

OPTIMIZING MANAGEMENT PRACTICES INFLUENCING ONION (*Allium cepa* L.) BULB AND SEED PRODUCTION AND QUALITY IN PARTS OF AMHARA REGION, ETHIOPIA

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A PhD DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE ACADEMIC DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN HORTICULTURE

October, 2024

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DEDICATION

I dedicate this PhD dissertation to my late father Ashagrie Guangul.

ACKNOWLEDGEMENTS

Throughout the program's study period, I had encountred several obstacles. But I passed all them reached to this date throuhgh the grace and strength of God henece I owe my utmost and deppest thankfullness to the **Almighty GOD** who made me complete my study.

I am also highly indebted to express my gratitude to my major advisor, Professor Derbew Belew for his strong and continuous guidance, mentorship, and outstanding support during the whole of my study period. I am also greatly thankful to my co-advisor, Dr. Amsalu Nebiyu, who put me on alert and helped me finish my research work. Your key contribution to guiding me in writing the thesis manuscript was also super and deserve due acknowledgement.

I am also indebeted to express my hereatfelt gratitude to the Amhara Agricultural Research Institute (AARI), the Sirinka Agricultural Research Center (SARC), and the Agricultural Growth Program (AGP II) Project for granting a study leave and financial provision for this research. Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) worth thankfulness for hosting and equipping me with required knowledge. My special gratitude also extends to the Department of Horticulture and Plant Sciences and the School of Graduate Studies for their invaluable collaboration and seamless progress during the study term. My appreciation also extends to Facality of Chemical and Food Engineering, Bahir Dar Institute of Technology for their laboratory services. I also express my gratitude to the management of the Kobo and Woramit Agricultural Research Sub-centers for providing technical and logistical support throughout the field experimentation.

Numerous individuals have greatly supported me throughout my extensive journey for without their support and encouragement this study could not have been completed. My dear friends and colleagues, Dr. Amare Alemnew, Dr. Tilahun Tadesse, Mr. Tilahun Bekele, Mr. Berhan Kelemu, Mr. Seyoum Teshome, Mr. Tesfaye Wubu and Mr. Adisie Degu; are deepely appraciated for their encouragement and support throughout my research work.

I wish to express my deep and heartfelt gratitude to all my family for their support, unreserved encouragement, and inspiration during my studies. I would like to extend my sincere gratitude to Mr. Abate Guangul and Mrs.Tshaynesh Arega for their support and encouragement. It is my great pleasure to express my love, respect and gratitude to my wife, Mrs. Almaz Yimer whose,

continuous support and encouragement was a source of my energy to stay focused my study, shouldering the full responsibility of taking care of our beloved doughetrs and son, Kidanekal, Mahlet, Tsgemariam and Yosef, during those taugh and challenging times, and for their love, care, understanding, and encouragement throughout my study.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGR	Absolute Growth Rate
ATA	Agricultural Transformation Agency
BoFED	Bureau of Finance and Economic Development
CGR	Crop Growth Rate
CIMMYT	International Maize and Wheat Improvement Center
CSA	Ethiopia Central Statistical Agency
CSSE	Crop Science Society of Ethiopia
EAMSC	East Amhara Meteorological Service Annual Report
EARO	Ethiopian Agricultural Research Organization
FAO	Food and Agricultural Organization of the United Nations
GFB	Gross Field Benefit
ISTA	International Rules for Seed Testing
MARC	Melkasa Agricultural Research Center
MOA	Mnistry of Agriculture
MRR	Marginal Rate of Return
NAR	Net Assimilation Rate
NB	Net Benefit
SARC	Sirinka Agricultural Research Center
SAS	Statistical Analysis System
SLA	Specific Leaf Area
SLW	Specific Leaf Weight
TVC	Total Variable Cost

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OPTIMIZING MANAGEMENT PRACTICES INFLUENCING ONION (*Allium cepa* L.) BULB AND SEED PRODUCTION AND QUALITY IN PARTS OF AMHARA REGION, ETHIOPIA

ABSTRACT

Onion (Allium cepa L.) is one of the most important vegetable crops in Ethiopia. However, the yield and quality of both bulb and seed production are far below the global average due to several factors. Practices such as nutrient management, planting date, bulb size, packaging, and storage period are among factors influencing bulb and seed yield and quality. The objectives of this research were to (1) determine the optimum rate of blended NPSB fertilizer and onion variety for highest bulb yield and better nutritional quality (2) determine the optimum rate of blended NPSB fertilizer rate and variety on onion seed yield and quality (3) determine the effects of bulb size and planting date on onion seed yield and quality (4) evaluate the appropriate packaging material and the optimum storage period to maintain the quality of onion seed.The experiment was carried out during the period between January to April 2019 growing season under irrigation at Kobo (north eastern) and Woramit sites (northwestern). Treatments contained seven blended fertilizer (NPSB) rates (0, 30.5, 61, 91.5, 122,152.5 & 183 kg ha^{-1}) and two onion varieties (Bombay red and Nafis). The experiment was carried out using the complete randomized block design with three replications. The results showed that most of the yield, yield components and quality parameters were significantly influenced by variety and rate of blended fertilizer.The onion variety Bombay red onion variety gave maximum total bulb yield (50.23 tons ha^{-1}) at Kobo under the blended NPSB fertilizer rate of 61 kg ha^{-1}. However,at Woramit the variety Nafis gave total bulb yield of 30.06 tons ha^{-1}. from the blended NPSB fertilizer rate of 91.5 kg ha^{-1}. The partial budget analysis showed that Bombay red variety gave the maximum economic benefit of 817,322.5 ETB ha^{-1}, with the application of 61 kg ha^{-1} NPSB with a marginal rate of return of 27584.05 %. The effects of blended fertilizer rate and variety on onion seed yield and quality were carried out from October 2018 to April 2019 growing season under irrigation conditions. The treatments contained seven NPSB blended fertilizer rates (0, 30.5, 61, 91.5, 122,152.5 &183 kg ha^{-1}) and two onion varieties (Bombay red and Nafis). Of the two types of varieties, Bombay red had the highest seed yield (2.3 tons ha^{-1}) when 183 kg ha^{-1} NPSB blended fertilizer was applied.The highest germination percentage (91.33) was

recorded from Bombay red variety from application of 183 kg ha^{-1} NPSB blended fertilizer. The partial budget analysis showed that Bombay red variety gave a maximum net benefit of 1,857,967.5 ETB ha^{-1}with the application of 183 kg ha^{-1} NPSB with a marginal rate of return of 48,186.14%. The results of a trial related to the influence of planting date and bulb size on yield and quality of the onion seed production that was conducted from October 2018 to April 2019, involving three treatments levels of mother bulb sizes of ; small (2- 3cm), medium (3.1- 4 cm) and large (4.1- 5cm), and four levels of planting dates; 5 October, 15 October, 25 October, and 5 November revealed the significant planting date and size of the mother bulb on most parameters. The highest seed yield (2.58 tons ha^{-1}) was recorded from a large mother bulb planted on 5 October. Planting bulbs on the 5th of October increased seed yield by 29.07% compared to planting on the 5th of November, a delay by one month. Regarding the size of the onion bulb, large bulbs increased seed yield by 42.04% compared to seed yield obtained from planting small bulbs. The highest germination percentage (96.67%) was also recorded from large onion bulbs planted on the 5th of October. Evaluation of effects of packaging materials on seed quality and storage period from June 2019 to June 2021 at Sirinka Agricultural Research Center seed laboratory, using combinations 10 treatment made of two factors(two storage periods (1 and 2 years) and five types of packaging materials (aluminium bags, nylon sacks, polythene bags, cloth bags, and glass jars) revealed the grudal decrease of percentage of germination with an increase in the storage period. The highest percentage of germination (99.3%) was recorded from a one-year storage period using polythene bag packaging materials.The maximum field emergence percentage (90.67%) was also recorded from a one-year storage period in polythene bag packaging materials. The present study confirmed that for bulb production Bombay red variety gave better performance at Kobo with the application of 61 kg ha^{-1} NPSB blended fertilizer, while at Woramit Nafis variety with the application of 91.5 kg ha^{-1} NPSB blended fertilizer. Regarding onion seed trial, Bombay red variety produced better yield and quality from application of 183 kg ha^{-1} NPSB blended fertilizer. Onion bulb planted on 5th of October (early October) using large bulbs (4.1-5cm), and a one year storage period of onion seeds in polythene bags can be recommended for the study areas. Future studies on the management of nutrients in different soil types and climate zones are necessary.

Keywords: NPSB blended fertilizer, planting date, quality, seed, variety,yield

CHAPTER 1. GENERAL INTRODUCTION

Agriculture is the backbone for Ethiopia's economic growth and nutritional security. It directly supports 85% of the population's livelihoods, offers 47% of the Gross Domestic Product, and accounts for more than 80% of the Ethiopia's export value (Gemechis, 2017 Cf. AfDB, 2009).

Optimal management practices are among the various ways by which onion yields per hectare can be improved to meet the increasing onion demand of Ethiopia. Some of the onion management practices such as nutrient management (i.e. NPSB blended fertilizer rate), planting date, bulb size, packaging material type and storage period play vital role for improving crop yields reducing risks associated with agriculture, increasing bulb and seed quality and reducing pest pressures. An overall improvement in food and nutrition security hence necessitates addressing challenges related to access of improved seed at an affordable price at the right time to users as well as associated economically viable optimal management practices.

1.1. The Onion Crop

Onion (*Allium cepa* L.) is the most common member of the family Alliaceae. It is a widely grown herbaceous biennial vegetable crop with cross-pollinating and monocotyledonous behavior having a diploid chromosome number (2n=16) (Bassett, 1986). Onion is different from the other edible species of alliums for its single bulb and is usually propagated by true botanical seed. The primary center of origin of the onion is Central Asia, with secondary centers in the Middle East and the Mediterranean region. From these centers, onion has spread widely to many countries of the world (Dahlgren *et al.*, 1985).

According to the Food and Agriculture Organization of the United Nations, onions are the third most produced crop after tomato and potato. Comparing the data of several years, it can be seen that there are years when onions are grown more than potato (FAO, 2023). Onion is a biennial crop that takes two seasons for seed production. During the first season, bulbs form, while flower stalks and seeds develop in the second season. Onions can be established through either transplanting of seedlings, direct sowing of seed, or planting of onion sets. The production cycle of onion involves vegetative growth, bulbing, sprouting, flowering, and seed production. Compared to other vegetable crops, onions grow very slowly during seedling and take two to three months (Lemma and Shimeles, 2003; Brewster, 2008). The onion bulb consists of the

swollen bases (sheaths) of bladed leaves surrounding swollen bladeless leaves. Each leaf has a blade and sheath; the blade may or may not be distinctive. The sheath develops to encircle the growing point, forming a tube enclosing younger leaves and the shoot apex. Collectively, the grouping of these sheaths comprises the pseudostem. Leaves arise from the short, compressed, disliked stem, which increases in diameter with maturation and resembles an inverted cone. The onion skin is formed from the dry paper-like outermost leaf scales that lose their freshness during bulbing. Major bulb features are uniformity of shape, size, skin color, pungency, and dry matter (Rabinowitch and Brewster,1990). Onion varieties vary in morphological characteristics; the stem is a flattened disk at the base of the plant and occurs below the soil surface. At the center of the stem is the shoot apex from which all new leaves and roots are produced. Each leaf is made up of a blade and sheath. The leaf sheaths appear to be the plant stem above soil level but are, in fact, a false or pseudostem. As the leaf sheath develops, it surrounds the growing point and forms a tube enclosing the youngest developing leaves and near the base of young leaves is where new roots form (Bosekeng, 2012).



Figure 1. Onion plant parts

Source: https://www.dreamstime.com/illustration/parts-onion.html



Figure 2. Onion plant life cycle

Source: https://in.pinterest.com/pin/life-cycle-of-a-onion-plant-on-a-white-background-ad-onion-cycle-life-background-white--3804

Onion root is shallow, mostly occurring within 15-20 cm of the surface, and seldom extends horizontally beyond 50 cm. Onion roots are short-lived and continuously produced. Roots rarely have branches and root hairs and rarely increase in diameter. The terminal inflorescences develop from the ring-like apical meristem scapes and elongate in height from 30 cm to more than 100 cm. The umbel is an aggregate of many flowers at various stages of development; usually, there are 2000-6000 small individual flowers. The flowering periods may last four or more weeks. The flowers are perfect, having six white petals, six stamens, and three carpel pistils. Flowers have nectarines, an attractant to pollinating insects, usually honey bees. Onion seeds mature in about 45 days after anthesis. Seeds are black, irregular shaped, and relatively small, and about 200 seeds weigh one gram (Tindall, 1983).

In the onion crop, the main stimulus to flowering is cold temperature. Development of the flowerhead can be divided into three stages: the "vernalization" period, when cold temperatures induce the plant to form a floral bud at the growing point down in the base of the bulb; a period during which warm conditions and long days may still suppress the growth of a floral bud after it has formed, stopping the plant bolting and encouraging bulbing and the final period, when warm

conditions hasten bolting. Onion varieties differ in how cold they require for bolting, but temperatures for long enough periods at 9-13°C are generally sufficiently cold. There appears to be a minimum plant size for the cold to induce a floral bud, and a large plant or set size during the cold period favors bolting. The exposure of sets to cold during storage also influences how soon the plants bolt during subsequent growth (5-10 °C during storage encourages bolting). Day length is not a factor in the onion plant forming a floral bud. However, in the final flowering period, long days stimulate more rapid growth of the flower head. Choice of variety and sowing date is the means of avoiding bolting problems. Varieties that require prolonged exposure to cold should be used if conditions may favor bolting (Sinclai, 1989).

Onion is one of the important vegetable crops and occupies an important place in vegetable production as it is demanded and grown around the globe (Saud *et al*., 2013). Onion plays a key role in generating income and employment for rural communities and contributes to the food security of millions of people in many developing countries (Boyhan *et al*., 2001). It is an essential crop worldwide for its multi-purpose uses (Muluneh *et al*., 2019). It is a very important vegetable used for fresh and various processed products (Manohar *et al*. 2017). It contributes significant nutritional value to the human diet. It has medicinal properties and is primarily consumed for its unique flavor, aroma, and pungency or its ability to enhance the flavor of other foods (Randle, 2000; Bhattacharjee *et al*., 2013). Onion contains medicinal compounds used for cardiovascular disease and cancer treatment due to its hypocholesterolemic, thrombolitic, and antioxidant effects. In addition, onion contains vitamins C and B6 (Mitra *et al*. 2012). According to Olalusi (2014), onions have large quantities of minerals like sodium, calcium, phosphorus, potassium, iron, and magnesium. Regular consumption of onions reduces the risk of different diseases in the human body (Arung *et al.* 2011).

Onion requires an intensive supply of plant-available macronutrients, such as Nitrogen, Phosphorus, Potassium, and micronutrient-like Zinc sulfate (ZnSO4 at 0.5%), Iron sulfate (FeSO4 at 1.0%), and Boron (B at 0.5%) to attain maximum yield and quality (Khalid, 2019). A number of production constraints cause low productivity of onion in Ethiopia. These include scarce availability of improved onion seed,low soil fertility, high costs of commercial fertilizers, inappropriate use of fertilizer rates, and pests (Melkamu *et al*., 2015). Most Ethiopian soils are deficient in macronutrients (N, P, and S) and micronutrients (Cu, B, and Zn) (EthioSIS, 2014).

Inorganic fertilizers have been important tools for overcoming soil fertility problems, and they are also responsible for a large part of the food production increases worldwide (Power *et al*., 2008). However, onion yields have not increased as expected, even when the recommendation rates for N and P fertilizers are applied. This is mainly due to the use of two types of fertilizers (DAP and Urea) alone and unbalanced fertilizers use (Chillot and Hassan, 2010).

Onion bulb production could be affected by inappropriate spacing, poor fertilizer application and unavailability of quality seeds together with other agronomic practices (FAO, 2017). The optimum fertilizer rate significantly enhanced the yield of onion bulbs (Assefa *et al*., 2015). The increased awareness on the nutritional and health importance of the onion crop has resulted in increased demand for quality onion seed (Amsalu *et al*., 2014). Many factors like variety, soil, climate, season, production method, bulb size, date of planting, storage period and seed packaging materials influence onion seed yield and quality. The determination of the best or optimal combination of these factors helps can be used to improve onion seed production and quality (Asaduzzaman *et al*., 2012).

Most of the time, the informal seed sector supplies the demand for onion seed. However, there are problems related to inadequate seed supply, increment of onion seed price, and poor quality of seed, which resulted in poor germination percentage. Under favorable conditions, the shelf life of onion seeds is one year. Due to these problems, farmers started onion seed production in different parts of the country (Nikus and Mulugeta, 2010). Onion seeds have a high commercial value, however satisfactory vigor tests for onion seeds are desirable (Patel *et al.* 2012). Compared with many other crops, the onion has a fairly complex life cycle involving several development phases. Onion seed is one of the shortest-lived seeds of the common vegetable crops, rapidly losing viability after harvest unless special precautions are taken in its storage.

In different parts of the world, the effect of planting date and bulb size on onion seed production and its significant effects on both productivity and quality were studied and reported.The effect of different planting dates on onion seed production in Bangladesh was investigated, and October 30th was recommended as the best planting date (UD-Deen, 2008). Under Ethiopian conditions, the highest seed yield (0.2-2.5 tones/ha) was obtained from bulbs planted from September to December for different onion varieties. Warm and drier conditions and ample sunshine are desirable for seed maturity, ripening, harvesting, and seed processing operations. Excessive

rainfall and cooler conditions during flowering lead to disease and poor seed setting and ripening and make harvesting difficult (Lemma and Shimelis, 2003). Bulb size have also been reported to having influence on seed yield. Mohammad *et al*., (2015) reported observation of significant variations in seed yield ha^{-1} due to different bulb sizes. One of the major constraints in onion cultivation is the limited availability of vigorous seeds at the time of sowing due to poor storability under fluctuating ambient temperatures. Storage temperature and moisture content are the most important factors affecting seed longevity, with seed moisture content usually being more important than temperature. Researchers have reported that the speed of decline in seed quality is largely dependent on storage temperature, relative humidity, seed moisture content, length of storage, type of seed storage material, and seed quality (Alhamdan *et al*., 2011). The seed is said to be in storage at all stages between harvests and sowing. These stages are considered actually part of the storage process. The extent of storability is influenced by the type of packaging material (Amjad and Anjum, 2002). According to Jyotindra *et al.* (2013) onion germination percentage gradually decreased with an increase in storage period.

1.1.1. Origin, Taxonomy and Genetics of Onion

There has been a great deal of research done on the genetics, taxonomy, and origins of onions. It is thought that the origins of onions can be traced back to central Asia, more precisely to the area that includes western Pakistan and eastern Iran. Onions are among the oldest known cultivated crops, having reportedly been farmed for over 5,000 years (Brewster, 2008). The first cultivated, farmed onions are the subject of much debate, but the two regions that many archaeologists, botanists, and food historians point to are central Asia or Persia. They were probably and almost simultaneously domesticated by people all over the globe, as there are species of the onion found worldwide (Greeley, 2011). Food uses of onions date back thousands of years in China, Egypt, and Persia (Cumo, 2015; Greeley, 2011).

Allium and related taxa' taxonomic status has long been a source of debate. Allium is a genus of the Amaryllidaceae family, which includes onions. Leeks, shallots, and garlic are just a few of the cultivated plants that belong to the broad genus Allium. *Allium cepa* is the scientific name for the common onion. There are numerous cultivars and varieties of this species, such as shallot, green onion, and bulb onion (Brewster, 2008). In early classifications of the angiosperms, they were placed in the Liliaceae. Later, they were more often included in the *Amaryllidaceae* based

on their inflorescence structure. Recently, molecular data have favored division into several small mono-phyletic families. In the most recent and competent taxonomic treatment of the monocotyledons, *Allium* and its close relatives were recognized as a distinct family, the *Alliaceae*, close to the *Amaryllidaceae* (Takhtajan, 1997). There is no common shared view on the intra-specific classification of *Allium cepa* because of the large variation present within its gene pool, which is also due to interspecific hybridization. According to Hanelt's (1990) classification of the species *Allium cepa* is subdivided into two large groups, the common onion, the Aggregatum group, and one smaller group, namely the ever-ready onion group. In the common onion group, the bulb is formed by thickening the leaf bases a short distance above the stem. Outer leaf bases are thin, fibrous, and dry, variously colored, forming the protective bulb coat. Mature bulbs have a globose shape, are up to 15 cm in diameter, and vary in size, color, and weight. The bulbs are normally single; plants reproduce from seeds or seed-grown sets. The crop includes hundreds of open-pollinated, traditional, and modern F1 hybrid varieties (Fritsch and Fresen, 2002). Onions are diploid plants in terms of genetics, having 16 chromosomes altogether. The genome of an onion is comparatively large, with about 15.9 billion base pairs. The onion genome is now better understood, and particular genes and alleles linked to different features can be identified thanks to developments in molecular biology techniques like DNA sequencing (Kuhl *et al*., 2001).

1.1.2. Ecological Requirement of Onion Crop

Onion is adapted to a wide range of temperatures and is relatively frost tolerant. Best production is obtained when cool temperatures prevail over an extended period, permitting considerable foliage and root development before bulbing starts. Bulb formation is favored by relatively high temperatures (Raemaekers, 2001). An optimum temperature for onion production ranges from 18 to 27 °C. Temperatures below the optimum ranges caused plant bolting, consequently reducing bulb yield. Similarly, temperatures above 30 °C lead to early maturity of the plant and reduced bulb yield. In Ethiopia, day time temperatures ranging from 20 °C - 26 °C and night time temperatures of 11°C - 15 °C are ideal for bulb production. In contrast, temperatures between 9 °C and 17 °C is required for onion seed production since these temperatures induce flower stalk development in onions (Lemma,1998; Singh,2001).

Onion requires varying temperatures and day lengths for bulb production (Ansari, 2007). Long days and high temperatures promote bulb formation (Brewster, 1997).The crop requires cool conditions during the early part of its development and warm conditions during bulbing, bulb maturity, harvesting, and curing stages. High temperature favors bulbing and accelerates maturity, then results in small, split, double, and low yield and quality bulbs. At lower temperatures, bulb maturity is delayed by at least 2-3 weeks, and yield will also be low (Brewster, 2002; Lemma and Shimeles, 2003). A relatively high temperature and long photoperiod are required for bulb formation, and for seed production, the temperature is of very important than the day length (Dawar *et al*., 2007). For good seed germination, a temperature between 7.5 and 30°C is needed (Abu-Rayyan *et al*., 2012). Seed production of onions are controlled by temperature and photoperiod, and seed production is more demanding than bulb production (Rabinowitch, 1990). Temperature greatly influences the flowering of onions. Cool temperatures with adequate water supply are most suitable for earlier growth, followed by warm, drier conditions for maturation.

Large differences in yield can be explained mainly by differences in the percentage of light interception by the leaf canopy during bulbing. Light interception increases with the leaf area index (Mondal *et al*., 1986). Late maturing cultivars have a longer time than early maturing types to develop a high leaf area index before switching to bulb growth. Leaf area index (LAI) increases as planting density increases; although yield increases, individual bulb size reduces. To achieve a high yield of medium to large bulbs, a cultivar must be capable of producing sufficient leaf area to intercept a high proportion (>60%) of the incident light to this effect growing at 50 to 100 plants per m^2 area is reported ideal (Brewster, 1982).The yield of any crop is determined by the quality of light absorbed by the leaves (Brewster, 2008). The leaves of the onion plant react to day length, and as soon as the minimum daylight length is reached, the leaf sheaths that will swell and form the bulb contribute to the yield of onions (Quadir and Boulton, 2005).

Due to altitudinal differences in the country, Ethiopia has diverse agro-ecologies that enable the country to produce tropical, subtropical, and temperate vegetables, including onion, throughout the year (Kubsa *et al*., 2006). The country, including the Amhara region, is endowed with underground and surface water potential, which can be used for the production of horticultural crops, including onion (Awulachew, 2010). Moreover, the existence of vast areas of cultivable

land and fertile soils make the country suitable for the commercial production of onions (Joosten *et al*., 2011). Onion can grow between 500 and 2400 meters above sea level (m.a.s.l). However, the best-growing altitude so far known is between 700 and 1800 meters above sea level (Lemma *et al*., 1994).

Onion can be grown in all types of soils; sandy, heavy clay, peat organic soils, or volcanic soils. However, for higher yields, drained and friable loam soil with a pH of 6.0-6.8 is ideal for higher yields (Brewster, 1994). Onion does not thrive in soils with pH below 6.0 because of deficiencies of trace elements or, occasionally, aluminum or manganese toxicity. On acid soils with pH <6.0, lime is applied 2-3 months before land preparation to bring the soil pH into the 6.2-6.5 range (Kelley and Granberry, 2000). On organic soils, a pH of 5.5 is considered sufficient. Poorly drained soils are not recommended for onion production because of frequent problems with bulb diseases at harvest time that lead to more problems in marketing (Corgan *et al*., 2000).

1.1.3. Status of Onion Production in the World and Ethiopia

Onions are grown in many parts of the world and are produced more than many green vegetables because they are consumed all over the world. Regarding world onion production, Asia produces the highest (65.1 %) share of onion followed by Africa (11.7 %) , America (11.6%) and Europe (11.3%). China was the top onion producer during the years 2000-2021 with a total volume of 20,925,874.48 tons and India followed with 15,334,316.82 tons. America is the third top world producer of onion with 3,352,171.32 tons and Turkey stand fourth with 2,013,635.91 tons. Egypt, Iran, Pakistan, Sudan, Russia and Brazil followed in their order (FAO, 2023).

Owing to the widespread cultivation and use of onions, there is also a remarkable global increase in seed production. Although annual data may differ, the United States, Pakistan, China, and India are the top producers of onion seeds (FAOSTAT, 2021). These countries produce a significant amount of onion seeds because of their ideal farming methods and favorable climate. Furthermore, other nations including Egypt, Turkey, and Mexico are important producers of onion seeds (Mordor Intelligence, 2021). Compared to other regions, Africa produces very little onion seeds despite its potential for more cultivation, African nations must overcome several obstacles to become self-sufficient in onion seeds that could cover its production needs. A dearth of certified seed growers and a scarcity of high-quality onion seeds are major obstacles to

production. Many farmers depend on leftover seeds from past harvests, which leads to consistent low crop quality and lower yields. In most areas, there are also shortages of appropriate methods and tools for the cultivation and preservation of the seeds (Tadesse *et al.,* 2019). Numerous countries and groups are working to boost the production of onion seeds in Africa. To improve onion seed production and quality in Nigeria, Ethiopia, and Tanzania, for instance, the Partnership for Aflatoxin Control in Africa initiative was started by the African Union Commission. The objectives of the project are to increase market access for onion seed producers in these nations, develop seed systems, and implement cutting-edge production technology (Tekalign *et al*., 2018).

In Ethiopia a total amount of 207,662.67 tons of onion was produced from about 25,129 hectares of land. The average productivity is 8.26 tons ha^{-1} (CSA,2021). It is grown by both small-scale farmers and commercial growers, especially under irrigation. The major production area is in the Rift Valley. Besides bulb production, there is a great potential for seed production in these areas (Yohanes, 1987). The diverse agro-climatic conditions that prevail in the country provide the opportunity for producing onion seeds and bulbs (CSSE, 2006). According to the Ethiopian Institute of Agricultural Research (EIAR, 2022) Ethiopia now produces a significant amount of onion seeds, and attempts are being made to enhance output and productivity.The production of onion seeds has drawn a lot of interest lately, since more and more farmers are implementing seed production techniques. Research centers has also developed onion varieties like Adama Red, Bombay Red, Red Creole, Melkam, Mermiru Brown, and Nasik Red that are being widely disseminated to farmers (EARO,2004). The increase in onion production contributed to the commercialization of the rural economy and created many off-farm jobs (Nikus and Mulugeta, 2010). The productivity of onion in Ethiopia is far below the global average bulb yield of 18.8 t Ha^{-1}.Various factors have contributed for the low productivity in the country among which limited access to production technology, poor market access, lack of technological innovations, and environmental degradation worth mention (Gemechis, 2017).

Like in other parts of the country, Onion is among the widely grown vegetable crops by smallholder farmers in Amhara Region. During 2020/2021 Meher season a total of 91,740.728 tons of onion was produced in this Region. North Shewa, West Gojam, East Gojam, North

Wollo, South Gondar, Oromia Special Zone, Central Gondar, South Wollo and North Gondar zones are parts the region suitable for onion production (CSA, 2022).

1.1.4. Nutrient Management of Onion

Plant nutrient management is crucial for healthy plant development, particularly for the vegetative plant stage to produce the highest yields. Producers profit when manure, compost, and/or inorganic fertilizer are used for they increase onion production (Zeleke and Derso, 2015). Assefa *et al*. (2015) reported the significant effect of applying sufficient amount of fertilizer nutrients in increasing the productivity of onion bulbs in addition to using improved varieties. Since onions are heavy feeders, they require more mineral fertilizers than other vegetables for both bulb and shot growth (Yohanes *et al*., 2013).

Like other horticultural crops, onion is produced using traditional farming practices. Farmers lack access to improved onion production technologies. Improved onion seeds are scarce because of the region's undeveloped onion seed production system. Fertilizers are available mostly for main-season crops. For irrigated vegetable crops like onions, fertilizers are not available in sufficient quantity (Melkamu *et al*., 2015). Nutrient management practices play an important role in a good crop like other crops. Organic nutrient management has recently gained rapid momentum due to the consciousness to health hazards and environmental safety. Integrated nutrient management provides excellent opportunities to overcome all the imbalances besides sustaining soil health and enhancing crop production. It optimizes the benefits from all possible sources of plant nutrients in an integrated manner (Maji, 2013).

Fertilizer application is one of the most important factors in onion production because it directly affects growth, development, and yields. Micronutrients play an active role in the plant metabolic process, from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity, and nitrogen fixation (Ballabh and Rana, 2012). Applying optimum fertilizer rates and cultivating suitable varieties with appropriate agronomic practices in specific environments are necessary for obtaining good yields of onion (Guesh, 2015). The blanket recommended amount under irrigated permanent fields for onion crops is reported to be 200 and 100 kg ha^{-1} of DAP and Urea, respectively. However, very few farmers use higher doses of these

fertilizers, while a significant number of farmers use small doses of N fertilizer in the form of Urea (Nikus and Mulugeta, 2010).

Nitrogen plays a vital role in all living tissues of the plant. According to Abas *et al.* (2015), nitrogen fertilization significantly increased the length of leaves, number of leaves, length of the flowering stalk, and number of flowers per umbel, and the highest records for these parameters were obtained by the application of 90 kg N ha^{-1}. No other element has such an effect on promoting vigorous plant growth as N. Abundant protein tends to increase the size of the leaves and, accordingly, increases carbohydrate synthesis. Plants absorb N while actively growing but do not always absorb it at the same rate. A deficiency of N limits cell division and expansion, chloroplast development, chlorophyll concentration, and enzyme activity. Its deficiency symptoms include general stunting and yellowing, particularly of older plant parts (Birhanu, 2016). As a shallow-rooted crop, onion is a heavy feeder of nutrients and requires ample nitrogen for optimum yield. Too much nitrogen, however, can result in excessive vegetative growth and thus delay maturity. Moreover, excessive vegetative growth increases the susceptibility of onion plants to diseases and reduces the dry matter content and storability of onion bulbs. Consequently, excess nitrogen results in reduced onion bulb yield both in quantity and quality (Sorensen and Grevsen, 2010; Birhanu, 2016). Plant roots absorb nitrogen from the soil solution principally as nitrates (NO_{3-}) and NH_{4+} ions. Nitrate is the preferred form of N for uptake by onion plants, and usually, it is the most abundant form that can be absorbed in well-aerated soils. Onion also takes up nitrates in much greater amounts than ammonium (Bosch and Currah, 2002). Nitrate anions move easily to the root with the flow of soil water and exchange at the root surface with HCO_{3-} or OH- ions that, in turn, stimulate an increase in the pH of the soil solution immediately around the root. In contrast, ammonium cations exchange at the root surface with hydrogen ions, lowering the solution's pH around the roots. The effects of these two ions on the pH of the root environment are known to influence the uptake of other companion ions, such as phosphates (Brady and Weil, 2002).

