1 <sup>abc</sup>  | 32.7 <sup>abc</sup>  |
|                      | High (666,666)   | 51.6 <sup>a</sup>    | 12.4 <sup>d</sup>    |
| Bombay Red           | Low (222,222)    | 38.2 <sup>bc</sup>   | 3.8 <sup>d</sup>     |
|                      | Medium (333,333) | 51.3 <sup>a</sup>    | 19.5 <sup>bcd</sup>  |
|                      | High (666,666)   | 45.4 <sup>abcd</sup> | 20.5 <sup>bcd</sup>  |
| P values             |                  | **                   | *                    |
| THSD <sub>0.05</sub> |                  | 17.0                 | 25.3                 |
| CV (%)               |                  | 29.14                | 30.89                |

Where; \*\* = highly significant at  $P < 0.01$ ; \* = significant at  $P < 0.05$ . means followed by the same letter (s) within a column are not significantly different; THSD<sub>0.05</sub> = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation

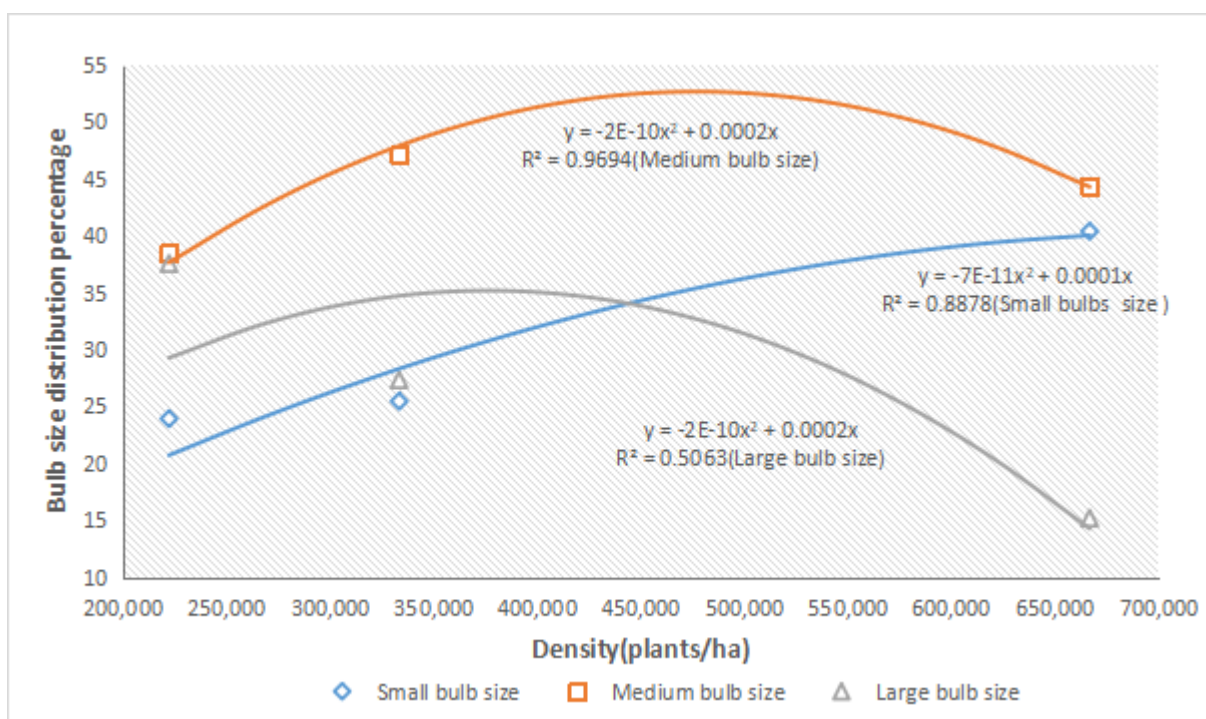


Figure 5.5. Trends of bulb size distribution as affected by plant density across the three locations

#### 5.3.4. Quality parameters of onion as influenced by variety and plant density

The combined analysis of variance showed that variety, plant density, and their interaction influenced ( $p < 0.01$ ) the total soluble solid (TSS) of the onion plants (Appendix Table 5.1). Bombay Red, grown at the lowest density, recorded the highest total soluble solids, followed by Jambar, while the Red Coach variety recorded the lowest TSS. Overall, onion bulbs harvested from plants grown in the lowest plant population recorded the highest TSS, while those from highly populated plants recorded the lowest TSS (Table 5.7).

Total soluble solids are the amounts of soluble solids in liquid. The TSS affects the taste of a given product and is dominated by the total sugar content and a small portion of soluble proteins, amino acids, and other organic materials. Therefore, the level of sweetness of a product is proportional to its TSS content, as indicated by Kusumiyati *et al.* (2020), which could be affected by the variety, growing environment, and agronomic practices. The reduced TSS of bulbs produced from densely populated onion plants is apparently due to the strong

competition of plants for growth factors that lead to low-soluble solids, thus lowering TSS in the bulbs.

### ***Firmness of the bulb (Newton)***

The firmness of the bulb was influenced ( $p < 0.01$ ) by the main effects of onion variety and plant density, as well as their interaction (Appendix Table 5.1).

Bulbs of the Russet variety had the highest firmness, which is at par with that of the Jamber variety, while the bulbs of the Bombay Red cultivar had the lowest firmness. Firmer bulbs were also obtained from plants grown at the lowest plant density, while bulbs from the highest and medium plant densities were less firm (Table 5.7). This could be attributed to lower planting density, which allows individual onion plants to get more water and nutrients from the soil than they would in congested areas. Firmer bulbs may result in higher cellulose deposition and thicker cell wall growth, which are facilitated by better resource intake (Wubetie Adinew *et al.*, 2022). These findings agree with Larsen *et al.* (2009) and Lancaster *et al.* (2001), who reported significant variation among onion varieties in bulb firmness.

Table 5.7. Onion quality parameters as influenced by the interaction effect of variety and plant density across three locations

| Varieties            | Density          | TSS (%)            | Firmness (Newton)   |
|----------------------|------------------|--------------------|---------------------|
| Russet               | Low (222,222)    | 9.3 <sup>cde</sup> | 9.2 <sup>a</sup>    |
|                      | Medium (333,333) | 8.3 <sup>e</sup>   | 8.6 <sup>cd</sup>   |
|                      | High (666,666)   | 8.2 <sup>e</sup>   | 8.72 <sup>abc</sup> |
| Red Coach            | Low (222,222)    | 8.3 <sup>e</sup>   | 8.8 <sup>ab</sup>   |
|                      | Medium (333,333) | 8.2 <sup>e</sup>   | 8.6 <sup>abc</sup>  |
|                      | High (666,666)   | 8.2 <sup>e</sup>   | 8.46 <sup>d</sup>   |
| Jambar               | Low (222,222)    | 10.6 <sup>bc</sup> | 9.0 <sup>ab</sup>   |
|                      | Medium (333,333) | 9.5 <sup>cde</sup> | 8.6 <sup>abc</sup>  |
|                      | High (666,666)   | 9.0 <sup>de</sup>  | 8.0 <sup>cde</sup>  |
| Bombay Red           | Low (222,222)    | 12.3 <sup>a</sup>  | 8.5 <sup>cd</sup>   |
|                      | Medium (333,333) | 12.1 <sup>ab</sup> | 7.7 <sup>de</sup>   |
|                      | High (666,666)   | 9.9 <sup>cde</sup> | 7.4 <sup>e</sup>    |
| P values             |                  | ***                | ***                 |
| THSD <sub>0.05</sub> |                  | 1.52               | 0.73                |
| SE $\pm$             |                  | 0.38               | 0.31                |
| CV (%)               |                  | 5.34               | 9.28                |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; means followed by the same letter (s) within a column are not significantly different;  $THSD_{0.05}$  = Tukey's Honestly Significant Difference at 5%; and CV = coefficient of variation

## 5.4. Conclusion and Recommendations

In conclusion, this comprehensive study demonstrated the significant influence of plant density and variety on the growth and yield parameters of onions in three diverse locations. The hybrid (Russet and Jambar) varieties exhibited early maturation, producing firmer bulbs with superior length, diameter, and weight, resulting in the highest marketable bulb yield compared to the open-pollinated variety (Bombay Red). Increasing plant population improved key attributes of the onion bulb, such as diameter, weight, total yield, and marketable yield. In particular, the use of hybrid onion varieties such as Russet ( $28.54 \text{ t ha}^{-1}$ ) and Jambar ( $26.61 \text{ t ha}^{-1}$ ) proved to be a promising strategy for improving onion productivity in the study area and similar agro-ecology.

Furthermore, the study recommends using a higher plant density ( $666,666 \text{ plants ha}^{-1}$ ) with a spacing of 5 cm between plants, 10 cm between rows and 40 cm between double rows to optimize onion productivity ( $28.42 \text{ t ha}^{-1}$ ).

This study underscores the need for further exploration, particularly to evaluate various hybrid onion varieties at elevated plant density levels in multilocation and through repeated experiments in different seasons. These insights offer valuable guidance for onion growers, contributing to sustainable and improved production and productivity of onion in Ethiopia, where temperatures are different from the prescribed optimal conditions for cultivating onions.

## Chapter 6: EFFECTS OF HYBRID VARIETIES, NITROGEN FERTILIZER AND PACKAGING ON POSTHARVEST QUALITY OF ONION IN NORTHWEST ETHIOPIA

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### **Abstract**

*Production seasonality and the perishable nature of the crop cause fluctuation in the market supply of onions and the incomes of farmers. On the other hand, the storage potential, quality, and shelf life of onions depend on agronomic practices, including fertilizer application, choice of varieties and packaging materials. The study was therefore initiated to evaluate onion packaging materials (sack, shelf, and floor) on postharvest quality of onion varieties that were grown in different environments (Koga, Woramit, and Woreta) with the application of different levels of nitrogen fertilizer (0, 41, 82, and 123 kg ha<sup>-1</sup>). The combination of variety, nitrogen fertilizer, and packaging materials were arranged in a factorial arrangement laid out in the randomized complete block design (RCBD) with three replications. The results indicated that the quality attributes of onion after harvest, particularly the shelf life of onion, were greatly influenced by onion varieties, packaging materials, and nitrogen fertilizer rates across the three locations. The study showed that hybrid onion bulbs with proper handling can be stored for one month without significant postharvest losses, regardless of the packaging materials. Bulbs of Jambar and Russet varieties that were stored on shelves and grown with 82 kg ha<sup>-1</sup> nitrogen fertilizer sprouted relatively late, recorded the lowest decay percentage and weight loss, better firm, and the highest percentage of marketable bulbs after a four-month storage period. Bombay Red variety recorded the highest storage loss, the highest percentage of sprouting, decay, and weight loss, as well as the lowest percentage of marketable bulbs after four months of storage. Storing hybrid varieties of Jambar and Russet on well-ventilated shelves prolonged the shelf-life of onion bulbs by reducing postharvest losses. Varietal selection, proper storage*

*practices, and nutrient management are vital in maintaining quality, extending shelf life, mitigating postharvest losses and ensuring sustainable onion supply.*

Keywords: Onion, packaging material, postharvest, shelf life, storage period

## **6.1. Introduction**

Increasing food availability increases crop productivity, and reducing postharvest losses (Kader, 2005). Unfortunately, a substantial amount of food and products do not reach consumers due to postharvest losses in the food value chain from harvesting to consumption. About 40 to 50% of the food and products produced worldwide are lost in this manner (Reardon and Bart, 2016; Kitinoja and Julie, 2015).

Postharvest losses can result in multiple adverse outcomes, including seed loss, financial loss, food loss, and damage to reputation, all of which negatively affect marketing efforts (FAO and World Bank, 2010; Gross *et al.*, 2000). Being highly susceptible to sprouting, rotting, and weight loss, onions face significant challenges. These challenges are often exacerbated by various factors such as agronomic practices (e.g., plant nutrition and variety selection) and postharvest handling methods, including storage types and techniques (Downes *et al.*, 2010; Ebad *et al.*, 2010; Ullah *et al.*, 2008; Adamicki, 2005).

Onions are highly perishable and require proper storage conditions to maintain quality and reduce postharvest losses. Proper storage has proven effective in minimizing sprouting, rotting, and weight loss, thereby prolonging shelf life (El-Ramady *et al.*, 2015). However, despite recognizing the importance of such storage solutions, Ethiopian onion producers face significant losses, with estimates of annual losses from 13% to 36% of onion bulbs (Daniels and Fors, 2015). In the northwest region alone, nearly 30% of the onion harvest is lost due to improper handling and inadequate postharvest management practices (Yebirzaf Yeshiwas *et al.*, 2023).

The storage life of onions is influenced by factors such as variety, agronomic practices, and packaging materials (Hurst *et al.*, 2006). In Ethiopia, one of the major challenges is the lack of accessible and affordable cold storage infrastructure. As a result, many farmers depend on

traditional packaging materials, such as using burlap sacks or storing onions directly on the floor at room temperature (Yebirzaf Yeshiwas *et al.*, 2023). This lack of modern storage solutions forces farmers to sell surplus produce at low prices during peak production periods, leading to significant financial losses and discouragement. On the other hand, during the rainy season, when onion production is limited, market scarcity causes prices to spike, making onions unaffordable to many consumers. This cyclical issue highlights the urgent need to improve storage infrastructure to stabilize the market and support farmers and consumers.

The storage life of onions is significantly influenced by the variety of onions (Omar *et al.*, 2005). Studies have shown significant variations among onion varieties regarding yield, components, and storage capacity (Hurst *et al.*, 2006; Msuya *et al.*, 2005; Omar *et al.*, 2005). Hybrid varieties often outperform open-pollinated varieties in yield and storage capacity (Gupta *et al.*, 2021; Li *et al.*, 2020; Patel *et al.*, 2020).

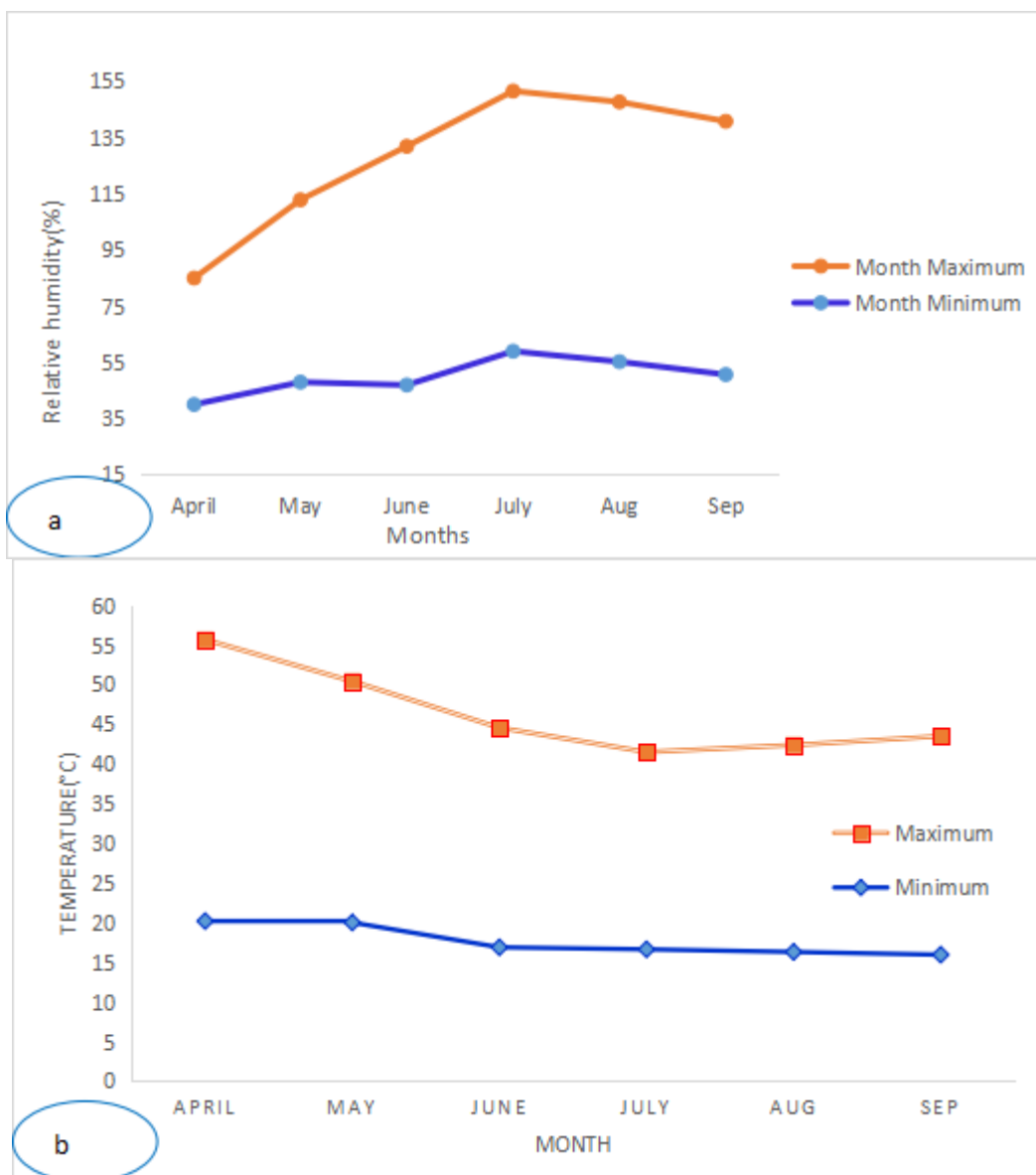
Agronomic practices also play a critical role. For instance, applying fertilizers enhances growth, yield, and bulb quality. However, excessive nitrogen can reduce storage life by increasing decay rates and premature sprouting (Gupta, 2021; Wang *et al.*, 2019; Sebsebe Woldetsadik and Seyoum Workneh, 2010). Furthermore, the choice of packaging materials affects storage duration. Packaging that minimizes physical damage and moisture loss while preventing sprouting and decay is crucial for extending onion shelf life (Khan *et al.*, 2021; Fatideh and Asil, 2012).

The lack of proper storage infrastructure is also one of the major challenges faced by farmers in Ethiopia. Many farmers rely on traditional packaging materials, such as using burlap sacks or storing onions directly on the floor at room temperature. However, the effects of these practices on onion bulbs have not been well studied (Yebirzaf Yeshiwas *et al.*, 2023; Endalew *et al.*, 2015;). In response to these challenges, this study aimed to identify the effects of different onion varieties, nitrogen fertilizer rates, and packaging materials on the postharvest quality of onions.

## **6.2. Materials and Methods**

### **6.2.1. Description of the study area**

The field experiment was conducted during the 2022/2023 irrigation season, as described under section 2.1. The storage experiment was conducted in the storage room of the Bahir Dar University College of Agriculture and Environmental Sciences (Zenzelma Campus) under ambient conditions. Zenzelma is geographically located between 11°35'N and 11°40'N latitude 37°24'E and 3°29' E longitude with an altitude of 1917 above mean sea level (Shiferaw *et al.*, 2022). The average maximum and minimum temperatures during the storage period were 35.3 °C and 16.3 °C, respectively. The minimum and maximum relative humidity of the storage atmosphere was recorded as 40% and 92.6%, respectively (Figure 6 1a and 6.1b).



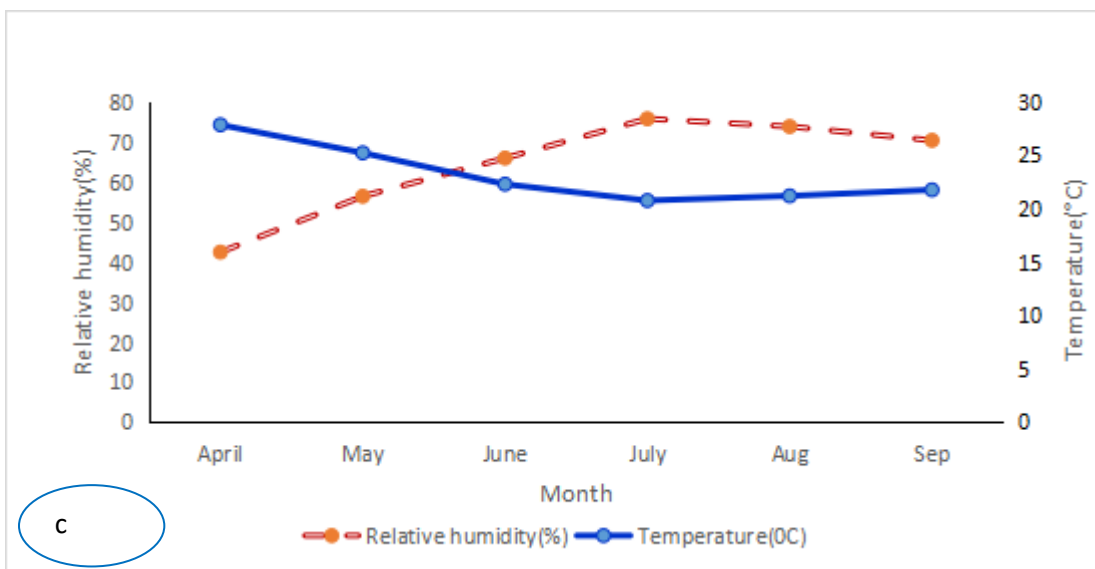


Figure 6.1. Temperature variations inside the storage room of onion; average relative humidity (%) (a), average temperature(°C) (b), and the relationship between relative humidity (%) and temperature (°C) (b) in 2022

### 6.2.2. Experimental treatments and design

The treatments consisted of bulbs of four onion varieties (Russet, Red Coach, Jambar, and Bombay Red) produced with the application of four nitrogen fertilizer rates ( $0 \text{ kg ha}^{-1}$ ,  $41 \text{ kg ha}^{-1}$ ,  $82 \text{ kg ha}^{-1}$  and  $123 \text{ kg ha}^{-1}$ ) and three types of packaging materials (burlap sack, wooden shelves, and floor). The treatments were arranged in a factorial arrangement and laidout in the randomized complete block design (RCBD) with three replications.