Phosphorus is an essential component of deoxyribonucleic acid (DNA), the seat of genetic inheritance, and ribonucleic acid (RNA), which directs protein synthesis in plants and animals. Among the significant functions it has enhancing photosynthesis, reproduction, and nitrogen fixation (flowering and fruiting), including seed production and maturation. Root growth,

particularly the development of lateral roots and fibrous rootlets, is encouraged by phosphorus. Good phosphorus nutrition strengthens structural tissues; crop quality improvement, especially in forages and vegetables, is another benefit attributed to this nutrient (Brady and Weil, 2002). Phosphorus deficiency reduces plant height, stem diameter, leaf size, and duration. When P is deficient, cell and leaf expansions are retarded more than chlorophyll formation. Thus, the chlorophyll content per unit of leaf area increases, but the photosynthetic efficiency per unit of chlorophyll decreases (Fageria, 2003). In onions, phosphorus deficiencies reduce root and leaf growth, bulb size, and yield and can delay maturation (Greenwood *et al*., 2001). In soils that are moderately low in phosphorus, onion growth and yield can be enhanced by applying phosphorus. Depending on yield levels, phosphorus uptake rates in onions are estimated to be 15-30 kg ha^{-1} (Salo *et al*., 2002). Phosphorus fertilization has a great effect on seed yield and quality of onion. According to Ali *et al*. (2008), phosphorous fertilization increased seed yield per umbel, plot, and hectare. Phosphorus fertilization at 46 kg ha^{-1} P_2O_5 showed significant effects on umbel diameter, number of umbels per plant, number of seeds per umbel, seed yield per plant, seed germination at harvest and 30 days later (Tamrat, 2006).

Onion is a sulfur-loving plant and is required much for proper growth and yield of onion. Sulfur is also an essential plant nutrient needed for growth and development. As a macronutrient, sulfur positively affects the quality of onion. It is important in the expression of the flavor intensity of bulbs which is associated with the pungency (propyl disulfides and other disulfides) and sugars (glucose, fructose, sucrose) contents of the onion (Bloem *et al*., 2004). Onion is a bulbous herb having a distinctive and pungent odor due to a volatile sulfurous oil known as allyl propyl disulphide ($C_6H_{12}S_2$) (Paul *et al*., 2007). Nasreen and Huq (2005) reported that sulphur levels up to 45 kg ha^{-1} increased S-uptake throughout the season and produced the highest bulb yield. Sulfur is an important component of enzymes and other proteins and is required for chlorophyll formation. It has a marked effect on the onion's pungency by increasing the bulb's pyruvic acid content. Most sulfur uptake occurs in the late season during bulb growth. Sulfur helps to improve the crop's utilization of nitrogen. Plants with high sulfur content have greater tolerance to pest and disease attacks. Sulfur has also been linked to increasing skin strength and color. Sulfur-containing secondary compounds were not only of importance for nutritional value and flavor but also for resistance against pests and diseases. The yield potential of onion has not been exploited fully since sulfur fertilizer is used in very low quantities aganist its very high

requirement. Sulfur is essential for building up sulfur-containing amino acids in plant cells, particularly in the early stages of plant growth (Mishu *et al*., 2013). The amount and type of sulfur compounds in the bulb differ with onion varieties. Moreover, sulfur is essential for building sulfur-containing amino acids (Anwar *et al*., 2001). According to Hasan *et al*.(2013), individual bulb weight, dry weight of (root, bulb, shoot, leaf) total dry matter, leaf area index, absolute growth rate, relative growth rate, net assimilation rate, and bulb yield of onion and sulfur content were increased significantly with the application of sulfur fertilizer.

Boron is an essential micronutrient required for normal plant growth and development. It performs a wide range of functions in onion plants. It is a very sensitive element, and plants differ widely in their requirements, but the ranges of deficiency and toxicity are narrow. Boron balances sugar and starch in the plant body (Ali, 2013). It is important in pollination and seed reproduction. It is necessary for normal cell division, nitrogen metabolism, and protein formation. It is essential for proper cell wall formation (Hania, 2012). Plant requirements for boron are lower than those for all other nutrients except molybdenum and copper. It is the only non-metal among the micronutrients and also the only micronutrient present over a wide pH range as a neutral molecule rather than an ion (Epstein and Bloom, 2005). Plants contain boron both in a water-soluble and insoluble forms. In intact plants, water-soluble boron fluctuates with the amount supplied, while insoluble boron does not. The appearance of boron deficiency coincides with the decrease of water-insoluble boron. The insoluble boron is the functional form, while the soluble boron represents the surplus (Koshiba *et al*., 2009). The trace elements of boron significantly affected bulb development, yield, and bulb quality when applied with other trace elements (Bhonde *et al*., 1995). Application of boron at different levels showed a positive response on the yield of onion (Kabir *et al*., 1994).

1.1.5. Methods of Onion Seed Production

Onion seeds can be produced in two different methods. The bulb to seed and seed to seed methods. The most popular technique for cultivating seeds is the bulb-to-seed method (Nikus and Mulugeta, 2010).

Seed to seed method

Using this technique, seedlings are moved during the first week of October to enable bolting, or flowering, and overwintering at the same location. The fully grown umbel sheds its seeds. The seed-to-seed method is not widely used since all of the varieties have poor bolting behaviors and low seed yields, making them unsuitable for producing annual seeds. This approach does not yield seed that is appropriate for additional multiplication. The low cost of seed production in this case, as opposed to bulb-to-seed production, outweighs the low genetic purity of the seeds generated by this method (Nikus and Mulugeta,2010).

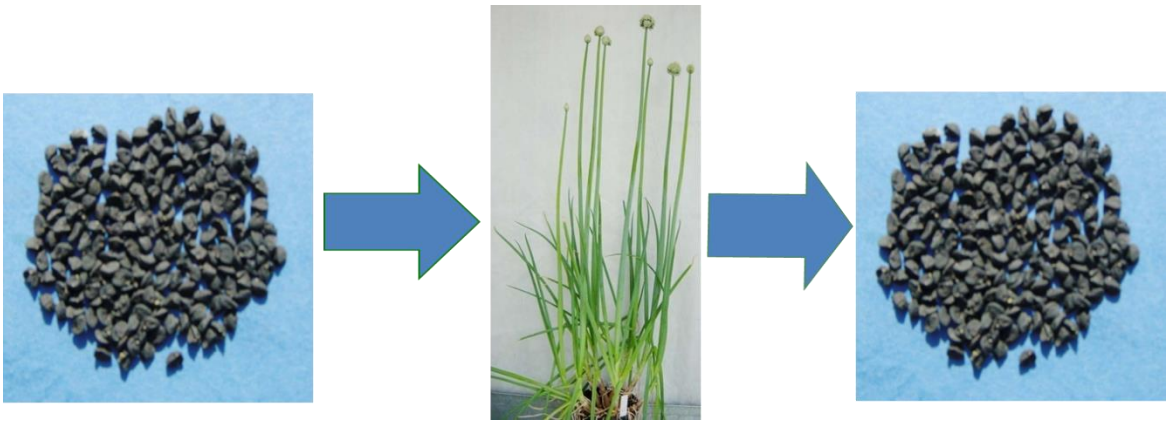


Figure 3. Seed to seed production method

Bulb to seed method

There are several advantages to this procedure, including the ability to choose bulbs that are healthy, disease-free, uniform in color, and free from physical damage. It yields more seeds since each bulb produces many stalks. The technique does a good job of preserving the variety's uniqueness. It takes 10 and a half months to produce seed using this strategy, but (4 and a half months for bulb creation and 6-7 months for seed set and maturity). Here, bulbs are grown in the first season and collected when they reach maturity, and true-to-type bulbs are sorted and preserved. The bulbs are kept for one to two months. To generate seeds, the preserved bulbs are planted the next growing season. Pick bulb sizes ranging from medium to large. Because this technique is very popular and enables us to study the traits of unwanted bulbs and rouge them up, the genetic purity of the seeds produced using this method is very high. For the production of seeds, one hectare of bulbs from the first will plant three to five hectares. The 4-6 cm size bulbs

are chosen for a good crop and are commonly referred to as mother bulbs. These bulbs are chosen for seed production (Pandey, 1996, Nikus and Mulugeta, 2010).

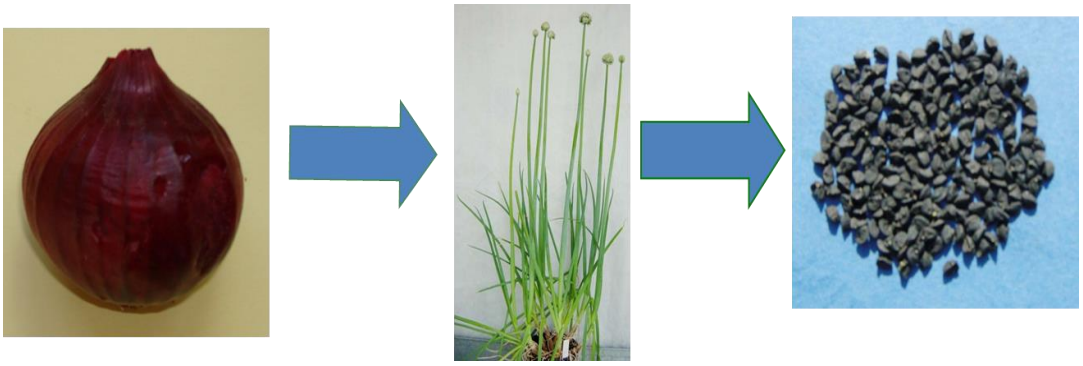


Figure 4. Bulb to seed production method

1.1.6. Factors Affecting Onion Seed Production

Planting Date and Bulb Size

Planting date is one of the most important factors that greatly influence the growth and yield of onions (Mondal *et al*., l986; Amin and Rahim, 1995). Early planting is best for onion seed production. The last week of October is the best planting time for the highest yield and best quality onion seeds (Mondal,1980). According to Tekle *et al*, (2020), early planting time of September 30 was appropriate planting time to produce high and quality seed yield of onion in Central Zone of the Tigray region. Farghali (1995) studied the effect of the onion variety Giza 20 in Egypt. Their results showed a significant increase in the number of umbel in plants and the number of capsules in the umbel, the highest seed yield, and thousand seed weight in 1st September planting compared to November and October planting dates. A similar study by (Khodadadi (2009) in Iran showed the production of the highest seed yield of onion Gholi Ghese variety from planting in mid-September compared to planting in mid-November. Mostafa (1983) pointed out that late planting in January was associated with decreased number of seed stalks per plant, fewer capsules per umbel, the maximum percentage of seed set, and reduced seed yield. In seed production, it is necessary to plant the mother bulb in the field at the appropriate time. On the other hand, the mother bulb's proper planting time is valuable because of the optimum use of the land that favors seed production both quantitatively and qualitatively (Mohsen and Davoud, 2012).

Planting bulbs of suitable size increase the seed yield of onions (Khokhar *et al*., 2001). Planting large bulbs at the appropriate growing conditions resulted in significantly larger numbers of seed stalks than those medium and small ones (Maria and Roman, 2009). Mother bulb size has a pronounced effect on the growth and yield of an onion. According to the findings of Lemma and Shimelis (2003), the number of flower stalks per plant and seed yield was positively influenced by the size of the mother bulb from 2-3cm to 4.1-5cm bulb diameter. According to Mosleh (2008), mother bulb size and planting dates significantly influenced the growth, bulb, and seed yield of onions. The large mother bulb and early planting were favorable for getting higher bulb and seed yields. The readiness of an onion plant to bolt is often dependent on the size of the plant. Onion seeds have a high commercial value, and the availability of satisfactory vigor tests for onion seeds is desirable. On the other hand, it is possible to detect the effects of seed vigor on subsequent plant growth and performance. A more precise identification of this relationship is vital. The demand for high-quality onion seeds increased as new technology (seed enhancements, germination in plug flats, precision mechanical planting, transplant systems, and greenhouse) spurred production interest, thus emphasizing the attention to seed performance. Although research considers all attributes of seed quality, e.g., genetic, physical, physiological, and pathological, literature shows that the physiological component has received more attention with an emphasis on studies regarding reliable procedures for seed vigor evaluation and identification of the relationship between seed vigor and seedling emergence (Rodo and Marcos-Filho, 2003).

Packaging Materials and Storage Period

The seed is said to be in storage at all stages between harvest and sowing. These stages are considered actually part of the storage process. The type of packaging material used in keeping this seed influences the extent of its storability. In general, seed stored in moisture-impervious sealed containers provides a suitable environment for storage, offerings protection against contamination, and acts as a barrier against the escape of seed treatment chemicals than in moisture pervious containers. Storage temperature and moisture content are the most important factors affecting seed longevity, with seed moisture content usually being more important than temperature. Many investigators have reported that the speed of decline in seed quality is largely dependent on storage temperature, relative humidity, seed moisture content, length of storage, type of seed, and seed quality (Alhamdan *et al*., 2011). Kumari *et al*. (2001) reported that onion

varieties Hisar and N-53 retained higher germinability over certification standards of 77 0% and 87.5% under ambient conditions in cloth bags up to eight and four months of storage, respectively. Doijode (1995) stored seeds of capsicum and onion in aluminum foil, polythene bags under partial vacuum and in paper bags (control) and observed no germination after 30 months in both cases. After 18 months, the vaccum packed and controlled in onion seeds gave 54 and 27 percent germination, respectively, and the corresponding values for capsicum were 59 and 41 percent. Shelar *et al.* (1992), stored onion seed with 5 percent moisture content in moisture permeable cloth bag, paper bag, cardboard box lined with wax paper, plastic bag and aluminum foil packets and observed a germination percent above 70 even after one year storage in plastic and aluminum foil packets, whereas 70 percent germination was seen only 10 months in other three containers. Caneppele *et al.* (1995) stored onion seeds in six types of packing materials. The highest loss of germination was observed in permeable containers than in impermeable containers. This difference was due to changes in seed moisture content in permeable packaging materials and the degree of hygroscopic equilibrium between seeds and their surroundings.

Onion seeds are difficult to store for extended periods as they may lose viability and vigor quickly (Mumtaz Khan *et al*., 2004). Saxena *et al*. (1987) stored seeds of onion, cabbage, radish, cauliflower, okra, and peas in polythene and cloth bags at room temperature for 24 months. The decreases in germination, root length, shoot length, and vigor index with the increase in storage period were greatest in the seeds stored in cloth bags and were least in a polythene bag. Onion, carrot, lettuce, and cabbage seeds were stored for 65 months in paper biaxially oriented polypropylene film and triple-laminated aluminum foil packets, but the wrapping material had no effect on germination percent, and the percent germination decreased with an increase in storage period in all species (Horky, 1988). According to Jyotindra *et al*. (2013), the onion germination percentage gradually decreased with an increase in the germination period. The seeds in plastic bags showed the highest germination compared to paper bags and cloth. One of the major constraints in onion cultivation is the limited availability of vigorous seeds at the time of sowing due to poor storability under fluctuating ambient temperatures.

1.1.7. Onion seed system

The production of onions around the world is greatly influenced by the onion seed system, an essential part of global agriculture. For farmers and horticulturists, the onion seed system guarantees a consistent supply of premium onion seeds due to its exceptional diversity and adaptability (McGrath and Pritts, 2016). Its impact on onion output is one of the main reasons the onion seed system is regarded as important. Worldwide, onions are grown and eaten in large quantities, and maintaining steady crop yields and quality requires a dependable seed system. The onion seed system consists of multiple phases, such as the selection, production, storage, distribution, and use of the seeds (Nayar & Dahling, 2007). Onion seed is available in two seed systems: formal and informal. The official seed system is mostly funded by the government, with participation from public institutions as well. The informal seed system, sometimes referred to as the local system or a "farmers" system, is so named due to the fact that it functions under rules that are not governed by the law and is defined by the trade of seeds between farmers. Ethiopia produces onion seeds successfully, albeit their system of distribution is less formal (Binalfew, 2018). A vital component of Ethiopia's agricultural sector is the seed system. As one of the top producers of onions in Africa, Ethiopia depends heavily on its seed system to produce high-quality onions that can satisfy demand from both internal and international markets (NORP, 2021). Onion seed output is substantially lower in Ethiopia than in other African countries. By providing such seeds, the informal sector plays a crucial role in reaching many farmers. The private sector, unorganized initiatives, and imported seeds supply most of the need for onion seeds. Onion seeds are typically not supplied by Ethiopian Seed Enterprise, the official sector. Limited outreach programs are offered by public sector institutions like the Ethiopian Institute of Agricultural Research (Nikus and Mulugeta, 2010). The majority of seed is sourced from untrustworthy sources, such as late-harvest fruit or portion of the crop stored for seed after being sold. These seeds typically have low genetic purity, viability, and vigor. Still, the excess is sold to other farmers and they are stored for the following growing season (Helen *et al,* 2015).

The main channels through which seeds are supplied and sold to farmers in the Amhara region for major crops are cooperatives and farmers' unions. In contrast to enhanced seeds like hybrid corn, wheat, Teff, and so forth, onion seeds are not included in this seed system. Farmers in the area can not obtain onion seeds from research institutes or national seed corporations since they

do not produce onion seeds. The few seeds that are available are from private merchants, most of whom acquire their seeds from unidentified sources. As a result, farmers' seeds and bulbs cannot be included in the region's national seed distribution network. As a result, only private traders are able to distribute seeds. Care must be taken to include onion seeds into the current seed supply system because onions are a crop that is becoming more and more significant (GBIF, 2023).

1.2. Statements of the problem

The production of horticultural crops, in general, and of onions in particular, is a labor-intensive enterprise (EIA, 2012). The increasing demand in the export market can also be considered an important opportunity for farmers in Ethiopia, including those in Amhara region, to produce onions having export quality since the country is near to the world market compared to other exporters (Joosten *et al*., 2011).

Despite the high potential and conducive environment, the production and productivity of onion, in Ethiopia in general and in the Amhara Region in particular is very low. Onion is mostly produced by smallholder farmers employing where inappropriate agronomic practices like agricultural inputs such as fertilizers, improved varieties, and pesticides are not sufficiently used, and inappropriate postharvest handling practices are employed. Generally, farmers produce horticultural crops using traditional farming practices that lead to low production and productivity (Melkamu *et al*., 2015). According toYemane *et al.* (2013), onion production and productivity have been limited due to inappropriate agronomic management practices such as plant population, planting date, harvesting date, fertilizer rate, and quality of planting materials. Higher yield and better control of over or under-sized bulbs could be obtained if plants are grown at optimum intra-row spacing. However, one of the major problems with onion production in the country is the use of blanket fertilizer recommendation rates for different varieties (Geremew *et al*., 2010).

There are various obstacles associated with the application of blanket fertilizer for onion production in Ethiopia. First, an inadequate understanding of sustainable nutrient management which might result in excessive or insufficient fertilizer application, which could waste resources and cause the crop to absorb nutrients poorly (Kihara *et al*., 2010). Onion yield and quality may suffer as a result of nutrient availability problems. Geographic variations in soil nutrient levels

between various onion fields are not taken into account when applying blanket fertilizer. Ethiopian soils exhibit wide variations in their nutrient status, and consistent application of fertilizer on all fields may not suffice to meet the particular nutrient requirements of individual plots (Nigussie *et al.,* 2012).

To improve onion bulb and seed yield and quality, using balanced fertilizers is one of the most important crop management practices to be considered. Nutrients such as N, P, S, and B are included in the new fertilizer formula for deficient soils since these nutrients can significantly improve fertilizer-use efficiency and crop profitability. Ethiopian Agricultural Transformation Agency (ATA) indicated that; Diammonium Phosphate (DAP) fertilizer was substituted with N: P_2O_5: S: B (18.9 N + 37.7 P_2O_5 + 6.95S + 0.1B) (ATA, 2016). So far, this has not yet been determined in the study areas.

Onion producton in Ethiopia has suffered as a result of improper fertilizer rate application (Fekadu *et al.,* 2019; Mekonnen *et al.,* 2020). Fertilizer application errors, such as applying too much or too little, can cause soil deterioration, nutrient imbalances, and lower crop yields (Mohammed and Mohammed, 2017). Applying fertilizers incorrectly can have a number of detrimental effects, depending on whether they are used excessively or not. When fertilizers are used excessively, the soil can deteriorate, water can become contaminated, and greenhouse gas emissions can rise (Tekalign,2009). Conversely, inadequate application of fertilizers may result in inadequate nutrient uptake, reduced crop yields, and reduce food production (Wonya and Assefa, 2015).

In addition to nutrient management, the effect of planting date and bulb size on onion seed production and its significant effects on both productivity and quality was studied and reported in different parts of the world. The effect of different planting dates on onion seed production in Bangladesh was studied, and October 30th was recommended as the best planting date (UD-Deen 2008). In Iran, the best planting dates for onion seed production were from September 22 to October 6 with mean minimum and maximum temperature of 21.48 and 9.09 $^{\circ}$C, respectively (Mehri *et al*., 2015). Studies in Central Ethiopia showed that onion seed production is best if mother bulbs are planted in September and October, which helped to align the time of flowering during the months of January and February, during cooler and drier months (Nikus and Mulugeta, 2010). Bulb size determines the vigor of the reproductive phase and the number of

reproductive shoot initials. This is directly related to the number of seed stalks and subsequent seed yield. Various onion bulb sizes were tested for seed production potential at Melkassa for three seasons in order to determine the optimum size for high seed yield and quality. Large bulbs in excess of 4.1 cm diameter produced vigorous umbels of above 5 cm diameter; a large number of flower stalks (as many as 360/100 m^2 kg/m^2) and with almost double the seed yield (695 kg/100 m^2) of bulbs of ware-size (Lemma and Shimeles, 2003). According to (Mohammad and Gaafar, 2015) significant variations due to different bulb size were observed in respect of seed yield ha^{-1}.

The type of storage materials and storage periods are important factors in determining the quality of onion seeds. Using inferior or uncertified seeds in conjunction with inappropriate agronomic techniques results in lower crop yields, lower-quality produce, and less market opportunities (Abebe *et al*., 2017; Kassie *et al*., 2013), Inadequate access to premium quality seeds has impeded Ethiopia's adoption of improved onion varieties. Farmers frequently turn to storing seeds from their own crop or buying uncertified seeds from nearby markets, which could not have the required qualities or be resistant to disease (Bekele *et al*., 2016). The quality and viability of onion seeds negatively impacted by the improper application of post-harvest management techniques during storage in Ethiopia. According to Shimelis *et al.* (2012), improper handling and storage conditions can lead to decreased germination rates and increased seed deterioration.

In summary, identification of the appropriate variety, optimal crop production and seed management technologies, and promoting the adoption of these improved varieties and high-quality seeds is a critical task for stakeholders, including the Ethiopian government, agricultural institutions, and development organizations, in order to address this issue. Enhancing seed production and distribution networks, establishing seed certification programs, and offering farmers extension and training services should all be priorities (Abebe *et al*., 2017; Kassie *et al*., 2013). For the production of better bulb, and seed yield and quality of onion; management practices are very important. This sudy presents the results of field and laboratory experiments that targeted at determining optimum management practices ensuring better yield and quality of bulb and seed of onion production with the following objectives:

1.3. Research Objectives

General Objective

- To determine optimal management practices for maximizing the yield and quality of bulb and seed of onion

Specific Objectives

- To determine the optimum NPSB blended fertilizer rates for onion bulb production
- To determine the optimum NPSB blended fertilizer rates for onion seed production
- To determine optimum mother onion bulb size and planting date for better onion seed production
- To evaluate appropriate storage material type and optimum storage period for maintaining seed viability and high germination percentage

1.4. Dissertation Outline

This thesis is organized into six chapters. The first chapter is general introduction, where general information, a statement of the problem, and the objectives of the study are provided. Chapters two through six present the results of the investigation. In chapter 2, an evaluation of NPSB blended fertilizer rates and varieties on bulb yield and quality of onion was done. In Chapter 3, the effects of NPSB blended fertilizer rate and variety on yield and quality of onion seed production is studied. In Chapter 4, the effects of planting date and bulb size on yield and quality of onion seed production were investigated and in chapter 5, the evaluation of packaging material type and storage period on onion (*Allium cepa* L.) seed quality was done. Finally, in Chapter 6, the main findings and the contribution of this study were discussed. Recommendations for science (future research directions) and practices are also presented in this chapter.

CHAPTER 2. EVALUATION OF NPSB BLENDED FERTILIZER RATE AND VARIETIES ON BULB YIELD AND QUALITY OF ONION (*Allium cepa* L.) AT KOBO AND WORAMIT IN AMHARA REGION, ETHIOPIA

ABSTRACT

The quantity and quality of the onion bulb can be greatly increased with the use of balanced nutrient management practices. The newly recommended blended fertilizer provide a balanced and customized strategy to meet the unique requirements of onion crops by combining a variety of nutrients. This study was initiated to determine the influences of NPSB blended fertilizers and varieties on onion bulb yield and quality. Two onion varieties (Bombay red and Nafis) and seven blended fertilizer rates (NPSB) (0, 30.5, 61, 91.5, 122, 152.5; 183 kg ha^{-1}) were included in the treatments. The experiment was set up in a complete randomized block design with three replications. The results of this study revealed the substantial impact of locations, varieties and blended fertilizer rates on onion bulb yield, yield components, and quality parameters. At Kobo Bombay red onion variety nourished with the combination of 61 kg ha^{-1} NPSB blended fertilizer produced the maximum total bulb yield (50.23 tons ha^{-1}). At Woramit, the maximum total bulb (30.06 tons ha^{-1}) was recorded from the variety Nafis complemented with 91.5 kgha^{-1} NPSB blended fertilizer rate. In Kobo the highest Pyruvic Acid (Pungency) 0.32 (mg.g^{-1}) content was recorded from Bombay red variety fertilized at the combination of 30.5 kg ha^{-1} blended fertilizer. The highest Vitamin C content (23.21 mg 100g^{-1}) was recorded from the variety Bombay red planted at Kobo with the combination of 91.5 kg ha^{-1} NPSB blended fertilizer. The partial budget analysis showed maximum economic benefit of 817,322.5 ETB ha^{-1} with a marginal rate of return of 27584.05% from the variety Bombay red planted at Kobo from application of 61 kg ha^{-1} NPSB blended fertilizer rate. At Woramit the higher economic benefit of 525,963.75 ETB ha^{-1} with a marginal rate of return of 16424.59% was obtained from variety Nafis with the application of 91.5 NPSB kg ha$^{-.1}$ The study showed promising results for the sudy areas. However, repeating the experiment over years and locations is suggested in order to provide sound recommendations.

Key words: Blended fertilizer, bulb quality, bulb yield , onion ,variety

2.1. INTRODUCTION

Onion (*Allium cepa* L.) is an essential vegetable crop worldwide grown for their multi-purpose uses (Muluneh *et al*., 2019). Onion is a very important vegetable used for fresh and various processed products (Manohar *et al.* 2017). It contributes significant nutritional value to the human diet, has medicinal properties, and is primarily consumed for its unique flavor, aroma, and pungency or for its ability to enhance the flavor of other foods (Randle, 2000; Bhattacharjee *et al*., 2013). Onion contains medicinal compounds for cardiovascular disease and cancer treatment due to its hypocholesterolemic, thrombolitic, and antioxidant effects. Consumption of onions reduces the risk of different diseases in the human body (Arung *et al*., 2011). In addition, onion contains vitamins C and B6 (Mitra *et al*. 2012). According to Olalusi (2014), onions have several minerals like sodium, calcium, phosphorus, potassium, iron, and magnesium.

In Ethiopia, onion is produced on about 25,129 hectares of land with a total annual bulbs production of 207,662.67 tons and average productivity of 8.26 tons ha^{-1} (CSA, 2021). Even if the productivity is low, the area is gradually increasing mainly due to its high profitability per unit area and the expansion of small-scale irrigation areas throughout the country (Nikus and Mulugeta, 2010).

Onion requires an intensive supply of plant-available macronutrients, such as nitrogen, phosphorus, potassium, and micronutrient-like zinc sulfate ($ZnSO_4$ at 0.5%), iron sulfate ($FeSO_4$ at 1.0%), and boron (B at 0.5%) to get optimum yield (Khalid, 2019). A number of production constraints cause low productivity of onion in Ethiopia. These include low soil fertility; inappropriate use of fertilizer amounts, lack of quality onion seeds, pests; high cost of commercial fertilizers which sometimes unaffordable by the smallholder farmers (Melkamu *et al*., 2015). Many researchers around the world have studied and described the effect of fertilizer amounts and onion varieties on onion yield and quality. Optimum fertilizer amount per plant significantly increased the yield of onion bulbs (Assefa *et al*., 2015). Different onion varieties were tested in Southern Ethiopia and the results showed that application of N and P fertilizers showed an increase in onion yield with increasing fertilizer amounts (Simon *et al*., 2015). Mota *et al*. (2010) showed that soil composition, among other factors, influences the nutritional composition of onion. Kołota *et al*. (2013) described that nutrient sources affect onion yield and quality.

Thus improving onion production, using balanced fertilizers is an essential crop management practices. Application of blended fertilizers like NPSB in nutrient deficient soils have the potential to increase onion productivity and quality. Ethiopian Agricultural Transformation Agency (ATA) indicated that; N: P_2O_5: S: B (18.9 N + 37.7 P_2O_5 + 6.95S + 0.1B) fertilizer substituted Diammonium Phosphate (DAP) (ATA, 2016). However, the response of onion to the application rates of the newly introduced NPSB blended fertilizer is perceived to vary with locations, and so far, very little is known about the NPSB rates of Kobo and Woramit onion production areas of the Northeastern and Northwestern parts of Ethiopia. Therefore, this experiment was conducted to determine the effects of NPSB blended fertilizer rate and of onion varieties on bulb yield and nutritional quality of onion at Kobo and Woramit in the Amhara region, Ethiopia.

2.2. MATERIALS AND METHODS

2.2.1. Description of the Study Areas

The study was conducted at Kobo and Woramit sub-center research stations in North Wollo and West Gojam zones in the Amhara National Regional State of North-eastern and North-westren of Amhara region, respectively. Kobo is located at 12° 08' 21''N latitude and 39°38' 21''E longitude at 1500 m above sea level (m.a.s.l). The long-term mean annual rainfall of the area is 668mm, with a maximum and minimum temperatures of 31°C and 15°C (EAMSC, 2019). Woramit is located at 11°38′ N latitude and 37°10′E longitude at an altitude of 1800 m.a.s.l. The area receives a mean annual rainfall of 800 to 1250 mm with mean daily maximum and minimum temperatures of 29.5°C and 6.2°C, respectively (Habtamu *et al*., 2016).

2.2.2. Experimental Design, Treatments and Field Management

The experiment was laid out in Randomized Complete Block Design with three replications. The treatments included two onion varieties (Bombay red and Nafis) and seven levels of NPSB blended fertilizer (0, 30.5, 61, 91.5, 122,152.5, and 183 kg ha^{-1}). The detailed treatment combinations are presented in Table 2. The base for these levels was taken from 100 kg DAP ha^{-1} and 150 kg Urea ha^{-1} (EARO, 2004). The calculation was made according to the fertilizer formula of NPSB blended (18.9N: 37.7 P_2O_5:6.95S: 0.1B). The gross plot size of the experimental plot was 2m × 2m (4 m^2). Planting was done in double rows of 40 cm, 20 cm, and 10 cm between furrows, rows, and plants, respectively. NPSB blended fertilizer application was done according to the trial plan and placed in rows along the onion plants 5 cm away from the seedlings. The plots were irrigated at 3-5 days intervals during the first phase of active growth of the plants. Later, the irrigation gap was increased to a seven-day interval. Cultivation was done manually and kept weeds-free during the growing period. For the control of onion thrips, the insecticide selecron was used. All other agronomic practices were applied uniformly for all the plots as per the recommendation made for the crop (EARO, 2004). The experimental material for this study was Bombay red and Nafis onion varieties. These varieties were obtained from Melkasa Agricultural Research Center (MARC). They are adapted to area from 700-2000 m.a.s.l (EARO, 2004).

Table 1. Characteristics of onion varieties used for experimental material

Variety	Maturity Days	Seed set	Bulb skin colour	Dry bulb yield t/ha	Leaf color	Bulb weight (g)	Bulb shape	TSS %	Leaf arrangment
Bombay Red	90-100	High	Light red	30	Dark green	85-100	Flat globe	9-10	Medium
Nafis	100 -120	High	Medium Red	40	Deep green	100-130	globe	10-18	Erect

Source: Zeleke and Derso, (2015)

Table 2. Treatment combination of blended fertilizer rate and onion varieties on onion bulb trial

Treatment setting (%)	Treat-ments	Variety	NPSB Kg ha $^{-1}$	Elemental form of $N/P_2O_5/S/B$ (Kg ha^{-1})	NPSB (g/ plot)
0	T1	Bombay red	0	0/0/0/0	0
25	T2		30.5	5.76/11.49/2.11/0.031	36.6
50	T3		61	11.53/22.99/4.24/0.061	73.2
75	T4		91.5	17.3/34.5/6.4/0.09	109.8
100	T5		122	23/46/8.5/0.12	146.4
125	T6		152.5	28.8/57.5/10.6/0.15	183
150	T7		183	34.6/68.9/12.7/0.18	219.6
0	T8	Nafis	0	0/0/0/0	0
25	T9		30.5	5.76/11.49/2.11/0.031	36.6
50	T10		61	11.53/22.99/4.24/0.061	73.2
75	T11		91.5	17.3/34.5/6.4/0.09	109.8
100	T12		122	23/46/8.5/0.12	146.4
125	T13		152.5	28.8/57.5/10.6/0.15	183
150	T14		183	34.6/68.9/12.7/0.18	219.6

Where; N: Nitrogen, P: Phosphorous, S: Sulphur, B: Boron

2.2.3. Soil Sampling and Analysis

Independent surface soil (0-20 cm depth) samples were collected from the respective experimental sites using an auger. Samples from each site were drawn from different spots of the experimental field before planting, and these samples were composited to yield one representative sample. Samples were subjected to air drying and ground using a mortar and passed through a 2 mm sieve before laboratory analysis. Working samples obtained from the

submitted samples were analyzed for selected physicochemical properties, mainly texture, soil pH, cation exchange capacity, electric conductivity, organic carbon, organic matter content, total nitrogen, and available phosphorus. The organic matter content of the soil was determined by the volumetric method (Walkley and Black, 1934). Total nitrogen was analyzed using the Kjeldahl digestion, distillation, and titration method described by Black *et al*. (1965) by oxidizing the OM in a concentrated sulfuric acid solution (0.1N H_2SO_4). The pH of the soil was determined on a 1:2 (weight/volume) soil samples-to-water ratio using a pH meter (Motsara and Roy, 2008). Cation exchange capacity (CEC) was measured titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). Available phosphorus was determined by using Olsen methods for estimation of available phosphorus in soils by extracting with sodium bicarbonate (Olsen *et al*., 1954). The soil samples were analyzed at the soil laboratory of Sirinka Agricultural Research Center (SARC).

Results of the soil analysis before NPSB blended fertilizer application are presented in Table 3. The soil analysis indicated that the soil of Kobo is clay-loam while that of Woramit is clay in texture with (pH 6.21 & 6.17) respectively. The soil at Kobo had total nitrogen (0.13 %), available phosphorus (32.1 mg kg^{-1}), available sulphur (9.3 mg kg^{-1}), and boron (2.8 mg kg^{-1}), while at Woramit, total nitrogen (0.11%), available phosphorus (25 mg kg^{-1}), available sulphur (22.2 mg kg^{-1}) and boron (2.9 mg kg^{-1}) were recorded. ATA (2016) classified the levels of total nitrogen (very low < 0.1, low 0.1- 0.5, optimum 0.15-0.3, high 0.3 - 0.5, very high > 0.5 %); available phosphorus (very low 0-15, low 15-30, optimum 30-80, high 80-150, very high > 150 mg kg^{-1}); available sulphur (very low <10, low 10 - 20, optimum 20 - 80, high 80 - 100, very high > 100 mg kg^{-1}) and boron (very low < 0.5, low 0.5 - 0.8, optimum 0.8 - 2., high 2- 4, very high > 4 mg kg^{-1}). According to these classifications, the experimental site Kobo was very low in available sulfur, low in total nitrogen, and optimum in available phosphorus and high in boron. Whereas the experimental soil at Woramit was low in total nitrogen and available phosphorous, optimum in available sulfur and high in boron.

Table 3. Physical and chemical properties of soil in the experimental field before planting at Kobo and Woramit

Location	Soil properties	Units	Value
Kobo	Sand	%	36.25
	Clay	%	27.5
	Silt	%	36.25
	Textural classes		Clay loam
	pH (water 1: 2.5 g soil)	-	6.21
	Total Nitrogen (N)	%	0.126
	Organic Carbon (OC)	%	0.96
	Organic Matter (OM)	%	1.65
	Available Phosphorus	Ppm	32.05
	Available Sulphur	Ppm	9.33
	Available Boron	Ppm	2.84
	Electric conductivity (EC)	ds m^{-1}	0.209375
	Cation exchange capacity(CEC)	meq per 100 g soil	40.8
Woramit	Sand	%	18.75
	Clay	%	50
	Silt	%	31.25
	Textural classes		Clay
	pH (water 1: 2.5 g soil)	-	6.17
	Total Nitrogen (N)	%	0.112
	Organic Carbon (OC)	%	1.52
	Organic Matter (OM)	%	2.62
	Available Phosphorus	Ppm	25
	Available Sulphur	Ppm	22.2
	Available Boron	Ppm	2.89
	Electric conductivity (EC)	ds m^{-1}	0.0296875
	Cation exchange capacity (CEC)	meq per 100 g soil	18.8

2.2.4. Data Collection

Growth Parameters

Number of leaves per plant: The number of fully developed leaves of ten randomly sampled plants was counted at the active green leaf stages, and the average was computed to obtain the number of leaves per plant.

Leaf length (cm): Leaf length was recorded as the average length of the longest leaves in ten randomly taken plants.

Specific Leaf Area ($cm^2\ g^{-1}$)**:** It is the ratio between leaf area in cm^2 and total leaf dry weight in grams. This is used as a measure of leaf density. The mean SLA can be calculated according to Lambers *et al*., (2008) as: $\mathrm{SLA} = \frac{\mathrm{A}}{\mathrm{WL}}$

Specific Leaf Weight (g cm^2):The reversal of SLA is called as SLW. It is defined as the ratio between total leaf dry weight in grams and leaf area in cm^2. It indicates the relative thickness of the leaf of different genotypes or treatments according to Hirose *et al*. (1988) as:

$$SLW = \frac{WL}{A}$$

Crop Growth Rate (g m^{-2} d^{-1}): It is defined as the increase in total dry weight per unit land area of a crop per unit time. The mean CGR over an interval of time T1 and T2 is usually calculated according to (Radford, 1967) as:

$$CGR = \frac{W2 - W1}{T2 - T1} \ X \ \frac{1}{A}$$

Where, W 1 and W2 are total dry weights of crops over a sampling area of A at times T1 and T2 days after planting.

Absolute Growth Rate (g d^{-1}), Increase in total dry weight per plant per unit time. It is used specifically to quantify growth of single plants according to Robert Solow (1956) as:

$$AGR = \frac{W2 - W1}{T2 - T1}$$

Net Assimilation Rate (g m^{-2} day^{-1}): Increase of total dry weight per unit time per unit leaf area. It defines the efficiency of biomass production specifically in terms of the amount of photosynthetic tissue according to Monteith (1977) as:

$$NAR = \frac{W2 - W1}{T2 - T1} \ X \frac{1}{LA}$$

Bulb Yield Components and Yield

Bulb diameter (cm): The horizontal cross-sectional length of matured bulbs of ten randomly sampled plants was measured using a vernier caliper at the widest point in the middle portion of the bulbs, and the average was taken as bulb diameter per plant for each plot.

Bulb length (cm): The average vertical length of the matured bulb of ten randomly selected plants was taken in each plot using a vernier caliper.

Bulb neck thickness (cm): Using a vernier caliper, the average neck thicknesses of ten randomly sampled plants in each plot was obtained by measuring the neck of bulbs at the narrowest point at the junction of the bulb and leaf sheath.

Mean bulb weight (g plant^{-1}): The average weight of 10 bulbs harvested from net plots was calculated as the mean bulb weight after curing. The weight was taken by using a sensitive balance.

Bulb dry weight (g plant^{-1}): Bulbs of ten sampled plants were chopped into small pieces with the help of a stainless steel knife; samples were placed on drying materials and kept under open sun for seven days and then placed in paper bags and were dried in an oven at 65° C for 48 hrs. to obtain a constant weight. Each sample was weighed by using a digitally sensitive balance, and the average was computed and recorded as the dry weight of a bulb per plant (Gessesew *et al*., 2015).

Unmarketable bulb yield (t ha^{-1}): Unmarketable bulb yield was recorded as the total weight of damaged, small bulbs (less than 2 cm), splitter, thick-necked, doubles, rotten, off-color, and discolor bulbs after curing, converted per ha^{-1}.

Marketable bulb yield (t ha^{-1}): Marketable bulb yield was determined after discarding the unmarketable bulb, weighting healthy bulbs, and having marketable bulb weight of 60g at harvest in each plot (Tegbew, 2011).

Total bulb yield (t ha^{-1}): Total bulb yield is recorded as the sum of marketable and unmarketable bulb yield.

Harvest index: It was recorded as the proportion of the dry weight of the bulb to the total mass weight of the plant. This was calculated based on Rasmussen (1963)as:

$$HI = EY/BY \times 100$$

Where, HI: Harvest index

EY: weight of matured dry bulb (Economic Yield);

BY: weight of biological yield (above-and below-ground dry weight).

Bullb Quality Parameters

After harvesting the onion bulbs, quality analysis was done at Bahir Dar University, Facality of Chemical and Food Engineering, Bahir Dar Institute of Technology according to the following procedure.

Pungency (Pyruvic acid content)

Pyruvate analysis was performed according to Schwimmer and Weston (1961) procedures. Onions were sliced in half longitudinally, and the outer skin and ends were removed. One half of the onion was homogenized for 1 minute in a Warring blender at a ratio of 1 ml of added water per gram of onion. The homogenate was allowed to stand for 10 minutes at room temperature and then filtered through two layers of cheesecloth. An aliquot of this filtrate was transferred to a 1.5 ml centrifuge tube and clarified by centrifugation at 10 000 × g for 5 minutes. Two different procedures were used. The first closely followed the procedure outlined by Schwimmer and Weston, except that the volumes of all reagents were reduced by half. In this procedure, a 100-fold dilution of onion juice was made by adding 10 µl of the clarified onion filtrate with a Drummond positive displacement pipette to 0.5 ml of water in a 13mm× 100mm test tube. It was added to an additional 0.5 ml of water and 0.5 ml of 0.125 g L^{-1} DNPH (dinitrophenylhydrazine) in 2M HCl. The samples were placed in a 37 °C water bath, then removed after 10 min and 2.5 ml of 0.6M NaOH was added. The absorbance at 420 nm was then determined. Standards were prepared by adding 25–200 µl of 1mM sodium pyruvate and reducing the amount of water in the assay accordingly.

Total titratable acidity (TTA)

Titratable acidity was determined based on official methods of analysis (AOAC, 1990). Total titratable acidity was determined by first blending the samples. One hundred grams (100 g) of the onion bulb was homogenized using a blender, and the homogenized samples were filtered. An equal volume of the sample (juice) was added to the extracting solution (HPO^3-CH^3CHOOH) to obtain the total volume of the solution. For the standard ascorbic acid (test solution),2.0 ml acetic acid standard solution was transferred in to three beakers containing 5 ml of extracting solution and titrated rapidly against the indophenols solution until a light but distinct rose pink color

persisted. Three blanks composed of 7.0 ml of extracting solution were titrated against the indophenols solution.

Vitamin C

Vitamin C was determined spectrophotometrically using the procedure described by Vazquez Oderiz *et al*. (1994). Five grams of sample were homogenized with 25 ml of metaphosphoric acid - acetic acid solution, and it was quantitatively transferred in to a 50 ml volumetric flask and shaken gently to homogenize the solution.Then it was diluted up to the mark by the metaphosphoric acid-acetic acid solution. The obtained solution was filtered and centrifuged at 4000 rpm for 15 minutes, after which the supernatant solution was used for spectrophotometric determination (Perkin Elmer spectrophotometer Lambda 25) of vitamin C content. Estimation of vitamin C was done according to the following procedure; 0,23 ml of 3% bromine water was added into 4 ml of centrifuged sample solution to oxidize the ascorbic acid to dehydroascorbic acid, and after that, 0,13 ml of 10 % thiourea to remove the excess of bromine. Then 1 ml of 2, 4-DNPH solution was added to form osazone. All standards, samples, and blank solution were kept at 37 °C temperature for 3 hours in a thermostatic bath. After it all was cooled in an ice bath for 30 minutes and treated with 5 ml chilled 85 % H_2SO_4, with constant stirring. As a result, a colored solution's absorbance was taken at 521 nm.

Total soluble solid (TSS)

Onion bulbs were cut into small pieces and homogenized using a laboratory blender to produce juice. Total soluble solids (TSS; °Brix) of the onion juice was determined using a hand-held refractometer (PAL-1, ATAGO®, Tokyo, Japan) as indicated by Mbulelo *et al.* (2018).

2.2.5. Data Analysis

The data were checked for all ANOVA assumptions. Analysis of variance was done using SAS 9.4 statistical software. The data of each location were tested for normality and homogeneity of variance. The data were considered to follow normal distribution when tested nonsignificant at 5% level of significance. Since the test showed nonsignificant at 5% level of significance the variance was also considered homogeneous. After confirming the assumptions of normality of data ANOVA of each location was undertaken. Test of homogeneity of variance of the two errors mean squares was also performed prior to undertaking combined analysis of the two

locations. According to Gomez and Gomez (1984), the error variance could be considered homogeneous when the highest error mean square was not three- fold larger than the smallest error mean square. For variables which could not be combined across the two locations, the analysis was under taken and presented for each location. When ANOVA was found significant, means were compared using the least significant difference (LSD) test at 5% probability level.

2.2.6. Partial Budget Analysis

Partial budget analysis was employed for economic analysis of NPSB blended fertilizer application and carried out for combined bulb yield data. The potential response of the crop towards the added fertilizer and the price of fertilizers during planting ultimately determined the economic feasibility of fertilizer application. The economic analysis was computed using the procedure described by CIMMYT (1988).

Gross average bulb yield (kg ha^{-1}) (AvY): is the average yield of each treatment.

Adjusted yield (AjY): is the average yield adjusted downward by a 10 % to reflect the difference between the experimental yield and the yield of farmers (CIMMYT,1988).

$$\mathrm{AjY} = \mathrm{AvY} - (\mathrm{AvY} - 0.1)$$

Gross field benefit (GFB): is computed by multiplying the field/farm gate price that farmers receive for the crop when they sell it as adjusted yield.

Total cost: is the cost of blended (NPSB) fertilizer used for the experiment. The price was based on the buying price during planting.

Net benefit (NB): calculated by subtracting the total costs from gross field benefits for each treatment.

$$\mathrm{NB} = \mathrm{GFB} - \text{total cost}$$

Marginal rate of return (MRR %): was calculated by dividing the change in net benefit by the change in cost, which was the measure of the increase in return by increasing input.

$$\text{Marginal rate of return (\%)} = \frac{\text{Change in net benefit}}{\text{Change in tolal cost}} \text{ X } 100$$

A partial budget analysis of the treatments was carried out by taking only fertilizer variable costs. NPSB blended fertilizer cost of 14 ETB kg^{-1} and Urea fertilizer cost of 13.50 ETB kg^{-1} were considered in the partial budget analysis. The marketable onion bulb yield was adjusted downward by 10 % to reflect the difference between the experimental and farmers' yields except from the same treatment. The average open market price of onion bulb was 20 ETB kg^{-1} at the nearest market during harvesting time (May 2019) at Kobo and Bahir Dar.

2.3. RESULTS AND DISCUSSION

2.3.1. Growth Parameters

Number of leaves per plant

The results of ANOVA showed that number of leaves per plant were significantly ($p<0.01$) affected by the interaction effects of location, variety and NPSB blended fertilizer rates (Appendix Table 1). The maximum number of leaves per plant (15) was recorded from variety Bombay red planted at Kobo at the application of 61 and 183 kg ha^{-1} NPSB blended fertilizer and no application of NPSB blended fertilizer, while the minimum number of leaves per plant (9.3) was recorded from variety Nafis planted at Woramit with the application 152.5 kg ha^{-1} NPSB blended fertilizer rate (Table 4). The difference might be due to genetic make-up differences between the two onion varieties and the soil fertility status of the two trial sites. This finding is in agreement with Sharangi *et al.* (2009), reported that increases in number of leaves of onions due to optimum P at Kobo soil. However, the current study contradicted with Abdul *et al.* (2003), reported that the maximum number of leaves per plant was recorded from the application of NPK, while the minimum number was produced in the control. Farooqui *et al*., (2009) revealed increased number of leaves with increasing rates of nitrogen. In addition, Negasi *et al.* (2018) reported that increasing the rate of nitrogen enhanced leaf number per plant. Muluneh (2018) reported that leaf number per plant at physiological maturity was affected by application of potassium.The highest number of leaves was recorded from the application of 120 kg ha^{-1}, whereas the least number was recorded in the control treatment. Application of nitrogen significantly influenced the number of leaves produced by the onion plant. Number of leaves increased by about 8% in response to the application of 92 kg N ha^{-1} over the control. This could be attributed to the increase in the vegetative growth of onion plants through its effect in the synthesis of the different components of protein required for leaf development (Abdissa *et al*., 2011).

Leaf length

Analysis of variance indicated that main effects of location, variety, NPSB blended fertilizer rate, and their interaction effects were highly significantly influenced leaf length (Appendex Table1). Similarly, the three-way interaction significantly affected leaf length (same appendix Table

above). The two varieties were significantly different from each other. The tallest leaf length (60.12 cm) was recorded from variety Nafis with the application of 122 kg ha^{-1} NPSB blended fertilizer rate planted at Kobo, whereas the shortest leaf length (32.07 cm) was recorded from variety Bombay red with no application of NPSB blended fertilizer planted at Woramit (Table 4). The results showed that an increase in NPSB blended fertilizer rate resulted in an increase in the leaf length of onion varieties. The investigation also revealed that the genetic makeup of the two onion varieties and the fertility of the experimental site were different from each other.The positive effect of NPSB blended fertilizer on leaf length may be due to its role in chlorophyll, enzymes, and protein synthesis. The current study is in line with Abdul *et al*. (2003), reported that application of NPK produced the longest leaf length, whereas the shortest leaf length was recorded in the control. Negasi *et al*. (2018) indicated that nitrogen and phosphorus significantly affected the leaf length of onion plants; the tallest leaves were recorded at the application of P_2O_5 ha^{-1}, while the shortest leaf was recorded for the control treatment. According to Weldemariam *et al*. (2015), the longest leaf length was obtained by the application of nitrogen, while the shortest leaf length was observed in the control plots. Muluneh *et al*. (2018) also depicted that the application of different rates of NPS fertilizer significantly influenced the length of onion leaves. Gebremedhn *et al*. (2018) reported that leaf length was affected by different onion varieties. He showed that Nasik Red and Adama red onion varieties had the highest leaf length than the Bombay red variety.

Crop growth rate

The crop growth rate was significantly ($p<0.01$) affected by the interaction effects of location, variety, and NPSB blended fertilizer rate, and interaction effects of variety and NPSB blended fertilizer rate (Appendex Table 1). The maximum crop growth rate (2.83 g m^{-2} day^{-1}) was recorded from the variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer rate planted at Kobo. However, the minimum crop growth rate (2.03) was obtained from the variety Bombay red with the application of 152.5 kg ha^{-1} NPSB blended fertilizer rate planted at Woramit (Table 4). The difference might be due to the influence of location, variety, and NPSB blended fertilizer rates. According to Shamima *et al*. (2003), Sulphur fertilization profoundly influenced crop growth rates at different growth stages of onion plants. The maximum crop growth rate was recorded at 45 kg S ha^{-1} application, and the minimum crop growth rate was obtained from control treatment across the growth stages. Dhin *et al*. (2018)

reported that the effect of micronutrients significantly affected the crop growth rate of rice. Micronutrient application enhances plant growth through increased plant photosynthesis and other physiological activities. Using micronutrients helped the plants utilize the available nutrients with increased leaf area, high photosynthesis, and dry matter accumulation, which enhanced crop growth rate. Asad and Rafique (2002) reported that boron fertilization increased the dry matter production of wheat.

Specific leaf weight

Specific leaf weight is related to drought tolerance in several crops and has been suggested as a selection criterion for breeding programs targeting low-rainfall areas. Genotypes with a high specific leaf weight (thick leaves) have leaves with a small surface area-to-volume ratio, which is thought to be an advantage in using water efficiently (Anonymous, 2012). The interaction effect of location, variety, and NPSB blended fertilizer rate, was highly significantly ($p<0.01$) affected the specific leaf weight of onion plants (Appendex Table1). The main effects of location, variety, and NPSB blended fertilizer rate were also highly significantly ($p<0.01$) affected the specific leaf weight (same appendix Table above). The highest specific leaf weight (30.86 mg cm^{-2}) was recorded from variety Nafis with the combination of 91.5 kg ha^{-1} NPSB blended fertilizer rate planted at Woramit, whereas the lower specific leaf weight (10.02 g cm^{-2}) was recorded from the same variety with the application of 61 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 4).This is probably because of Nafis adabtability to temperature range of 6.5 to 29.5°C and the optimum sulphur in the soil of Woramit compared to that of Kobo and increased amount of NPSB. Specific leaf weight is one of the few morphological characteristics of plants that show large changes over the course of a single day. Specific leaf weights are easy to measure and provide information about dry matter production. But also about how efficiently photosynthesis gets moved out of leaves and around the plant (David and Albert, 1986). According to Amanullah (2015), the interaction between NPK source crops indicated that the higher specific leaf weight was recorded from wheat, but the lowest specific leaf weight was attained from oats. High specific leaf weight, the dry mass of tissue per unit leaf area, was associated with increasing leaf photosynthesis (Dornhoff and Shibles, 1970). The highest rate of N application induced plants to the highest SLW and whole plant biomass. The response of soybeans to no

nitrogen application showed the lowest specific leaf weight values at both stages (Myint *et al*., 2011).

Table 4. Mean leaf number per plant **(**LNP), leaf length (LL), crop growth rate (CGR) and specific leaf weight (SLW) at Kobo and Woramit (January – April, 2019)

Treatments			Variables			
Location	Variety	Frtilizer rate kg ha $^{-1}$	LNP^{-1}	LL(cm)	CGR(g m^{2} d $^{-1}$)	SLW(g cm^{-2})
Kobo	Bombay red	0	15.0^{a}	48.33^{gh}	2.40^{bcdefgh}	15.91^{fghi}
		30.5	13.6^{b}	53.07^{ef}	2.23^{fghij}	14.56^{ghij}
		61	15.0^{a}	52.67^{ef}	2.33^{cdefghij}	13.13^{hijk}
		91.5	12.6^{bc}	49.53^{g}	2.33^{cdefghij}	14.07^{hij}
		122	12.6^{bc}	53.73^{e}	2.57^{abcde}	14.43^{ghij}
		152.5	12.0^{cde}	54.07^{de}	2.57^{abcde}	17.98^{efg}
		183	15.0^{a}	54.30^{de}	2.83^{a}	13.29^{hijk}
	Nafis	0	12.0^{cde}	50.63^{fg}	2.40^{bcdefgh}	21.01^{cde}
		30.5	12.0^{cde}	54.50^{cde}	2.33^{cdefghij}	19.50^{ef}
		61	11.0^{efg}	56.93^{bc}	2.20^{ghij}	10.02^{kl}
		91.5	12.6^{bc}	54.27^{de}	2.37^{bcdefghi}	12.06^{jkl}
		122	12.3^{cd}	60.12^{a}	2.30^{defghij}	13.16^{hijk}
		152.5	12.3^{cd}	57.83^{ab}	2.50^{bcdefg}	19.13^{ef}
		183	11.6^{cde}	56.47bcd	2.07^{ij}	11.76^{jkl}
Woramit	Bombay red	0	11.3^{def}	32.07^{n}	2.47^{bcdefg}	24.29^{bc}
		30.5	12.0^{cde}	39.53^{lm}	2.63^{abc}	18.42^{ef}
		61	10.3^{fgh}	39.33^{lm}	2.10^{hij}	10.05^{kl}
		91.5	11.3^{def}	39.53^{lm}	2.43^{bcdefg}	23.75^{bcd}
		122	10.9^{efg}	40.73^{klm}	2.67^{ab}	16.81^{fgh}
		152.5	10.0^{gh}	38.80^{lm}	2.03^{j}	10.16^{kl}
		183	11.6^{cde}	44.40^{ij}	2.30^{defghij}	8.68^{l}
	Nafis	0	10.3^{fgh}	32.80^{n}	2.60^{abcd}	27.42^{ab}
		30.5	11.3 ^{def}	38.53^{m}	2.53^{bcdef}	20.55^{ed}
		61	10.3^{fgh}	42.80^{jk}	2.67^{ab}	20.77^{cde}
		91.5	10.0^{gh}	40.0^{lm}	2.83^{a}	30.86^{a}
		122	10.0^{gh}	41.13^{kl}	2.27^{efghij}	10.89^{jkl}
		152.5	9.3^{h}	46.0^{hi}	2.50^{bcdefg}	12.19^{ijkl}
		183	10.0^{gh}	44.20^{ij}	2.23^{fghij}	13.90^{hij}
LSD (5%)			1.2	2.5	0.30	3.7
CV (%)			6.5	3.19	7.3	31.3

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Specific leaf area

Analysis of variance depicted that specific leaf area was significantly ($p<0.01$) influenced by interaction effects of variety by NPSB blended fertilizer rate at both Kobo and Woramit (Appendex Tables 2 & 3). In addition at Woramit both main effects of variety and fertilizer rate were highly significantly ($p<0.001$) affected specific leaf area, while at Kobo main effects of variety did not affected it. At Kobo the highest specific leaf area (0.1 cm^2 g^{-1}) was recorded from variety Nafis with the application of 61 kg ha^{-1} NPSB blended fertilizer rate;Whereas at Woramit the highest specific leaf area (0.12 cm^2 g^{-1}) was recorded from the variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer rate. However, the least specific leaf area (0.03 cm^2 g^{-1}) was recorded from the Nafis variety with the application of 91.5 kg ha^{-1} NPSB blended fertilizer (Table 5). According to Lambers and Poorter (1992), high specific leaf area species are characterized by high concentrations of N; high rates of CO_2 and N uptake per unit leaf and root mass, respectively; and a high rate of photosynthesis per unit leaf N. Amanullah (2015) also reported that specific leaf area differed with change in crop species, growth stage, and NPK source. Specific leaf area can be used as an indirect measure of several basic leaf processes, such as leaf-water relations, photosynthetic capacity, and growth potential (Dong *et al*., 2011). Crop nutrition plays an important role in leaf characteristics in crop plants. Amanullah *et al*. (2007) reported that specific leaf area increased with an increase in the rate and number of nitrogen splits.

Absolute growth rate

The absolute growth rate is the total weight gain in the plant within a specific time interval expressed as (g $plant^{-1}$ day^{-1}). The results indicated that the absolute growth rate was significantly ($p<0.01$) affected by main effects of variety and interaction effects of variety by NPSB blended fertilizer rate at Kobo (Table 5; Appendix Table 2). At Woramit also both main and interaction effects of variety and NPSB blended fertilizer rates highly significantly ($p<0.001$) affected absolute growt rate (Appendix Table 3). From Table 5 the highest absolute growth rate (4.47 g d^{-1}) was depicted from Bombay red variety with the application of 183 kg ha^{-1} NPSB blended fertilizer planted at Kobo. However, the least absolute growth rate (3.27 g d^{-1}) from the variety Nafis with the application of 183 kg ha^{-1} NPSB blended fertilizer. At Woramit the highest absolute growth rate (4.47 g d^{-1}) was recorded from Nafis variety with the application of 91.5)

kg ha^{-1} NPSB blended fertilizer. However, the least absolute growth rate (3.10 g d^{-1}) from Bombay red variety with the application of 152,5 kg ha^{-1} NPSB blended fertilizer (Table 6). According to Hasan *et al*. (2013), absolute growth rate was significantly affected by sulfur on onion crop. The absolute growth rate showed the highest value at 65 to 75 days after transplanting and continued to decline till 75 to 85 days after transplanting. Sulfur significantly stimulated the absolute growth rate in onion at 40 kg ha^{-1} in all growth periods except 75 to 85 days after transplanting. Soubeih (2018) reported that the total accumulation rate of dry matter in onion shoots was affected by the application of NPK fertilizers.

Net assimilation rate (mg m^{-2} day^{-1})

The plant's capacity to increase dry weight in terms of the area of its assimilatory surface expresses the net assimilation rate (NAR).The NAR was highly significantly ($p<0.01$) influenced by main effects of variety and NPSB blended fertilizer rate, and significantly affected by their interaction effects at Kobo (Appendix Table 2). In a similar way, NPSB blended fertilizer rate also affected NAR at Woramit (Appendix Table 3). At Kobo the maximum net assimilation rate (2.46 mg m^{-2} day^{-1}) was recorded from variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer; however at Woramit the maximum net assimilation rate (4.13 mg m^{-2} day^{-1}) was recorded from variety Nafis with no application of NPSB blended fertilizer. The least net assimilation rates (1.51 mg m^{-2} day^{-1}) was recorded from the same variety with the application of 122 kg NPSB blended fertilizer rate planted at Kobo (Table 5). This might have been attributed to Nafis adabtability toWoramit's soils, temperatures and precipitation than Kobo as explained for SLW earlier. Hasan *et al*. (2013) revealed that sulphur dose at 40 kg ha^{-1} produced a higher net assimilation rate than the other doses. In contrast, the control plants maintained the lowest net assimilation rate over its growth period. Dhin *et al*. (2018) revealed that different micronutrients and spacing significantly affected the net assimilation rate of rice. Shukla and Warsi (2000) also obtained the highest net assimilation rate with the application of Zn along with NPK in wheat.