### 6.2.3 Experimental design and treatments

The treatments consisted of bulbs of four onion varieties (Russet, Red Coach, Jambar, and Bombay Red) produced with the application of four nitrogen fertilizer rates ( $0 \text{ kg ha}^{-1}$ ,  $41 \text{ kg ha}^{-1}$ ,  $82 \text{ kg ha}^{-1}$  and  $123 \text{ kg ha}^{-1}$ ) at three different locations subjected to three types of packaging materials (burlap sack, wooden shelves, and floor). The experiment was laidout in a  $4 \times 4 \times 3$  factorial arranged in a randomized complete block design (RCBD) with three replications.

### 6.2.4. Experimental procedures

Sample onion bulbs at the proper maturity stage were collected from the Koga, Woramit, and Woreta experimental sites produced during the 2022 irrigation season. Onion bulbs were harvested at the physiological maturity stage. The bulbs were sorted according to uniformity and as marketable bulb size in the absence of defects. The bulbs were cured for five days in partial shade conditions. The selected bulbs were stored in naturally ventilated houses constructed from corrugated iron sheet roofing. Five-kilogram sample onion bulbs were used for storage. The air temperature and relative humidity of the storage rooms were continuously recorded throughout the storage period from April to September using a digital psychrometer.

#### **6.2.5. Data collection**

Data collection methods were described in 2.5.

#### **6.2.6. Data analysis**

The combined analysis of variance across locations was calculated for the parameters that showed homogeneous variance and subjected to the analysis of variance (ANOVA) using the PROC MIXED procedure of SAS version 9.0 computer software (SAS Institute Inc., 2008). The storage condition, nitrogen fertilizer rate, and varieties were considered as fixed effects, while location was considered a random effect. When the analysis showed significant ( $P < 0.05$ ), the mean separation was carried out using DNMRT (Duncan's new multiple range test) at a significance level of 5% (Gomez and Gomez, 1984).

### **6.3. Results and Discussion**

#### **6.3.1. Days to first sprouting**

The combined analysis of variance across the locations indicated that days to the first sprouting of onion bulbs in storage were highly significantly ( $P < 0.01$ ) influenced by the main effects of variety, packaging material, and nitrogen fertilizer rate. However, all possible interaction effects did not influence ( $P > 0.05$ ) the first days of bulb sprouting (Appendix Table 6.1).

The variety Jambar sprouted relatively late after 75.94 days of storage, while the local check variety, Bombay Red, sprouted early after 37.93 days of storage (Table 6.1). Similarly, bulbs stored on the shelf sprouted late after 62.97 days of storage, followed by bulbs stored in burlap sacks (59.98 days) and the floor (60.99 days). The nitrogen fertilizer rate also affected the sprouting of onion bulbs. Bulbs grown with the application of 82 kg ha<sup>-1</sup> nitrogen exhibited delayed sprouting compared to those grown with the supplement of 123 kg ha<sup>-1</sup> nitrogen (60.25 days), as shown in Table 6.1.

The present findings indicated that onion bulb sprouting did not occur until 37 days of storage across locations. The first visible sprout initiation was observed on the 37<sup>th</sup> day of storage in Bombay Red bulbs, while the bulbs of the hybrid variety Jambar did not show sprouting until the 75<sup>th</sup> day of storage (Table 6.1). This indicates the presence of a physiological rest period (dormancy) of onion bulbs in this storage environment. Furthermore, the results also indicated that open-pollinated variety can be stored for four weeks, while hybrid varieties can be stored for about 6-10 weeks regardless of the packaging materials used, fertilizer rates applied, and production site by harvesting at proper maturity stage, curing and regular inspection during storage.

The difference in varieties towards sprout initiation can be attributed to their variations in the genetic makeup that lead to differences in the time required to break dormancy. Sprouting of stored onion bulbs results from physiological changes and is highly affected by storage conditions. Onion sprouting is detrimental as it transfers dry matter and water from edible fleshy scales to sprouts, leading to shrinking and loss of appearance, ultimately affecting bulbs' marketability (Getenesh Nega *et al.*, 2015). The delayed sprout initiation on bulbs stored on shelves could be associated with proper ventilation that dissipates hot air, which in turn reduces the respiration rate and metabolic processes. On the other hand, the microenvironment in burlap sacks is poorly ventilated, increasing transpiration and metabolic processes, which might enhance earlier sprout initiation of bulbs, as indicated in the present study. In this regard, Hayma (2003) reported that higher temperatures promote sprouting and increase respiration, leading to heat production. The present study result aligns with the findings of Bongiwar and Shirsat (2000), who reported variations of onion bulb sprouting

stored in different packaging materials. According to Gupta and Patel (2020), storing bulbs on shelves provides more temperature control compared to storing them directly on the floor, where temperature fluctuations are more frequent.

Excessive nitrogen availability potentially accelerates the sprouting processes and negatively affects bulb quality, as indicated in the present study, which is in line with the works of Etana *et al.* (2019).

### **6.3.2. Bulb sprouting percentage**

The combined analysis of variance (ANOVA) over locations revealed that the sprouting percentage of onion bulbs was highly significantly ( $P < 0.001$ ) influenced by the main effects of variety and packaging material. However, nitrogen levels and any interactions among them didn't significantly ( $P > 0.05$ ) influence this parameter of onion bulbs (Appendix Table 6.1).

The highest percentage of sprouting (68.7%) was observed on the bulbs of the Bombay Red variety, followed by the Red Coach variety (60.80%). On the contrary, Bulbs of Russet (43.93%) and Jambar varieties (56.17%) recorded the lowest percentage of sprouting after five months of storage. Bulbs packed in burlap sacks recorded the lowest sprouting percentage (54.50%), while bulbs stored on shelves (58.87%) and floors (58.83%) showed the highest sprouting percentage across the locations (Table 6.1).

Contrary to the previous findings, the nitrogen fertilizer rate in the present study did not significantly affect the sprouting percentage of bulbs. Benti (2017) reported a significant influence of nitrogen fertilizer on sprouting, while Smith *et al.* (2020) and Patel and Gupta (2019) indicated the limited effect of nitrogen fertilizer on the actual sprouting percentage of onion bulbs during storage. The observed varietal differences in onion sprouting highlight their genetic difference, which is in line with the findings of other scholars (Gateri, 2019; Benti, 2017; Adamicki, 2005).

Sprouting and rotting are the main causes of storage losses that decrease the quality of stored onion bulbs (Adamicki, 2005). Dormancy plays a crucial role in onion bulb storage, longevity, and sprout suppression (D'Angelo and Goldman, 2019). The length of dormancy depends on genotype and storage conditions (Chávez-Mendoza *et al.*, 2016). Storing onion in fully ventilated storage structures reduces the sprouting percentage of onion bulbs (Selam Getachew, 2020). Changes in growth regulators during postharvest storage can also influence the onion bulb sprouting, with cytokinins inducing sprouting by reducing the concentrations of abscisic acid and stress factors (Chope *et al.*, 2012; Qadir *et al.*, 2007).

### **6.3.3. Decay percentage**

The combined analysis of variance indicated that the decay percentage of onion bulbs was highly influenced ( $P<0.01$ ) by the main effects of variety, packaging material, and nitrogen, as well as by the two-way interaction of packaging material and variety. However, the other two-way and three-way interactions did not influence the decay percentage ( $P>0.05$ ) (Appendix Table 6.1).

The highest decay percentage (9.49%) was observed on the variety Bombay Red, while the hybrid variety Russet (6.94%) and Jambar (7.54%) recorded relatively the lowest decay percentages after a five-month storage period. Onion bulbs stored on shelves had the lowest decay percentage (4.78%), whereas bulbs stored in the sack had the highest decay percentage (10.99%), followed by those stored on the floor (8.6%), as shown in Table 6.1. Onion bulbs supplied with nitrogen at the rate of 123 kg ha<sup>-1</sup> (8.66%) and 0 kg ha<sup>-1</sup> (8.18%) exhibited the highest decay percentage, while bulbs produced with nitrogen supplement of 82 kg ha<sup>-1</sup> (7.41%) recorded the lowest decay percentage. Regarding the interaction effect over locations, bulbs of Bombay Red variety stored in burlap sack packaging material exhibited the highest decay percentage (13.43%), while bulbs of Jambar (3.3%) and Russet (4.4%) stored on the shelf showed the lowest decay percentage (Figure 6.2).

The decay of bulbs is primarily caused by microbial infections, which include bacteria, fungi, and molds. The extent of decay depends on the variety, mechanical damages, storage environment, and freedom from diseases and insect pests. In the present study, hybrid

varieties generally showed lower decay percentages compared to the open-pollinated variety, which could be associated with the genetic makeup. Hybrid onion varieties stored better due to their thicker skins, better storage physiology, and enhanced resistance mechanisms against decay-causing organisms (Randhawa *et al.*, 2022; Jones *et al.*, 2021; Mota *et al.*, 2019; Singh *et al.*, 2015). Benti (2017) and Diaz-Perez *et al.* (2003) also observed varietal differences in decay percentage during storage.

Excessive application of nitrogen fertilizer experiences overstimulated vegetative growth, which can result in tissue softening and making bulbs more susceptible to mechanical damage and decay during storage (Smith *et al.*, 2020; Etana *et al.* 2019), which agrees with the results of the present study. On the contrary, bulbs grown without nitrogen fertilizers may have inadequate vital nutrients needed for optimal development and defense against decaying pathogens that may increase vulnerability to spoilage during storage (Patel and Gupta, 2019).

As indicated in the present study, packaging materials influence the postharvest life of onion bulbs, including sprouting and decay percentage and storage life. Packaging materials with the provision of ventilation is necessary to reduce postharvest losses. In this regard, Selam Getachew (2020) reported that onion producers and traders in the North West Amhara region stored their bulbs in burlap sacks without proper aeration, which can potentially increase bulb rotting. Proper drying and moisture content reduction reduces rooting on stored onion bulbs (Mota *et al.*, 2019; Patel and Gupta, 2020; Smith *et al.*, 2021; Rahman *et al.*, 2022). Benti (2017) reported that the percentage of rotten bulbs was not significantly influenced by nitrogen after 60 days of storage. Furthermore, Debnath and Hemavathy (2016) found that higher rotting was recorded in netlon bags compared to hessian cloth bags under ambient storage conditions.

Table 6 1. Effects of variety, packaging material and nitrogen fertilizer rate combined over growing locations on selected postharvest parameters of onion bulbs

| <b>Packaging material</b> | <b>Days to first sprouting</b> | <b>Bulb sprouting percentage</b> | <b>Decay percentage</b> |
|---------------------------|--------------------------------|----------------------------------|-------------------------|
| Shelf                     | 62.97 <sup>a</sup>             | 58.87 <sup>a</sup>               | 4.78 <sup>c</sup>       |
| Burlap sack               | 59.98 <sup>b</sup>             | 54.50 <sup>b</sup>               | 10.99 <sup>a</sup>      |
| Floor                     | 60.99 <sup>b</sup>             | 58.83 <sup>a</sup>               | 8.6 <sup>b</sup>        |

|                                           |                    |                    |                   |
|-------------------------------------------|--------------------|--------------------|-------------------|
| P value                                   | **                 | **                 | ***               |
| <b>Variety</b>                            |                    |                    |                   |
| Russet                                    | 71.39 <sup>b</sup> | 43.93 <sup>d</sup> | 6.94 <sup>c</sup> |
| Red Coach                                 | 59.99 <sup>c</sup> | 60.80 <sup>b</sup> | 8.62 <sup>b</sup> |
| Jambar                                    | 75.94 <sup>a</sup> | 56.17 <sup>c</sup> | 7.54 <sup>c</sup> |
| Bombay Red                                | 37.93 <sup>d</sup> | 68.70 <sup>a</sup> | 9.49 <sup>a</sup> |
| P value                                   | ***                | ***                | ***               |
| SE±                                       |                    |                    |                   |
| <b>Nitrogen Rate (kg ha<sup>-1</sup>)</b> |                    |                    |                   |
| 0                                         | 60.01 <sup>c</sup> | 58.28              | 8.18 <sup>a</sup> |
| 41                                        | 61.21 <sup>b</sup> | 57.35              | 7.91 <sup>b</sup> |
| 82                                        | 63.77 <sup>a</sup> | 56.82              | 7.41 <sup>c</sup> |
| 123                                       | 60.25 <sup>c</sup> | 57.15              | 8.66 <sup>a</sup> |
| P value                                   | **                 | ns                 | *                 |
| SE±                                       | 0.21               | 0.46               | 0.37              |
| CV (%)                                    | 13.65              | 26.01              | 27.34             |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \*\* = highly significant at  $P < 0.01$ ; \* = significant at  $P < 0.05$ ; ns = non-significance; means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5%; and CV = coefficient of variation

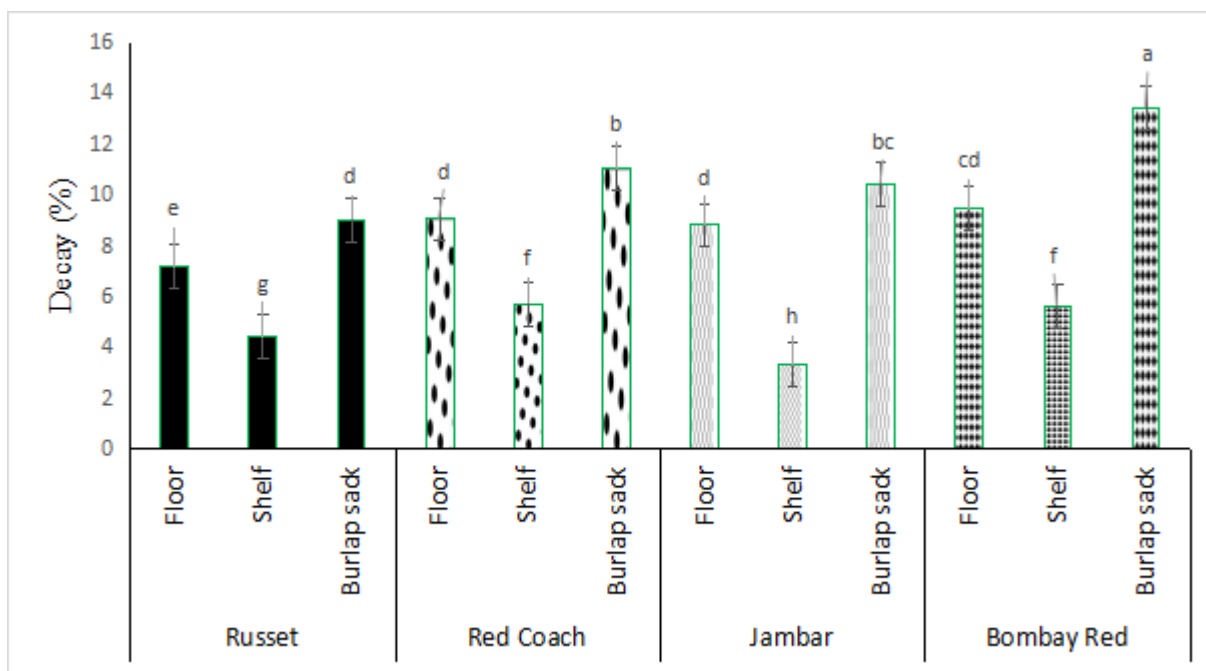


Figure 6.2. Interaction effect of variety and packaging materials on the decay percentage of onion bulbs combined over the three locations

#### 6.3.4. Percentage of weight loss

Weight loss of onion bulbs was highly influenced ( $P<0.001$ ) by the main effects of the packaging material, nitrogen rate, and variety. However, all kinds of interactions did not significantly influence ( $P>0.05$ ) the percentage of weight loss of onion after five months of storage (Appendix Table 6.1).

Bulbs stored on shelves recorded the lowest percentage of weight loss throughout the storage period, while bulbs stored in sacks and on the floor recorded the highest weight loss. Similarly, applying 82 kg ha<sup>-1</sup> of nitrogen resulted in the lowest percentage of weight loss, which was statistically similar to the application of 123 kg ha<sup>-1</sup> nitrogen. Conversely, the highest weight loss was observed with applications of 0 and 41 kg ha<sup>-1</sup> of nitrogen (Figure 6.3). The higher weight loss observed from low nitrogen levels might be attributed to insufficient nitrogen, possibly causing the development of weaker cell wall and lower carbohydrate reserves that make bulbs more susceptible to dehydration during storage. Low nitrogen also limits the formation of amino acids and proteins essential for maintaining cell turgor and structural integrity. On the other hand, adequate nitrogen enhances the synthesis of proteins and structural compounds that strengthen cell walls, improving the bulb's resistance to physical damage and weight loss (Brewster, 2008).

Weight loss is one of the postharvest losses occurred in vegetable crops including onion. It results from moisture loss and is usually known to occur due to dehydration, transpiration, respiration, rotting, sprouting, etc. Weight loss is generally increased with the prevailing temperature and low humidity in the environment. During the storage period, sprouting and decay apparently occur through increased respiration rate (Shippers, 1968). Benti (2017) found that there was an increase in the percent weight loss under ambient storage conditions throughout the storage period. Furthermore, Chala *et al.* (2019) reported that a high percentage of weight loss is observed when tubers are stored for more than 20 days, while Ctripathi (2008) observed 40% to 50% weight loss when bulbs were stored for more than 20 days.

Regarding varieties, in the present study, the highest percentage of weight loss was recorded from the Bombay Red variety, while the lowest percentage of weight loss was recorded for

the Jambar and Russet varieties after five months of storage. Variation in percentage weight loss was significantly influenced by variety throughout the storage period. As indicated in Figure 6.3, hybrid varieties exhibited a relatively low water loss percentage compared to the open-pollinated variety (Bombay Red), which could be due to their thicker skin that may help to reduce the loss of water from the bulb surface and due to their genetic variation. These present findings align with the previous findings of Hygrotech (2010), who reported that onion varieties exhibit different storage potential due to their genetic composition. According to Gebremedhn Gebretsadkan *et al.* (2018), the Bombay Red variety recorded a weight loss of 97% in five months of storage duration.

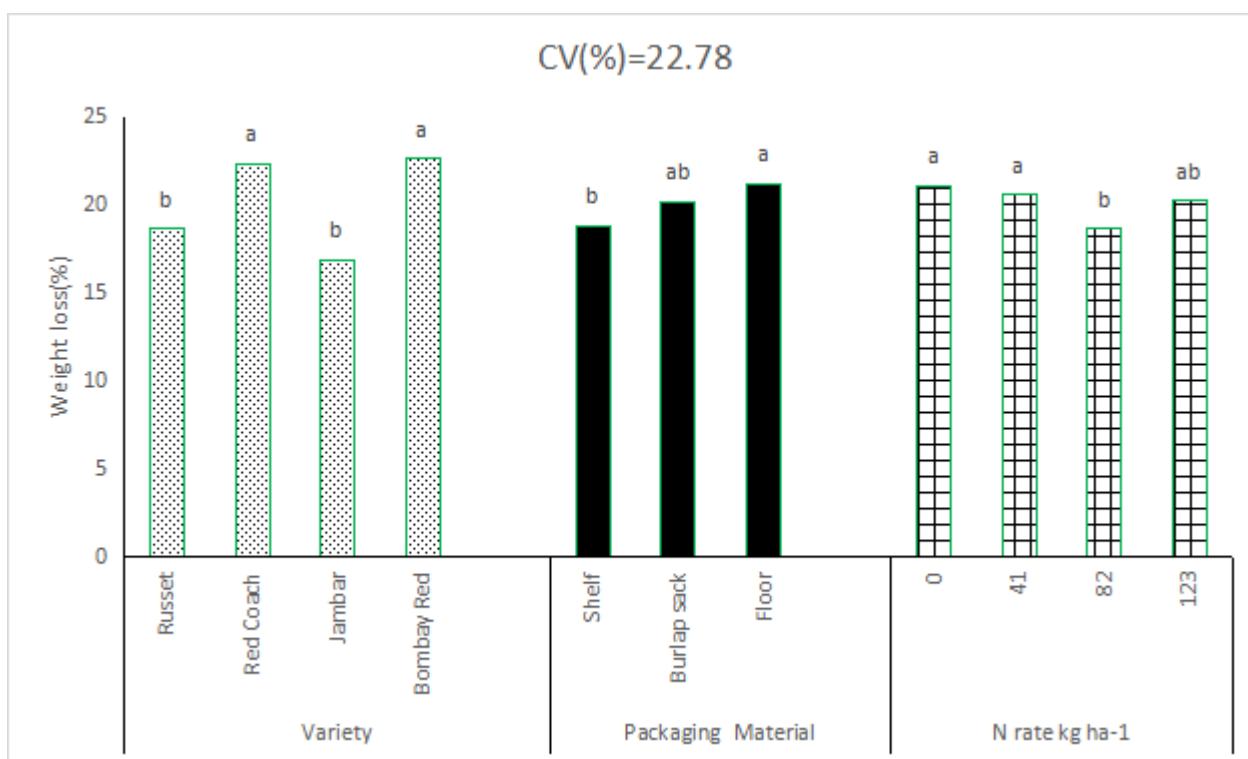


Figure 6.3. Effects of packaging material and variety on weight loss percentage of onion after five months storage duration combined over the three locations

### 6.3.5. Percentage of marketable bulbs

The combined analysis of variance indicated that the main effects of variety and the packaging material had a highly significant effect ( $P<0.001$ ) on marketable bulbs after four months of storage duration. Similarly, the interaction between packaging material and variety significantly ( $P<0.01$ ) influenced the percentage of marketable onion bulbs throughout

storage periods. However, the two-way interaction between nitrogen and variety, and the three-way interaction of the three factors did not influence ( $P>0.05$ ) the percentage of marketable bulbs of onion at the specified storage periods (Appendix Table 6.1).