Harvest index

The harvest index was significantly ($p<0.01$) affected by the main effects of variety at Kobo; however, other main and interaction effects had no significant effect (Table 5; Appendix Table 2). At Woramit both main and interaction effects had no significant effect (Appendix Table 3).

The maximum harvest index (86.04) was recorded from variety Bombay red. In contrary with the current study, Abdissa *et al*. (2011), reported that nitrogen fertilization significantly affected the harvest index and increased by about 3.6 % over the control in response to the application of 69 kg N ha^{-1}.

Table 5. Mean specific leaf area (SLA), absolute growth rate (AGR), net assimilation rate (NAR) and harvest index (HI) at Kobo (January – April, 2019)

Treatments		Variables			
		SLA cm^2 g^{-1}	AGR g d^{-1}	NAR g m^{-2} d^{-1}	HI
Variety		ns	*	**	*
Bombay red		0.071^{a}	3.86^{a}	2.03^{a}	86.04^{a}
Nafis		0.068^{a}	3.63^{b}	1.75^{b}	81.46^{b}
LSD (5%)		0.01	0.20	0.12	3.36
Fertilizer (NPSB) rate		**	ns	*	ns
0		0.055^{c}	3.75	2.27^{a}	81.54
30.5		0.060^{c}	3.58	1.84^{bc}	81.06
61		0.089^{a}	3.57	1.75^{c}	84.53
91.5		0.078^{b}	3.68	1.77^{c}	85.63
122		0.073^{b}	3.82	1.70^{c}	86.70
152.5		0.054^{c}	3.95	1.91^{bc}	83.42
183		0.081^{ab}	3.87	1.99^{b}	83.36
LSD (5%)		0.01	0.38	0.23	6.28
Variety * Fertilizer interaction		*	*	*	ns
Bombay red	0	0.06^{def}	3.70^{bcd}	2.26^{abc}	82.77
	30.5	0.06^{cde}	3.50^{bcd}	1.82^{defg}	86.38
	61	0.07^{bcd}	3.67^{bcd}	1.94^{cde}	87.54
	91.5	0.07^{cd}	3.63^{bcd}	1.79^{defg}	86.42
	122	0.06^{cde}	4.03^{ab}	1.89^{de}	88.55
	152.5	0.05^{efg}	4.00^{abc}	2.07^{bcd}	87.67
	183	0.07^{bcd}	4.47^{a}	2.46^{a}	82.94
Nafis	0	0.04^{g}	3.80^{bcd}	2.29^{ab}	80.31
	30.5	0.05^{fg}	3.67^{bcd}	1.86^{def}	75.75
	61	0.10^{a}	3.47^{cd}	1.56^{fg}	81.51
	91.5	0.08^{bc}	3.73^{bcd}	1.76^{defg}	84.83
	122	0.07^{bcd}	3.60^{bcd}	1.51^{g}	84.86
	152.5	0.05^{fg}	3.90^{bc}	1.75^{efg}	79.16
	183	0.09^{ab}	3.27^{d}	1.54^{fg}	83.78
LSD (5%)		0.02	0.54	0.32	8.88
CV (%)		12.43	8.58	10.06	6.34

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Table 6. Mean specific leaf area (SLA), absolute growth rate (AGR) and net assimilation rate (NAR) at Woramit (January – April, 2019)

Treatments		Variables		
		SLA cm^2 g^{-1}	AGR g d^{-1}	NAR g m^{-2} d^{-1}
Variety		**	*	ns
Bombay red		0.07^{a}	3.70^{b}	2.89^{a}
Nafis		0.05^{b}	3.93^{a}	2.98^{a}
LSD (5%)		0.01	0.16	0.39
Fertilizer (NPSB) rate		**	**	*
0		0.04^{c}	3.95^{ab}	3.93^{a}
30.5		0.05^{c}	4.00^{ab}	2.94^{bc}
61		0.07^{b}	3.75^{bc}	2.78^{bc}
91.5		0.04^{c}	4.13^{a}	3.23^{ab}
122		0.07^{b}	3.85^{ab}	2.79^{bc}
152.5		0.08^{ab}	3.51^{c}	2.27^{c}
183		0.09^{a}	3.53^{c}	2.59^{bc}
LSD (5%)		0.02	0.2925	0.75
Variety * Fertilizer interaction		*	**	ns
Bombay red	0	0.04^{ef}	3.87^{bcd}	3.74
	30.5	0.05^{cdef}	4.07^{ab}	3.07
	61	0.10^{ab}	3.33^{ef}	2.29
	91.5	0.04^{def}	3.80^{bcd}	2.93
	122	0.06^{cde}	4.17^{ab}	3.25
	152.5	0.09^{ab}	3.10^{f}	2.23
	183	0.12^{a}	3.60^{cde}	2.69
Nafis	0	0.04^{ef}	4.03^{b}	4.12
	30.5	0.04^{def}	3.93^{bc}	2.82
	61	0.04^{def}	4.17^{ab}	3.27
	91.5	0.03^{f}	4.47^{a}	3.52
	122	0.08^{bc}	3.53^{cde}	2.35
	152.5	0.07^{bcd}	3.91^{bc}	2.31
	183	0.07^{bcd}	3.47^{def}	2.48
LSD (5%)		0.03	0.41	1.05
CV (%)		27.72	6.48	21.48

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

2.3.2. Yield Components and Bulb Yield

Bulb Neck thickness

Bulb neck thickness was significantly ($p<0.05$) affected by the main effects of NPSB blended fertilizer, however, main effect of variety and interaction effects had no significant effect (Table 7) at Kobo. At Woramit except main effects of NPSB blended fertilizer the other effects were

non significant (Appendix Tables 4 & 5).The highest bulb neck thickness (1.29 cm) was recorded from the application of 30.5 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 7). At woramit the highest bulb neck thickness (1.29 cm) was recorded from variety Nafis (Table 8). The variability in bulb thickness in the present study might be due to the synergetic effects of NPSB blended fertilizer.This study, in agreement with the suggestion of Brewster (1997), reported that neck thickness is a physiological event influenced by seasons, sites, and varieties. Onions with a thinner neck diameter store better than those with a thicker neck diameter (Coolong *et al*., 2008). Therefore, knowing the onion bulb thickness of different varieties is important. According to Khatemenla *et al. (*2018) the highest neck thickness of bulbs at the maturity stage was found in the treatment combination Zn and B and the lowest under control. Contrary to our results, Conn *et al*. (2012), reported that nitrogen application in less levels resulted in a thinner neck diameter, while nitrogen application of high levels gave the thickest neck diameter.

Bulb length

The results revealed that only the main effects of variety significantly ($p<0.05$) affected bulb length at both locations, however the other main and interaction effects were non significant (Appendix Tables 4 & 5). The tallest bulb length (5.5 cm) was obtained from the Nafis variety (Tables 7 & 8). The difference might be due to genetic makeup differences between the two varieties. Abdissa *et al*. (2011) reported that application of nitrogen and phosphorus fertilizer and their interaction did not significantly influence bulb length.

Bulb dry weight per plant

Analysis of variance showed that bulb dry weight was highly significantly ($p<0.01$) affected by the main effects of variety, significantly ($p<0.05$) by and interaction effects of variety and NPSB blended fertilizer rate at Kobo (Appendix Tables 4; Table 7). At Woramit bulb dry weight per plant was significantly ($p<0.05$) affected only by the interaction effects (Table 8). The highest bulb dry weight (203.23 g) was obtained from the variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 7). However, the least bulb dry weight (127.63g) was gained from the variety Bombay red with the application of 152.5 kg ha^{-1} NPSB blended fertilizer rate planted at Woramit (Table 8). In contrary with the current report,

Abdissa *et al.* (2011) indicated that nitrogen fertilization significantly affected bulb dry weight and increased by about 24 % over the control in response to the application of 69 kg N ha^{-1}.

Table 7. Mean bulb neck thickness (BNT), bulb length (BL) and bulb dry weight per plant (BDW) at Kobo (January- April, 2019)

Treatments		Variables		
		BNT(cm)	BL(cm)	BDW (g p^{-1})
Variety		ns	*	**
Bombay red		1.06	5.35^{b}	172.48^{a}
Nafis		1.15	5.55^{a}	155.54^{b}
LSD (5%)		0.09	0.18	8.82
Fertilizer (NPSB) rate		*	ns	ns
0		0.97^{c}	5.45	164.53
30.5		1.29^{a}	5.47	152.78
61		1.04^{bc}	5.48	157.02
91.5		1.18^{ab}	5.61	166.52
122		1.09^{bc}	5.43	163.20
152.5		1.05^{bc}	5.43	170.65
183		1.11^{bc}	5.29	173.37
LSD (5%)		0.1637	0.34	16.506
Variety * Fertilizer interaction		ns	ns	*
Bombay red	0	1.03	5.37	172.90^{bc}
	30.5	1.21	5.56	153.90^{cde}
	61	1.07	5.28	159.53^{bcde}
	91.5	1.07	5.34	165.07^{bcde}
	122	1.01	5.54	177.90^{b}
	152.5	1.05	5.34	174.80^{bc}
	183	0.98	5.03	203.23^{a}
Nafis	0	0.91	5.52	156.17^{bcde}
	30.5	1.37	5.37	151.67^{cde}
	61	1.01	5.68	154.50^{cde}
	91.5	1.29	5.86	167.97^{bcd}
	122	1.17	5.31	148.50^{de}
	152.5	1.05	5.53	166.50^{bcde}
	183	1.23	5.57	143.50^{e}
LSD (5%)		0.23	0.48	23.34
CV (%)		12.53	5.29	8.51

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Table 8. Mean bulb neck thickness (BNT), bulb length (BL) and bulb dry weight per plant (BDW) at Woramit (January – April, 2019)

Treatments		Variables		
		BNT(cm)	BL(cm)	BDW(g p^{-1})
Variety		ns	*	ns
Bombay red		1.12	5.35[b]	162.50
Nafis		1.17	5.55[a]	167.81
LSD (5%)		0.0693	0.1826	9.166
Fertilizer rate		**	ns	ns
0		1.29[a]	5.45	173.20
30.5		1.21[ab]	5.47	173.50
61		1.15[b]	5.48	163.05
91.5		1.14[b]	5.60	170.33
122		0.97c	5.43	166.53
152.5		1.11[b]	5.43	149.37
183		1.12[b]	5.29	160.12
LSD (5%)		0.13	0.34	17.15
Variety * Fertilizer interaction		ns	ns	**
Bombay red	0	1.33	5.37	170.50[abcd]
	30.5	1.17	5.56	179.30[ab]
	61	1.13	5.28	149.30[de]
	91.5	1.06	5.34	157.40[bcd]
	122	1.03	5.54	185.27[a]
	152.5	1.04	5.34	127.63[e]
	183	1.05	5.03	168.10[abcd]
Nafis	0	1.27	5.52	175.90[abc]
	30.5	1.25	5.37	167.70[abcd]
	61	1.16	5.68	176.80[ab]
	91.5	1.22	5.86	183.27[a]
	122	0.91	5.31	147.80[de]
	152.5	1.18	5.53	171.10[abcd]
	183	1.18	5.57	152.13[cd]
LSD (5%)		0.18	0.48	24.25
CV (%)		9.61	5.29	8.78

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Bulb diameter

The three-way interaction effect significantly ($p<0.05$) influenced bulb diameter (Appendix Table 6). The maximum bulb diameter (6.7 cm) was recorded on the variety Bombay red with the combination of 183 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 9). The minimum bulb diameter (5.6 cm) was recorded from the Nafis variety combined with 61 kg ha^{-1} blended

fertilizer planted at Kobo (Table 9). The current study indicated that the bulb diameter increased with increasing NPSB blended fertilizer rates regardless of location. This might be due to the role of NPSB blended fertilizers in different physiological and metabolic processes through growth in dry matter production. In line with this, Shaheen *et al*. (2007), reported that bulb diameter significantly increased with increases in phosphorus fertilizer. Tibebu *et al*. (2014) also reported that the highest bulb diameter was obtained from the application of P_2O_5 ha^{-1}. Paul *et al*. (2007) reported adding boron and sulphur increased the onion bulb diameter, however, the minimum bulb diameter was obtained from the control. According to Khatemenla *et al*. (2018), the maximum bulb diameter) was obtained by applying Zn 25 kg + B 5 kg ha^{-1} .

Mean bulb weight

Mean bulb weight was highly significantly ($p<0.01$) influenced by main effects of NPSB blended fertilizer rate, interaction effects of location by variety, location by NPSB blended fertilizer rate (Appendix Table 6). Similarly, it was significantly affected ($p<0.05$) by the main effects of variety and the three-way interaction effects (Appendix Table 6). The maximum mean bulb weight (142.7 g) was recorded from the variety Bombay red with the combination of 183 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 9). However, the minimum mean bulb weight (90.3 g) was obtained from the same variety with the application of 152.5 kg ha^{-1} NPSB blended fertilizer rate planted at Woramit indicating that Bombay red is more productive at Kobo (Table 9). The change might be due to location, variety, and NPSB blended fertilizer rate differences. The current study result is, in agreement with Abdissa *et al.* (2011), reported that nitrogen fertilizer significantly increased the average bulb weight of the Bombay red onion variety, and mean bulb weight increased by about 26% in response to the application of 69 kg N ha^{-1} as compared to the control. Muluneh *et al*. (2018) also reported that bulb weight was highly significantly influenced by the application of different NPS fertilizer rates.

Marketable bulb yield ton ha^{-1}

Marketable bulb yield (t ha^{-1}) was highly significantly ($p <0.0001$) affected by both main and interaction effects of location, variety, and NPSB blended fertilizer rate (Appendix Table 6). The highest marketable yield, 45.5 t ha^{-1}, was recorded from the variety Bombay red with the application of 61 kg ha^{-1} NPSB blended fertilizer planted at Kobo. But, the least marketable bulb

yield, 15.46 t ha^{-1}, was recorded from variety Nafis with no application of NPSB blended fertilizer planted at Woramit (Table 9). From the present result, it can be deduced that location, variety, and NPSB blended fertilizer rate contributed to increase average bulb weight that gave an advantage to increase the marketable bulb yield. According to Mbulelo *et al*. (2018), an increase in N application to 120 and, even more so, to 180 kg N ha^{-1} was aligned with a tendency towards an increase in marketable yield. The marketable bulb yield of onion was influenced by the application of NPS fertilizer rates. The highest marketable bulb yield (20.9 t ha^{-1}) was obtained from onion plants supplied with NPS fertilizer at the concentration of 105:119.6:22 kg ha^{-1} N: P_2O_5: S (Muluneh *et al*., 2018).

Unmarketable bulb yield (ton ha^{-1})

The results of this study indicated that differences were observed due to the onion varieties and application of fertilizer rates on the unmarketable bulb yield per hectare.The results depicted that highly significant difference ($p< 0.01$) was observed on unmarketable bulb yield due to main effects of location, variety, application of fertilizer rates, and all interaction effects (Appendix Table 6). The highest unmarketable yield, 5.8 t ha^{-1}, was recorded from variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer rate planted at Kobo; while the least unmarketable yield ton ha^{-1} (0.7) was obtained from variety Nafis with the application of 91.5 kg ha^{-1} NPSB blended fertilizer rate planted at Woramit (Table 9). This result conradicts to that of Tibebu *et al*. (2014), stated that phosphorus had no significant effect on the unmarketable yield of onion, which might be due to the adequate amount of available P which was found in the soil of Kobo experimental site (Table 3).

Total bulb yield ton ha^{-1}

Total bulb yield was highly significantly ($p<0.0001$) affected by the main and interaction effects of location, variety, and NPSB blended fertilizer rates (Appendix Table 6). The highest total bulb yield, 50.23 t ha^{-1}, was recorded from Bombay red variety with the combination of 61 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 9). While the lowest total bulb yield, 16.86 t ha^{-1}, was recorded on the Nafis variety in the control treatment planted at Woramit (Table 9). This difference might be due to the interactive effects of nutrients in the NPSB blended fertilizer to stimulate bulb growth and development, such as an increase in bulb size weight. The study is in agreement with the findings of Mbulelo *et al*. (2018), who reported that the highest total yield of

of onion was recorded from the application of nitrogen, whereas the lowest yield was recorded at control. Khan *et al*. (2002) also depicted that with the application of nitrogen, maximum onion yield can be obtained more than the minimum nitrogen fertilization regimes. Muluneh *et al*. (2019) also reported that the application of 150 kg N ha^{-1} increased the bulb yield more than the control plot. In addition, Paul *et al*. (2007) reported that the maximum total onion bulb yield was obtained from 1 kg boron ha^{-1}, whereas the lowest yield was obtained from the control. Bulb yield is also affected by the application of sulphur.

Table 9. Mean bulb diameter (BD), bulb weight (MBW), marketable (MY) and unmarketable (UMY), and totalbulb yield (TBY) at Kobo and Woramit (January - April, 2019)

Treatments			Variables				
Location	Variety	Fertilizer rate	BD(cm)	MBW(g)	MY t ha^{-1}	UMY t ha^{-1}	TBYt ha^{-1}
Kobo	Bombay red	0	6.2^{bcdef}	115.8^{bcde}	32.33^{e}	3.23^{cd}	35.56^{efg}
		30.5	6.1^{bcdefg}	97.8^{ij}	32.60^{e}	3.16^{d}	35.76^{ef}
		61	6.5^{abcd}	$112.1^{bcdefgh}$	45.50^{a}	4.73^{b}	50.23^{a}
		91.5	6.5^{abcd}	$112.6^{bcdefgh}$	30.06^{fg}	4.43^{b}	34.50^{fgh}
		122	6.3^{abcde}	118.3^{bcde}	38.23^{c}	4.13^{bc}	42.36^{c}
		152.5	6.5^{ab}	122.3^{bc}	36.76^{c}	2.53^{defg}	39.30^{d}
		183	6.7^{a}	142.7^{a}	41.53^{b}	5.80^{a}	47.33^{b}
	Nafis	0	6.3^{abcde}	102.9^{ghi}	29.70^{gh}	2.73^{def}	32.43^{hi}
		30.5	6.0^{edfg}	103.7^{fghi}	28.06^{hi}	2.43^{defgh}	30.50^{ij}
		61	5.6^{g}	98.5^{ij}	32.83^{de}	1.33^{ijkl}	34.16^{fgh}
		91.5	6.5^{abc}	116.1^{bcde}	31.66^{ef}	2.36^{defgh}	34.03^{fgh}
		122	6.4^{abcde}	107.5^{efghi}	30.43^{fg}	3.03^{de}	33.46^{gh}
		152.5	6.1^{bcdef}	$112.3^{bcdefgh}$	32.73^{de}	2.03^{fghi}	34.76^{fg}
		183	6.2^{bcdef}	111.5^{cdefgh}	34.50^{d}	2.40^{defgh}	36.90^{e}
Woramit	Bombay red	0	6.3^{abcde}	111.6^{cdefgh}	17.70^{n}	1.30^{ijkl}	19.0^{p}
		30.5	6.3^{abcde}	107.9^{efghi}	22.0^{m}	1.93^{fghij}	23.93^{no}
		61	5.9^{efg}	109.0^{defghi}	25.36^{jkl}	1.36^{ijkl}	26.73^{lm}
		91.5	6.1^{bcdefg}	109.5^{defghi}	26.66^{ij}	1.66^{ghijk}	28.33^{kl}
		122	6.3^{abcde}	120.3^{bcd}	20.83^{m}	1.86^{fghij}	22.70^{o}
		152.5	5.8^{fg}	90.3^{j}	26.30^{ijk}	2.13^{efghi}	28.43^{jkl}
		183	6.1^{bcdefg}	115.9^{bcde}	24.13^{l}	1.56^{hijkl}	25.66^{mn}
	Nafis	0	6.0^{cdefg}	109.6^{defghi}	15.46^{o}	1.40^{ijkl}	16.86^{q}
		30.5	6.3^{abcde}	108.2^{defghi}	27.53^{i}	0.80^{kl}	28.33^{kl}
		61	6.3^{abcde}	114.3^{bcdefg}	21.66^{m}	1.10^{jkl}	22.76^{o}
		91.5	6.3^{abcde}	123.8^{b}	29.36^{gh}	0.70^{l}	30.06^{jk}
		122	5.9^{efg}	100.6^{hij}	23.93^{l}	1.53^{hijkl}	25.46^{mn}
		152.5	5.9^{defg}	112.7^{bcdefg}	24.76^{kl}	1.56^{hijkl}	26.33^{ml}
		183	6.4^{abcd}	115.4^{bcdef}	24.60^{kl}	1.33^{ijkl}	26.03^{mn}
LSD (5%)			0.4	12.1	1.7	0.9	2.1
CV (%)			4.8	6.5	3.7	23.9	4.1

LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation.

2.3.3. Bulb Quality

The quality of onions depends on variety, soil nutrient type, environmental conditions, and other factors. Flavor in onions is dominated by organosulfur compounds arising from the enzymatic decomposition of S-oxide flavor precursors. From the onion quality parameters, some of them are Total soluble solid (TSS), Ttitratable acidity (TA), Vitamin C and Pyruvic Acid (Pungency).

Total soluble solid (TSS)

Total soluble solids were highly significantly ($p<0.0001$) affected by both main and interaction effects of location, variety, and NPSB blended fertilizer rate (Appendix Table 7). The highest TSS level (17.9 ^{o}Brix) was recorded from onion variety Nafis with the application of 183 kg ha^{-1} blended (NBSP) fertilizer rate planted at Kobo and followed by the same variety (17.05 ^{o}Brix) with the application of 152.5 kg ha^{-1} NPSB blended fertilizer planted at Woramit. However, the lowest TSS level (11.7 ^{o}Brix) was obtained from the onion variety Bombay red planted at Woramit on a rate of 122 kg ha^{-1} NBSP blended fertilizer rate (Table 10). A positive interaction between the micronutrients in blended fertilizer and the variety of onion might have contributed to enhancing metabolic processes involved in the biosynthesis of total soluble solids such as carbohydrates, organic acids, amino acids, and other inorganic constituents. In line with the present finding, Mohammed and Gaafar (2015) reported that different onion varieties had dissimilar total soluble solids. Mbulelo *et al.* (2018) also reported that onion varieties depicted significant differences with regard to TSS, with the highest TSS (9.07) recorded for the brown onion 'Mikado'. The application of micronutrients in the onion bulb varied from 10.73 ^{o}Brix to a maximum of 13 ^{o}Brix in total soluble solids. The improvement in total soluble solids content in onion bulbs with the application of micronutrients might be attributed to enhanced metabolic processes involved in the biosynthesis of total soluble solids. According to Muluneh *et al*. (2019), the maximum TSS value was recorded in the application of nitrogen, whereas the minimum TSS value was obtained in control treatments. Khatemenla *et al*. (2018) also reported that the maximum TSS value was recorded from application of Zn and B, but the lowest was recorded from the control.

Ttitratable acidity (TA)

Titratable acidity is a measure of the amount of acid present in a solution. The results showed that titratable acidity was highly significantly ($p<0.0001$) affected by the interaction effects of location, variety, and NPSB blended fertilizer rate (Appendix Table 7). The maximum (0.35 %) total titratable acidity was obtained from the onion variety Bombay red with the application of 183 kg NPSB blended fertilizer ha^{-1} planted at Kobo and Nafis with application of 30.5 kg ha^{-1} NPSB blended fertilizer planted at Woramit while the lowest (0.20 %) was recorded from variety Nafis with 30.5 kg ha^{-1} application of NPSB, blended fertilizer planted at Kobo (Table 10). The same variety Nafis with application of 30.5 kg ha^{-1} NPSB blended fertilizer grown at Woramit yilded high TA value (0.35 %), whereas low TA value (0.20) at Kobo.This might have attributed to the higher pH value of 6.21 of the soil and CEC (40.8 meq $100g^{-1}$ soil) of the soil at Kobo compared to pH of 6.17 of the soil and intermidate CEC (18.8 meq $100g^{-1}$ soil) (Table 3). With regard to variety Bombay red application of 183 kg ha^{-1} NPSB blended fertilizer grown at Kobo registered higher TA (0.35%), while 152.5 kg ha^{-1} NPSB blended fertilizer grown at Woramit recorded low TA (0.21%) implying differential variety response to NPSB blended fertilizer (Table 10). According to Francisco *et al*. (2019), the interaction between varieties and nitrogen doses was significant for the percentages of onion bulbs in titratable acidity.

Vitamin C

The analysis of variance indicated that the Vitamin C content of onion was highly significantly ($p<0.0001$) affected by interaction effects of location, variety, and NPSB blended fertilizer rate (Appendix Table 7). The highest Vitamin C content (23.21 mg.100 g^{-1}) was recorded from the onion variety Bombay red with the combination of 91.5 kg ha^{-1} NPSB blended fertilizer planted at Kobo, followed by onion variety Nafis (21.56 mg.100 g^{-1}) with the application of 183 kg ha^{-1} NPSB blended fertilizer planted at the same location (Table 10). However, the lowest Vitamin C content (9.34 mg.100 g^{-1}) was found in the variety Bombay red with the combination of 122 kg NPSB blended fertilizer rate ha^{-1} planted at Woramit (Table 10). The current investigation is different from Lawande (2001), reported that vitamin C content in the wild onion varieties with the range of 5-10 mg.100 g^{-1} fresh weight, it might be due to variatial differences. Mbulelo *et al.* (2018) reported that onion bulb vitamin C concentration was not affected by fertilizer treatment

and varieties. Jurgiel-Malecka *et al*. (2015) depicted that red onions were characterized by higher ascorbic acid (vitamin C) concentrations than yellow and white varieties.

Table 10. Mean values of different chemical properties of onion at Kobo and Woramit (January – April, 2019)

Treatments			Variables		
Location	Variety	Fertilizer rate	TSS °Bx)	TTA(%)	VC(mg.100g^{-1})
Kobo	Bombay red	0	13.85^{jk}	0.22^{gh}	14.53^{fgh}
		30.5	14.40^{f}	0.27^{cde}	14.14^{fghi}
		61	11.95^{s}	0.22^{gh}	12.92^{ghijk}
		91.5	14.50^{e}	0.28^{bcd}	23.21^{a}
		122	14.55^{e}	0.22^{gh}	13.11^{ghijk}
		152.5	13.80^{k}	0.22^{gh}	15.89^{ef}
		183	13.95^{i}	0.35^{a}	18.19^{de}
	Nafis	0	13.65^{l}	0.23^{fg}	11.98^{hijkl}
		30.5	12.75^{o}	0.20^{h}	13.93^{fghij}
		61	13.45^{m}	0.26^{de}	14.64^{fg}
		91.5	14.30^{g}	0.28^{bcd}	14.79^{fg}
		122	14.75^{d}	0.26^{de}	20.38^{bcd}
		152.5	15.85^{c}	0.25^{ef}	12.24^{ghijkl}
		183	17.90^{a}	0.29^{bc}	21.56^{ab}
Woramit	Bombay red	0	12.75^{o}	0.27^{cde}	13.61^{fghijk}
		30.5	13.60^{l}	0.28^{bcd}	10.06^{lm}
		61	12.80^{o}	0.22^{gh}	13.59^{fghijk}
		91.5	12.59^{p}	0.25^{ef}	14.14^{fghi}
		122	11.70^{t}	0.22^{gh}	9.34^{m}
		152.5	12.10^{r}	0.21^{gh}	11.15^{klm}
		183	14.75^{d}	0.26^{cde}	21.29^{abc}
	Nafis	0	12.90^{n}	0.22^{gh}	11.50^{jklm}
		30.5	13.90^{ij}	0.35^{a}	20.91^{abc}
		61	12.25^{q}	0.26^{de}	12.64^{ghijkl}
		91.5	14.20^{h}	0.27^{cde}	11.87^{ijklm}
		122	13.90^{ij}	0.28^{bcd}	12.43^{ghijkl}
		152.5	17.05^{b}	0.30^{b}	18.89^{cd}
		183	13.85^{jk}	0.23^{fg}	14.61^{fg}
LSD (5%)		0.05	0.02	2.5	0.03
CV (%)		0.2	5.9	10.6	15.1

Where; TSS (Total soluble solid), TTA (Ttitratable acidity), VC (Vitamin C)

Pyruvic Acid (Pungency)

Determining pyruvate as an indicator of pungency is perhaps the most established method for assessing pungency in vegetables like onions. The current study indicated that pyruvic acid was highly significantly ($p<0.0001$) influenced by the main and interaction effects of variety and NPSB blended fertilizer rates at Kobo (Appendix Table 8). However, at Woramit only main effect of NPSB blended fertilizer rate significantly affected pyruvic acid (Appendix Table 8). The maximum pyruvic acid content (0.32 $mg.g^{-1}$) was recorded from the onion variety Bombay red with the combination of 30.5 kg ha^{-1} NPSB blended fertilizer planted at Kobo (Table 11). According to this study, pyruvic acid content was reduced when the application of NPSB blended fertilizer increased. In addition, a difference was observed between varieties. The two varieties had the same pyruvic acid content at Woramit; however, there was a difference at Kobo. This might be due to the interaction effects of both variety and NPSB blended fertilizer rates. Orzolek (2010) reported that among the non–genetic factors affecting pungency in onions, water stress has to be considered. Kandoliya *et al.* (2015) reported that pyruvic acid content varied from 1.09 to 1.33 $mg.g^{-1}$ in his study. However, the current study indicates that the range of pyruvic acid is from 0.05- 0.31 $mg.g^{-1}$. The difference might be due to variety and other environmental factors.

Table 11. Mean of pyruvic acid at Kobo and Woramit (January – April, 2019)

Treatments		Variable	
		Pyruvic Acid (Pungency)	
		Kobo	Woramit
Variety		**	ns
Bombay red		0.24[a]	0.09
Nafis		0.20[b]	0.09
LSD (5%)		0.01	0.02
Fertilizer (NPSB) rate		**	**
0		0.19[d]	0.08[bc]
30.5		0.26[a]	0.18[a]
61		0.22[c]	0.09[bc]
91.5		0.24[b]	0.07[c]
122		0.21[c]	0.07[c]
152.5		0.23[b]	0.08[bc]
183		0.20[cd]	0.11[b]
LSD (5%)		0.02	0.04
Variety * Fertilizer interaction		**	ns
Bombay red	0	0.21[c]	0.06
	30.5	0.32[a]	0.15
	61	0.30[a]	0.10
	91.5	0.21[c]	0.08
	122	0.21[c]	0.06
	152.5	0.16[d]	0.09
	183	0.27[b]	0.11
Nafis	0	0.16[d]	0.10
	30.5	0.21[c]	0.21
	61	0.13[e]	0.07
	91.5	0.27[b]	0.05
	122	0.20[c]	0.07
	152.5	0.31[a]	0.07
	183	0.14[e]	0.10
LSD (5%)		0.02	0.05
CV (%)		6.14	32.19

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

2.3.4. Partial Budget Analysis

The partial budget analysis depicted that the variety Bombay red planted at Kobo gave the maximum economic benefit of 817,322.5 ETB ha^{-1} with a marginal rate of return of 27584.05 % at the application rate of 61 kg ha^{-1} NPSB. And at Woramit variety, Nafis gave a higher economic benefit of 525,963.75 ETB ha^{-1} with a marginal rate of return of 16424.59 % at the application of 91.5 kg ha^{-1} NPSB. However, the least net benefit of 278,280 birr ha^{-1} was

recorded from the Nafis variety with no application of NPSB fertilizer at Woramit (Table 12). Birhanu *et al*. (2014) reported that application of nitrogen had the highest net benefit and mariginal rate of return than the control. According to the present study, economic benefit was determined based on location difference, genetic potential of onion varieties, and application rate of blended NPSB fertilizer rate. In this study 61 kg ha^{-1} NPSB and 91.5 kg ha^{-1} NPSB are showed better result at Kobo and Woramit, respectively.

Table 12. Partial budget analysis of the effects location, blended NPSB fertilizer rate and onion varieties at Kobo and Woramit (January – April, 2019)

Location	Variety	NPSB rate (kg h^{-1})	ABY (t ha^{-1})	GFB (Birr ha^{-1})	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	MRR%
Kobo	Bombay red	0	29.097	581940	0	581940	-
	Nafis	0	26.730	534600	0	534600	-
	Bombay red	30.5	29.340	586800	838.75	585961.25	479.43
	Nafis	30.5	25.254	505080	838.75	504241.25	D
	Bombay red	61.0	40.950	819000	1677.5	817322.5	27584.05
	Nafis	61.0	29.554	591080	1677.5	589402.5	10153.35
	Bombay red	91.5	27.054	541080	2516.25	538563.75	D
	Nafis	91.5	284.94	569880	2516.25	567363.75	D
	Bombay red	122	34.407	688140	3355	684785	17433.23
	Nafis	122	27.387	547740	3355	544385	D
	Bombay red	152.5	33.084	661680	4193.75	657486.25	D
	Nafis	152.5	29.457	589140	4193.75	584946.25	4835.92
	Bombay red	183	37.377	747540	5032.5	742507.5	10138.66
	Nafis	183	31.050	621000	5032.5	615967.5	3698.51
Woramit	Bombay red	0	15.93	318600	0	318600	-
	Nafis	0	13.914	278280	0	278280	-
	Bombay red	30.5	19.8	396000	838.75	395161.25	9128.02
	Naafis	30.5	16.05	321300	838.75	320461.25	5029.06
	Bombay red	61	22.824	456480	1677.5	454802.5	7110.73
	Nafis	61	19.494	389880	1677.5	388202.5	8076.45
	Bombay red	91.5	23.994	479880	2516.25	477363.75	2689.86
	Nafis	91.5	26.424	528480	2516.25	525963.75	16424.59
	Bombay red	122	18.747	374940	3355	371585	D
	Nafis	122	21.537	430740	3355	427385	D
	Bombay red	152.5	23.67	473400	4193.75	469206.25	11638.89
	Nafis	152.5	22.284	445680	4193.75	441486.25	1681.22
	Bombay red	183	21.717	434340	5032.5	429307.5	D
	Nafis	183	22.14	442800	5032.5	437767.5	D

Where, ABY: Adjusted bulb yield ton ha^{-1}, GFB: Gross field benefit, TVC: Total variable cost, NB: Net benefit, MRR: marginal rate of return (%), D: dominated treatment

2.4. CONCLUSIONS

Onion is a very valuable crop that generates cash for both commercial growers and smallholder farmers. The objective of the current experiment was to ascertain how different onion varieties and the rate of NPSB blended fertilizer affect the production and quality onion bulbs.The results of the current study revealed that the two onion varieties tested in the present study responded differently to the different rates of the blended fertilizer in terms of bulb yield and quality at the two locations suggesting that bulb yield and quality in onion is a function of variety, fertilizer, and growing environment. When compared to the yield advantage of the control, the application of 61 kg ha^{-1} of NPSB blended fertilizer with the variety Bombay red at Kobo increased the yield by 41.25%. In addition, at Woramit application of 91.5 kg ha^{-1} of NPSB blended fertilizer with variety Nafis, increased bulb yield by 78.29%. Regarding the quality of onions, differences were observed in all quality parameters due to the differences in the varieties and the amount of fertilizer added. The economic significance of the two fertilizer rates mentioned above was also revealed by the partial budget analysis. However,further experiment undertaking across years and places is recommended to arrive at a solid recommendations, as the study area demonstrated encouraging results.

CHAPTER 3: EFFECTS OF NPSB BLENDED FERTILIZER RATE AND VARIETIES ON YIELD AND QUALITY OF ONION (*Allium cepa* L.) SEED PRODUCTION IN NORTHEASTERN PARTS OF AMHARA REGION, ETHIOPIA

ABSTRACT

Blended fertilizers play a crucial role in improving onion seed production. By combining different nutrient sources in a balanced manner, blended fertilizers provide a comprehensive range of essential elements for healthy growth and development of onion plants. High-quality onion bulbs require high-quality seeds as a necessary input. But the main barrier to growing higher yield and higher quality bulbs is onion seeds. The purpose of this study was to determine how NPSB blended fertilizers and varieties affect the yield and quality of onion seeds. The treatments consisted of two onion varieties (Bombay red and Nafis) and seven NPSB blended fertilizer rates (NPSB) (0, 30.5, 61, 91.5, 122, 152.5; 183 kg ha^{-1}). The experiment was setup using a complete randomized block design with three replications. The results of the analysis of variance indicated that the changes in onion varieties and the NPSB blended fertilizer rate had a substantial impact on most variables. With the treatment of 183 kg ha^{-1} of NPSB blended fertilizer, Bombay red produced the highest seed yield (2.3 tons ha^{-1}) out of the two onion varietal types. However, the lowest yield (0.5 tons) was recorded from the Nafis variety without application of NPSB blended fertilizer. Regarding the percentage of germination, with combinations of 183 kg ha^{-1} of NPSB, the Bombay red onion variety had better percentage of germination (91.33%). The partial budget analysis showed that the Bombay red variety with application of 183 kg ha^{-1} NPSB gave a maximum net benefit of 1,857,967.5 ETB ha^{-1} with a marginal rate of return of 48,186.14%. Since this research result showed promising indicator, it is recommended to further undertake this work in the region in the future under a wider area and for more number of year.

Keywords: Blended fertilizer, onion, seed quality, seed yield,variety

3.1. INTRODUCTION

Onion (*Allium cepa* L.) is a commonly consumed vegetable crop worldwide. Onion is consumed in small quantities and used in many homes almost daily, primarily for seasoning or flavoring various dishes. It is processed into various products such as ketchup, chutney, sauce, puree, salsa, and dry soup. Onion contains traces of vitamins B and C. The outstanding character of onion is its pungency because of the presence of sulfur-based compounds (allyl propyl disulfides). Onion contributes significant nutritional value to the human diet and has medicinal properties. It is primarily consumed for its unique flavor or ability to enhance the flavor of other foods (Randle, 2000). It is used in the preparation of different foods and therapeutic medicine in the country (Shiberu and Mahammed, 2014). In Ethiopia, onion is an essential crop for increasing the income of producers and traders (Lemma and Shimeles, 2003).

Nutrients play a significant role in improving the productivity and quality of vegetable crops. Onions are the most susceptible crop to extracting nutrients, especially the immobile types, because of their shallow and unbranched root system.Onions require and often respond well to the addition of fertilizers (Rizk *et al*., 2012). Fertilizer application affects the yield and quality of onion seed production (Nandpuri *et al*., 1990). Nitrogen has been found to increase the number of umbels per plant, the number of florets per umbel, umbel size, and seed yield (Nehra *et al*., 1988). There are a number of production constraints that cause low productivity of onion seed in Ethiopia. These include lack of appropriate agronomic package, low soil fertility, inappropriate use of fertilizer rates, shortage of seeds of improved varieties, diseases, insect pests, poor extension services, high costs of commercial fertilizers, and sometimes unavailable to small-scale farmers (Melkamu *et al*., 2015). To improve onion seed yield and quality, using balanced fertilizers is one of the most important crop management practices to be considered. Nutrients such as N, P, S, and B are included in the new fertilizer formula for deficient soils since these nutrients can significantly improve fertilizer-use efficiency and crop profitability. Ethiopian Agricultural Transformation Agency (ATA) indicated that; N: P_2O_5: S: B (18.9 N + 37.7 P_2O_5 + 6.95S + 0.1B) fertilizers substituted Diammonium Phosphate (DAP) (ATA, 2016). However, the response of onion to the application rate of the blended fertilizer (NPSB) doses varies with locations, and so far, this has not yet been determined at Kobo and Libso. Therefore, this experiment was conducted to determine economically viable NPSB blended fertilizer rates and

onion varieties for high onion seed yield and quality at Kobo and Libso areas of Northeastern Amhara, Ethiopia.

3.2. MATERIALS AND METHODS

3.2.1. Description of Experimental Site

The study was carried out under irrigation at Kobo sub-center research field and Libso investment farm from September 2018 to May 2019. Kobo is located 571 km from Addis Ababa at 12° 08' 21''N and 39°38' 21''E, at an altitude of 1500 m.a.s.l. The long-term mean annual rainfall in the area is 668 mm with a maximum and minimum temperature of 31°C and 15°C, respectively. Libso is located at 11°33.21' 59'' N and 39°39.32' 17'' E, at 1630 m above sea level at 475 km north of the capital city, Addis Ababa. The long-term mean annual rainfall of the area is 848 mm with a maximum and minimum temperature of 30 °C and 11.6 °C, respectively (EAMSC, 2019).

3.2.2. Experimental Design, Treatments and Field Management

The experiment was laid out as a 2x7 factorial in Randomized Complete Block Design (RCBD) with three replications. The treatments included two onion varieties (Bombay red, Nafis) and seven levels of blended (NPSB) fertilizer (0, 30.5, 61, 91.5, 122,152.5, and 183 kg ha^{-1}). The bases for these levels are 100 kg ha^{-1} DAP and 150 kg ha^{-1} Urea (EARO, 2004). And the calculation was made according to the new fertilizer formula of NPSB blended (18.9N: 37.7 P_2O_5:6.95S:0.1B). Each treatment combination was assigned randomly to the experimental units within a block. The distance between plots and blocks was 1 m and 1.5 m, respectively. There were 42 plots corresponding to the 14 treatment combinations. Detailed information on the treatments is described in Table 13. The onion seed was obtained from Melkasa Agricultural Research Center (MARC). Bulb planting was done in single rows of 50 cm, 30 cm, and 20 cm between furrows, rows, and plants, respectively. Fertilizer application was done according to the trial plan and applied in band parallel to onion rows five centimeters away from the seedlings. For the control of onion thrips, the insecticide selecron was used. When each umbel in the net plot reached maturity, it was harvested with a sharp sickle. After being sun-dried on canvas, the umbels were manually threshed. Winnowing was used to separate the seeds from stalks and other detritus, and soaking the seeds in buckets of water to separate the chaff from the well-filled seeds was another method. The seeds that sank in the water were deemed viable and well-filled, whereas the floating seeds were thrown away as chaffy seeds due to their hollow nature. Once

the sinking seeds had been adjusted to an 8% moisture content, they were drained, dried under shade, weighed, and recorded as seed weight per plot. Tests for seed quality were then conducted.

Table 13. Treatment combination of blended fertilizer rates and varieties on onion seed trial

Treatment setting (%)	Treat-ments	Variety	NPSB Kg ha $^{-1}$	Elemental form of $N/P_2O_5/S/B$ (Kg ha^{-1})	NPSB (g/ plot)
0	T1	Bombay red	0	0/0/0/0	0
25	T2		30.5	5.76/11.49/2.11/0.031	36.6
50	T3		61	11.53/22.99/4.24/0.061	73.2
75	T4		91.5	17.3/34.5/6.4/0.09	109.8
100	T5		122	23/46/8.5/0.12	146.4
125	T6		152.5	28.8/57.5/10.6/0.15	183
150	T7		183	34.6/68.9/12.7/0.18	219.6
0	T8	Nafis	0	0/0/0/0	0
25	T9		30.5	5.76/11.49/2.11/0.031	36.6
50	T10		61	11.53/22.99/4.24/0.061	73.2
75	T11		91.5	17.3/34.5/6.4/0.09	109.8
100	T12		122	23/46/8.5/0.12	146.4
125	T13		152.5	28.8/57.5/10.6/0.15	183
150	T14		183	34.6/68.9/12.7/0.18	219.6

Where; N: Nitrogen, P: Phosphorous, S: Sulphur, B: Boron

3.2.3. Soil Sampling and Analysis

Surface soil (0-20 cm depth) samples were collected using an auger from different spots of the experimental field of the respective sites before planting. The samples from each location were composited saparetely to yield one representative sample for each location. The samples were air dried, ground using a mortar and sieved to pass through a 2 mm sieve before laboratory analysis. Working samples were drawn from the submitted sample and were analyzed for selected physicochemical properties: texture, pH, cation exchange capacity (CEC), electric conductivity (EC), organic carbon, organic matter content, total nitrogen, and available phosphorus, using standard laboratory procedures at soil laboratory of Sirinka Agricultural Research Center

(SARC). The organic matter content of the soil was determined by the volumetric method (Walkley and Black, 1934). Total nitrogen was analyzed using the Kjeldahl digestion, distillation, and titration method described by Black *et al.* (1965) by oxidizing the OM in a concentrated sulfuric acid solution (0.1N H_2SO_4). The pH of the soil was determined on a 1:2 (weight/volume) soil samples-to-water ratio using a pH meter (Motsara and Roy, 2008). Cation exchange capacity (CEC) was measured titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). Available phosphorus was determined by using procedures of Olsen methods for estimation of available phosphorus in soils by extracting with sodium bicarbonate (Olsen *et al*., 1954).

Table14. Physical and chemical properties of soil in the experimental fields at Kobo and Libso before planting

Location	Soil properties	Units	Value
Kobo	Sand	%	36.25
	Clay	%	32.5
	Silt	%	31.25
	Textural classes		Clay loam
	pH (water 1: 2.5 g soil)	-	6.07
	Total Nitrogen (N)	%	0.154
	Organic Carbon (OC)	%	0.970452
	Organic Matter (OM)	%	1.673059
	Available Phosphorus	Ppm	31.25
	Electric conductivity (EC)	ds m^{-1}	0.2
	Cation exchange capacity(CEC)	meq per 100 g soil	39.8
Libso	Sand	%	33.75
	Clay	%	37.5
	Silt	%	28.75
	Textural classes		Clay loam
	pH (water 1: 2.5 g soil)	-	6.32
	Total Nitrogen (N)	%	0.112
	Organic Carbon (OC)	%	1.040719
	Organic Matter (OM)	%	1.7942
	Available Phosphorus	Ppm	29.55
	Electric conductivity (EC)	ds m^{-1}	0.207813
	Cation exchange capacity (CEC)	meq per 100 g soil	40.6

3.2.4. Data Collection

Growth Parameters and Crop Phenology

Number of leaves/plant: Leaves of ten plants of onion were counted after 75 days of bulb planting and the average was calculated and recorded as number of leaves per plant.

Flower stalk diameter (cm): Flower stalk diameter was measured from ten plants in the central rows from each plot at the flowering stage.

Flower stalk height (cm): Flower stalk height was measured by using a ruler.

Days to 50% bolting: The number of days from planting date up to when 50% of the plants in a plot produced flower stalks.

Days to 50% flowering: The number of days from planting date up to when 50% of the flower stalks in each plot produced flowers.

Seed Yield and Yield Components

Number of flower stalks per plant: The average number of flower stalks of ten randomly selected plants per plot at central rows was counted.

Number of umbels per plant: The average number of umbels from ten randomly sampled plants was counted.

Umbel diameter (cm): The umbel diameters of ten randomly sampled plants in each plot was measured using a caliper and averaged.

Number of seeds per umbel: Five umbels were randomly selected from ten randomly sampled plants and their seeds were threshed and counted.

Seed weight per umbel (g): The average seed weight of five randomly sampled umbels.

Seed yield (t ha^{-1}): Seed yield ton ha^{-1} was estimated from seed yield per plot.

Seed Quality Parameters

Germination percentage (%): The test was performed according to ISTA (1985) rules. Seeds were placed on Petri dishes covered with filter paper and allowed to imbibe water with distilled water, which was kept at room temperature until germination ceased in each Petri dish for 12 days. A seed is considered germinated when the radicle protrusion has attained approximately 1 mm. Then germination percentage was determined from counts of normal seedlings and the total number of seeds placed on Petri dishes.

Speed of germination: Seeds were placed on Petri dishes, and the germinated seeds were counted, picked, and removed from the Petri dishes starting from the 3rd day after placing the seeds on Petri dishes to the final count when germination finished. The speed of germination was then determined by counting the germinated seed every day, and it was divided by the number of days for which the test was run. The speed of germination (SPG) was calculated according to the formula of Maguire (1962).

$$\text{Speed of germination} = \frac{\text{N1}}{C1} + \frac{N2}{C2} + \cdots + \frac{NF}{CF}$$

Where N1 = number of normal seedlings at first count, N2 = number of normal seedlings at second count, NF = number of normal seedlings at final count, C1 = days to the first count, C2= days to the second count, CF = days to the final count

Seed vigor index I and II: After measuring the seedling shoot and root length as well as seedling dry weight, the seedling vigor index I and II were calculated according to the formula described by Abdul-Baki and Anderson (1973) as follows:

Seed vigor index I: It was determined by multiplying seed germination percentage by the sum of shoot and root length as: Germination (%) x Seedling length [Seedling root length + Shoot length (cm)].

Seed vigor index II: It was determined by multiplying seed germination percentage by seedling dry weight as: Germination (%) x seedling dry weight (g).

3.2.5. Data Analysis

All of the ANOVA assumptions were verified for the dataset. SAS 9.4 statistical software was used to analyze the variance (SAS-Institute, 2008). The homogeneity of variance and normality of the data were examined for each site. When examined at a 5% level of significance and found to be nonsignificant, they were regarded as normal distributions. The variance was also regarded as homogeneous because the test resulted in nonsignificant results at the 5% level of significance. An ANOVA of each location was conducted after the assumptions of normality of variance were verified. Before doing a combined analysis of variance of the two locations, a test of homogeneity of variance of the two error mean squares was conducted. According to Gomez and Gomez (1984), the error variance could be considered homogeneous when the highest error mean square was not three- fold larger than the smallest error mean square. For variables which could not be combined across the two locations, the analysis was under taken and presented for each location. When ANOVA was found significant, means were compared using the least significant difference (LSD) test at 5% probability level.

3.2.6. Partial Budget Analysis

Partial budget analysis was employed for economic analysis of fertilizer application and carried out for combined seed yield data. The potential response of the crop towards the added fertilizer and the price of fertilizers during planting ultimately determined the economic feasibility of fertilizer application. The economic analysis was computed using the procedure described by CIMMYT (1988).

Gross average seed yield (kg ha^{-1}) (AvY): is the average yield of each treatment.

Adjusted yield (AjY): is the average yield adjusted downward by a 10 % to reflect the difference between the experimental yield and the yield of farmers (CIMMYT,1988).

$$\mathrm{AjY} = \mathrm{AvY} - (\mathrm{AvY} - 0.1)$$

Gross field benefit (GFB): is computed by multiplying the field/farm gate price that farmers receive for the crop when they sell it as adjusted yield.

Total cost: is the cost of blended (NPSB) fertilizer used for the experiment. The price was based on the buying price during planting.

Net benefit (NB): calculated by subtracting the total costs from gross field benefits for each treatment.

$$\text{NB} = \text{GFB} - \text{total cost}$$

Marginal rate of return (MRR %): was calculated by dividing the change in net benefit by the change in cost, which was the measure of the increase in return by increasing input.

$$\text{Marginal rate of return (\%)} = \frac{\text{Change in net benefit}}{\text{Change in tolal cost}} \text{ X } 100$$

A partial budget analysis of the treatments was carried out by taking only fertilizer variable costs. NPSB blended fertilizer cost of 14 ETB kg^{-1} and Urea fertilizer cost of 13.50 ETB kg^{-1} were considered in the partial budget analysis. The seed yield was adjusted downward by 10 % to reflect the difference between the experimental and farmers' yields except from the same treatment. The average open market price of onion seed was 900 ETB kg^{-1} at the nearest market during harvesting time (May 2019) at Kobo and Libso.

3.3. RESULTS AND DISCUSSION

3.3.1. Growth Parameters and Crop Phenology

Number of leaves per plant

The number of leaves per plant was highly significantly ($p<0.01$) affected by main effects of location and fertilizer, and significantly ($p<0.05$) influenced by interaction of variety and NPSB blended fertilizer rate (Appendix Table 9). The maximum number of leaves per plant (37) was recorded from variety Bombay red with the application of 152.5 kg ha^{-1} NPSB blended fertilizer, whereas the least number of leaves per plant (24.5) was obtained from variety Nafis with no application of NPSB blended fertilizer (Table 15). Chowdhury *et al*. (2004) reported that the number of leaves per plant increased with the application of micronutrients. Mozumder *et al*. (2007) also observed similar results from applying NKS fertilizers, and Ghaffoor *et al*. (2003) observed from applying NPK fertilizers. From the results of the present study, it can be concluded that NPSB blended fertilizer provided better-growing conditions, perhaps due to the supply of adequate plant nutrients and genetic differences between the two onion varieties resulting in the maximum number of leaves per plant.

Days to 50% bolting

The result indicated that both main effects of variety and NPSB blended fertilizer, and interaction effects of variety and NPSB blended fertilizer rates had highly significantly ($p<0.0001$) influenced date to 50% bolting (Appendix Table 9). Early bolting date (56.83 days after bulb planting) was reported from Bombay red variety fertilized with 61 kg ha^{-1} NPSB blended fertilizer rate, whereas late bolting date (79.67 days after bulb planting) from treatments without NPSB blended fertilizer application. However, there is no clear trend with increasing NPSB blended fertilizer for both varieties (Table 15). This might be due to the differences in the genetic make up than the different rates of blended fertilizers. Getachew (2014) reported that days to bolting of a similar onion variety were between 63-67 days. The present findings is inline with Sorensen and Grevsen (2010), reported that too much nitrogen promoted excessive vegetative growth and delayed bolting and maturation of the onion.

Days to 50% flowering

The main effects of variety highly significantly ($p<0.0001$) influenced days to 50% flowering, but main effects of fertilizer rate and interaction effects had non significant effect (Appendix Table 9). Early flowering date (76.83 days after planting) was observed from Bombay red variety grown without NPSB blended fertilizer rate (Table 15),while late flowering (108.33 days after planting) was recorded by Nafis variety grown with 30.5 kg ha^{-1} NPSB blended fertilizer rate (Table 15). Limeneh *et al*. (2019) revealed that P fertilizer alone promoted early flowering while the addition of N delayed flowering of onion. Further increase in N resulted in a progressive increase in days to flowering. However, Tamrat (2006) indicated that increased days to flowering were recorded due to increased N fertilizer from 0 to 138 kg ha^{-1} on Adama red onion variety.

Flower stalk height

Flower stalk height was highly significantly ($p<0.0001$) affected by both main and interaction effects of variety and NPSB blended fertilizer rates (Appendix Table 9). The highest flower stalk height (85.5 cm) was recorded from variety Nafis with the application of 61 kg NPSB blended fertilizer ha^{-1}. Conversely,the lowest flower stalk height (67.83 cm) was obtained from variety Bombay red at the same fertilizer rate application (Table 15). implying the differential response of variety to NPSB blended fertilizer. The result was in accordance with Tamrat (2006) and Debashis *et al*. (2017), who found stalk heights for other varieties of onion in the range of 76-93 cm, which was similar to the height recorded in the present study. According to Abas *et al.* (2015), nitrogen fertilization significantly increased the length of the flowering stalk,whereas the lowest was recorded from control treatment of no fertilizers.

Table 15. Mean number of leaves per plant (NLP), 50% bolting date (BD), 50% flowering date (FD) and flower stalk height (FSH) at Kobo and Libso (October 2018 to April 2019)

Treatments		Variables			
		NLP	50% BD	50% FD	FSH
Variety		**	**	**	**
Bombay red		33.90[a]	57.74[b]	77.55[b]	69.12[b]
Nafis		26.05[b]	77.90[a]	106.93[a]	82.31[a]
LSD (5%)		0.99	0.69	1.02	0.94
Fertilizer (NPSB) rate		**	**	ns	**
0		27.75[c]	69.17[a]	92.00	77.00 [a]
30.5		31.00[a]	68.92[ab]	93.00	74.33[b]
61		29.83[ab]	67.83[b]	92.50	76.67 [a]
91.5		31.00[a]	66.00[c]	91.75	76.58 [a]
122		28.67[bc]	66.17[c]	92.42	75.33[ab]
152.5		31.25[a]	68.08[ab]	92.50	73.75[b]
183		30.33[ab]	68.58[ab]	91.50	76.33 [a]
LSD (5%)		1.86	1.31	1.89	1.75
Variety * Fertilizer interaction		*	**	ns	**
Bombay red	0	31.00[d]	58.67[c]	76.83	68.83[f]
	30.5	34.50[abc]	58.33 [c]	77.67	68.00 [f]
	61	34.83[ab]	56.83 [c]	77.17	67.83 [f]
	91.5	34.00[bc]	57.33 [c]	77.17	72.50[e]
	122	32.00[cd]	58.00 [c]	77.83	69.00 [f]
	152.5	37.00[a]	57.33 [c]	78.00	68.00 [f]
	183	34.00[bc]	57.67 [c]	78.17	69.67 [f]
Nafis	0	24.50[g]	79.67 [a]	107.17	85.17[ab]
	30.5	27.50[ef]	79.50 [a]	108.33	80.67[cd]
	61	24.83[g]	78.83 [a]	107.83	85.50[a]
	91.5	28.00[e]	74.67[b]	106.33	80.67[cd]
	122	25.33[fg]	74.33[b]	107.00	81.67[cd]
	152.5	25.50[efg]	78.83 [a]	107.00	79.50[d]
	183	26.67[efg]	79.50[a]	104.83	83.00[bc]
LSD (5%)		2.63	1.85	2.69	2.48
CV (%)		7.61	2.37	2.53	2.84

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Flower stalk diameter

Main effects of variety significantly ($p<0.05$) affected flower stalk diameter at both locations; however, the other main and interaction effects did not have significant effect (Appendix Table 6). The maximum flower stalk diameter (1.11cm) was recorded from variety Nafis. Nevertheless, the lowest flower stalk diameter (1.01cm) was obtained from the variety Bombay red (Table 16). The difference might be due to genetic differences between the two onion varieties. This study

was in contrary with Amare *et al*. (2020), who reported that the highest flower stalk diameter was recorded from NP fertilizers and the lowest was from the control.

Table 16. Mean of flower stalk diameter at Kobo and Libso (October 2018 to April 2019)

Treatments		Variable	
		Flower stalk diameter	
		Kobo	Libso
Variety		*	*
Bombay red		1.05[b]	1.01[b]
Nafis		1.11[a]	1.10[a]
LSD (5%)		0.04	0.08
Fertilizer (NPSB) rate		ns	ns
0		1.08	1.02
30.5		1.07	1.04
61		1.09	1.09
91.5		1.08	1.08
122		1.11	1.02
152.5		1.04	1.09
183		1.09	1.06
LSD (5%)		0.08	0.15
Variety * Fertilizer interaction		ns	ns
Bombay red	0	1.01	0.97
	30.5	1.02	0.97
	61	1.03	1.07
	91.5	1.07	1.01
	122	1.09	0.98
	152.5	1.02	1.03
	183	1.10	1.03
Nafis	0	1.15	1.06
	30.5	1.12	1.10
	61	1.16	1.12
	91.5	1.09	1.14
	122	1.13	1.05
	152.5	1.06	1.16
	183	1.08	1.09
LSD (5%)		0.11	0.21
CV (%)		6.31	12.06

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

3.3.2. Seed Yield and Yield components

Flower stalk per plant

The main effect of variety and interaction effects of variety and NPSB blended fertilizer rates highly significantly ($p<0.001$) affected flower stalk per plant while main effect of NPSB blended fertilizer significantly ($P<0.05$) affected flower stalk per plant (Appendix Table 11). The maximum flower stalk per plant (9) was obtained from the variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer. But the lowest flower stalk per plant (4.5) was recorded from the variety Nafis, with the application of 183 kg ha^{-1} NPSB blended fertilizer (Table 17).The present study revealed that the highest difference in flower stalk per plant was observed due to the differential response of variety to the application of NPSB blended fertilizer. This finding is in agreement with the reports of Ahmed and Abdalla (2006) and Getachew (2014), who reported that nitrogen and phosphorus separately or in combination proved to have no effect on the number of branches or flower stalks produced per plant.

Number of umbels per plant

The main effects of variety, NPSB blended fertilizer and the interaction of variety and NPSB blended fertilizer rate had highly significant ($p<0.0001$) influenced the number of umbels per plant (Appendix Table 11). The highest number of umbels per plant (8.83) was recorded from variety Bombay red with the combination of 183 kg ha^{-1} NPSB blended fertilizer. While the least number of umbels per plant (4.5) was recorded from variety Nafis with the same application of 183 kg ha^{-1} NPSB blended fertilizer (Table 17). This study indicated that the number of umbels per plant was more dependent on the varietal differences than fertilizer rate differences. However, the combination of variety and fertilizer rate creates differences in umbel diameter per plant. Tamrat (2006) and Debashis *et al.* (2017) reported that an increase in nitrogen fertilization increases the number of umbels per plant. The number of umbels was the most important trait for onion seed yield (Prats *et al*., 1996).

Umbel diameter

Umbel diameter was highly significantly ($p<0.0001$) influenced by both main and inteaction effects of variety and NPSB blended fertilizer rates (Appendix Table 11). The maximum umbel

diameter (7.3 cm) was recorded from Nafis onion variety with the application of 91.5 kg ha^{-1} NPSB blended fertilizer.The lowest umbel diameter (6.13cm) was recorded from the variety Bombay red with no application of NPSB blended fertilizer (Table 17). This might be due to the fact that flower setting and seed formation are highly controlled by phosphorous, and the application of nitrogen increases the vegetative growth, producing good quality foliage and promoting carbohydrate synthesis, thereby producing larger umbel diameters. According to Ali *et al*. (2007), phosphorous and nitrogen fertilization indicated a significant effect on umbel diameter.

Table 17. Mean flower stalk per plant (FSPP), number of umbels per plant (NUPP) and umbel diameter (UD) at Kobo and Libso (October 2018 to April 2019)

Treatments		Variables		
		FSPP	NUPP	UD (cm)
Variety		**	**	**
Bombay red		8.05^{a}	7.91^{a}	6.64^{b}
Nafis		5.24^{b}	5.21^{b}	7.01^{a}
LSD (5%)		0.34	0.33	0.12
Fertilizer (NPSB) rate		*	**	**
0		6.08^{c}	5.92^{c}	6.58^{d}
30.5		6.42^{bc}	6.33^{bc}	6.54^{d}
61		7.25^{a}	7.25^{a}	7.10^{a}
91.5		6.58^{bc}	6.50^{bc}	7.03^{ab}
122		6.42^{bc}	6.33^{bc}	6.85^{bc}
152.5		7.00^{ab}	6.92^{ab}	6.71^{cd}
183		6.75^{ab}	6.67^{ab}	6.98^{ab}
LSD (5%)		0.64	0.62	0.23
Variety * Fertilizer interaction		**	**	**
Bombay red	0	7.33^{c}	7.00^{de}	6.13^{g}
	30.5	8.17^{abc}	8.00^{abc}	6.25^{fg}
	61	8.50^{ab}	8.50^{ab}	7.20^{ab}
	91.5	8.00^{bc}	7.83^{bcd}	6.77^{de}
	122	7.50^{c}	7.50^{cd}	6.77^{de}
	152.5	7.83^{bc}	7.67^{bcd}	6.53^{ef}
	183	9.00^{a}	8.83^{a}	6.85^{cde}
Nafis	0	4.83^{f}	4.83^{h}	7.02^{abcd}
	30.5	4.67^{f}	4.67^{h}	6.83^{cde}
	61	6.00^{de}	6.00^{fg}	7.00^{abcd}
	91.5	5.17^{ef}	5.17^{gh}	7.30^{a}
	122	5.33^{def}	5.17^{gh}	6.93^{bcd}
	152.5	6.17^{d}	6.17^{ef}	6.88^{bcd}
	183	4.50^{f}	4.50^{h}	7.10^{abc}
LSD (5%)		0.89	0.87	0.33
CV (%)		11.75	11.54	4.15

LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation.