Russet variety maintained the highest percentage of marketable bulbs (56.73%), followed by Jambar (44%) and Red Coach (44.09%). On the other hand, Bombay Red variety recorded the lowest percentage of marketable bulbs (32.52%) after 16 weeks of storage duration. The highest proportion of marketable bulbs from hybrid varieties Jambar and Russet, compared to the open-pollinated Bombay Red variety, might obviously be attributed to their better storability potential controlled by the genetic makeup of the crop. The level of nitrogen fertilizer did not significantly influence the marketable bulbs of onion (Table 6.2).

Onion sprouting began after five weeks of storage period and persisted throughout the four-month period. After four months of storage, the highest percentage of marketable onion bulbs (47.87%) was maintained from bulbs stored on shelves, followed by those stored in burlap bags (44.34%) and on the floor (40.79%). Tripathi and Lawande (2016) similarly highlighted that a storage duration of three months resulted in 76% marketable bulbs, revealing the efficacy of fully ventilated structures as ideal packaging materials for onions.

In the interaction effect, Russet and Jambar varieties stored on shelves consistently had the highest proportion of marketable bulbs during the four-month storage period. On the other hand, the lowest percentage of marketable bulbs was observed in the Bombay Red variety stored on the floor (Table 6.3).

The marketable percentage of bulbs generally decreased with the increased storage period and reached its lowest level at the end of the storage due to bulb aging and sustainability to sprouting and rotting (Hatem *et al.*, 2014). This scenario is in line with the findings of the present study (Table 6.3). The extended availability of a greater quantity of healthy and acceptable bulbs at the end of the storage period is of paramount importance to reduce postharvest loss, meet consumer demand, and enhance the income of farmers. According to Smith *et al.* (2020) hybrid varieties are specifically bred to exhibit better storage traits,

including thicker skins, better disease resistance, and enhanced physiological characteristics that contribute to better bulb quality during storage. Singh *et al.* (2015) also observed low storage loss of marketable bulbs that were stored in well-ventilated packaging materials compared to less-ventilated bags, which is in line with the results of the present study.

Table 6.2. Effects of variety, packaging material and nitrogen fertilizer after four months storage duration on marketability of onion bulbs three across locations

| <b>Packaging material</b>                 | <b>Marketable bulbs (%)</b> |
|-------------------------------------------|-----------------------------|
| Shelf                                     | 47.87 <sup>a</sup>          |
| Burlap sack                               | 44.34 <sup>b</sup>          |
| Floor                                     | 40.79 <sup>c</sup>          |
| P value                                   | **                          |
| <b>Variety</b>                            |                             |
| Russet                                    | 56.73 <sup>a</sup>          |
| Red Coach                                 | 44.09 <sup>b</sup>          |
| Jambar                                    | 44.00 <sup>b</sup>          |
| Bombay Red                                | 32.52 <sup>c</sup>          |
| P value                                   | **                          |
| <b>Nitrogen rate (kg ha<sup>-1</sup>)</b> |                             |
| 0                                         | 44.37                       |
| 41                                        | 44.81                       |
| 82                                        | 43.83                       |
| 123                                       | 44.32                       |
| P value                                   | ns                          |
| SE±                                       | 1.02                        |
| CV (%)                                    | 12.5                        |

Where; \*\* = highly significant at  $P < 0.01$ ; \* = significant at  $P < 0.05$ ; ns = non-significance means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5%; and CV = coefficient of variation

Table 6 3. Proportion of marketable onion bulbs in different weeks of storage as influenced by the interaction effect of variety and packaging materials combined over the three locations

| <b>Variety</b> | <b>Packaging material</b> | <b>Marketability (%)</b> |                     |                      |
|----------------|---------------------------|--------------------------|---------------------|----------------------|
|                |                           | 8 weeks                  | 12 weeks            | 16weeks              |
| Russet         | Shelf                     | 90.74 <sup>ab</sup>      | 83.95 <sup>a</sup>  | 60.44 <sup>a</sup>   |
|                | Burlap sack               | 90.27 <sup>ab</sup>      | 77.31 <sup>bc</sup> | 54.08 <sup>ab</sup>  |
|                | Floor                     | 89.04 <sup>b</sup>       | 73.14 <sup>cd</sup> | 38.73 <sup>def</sup> |
| Red Coach      | Shelf                     | 75.30 <sup>cd</sup>      | 47.68 <sup>g</sup>  | 43.55 <sup>cd</sup>  |
|                | Burlap sack               | 73.30 <sup>cde</sup>     | 55.70 <sup>ef</sup> | 47.99 <sup>bc</sup>  |
|                | Floor                     | 71.75 <sup>de</sup>      | 46.14 <sup>g</sup>  | 40.74 <sup>de</sup>  |
| Jambar         | Shelf                     | 94.75 <sup>a</sup>       | 84.25 <sup>a</sup>  | 55.0 <sup>a</sup>    |

|            |             |                     |                     |                      |
|------------|-------------|---------------------|---------------------|----------------------|
|            | Burlap sack | 92.59 <sup>ab</sup> | 80.24 <sup>ab</sup> | 54.73 <sup>a</sup>   |
|            | Floor       | 89.35 <sup>b</sup>  | 69.72 <sup>d</sup>  | 39.19 <sup>def</sup> |
| Bombay Red | Shelf       | 77.77 <sup>c</sup>  | 60.64 <sup>e</sup>  | 35.64 <sup>ef</sup>  |
|            | Burlap sack | 70.06 <sup>e</sup>  | 50.30 <sup>fg</sup> | 33.42 <sup>fg</sup>  |
|            | Floor       | 70.83 <sup>de</sup> | 50.61 <sup>fg</sup> | 28.48 <sup>g</sup>   |
| P value    |             | **                  | **                  | **                   |
| CV (%)     |             | 16.6                | 19                  | 21                   |
| SE $\pm$   |             | 0.78                | 1.02                | 0.83                 |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \*\* = highly significant at  $P < 0.01$ ; \* = significant at  $P < 0.05$ ; ns = non-significance means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5%; and CV = coefficient of variation

### 6.3.6. Total soluble solid (%)

The combined analysis of variance indicated that total soluble solids (TSS) were highly significantly ( $P < 0.001$ ) influenced by the main effects of variety, packaging material, and nitrogen fertilizer rate, as well as by their two-way and three-way interactions after four months of storage period. However, three-way interactions have a significant influence ( $P > 0.05$ ) on TSS throughout the storage period (Appendix Table 6.1).

Onion bulbs stored on shelves maintained their TSS levels significantly better than those of other storage conditions throughout the storage period, while onion bulbs stored on the floor exhibited the lowest TSS. The highest TSS was recorded from the Bombay Red variety, while the lowest TSS was recorded from the Russet variety. Furthermore, onion TSS levels were significantly influenced by nitrogen fertilizer rates, and the highest TSS was recorded from the application of 123 kg ha<sup>-1</sup>, followed by 82 kg ha<sup>-1</sup>. On the other hand, the lowest TSS was recorded from the control without nitrogen application (Figure 6.4). The floor storage condition resulted in the lowest TSS for onion bulbs throughout the storage period. The onion bulbs stored in these storages were subjected to the highest percentage of weight loss during storage periods, as shown in Figure 6.4. The lowest TSS in the bulb stored on the floor can be attributed to factors such as ventilation, temperature, and humidity, which affect bulb respiration and biochemical changes that lead to TSS variation. The present finding aligns with the previous findings reported by Berno *et al.* (2014).

The interaction effect of variety, nitrogen rate, and packaging material on TSS content was significant. The highest TSS values were recorded in Bombay Red bulbs that were stored on shelves and their plants received higher nitrogen rates (82 and 123 kg ha<sup>-1</sup>) in the fields. Jambar variety bulbs stored on a shelf and received higher nitrogen rates also showed high TSS, while Russet and Red Coach bulbs stored on shelf and received higher nitrogen rates exhibited moderate TSS (Table 6.4).

Studies by Singh and Dhankar (1989) showed that the TSS of onion varieties stored in different packaging materials slightly increased up to four weeks during the storage period and then consistently decreased throughout the storage period. According to Benklebia *et al.* (2005), sugar metabolism is closely linked to the dormancy and sprouting rate of onion, and its quantitative variations are the most important biochemical changes during long periods of conservation. On the other hand, Chope *et al.* (2012) suggested a different mechanism, namely respiration, and remobilization of carbohydrates, to provide energy for the initiation of sprouts. This could explain the sudden reduction in TSS observed in onions after five months of conservation since they showed internal sprouts in one hundred percent of bulbs tested at the end of the storage.

As observed in the present study, the total soluble solid content during the storage period varies with genotypic differences (Benti, 2017) and the packaging materials (Berno *et al.*, 2014). Onion varieties may have genetically different levels of TSS content (Patel *et al.*, 2020), as observed in the present study (Figure 6.4a).

The onion variety (Bombay Red), with the highest TSS, also exhibited a higher percentage of sprouting, decay and weight loss (Figure 6.3). According to Lee and Kim (2019), onion varieties with higher levels of sugar content (TSS) might result in a higher weight loss during storage due to increased sugar respiration rate, which is consistent with the findings of the present study. On the other hand, Patel *et al.* (2020) reported that higher TSS may correlate with better storage characteristics in some varieties, while others might have lower TSS but possess traits that contribute to improved storability. The results of the present study contradict the findings of other scholars who associated higher TSS content with better

preservation of bulb quality. This might be attributed to differences in varieties, postharvest handling practices, storage duration, and other factors influencing bulb quality (Chávez-Mendoza *et al.*, 2016; Devendrappa, 2015; Yemane, 2013).

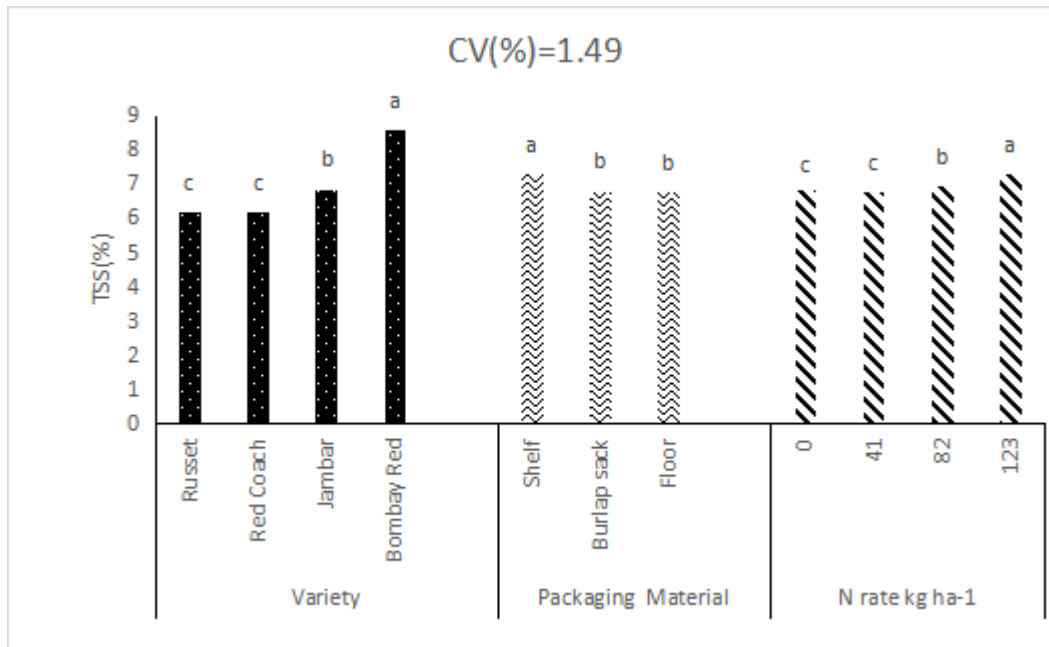


Figure 6.4. Main effects of variety, packaging material and nitrogen fertilizer on the TSS content of stored onion bulbs for four months combined across three locations

Table 6 4. Three-way interaction effect of variety, packaging material, and nitrogen fertilizer on the TSS content of stored onion bulbs across locations

| Variety    | Packaging material | TSS                            |                           |                            |                          |
|------------|--------------------|--------------------------------|---------------------------|----------------------------|--------------------------|
|            |                    | N kg ha <sup>-1</sup>          |                           |                            |                          |
|            |                    | 0                              | 41                        | 82                         | 123                      |
| Russet     | Shelf              | 5.92 <sup>nopqrst</sup>        | 6.42 <sup>lmnopqrs</sup>  | 6.81 <sup>ijklmno</sup>    | 6.60 <sup>klmnopq</sup>  |
|            | Floor              | 5.10 <sup>t</sup>              | 6.28 <sup>lmnopqrs</sup>  | 6.26 <sup>lmnopqrs</sup>   | 6.036 <sup>mnopqrs</sup> |
|            | Sack               | 5.62 <sup>pqrst</sup>          | 6.36 <sup>lmnopqrs</sup>  | 6.6367 <sup>ijklmnop</sup> | 6.27 <sup>lmnopqrs</sup> |
| Jambar     | Shelf              | 6.76 <sup>ijklmno</sup>        | 7.69 <sup>defgh</sup>     | 8.03 <sup>defg</sup>       | 7.18 <sup>fghijk</sup>   |
|            | Floor              | 5.82 <sup>opqrst</sup>         | 7.04 <sup>hijklm</sup>    | 6.58 <sup>ijklmnopq</sup>  | 6.62 <sup>klmnop</sup>   |
|            | Sack               | 6.23 <sup>mnopqrs</sup>        | 6.4 <sup>lmnopqrs</sup>   | 6.94 <sup>hijklmn</sup>    | 6.60 <sup>klmnopq</sup>  |
| Red Coach  | Shelf              | 6.96 <sup>hijklmn</sup>        | 6.33 <sup>klmnopqrs</sup> | 6.96 <sup>hijklmn</sup>    | 7.18 <sup>fghijk</sup>   |
|            | Floor              | 5.53 <sup>rst</sup>            | 5.43 <sup>st</sup>        | 5.96 <sup>mopqrst</sup>    | 6.20 <sup>lmnopqrs</sup> |
|            | Sack               | 5.56 <sup>q<sup>st</sup></sup> | 5.94 <sup>nopqrst</sup>   | 5.85 <sup>opqrst</sup>     | 6.56 <sup>lmnopqr</sup>  |
| Bombay Red | Shelf              | 8.61 <sup>bcde</sup>           | 8.91 <sup>bcd</sup>       | 10.30 <sup>a</sup>         | 9.37 <sup>ab</sup>       |
|            | Floor              | 7.53 <sup>fghij</sup>          | 7.86 <sup>defgh</sup>     | 9.09 <sup>bc</sup>         | 7.56 <sup>efghij</sup>   |
|            | Sack               | 8.10 <sup>cdef</sup>           | 7.37 <sup>fghijk</sup>    | 9.51 <sup>ab</sup>         | 8.60 <sup>bcde</sup>     |

|          |      |
|----------|------|
| P values | ***  |
| CV (%)   | 1.49 |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \*\* = highly significant at  $P < 0.01$ ; \* = significant at  $P < 0.05$ ; ns = non-significance means followed by the same letter (s) within a column are not significantly different;  $ISD_{0.05}$  = Least significant difference at 5%; and CV = coefficient of variation

### 6.3.7. Bulb firmness

The combined analysis of variance showed that the main effects of variety, packaging material, and nitrogen fertilizer rate, as well as their two-way and three-way interactions, highly significantly ( $P < 0.001$ ) influenced bulb firmness after 12 weeks of storage period (Appendix Table 6.1).

The Russet and Jambar varieties showed the highest bulb firmness, while the lowest firmness was recorded from the Bombay Red variety throughout the storage period (Figure 6.5). The difference in firmness among onion varieties could be attributed to their genotypic differences. The highest firmness of onion from hybrid varieties might be due to different cell wall structures where hybrid onion varieties have naturally firmer cell walls than open-pollinated varieties. Such thicker cell walls make hybrid varieties more resistant to bruising, damage and spoilage compared to open-pollinated varieties (Yuan *et al.*, 2021; Coolong *et al.*, 2008). In line with this, Russet and Jambar varieties in the present study showed the lowest spoilage during the storage period (Table 6.1).

Bulb firmness was also influenced by nitrogen fertilizer. Bulbs produced by the application of 82 kg ha<sup>-1</sup> N recorded the highest firmness, while those produced by the application of 123 kg ha<sup>-1</sup> were less firm throughout the storage period (Fig. 6.5). The firmness of onion bulbs is directly related to the freshness and crispness index of the vegetable (González *et al.*, 2012).

Regarding packaging materials, onion bulbs stored on shelves maintained better firmness, as shown in Figure 6.5. The hardness of bulbs stored on shelves might be because shelf storage led to the surface drying of onions, which resulted in rigidity and firmness of the bulb's outer skin.

In the two-way interaction effect, bulbs of Russet and Jambar varieties that were stored on shelves maintained higher firmness, whereas the bulbs of Bombay Red variety stored in burlap bags showed the lowest firmness throughout the storage period (Table 6.4). Generally, bulb firmness decreased as the storage period increased, which could be associated with cell wall degradation during the process of ripening and senescence of horticultural products through biochemical reactions (Chávez-Mendoza *et al.*, 2016; Melo *et al.*, 2012).

Parameters like weight loss percentage, sprouting percentage, date of sprouting, decay percentage, and proportion of marketable bulb and bulb firmness serve as crucial indicators for the shelf life of onion bulbs. According to the results indicated above, using hybrid varieties (Russet and Jambar), storing bulbs on shelves, and applying 82 kg ha<sup>-1</sup> N maintained the shelf-life of onion bulbs better compared to other treatments.