Number of seeds per umbel

Highly significant difference ($p<0.01$) was observed for number of seeds per umbel due to main effects of variety, NPSB blended fertilizer rate, and interaction effects of variety and NPSB blended fertilizer rate (Appendix Table 12). In a similar manner, the main effects of location, interaction effects of location and NPSB blended fertilizer, and the three-way interaction effects significantly ($p<0.05$) influenced number of seeds per umbel (same Appendix Table above). The highest number of seeds per umbel (1577) was recorded from variety Nafis with the combination of 122 kg ha^{-1} NPSB blended fertilizer planted at Kobo, whereas the lowest (822) was recorded from variety Bombay red without application of NPSB blended fertilizer planted at the same location (Table 18). Abu-Sara (1999) reported that the highest number of seeds per umbel was obtained from optimum fertilization and the lowest from lower nitrogen levels. This might be due to the role of nitrogen in the reduction of flower abortion and the effect of phosphorus on flower and seed production. Ali *et al*. (2007) also reported that the highest number of seeds per umbel was recorded from 150 kg ha^{-1} N and the lowest from the control.

Seed weight per umbel

Except for the main effects of variety, all other main and interaction effects highly significantly ($p<0.0001$) affected seed weight per umbel (Appendix Table 12). The maximum seed weight per umbel (6.4 g) was recorded from variety Nafis with the application of 152.5 kg ha^{-1} NPSB blended fertilizer rate planted at Kobo. But, the least seed weight per umbel (2.8g) was obtained from the variety Nafis without application of NPSB blended fertilizer planted at Libso (Table 18).The difference might be due to the soil status and environmental conditions of the locations. Amare *et al*. (2020) reported lowest seed weight per umbel from the plants grown under zero NP fertilizer application. High seed weight per umbel under high NP fertilizers might be due to the role of nitrogen in the buildup of carbohydrates and different metabolites and the role of phosphorous in seed formation and development (Marschner, 1995).

Seed yield (tons ha^{-1})

The interaction effects of location, variety and NPSB blended fertilizer rates were highly significantly ($p<0.001$) influenced seed yield (Appendix Table 12). The highest seed yield (2.3 t ha^{-1}) was recorded from the variety Bombay red with the application of 183 kg ha^{-1} NPSB

blended fertilizer rate planted at Kobo. However, the lowest seed yield (0.5 t ha^{-1}), was obtained from Nafis variety without the application of NPSB fertilizer planted at Libso (Table 18). The yield difference might be due to the application of different rates of NPSB blended fertilizer and genetic differences of the onion varieties. According to Amare *et al*. (2020), the highest seed yield per hectare was obtained from the application of P_2O_5 and N fertilizers and the lowest seed yield was recorded from plants that did not receive fertilizer.

Table18. Mean number of seeds per umbel (NSPU), seed weight per umbel (SWPU) and seed yield (SY) at Kobo and Libso (October 2018 to April 2019)

Treatments			Variables		
Location	Variety	FR	NSPU	SWPU	SY (t ha^{-1})
Kobo	Bombay red	0	822.3^{p}	3.2^{jk}	1.3^{jk}
		30.5	1365.3^{hgi}	5.4^{efgh}	1.7^{cde}
		61	1413.0^{fg}	5.5^{defgh}	1.8^{c}
		91.5	1318.3^{ijklm}	5.2^{fgh}	1.7^{def}
		122	1271.0^{m}	5.0^{h}	1.8^{cd}
		152.5	1403.0^{fgh}	5.5^{defgh}	1.8^{c}
		183	1413.3^{fg}	5.6^{cdef}	2.3^{a}
	Nafis	0	1469.3^{de}	6.1^{abcd}	0.8^{m}
		30.5	1345.6^{ijk}	5.3^{fgh}	1.2^{k}
		61	1531.6^{ab}	6.1^{abc}	1.5^{gh}
		91.5	1129.3^{n}	4.5^{i}	1.5^{hi}
		122	1577.0^{a}	6.2^{ab}	1.6^{fgh}
		152.5	1553.0^{ab}	6.4^{a}	1.5^{hi}
		183	1505.0^{bcd}	6.1^{abcd}	1.8^{cd}
Libso	Bombay red	0	917.3^{o}	3.6^{j}	1.4^{ij}
		30.5	1284.0^{lm}	5.1^{gh}	1.7^{def}
		61	1352.6^{hij}	5.4^{efgh}	1.7^{cde}
		91.5	1326.3^{ijkl}	5.2^{fgh}	1.6^{efg}
		122	1295.0^{klm}	5.1^{fgh}	1.7^{cd}
		152.5	1351.3^{hij}	5.3^{efgh}	1.7^{cde}
		183	1403.6^{fgh}	5.6^{cdefg}	2.1^{b}
	Nafis	0	1421.3^{ef}	2.8^{k}	0.5^{n}
		30.5	1307.3^{jklm}	5.1^{fgh}	0.9^{l}
		61	1518.6^{bcd}	6.1^{abcd}	1.4^{ij}
		91.5	1102.6^{n}	2.9^{k}	1.4^{ij}
		122	1525.3^{abc}	3.0^{k}	1.5^{gh}
		152.5	1473.3^{cde}	5.8^{bcde}	1.6^{fgh}
		183	1560.0^{ab}	3.1^{k}	1.6^{efg}
LSD (5%)			55.16	0.52	0.13
CV (%)			2.4	6.3	5.1

LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation.

3.3.3. Seed Quality Parameters

Germination percentage

The main effects of variety, NPSB blended fertilizer rate, and interaction effects of variety by NPSB blended fertilizer rate highly significantly ($p<0.0001$) affected germination percentage (Appendix Table 13).The maximum germination percentage (91.33%) was recorded from variety Bombay red with the application of 183 kg ha^{-1} NPSB blended fertilizer rates. The lowest value of germination percentage (68.83%) was obtained from the variety Nafis without application of NPSB blended fertilizer (Table 19). In agreement with the present study, Debashis *et al*. (2017) reported that the highest germination percentage of harvested seed was observed in treatment that received 175 kg N ha^{-1}. Tamrat (2006) and Ali *et al*. (2007) also reported that phosphorus and nitrogen fertilization had significant effects on seed germination percentage, in which mostly higher germination percentage was recorded from high fertilizer application. A seed germination percentage of 90-94% is considered the highest, and 70% is a minimum germination requirement for most onion varieties under the Ethiopian condition (Lemma and Shimeles, 2003).

Table19. Mean of germination percentage at Kobo and Libso (October 2018 to April 2019)

Treatments		Variable
		Germination percentage
Variety		**
Bombay red		86.19[a]
Nafis		81.36[b]
LSD (5%)		1.17
Fertilizer (NPSB) rate		**
0		75.42[d]
30.5		84.67[b]
61		89.08[a]
91.5		81.58[c]
122		80.17[c]
152.5		89.50[a]
183		86.00[b]
LSD (5%)		2.19
Variety * Fertilizer interaction		**
Bombay red	0	82.00[ef]
	30.5	83.83[de]
	61	87.00[bc]
	91.5	81.67[ef]
	122	87.17[bc]
	152.5	90.33[a]
	183	91.33[a]
Nafis	0	68.83[h]
	30.5	85.50[cd]
	61	91.17[a]
	91.5	81.50[ef]
	122	73.17[g]
	152.5	88.67[ab]
	183	80.67[f]
LSD (5%)		3.10
CV (%)		3.22

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Speed of germination

The main effects NPSB blended fertilizer, interaction effects of location and NPSB blended fertilizer,variety and NPSB blended fertilizer, and three-way interaction effects highly significantly ($p< 0.01$) affected the speed of germination (Appendix Table 14). The maximum speed of germination (8.7) was recorded from variety Nafis with the application of 61 kg ha^{-1} NPSB blended fertilizer planted at Kobo, while the minimum speed of germination (4.4) was also recorded from variety Nafis with the application of 91.5 kg ha^{-1} NPSB blended fertilizer

planted at Libso (Table 20). This result was in agreement with Ndor *et al*.(2012) and Cuocola and Barbieri (1988) as they explained that the earlier germination of the small seeds could be that the seeds required less moisture and nutrients to germinate and small seeds also have small surface area and can imbibe enough moisture at a short time and commenced the process of germination. According to this finding, seeds produced at Kobo were of better quality than those produced at Libso. This might be due to the environmental conditions of Kobo areas that are more suitable for onion seed production than Libso.

Seed vigor index I

Main effects of NPSB blended fertilizer and interaction effects of variety by NPSB blended fertilizer rate and three-way interaction highly significantly ($p<0.0001$) affected seed vigor index I (Appendix Table 14). The maximum seed vigor index I (926.7) was recorded from the variety Bombay red with the application of 61 kg NPSB blended fertilizer rate planted at Kobo. However, the lowest seed vigor index I (618) was recorded from the variety Nafis without application of NPSB blended fertilizer planted at Libso (Table 20). This might be due to large seed sizes; there is more food reserve in the cotyledon of the seed to sustain seedling growth and make seedlings vigorous than the smaller seed sizes whose food reserve could be exhausted very soon. The present finding is in agreement with Amare *et al.* (2020), who reported that the highest seedling vigor index I was obtained from 115 P_2O_5 and 114 N kg ha^{-1} and the lowest seedling vigor index I was recorded for seeds that did not receive fertilizer. In addition, Singh and Singh (2002) and Ashenafi *et al*. (2014) indicated that the highest seed vigor index I was recorded from plants that were grown at optimum fertilization.

Seed vigor index II

The main, two-way and three-way interaction effects highly significantly ($p<0.0001$) influenced seed vigor index II (Appendix Table 14). The highest value of seed vigor index II (18.1) was recorded from variety Nafis with the application of 61 kg NPSB blended fertilizer rate planted at Libso. However, the lowest seed vigor index II (6.7) was obtained from the same variety and location without application of NPSB blended fertilizer rate (Table 20). The results of this study agreed with Amare *et al*. (2020), who reported that the maximum seed vigor index II was recorded from 115 P_2O_5 and 114 N kg ha^{-1} fertilizers,whereas the lowest vigor index II was obtained without fertilizer application. Ashenafi *et al*. (2014) and Singh and Singh (2002)

depicted that optimum fertilizer application produced large-sized seeds and gave high seed vigor index II.

Table 20. Mean speed of germination % (SPG), seed vigor index I (SVI I) and seed vigor index II (SVI II) at Kobo and Libso (October 2018 to April 2019)

Treatments			Variables		
Location	Variety	Ferilizer rate	SPG%	SVI	SVII
Kobo	Bombay red	0	8.0^{abcde}	708.4^{kl}	8.3^{fg}
		30.5	7.2^{cdefgh}	777.2^{ij}	8.3^{fg}
		61	8.5^{abc}	926.7^{a}	17.6^{a}
		91.5	6.3^{fghij}	735.5^{jk}	$8.2f^{g}$
		122	7.5^{abcdef}	790.9^{ghi}	17.1^{a}
		152.5	8.6^{ab}	843.5^{cdefg}	9.1^{efg}
		183	6.4^{fghij}	819.7^{defghi}	9.1^{efg}
	Nafis	0	6.9^{defgh}	672.2^{l}	14.0^{bc}
		30.5	8.1^{abcd}	862.4^{bcde}	17.2^{a}
		61	8.7^{a}	871.1^{bcd}	12.3^{cd}
		91.5	7.6^{abcdef}	780.5^{ij}	16.2^{ab}
		122	6.8^{efghi}	692.5^{kl}	14.1^{bc}
		152.5	6.8^{efghi}	821.5^{defghi}	8.8^{efg}
		183	7.6^{abcdef}	808.8^{efghi}	16.7^{a}
Libso	Bombay red	0	6.8^{efghi}	703.6^{kl}	8.0^{fg}
		30.5	8.3^{abc}	792.6^{fghi}	8.4^{fg}
		61	6.9^{defgh}	814.0^{efghi}	8.6^{efg}
		91.5	7.4^{bcdefg}	785.1^{hij}	10.8^{de}
		122	8.5^{abc}	844.9^{cdef}	8.9^{efg}
		152.5	7.2^{cdefgh}	806.9^{fghi}	8.9^{efg}
		183	6.3^{fghij}	797.9^{fghi}	9.2^{ef}
	Nafis	0	5.9^{hij}	618.0^{m}	6.7^{g}
		30.5	6.1^{ghij}	835.5^{cdefgh}	8.5^{efg}
		61	5.6^{ijk}	878.9^{abc}	18.1^{a}
		91.5	4.4^{k}	721.7^{kl}	8.2^{fg}
		122	5.3^{jk}	710.9^{kl}	7.5^{fg}
		152.5	6.0^{hij}	901.5^{ab}	8.8^{efg}
		183	6.4^{fghij}	699.2^{kl}	7.7^{fg}
LSD (5%)			1.3	54.06	2.34
CV (%)			11.4	4.2	13.1

Where; LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation.

3.3.4. Partial Budget Analysis

The partial budget analysis was computed using CIMMYT (1988) description and guidelines for economic analysis of fertilizer application. As the rate of NPSB blended fertilizer application

increased, each additional kilogram of the fertilizer affected seed yield. To estimate the total costs, the mean current prices of NPSB blended fertilizer and Urea were collected at planting, and the market price of onion seed was taken at harvest. The partial budget analysis revealed that the variety Bombay red planted at Kobo with the application of 183 kg ha^{-1} NPSB gave the maximum net benefit of 1,857,967.5 ETB ha^{-1} with a marginal rate of return of 11971.5 % (Table 21). In addition, the lowest net benefit (105, 3000 ETB ha^{-1}) was recorded from the Bombay red variety without the application of NPSB fertilizer (Table 21). The highest economic benefit might be due to the highest seed yield produced by the Bombay red variety at the rate of 183 kg ha^{-1} NPSB. The results revealed that the use of the Bombay red variety with the application of 183 kg NPSB blended fertilizer ha^{-1} was cost-effective as compared to the other treatments.

Table 21.Partial budget analysis for the effects of location, NPSB blended fertilizer and varieties

Location	Variety	NPSB rate (kg h^{-1})	ASY (t ha^{-1})	GFB (birr ha^{-1})	TVC (birr ha^{-1})	NB (birr ha^{-1})	MRR%
Kobo	Bombay red	0	1.17	1053000	0	1053000	-
	Nafis	0	0.72	648000	0	648000	D
	Bombay red	30.5	1.53	1377000	838.75	1376161.25	38528.91
	Nafis	30.5	1.08	972000	838.75	971161.25	D
	Bombay red	61	1.62	1458000	1677.5	1456322.5	9557.23
	Nafis	61	1.35	1215000	1677.5	1213322.5	D
	Bombay red	91.5	1.53	1377000	2516.25	1374483.75	D
	Nafis	91.5	1.35	1215000	2516.25	1212483.75	D
	Bombay red	122	1.62	1458000	3355	1454645	D
	Nafis	122	1.44	1296000	3355	1292645	D
	Bombay red	152.5	1.62	1458000	4193.75	1453806.25	D
	Nafis	152.5	1.35	1215000	4193.75	1210806.25	D
	Bombay red	183	2.07	1863000	5032.5	1857967.5	11971.5
	Nafis	183	1.62	1458000	5032.5	1452967.5	D
Libso	Bombay red	0	1.26	1134000	0	1134000	-
	Nafis	0	0.45	405000	0	405000	D
	Bombay red	30.5	1.53	1377000	838.75	1376161.25	28871.68
	Nafis	30.5	0.81	729000	838.75	728161.25	D
	Bombay red	61	1.53	1377000	1677.5	1375322.5	D
	Nafis	61	1.26	1134000	1677.5	1132322.5	D
	Bombay red	91.5	1.44	1296000	2516.25	1293483.75	D
	Nafis	91.5	1.26	1134000	2516.25	1131483.75	D
	Bombay red	122	1.53	1377000	3355	1373645	D
	Nafis	122	1.35	1215000	3355	1211645	D
	Bombay red	152.5	1.53	1377000	4193.75	1372806.25	D
	Nafis	152.5	1.44	1296000	4193.75	1291806.25	D
	Bombay red	183	1.89	1701000	5032.5	1695967.5	7625.782
	Nafis	183	1.44	1296000	5032.5	1290967.5	D

Where, ASY: Adjusted seed yield ton ha^{-1}, GFB: Gross field benefit, TVC: Total variable cost, NB: Net benefit, MRR: marginal rate of return (%), D: dominated treatment

3.4. CONCLUSIONS

Knowledge of the effects of varieties and fertilizer rates used is essential for increasing the yield and quality of onion seeds. This experiment was carried out to determine the influence of onion varieties and NPSB blended fertilizer rate on the production of better onion seed yield and quality. The investigation revealed that different parameters responded well to blended NPSB fertilizer rates on the two onion varieties. The application of 183 kg ha^{-1} NPSB blended fertilizer rate increased onion seed yield by 76.92% than the non-application of blended fertilizer on the variety Bombay red. Application of 183 kg ha^{-1} NPSB blended fertilizer rate also increased the germination percentage by 18.66% than the non-application of NPSB blended fertilizer.The partial budget analysis indicated that the variety Bombay red, with the application of 183 kg ha^{-1} of NPSB fertilizer, resulted in the maximum net benefit at both locations. It would be beneficial if further study was done in the area encompassing a larger area and for extended number of years in the will help draw a reliable recommendation for wider use.

CHAPTER 4: EFFECTS OF PLANTING DATE AND BULB SIZE ON SEED YIELD AND QUALITY OF ONION (*Allium cepa* L.) IN NORTHEASTERN PARTS OF AMHARA REGION, ETHIOPIA

ABSTRACT

Even if onion seed production in Ethiopia is substantial,its productivity and quality is affected by various factors. This study is aimed at determing the influence of planting date and size of the bulb on the yield and quality of onion seed.This experiment was carried out in a randomized complete block design with three replications and involved three levels of onion bulb sizes small (2- 3 cm), medium (3.1- 4 cm), and large (4.1- 5 cm) and four levels of planting dates viz., 5 October, 15 October, 25 October, and 5 November.The results of the study revealed that planting date and mother bulb size influenced the seed yield ton ha^{-1}, germination percentage, seed vigor index I, and seed vigor index II. The highest seed yield (2.58 tons ha^{-1}) was harvested from large mother bulb which significantly affected seed yield ton ha^{-1}, germination percentage, and this highest seed yield is recorded from a large onion bulb planted in early October.The highest (96.67%) germination percentage was recorded from large onion bulbs planted in early October. Therefore, for better yield and quality of onion seeds production, planting of large onion bulbs (4.1-5cm) in early October can be recommended for the study areas and other similar agro-ecological areas of the country.

Keywords: Bulb size, onion seed, planting date, seed quality, seed yield

4.1. INTRODUCTION

Onion (*Allium cepa* L.) is a bulb crop belonging to the Alliaceae family. It is an important bulb crop worldwide and significantly important in the Ethiopian diet. It is also an essential crop for increasing the income of producers and traders (Lemma and Shimeles, 2003). Increased awareness of the nutritional and health importance of the crop has resulted in increased demand for quality onion seed (Amsalu *et al*., 2014). Most of the time, the demand for onion seed is supplied by the informal seed sector. However, there are problems related to inadequate seed supply, increment of onion seed price, and poor quality seed, which result in poor germination percentage. Quality storage condition of onion seed in tern is affected by length of storage and packaging materials used for their storage. Under favorable conditions, the shelf life of onion seed is one year. Due to these problems, farmers started onion seed production in different parts of the country (Nikus and Mulugeta, 2010). However, many factors that like variety, bulb size, date of planting, and plant density are among the major factors that has influenced onion seed yield and quality. The determination of the best combination of these can be used to improve onion seed production and quality (Asaduzzaman *et al.*, 2012). The effect of different planting dates on onion seed production in Bangladesh was investigated, and October 30th was recommended as the best planting date (UD-Deen, 2008). Similarly, November 15th was identified as the best planting date for onion seed production in the Borga region of Bangladesh (Mollah *et al*., 2015). In Iran, the best planting dates for onion seed production were from September 22nd to October 6th and from October 21st to November 5th for onion varieties Texas Early Grano 502 and Germez Iranshah, respectively, with mean maximum and minimum temperatures of 21.48 and 9.09 °C, respectively (Mehri *et al*., 2015). Studies in central part of Ethiopia showed that onion seed production is best if mother bulbs are planted in September and October, which helped to align the time of flowering during January and February, during cooler and drier months (Nikus and Mulugeta, 2010).

Bulb size determines the vigor of the reproductive phase and the number of reproductive shoot initials. This is directly related to the number of seed stalks and subsequent seed yield. Various onion bulb sizes were tested for seed production potential at Melkassa for three seasons to determine the optimum size for high seed yield and quality. Large bulbs in excess of 4.1 cm diameter produced vigorous umbels of above 5 cm diameter; a large number of flower stalks (as many as 360/100 m^2 kg/m^2) and with almost doubled the seed yield (695 kg/100 m^2) of bulbs of

ware- size (Lemma and Shimeles, 2003). According to Mohammad and Gaafar, (2015) significant variations due to different bulb size were observed with respect to seed yield ha^{-1}. Large bulbs produced the highest seed yield of 1563.33 kg ha^{-1}, followed by medium-size bulbs, 1383.33 kg ha^{-1}, whereas small bulbs produced the lowest seed yield, 1193.33 kg ha^{-1}. The study areas have a high potential for vegetable crop production, including onion. Therefore, this study was conducted to determine the appropriate planting date and bulb size on onion seed yield and quality at Kobo and Libso, Northeastern Amhara, Ethiopia.

4.2. MATERIALS AND METHODS

4.2.1. Description of Experimental Areas

The study was carried out under irrigation at Kobo sub-center research station and Libso investment farm from October 2018 to April 2019. Kobo is located 571 km from Addis Ababa at 120° 08' 21''N and 39°38' 21''E, at an altitude of 1500 m.a.s.l. Figure 5 shows that the long-term mean annual rainfall of the area is 510.6 mm with a maximum and minimum temperature of 31°C and 15.1°C, respectively. Libso is located at 11°33.21' 59'' N and 39°39.32' 17'' E, at 1630 m and 475 km far from the capital city to the north of Addis Ababa. The long-term mean annual rainfall of the area is 848mm, with a maximum and minimum temperature of 30°C and 11.6°C, respectively (EAMSC, 2019).

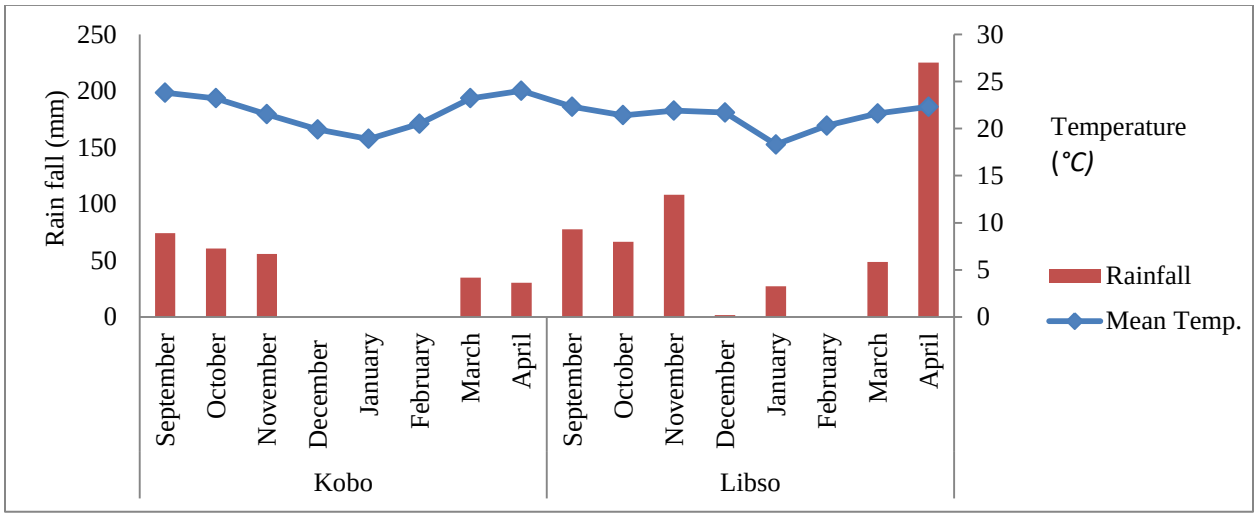


Figure 5. Mean monthly temperature (°C) and rain fall (mm) at Kobo and Libso Northeastern Amhara, Ethiopia during the trial period.

Source: East Amhara Meteorological Service Center annual report. Kombolcha (2019).

4.2.2. Experimental Material

The onion variety Bombay red seed was obtained from Melkasa Agricultural Research Center to proceed the study. The variety was released by Melkasa Agricultural Research Center. Its area of production is from 700-2000m above sea level, and the seed yield potential of the variety is 1.3-2 tons ha^{-1} (Lemma and Shimelis, 2003).

4.2.3. Experimental Design, Treatments and Agronomic Practices

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.The treatments involve three levels of mother bulb size viz., small (2- 3 cm), medium (3.1- 4 cm), and large (4.1- 5 cm) and four levels of planting dates; 5 October, 15 October , 25 October and 5 November. The planting material for the trial was harvested and stored on wooden shelves for two months in a shaded storage house. The distance between plots and blocks was 1 m and 1.5 m, respectively.There were 36 plots corresponding to 12 treatment combinations. One day before planting, the field was irrigated to moisten the soil, and the next day the selected bulbs were planted according to the trial plan. Planting was done in single rows, 50 cm between furrows, 30 cm between rows on the bed, and 20 cm between plants in the rows. The plots were irrigated at 4-5 days intervals during the first phase of active growth of the plants. Later, the irrigation interval was extended to a seven-day interval. Cultivation was done manually, and the field was kept free of weeds during the growing period. Selecron was used for the control of onion thrips. Agronomic practices were applied uniformly for all the plots as per the recommendation made for the crop. The harvesting of umbels in the net plot area was done by a sharp sickle at the maturity of the umbel in each plot. The umbels were dried on canvas and threshed by hand. The seeds were separated from stalks and other debris by winnowing, and the chaff seeds were separated from well-filled seeds by soaking seeds in water filled buckets. The floating seeds were discarded as chaffy seeds, while the sinking seeds were considered well-filled and viable. The sinking seeds were drained and dried to 8% under shade, weighted, and recorded as seed weight per plot. Finally, quality tests (germination percentage, seed vigor index I and II) were carried out.

4.2.4. Data Collection

Growth Parameters and Crop Phenology

Number of leaves/plant : Onion leaves of ten randomly selected plants were counted after 75 days of bulb planting and the average was recorded.

Days to 50% flowering: Days to 50% flowering was recorded as number of days from the date of planting up to when 50% of the plants produced flower stalks.

Seed Yield and Yield components

Number of flower stalks per plant: Ten randomly selected plants per plot was counted and averaged.

Umbel diameter (cm): Ten randomly sampled plants in each plot was measured using a caliper.

Number of seeds per umbel: Five umbels were randomly selected and counted.

Seed weight per umbel (g): Five randomly sampled umbel seeds were weighted using sensetive balance.

Seed yield (t ha^{-1}): Seed yield ton ha^{-1} was estimated from seed yield per plot.

Seed Quality Parameters

Germination percentage (%): The test was performed according to ISTA (1985) rules. Seeds were placed on Petri dishes covered with filter paper and allowed to imbibe water with distilled water, which was kept at room temperature until germination ceased in each Petri dish for 12 days. A seed is considered germinated when the radicle protrusion has attained approximately 1mm. Then percent germination was determined from counts of normal seedlings and the total seeds placed on Petri dishes.

Seed vigor index I and II: After measuring the seedling shoot and root length as well as seedling dry weight, the seedling vigor index I and II were calculated according to the formula described by Abdul-Baki and Anderson (1973) as follows:

Seed vigor index I: It was determined by multiplying seed germination percentage by the sum of shoot and root length as: Germination (%) x Seedling length [Seedling Root length + Shoot length (cm)].

Seed vigor index II: It was determined by multiplying seed germination percentage by seedling dry weight as: Germination (%) x seedling dry weight (g).

4.2.5. Data Analysis

Analysis of variance was done using SAS 9.4 statistical software (SAS-Institute, 2008). The data of each location were tested for normality and homogeneity of variance. There were considered to follow normal distribution when tested nonsignificant at 5% level of significance. Since the test showed nonsignificant at 5% level of significance the variance was also considered homogeneous. After confirming the assumptions of normality and homogeneity of variance ANOVA of each location was undertaken. Test of homogeneity of variance of the two errors mean squares was performed prior to undertaking combined analysis of the two locations. According to Gomez and Gomez (1984), the error variance could be considered homogeneous when the highest error mean square was not three-fold larger than the smallest error mean square. For variables which could not be combined across the two locations, the analysis was under taken and presented for each location. When ANOVA was found significant, means were compared using the least significant difference (LSD) test at 5% probability level.

4.3. RESULTS AND DISCUSSION

4.3.1. Growth parameters

Number of flower stalks per plant

The main effect of location, bulb size, and planting date had highly significantly ($p<0.001$) influence and the three-way interaction effects of location, bulb size and planting date significantly ($p<0.05$) affected the number of flower stalks per plant (Appendix Table 15; Table 22). However, there was a non-significant effect on the interaction effects of location and bulb size, location and planting date, bulb size and planting date. The highest number of flower stalks per plant (11) were recorded on large bulb sizes planted at Libso on 5 November, while the least number of flower stalks (6) were recorded on small bulb sizes planted at Libso on 5 October (Table 22). Large bulb sizes increased the number of flower stalks by (59.4 %) as compared to the small bulb sizes. This difference might be due to the superiority of large bulbs in having more stored food and more sprouts, leading to more flower stalks per plant. The result is in aggrement with the findings of Hussain *et al*., (2001) and Asaduzzaman *et al*., (2012). They reported that the number of flower stalks per plant was significantly high in large-sized bulbs, while the minimum was recorded in small-sized bulbs. Tesfaye *et al*. (2018) reported that the number of flower stalks per plant was highly significantly influenced by planting date. Islam and Mondal (2005) also indicated that planting date significantly influenced number of flower stalks per plant. Moreover, Sedigheh *et al*. (2015) showed that planting date had significant effect on flower stalks per plant.