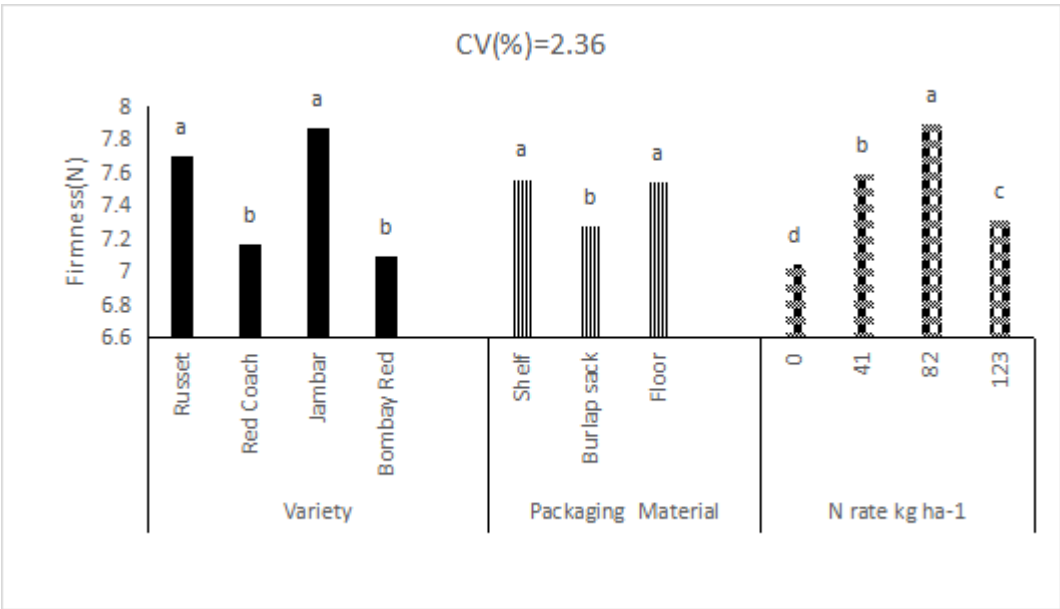


Figure 6.5. Main effects of variety, packaging material and nitrogen fertilizer on bulb firmness of onion combined over three locations

Table 6.5. Two-way interaction effect of variety and packaging materials on firmness (Newton) of onion bulb combined over the three locations

| Variety | Packaging material | Firmness                 |   |   |    |
|---------|--------------------|--------------------------|---|---|----|
|         |                    | Storage duration (weeks) |   |   |    |
|         |                    | 0 (initial)              | 4 | 8 | 12 |

|            |             |                     |                    |                      |                      |
|------------|-------------|---------------------|--------------------|----------------------|----------------------|
| Russet     | Shelf       | 9.85 <sup>a</sup>   | 8.74 <sup>ab</sup> | 8.13 <sup>a</sup>    | 7.86 <sup>a</sup>    |
|            | Floor       | 8.78 <sup>de</sup>  | 9.12 <sup>a</sup>  | 7.96 <sup>abc</sup>  | 7.69 <sup>abc</sup>  |
|            | Burlap sack | 9.18 <sup>dc</sup>  | 8.26 <sup>cd</sup> | 7.84 <sup>abcd</sup> | 7.57 <sup>abcd</sup> |
| Jambar     | Shelf       | 9.52 <sup>ab</sup>  | 8.98 <sup>ab</sup> | 8.20 <sup>a</sup>    | 7.93 <sup>a</sup>    |
|            | Floor       | 9.30 <sup>bc</sup>  | 8.83 <sup>ab</sup> | 8.11 <sup>ab</sup>   | 7.84 <sup>ab</sup>   |
|            | Burlap sack | 9.12 <sup>cd</sup>  | 8.63 <sup>bc</sup> | 8.10 <sup>ab</sup>   | 7.83 <sup>ab</sup>   |
| Red Coach  | Shelf       | 8.86 <sup>de</sup>  | 8.04 <sup>de</sup> | 7.50 <sup>de</sup>   | 7.23 <sup>de</sup>   |
|            | Floor       | 8.54 <sup>e</sup>   | 7.96 <sup>de</sup> | 7.48 <sup>de</sup>   | 7.20 <sup>de</sup>   |
|            | Burlap sack | 9.06 <sup>cd</sup>  | 7.85 <sup>ef</sup> | 7.35 <sup>ef</sup>   | 7.08 <sup>e</sup>    |
| Bombay Red | Shelf       | 8.93 <sup>cde</sup> | 8.10 <sup>de</sup> | 7.63 <sup>cde</sup>  | 7.30 <sup>cde</sup>  |
|            | Floor       | 9.06 <sup>cd</sup>  | 8.27 <sup>cd</sup> | 7.69 <sup>bcde</sup> | 7.42 <sup>bcde</sup> |
|            | Burlap sack | 8.98 <sup>cd</sup>  | 7.49 <sup>f</sup>  | 6.98 <sup>f</sup>    | 6.63 <sup>f</sup>    |
| P values   |             | ***                 | ***                | ***                  | ***                  |
| CV (%)     |             | 3.21                | 3.70               | 2.89                 | 3.19                 |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5%; and CV = coefficient of variation

## 6.4. Conclusion and Recommendations

The postharvest life of onion bulbs was significantly influenced by onion variety, packaging material and nitrogen fertilization rate combined in the three locations. They affected the initiation of sprouting, the percentage of decay, the percentage of marketable bulbs, the weight loss, the total content of soluble solids, and the firmness of the bulb during storage. The bulbs of Jambar and Russet varieties and the application of nitrogen fertilizer at the rate of 82 kg ha<sup>-1</sup> as well as storing them on shelves, recorded prolonged sprouting initiation, reduced decay percentage and weight loss, better firmness of bulbs as well as the highest percentage of marketable bulbs during the four months storage period. The highest storage loss of onion bulbs (highest sprouting percentage, decay percentage, weight loss percentage, and low marketable bulbs) was recorded from the Bombay Red variety. The longer shelf life (lower sprouting percentage, decay percentage, weight loss percentage, and higher percentage of marketable bulbs) was observed in the Jambar and Russet varieties, which were stored on the shelves. Hybrid onion varieties (Russet and Jambar) had a longer shelf-life compared to open-pollinated variety (Bombay Red). Packaging materials also played a significant role in influencing the postharvest quality of onion bulbs. Storing bulbs on shelves maintained their shelf life better than those stored in burlap sacks or directly on the floor. Similarly, the

application of optimum rates of nitrogen fertilizer is necessary to maintain the quality of onion bulbs in storage. The use of hybrid varieties (Russet and Jamber), storing onion bulbs on well-ventilated shelves constructed from locally available materials (wood), and the use of the optimum rate of nitrogen fertilizer are recommended to extend the shelf life and reduce the postharvest losses of onion bulbs.

## **Chapter 7: INFLUENCE OF TOPPLING AND STORAGE DURATION ON POSTHARVEST QUALITY AND SHELF LIFE OF ONION (*Allium cepa* L.) VARIETIES IN BAHIR DAR ZURIA DISTRICT, AMHARA REGION**

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"Influence of Variety, Topping, and Storage Duration on Postharvest Quality and Shelf Life of Onion (*Allium cepa* L.) in Bahir Dar Zuria District, Amhara Region"

### **Abstract**

*Onion is the most important and widely cultivated bulb vegetable in Ethiopia. High postharvest loss during storage is one of the main challenges of onion market supply and consumption. The present study was therefore conducted to evaluate the effects of selected pre-harvest treatments on the shelf life and postharvest quality of onion varieties stored in diffused light storage structure. Onion bulbs of three hybrids (Red Coach, Russet, Jambar) and one open-pollinated (Bombay Red) variety, produced in Woramit Research and Training sub-center of ARARI during the 2022/2023 irrigation season using uniform and standard agronomic practices, were used for the study. The pre-harvest treatments were topping at 70% neck fall with irrigation (ease of pulling up) and without irrigation, topping at 90% neck fall, and harvesting at 70% neck fall without topping and storage duration (4, 8 and 12 weeks). The treatments were arranged with 4\*4\*3 factorial combination in RCBD with three replications. Based on the treatment setup, bulbs were stored in a ventilated storage room in the Zenzelma campus of Bahir Dar University for three months. Data on postharvest quality parameters were collected in monthly intervals and analyzed using a SAS (version 9.0) software. The results revealed that variety, pre-harvest treatment, and storage duration influenced most of the tested parameters of onion in the storage. Similarly, the interaction of variety and pre-harvest treatments significantly influenced decay percentage, sprouting*

percentage, bulb firmness, total soluble solid of onion bulb, weight loss percentage, and marketable bulb percentage throughout the storage duration. The varieties Jambar and Russet and the practice of toppling at 90% maturity recorded the lowest sprouting and weight loss percentage of onion bulbs in the storage and the highest proportion of marketable bulbs and bulb firmness. On the other hand, the Bombay Red variety, which toppled at 70% maturity with irrigation, recorded the highest sprouting, decay percentage, bulb weight loss, and the lowest bulb firmness. The use of Jambar and Russet hybrid varieties with the practice of toppling at 90% maturity is therefore suggested to maintain the quality and reduce postharvest losses of onion bulbs in the storage. As the study is limited to a single location and season, it is recommended to repeat the study in multilocation and seasons. Additionally, evaluating the effect of plant growth hormones on extending shelf life is recommended.

Key words: Hybrid varieties, onion varieties, postharvest quality, pre-harvest treatments, shelf life, storage duration, toppling

## **7.1. Introduction**

Onion production plays a significant role in Northwest Ethiopia, contributing to the livelihoods of farmers and the Regional economy. As one of the principal cash crops cultivated in the Region, onions substantially enhance agricultural income, food security, and economic and health outcomes for smallholder farmers and large-scale commercial enterprises (Habtamu Mossie, 2020).

Despite its economic and agricultural importance, onion production and productivity in Ethiopia remain low, particularly in the study area. This is attributed to several factors, including poor-quality seeds, inappropriate cultural practices, and inadequate pre- and postharvest handling methods (Nikus Olani and Fikre Mulugeta, 2010; Melkamu Alemayehu *et al.*, 2015). These limitations lead to high postharvest losses, significantly affecting farmers' incomes. The widespread use of open-pollinated onion varieties in the region, which are characterized by low yield potential and poor storability, exacerbates this problem. As noted by Rahman *et al.* (2007), postharvest losses and short shelf lives in open-pollinated onion varieties can reach up to 100%. Farmers are often forced to sell their produce immediately

after harvest at low prices due to surplus production, further impacting their livelihoods (Yebirzaf Yeshiwas *et al.*, 2023).

The postharvest life of onions is influenced by factors such as the choice of variety, and agronomic practices like curing, toppling, and irrigation management. Farmers in the study area predominantly grow open-pollinated onion varieties, known for their limited storability. On the other hand, hybrid onion varieties, are reported to have better postharvest qualities and longer shelf lives (Rahman *et al.*, 2007).

Toppling, or bending onion plants, is a pre-harvest practice facilitating bulb-neck drying before harvest. Farmers in Ethiopia, including those in the Bahir Dar Zuria district, typically practice toppling by bending onion plants manually or using tools such as wooden planks (Alemu Melaku, 2015). This process helps accelerate bulb curing, reducing the neck's moisture content and minimizing the risk of microbial infections during storage. However, improper or prolonged toppling can expose bulbs to adverse environmental conditions, such as sunburn or pest infestations, potentially compromising postharvest quality (Yebirzaf Yeshiwas *et al.*, 2023). Research is needed to optimize the timing and method of toppling to balance its benefits and potential risks.

Irrigation practices during the harvest period are critical for maintaining onion quality. Excessive irrigation close to harvest increases the moisture content of bulbs, making them prone to decay and reducing their shelf-life (Yebirzaf Yeshiwas *et al.*, 2023; Patil *et al.*, 2018). Conversely, reduced irrigation frequency can promote bulb maturation and improve storability. In the study area, some farmers irrigate their onion fields just before harvest to ease manual pulling, while others adjust irrigation schedules to promote bulb quality. This variation highlights the need for guidance on optimal irrigation practices during the harvest period.

Farmers in the study area exhibit diverse practices regarding toppling and irrigation management. While some use manual or tool-assisted toppling to facilitate bulb curing, others irrigate their fields immediately before harvest to simplify the pulling process (Alemu

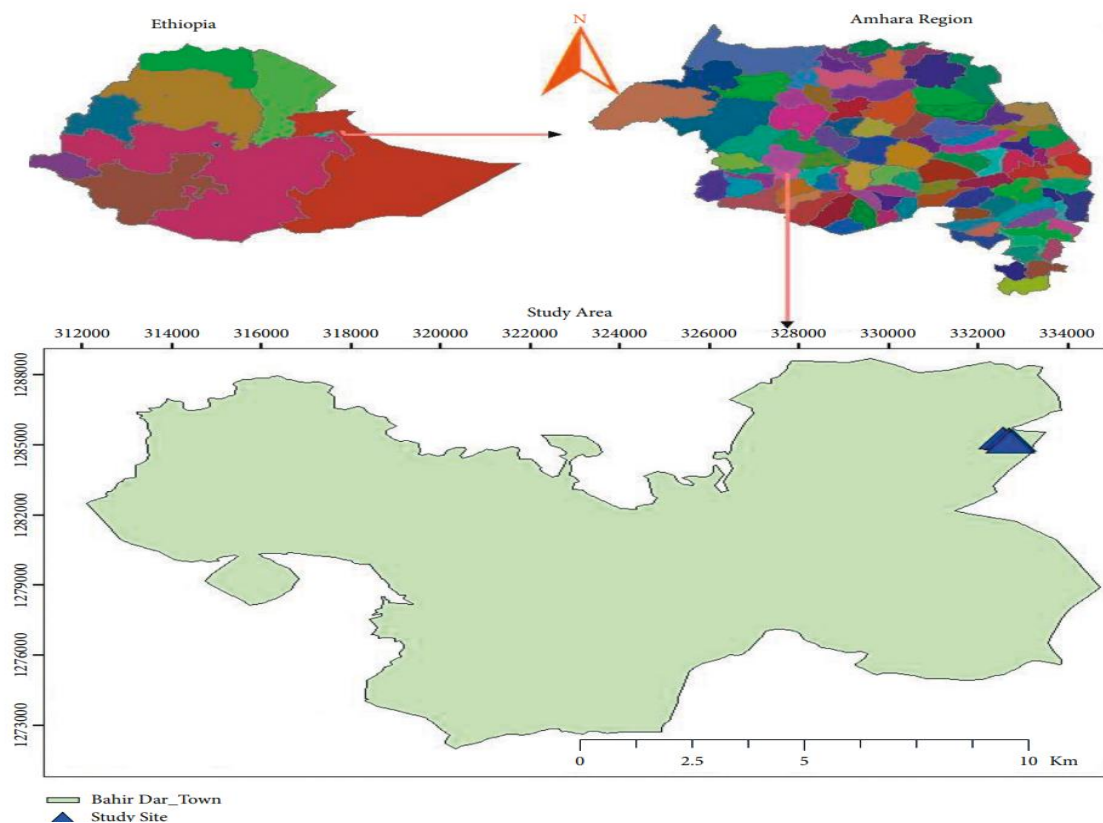
Melaku, 2015). The timing of these practices varies widely, with some farmers toppling their plants for extended durations. However, the effects of these agronomic practices on the postharvest loss and shelf life of onion bulbs have not been well studied. Therefore, this study was initiated for the following objectives:

- To identify the appropriate pre-harvest treatments, such as toppling timing and irrigation management, for maintaining the quality and shelf life of onion bulbs, and.
- To identify variety/ies with prolonged shelf life and better postharvest quality.

## 7.2. Materials and Methods

### 7.2.1. Description of the study area

The study area is described in 6.2.1.



Source; Mekuanint Lewoyehu et al. (2022)

Figure 7.1. Maps of field experimental site (Zenzelma campus).

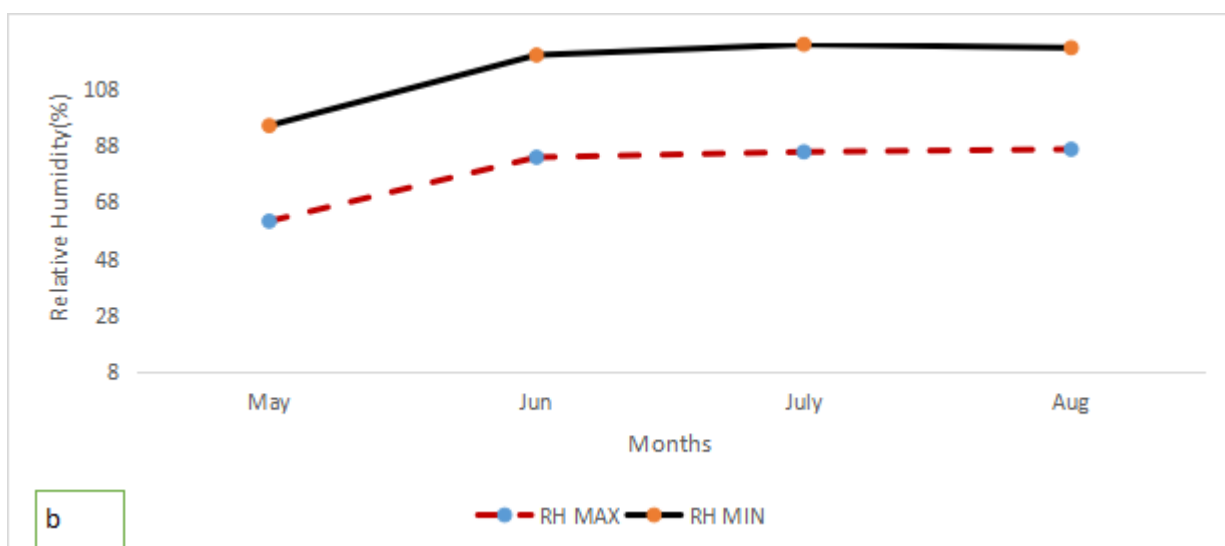
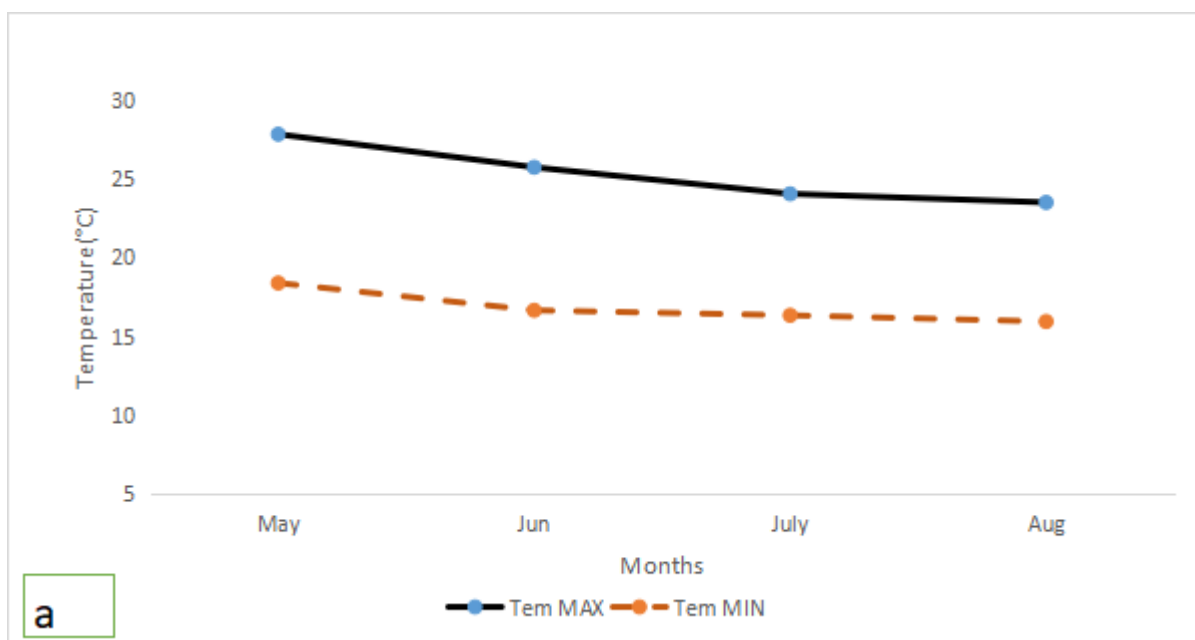


Figure 7.2. Average atmospheric temperature (a) and relative humidity (b) in storage structure during storage period in 2023.

### 7.2.2. Sources of bulbs and their preparation for storage

Bulbs from four onion varieties, three hybrids (Red Coach, Russet, and Jambar), and one open-pollinated variety (Bombay Red) were grown during the 2023 irrigation season at the Woramit Horticultural Crops Training and Testing Site. The onions were cultivated using standard agronomic practices recommended for onion production (MoARD, 2019). Best

performing plant density (40 cm x 20 cm x 5 cm between double rows, rows and plants respectively) and optimal nitrogen fertilizer rate at 82 kg ha<sup>-1</sup> (recommended from the first-year study) were used for this experiment (Yebirzaf Yeshiwas *et al.*, 2024 a, b). Before bulb-harvesting, onion plants were treated with four pre-harvest treatments, namely toppling at 70% plant fall followed by irrigation 3 days before harvesting, toppling at 70% neck fall without irrigation, toppling at 90% plant fall, Control (un-toppled, un-irrigated and harvested at 70% neck fall). Selecting toppling percentages at 70% and 90%, as well as scheduling irrigation three days prior to harvest, is based on common farmers' practices. Irrigation water was applied at a four-day interval for the 1<sup>st</sup> four weeks and then extended to seven days' intervals until the physiological maturity stage. Based on the treatments, irrigation water application was completely stopped 15 days before harvest. Harvesting of onion bulbs was done depending on the nature of the treatments. Except for the control plots harvested at 70% neck fall of plants in each plot, while the remaining treatments were harvested after seven days of toppling.

In all cases, irrigation ceased a week prior to implementing the toppling procedure, except for the plots toppled at 70% neck fall and receiving irrigation three days before harvesting. Harvesting took place seven days after the implementation of the toppling treatment. Toppling was done manually by trampling the plants and harvesting by pulling the plants at the onion neck. After harvest, bulbs were cured for five days under shade and ambient temperature (26.75 °C). After curing, the onion tops were removed. A total of 40 uniform and marketable bulb samples from each experimental plot and treatment that weighed five kg were selected for storage. Onion bulbs were put on shelves constructed with dried wood. Onion bulbs were stored for three months, and data were collected at monthly intervals depending on the parameters collected. In addition to 40 sample bulbs, 10 tagged bulbs were designated for destructive data collection of firmness and TSS.

### **7.2.3. Experimental treatments and design**

The storage experiment consisted of four onion varieties (Bombay Red, Red Coach, Russet, and Jambar), and four pre-harvest treatments (Toppling at 70% maturity/neck fall with

irrigation, toppling at 70% neck fall without irrigation, toppling at 90% neck fall without irrigation, harvesting at 70% neck fall with no toppling and no irrigation (control)] and three storage durations (4, 8 and 12 weeks). The experimental treatments in the storage room were arranged in 4\*4\*3 factorial arrangements, laid out in a randomized complete block design (RCBD) with three replications.

#### **7.2.4. Data collection**

Data collection methods were described in section 2.5.

#### **7.2.5. Data analysis**

Data were subjected to the analysis of variance (ANOVA) by using the ROC GLM procedure of the SAS version 9.0 computer software. The collected data were initially checked to meet all ANOVA assumptions (normality and homogeneity). When ANOVA showed significant differences ( $P < 0.05$ ), the mean separation was carried out using the least significant difference (LSD) (Gomez and Gomez, 1984).

### **7.3. Results and Discussion**

#### **7.3.1. Bulb sprouting percentage**

The analysis of variance showed that the main effects of variety, pre-harvest treatment, and storage duration, as well as two-way interactions of variety x storage duration and storage duration x pre-harvest treatments, influenced ( $P < 0.001$ ) bulb sprouting percentage of onion. Conversely, the three-way interaction of variety x pre-harvest treatments x storage duration did not influence ( $P > 0.05$ ) this parameter (Appendix Table 7.1). Bombay Red variety recorded the highest sprouting percentage (27.22%), followed by Red Coach (21.94%), while the lowest was recorded from the Russet (18.24%) and Jambar (19.16%) varieties during the three-month storage period (Figure 7.2). The difference between varieties for sprouting percentage is associated with the genetic variations of the varieties on their dormancy characteristics. Variations in the sprouting potential of onion varieties were also reported by other researchers (Gateri, 2019; Gebisa Bededa, 2017; Adamicki, 2005).

Bulbs that were toppled at 90% plant fall recorded the lowest sprouting percentage (14.53%), while those bulbs harvested at 70% plant fall (control) and toppled at 70% plant fall and irrigated three days before recorded the highest sprouting percentages of 25.46% and 27.03% respectively (Figure 7.2). Toppling is an important cultural practice of onion production, which facilitates drying the outer skin of onion bulbs and thus reduces the risk of sprouting during storage. Toppling at 90% and 70% neck fall of onion plants reduced bulb sprouting by 42.93% and 23.29% compared to the 70% neck fall without toppling(control) (Figure 7.3).

As the storage duration increases, there is a linear increase in the sprouting percentage of onion varieties. Specifically, the highest sprouting percentage (43.05%) was observed from the Bombay Red variety stored for 12 weeks, followed by The Red Coach variety (35.55%). The increase in sprouting as the storage period extends might be caused by the rise of relative humidity and reduction of temperature in the storage room during the storage period (Table 7.1; Figure 7.1).

Similar to the present findings, different researchers also reported that proper toppling reduces bulb sprouting during storage (Bizuyehu Desta *et al.*, 2021; Seid Hussen, 2022). On the other hand, toppling of onion plants at early developmental stages might lead to the production of bulbs that are not fully matured, which may potentially be more susceptible to premature sprouting during storage (Khire *et al.*, 2019). The application of irrigation at a late stage of onion maturity increases bulb moisture content, which creates a conducive environment for sprouting during storage, as indicated in the present study and other researchers (Tasisa Temesgen, 2021; Gorreapti *et al.*, 2017). Generally, physiological weight loss, rotting and sprouting, increase postharvest losses and ultimately reduce the shelf life of onions (Bizuyehu Desta *et al.*, 2021).

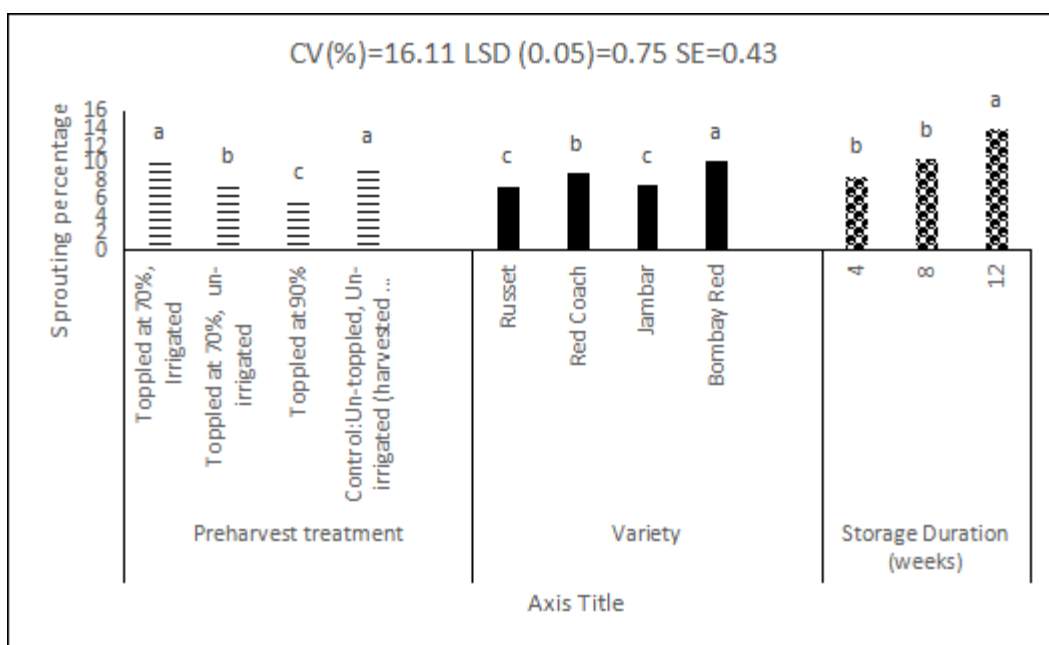


Figure 7.3. Sprouting percentage of onion bulbs as influenced by varieties, pre-harvest treatments and storage durations

Table 7 1. Spouting percentage of onion as affected by interaction variety and storage period

| Onion Varieties     | Storage duration   |                    |                     |
|---------------------|--------------------|--------------------|---------------------|
|                     | 4 week             | 8 week             | 12 week             |
| Russet              | 7.77 <sup>g</sup>  | 18.05 <sup>e</sup> | 28.88 <sup>cd</sup> |
| Jambar              | 7.77 <sup>g</sup>  | 18.88 <sup>e</sup> | 30.83 <sup>c</sup>  |
| Red Coach           | 9.16 <sup>fg</sup> | 21.11 <sup>e</sup> | 35.55 <sup>b</sup>  |
| Bombay Red          | 11.94 <sup>f</sup> | 26.66 <sup>d</sup> | 43.05 <sup>a</sup>  |
| P values            | **                 |                    |                     |
| LSD <sub>0.05</sub> | 1.77               |                    |                     |
| SE±                 | 0.35               |                    |                     |
| CV (%)              | 16.11              |                    |                     |

Where; \*\* = very highly significant at  $P < 0.001$  means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5% level; CV = coefficient of variation

### 7.3.2. Decay percentage

The analysis of variance showed that the main effects of variety, pre-harvest treatment, and storage duration, as well as their two-way interactions significantly ( $P < 0.01$ ), influenced the

bulb decay percentage of onion in the storage, whereas the three-way interaction did not influence this parameter (Appendix Table 7.1).

The highest decay percentage (23.51%) was observed from the variety Bombay Red, followed by the variety Red Coach (18.05%), while the lowest was observed from the variety Russet (15.27%) and Jamber (16.01%) during the three-month storage period (Figure 7.3). The present results indicate that hybrid onion varieties Jambar and Russet generally have higher storability compared to open-pollinated varieties like Bombay Red. In this regard, Diaz-Perez *et al.* (2003) also reported that hybrid onion varieties often have a longer shelf life than open-pollinated onions due to their thicker and dried skins, which help them to protect the bulbs from mechanical damage during handling and storage, which in turn reduce the incidence of disease infection. Differences in decay percentage among varieties observed in the present study are associated with the genetic makeup of varieties. Differences among onion varieties toward spoilage/decay percentage were also observed by various researchers (Randhawa *et al.*, 2022; Mota *et al.*, 2019; Gebisa Bededa; 2017; Singh *et al.*, 2015).

Among pre-harvest treatments, the lowest decay percentage (14.07%) was recorded from bulbs toppled at 90% maturity, followed (16.66%) by toppling at 70% maturity and irrigated. On the other hand, the highest decay percentage (22.12%) was recorded from bulbs harvested at 70% maturity (control). As the storage duration increases, a linear increase in the onion decay percentage was observed in bulbs stored for 12 weeks (Figure 7.3). This could be attributed to the increase of relative humidity and decrease in temperature in the storage room during the storage period, which leads to condensation, can promote mold and fungi growth, sprouting, decay, and rotting of onion bulbs (Figure 7.2).

Toppling at the right time of maturity is an important agronomic practice that helps to dry the outer skin of bulbs, thereby leading to reduced decay, shrinking and sprouting in the storage as indicated in the present study. Toppling at 90% and 70% maturity reduced the bulb decay percentage by 53% and 39%, respectively, compared to un-toppled 70% maturity (Figure 7.4). Similarly, regulated irrigation, especially at the time of maturity, is also critical to reducing the moisture content of the bulbs (Seid Hussen, 2022). Irrigation on toppled and

harvested at 70% maturity in the present study increased the decay by 24% compared to non-irrigated and toppled at 70% maturity (Figure 7.4). Harvesting the bulbs too early may also lead to more decay in the storage due to un-matured bulbs.

The effect of storage duration on decay percentage varies depending on the onion variety. Russet and Jambar varieties show consistently lower decay percentages across all storage durations. This indicates these varieties are more decay-resistant and have better storage quality. On the other hand, the Bombay Red variety exhibits significantly higher decay percentages at each storage duration, which makes it less suitable for long-term storage (Table 7.2). The increasing trend of decay with the storage length can be attributed to the fact that onions may undergo physiological changes and metabolic activities that make them more susceptible to decay during the early stages of storage (Coolong., 2008).

Maintaining an appropriate moisture level in bulbs, particularly during storage, is essential to prevent favorable conditions for fungal growth and decay (Tasisa Temesgen, 2021; Khire *et al.*, 2019). The lowest decay percentage of bulbs toppled at 90% maturity in the present study is, therefore, associated with drying the outer skin which leads to reduced disease infection in the storage (Getenesh Nega *et al.*, 2015). Generally, toppling at different stages of maturity contributes to the reduction of onion bulb decay during postharvest handling and storage. Proper handling techniques, including careful sorting and regular inspection, can also help to minimize damage and prolong the shelf life of onions.

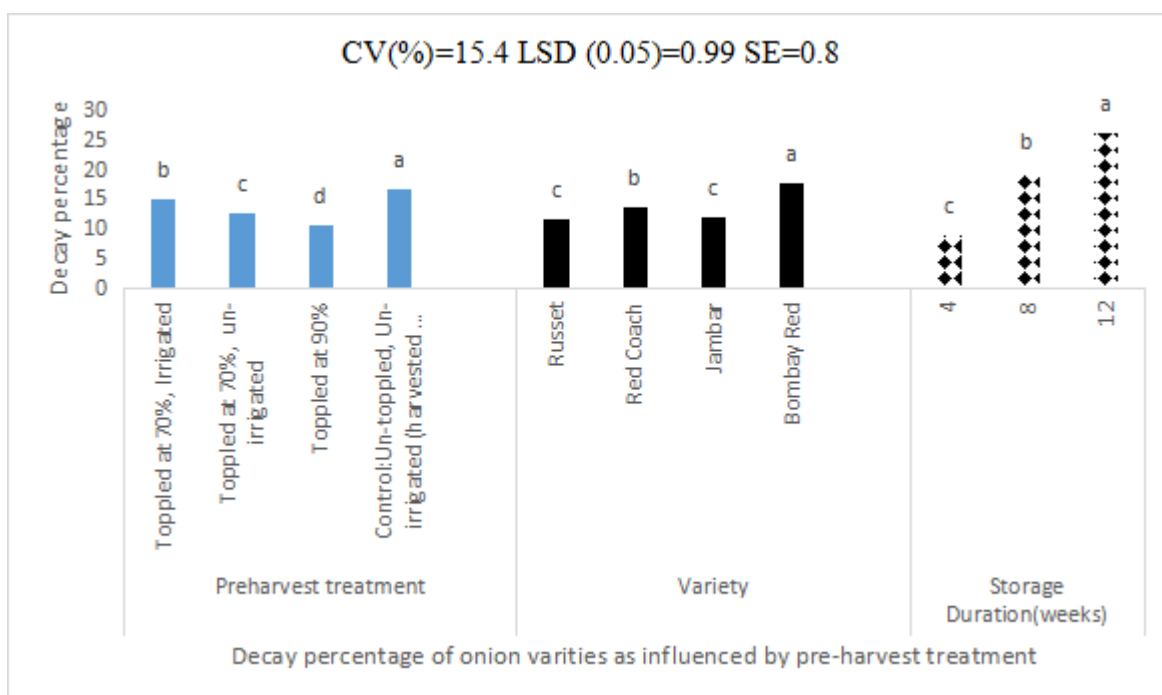


Figure 7.4. Decay percentage of onion bulbs as influenced by pre-harvest treatment, variety, toppling and storage duration

Table 7.2. Interaction effects of variety and storage duration on bulb decay percentage

| Onion Varieties     | Storage duration   |                     |                     |
|---------------------|--------------------|---------------------|---------------------|
|                     | 4 weeks            | 8 weeks             | 12 weeks            |
| Russet              | 7.77 <sup>h</sup>  | 16.38 <sup>f</sup>  | 21.66 <sup>cd</sup> |
| Jambar              | 6.94 <sup>h</sup>  | 17.22 <sup>ef</sup> | 23.88 <sup>bc</sup> |
| Red Coach           | 8.61 <sup>h</sup>  | 19.44 <sup>de</sup> | 26.11 <sup>b</sup>  |
| Bombay Red          | 12.22 <sup>g</sup> | 25.00 <sup>b</sup>  | 33.33 <sup>a</sup>  |
| P values            | ***                |                     |                     |
| LSD <sub>0.05</sub> | 2.91               |                     |                     |
| SE±                 | 0.34               |                     |                     |
| CV (%)              | 15.4               |                     |                     |

Where; \*\*\* =very highly significant at  $P < 0.001$  means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5% level; CV = coefficient of variation

### 7.3.3. Total soluble solid (TSS)

Onion variety ( $P<0.0001$ ) and its interaction with pre-harvest treatment ( $P<0.0001$ ) influenced the total soluble solids (TSS) content of the stored onion bulbs. Similarly, the main effect of pre-harvest treatment and storage duration significantly influenced ( $P<0.001$ ) the TSS of the stored onion bulbs. However, the interactions between pre-harvest treatment x storage duration, variety x storage duration, and pre-harvest treatment x storage duration x variety did not influence the TSS of stored onion bulbs (Appendix Table 7.1). Bombay Red variety recorded the highest TSS value compared to the tested hybrid onion varieties throughout the storage period (Figure 7.4). Similarly, the Bombay Red variety topped at 90% and recorded the highest TSS value (Table 7.3). The differences among varieties for TSS may be due to the variations in the genetic makeup. In this regard, Choje *et al.* (2007) and Mohammed and Gaafar (2005) reported variations in the TSS content of onion varieties, which was attributed to their genetic variations.

Extended maturation periods allow prolonged accumulation and conversion of starches into sugars, resulting in higher TSS levels at harvest Brewster (2008), which is observed in the Bombay Red variety in the present study (Table 4.1; Table 5.1). In addition, low-yielder onion varieties possess genetic traits that favor the accumulation of sugars or other soluble solids in the bulb. These genetic factors may influence metabolic pathways involved in sugar synthesis, transport, and storage within the plant tissues (Fait *et al.*, 2008; Kader, 2008). Similar to the results of the present study, Mallor and Sales (2012) indicated that varieties with higher bulb yields have lower TSS content compared with varieties with the lowest yields due to the production of small-sized bulbs. Relatively higher TSS was reported in open-pollinated tomato varieties compared to the hybrid ones, as hybrid varieties could be bred for specific traits such as better storability, yield potential, and uniformity rather than higher TSS (Berno *et al.*, 2014; Dwivedi *et al.*, 2013; Giovannoni, 2004). Lee and Kim (2014) reported that onions with higher sugar content might result in a higher weight loss during storage due to increased respiration rates. A higher level of TSS could result in more active metabolic processes, leading to greater weight loss as sugars are used during respiration. Furthermore, Patel *et al.* (2020) indicated that different onion varieties display various levels of TSS.

In general, there was a gradual decreasing trend of TSS as the storage period extended (Figure 7.5). According to Chávez-Mendoza *et al.* (2016), sugar metabolism is closely linked to the breaking of dormancy and the start of sprouting of onion. Similarly, Chohe *et al.* (2012) reported that changes during storage are related to respiration and re-mobilization of carbohydrates to provide energy for the development of sprouts associated with the sudden reduction of TSS.

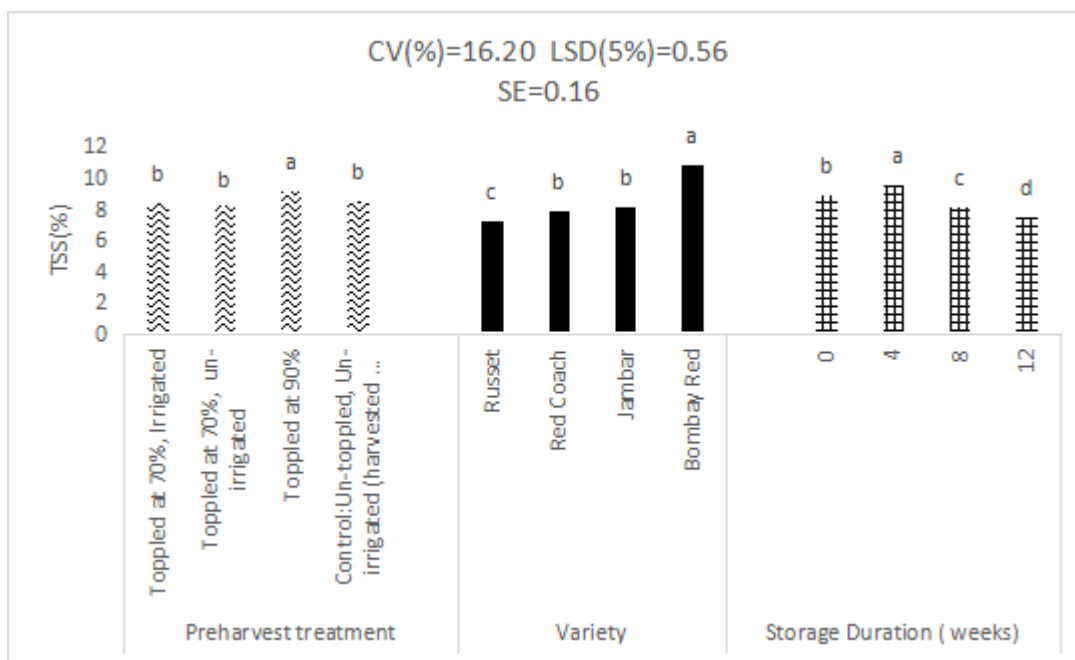


Figure 7.5. Total Soluble Solid (TSS) of onion bulbs as influenced by pre-harvest treatments, variety and storage duration (weeks)

#### 7.3.4. Bulb firmness

The analysis of variance showed that the main effects of variety, storage duration, and pre-harvest treatment had a very highly significant ( $P < 0.0001$ ) effect on bulb firmness. In addition, the interaction of variety x pre-harvest treatment showed a highly significant ( $P < 0.001$ ) effect on bulb firmness. However, the other two way and three-way interactions did not influence ( $P > 0.05$ ) the bulb firmness (Appendix Table 7.1). Bulb firmness was generally decreased as the storage period extended. Bulbs of Jambar (9.48 Newton) and Russet (9.32 Newton) varieties had relatively higher firmness during storage period compared to other varieties. Similarly, bulbs from plants toppled at 90% neck fall recorded the highest firmness (8.90 Newton) compared to other pre-harvest treatments (Figure 7.5). Likewise,

Jambar and Russet showed the highest firmness under toppling at 90% neck fall, whereas Bombay Red tended to have lower firmness across pre-harvest treatments, especially under Toppling at 70% neck fall with irrigation (Table 7.3).

Bulb firmness is an important feature that enhances the shelf life of a given onion variety, which could be associated with the genetic makeup of the varieties (Smith *et al.*, 2020). In agreement with the present results, Romo and Maria (2021) reported that different onion varieties possess distinct genetic characteristics that can influence bulb firmness.

Khire *et al.* (2019) reported that different toppling stages affect bulb maturity and dry matter accumulation. Bulbs harvested at 90% maturity stages might have higher dry matter content with more completed bulb maturity and reduced moisture content, contributing to increased bulb firmness. On the other hand, irrigation after toppling increases the bulb moisture content, which affects the bulb firmness, as indicated in the present study (toppling at 70% maturity and irrigated). Excessive moisture could lead to softer bulbs (Tasisa Temesgen, 2021). The decrease in firmness during storage is related to biochemical reactions of cell wall degradation (Chávez-Mendoza *et al.*, 2016), which reduce structural integrity and firmness, resulting in moisture losses through transpiration and respiration processes in onion bulbs.

As the moisture levels decrease, the cells in the onion bulbs lose turgor pressure, softening the tissues and firmness losses. In addition, enzymatic activities such as cell wall degrading enzymes (e.g., pectinases) contribute to the breakdown of cell walls and other structural components, resulting in softer bulbs over time (Kader, 2008; Adams and Hicks, 2005).