Table 22. Mean number of flower stalks per plant (NFSPP) at Kobo and Libso grown during October 2018 to April 2019

Treatments			Variable
Lo	BS	PD	NFSPP
Kobo	Large	5 October	10.0^{abc}
		15 October	9.6^{bcd}
		25 October	9.6^{bcd}
		5 November	10.3^{ab}
	Medium	5 October	8.3^{ef}
		15 October	7.6^{fgh}
		25 October	8.6^{def}
		5 November	10.6^{ab}
	Small	5 October	7.0^{ghi}
		15 October	6.0^{i}
		25 October	6.6^{hi}
		5 November	7.6^{fgh}
Libso	Large	5 October	9.0^{cde}
		15 October	9.0^{cde}
		25 October	10.0^{abc}
		5 November	11.0^{a}
	Medium	5 October	7.6^{fgh}
		15 October	7.0^{ghi}
		25 October	8.0^{efg}
		5 November	8.0^{efg}
	Small	5 October	6.0^{i}
		15 October	6.3^{i}
		25 October	6.0^{i}
		5 November	6.6^{hi}
LSD (5%)			1.2
CV (%)			9.3

Where, LO = location; BS = Bulb size; PD = Planting date LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Number of leaves per plant

Both main and interaction effects of bulb size and planting date highly significantly ($p<0.0001$) influenced the number of leaves per plant (Appendix Table 16). The highest number of green leaves per plant (48.67) was recorded from large bulb size planted in late-October, while the least was from small bulb size (24.67) planted in early-October (Table 23). As bigger bulbs contain more sprouting initials and reserve food material, they might have been responsible for

producing more leaves than smaller ones. This result conforms with the results of Asaduzzaman *et al*. (2012), Hussain *et al.* (2001), and Islam (2002), who reported maximum number of green leaves per plant from large bulbs. In addition, Ud-Deen (2008) reported that, the maximum number of leaves per plant was produced by large mother bulbs. According to Sedigheh *et al*. (2015), Tesfaye *et al*. (2018), Islam and Mondal, (2005) planting date had significant differences or effect in the number of leaves per plant. Mollah *et al*. (2015) also reported that the number of leaves per plant was significantly influenced by planting dates.

Days to fifty percent flowering date

The main effects of planting date and interaction effects of bulb size and planting date highly significantly ($p<0.001$), and main effects of bulb size significantly ($p<0.05$) influenced days to fifty percent flowering (Appendix Table 16). Large bulbs planted in early- October flowered early (73.83 days after bulb planting), while medium bulb size planted in mid-October took the longest days (94 days after bulb planting) to attain fifty percent flowering (Table 23). This might be due to low temperature which could enhance bolting and subsequent flower development,while late planting delayed bolting and subsequent flowering because of increasing temperature. Anisuzzaman *et al.* (2009) reported that planting date had a marked influence on the number of days required for fifty percent flowering, and sometimes early maturing is good, as it can escape from bad weather and diseases.

Table 23. Mean number of leaves per plant (NLPP) and days to 50% flowering date (FD) at Kobo and Libso grown during October 2018 to April 2019

Treatments		Variables	
		NLPP	50% FD
Bulb Size		**	*
Small		28.58^{c}	81.92^{a}
Medium		36.38^{b}	81.50^{a}
Large		44.63^{a}	80.54^{b}
LSD (5%)		1.59	0.86
Planting date		**	**
5 October		34.17^{c}	75.56^{c}
15 October		35.33^{bc}	90.94^{a}
25 October		39.67^{a}	83.78^{b}
5 November		36.94^{b}	75.00^{c}
LSD (5%)		1.84	0.98
Bulb size * planting date interaction		**	**
Small	5 October	24.67^{f}	78.50^{f}
	15 October	30.50^{de}	85.83^{c}
	25 October	31.33^{d}	88.00^{b}
	5 November	27.83^{ef}	75.33^{g}
Medium	5 October	30.50^{de}	74.33^{g}
	15 October	36.83^{c}	94.00^{a}
	25 October	39.00^{c}	82.67^{d}
	5 November	39.17^{c}	75.00^{g}
Large	5 October	47.33^{a}	73.83^{g}
	15 October	38.67^{c}	93.00^{a}
	25 October	48.67^{a}	80.67^{e}
	5 November	43.83^{b}	74.67^{g}
LSD (5%)		3.18	1.71
CV (%)		7.57	1.82

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

4.3.2. Yield and yield component parameters

Umbel diameter

Main effects of bulb size and planting date and their interaction effects highly significantly ($p<0.01$) affected umbel diameter (Appendix Table 17). The maximum umbel diameter (6.6 cm) was recorded from a small bulbs planted on 5 October, whereas the least (5.1 cm) was recorded from a large bulb size planted on 5 November (Table 24). This might be due to less number of umbels and less competition in small bulb sizes than in large bulb sizes. Afterward, the

maximum umbel diameter was recorded in small bulb sizes. This result contradicts other researchers regarding bulb size; however, concerning the planting date in agreement with different scholars. Patil *et al*. (1993) reported earliness to significantly affect the umbel diameter. El-Helaly and Karam (2012) also reported that the maximum diameter of the umbel was obtained with early planting. Asaduzzaman *et al*. (2012) revealed that plants from large bulbs produced the highest umbel diameter, while the smallest bulb size produced the lowest umbel.

Number of seeds per umbel

The number of seeds per umbel was highly significantly ($p<0.001$) affected by the main effect of bulb size, planting date, and their interaction effects (Appendix Table 17). The highest number of seeds per umbel (1354.33) was recorded from a small bulb planted on 5 October. Nevertheless, the lowest number of seeds (852.17) was obtained from a small bulb planted on 5 November (Table 24). The variation in the number of seeds per umbel might be due to flower abortion caused by high temperatures, lack of efficient pollinators of the flowers in the umbel, shortage of nutrition which is caused by high competition, and death of the weak florets in the umbel. The delayed planting resulted in poor plant growth and delayed bolting. Moreover, high temperatures at the flower stalk-forming stages might have reduced the number of seeds per umbel.

Seed yield (tons ha^{-1})

The main effects of bulb size, planting date and their interaction had highly significantly ($p<0.0001$) affected seed yield t ha^{-1} (Appendix Table 17). The highest seed yield (2.58 tons ha^{-1}) was obtained from a large bulb size planted on 5 October, followed by a large bulb size planted on 15 October (2.32 t ha^{-1}), while the least (1.3 tons ha^{-1}) was recorded from small bulb size planted on 5 November (Table 24). The difference in seed yield might be due to the relatively large amount of food reserves stored in large bulbs, which enhanced the production of healthy and vigorously growing plants with a large number of seed heads and, consequently, increased seed yield tons ha^{-1}. This result agreed with the findings of Ud-Deen (2008), who reported that onion seed yield per hectare could be affected by the mother bulb size and planting date, and the highest seed yield was obtained from large onion bulbs with early planting while the lowest seed yield was obtained from small mother bulbs with late planting. In addition, this result agreed with the findings of Ali *et al*. (2015), Mollah *et al*. (2015), and Debashis *et al*. (2016), who reported that large-sized bulb produced a higher seed yield per hectare.

Table 24. Mean umbel diameter (UD), number of seeds per umbel (NSPU) and seed yield (SY) at Kobo and Libso from October 2018 to April 2019

Treatments		Variables		
		UD (cm)	NSPU	SY (t ha^{-1})
Bulb Size		**	**	**
Small		6.27^{a}	1133.25^{a}	1.57^{c}
Medium		5.96^{b}	1145.67^{a}	2.02^{b}
Large		5.76^{c}	1110.36^{b}	2.23^{a}
LSD (5%)		0.14	15.45	0.11
Planting date		**	**	**
5 October		6.45^{a}	1324.50^{a}	2.22^{a}
15 October		6.24^{b}	1168.39^{b}	2.06^{b}
25 October		5.65^{c}	1073.28^{c}	1.77^{c}
5 November		5.64^{c}	952.89^{d}	1.72^{c}
LSD (5%)		0.16	17.84	0.13
Bulb size * planting date interaction		**	**	**
Small	5 October	6.60^{a}	1354.33^{a}	1.85^{efg}
	15 October	6.56^{a}	1223.67^{c}	1.70^{g}
	25 October	5.69^{d}	1102.83^{e}	1.43^{h}
	5 November	6.23^{b}	852.17^{g}	1.30^{h}
Medium	5 October	6.53^{a}	1325.00^{ab}	2.23^{bc}
	15 October	5.99^{bc}	1155.00^{d}	2.15^{bcd}
	25 October	5.73^{cd}	1099.50^{e}	1.92^{efg}
	5 November	5.59^{d}	1003.17^{f}	1.78^{fg}
Large	5 October	6.21^{b}	1294.17^{b}	2.58^{a}
	15 October	6.17^{b}	1126.50^{de}	2.32^{b}
	25 October	5.55^{d}	1017.50^{f}	1.95^{def}
	5 November	5.10^{e}	1003.33^{f}	2.07^{cde}
LSD (5%)		0.28	30.89	0.23
CV (%)		4.08	2.37	10.04

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Seed weight per umbel

Both main and interaction effects of bulb size and planting date had highly significantly ($p<0.001$) influenced seed weight per umbel at Kobo (Appendix Table 18). The highest seed weight per umbel (5.43g) was obtained from a small bulbs planted on 5 October. However, the least (3.43g) was recorded from a small bulb planted on 5 November (Table 25). Similarly, at Libso, both main and interaction effects highly significantly ($p<0.001$) influenced seed weight per umbel (Appendix Table 18). The higest seed weight per umbel (5.33 g) was recorded from small and medium bulbs planted on 5 October, while the least seed weight per umbel (1.67 g)

was obtained from small bulb size planted on 5 November.The highest weight of seeds per umbel might be due to early planting created conducive temperature for growth and development of flowers and seed set. The result is in contrast to that of EL-Aweel and Gobashi (1999), El-Helaly and Karam (2012), and Asaduzzaman *et al.* (2012) who reported that large bulbs produced higher seed weight per umbel. However, there is in agreement with planting dates, which reported that the maximum seed weight per umbel was recorded from early planting date. The contradiction might be due to differences in the variety of the onion.

Table 25. Mean seed weight per umbel at Kobo and Libso from October 2018 to April 2019

Treatments		Variable	
		Seed weight per umbel	
		Kobo	Libso
Bulb Size		*	**
Small		4.56[a]	3.63[b]
Medium		4.61[a]	4.03[a]
Large		4.44[b]	3.87[a]
LSD (5%)		0.08	0.16
Planting date		**	**
5 October		5.29[a]	5.26[a]
15 October		4.73[b]	4.58[b]
25 October		4.30[c]	3.69[c]
5 November		3.82[d]	1.84[d]
LSD (5%)		0.09	0.18
Bulb size * planting date interaction		**	**
Small	5 October	5.43[a]	5.33[a]
	15 October	5.00[c]	4.77[b]
	25 October	4.37[f]	2.77[e]
	5 November	3.43[h]	1.67[f]
Medium	5 October	5.23[b]	5.33[a]
	15 October	4.67[d]	4.53[bc]
	25 October	4.47[ef]	4.30[cd]
	5 November	4.07[g]	1.93[f]
Large	5 October	5.20[b]	5.10[a]
	15 October	4.53[de]	4.43[c]
	25 October	4.07[g]	4.00[d]
	5 November	3.97[g]	1.93[f]
LSD (5%)		0.16	0.32
CV (%)		2.14	4.93

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

4.3.3. Quality parameters

Germination percentage

Germination percentage was highly significantly ($p<0.0001$) affected by both main and interaction effects of bulb size and plating date (Appendix Table 19). Seeds obtained from large bulb size planted on 5 October gave the highest (96.67) germination percentage, followed by medium bulbs (95.67). However, the lowest germination percentage (74.17) was recorded from small bulbs planted on 25 October (Table 26). Increased germination percentage might be due to high food reserves present in a large bulbs which, might supply nutrients to the seeds. Early planting also produced high quality seeds. This result conforms to the findings of Muktadir *et al*. (2001) who reported a higher seed germination percentage from larger mother bulbs. El-Helaly and Karam (2012) also concluded that the highest percentage of seed germination was obtained from bulbs planted in October as compared to November. Asaduzzaman *et al.* (2012) also reported that seeds obtained from the largest-sized bulb gave the highest germination percentage, while those produced from the smallest bulbs showed the lowest germination percentage.

Table 26. Mean germination percentage at Kobo and Libso from October 2018 to April 2019

Treatments		Variable
		Germination percentage
Bulb Size		**
Small		79.58[c]
Medium		85.33[b]
Large		88.29[a]
LSD (5%)		1.29
Planting date		**
5 October		93.78[a]
15 October		84.78[b]
25 October		83.89[b]
5 November		75.17[c]
LSD (5%)		1.49
Bulb size * planting date interaction		**
Small	5 October	89.00[c]
	15 October	76.33[ef]
	25 October	74.17f
	5 November	78.83[e]
Medium	5 October	95.67[a]
	15 October	85.50[d]
	25 October	91.33[bc]
	5 November	68.83[g]
Large	5 October	96.67[a]
	15 October	92.50[b]
	25 October	86.17[d]
	5 November	77.83[e]
LSD (5%)		2.58
CV (%)		2.64

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Seed vigor index I and II

Seed vigor index I was highly significantly ($p<0.001$) affected by both main and interaction effects at the two locations (Appendix Table 20). The maximum seed vigor index I value (1334.1) was recorded from medium bulbs planted at Kobo on 25 October, followed by large bulbs planted at Kobo on 5 October planting date. However, the lowest value (591.5) was obtained from medium bulb planted at Libso on 5 November (Table 27). Seed vigor index II was significantly ($p< 0.05$) affected by the interaction effects of bulb size and planting date at Kobo, whereas at Libso both main and interaction effects of bulbs and planting date highly

significantly ($p<0.001$) affectd seed vigor index II (Appendix Table 21). At Kobo, the highest seed vigor index II (18.40) was recorded from large bulbs planted on 15 October, while the lowest seed vigor index II (7.07) was gained from medium bulbs planted on 5 November. At Libso, the highest seed vigor index II (19.07) was recorded from medium bulbs planted on 5 October, but the lowest seed vigor index II (7.3) was recorded from small bulbs planted on 25 October (Table 28). The difference in seed vigor might be due to the quality differences of seed lots, which were caused by the planting date. This finding was related to that of Malik *et al*. (1999), who reported the highest seed vigor index with early planting.

Table 27. Mean seed vigor index I at Kobo and Libso from October 2018 to April 2019

Treatments			Variable
Location	Bulb size	Planting date	SVI
Kobo	Large	5 October	1271.9^{a}
		15 October	1153.6^{bc}
		25 October	1117.9^{cde}
		5 November	1086.8^{def}
	Medium	5 October	1206.5^{b}
		15 October	1066.8^{ef}
		25 October	1334.1^{a}
		5 November	904.4^{ij}
	Small	5 October	1127.4^{cde}
		15 October	943.1^{hi}
		25 October	949.2^{hi}
		5 November	955.9^{hi}
Libso	Large	5 October	1139.2^{cd}
		15 October	1038.4^{fg}
		25 October	938.3^{ij}
		5 November	762.7^{k}
	Medium	5 October	1143.7^{cd}
		15 October	1029.5^{fg}
		25 October	1024.3^{fg}
		5 November	591.5^{m}
	Small	5 October	1004.2^{gh}
		15 October	878.6^{j}
		25 October	654.8^{k}
		5 November	789.3^{k}
LSD (5%)			62.5
CV (%)			3.7

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

Table 28. Mean seed vigor index II at Kobo and Libso from October 2018 to April 2019

Treatments		Variable	
		Seed vigor index II	
		Kobo	Libso
Bulb Size		ns	*
Small		10.78	7.89[b]
Medium		10.92	10.88[a]
Large		11.77	10.36[a]
LSD (5%)		3.20	1.82
Planting date		ns	**
5 October		12.60	13.53[a]
15 October		12.33	8.53[b]
25 October		10.36	9.29 [b]
5 November		9.32	7.47 [b]
LSD (5%)		3.69	2.09
Bulb size * planting date interaction		*	**
Small	5 October	12.13[abc]	8.73[cd]
	15 October	10.20[bc]	7.60[d]
	25 October	10.20[bc]	7.30[d]
	5 November	10.57[bc]	7.87[d]
Medium	5 October	15.93[ab]	19.07[a]
	15 October	8.40[c]	8.70[cd]
	25 October	12.27[abc]	9.07 [cd]
	5 November	7.07[c]	6.70[d]
Large	5 October	9.73[bc]	12.80[b]
	15 October	18.40[a]	9.30[bcd]
	25 October	8.60[c]	11.50[bc]
	5 November	10.33[bc]	7.83[d]
LSD (5%)		6.40	3.63
CV (%)		34.07	22.21

Where, LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation

4.4. CONCLUSIONS

The present study was conducted to determine the effects of planting date and mother bulb size on onion seed yield and quality. The finding showed significant differences because of planting date and mother bulb size treatment combinations for most seed yield and quality variables. The outcomes of the study indicated that both planting date and bulb size are determining factors for onion seed production. Onion bulbs planted on 5 October increased seed yield by 29.07 % more than those planted on 5 November. On the other hand, large sized bulbs had 42.04 % more seed yield than small sized bulbs. The findings of the study, could lead us to conclude that an appropriate planting date with accurate bulb size should be practiced to increase yield and quality of onion seeds. Therefore, onion seed producers in the study areas should be encouraged to plant onion bulbs in early October with (4.1-5 cm) bulb size to produce better yield and quality of onion seed.

CHAPTER 5: EVALUATION OF PACKAGING MATERIAL TYPE AND STORAGE PERIOD ON ONION (*Allium cepa* L.) SEED QUALITY

ABSTRACT

Proper seed storage is among the vital postharvest practices of onion seeds. Therefore, this investigation was carried out from June 2019 to June 2021 to determine the effects of different packaging materials and storage periods on the onion seed quality of the Bombay red variety. The treatment consisted of five packaging materials including aluminum bags, nylon sacks, polythene bags, cloth bags & glass jars and two storage periods (I and II years). The study revealed that almost all variables were affected by the types of packaging material and storage periods. Consequently, maximum germination percentage (99.3%), germination index (4.2), germination rate index (0.042), seed vigor index I (1467.4) and II (9.9) and field emergence (90.7%) were observed from polythene bag storage material which is stored for one year period. Therefore, use of polythene bags as storage material for one year is found to safely keep the onion seed quality without affecting seed quality.

Key words: onion, packaging material, seed quality, storage period

5.1. INTRODUCTION

Onion (*Allium cepa* L.) is one of the major bulb crops of the world and an important commercial vegetable grown worldwide. Onion seeds have a high commercial value, and satisfactory vigor tests for onion seeds are desirable (Patel JN *et al*. 2012). Compared with many other crops, onion has a fairly complex life cycle involving several distinct development phases. Onion seed is one of the shortest-lived seeds of the common vegetable crops, rapidly losing viability after harvest unless special precautions are taken in its storage. The seed is said to be in storage at all stages between harvest and sowing. These stages are considered actually part of the storage process. The extent of storability is influenced by the type of packaging material (Amjad and Anjum,2002).

Seed stored in moisture-impervious sealed containers provide a suitable environment for storage, offer protection against contamination, and act as a barrier against the escape of seed treatment chemicals than in moisture pervious containers. The percentage and rate of germination of onion seeds also vary considerably among seed lots, leading to difficulties in establishing optimum plant populations. It has long been known that the factors, which have the greatest influence on the longevity of seeds in storage, are moisture, temperature, and oxygen partial pressure (Amjad and Anjum 2002). Storage temperature and moisture content are the most important factors affecting seed longevity, with seed moisture content usually being more important than temperature. Many investigators have reported that the speed of decline in seed quality is largely dependent on storage temperature, relative humidity, seed moisture content, length of storage, type of seed, and seed quality (Alhamdan *et al*., 2011).

Currah and Msika (1994) revealed that when seeds of two onion varieties were stored under ambient conditions for three years, the seeds stored in airtight jars retained their viability for three years with little change in germination, but it declined in the seeds, which are kept in paper packets. Kumari *et al*. (2001) also reported that onion varieties Hisar and N-53 retained higher germinability over certification standards in ambient conditions in cloth bags up to eight and four months of storage. Stored onion seeds with five percent moisture content in a moisture-permeable cloth bag, paper bag, cardboard box line with wax paper, plastic bag, and aluminum foil packets and observed a germination above 70 % even after one-year storage in plastic and

aluminum foil packets, whereas 70 % germination was seen only ten months in other three containers (Shelar *et al.,* 1992).

Saxena (1994) concluded that polythene bags could be used for long-term storage of various vegetable seeds like onion, tomato, okra, and cabbage at six percent moisture content. Sahee *et al*. (1994) stored seeds of tomatoes in impermeable and permeable packets. They observed a decline in germination percent below certification standard (70%) before one year in the seeds stored in a permeable pack. In contrast, the seeds of impermeable packets maintained higher viability for more than one year. Caneppele *et al*. (1995) reported that the highest loss of onion seed germination was observed in permeable containers than in impermeable containers, and the difference was due to change in seed moisture content in permeable packing materials and the degree of hygroscopic equilibrium between seeds and their surroundings. Padma and Reddy (2002) reported the fluctuation of moisture content in brinjal seeds to the extent of 2.4 per cent in moisture-pervious and moisture-semi-pervious containers, while no such fluctuation in vapour-proof containers (polythene and aluminum pouch) was observed. Electrical conductivity increases with an increase in the storage period. Brinjal seeds stored in cloth bags and paper bags retain the germination of certification standards for up to 28-30 months, while seed stored in polythene and aluminum pouches for up to 44-46 months.

Onion seeds are difficult to store for extended periods as they may lose viability and vigor quickly (Mumtaz Khan *et al*., 2004). Saxena *et al*. (1987) stored seeds of onion, cabbage, radish, cauliflower, okra, and peas in polythene and cloth bags at room temperature for 24 months. The decreases in germination, root length, shoot length, and vigor index with the increase in storage period were greatest in the seeds stored in cloth bags and were least in polythene bags. Onion, carrot, lettuce, and cabbage seeds were stored for 65 months in paper biaxially oriented polypropylene film and triple-laminated aluminum foil packets, but the wrapping material had no effect on germination percent, and the percent germination decreased with an increase in storage period in all species (Horky, 1988).

Doijode (1995) reported that the onion variety Nasik red seed was stored for seven years at 6.5 percent moisture content in a glass container and aluminum foil-laminated pouches compared to polythene bags and kraft paper. The germination and vigor were greater in seeds stored in glass containers, aluminum foil laminated pouches than in polythene and paper bags. Onion

germination percentage gradually decreased with an increase in the germination period. The seeds stored in plastic bags showed the highest germination compared to paper bags and cloth (Jyotindra *et al*. (2013). One of the major constraints in onion cultivation is the limited availability of vigorous seeds at the time of sowing due to poor storability under fluctuating ambient temperature. Even if onion seed production in Ethiopia was started long ago, there was no research carried out regarding the seed storage material type and period. Therefore, this study was conducted to evaluate the effects of packaging material types and storage period on the quality of onion seed.

5.2. MATERIALS AND METHODS

5.2.1. Description of the Study Area

The study was conducted at Sirinka Agricultural Research Center Seed Laboratory for two years, from June 2019 to June 2021. Sirinka is located 508 km from Addis Ababa on the main road to Woldia at 11°45’00’’N latitude and 39°36’36’’E longitude with an altitude of 1850 m.a.s.l. The long-term mean annual rainfall for the area is 945mm, with a maximum and minimum temperature of 26°C and 13°C, respectively (SARC, 2009).

5.2.2. Experimental Material,Treatments and Design

The onion variety Bombay red was used for the study. Farmers widely accepted this variety for its early maturity and higher bulb yield. The variety was released by Melkasa Agricultural Research Center (MARC). It’s area of adaptation is from 700-2000m above sea level, and the seed yielding ability of the variety is 1.3-2.0 tons/ha (Lemma and Shimelis, 2003). Before storage 1000 seed weight of seed was 4 g and the germination was 100 %. The same standard 50 g Bombay red seed was placed in each packaging material according to the treatment combination.The experiment consists of ten treatment combinations involving two factors, viz., two storage periods (one year, two years) as the first factor and five storage materials types (aluminium bags, nylon sacks, polythene bags, cloth bags, and glass jars) as the second factor. The experiment was designed as a factorial Complete Random Design (CRD) with three replications.

5.2.3. Experimental Procedure and Management

The test was performed according to ISTA (1985) rules. Germination percentage was determined using 50 seeds in three replications. Seeds were placed on Petri dishes covered with filter paper and allowed to imbibe water with 4 ml of distilled water, which was kept at room temperature until germination ceased in each petri dish for 12 days. The seeds were distributed evenly within each Petri dish. Each petri dish was watered with distilled water daily according to its requirements. Germination regarding radical emergence of 1 mm was assessed each day from the second day until no further radical emergence was noted on twelve successive days.

5.2.4. Data Collection

Germination percentage: The germination percent was determined from counts of normal seedlings and the total seeds placed on petri dishes.

$$\text{Germination percentage} = \frac{\text{No. seedlings germinated}}{\text{Total no. of seeds planted}} \text{ X } 100$$

Germination index was calculated as:

$$\text{Germination index} = \frac{\sum(\text{No. of plants emerged in a day})}{\text{Total No. of plants emerged by the 12th day}}$$

$$\text{Germination rate index} = \frac{\text{Germination index}}{\text{Total Germination percentage (Decimal)}}$$

Shoot length (cm): The shoot length of ten normal seedlings from the germination test was measured from the collar region to the point of attachment to the cotyledon, and the average shoot length was calculated.

Root length (cm): The final count was observed on the 12^{th} day, and 10 normal seedlings were selected randomly and measured for their root length. The root length was measured from the tip of the primary root to the base of the hypocotyl.

Seedling vigour index: The vigor index of seedlings was calculated by adopting the method suggested by Abdul-Baki and Anderson (1973) and expressed as a whole number for each treatment.

Seed vigor index I: It was determined by multiplying seed germination percentage by the sum of shoot and root length as: Germination (%) x Seedling length [Seedling Root length + Shoot length (cm)].

Seed vigor index II: It was determined by multiplying seed germination percentage by seedling dry weight as: Germination (%) x seedling dry weight (g).

Field emergence (%): A sample of 100 seeds was drawn randomly from each of the three replications in all the treatments, sown manually, and covered with fine soil. Adequate soil

moisture of seed bed was maintained by watering the bed a deemed necessary.The spacing between the seeds was 2 cm and between rows was 10 cm, and adequate soil moisture was maintained in the seed bed. Emergence count was taken on the 15th day after sowing. The seedlings appearing on the surface of the soil were considered to have emerged. The field emergence values were expressed in percentages.

5.2.5. Data Analysis

Analysis of variance was done using SAS 9.4 statistical software (SAS-Institute, 2008). The data of each year were tested for normality. The data were considered to follow normal distribution when tested nonsignificant at 5% level of significance. Since the test showed nonsignificant at 5% level of significance the variance was also considered homogeneous. After confirming the assumptions of normality ANOVA of each year was undertaken. Test of homogeneity of variance of the two errors mean squares was performed prior to undertaking combined analysis of the two years. Means were compared by using the Least Significant Difference (LSD) test at a 5% probability level**.**

5.3. RESULTS AND DISCUSSION

5.3.1. Germination Percentage, Index and Rate of Onion Seed

Germination percentage was highly significantly ($p<0.01$) influenced by the main effects of storage period and packaging material and their interaction effects (Appendix Table 22).The highest germination percentage (99.3%) was recorded from a one-year storage period with polythene bag packaging material. However, the lowest germination percentage (58.67%) was recorded from a two-year storage period with packaging materials of nylon sacks (Table 29). The lowest seed germination was recorded from nylon sacks storage might be due to the moisture-pervious nature of nylon sacks than the other packaging materials. In addition, onion seeds are hygroscopic, absorb moisture from the surrounding environment, and rapidly lose viability. An increase in storage duration causes higher deterioration due to higher seed leachate. It is a probable reason for its higher rate of high seed moisture content, which resulted in reduced germination. The higher moisture content might have increased the respiratory activities of seeds and shortened the seeds' life. Baldaniya Natubhai *et al*. (2018) reported that the combined effect of storage containers and durations was found to have a significant influence on the germination of onion seeds packed in polythene bags for 3 months. Patel *et al*. (2012) also showed that storage time and conditions greatly affected onion seed germination. He indicated that the highest germination of 87% was observed from the onion stored in polythene bags for three and six months. Patel *et al*. (2017) found that onion seeds packed in polythene bags recorded higher germination (79.77 %) after 24 months of storage which is more than the minimum required for seed certification standard, while seeds stored in cloth bags had 79.10 %, only after four months of storage.

Analysis of variance indicated that the germination index was highly significantly ($p<0.01$) affected by main effects of storage period and packaging material and significantly influenced by their interaction effects (Appendix Table 22). The maximum germination index (4.17) was recorded from seeds stored in polythene bag for one-year; whereas the minimum germination index (2.43) was obtained from a two-year storage period with packaging materials of nylon sacks (Table 29). The germination rate index was significantly ($p<0.05$) influenced by the main effects of packaging materials, but main effects of storage period and interactions were non significant. Numerically the highest germination rate index (0.042) was recorded from a one-year

storage period with the packaging material of polythene bags. However, the other packaging materials had the same value (0.041) of the germination rate index for both years one and two storage periods (Table 29).

Table 29. Mean germination percentage, germination index and germination rate index at Sirinka from June 2019 to June 2021

Treatments		Variables		
		Germination percentage	Germination index	Germination rate index
Storage period		**	**	ns
Year I		92.47[a]	3.76[a]	0.041
Year II		70.33[b]	2.85[b]	0.041
LSD(5%)		1.59	0.15	0.0003
Packaging Materials		**	**	*
Polythene bags		88.00[a]	3.63[a]	0.0418[a]
Almunium bags		87.33[a]	3.58[a]	0.0415[ab]
Cloth bags		77.83[b]	3.10 [b]	0.0413[ab]
Glass jars		77.50[b]	3.15 [b]	0.0411 [b]
Nylon sacks		76.33[b]	3.07 [b]	0.0410 [b]
LSD(5%)		2.51	0.24	0.001
Storage P. * Packaging M . interaction		**	*	ns
Year I	Polythene bags	99.33[a]	4.17[a]	0.0420
	Almunium bags	92.67[b]	3.80[b]	0.0417
	Cloth bags	88.00[c]	3.60b[c]	0.0410
	Glass jars	88.33[c]	3.50[bc]	0.0410
	Nylon sacks	94.00[b]	3.70[bc]	0.0413
Year II	Polythene bags	76.67[e]	3.07[de]	0.0417
	Almunium bags	82.00[d]	3.37[cd]	0.0413
	Cloth bags	67.67[f]	2.66[f]	0.0413
	Glass jars	66.67[f]	2.77[ef]	0.0410
	Nylon sacks	58..67[g]	2.43[f]	0.0413
LSD (5%)		3.55	0.34	0.001
CV (%)		2.56	6.13	1.08

Where; LSD (5%) = least significant difference at 5%, CV (%) = Coefficient of variation.

5.3.2. Shoot and Root Length

Shoot length was highly significantly affected ($p<0.0001$) by the main effects of storage period and packaging materials (Appendix Table 23). The highest shoot length (10.65 cm) was recorded from one year storage period with packaging materials of polythene bags (Table 30). In contrast, numerically the least shoot length (8.63 cm) was recorded from the two-year storage period with

packaging materials of cloth bags (Table 30). This might be due to cloth bags being easier to absorb moisture from its surrounding than polythene bags, and naturally, onion seeds lose its stored food as the storage period increased. This study was in agreement with Baldaniya Natubhai *et al*. (2018) who depicted that the highest shoot length of onion was recorded from the seeds packed in polythene bags and preserved for three months of storage period, while the shortest shoot length (1.97cm) was recorded from 9 months of storage period with packaging materials of cloth bags. Patel *et al.* (2017) reported that onion seeds packed in polythene bags produced higher shoot length than onion seeds packed in cloth bags. Patel *et al*. (2012) also reported that the highest shoot length was recorded from three months of storage period and packaging material of polythene bags, whereas the shortest shoot length was obtained from six months of storage period and packaging material of cloth bags. Regarding root length non-significant effect was observed from both main and interaction effects of packaging materials and storage periods.