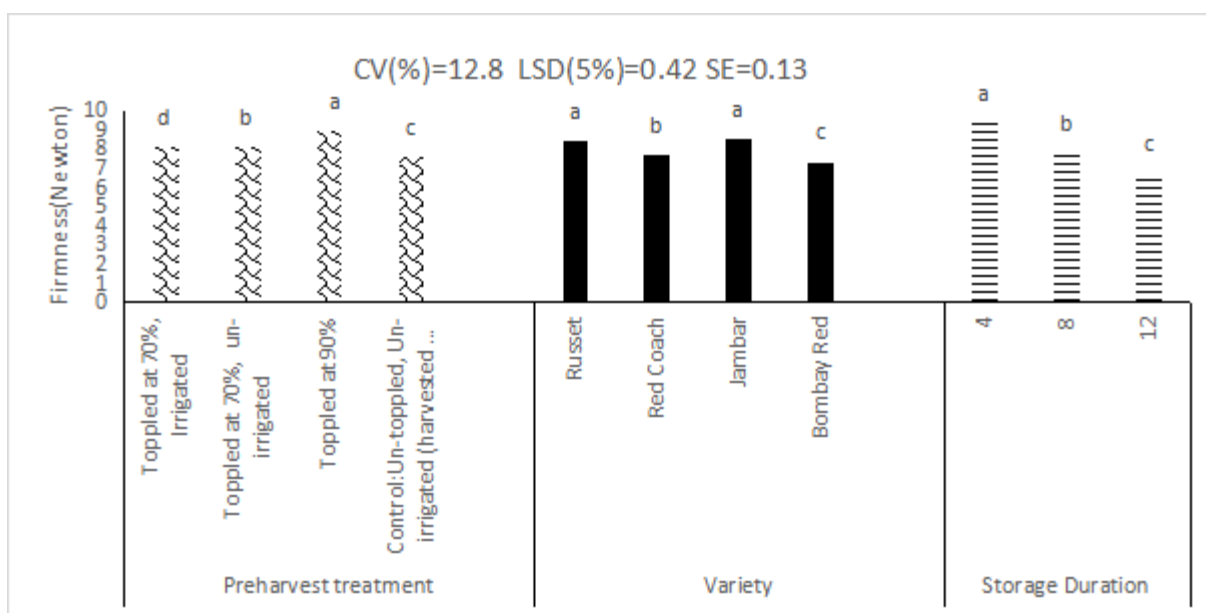


Figure 7.6. Main effects of variety, pre-harvest treatment and storage duration(weeks) on firmness of onion bulb

Table 7.3. Interaction effect of variety and pre-harvest treatment on the total soluble solid and firmness of onion bulbs on storage duration

| Pre-harvest treatment                          | Variety    | TSS                 | Firmness            |
|------------------------------------------------|------------|---------------------|---------------------|
| Toppling at 70% neck fall with irrigation      | Russet     | 7.03 <sup>def</sup> | 7.71 <sup>cde</sup> |
|                                                | Jambar     | 7.14 <sup>def</sup> | 7.20 <sup>def</sup> |
|                                                | Red Coach  | 7.62 <sup>cde</sup> | 6.96 <sup>ef</sup>  |
|                                                | Bombay Red | 11.05 <sup>b</sup>  | 6.83 <sup>f</sup>   |
| Toppling at 70 % neck fall, without irrigation | Russet     | 8.19 <sup>cd</sup>  | 8.60 <sup>b</sup>   |
|                                                | Jambar     | 8.17 <sup>cd</sup>  | 8.76 <sup>b</sup>   |
|                                                | Red Coach  | 8.40 <sup>c</sup>   | 7.35 <sup>def</sup> |
|                                                | Bombay Red | 6.87 <sup>ef</sup>  | 7.64 <sup>cde</sup> |
| Toppling at 90 % neck fall                     | Russet     | 7.95 <sup>cde</sup> | 9.63 <sup>a</sup>   |
|                                                | Jambar     | 8.18 <sup>cd</sup>  | 9.74 <sup>a</sup>   |
|                                                | Red Coach  | 8.66 <sup>c</sup>   | 8.58 <sup>b</sup>   |
|                                                | Bombay Red | 12.98 <sup>a</sup>  | 7.70 <sup>cde</sup> |
| Control (un toppling, un irrigated)            | Russet     | 6.36 <sup>f</sup>   | 7.75 <sup>cd</sup>  |
|                                                | Jambar     | 8.52 <sup>c</sup>   | 8.34 <sup>bc</sup>  |
|                                                | Red Coach  | 7.03 <sup>def</sup> | 7.56 <sup>def</sup> |
|                                                | Bombay Red | 10.95 <sup>b</sup>  | 7.05 <sup>def</sup> |
| P values                                       |            | ***                 | **                  |
| LSD <sub>0.05</sub>                            |            | 1.21                | 0.77                |
| SE±                                            |            | 0.16                | 0.13                |
| CV (%)                                         |            | 16.2                | 12.8                |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \*\* = highly significant at  $P < 0.01$ . means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5%; and CV = coefficient of variation

### 7.3.5. Percent bulb weight loss

The analysis of variance showed that the main effects of variety, storage duration, and pre-harvest treatment influenced ( $P < 0.001$ ) the bulb weight loss. The two-way interaction between variety and storage duration also highly significantly ( $P < 0.001$ ) influenced the bulb weight loss. However, the interaction of the variety x pre-harvest treatment, pre-harvest treatment x storage duration, and variety x pre-harvest treatment x storage duration did not affect ( $P > 0.05$ ) weight loss percentage of onion (Appendix Table 7.1). Weight loss generally increased as the storage period increased, and bulbs of Jambar and Russet varieties generally recorded the lowest weight loss compared to other varieties. Throughout the storage duration, weight loss increases, which is associated with a higher respiration rate. Similarly, bulbs from plants toppled at 90% neck fall recorded the lowest weight loss compared to other pre-treatments (Figure 7.6).

In addition, Russet under toppling at 90% neck fall shows the lowest weight loss percentage (3.25%), which is statistically similar to Jambar (3.36%), while Bombay Red under control conditions shows the highest weight loss (8.21%). Overall, the control (untopped and unirrigated) showed the highest negative effect on onion weight loss, especially for the Bombay Red variety, whereas toppling at 90% neck fall consistently showed the lowest weight loss across all varieties (Table 7.4). This indicates that toppling at 90% neck fall is preferable reducing postharvest issues.

Weight loss is among the major postharvest losses in onion, contributing to substantial economic losses for smallholder farmers. Selecting onion varieties with high storability is therefore necessary to reduce postharvest losses during storage. In this regard, bulbs of hybrid varieties, Jamber and Russet, recorded the lowest weight loss percentage throughout storage duration, which could be related to their genetic makeup. Hybrid varieties of onion are mainly bred to have thicker skins, which help protect onion bulbs from mechanical damage and are

associated with water loss leading to reduced weight loss. Therefore, hybrid onion varieties often have longer shelf life than open-pollinated onions (Cramer *et al.*, 2018).

Generally, weight loss of onion bulbs increased over a three-month storage duration, which differs with varieties and pre-harvest treatments (Figure 7.6). Toppling facilitates the drying of the outer skin of bulbs, which, in turn, reduces water and weight losses. The reduced weight loss on onions from plants toppled at 90% neck fall could be associated with a lower moisture content of the bulbs due to extended physiological maturity. Similar to the present findings, Khire *et al.* (2019) found that bulbs harvested at the 90% maturity stage recorded low weight losses in storing onion bulbs. Researchers also observed a low incidence of skin rot, lower weight loss, and more marketable grades of bulbs, reduced postharvest diseases and strong outer skins when onions were harvested at 80-100% leaf fall (Sebsebe Woldetsadik and Seyoum Workneh, 2010).

Irrigation practices before harvesting favours sprouting and weight loss of onion bulbs in the storage (Figure 7.2 and Figure 7.6). This is obviously attributed to the increased moisture content bulbs that initiate regrowth and weight losses in the storage conditions. These results are in agreement with the findings of Patel *et al.* (2020), who observed that onions irrigated close to harvesting have excess initial moisture leading to higher weight loss compared to unirrigated bulbs during storage. A combination of appropriate toppling techniques that initiate bulb drying and controlled irrigation practices generally help to achieve the optimal moisture content in bulbs, which reduces weight loss and sprouting during storage (Seid Hussen, 2022).

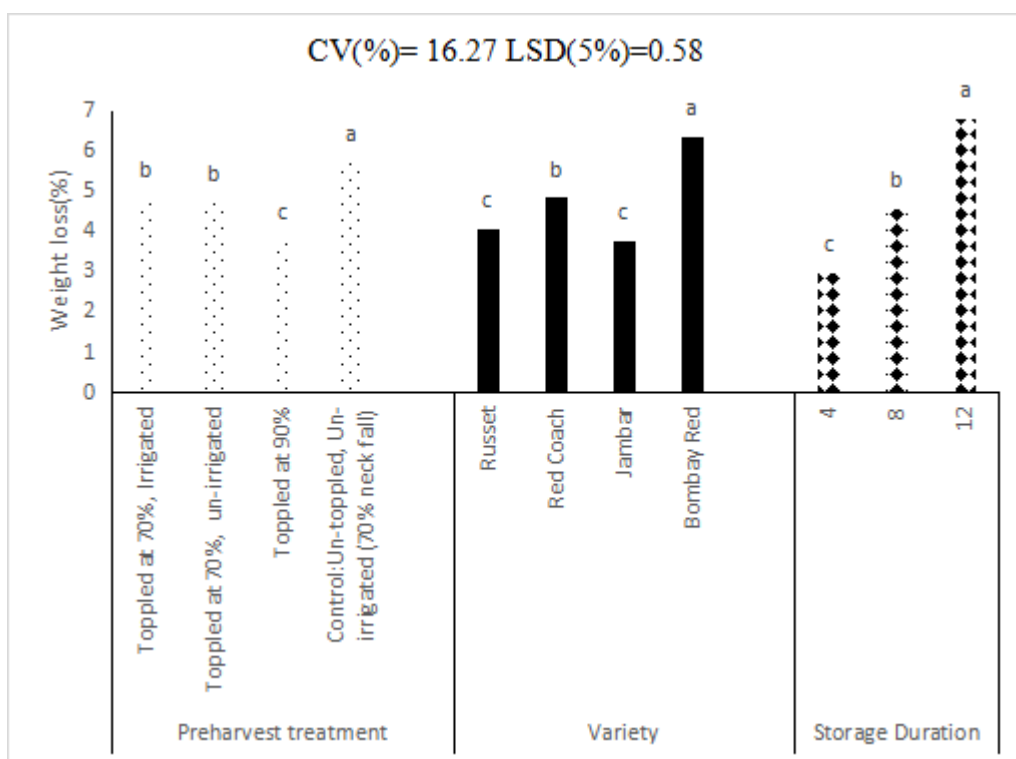


Figure 7.7. Main effects of varieties, pre-harvest treatments and storage duration (weeks) on the firmness of onion bulb

Table 7.4. Interaction effect of varieties and storage duration on bulb weight loss percentage

| Onion Varieties     | Toppling at 70% neck fall with irrigation | Toppling at 70% neck fall, without irrigation | Toppling at 90% neck fall | Control (un toppling, un irrigated): harvested at 70% maturity |
|---------------------|-------------------------------------------|-----------------------------------------------|---------------------------|----------------------------------------------------------------|
| Russet              | 3.54 <sup>efgh</sup>                      | 4.18 <sup>defgh</sup>                         | 3.25 <sup>h</sup>         | 5.193 <sup>cd</sup>                                            |
| Jambar              | 3.57 <sup>efgh</sup>                      | 3.45 <sup>efgh</sup>                          | 3.36 <sup>gh</sup>        | 4.56 <sup>def</sup>                                            |
| Red Coach           | 5.34 <sup>cd</sup>                        | 5.29 <sup>cd</sup>                            | 3.8 <sup>efgh</sup>       | 4.81 <sup>cde</sup>                                            |
| Bombay Red          | 6.75 <sup>b</sup>                         | 5.75 <sup>bc</sup>                            | 4.52 <sup>defg</sup>      | 8.21 <sup>a</sup>                                              |
| P values            | **                                        |                                               |                           |                                                                |
| LSD <sub>0.05</sub> | 1.17                                      |                                               |                           |                                                                |
| SE±                 | 0.4                                       |                                               |                           |                                                                |
| CV (%)              | 16.27                                     |                                               |                           |                                                                |

Where; \*\* = highly significant at  $P < 0.01$ ; means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = Least significant difference at 5%; and CV = coefficient of variation

### 7.3.6. Marketable bulb percentage

The percentage of marketable bulbs was influenced ( $P < 0.001$ ) by the main effects of variety, storage duration, pre-harvest treatment, as well as the interaction effect of variety x pre-harvest treatments. However, the interactions of variety x storage duration, pre-harvest treatment x storage period, and variety x pre-harvest treatment x storage duration did not influence this parameter (Appendix Table 7.1).

Among onion varieties, Russet and Jambar maintained the highest (74.9% and 73.98%, respectively) marketable bulbs throughout the storage duration. On the other hand, the lowest marketable bulb (62.31%) was observed from the variety Bombay Red (Figure 7.7). Among the pre-harvest treatments, toppling at 90% neck fall resulted in the highest marketable bulb percentage (77.96%), whereas control conditions (untopped, and unirrigated and 70% neck fall without toppling + irrigation) consistently showed lower marketable bulb percentages (64.53% and 66.03%, respectively) (Figure 7.7).

The interaction effect indicates that toppling at 90% neck fall generally resulted in the highest marketable bulb percentages across all varieties, with Jambar (84.83%) and Russet (80.84%) showing the best performance. In contrast, the control treatment (untopping, unirrigated, harvested at 70% neck fall) resulted in the lowest marketable bulb percentages, particularly for the Bombay Red variety (Table 7.5).

Sprouting, a crucial indicator of onion bulb marketability, began after four weeks of storage period and continued until the end of the three-month. The highest marketable bulbs recorded from hybrid varieties Jambar and Russet, compared to the open-pollinated variety Bombay Red throughout the storage duration, can be due to their genetic makeup. The results of the present study underscore the importance of careful selection of onion varieties in reducing the postharvest losses of onion in storage. Onion can be generally stored for four weeks and above with relatively low postharvest losses if appropriate variety is used and appropriate toppling practices are implemented.

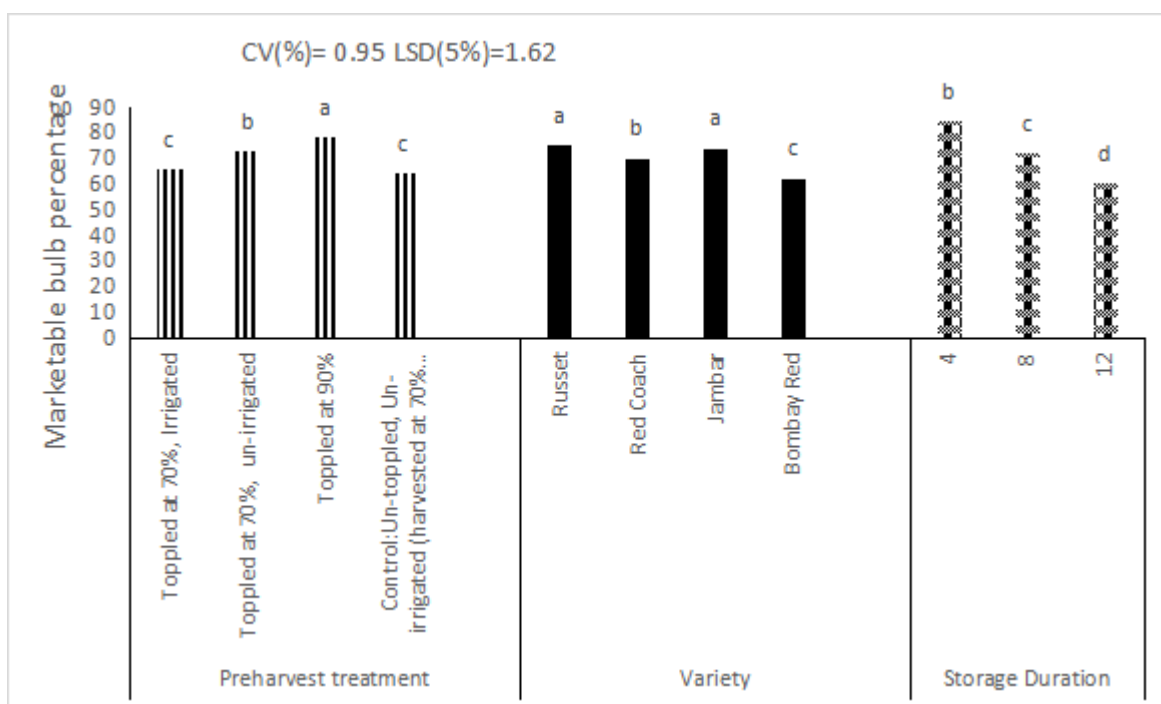


Figure 7.8. Main effects of varieties, pre-harvest treatments and storage duration on marketable bulb percentage

Table 7.5. Interaction effect of variety and pre-harvest treatments on marketable bulb percentage

| Onion Varieties | Toppling at 70% neck fall with irrigation | Toppling at 70% neck fall, without irrigation | Toppling at 90 % neck fall | Control (un toppling, un irrigation): harvested at 70% maturity |
|-----------------|-------------------------------------------|-----------------------------------------------|----------------------------|-----------------------------------------------------------------|
| Russet          | 71.11 <sup>d</sup>                        | 77.40 <sup>bc</sup>                           | 80.94 <sup>ab</sup>        | 70.3 <sup>d</sup>                                               |
| Jambar          | 69.25 <sup>de</sup>                       | 76.66 <sup>c</sup>                            | 84.81 <sup>a</sup>         | 65.18 <sup>f</sup>                                              |
| Red Coach       | 74.44 <sup>ef</sup>                       | 69.25 <sup>de</sup>                           | 75.92 <sup>c</sup>         | 69.25 <sup>de</sup>                                             |
| Bombay Red      | 57.7 <sup>g</sup>                         | 67.77 <sup>def</sup>                          | 70.37 <sup>d</sup>         | 53.33 <sup>h</sup>                                              |
| P values        | ***                                       |                                               |                            |                                                                 |
| LSD (0.05)      | 3.54                                      |                                               |                            |                                                                 |
| CV (%)          | 0.95                                      |                                               |                            |                                                                 |
| SE±             | 1.02                                      |                                               |                            |                                                                 |

Where; \*\*\* = very highly significant at  $P < 0.001$ . means followed by the same letter (s) within a column are not significantly different;  $LSD_{0.05}$  = least significant difference at 5%; and CV = coefficient of variation

## 7.4. Conclusion and Recommendations

The results of the present study clearly showed that variety and pre-harvest treatment

influenced the quality and shelf life of onion bulbs throughout the storage duration. Jambar and Russet varieties sprouted relatively late and recorded the lowest losses in bulb weight and decay percentage compared to Bombay Red and Red Coach varieties. Moreover, the bulbs of these varieties were relatively firm and recorded the highest proportion of marketable bulbs after three months of storage. Similarly, toppling of onion plants positively influenced the quality and shelf life of onion bulbs in storage, while irrigation some days before harvesting negatively influenced these parameters. Bulbs from plants toppled at 90% neck fall sprouted late, showed reduced decay percentage and weight loss, and were relatively firm and had relatively high total soluble solids and proportion of marketable bulbs in three months of storage. Selecting suitable onion varieties and implementing appropriate pre-harvest treatments are necessary to reduce the postharvest losses of onion bulbs in storage. Based on the results of the present study, toppling and harvesting onion plants at 90% neck fall and the use of Jambar and Russet hybrid onion varieties help to store onion for four weeks in Defused Light Storage without a significant postharvest loss of bulbs, which can be recommended for Bahir Dar Zuria district and areas with similar agro-ecology. As the work is limited to one season and location, repeating the study in multilocation and season is also recommended.

## **Chapter 8: GENERAL SYNTHESIS AND RECOMMENDATIONS**

A survey study and four separate experiments were conducted to optimize agronomic and postharvest practices for hybrid onion varieties in northwestern Ethiopia. The study aimed to improve yield and reduce postharvest losses by addressing challenges such as low productivity, high postharvest loss, and inadequate inputs. In addition, it focused on optimizing the nitrogen fertilizer application rate and plant density, and selecting of improved varieties with better yield and storability.

The key finding of the study showed that using hybrid onion varieties significantly increased onion yield and shelf life. Application of 82 kg N ha<sup>-1</sup> nitrogen fertilizer rate resulted in the highest marketable bulb yields and the greatest net benefit. Increasing the number of plant density to 666,666 plants ha<sup>-1</sup> resulted in the highest marketable bulb yield. Hybrid varieties like Jambar and Russet, and different packaging materials (shelf storage), and preharvest treatments (toppling at 90% maturity) maintain onion quality, extend shelf life, and reduce postharvest losses. Based on these results, the use of Russet and Jambar varieties, proper nitrogen fertilization, and improved storage methods are recommended to enhance onion production, reduce losses, and ensure food security and economic sustainability. To further strengthen these findings, future research should:

1. Repeat the study across multiple locations over more than one season.
2. Evaluate additional hybrid onion varieties and optimization of phosphorous fertilizer.
3. This study represents a pioneering effort in the area; future research could focus on evaluating various hybrid onion varieties combined with higher plant densities to optimize the yield and quality of onion bulbs.
4. It is also advisable to evaluate different storage structures and storage environments in multiple locations and seasons to validate findings under diverse agro-climatic conditions.
5. A combined study on optimization of plant density and nitrogen fertilizer rate experiment for hybrid cultivars
6. Ensure a sustainable supply of hybrid onion seeds through regional and national initiatives.

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## APPENDIX

Appendix 1. Questionnaire for survey on potential constraints and determinants of onion production and postharvest management practices in the supply-chain of onion in northwest Ethiopia

### General Comment

Dear Respondents: The questionnaire aims to collect important information along socioeconomic and ecological dimensions that are relevant for the research paper entitled **“Potential constraints and determinants of onion production and postharvest management in the supply-chain of onion in northwest Ethiopia.”** In this context, aver all scenarios of intervention areas and households at the heterogeneous scale are proposed for the onion production problem, magnitude of onion postharvest loss and its determinants to lay a foundation for change detection that considers in the study area. Thus, we would like to assure you that this questionnaire is used only for academic study purpose and not used for any other issues. Personal data/information is based on consent and keeps its confidentiality. We kindly ask you to cooperate for the successful accomplishment of the study. Thank you in advance.

Name of data collector: \_\_\_\_\_ Date \_\_\_\_\_ Code \_\_\_\_\_

### Part I- Interview with onion growers

#### I. Socio-demographic/General characteristics of households

1. Region \_\_\_\_\_ Zone \_\_\_\_\_ Woreda \_\_\_\_\_ Kebele \_\_\_\_\_
2. Age of the household head \_\_\_\_\_
3. Marital status    1. Married    2. Single    3. Widowed    4. Divorced
4. Sex of the household head    1. Male    0. Female
5. Educational status of the household head
  1. Illiterate    3. 1-6    5. 10-12
  2. Read and write only    4. 7-9    6. Higher education
  7. College level (10+ or 12+)
6. Family/household size \_\_\_\_\_
7. Family size by age category

| Category    | Male | Female | Total |
|-------------|------|--------|-------|
| 0-14 years  |      |        |       |
| 15-24 years |      |        |       |
| 25-65       |      |        |       |

|                |  |  |  |
|----------------|--|--|--|
| Above 65 years |  |  |  |
| Total          |  |  |  |

## II. Questions on Farming practices of onion

1. Family members who actively working on cultivating, harvesting, weeding etc? \_\_\_\_\_
2. Experience in producing onion \_\_\_\_\_ years
3. Main income source
  1. Vegetable production only                      2. Cereals production
  3. Livestock production                              4. Mixed                      5. Other sources \_\_\_\_\_
4. Comparative income source from vegetables?
  1. Onion    2. Tomato    3. Potato    4. Cabbage    5. Pepper    6. \_\_\_\_\_
5. Total land holding of the household? \_\_\_\_\_ ha
6. Area/land covered by onion? \_\_\_\_\_ ha
7. Amount harvested from land covered? \_\_\_\_\_ Q
8. Means of land acquisitions 1. Owned    2. Gift    3. Family    4. Rented    5 Inherited
9. How many times per year you produce onion? 1. Once    2. Twice    3. Other (specify)
10. At what stage you transplant your seedlings?
11. Did you trim your seedlings? 1. Yes    2. No
  - 11.1. If yes at what stage and why? \_\_\_\_\_
12. What is the planting distance you use? \_\_\_\_\_ cm between irrigation furrows \_\_\_\_\_ cm between plants and \_\_\_\_\_ cm between rows
13. Did you use irrigation? 1. Yes            2. No
14. How frequent do you irrigate your onion? \_\_\_\_\_ times/week
15. Do you have sufficient source of water for irrigation? 1. Yes            2. No
  - 14.1 If yes, what is the source for irrigation you most frequently use? Name of the river or pond \_\_\_\_\_
  - 14.2. If not, what are the reasons behind? \_\_\_\_\_
16. How many times do you produce onion per annual by using irrigation?
  1. Once    2. Twice    3. Other (specify) \_\_\_\_\_
17. What are the problems frequently you encounter in relation with use of irrigation? \_\_\_\_\_

## III - Questions on access for production inputs

### Hybrid seed varieties supply

18. Have you ever grown hybrid onion seed varieties? 1. Yes            2. No
  - 17.1. If yes , for how long \_\_\_\_\_ and name of cultivars \_\_\_\_\_

| No. | Name of hybrid Varieties | Years of 1 <sup>st</sup> grown | Under production or stopped | When stopped, production | Reasons for left prodn. High seed cost, unavailability of seeds, lack of , others... |
|-----|--------------------------|--------------------------------|-----------------------------|--------------------------|--------------------------------------------------------------------------------------|
|     |                          |                                |                             |                          |                                                                                      |
|     |                          |                                |                             |                          |                                                                                      |
|     |                          |                                |                             |                          |                                                                                      |
|     |                          |                                |                             |                          |                                                                                      |
|     |                          |                                |                             |                          |                                                                                      |

17.2. If no why? 1. Shortage of capital to purchase 2. Lack of water pumps 3. Lack of extension advice 4. High cost of production 5. Lack of experience 6. Others (specify)\_\_\_\_\_

19. Which hybrid onion variety you prefer?\_\_\_\_\_

18.1. Reasons for preference

1. Better yield advantage 3. Higher market demand 5. Low cost of purchase  
2. Long period of storage 4. Easy accessibility 6. Other (Specify)

20. Do you have sufficient access for hybrid seed varieties? 1. Yes 2.No

19.1. If yes, who are your sources of hybrid onion seed variety?

| Source of hybrid seed supply | Way of getting seeds through | Remark |
|------------------------------|------------------------------|--------|
| 1. Market                    | 1. Purchase                  | 1.     |
| 2. MoA/BoA                   | 2. On credit base            | 2.     |
| 3. Research centers          | 3. Gift                      | 3.     |
| 4. NGOs                      | 4. Exchange                  | 4.     |
| 5. Others (specify)          | 5. Other(specify)            | 5.     |

19.2. If No for Q.17, what is the reason behind?

1. Cash shortage 3. Being too expensive 5. Lack of knowledge  
2. Absence of credit access 4. other (specify)\_\_\_\_\_

### **Fertilizer and pesticide supply**

21. Do you use fertilize in onion farm? 1. Yes 2. No

20.1. If yes, what type of fertilizer do you use?

1. DAP 2. NPS/B 3. Urea 4. Organic 5. Other, specify \_\_\_\_\_

20.2. What is the amount of fertilizer you applied to produce onion? kg/ha

1. DAP\_\_\_\_\_ 2. NPS/B\_\_\_\_\_ 3. Urea\_\_\_\_\_ 4. Organic\_\_\_\_\_ 5. Other,

22. Method and time of your fertilizer application? \_\_\_\_\_

23. Which of the following inputs do you frequently use for onion production?

| No | Types of   | Name         | Sources (Local market, MoA/BoA, Research centers, NGO, Cooperative, Other Source | Quantity used(kg/ha) | Remark |
|----|------------|--------------|----------------------------------------------------------------------------------|----------------------|--------|
| 1. | Fertilizer | 1. DAP       | 1. .                                                                             | 1.                   | 1.     |
|    |            | 2. UREA      | 2.                                                                               | 2.                   | 2.     |
|    |            | 3. NPS/B     | 3.                                                                               | 3.                   | 3.     |
| 2. | Pesticide  | 1. Herbicide | 4.                                                                               | 4.                   | 4.     |
|    |            | 2. Fungicide |                                                                                  | 5.                   | 5.     |

24. Do you properly apply the recommended fertilizer rate? 1. Yes 2. No

23.1. If no why?\_\_\_\_\_

25. What factors you face on recommended rate fertilizer and pesticide application?\_\_\_\_\_

26. How do you see the above inputs purchase cost for onion production?

| Inputs       | Price situation |           |        |                |               |
|--------------|-----------------|-----------|--------|----------------|---------------|
|              | Very expensive  | Expensive | Medium | Less expensive | Not expensive |
| Hybrid seeds |                 |           |        |                |               |
| Fertilizer   |                 |           |        |                |               |
| Pesticide    |                 |           |        |                |               |
| Others       |                 |           |        |                |               |

27. Do you get fertilizer timely and adequately? 1. Yes 2. No

26.1. If no, why?

1. Cash shortage 2. High cost purchase 3. Lack of knowledge 4. Other (Specify)\_\_\_\_\_

26.2. What are your alternatives to solve this problem? \_\_\_\_\_

### Production

28. Do you face any constraints in onion production? 1. Yes\_\_\_\_\_ 2. No\_\_\_\_\_

27.1 If yes explain major onion production constraints by rank

| Constraints | Rank | Alternative solution taken |
|-------------|------|----------------------------|
| 1.          |      |                            |
| 2.          |      |                            |
| 3.          |      |                            |
| 4.          |      |                            |

29. How is the production trend of the volume of onion production for the past five years (qt/ha)? 1. Increasing 2. Decreasing

### Production costs

30. Indicate the average costs you incur for each production cost components and rate them in their descending order

| Production cost components                                | Average cost incurred | Remark |
|-----------------------------------------------------------|-----------------------|--------|
| 1. Cost of fertilizer                                     |                       |        |
| 2. Cost of seeds                                          |                       |        |
| 3. Cost of chemicals (fungicides, herbicides, pesticides) |                       |        |
| 4. Cost of fuel for water pumps(irrigation)               |                       |        |
| 5. Land preparation                                       |                       |        |
| 6. Sowing and transplanting                               |                       |        |
| 7. Cultivation                                            |                       |        |
| 8. Harvesting                                             |                       |        |
| 9. Labour                                                 |                       |        |

### **Disease and Insect pest**

31. What kind of disease protection chemicals is used?  
32. Do you use safety clothes during chemical spraying?

### **Price**

33. What was the market price of onion per quintal at its pick harvesting season in 2013?\_\_\_\_  
34. What was the market price of onion per quintal at its off season (summer) in 2013?\_\_\_\_  
35. How do you evaluate the price you received for two seasons comparatively?  
1. Increasing 2. Decreasing  
31.1. If the price is increasing, are you benefited from the increased price?  
1. Yes 2. No  
31.2. If no why?\_\_\_\_\_  
36. Who decides your selling price? 1. Yourself 2 Buyers 3. Brokers 4 Market demand and supply 5. By negotiation 6. Others (specify)\_\_\_\_\_  
37. What do you expect about the marketing problems with regard to onion price?  
1. Low selling price 2. High input price 3. Exploitation by middle men 4. Inaccessibility of market (long distance) 5. Other (specify)\_\_\_\_\_  
38. Are there brokers in your nearest area? 1. Yes\_\_\_\_\_ 2. No\_\_\_\_\_  
39. What is their role for you with regard to selling price?\_\_\_\_\_  
40. What are the problems created by brokers with regard to onion market?  
1. Took to limited client 2. Charged high brokerage 3. Cheating scaling (weighing)  
4. Wrong price (market) information 5. Others (specify)\_\_\_\_\_

### **Access to credit**

41. Did you buy farm inputs in cash? 1. Yes\_\_\_\_\_ 2. No\_\_\_\_\_  
42. If no, what was the reason?  
1. Lack of cash 2. Lack of access for credit 3 . Bureaucracy 4. Other (specify)\_\_\_\_\_  
43. Have you ever received credit? 1. Yes \_\_\_\_\_ 2. No\_\_\_\_\_

### **IV. Questions on Harvesting and Postharvest handling**

44. What is (are) your criterion to harvest onion? 1. Maturity 2. Market price 3. Other factors (mention) \_\_\_\_\_  
45. At what stage do you harvest onion? \_\_\_\_\_  
46. At what time of the day do you harvest onion?  
1. Morning 2. Afternoon 3. Evening 4. Any time  
47. For how long you cure onion bulbs ? \_\_\_\_\_  
48. What practice you apply before harvesting ? \_\_\_\_\_  
Why? \_\_\_\_\_  
49. When does you remove the top of the bulb?  
1. Before harvesting 2. Immediately after harvesting 3. Others (number of days from harvesting) \_\_\_\_\_  
50. What type of harvesting method you are practicing?  
1 Pulling by hand 2. Digging by hoe 3. Others \_\_\_\_\_  
51. How far is your farm from the local market? \_\_\_\_\_ walking minutes.  
52. How do you transport onion bulbs to the market?

1. Using animal driven cart 2. Using men's shoulder 3. Using women's back 4. Others, specify \_\_\_\_\_
53. How much produce are taking to the market? \_\_\_\_\_
54. Do you face market problems with regard to onion price? \_\_\_\_\_
55. What was the market price of onion per quintal at its pick selling season in 2013E.C? \_\_\_\_\_
56. Are you ever storing onion bulbs for late selling? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 55.1. If no why?
1. Lack of long-time stored varieties
  2. High cost of storage facilities
  3. Immediate cash need
  4. Lack of storage facility
  5. Lack of awareness on storage methods
  6. Other, specify \_\_\_\_\_
- 55.2. If yes for how long you stored the bulbs? \_\_\_\_\_
57. Is there any loss of onion after harvest? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 56.1. If yes? how many quintals of onion losses due to lack of storage last year (2013E.C)? \_\_\_\_\_
- 56.2. Can you explain the main reasons for the postharvest loss of onion? (rank them)
- | Causes for PHL | Rank |  |
|----------------|------|--|
| 1.             |      |  |
| 2.             |      |  |
| 3.             |      |  |
| 4.             |      |  |
| 5.             |      |  |
58. How much produce are taking to the market? \_\_\_\_\_
- 57.1. What type of container you are using? \_\_\_\_\_
- 57.2. By what means (transportation method)? \_\_\_\_\_
59. What type of storage/packaging material do use do you use for home consumption or late selling? 1. Jute/Burlap bag 2. Spread on ground 3. Shelf/alega 4. Others \_\_\_\_\_
60. Are you selling all the products you are harvested and are taking to the market / are there any loss? 1.Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 59.1. If no, why? 1. Disease 2. Small bulb size 3. Larger bulb size 4. Others (specify) \_\_\_\_\_
- 59.2. If no, why? 1. Disease 2. Small bulb size 3. Larger bulb size 4. Others (specify) \_\_\_\_\_
- 59.3. What will be the fate for the rest/unsold products? \_\_\_\_\_
61. For whom do you usually sell your onion?
1. Collectors
  2. Wholesalers
  3. Cooperatives
  4. Retailers
  5. Consumers
  6. Others (specify) \_\_\_\_\_
- 60.1. Why do you prefer selling to this buyer? 1. Better price 2. Customers 3. No quality discrimination 4. Large volume of purchase 5. Others(specify) \_\_\_\_\_
61. What are the reasons behind for reducing bulb quality? \_\_\_\_\_

1. Improper production practices 3. Inefficient care during harvesting and transport
2. Inadequate water resource 4. Immediate need for money 5. Others  
(specify)\_\_\_\_\_

62. What measures you are practicing to minimize loss after harvest? \_\_\_\_\_

63. Do you believe onion farming is a profitable venture? 1. Yes \_2. No\_\_

64. If no, what problems do you think are the major constraints? List (by priority) \_\_\_\_\_

65. Have you ever taken trainings related to postharvest handling of onion? 1. Yes \_2. No

66. If yes for Q64; when did you take trainings?\_\_\_\_\_

67. Is there a cooperative for onion to collect harvest bulbs? 1. Yes \_2. No\_\_

67.1. If yes are you a member of cooperatives? 1. Yes \_\_\_\_2. No\_\_\_\_\_

67.2. If no are you interested to sell your onion through cooperatives? 1. Yes \_\_2. No

#### **Information:**

##### **Access to market information (AMI)**

68. How do you get information about buyers/ transporters? \_\_\_\_\_

69. How do you know what price to take for your onions? \_\_\_\_\_

70. Does the farmer pay to brokers? How do the broker and farmer find each other?\_\_\_\_\_

71. How does you know how much onion is planted? \_\_\_\_\_

721. How does the farmer find sellers of fertilizers and disease protection? \_\_\_\_\_

## **Part II- Interview with onion wholesalers**

### **I. Socio-demographic characteristics**

1. City\_\_\_\_\_
2. Age \_\_\_\_\_
3. Sex 1. Male \_\_\_\_\_ 0. Female \_\_\_\_\_
4. Educational level (years of formal schooling) \_  
  1. Illiterate 3. 1-6 5. 10-12
  2. Read and write only 4. 7-9 6. higher education
  7. College level (10+ or 12+)
5. Family size\_\_\_\_\_
6. Marital status 1. Married 2. Single 3. Widowed 4. Divorced

### **II**

7. Experience in selling onion \_\_\_\_\_years
8. How do you collect your onion bulbs? 1.Through brokers 2. Collect from farm  
(Own) 3. Farmers delivers to you 4. Others \_\_\_\_\_
9. Do you get and evaluate samples of the onions before buying them?
10. Do you face quality problems from suppliers? 1. Yes\_\_\_\_ 2 No \_\_\_\_  
  - 10.1. If yes, what are the problems? 1. Type of variety 2. Drying problem 3. Bulb size 4.  
Disease 5. Others, specify\_\_\_\_\_

| Reason               | Rank |  |
|----------------------|------|--|
| 1. Variety type      |      |  |
| 2. Improper maturity |      |  |

|                |  |  |
|----------------|--|--|
| 3. Bruising    |  |  |
| 4. Bulb size   |  |  |
| 5. Rotting     |  |  |
| 6. Sprouting   |  |  |
| 7. Shrivelling |  |  |

11. On average, what amount of onion bulbs you bought from suppliers at a time? \_\_\_\_\_qt; what amount of it will be sold? \_\_\_\_\_qt.
12. Do you sell all you bought? 1. Yes\_\_\_\_ 2. No\_\_\_\_
- 11.1.If no, what are the reasons? 1. Poor quality 2. Reduced market demand 3. Others, specify\_\_\_\_\_
- 11.2.Are there any storage possibilities for onions at the market? 1. Yes\_\_\_\_ 2. No\_\_\_\_  
Method of storage \_\_\_\_\_and For how long?\_\_\_\_\_
13. What is the total estimated percentage of bulbs which are not-suitable for market? \_\_\_\_%
14. What do you do with bulbs rejected due to poor quality? 1. Sell with reduced price 2. Used for own consumption 3. Discard 4. Others \_\_\_\_\_
15. If onion is to be sold with discount price, by what amount will the price be reduced? \_\_\_\_\_birr
16. If onion is to be discarded, what do you do with it? 1. Manure 2. Cattle feed 3. Thrown to garbage tanks 4. Others specify \_\_\_\_\_
17. What are the reasons behind for unsuitability for market? Rank in their order of importance.

| Reason                                    | Rank |  |
|-------------------------------------------|------|--|
| 1. Variety type                           |      |  |
| 2. Immaturity                             |      |  |
| 3. Poor handling                          |      |  |
| 4. Poor packaging material                |      |  |
| 5. Poor transportation                    |      |  |
| 6. Absence of suitable storage conditions |      |  |
| 7. Others (specify)                       |      |  |

18. What measures do you undertake to reduce the amount of rejected bulbs? \_\_\_\_\_
19. Do you have any suggestions to minimize the amount of rejected bulbs?
20. How many days does it take to finish selling your onion bulbs? \_\_\_\_\_ days
21. At what date interval do you buy new onion from suppliers? \_\_\_\_\_ days

22. How do you store bulbs for selling? 1. Inside jute bag 2. Heaping on the floor 3. Spreading on the shelf 4. Others (specify) \_\_\_\_\_
23. Is there any loss at storage? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
24. What are the causes for loss? Rank \_\_\_\_\_
25. For whom do you usually sell your onion? 1. Restaurants, 2. Retailers 3. Consumers 4. All
26. How much is you sold for each customers?  
1. Resturants \_\_\_\_\_ 2. Retailers \_\_\_\_\_ 3. Consumers \_\_\_\_\_ 4. I don't know \_\_\_\_\_  
5. Varies every day \_\_\_\_\_
2. Do you face in supply shortage of onion bulbs in any of the seasons? 1. Yes 2. No
3. If yes, at which season of the year? \_\_\_\_\_; what are the reasons? \_\_\_\_\_
4. Is the demand for onion is seasonal? 1. Yes 2. No
5. If yes, when does the demand rises? (months of the year) \_\_\_\_\_; what are the reasons? \_\_\_\_\_
6. When does the demand fall? (months of the year) \_\_\_\_\_
7. What are the reasons for the fall in demand? \_\_\_\_\_
8. Is there a price variation for bulbs you sell? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
9. If yes, when does the price rises? (months of the year) \_\_\_\_\_
10. What are the reasons for the rise in price? \_\_\_\_\_
11. Have you benefited from rise in price? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
12. When does the price falls? (months of the year) \_\_\_\_\_
13. What are the reasons for the fall in price? \_\_\_\_\_
14. What type of packaging material do you use for the transport of onion to market?  
1. Plastic crates 2. Unpacked 3. Wooden-box 4. Sacks 5. Baskets 6. Others
15. What type of transportation /trucks you are using? 1. Open vehicle 2. Closed vehicle 3. Human (labor) 4. Others
16. How much onion can one truck carry? \_\_\_\_\_
17. Is there any loss during transportation? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 22.1. If yes causes for loss?  
\_\_\_\_\_
- 22.2. Amount of actual losses at the market per week/Extent of losses? Per week (Can for example be rotten onions, old onions, dry onion peel  
\_\_\_\_\_

| Avg. quantity purchased in Qt | Avg. quantity sold Qt | Grading loss kg | Storage loss kg | Transportation loss kg | Selling loss kg |  |
|-------------------------------|-----------------------|-----------------|-----------------|------------------------|-----------------|--|
|                               |                       |                 |                 |                        |                 |  |

18. What measures are you taking to minimize the losses during transportation, storage and selling? \_\_\_\_\_

19. Do you have contact with farmers? 1. Yes have direct contact 2. No direct contact with farmers, all contact goes through brokers 3. Sometimes direct contact with farmers but usually through a broker
20. What onion-varieties you bought? \_\_\_\_\_
21. Do different buyers pay different prices? \_\_\_\_\_
22. At what time you transport from the farm to you? \_\_\_\_\_
23. If the onion bulbs are damaged during the transportation, what is the most common cause \_\_\_\_\_

### Information

24. How does the wholesaler find trucks for the onion transportation? \_\_\_\_\_
25. Any contact with the farmers? \_\_\_\_\_

## Part III- Interview with onion retailers

### I. Socio Demographic characteristics

1. City \_\_\_\_\_
2. Age \_\_\_\_\_
3. Sex 1. Male \_\_\_\_\_ 0. Female \_\_\_\_\_
4. Educational level (years of formal schooling)
  1. Illiterate 3. 1-6 5. 10-12
  2. Read and write only 4. 7-9 7. higher education
  6. College level (10+ or 12+)
5. Family size \_\_\_\_\_
6. Marital status 1. Married 2. Single 3. Widowed 4. Divorced

### II

7. Experience in selling onion \_\_\_\_\_ years
8. Who is the source of your onion bulbs?
  1. Local retailers 2. Collect from farm (Own) 3. Farmers delivers to you 4. others \_\_\_\_
9. Do you face quality problems from suppliers? 1. Yes \_\_\_\_ 2. No \_\_\_\_
  - 9.1. If yes, what are the problems? 1. Drying problem 2. Bulb size 3. Disease 4. Others, specify \_\_\_\_\_
10. On average, what amount of onion bulbs you bought from suppliers at a time? \_\_\_\_\_ kg; what amount of it will be sold? \_\_\_\_\_ kg
11. Do you sell all you bought? 1. Yes \_\_\_\_ 2. No \_\_\_\_
  - 11.1. If no, what are the reasons? 1. Poor quality 2. Reduced market demand 3. Others, specify \_\_\_\_\_
12. If it is due to poor quality of the bulb, what is the reason? Rank in their order of importance based on their contribution to rejection:

| Reason               | Rank |  |
|----------------------|------|--|
| 1. Variety type      |      |  |
| 2. Improper maturity |      |  |

|                |  |  |
|----------------|--|--|
| 3. Bruising    |  |  |
| 4. Bulb size   |  |  |
| 5. Rotting     |  |  |
| 6. Sprouting   |  |  |
| 7. Shrivelling |  |  |

13. What is the total estimated percentage of bulbs which are not-suitable for market? \_\_\_\_%

14. What do you do with bulbs rejected due to poor quality? 1. Sell with reduced price

2. Used for own consumption 3. Discard 4. Others \_\_\_\_\_

15. If onion is to be sold with discount price, by what amount will the price be reduced? \_\_\_\_birr

16. If onion is to be discarded, what do you do with it? 1. Manure 2. Cattle feed 3. Thrown to garbage tanks 4. Others specify \_\_\_\_\_

17. What are the reasons behind for unsuitability for market? Rank in their order of importance.

| Reason                                    | Rank |  |
|-------------------------------------------|------|--|
| 1. Improper maturity                      |      |  |
| 2. Poor handling                          |      |  |
| 3. Poor packaging material                |      |  |
| 4. Poor transportation                    |      |  |
| 5. Absence of suitable storage conditions |      |  |
| 6. Others (specify)                       |      |  |

18. What measures do you undertake to reduce the amount of rejected bulbs?

\_\_\_\_\_

19. Do you have any suggestions to minimize the amount of rejected bulbs?

20. How many days does it take to finish selling your onion bulbs? \_\_\_\_ days

21. At what date interval do you buy new onion from suppliers? \_\_\_\_ days

22. How do you store bulbs for selling? 1. Inside crate 2. Heaping on the floor 3. Spreading on the shelf 4. Others (specify) \_\_\_\_\_

23. Is there any loss at storage? 1. Yes \_\_\_\_ 2. No \_\_\_\_

24. What are the causes for loss? Rank \_\_\_\_\_

25. For whom do you usually sell your onion? \_\_\_\_\_

26. Do you face in supply shortage of onion bulbs in any of the seasons? 1. Yes 2. No

27. If yes, at which season of the year? \_\_\_\_\_; what are the reasons? \_\_\_\_\_

28. Is there a price variation for bulbs you sell? 1. Yes 2. No

29. If yes, when does the price rises? (months of the year) \_\_\_\_\_
30. What are the reasons for the rise in price? \_\_\_\_\_
31. When does the price falls? (months of the year) \_\_\_\_\_
32. What are the reasons for the fall in price? \_\_\_\_\_
33. What type of packaging material do you use for the movement of fruits and vegetables to market? 1. Plastic crates 2. Unpacked 3. Wooden-box 4. Sacks 5. Baskets 6. Others
34. What type of transportation you are using? 1. Open vehicle 2. Closed vehicle 3. Human (labor) 4. Others
35. Is there any loss during transportation? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 35.1 If yes causes for loss? \_\_\_\_\_
- 35.2. Extent of losses? \_\_\_\_\_

| Avg. quantity purchased | Avg. quantity sold | Grading loss | Storage loss | Transportation loss | Selling loss |  |
|-------------------------|--------------------|--------------|--------------|---------------------|--------------|--|
|                         |                    |              |              |                     |              |  |

36. What measures are you taking to minimize the losses during transportation, storage and selling?
37. Observations:

#### Part IV- Interview with local consumer

##### I. Socio Demographic characteristics

1. City \_\_\_\_\_
2. Age \_\_\_\_\_
3. Sex 1. Male \_\_\_\_\_ 0. Female \_\_\_\_\_
4. Educational level (years of formal schooling)
  1. Illiterate 3. 1-6 5. 10-12
  2. Read and write only 4. 7-9 7. Higher education
  6. College level (10+ or 12+)
5. Family size \_\_\_\_\_
6. Marital status 1. Married 2. Single 3. Widowed 4. Divorced

##### II

7. Do you face quality problems from suppliers? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 7.1. If yes, what are the problems? 1. Drying problem 2. Bulb size 3. Bulb skin color 4. variety type 5. Disease 6. Others, specify \_\_\_\_\_
8. On average, what amount of onion bulbs you bought from the market at a time? \_\_\_\_\_ kg;
9. Do you use all you bought without loss? 1. Yes \_\_\_\_\_ 2. No \_\_\_\_\_
- 14.1 If no, what are the reasons? 1. Rotting 2. Sprouting 3. Bruising, 4. Others, specify \_\_\_\_\_
- 14.2 . If yes, what mechanism to use to reduce loss of onion during storage

| Mechanism | Rank |  |
|-----------|------|--|
|-----------|------|--|

|  |  |  |
|--|--|--|
|  |  |  |
|  |  |  |
|  |  |  |

10. What is the total estimated percentage of bulbs which lost/not utilized every week from you bought? \_\_\_\_\_%
11. How long you store onion bulbs?
12. How do you store onion bulbs for consumption?
13. What was the market price of onion per quintal at its pick selling season in 2013E.C?
14. What was the market price of onion per quintal at its off/summer selling season in 2013E.C? \_\_\_\_\_
15. From where do you buy onions and why do you buy onions from that certain place?
16. Is it hard to find onions? \_\_\_\_\_
17. Do you ever buy too much or too little amount of onions? How often and how much?

### **Part I- Interview with onion cooperative union leader**

1. Region \_\_\_\_\_ Zone \_\_\_\_\_ Woreda \_\_\_\_\_ Kebele \_\_\_\_\_
2. Name of the cooperatives \_\_\_\_\_
3. Members small-scale farmers \_\_\_\_\_
4. Year of establishment \_\_\_\_\_
5. Could you tell me about your working guidelines? \_\_\_\_\_
6. Do have sufficient input/onion? \_\_\_\_\_
7. What are your criteria to receive the commodity/onion? \_\_\_\_\_
8. How much produce do you receive daily, weekly? \_\_\_\_\_
9. Do you sell the whole product you receive? \_\_\_\_ How much on onion bulb will be lost? \_\_\_\_
10. Do you have sufficient space to store your received commodities? \_\_\_\_\_
11. For whom do you sell your produce/who are your customers? \_\_\_\_\_
12. Are your members are experiencing postharvest loss reduction technologies? What are they? \_\_\_\_\_
13. What are your major challenges? \_\_\_\_\_

### **Part VI: Interviews with Key informants**

1. Please introduce yourself and briefly describe your role in the onion industry.
2. How long have you been involved in onion production and distribution?
3. What are the main challenges faced by onion farmers during the cultivation process?
4. What are the key steps involved in postharvest handling of onions?
5. Are there specific technologies or practices used to minimize postharvest losses in your area?
6. What challenges do onion producers encounter during postharvest handling, and how are these addressed?

7. Can you outline the key stages of the onion supply chain from production to consumption?
8. Who are the primary actors or stakeholders involved in each stage of the onion supply chain?
9. How do onions move through the supply chain, from farms to markets or distribution centers?
10. What factors contribute to postharvest losses along the onion supply chain?
11. Are there particular stages of the supply chain where losses are more prevalent?
12. How do you quantify or measure postharvest losses in the onion industry?
13. What are the main challenges faced in reducing postharvest losses in the onion supply chain?
14. Are there any innovative solutions or initiatives aimed at addressing postharvest losses?
15. What are some common challenges experienced by onion producers and traders?
16. How can stakeholders collaborate to address the challenges identified and improve the onion supply chain?

## APPENDIX TABLE

Appendix Table 3.2.1. Authors contribution

| Contribution                                                                                 | Authors                                                                                                                                                                                                                                                                                                                                                                          | Description                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Supply chain dynamics, stakeholder roles, and constraints in onion production and marketing. | Insights from <ul style="list-style-type: none"> <li>▪ Gallo <i>et al.</i> (2007),</li> <li>▪ Van der Vorst <i>et al.</i> (2007),</li> <li>▪ FAO (2018),</li> <li>▪ Mira <i>et al.</i> (2002)</li> </ul>                                                                                                                                                                         | <ul style="list-style-type: none"> <li>▪ The study synthesizes and builds upon existing literature, integrate insights from), and other scholars to provide a comprehensive understanding of supply chain management in agriculture.</li> </ul>                                                                                                                                   |
| Stakeholder Analysis                                                                         | Based on insights from <ul style="list-style-type: none"> <li>▪ Minnens <i>et al.</i> (2019)</li> <li>▪ Adamashvili <i>et al.</i> (2021) and</li> <li>▪ WCDI (2021).</li> </ul>                                                                                                                                                                                                  | <ul style="list-style-type: none"> <li>▪ Conducted an in-depth examination of supply chain actors and their roles</li> <li>▪ Identified and analyzed contributions of various stakeholders, including input suppliers, producers, collectors, wholesalers, retailers, consumers, and support entities, elucidating complex interactions within the onion supply chain.</li> </ul> |
| Constraints Identification                                                                   | Sources including <ul style="list-style-type: none"> <li>▪ BoFED (2003)</li> <li>▪ Lemma Dessalegn and Shimelis Aklilu (2003)</li> <li>▪ Esheteu Bekele <i>et al.</i> (2006)</li> <li>▪ Kumilachew Alamerie <i>et al.</i> (2014)</li> <li>▪ Berhanu Gebremedhin <i>et al.</i> (2009)</li> <li>▪ Melkamu Alemayehu <i>et al.</i> (2015)</li> <li>▪ Agumas Yideg (2019)</li> </ul> | <ul style="list-style-type: none"> <li>▪ Identified key constraints affecting onion production in Ethiopia.</li> <li>▪ Analysis covers challenges related to soil fertility, postharvest technologies, agronomic practices, fertilizer and pesticide access, and market integration.</li> </ul>                                                                                   |

|                             |                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Marketing Channels Analysis | <p>Sources from</p> <ul style="list-style-type: none"> <li>▪ Kohls and Uhl (1985)</li> <li>▪ Emana Bezabih <i>et al.</i> (2017)</li> <li>▪ Kassa Getu and Ahmed Ibrahim (2018)</li> <li>▪ Addisu Hailu <i>et al.</i> (2017)</li> </ul> | <ul style="list-style-type: none"> <li>▪ Investigated into marketing channels of onions based on insights and other researchers.</li> <li>▪ Explored diverse routes through which onions move from producers to consumers, highlighting prevalence of direct sales, wholesaler-driven channels, and role of cooperatives.</li> <li>▪ By examining marketing landscape, provided valuable insights into market access and distribution strategies.</li> </ul> |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Source: own analysis based on literatures

Appendix Table 4.1. Mean squares and significance levels for onion traits tested

| Traits   | Block(L) | Variety (Var) | Nitrogen(N) | Var*N   |
|----------|----------|---------------|-------------|---------|
| df       | 6        | 3             | 3           | 9       |
| DPM      | 53.63ns  | 1143.00***    | 125.5**     | 7.58ns  |
| PH       | 95.67**  | 51.433*       | 186.387***  | 6.382ns |
| LNPP     | 1.54ns   | 11.75***      | 5.20**      | 0.12ns  |
| BD       | 20.88ns  | 78.25**       | 1084.97***  | 75.99ns |
| AVBW     | 428.92** | 1178.36***    | 3080.09***  | 58.89ns |
| TYTH     | 21.12ns  | 297.16***     | 373.20***   | 4.32ns  |
| UMYP     | 0.03ns   | 0.15***       | 0.096***    | 0.013ns |
| MYTH     | 6.75**   | 5.33**        | 0.64*       | 1.08ns  |
| TSS      | 0.02ns   | 116.46***     | 8.17***     | 2.49**  |
| Pungency | 0.73ns   | 38.28***      | 0.72**      | 0.006ns |

L=location, df=degrees of freedom, DPM = days to physiological maturity, PH = plant height, LNPP = leaf number per plant, BD = bulb diameter, AVBW = average bulb weight, TYTH = total yield ton per hectare, UMYP = unmarketable yield percentage, MYTH = marketable yield ton per hectare and TSS = total soluble solids; \*\*\*=  $P<0.001$ ; \*\* =  $P<0.01$ ; and Ns =  $P>0.05$ . Means followed by the same letter within the same column are not significantly different at 5% probability level

Appendix Table 5.1. Mean squares and significance level for onion traits tested

| Traits                                  | Source of variation |             |            |          |        |                |
|-----------------------------------------|---------------------|-------------|------------|----------|--------|----------------|
|                                         | Block (L)           | Variety (V) | Density    | V*D      | Error  | R <sup>2</sup> |
| Df                                      | 6                   | 3           | 2          | 6        | 70     |                |
| Days to physiological maturity          | 14.73ns             | 592.50***   | 4.92*      | 5.71ns   | 36.65  | 0.53           |
| Plant height                            | 108.58***           | 116.83***   | 129.04***  | 10.74ns  | 8.17   | 0.81           |
| Leaf number plant <sup>-1</sup>         | 0.59ns              | 11.47***    | 27.96***   | 0.16ns   | 0.649  | 0.73           |
| Leaf diameter                           | 0.52ns              | 24.08***    | 10.05**    | 1.72ns   | 1.65   | 0.71           |
| Bulb neck diameter                      | 0.49ns              | 29.47***    | 10.71**    | 3.44ns   | 2.618  | 0.56           |
| Bulb diameter                           | 303.46**            | 168.18**    | 241.23**   | 22.19ns  | 38.16  | 0.48           |
| Average bulb weight                     | 219.7ns             | 1905.61***  | 2597.55*** | 170.95ns | 158.83 | 0.64           |
| Harvest index                           | 62.13ns             | 273.29**    | 50.32ns    | 17.51ns  | 35.98  | 0.46           |
| Small bulb percentage                   | 192.92ns            | 1426.91***  | 2982.02*** | 230.11ns | 135.73 | 0.75           |
| Medium bulb percentage                  | 186.68ns            | 135.41ns    | 709.74**   | 380.92** | 159.65 | 0.46           |
| Large bulb percentage                   | 285.77ns            | 1771.88***  | 4521.23*** | 355.05*  | 233.07 | 0.7            |
| Total yield t ha <sup>-1</sup>          | 123.80*             | 479.48***   | 628.09***  | 34.20ns  | 50.58  | 0.57           |
| Marketable bulb yield tha <sup>-1</sup> | 127.15*             | 492.03***   | 615.71***  | 34.30ns  | 57.69  | 0.53           |
| Unmarketable bulb yield percentage      | 1.47**              | 8.860***    | 0.09ns     | 0.18ns   | 0.20   | 0.57           |
| Total Soluble Solids                    | 0.46ns              | 64.77***    | 6.94***    | 1.75***  | 0.25   | 0.95           |
| Firmness                                | 0.007ns             | 4.31***     | 1.23***    | 1.90***  | 0.24   | 0.98           |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \*\* = highly significant at  $P < 0.01$ ; \* = significant at  $P < 0.05$ ; ns = non-significance means followed by the same letter (s) within a column are not significantly different

Appendix Table 6.1. Mean square values and significance level for postharvest quality traits of onion

| Source of variation      | Block           | Variety (Var) | Nitrogen(N) | Packaging material (PKM) | Var*N    | PKM*N    | PKM*Var  | Var*N*PK M | Error  | R <sup>2</sup> | CV(%) |
|--------------------------|-----------------|---------------|-------------|--------------------------|----------|----------|----------|------------|--------|----------------|-------|
| Degree of freedom        | 2               | 3             | 3           | 2                        | 9        | 6        | 6        | 18         | 286    |                |       |
| Days to first sprouting  | 40.55ns         | 31106.15***   | 319.36**    | 332.34**                 | 56.15ns  | 33.30ns  | 21.55ns  | 54.82ns    | 55.08  | 0.87           | 12.1  |
| Number of bulbs sprouted | 7.59ns          | 361.58***     | 6.05ns      | 21.67**                  | 23.09**  | 6.74ns   | 7.63ns   | 7.42ns     | 6.56   | 0.54           | 25.15 |
| Sprouting (%)            | 448.84ns        | 11606.84***   | 42.16ns     | 909.10**                 | 465.52ns | 153.77ns | 362.11ns | 271.64ns   | 222.96 | 0.53           | 26.01 |
| Decay (%)                | 207.66***       | 143.57***     | 2.43*       | 1403.33***               | 3.03ns   | 0.93ns   | 28.49**  | 1.48ns     | 5.96   | 0.7            | 29.95 |
| Marketable bulbs(%)      | 10564.97**<br>* | 17.32***      | 1805.87**   | 298.91ns                 | 189.89*  | 758.81ns | 468.97** | 82.13ns    | 37.69  | 0.57           | 25.47 |
| Weight loss (%)          | 188.15**        | 858.57***     | 8120.09**   | 243.29**                 | 9.67ns   | 21.64ns  | 46.08ns  | 36.24ns    | 45.25  | 0.57           | 22.78 |
| TSS                      | 0.002ns         | 135.44        | 5.73***     | 12.24**                  | 2.56**   | 1.87**   | 3.57**   | 4.40**     | 0.001  | 0.98           | 1.49  |
| Firmness                 | 0.05ns          | 14.67***      | 15.20***    | 4.16***                  | 2.90***  | 2.03***  | 1.33***  | 1.41***    | 0.03   | 0.98           | 2.36  |

Where; \*\*\*= very highly significant at  $P<0.0001$ ; \*\*highly significant at  $P<0.001$ ; \*, significant at  $P<0.01$ ; Ns = non-significant at  $P>0.05$  and DF = Degree of freedom

Appendix Table 7.1. Mean square values and significance level for postharvest quality traits of onion

| Source of Variation          | DF | Sprouting percentage | Decay percentage | Total soluble solid | Firmness | Weight loss percentage | Marketable bulb percentage |
|------------------------------|----|----------------------|------------------|---------------------|----------|------------------------|----------------------------|
| Replication                  | 2  | 113.27**             | 37.34**          | 1.13Ns              | 5.03**   | 6.10**                 | 65.35**                    |
| Varieties (VAR)              | 3  | 587.11***            | 499.25***        | 90.85***            | 11.96*** | 47.63***               | 1183.02***                 |
| Pre-harvest treatment (PRHT) | 3  | 1183.41***           | 456.66***        | 7.26**              | 19.14*** | 22.82***               | 1396.81***                 |
| Storage duration (STD)       | 2  | 7759.79***           | 3677.39***       | 51.02**             | 79.87*** | 168.87***              | 5751.00***                 |
| VAR*PRHT                     | 9  | 63.86***             | 69.07***         | 14.7***             | 1.66*    | 4.28**                 | 82.68***                   |
| VAR*STD                      | 6  | 58.25**              | 26.56**          | 1.90ns              | 0.04ns   | 3.091ns                | 34.02**                    |
| PRHT*STD                     | 6  | 86.34***             | 18.23*           | 0.3ns               | 0.11ns   | 1.11ns                 | 18.80ns                    |
| VAR*PRHT*STD                 | 18 | 6.19ns               | 7.60ns           | 0.38 ns             | 0.03ns   | 0.974ns                | 13.21ns                    |
| CV(%)                        |    | 16.11                | 15.4             | 0.74                | 11.27    | 16.27                  | 0.94                       |

Where; \*\*\* = very highly significant at  $P < 0.001$ ; \* = significant at  $P < 0.05$ ; ns = non-significant and DF = Degree of freedom

## APPENDIX FIGURE



Appendix Figure 2.1. Onion seedling at nursery



Appendix Figure 2.2. Transplanting



Appendix Figure 2.3. Data collection in field



Appendix Figure 2.4. Field performance



Appendix Figure 2.5. Harvested bulb yield



Appendix Figure 2.6. Data collection on quality parameters



Appendix Figure 2.7. Field supervision



Appendix Figure 2.8. Stored onion bulbs



Appendix Figure 3.1.1. Field observation on onion production practices in the study area



Appendix Figure 3.1.2. Hybrid onion varieties (Jambar, Russet and Red Coach) under production in the study area