Table 30. Mean shoot length at Sirinka from June 2019 to June 2021

Treatments		Variables
		Shoot length (cm)
Storage period		**
Year I		10.40[a]
Year II		9.57[b]
LSD(5%)		0.25
Packaging Materials		**
Polythene bags		10.65[a]
Almunium bags		10.25[b]
Cloth bags		9.35[d]
Glass jars		9.98[bc]
Nylon sacks		9.68[cd]
LSD(5%)		0.39
Storage P * Packaging M.		ns
Year I	Polythene bags	10.87
	Almunium bags	10.57
	Cloth bags	10.07
	Glass jars	10.27
	Nylon sacks	10.23
Year II	Polythene bags	10.43
	Almunium bags	9.93
	Ccloth bags	8.63
	Glass jars	9.70
	Nylon sacks	9.13
LSD (5%)		0.55
CV (%)		3.23

5.3.3. Seed Vigor Index I, Seed Vigor Index II and Field Emergence Percentage

Seed vigor index I was highly significantly ($p<0.001$) influenced by the main effects of storage period and packing material and their interaction effects (Appendix Table 24). The maximum seed vigor index I (1467.4) was recorded from a one-year storage period with packaging materials of polythene bags; however, the minimum seed vigor index (771.53) was obtained from two years of storage period with packaging materials of nylon sacks (Table 31). Baldaniya *et al*. (2018) reported that the highest seed vigor index I was recorded from three months storage period with packaging materials of polythene bags; however, the least seed vigor index was recorded from nine months of storage period with packaging materials of cloth bag. Patel *et al*. (2017) also indicated that onion seeds packed in polythene bags gave higher seed vigor index I than onion seeds packed in cloth bag.

Seed vigor index II was significantly ($p<0.05$) affected by the interaction effects of the storage period and packaging materials. This parameter was also highly significantly ($p<0.01$) influenced by the main effects of storage period and packing material (Appendix Table 24). The highest seed vigor index II (9.93) was recorded from a one-year storage period with packaging materials of polythene bags; however, the lowest seed vigor index II (5.87) was obtained from a two-year storage period with packaging materials of nylon sacks (Table 31). According to Baldaniya *et al*., (2018), the highest seed vigor index II was recorded from three months storage period with packaging materials of polythene bag. However, the lowest seed vigor index was recorded from nine months of storage period with packaging materials of cloth bags. Patel *et al.* (2017) also reported that onion seeds packed in polythene bags recorded higher seed vigor index II than onion seeds packed in cloth bags.

The field emergency percentage was highly significantly ($p<0.001$) influenced by interaction effects of storage period and packaging materials (Appendix Table 24). The maximum field emergency percentage (90.67) was recorded from one year storage period with packaging materials of polythene bags; whereas the minimum field emergency percentage (76.33) was recorded from two years storage period with packaging materials of nylon sacks (Table 31). This indicates that for better field emergency of onion crop packaging the seeds with polythene bag is better even after one year of storage hence is advisable for the onion producer farmers and others.

Table 31. Mean seed vigor index I, seed vigor index II and field emergency percentage at Sirinka from June 2019 to June 2021

Treatments		Variables		
		Seed vigour index I	Seed vigour index II	Field emergency %
Storage period		**	**	**
Year I		1323.93[a]	9.11[a]	85.13[a]
Year II		963.12[b]	7.17[b]	79.53[b]
LSD(5%)		50.73	0.41	1.79
Packaging Materials		**	**	ns
Polythene bags		1304.93[a]	8.80 [a]	80.33
Almunium bags		1226.13[a]	8.73 [a]	82.50
Cloth bags		1047.17 [b]	7.78 [b]	82.17
Glass jars		1081.23 [b]	7.97 [b]	83.17
Nylon sacks		1058.17[b]	7.40 [b]	83.50
LSD(5%)		80.207	0.65	2.84
Storage P * Packaging M		**	*	**
Year I	Polythene bags	1467.40[a]	9.93[a]	90.67[a]
	Almunium bags	1315.67[b]	9.27[ab]	85.00[b]
	Cloth bags	1234.27[bc]	8.80[bc]	83.33[bc]
	Glass jars	1257.53[b]	8.60[bc]	84.33[b]
	Nylon sacks	1344.80[b]	8.93[bc]	82.33[bc]
Year II	Polythene bags	1142.47[c]	7.67[de]	82.67[bc]
	Almunium bags	1136.60[c]	8.20[cd]	82.00[bc]
	Cloth bags	860.07d[e]	6.77[ef]	77.33[d]
	Glass jars	904.93[d]	7.33[de]	79.33[cd]
	Nylon sacks	771.53[e]	5.87[f]	76.33[d]
LSD (5%)		113.43	0.92	4.02
CV (%)		5.82	6.67	2.86

Where, LSD (5%)= least significant difference at 5%, CV (%) = Coefficient of variation

5.4. CONCLUSIONS

Proper storage of onion seed is critical after harvesting the crop. The successful cultivation of any crop depends, to a large extent, on the viability of the seed during planting and its ability to germinate. The results of this study revealed that packaging materials and length of storage periods play a significant role in the germinability of onion seeds. The seed quality variables showed decreasing trend throughout the storage periods, irrespective of packaging materials. Among the packaging materials, polythene bags exhibited higher germination percentage and field emergency percentage in one year storage period. Therefore, it can be concluded that onion seeds can be stored for one year in polythene bags without significant loses in germination.

CHAPTER 6. GENERAL DISCUSSION

6.1. Overall Messages

Onion is an important crop worldwide due to its versatile utility for culinary uses, nutritional benefits, and economic value. It is widely cultivated and consumed in various cuisines, contributing to flavoring countless dishes. Additionally, onions contain essential nutrients, antioxidants, and anti-inflammatory properties that promote good health. However, there are certain limitations associated with the production of bulbs and onion seed. One major aspect is its sensitivity to environmental conditions, requiring specific temperature and moisture levels for optimal growth. As a result, cultivation can be limited to regions with suitable climates, which may restrict its production in certain areas. Additionally, due to the lack of appropriate recommended management practices such as fertilizers, planting dates, bulb sizes, type of packaging materials, and storage periods, the quantity and quality of onion bulb and seed production is low. Furthermore, onion bulbs and seeds have a relatively short shelf life and can easily deteriorate if not handled and stored properly. Despite these limitations, the global demand for onion continues to be huge, indicating its importance in both culinary and economic aspects worldwide.

To improve the yield and quality of both bulb and seed of onion, determining optimum management practices such as fertilizer rate and onion varieties, mother bulb size, planting date, packing material types and storage periods are very important. The objective of this study was to optimize different management practices that can help maximize the yield and quality of both bulb and seed of onion. The results of this dissertation demonstrated that the blended fertilizer and onion variety affected the yield and quality of the onion bulb. The additional nutrients in the blended fertilizer like S and B might have contributed to the observed yield and quality improvements. Research findings have also showen the importance of S and B in onion production in addition to N and P. NPSB provides combination of both macro and micro nutrients that improve availability of soil nutrients which in turn can highly influence crop growth, yield and quality of onion. Several studies indicated that micronutrients like B have a role in plant growth due to their effects on physiological processes and cellular functions within plants (Hansch and Mendel, 2009). Boron is an essential micronutrient that is required for normal cell division, nitrogen metabolism, protein formation, and phosphorus uptake. Boron at different doses

had positively influenced plant growth, germination percentage and quality of onion seed (Gateri *et al.* 2018). Onion is also sulfur loving plant that is required for proper growth and bulb development. Maximum mean bulb weight (142.7g) was recorded from Bombay red variety at the combination of 183 kg ha^{-1} of NPSB blended fertilizer rate. The change might be due to location, variety, and NPSB blended fertilizer rate differences. Especially the difference of the soil nutrient status of the experimental sites contribuited the bulb weight difference.The bulb size also contributed for the bulb weight. Mean bulb weight improvement in response to NPSB blended fertilizer could be attributed the increase in number of leaves produced, leaf length and extended physiological maturity in response to the fertilization all might have increased assimilate production and allocation to the bulbs.The current study is in agreement with Abdissa *et al*. (2011), who reported that nitrogen fertilizer significantly, increased the average bulb weight of the Bombay red onion variety. Muluneh *et al*. (2018) also reported that bulb weight was highly significantly influenced by the application of different fertilizer rates of NPS. The study also indicated that the diameter of the bulb increased with increasing rates of NPSB blended fertilizers regardless of the location. This might be due to the role of NPSB blended fertilizers in different physiological and metabolic processes through increase in dry matter production . Shaheen *et al*. (2007) reported that the diameter of the bulb increased significantly with increases in the application of phosphorus fertilizers. Tibebu *et al*. (2014) also reported that the highest bulb diameter was obtained from phosphorus. According to Khatemenla *et al*. (2018), the maximum bulb diameter was obtained by applying Zn and B.

Higher yield and improved quality of onion were observed from optimum management practice compared with other management practices in the treatments. Such optimum management practice has revealed promise for raising onion productivity and quality.The highest marketable bulb yield of 45.5 t ha^{-1} was recorded from the Bombay red variety with the application of a 61 kg ha^{-1} NPSB blended fertilizer rate. From the present result, it can be deduced that both location, variety, and fertilizer rate contributed to an increase in the vegetative growth of the plant, which has improved assimilate availability for storage and led to an increased average bulb weight that gave an advantage to increase the marketable bulb yield. According to Mbulelo *et al*. (2018), an increase in N application was aligned with a tendency towards an increase in marketable yield. Additionally, the highest total bulb yield, 50.23 t ha^{-1}, was recorded from Bombay red variety with the combination of 61 kg ha^{-1} of NPSB blended fertilizer. The study findings is in agreement

with the findings of Mbulelo *et al*. (2018), who reported that the highest total yield was recorded from the highest application rate, whereas the lowest yield was recorded at control. Khan *et al*. (2002) also showed that with the highest level of application of N, maximum onion yield was obtained more than the minimum N fertilization regimes. Muluneh *et al*. (2019) also reported that the application of N increased bulb yield more than the control plot.

In this study, quality indicators such as TSS and vitamin C contents were influenced by the application of NPSB blended fertilizer. It is possible that the onion variety and the micronutrients in the blended fertilizer positively interacted to enhance metabolic processes that are involved in the production of total soluble solids, including carbohydrates, amino acids, organic acids, and other inorganic elements. The present result was similar with the reports of Muluneh *et al*. (2019) who reported maximum TSS value from the application of N, whereas the minimum TSS value was obtained in control treatments. Khatemenla *et al*. (2018) reported that Zn + B treatment recorded the maximum TSS and the lowest from the control. The current investigation is in agreement with Lawande (2001), who reported that the vitamin C content in the wild onion varieties was in the range of 5- 10 mg.100g^{-1} fresh weight. Mbulelo *et al*. (2018) reported vitamin C concentrations of onion bulb were not affected by fertilizer treatment and varieties. Jurgiel-Malecka *et al*. (2015) reported that red onions were characterized by higher concentrations of ascorbic acid (vitamin C) than yellow and white varieties. Determining pyruvate acid as an indicator of pungency is perhaps the most established method for assessing pungency in vegetables like onions. According to this study, the pyruvic acid content was reduced when the application of the NPSB blended fertilizer increased.The study also indicated that different varieties of onions have different pungency thus may be suitable for different purposes. The pyruvic acid content of onions is highly correlated with their pungency. Therefore, studing the different onion variety pungency levels are very important. In their study, Kandoliya *et al*. (2015) reported that the content of pyruvic acid varied from 1.09 to 1.33 mg.g^{-1}. However, the current study indicated that the range of pyruvic acid was from 0.05 -0.31 mg.g^{-1}. The difference might be due to variety and other environmental factors.

The results of the current study has also indicated that onion seed yield and quality are affected by the blended fertilizer rate and onion variety. The maximum number of leaves per plant from Bombay red was recorded with the application of 152.5 kg ha^{-1} NPSB blended fertilizer of the

current study has also planted at Kobo. As a consequence of the genetic variations between the two onion varieties that result in the maximum number of leaves per plant and the availability of sufficient plant nutrients, it is possible to infer from the current study's results that NPSB blended fertilizer offered superior growing conditions. Chowdhury *et al*. (2004) reported that the number of leaves per plant increased with the application of micronutrients. Mozumder *et al*. (2007) also observed similar results by applying NKS fertilizers, and Ghaffoor *et al*. (2003) from applying NPK fertilizers. The highest value of days to 50% flowering (106.93) was recorded from variety Nafis. The research indicated that onions can take longer periods to flower when fertilizer rate increased. Limeneh *et al*. (2019) revealed that P fertilizer alone promoted early flowering, while the addition of N delayed onion flowering. Furthermore. increases in N resulted in a progressive increase in days of flowering. Tamrat (2006) indicated that longer days to flowering were taken due to increased N fertilizer.The number of flower stalks are the most important factors for onion seed production. Therefore, knowing the characteristics of onion varieties are essential.The study indicated high difference in flower stalk per plant due to varietal differences compared to the application of the NPSB blended fertilizer. This finding agrees with the report by Ahmed and Abdalla (2006) and Getachew (2014), who reported that nitrogen and phosphorus separately or in combination did not affect the number of branches or flower stalks produced per plant. The maximum umbel diameter (7.3cm) was recorded from the Nafis onion variety with the application of 91.5 kg ha^{-1} NPSB blended fertilizer. The study found a considerable increase in umbel diameter, which may have been caused by NPSB fertilizer. This fertilizer may have stimulated and encouraged flower setting, resulting in a wider umbel size with more flowers, followed by seed development and related reproductive activities. According to Ali *et al*. (2007), fertilization with phosphorus and nitrogen significantly affected the umbel diameter. The highest number of seeds per umbel was recorded for the Nafis variety with the combination of 122 kg ha^{-1} NPSB blended fertilizer,whereas the lowest was recorded for the Bombay red variety without the application of the NPSB blended fertilizer. The difference might be due to umbel diameter,variety and the role of NPSB blended fertilizer in the reduction of flower abortion. Ali *et al*. (2007) reported that the highest number of seeds per umbel was recorded from the N application and the lowest from the control. The highest seed yield 2.3 t ha^{-1} was recorded from the Bombay red variety with the application of 183 kg ha^{-1} NPSB blended fertilizer. However, the lowest seed yield, t ha^{-1} (0.5), was obtained from a variety of Nafis without the application of NPSB fertilizer

ha^{-1}. The genetic variations of the onion varieties and the application of varying rates of NPSB blended fertilizer might be the cause of the production differences observed. According to Amare *et al*. (2020), the highest seed yield per hectare was obtained from the application of P_2O_5 and N; however, the lowest seed yield per hectare was recorded from plants that did not receive fertilizer. Maximum germination (91.33%) was recorded from Bombay red variety with the application of 183 kg ha^{-1} NPSB blended fertilizer. On the contrary, the lowest germination values (68.83%) was recorded from Nafis variety without the application of NPSB blended fertilizer. Consistent with the present study, higher levels of fertilization may have improved the quality of the seed by increasing the percentage of seed originating from primary umbels. This is because seeds from higher application of fertilizer umbels have larger embryos than seeds from no application of fertilizer umbels and because minerals actively participate in the development of the embryo as well as the production and activation of germination hormones in seeds. Debashis *et al*. (2017) reported that the highest percentage of germination of harvested seed was observed in the nitrogen-treated treatment. The highest seedling vigor index I (926.7) was recorded from the Bombay red onion variety with the application of 61 kg ha^{-1} NPSB blended fertilizer. This could be because of larger seeds from fertilizer applications have more food stored in their cotyledon to support seedling growth and make them more vigorous than smaller seeds from no fertilizer application, whose food supply could run out quickly.The present finding agrees with Amare *et al*. (2020), who reported that it was obtained from the application of P_2O_5 and nitrogen than without application.

The current study also showed that planting date and bulb size determine the yield, the yield components and the quality of onion seed. The highest number of green leaves per plant was recorded from large bulbs planted in early October. Larger bulbs may have produced more stalks because they hold more sprouting initials and store more food material. These stalks then generate more leaves than smaller ones. In addition to the large bulb sizes, the low temperature during early October led to a higher number of stalks and green leaves per plant. Asaduzzaman *et al*. (2012) reported the maximum number of green leaves per plant of large bulbs. Tesfaye *et al*. (2018) also indicated that the planting date significantly affected the number of leaves per plant. The highest number of flower stalks per plant was recorded on large bulbs. The large bulb sizes increased the number of flower stalks by (59.4%) compared to the small bulb sizes. The superiority of large bulbs in having more stored food and more sprouts, which results in more

flower stalks per plant, might be the cause of this differences. Asaduzzaman *et al*. (2012) revealed that the number of flower stalks per plant was significantly high in large bulbs, while the minimum was in small bulbs. Sedigheh *et al*. (2015) showed that the effect of planting date differed significantly in flower stalks per plant. From Table 24 the highest number of seeds per umbel (1354.33) was recorded from a small bulb size in early October. However, the lowest number of seeds (852.17) was obtained from a small bulb planted in early November. These could be the reasons for the variation in the number of seeds per umbel, including flower abortion brought on by high temperatures, insufficient pollinators for the flowers in the umbel, strong competition-induced nutrition scarcity, and weak floret death in the umbel. Poor plant growth and delayed bolting were the results of the delayed planting. In addition, the difference might be due to the umbel diameter difference. The highest seed yield was obtained from a large bulb size planted in early October (2.58 tons ha^{-1}), while, the least (1.2 tons ha^{-1}) was recorded from small bulb size planted in early November. The difference in seed yield could have been due to the relatively large amount of food reserves stored in large bulbs, which enhanced the production of healthy and vigorously growing plants with a large number of seed heads and, consequently, increased seed yield tons ha^{-1}. Debashis *et al*. (2016) reported that onion seed yield per hectare could be affected by the size and date of the mother bulb, and the highest seed yield was obtained from large onion bulbs with early planting, while the lowest seed yield was obtained from small mother bulbs with late planting. From the findings of this study the large bulb size planted in early October gave the highest (96.67) germination percentage. High food reserves found in large bulbs may be the cause of an increased germination rate. These stores could provide the seeds with nutrition. Seeds of superior quality were also a result of early planting. El-Helaly and Karam (2012) also concluded that the planting date significantly affected seed germination and that the highest percentage of seed germination was obtained by early planting. Asaduzzaman *et al*. (2012) also reported that seeds obtained from the largest bulbs had the highest germination percentage,while those produced from the smallest bulbs showed the lowest germination percentage.

According to the present study, different packaging materials and storages influenced onion seed quality. The highest percentage of germination, germination index, germination rate index, shoot length, seed vigor index I and field emergence percentage were recorded from polythene bag packaging material during a storage period of one year. The better performance of polythene bag

than the nylon sack might be due to impervious nature which acted as moisture barrier in regulating lower moisture content in the seeds. Lower respiration rate and metabolic activity are governed by lower moisture content that played a significant role in regulating lower moisture content in the seeds during the storage period and exhibited higher germination percentage, germination index, germination rate index, shoot length and field emergence percentage. However, the lowest percentage of germination was recorded from a two-year storage period with nylon sack packaging materials. This might be due to nylon sack ability to retain moisture better than other packing materials and may be the reason for the lowest seed germination rates seen during storage. Moreover, onion seeds quickly lose their viability due to hygroscopicity and the absorption of moisture from their surroundings. Because of the increased seed leachate, longer storage times result in higher degradation. The likely cause of the elevated seed moisture content rate, which led to decreased germination is one possible explanation for the elevated moisture content in the seeds that caused them to breathe more heavily and to die earlier. This study is in aggrement with, Baldaniya *et al*. (2018) reported that the combined effect of storage containers and durations was found to have a significant influence on onion seed germination. Patel *et al*. (2017) found that onion seeds packed in polythene bags had higher germination. This is more than the minimum seed certification standard for twenty-four months, while in cloth bags only for four months.

This study indicated that the application of NPSB blended fertilizer to onion bulb and seed production had a pronounced positive effect on its better yield and quality. Onion bulb size and planting dates are also important ways to improve onion seed yield and quality. Additionally, the types of packaging materials and storage periods are extremely essential for increasing the shelf life and quality of onion seeds. According to the current investigation onion bulbs, seed yield and quality differed with locations, NPSB blended fertilizer rates, and varieties. The yield and quality of onion seeds vary by location, bulb sizes, and planting dates. Onion seed quality is also affected by the types of packaging materials and storage periods. Therefore, from the current finding, we can learn that both bulb and seed yield and onion quality can be improved by applying different management practices. This indicates that when the yield and quality of onion bulbs and seeds improved, it indirectly improve the livelihood of onion producers.

6.2. Strengths and Limitations of the Study

6.2.1. Strengths of the Study

- It is comprehensive approach, combining multiple management practices to enhance both the yield and quality of onion bulb and seed production.
- The study was done based on a solid scientific methodology that includes systematic experiments, data collection and analysis.

6.2.2. Limitions of the Study

- Limited number of onion farms or locations
- Lack of diversity in varieties (the study only evaluated a limited number of onion varieties)
- Focused only bulb and seed yield and quality, important factors such as disease, storage potential, and marketability of the onions are not addressed

6.3. Conclusions

This study stands out as contributions to the body of scientific knowledge. This knowledge may advance the quantity and quality of bulb and seed production of onion. The main research objectives of this research were to derive new information to inform the management of onion bulb and seed production and types of packaging materials, and storage periods for better shelf life of onion seed. According to this finding for onion bulb production, Bombay red variety was well advanced with the application of NPSB blended fertilizer at Kobo, however Nafis variety better at woramit. In addition, the maximum onion seed yield was recorded on the variety Bombay red with the application of NPSB blended fertilizer. Regarding onion bulb size and planting date, the highest seed yield was obtained from a large bulb size planted in early October. Concerning the types of packaging materials and storage period trial, the seed quality parameters showed decreasing trend throughout the storage periods irrespective of packaging materials. Among the packaging materials, polythene bags exhibited higher germination percentage and field emergence percentage.

6.4. Recommendation and Future Line of Work

6.4.1. Recommendation

- Onion variety Bombay red with the combination of 61 kg ha^{-1} NPSB blended fertilizer for Kobo areas and variety Nafis with the combination of 91.5 kg ha^{-1} NPSB blended fertilizer for Woramit areas showed better performance, however, to come up with conlusive recommendations it is advisable to run the study by increasing more locations and years.
- Bombay red onion variety with the combination of 183 kg ha^{-1} NPSB blended fertilizer depicted better yield and quality of onion seed at Kobo and Libso areas. However to increase the reliability of the study additional locations and years is necessary.
- For the production of better yield and quality of onion seeds, planting in early October with the combination of large sized onion bulbs (4.1-5cm) can be recommended in the study areas and other similar agro-ecology areas of the country.
- Onion seeds can be stored in a polythene bag for one year with the highest germination percentage (99.3%).

6.4.2. Future Line of Work

- Nutriement management study is necessary in different soil types of the region to improve the yield and quality of bulb and seed of onion.

7. REFERENCES

Abas A, Sahar IE, Alia M, Osman E, Mohamed A, Nourai H. 2015. Effect of nitrogen fertilization and bulb spacing on saggai red onion seed production in Berber area, River Nile State, Sudan Sudanese. *The Journal of Agricultural Science 2:35-43.*

Abdissa Y., Tekalign T. and Pant L. M. 2011. Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on vertisol I. Growth attributes, biomass production and bulb yield. *African Journal of Agricultural Research* Vol. 6(14), pp. 3252-3258.

Abdul-Baki A, Anderson JD. 1973. Vigor determination in Soybean seed by multiple criteria. Crop Sci. 13: 630-633.

Abdul G., Muhammad S. J, Ghulam K and Kashif W. 2003. Effect of different NPK levels on the growth and yield of three onion (*Allium cepa* L.) varieties. *Asian Journal of Plant Sciences 2(3):342-346.*

Abebe, W., Tesfaye, B., & Tura, A. 2017. Factors influencing smallholder farmers' adoption of improved onion varieties in Fogera District, Ethiopia. *Cogent Food & Agriculture, 3(1), 1338768.*

Abu-Sarra A F. 1999. Effect of cultivar, bulb size and nitrogen nutrition on onion seed yield. Agricultural Research Corporation, Rahad Research Station Annual Reports.

Agricultural Transformation Agency (ATA) 2016. Soil Fertility status and Fertilizer Recommendation Atlas of Amhara National Regional State, Ethiopia, Addis Ababa, Ethiopia.

Agricultural Transformation Agency (ATA) 2020. Annual Report 2019. Retrieved from https://www.ata.gov.et/wp-content/uploads/2020/10/ATA-2019-AnnualReport.pdf

Ahmed IH, Abdella AA. 2006. Nitrogen and phosphorus fertilization in relation to seed production in onion *Allium cepa* L. ISHS. African Symposium on Horticultural Crops. *Acta Horticulture* 143:8.

Alhamdan A M, Alsadon A A, Khalil S O, Allah M A, Nagar M E, Nagar M E and Ibrahim A A. 2011. Influence of storage conditions on seed quality and longevity of four vegetable crops. *American-Eurasian Journal of Agriculture and Environmental Sciences* 11(3): 353-359.

Ali MK, Alam MN, Islam MS, Islam MK, Baree MA. 2007. Effect of nitrogen and potassium level on yield and quality seed production of onion. Journal of Appl Sci Res. 3(12): 1889-99.

Ali MK, Alam MN, Islam MS, Islam MK, Baree MA. 2008. Effects of cow dung at different levels of phosphorus on growth, yield and quality seed production of onion. *Research Journal of Agriculture and Biological Sciences 4(1):86-93.*

Ali, M. A., M. M. Hossain, M. Zakaria, A. Naznin and M. M.Islam. 2015. Effect of bulb size on quality seed production of onion in Bangladesh. *Int. J. Agron. Agril. Res*., 6(4) :174-180.

Ali, M.S., 2013. Effects of micronutrients on growth, yield and quality of three varieties of summer onion (Doctoral dissertation).

Amanullah, M. J. Hassan, K. Nawab, and A. Ali. 2007. Response of specific leaf area (SLA), leaf area index (LAI) and leaf area ratio (LAR) of maize (*Zea mays* L.) to plant density, rate and timing of nitrogen application. *World Applied Science Journal* 2: 235–243.

Amanullah . 2015. Specific Leaf Area and Specific Leaf Weight in Small Grain Crops Wheat, Rye, Barley, and Oats Differ at Various Growth Stages and NPK Source, *Journal of Plant Nutrition,* 38:11, 1694-1708, DOI: 10.1080/01904167.2015.101705.

Amare G., Mohammed W. and Tana T. 2020. Effect of Plant Spacing and NP Fertilizer Levels on Growth, Seed Yield and Quality of Onion (*Allium cepa* L.) at Shewa Robit, Northern Ethiopia. *The Open Biotechnology Journal, Volume 14.*

Amjad M and Anjum M A. 2002. Evaluation of physiological quality of onion seed stored for different period. *International Journal of Agriculture and Biology* 4(3): 365-369.

Amin, M. M. U. and M. A. Rahim, 1995. Effect of plant density, planting time and nitrogen on the growth and yield of onion. Progress. Agric 6(2): 69-75.

Amsalu A, Afari-Sefa V, Bezabih E, Fekadu FD, Tesfaye B, Milkessa T.2014. Analysis of vegetable seed systems and implications for vegetable development in the humid tropics of Ethiopia. Int J Agric For. 4(4):325–37.

Anwar MN, Sarker JU, Rahman M, Islam MA and Begum M,, 2001. Response of onion to nitrogen, phosphorus, potassium, sulphur and zinc. *Bangladesh J Environ Sci*. 7: 68-72

Anisuzzaman, M., M. Ashrafuzzaman, M.R.Ismail, M.K. Uddin and M.A. Rahim. 2009. Planting time and mulching effect on onion development and seed production. Afr. J. Biotechnol., 8:412-416.

Anonymous. 2012. Is specific leaf weight an indicator of drought tolerance in Faba Beans? Available at: http://www.agric.wa.gov.au/PC 91649.html?s=0

Ansari, N.A. 2007. Effect of density, cultivars and sowing date on onion sets production. *Asian Journal of Plant Science,* 6: 1147-1150.

AOAC. 1990. Official Methods of Analysis of the Association of Official Analytical Chemists, 15 ed., AOAC, Virginia, USA.

Arung ET, Furuta S, Ishikawa H, Kusuma IW, Shimizu K, Kondo R.2011. Anti- melanogenesis properties of quercetin- and its derivative-rich extract from *Allium cepa*. Food Chem 124(3):1024–1028.

Asad A and Rafique R. 2002. Identification of micronutrient deficiency of wheat in the Peshawar valley. Commun. Soil Sci. Plant Anal. 33: 349-364.

Asaduzzaman, M., M. Mainul, M.H. Mahmudul, M. Moniruzzaman and H.K.H. Mohammad . 2012. Effect of bulb size and plant spacing on seed Production of onion (*Allium cepa* L.). *Bangladesh J. Agril. Res.* 37(3): 405-414.

Ashenafi Woldeselassie, Helen Teshome, Tibebu Simon. 2014. Influence of bulb treatment and spacing patterns on yield and quality of onion (*Allium cepa* Var. Cepa) seed at humbo larena, southern Ethiopia. J Biol Agric Healthcare . 4(13).

Assefa AG, SH Mesgina and YW Abriha, 2015. Effect of inorganic and organic fertilizers on the growth and yield of garlic crop (*Allium sativum* L.) in Northern Ethiopia. *J Agric Sci*, 7:80.

Awulachew Seleshi Bekele. 2010. Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. International Water Management Institute.

Baldaniya Natubhai, Kalyanrao, AP Karjule and DA Patel. 2018. Effect of Containers and Duration on Seed Quality of Onion under Ambient Storage Conditions. *Seed Res. J.* 45(2): 1-4.

Ballabh K, Rana DK. 2012. Response of micronutrients on qualitative and quantitative parameters of onion (Allium cepa L.). Progressive Horticulture 44, 40-46.

Bloem, E.S., Haneklaus and Schnug, E. 2004. Influence of nitrogen and sulfur fertilization on the alliin content of onions and garlic. *Journal of Plant Nutrition*, 27: 1827-1839.

Bassett, M.J., 1986. Breeding Vegetable Crops. AVI Publishing Co. Inc. West Port. Connecticut. 584p.

Bekele, B., Negussie, E., Tadesse, T., and Yilma, H. M. 2016. Evaluation of onion (*Allium cepa* L.) varieties for their yield and quality at different altitudes in rift valley of Ethiopia. *Journal of Agricultural and Biological Science*, 11(4), 162-168.

Bhattacharjee SA, Sultana MH, Sazzad MA, Islam M, Ahtashom MM. 2013. Analysis of proximate composition and energy values of two varieties of onion (*Allium cepa* L.) bulbs of different origin: A comparative study. *International Journal of Nutrition and Food Science* 2: 246–253.

Bhonde SR, Ram L, Pandey UB, Tiwari HN. 1995. Effect of micronutrients on growth, yield and quality of kharif onion. National Horticulture Research and DevelopmentFoundation14-15(1)16-24.

Birhanu Agumas, Anteneh Abewa, Dereje Abebe. 2014.Response of Irrigated Onion (*Allium cepa* L.) to Nitrogen and Phosphorus Fertilizers at Ribb and Koga Irrigation Schemes in Amhara Region, North western Ethiopia. *International Research Journal of Agricultural Science and Soil Science (ISSN: 2251-0044) Vol. 4(4).*

Birhanu M .2016. Effects of Nitrogen and Phosphorus Rates on Growth, Yield, and Quality of Onion (*Allium cepa* L.) at Menschen Für Menschen Demonstration Site, Harar, Ethiopia. Agricultural Research and Technology 1(3):555563.

Binalfew T.. 2018. Vegetable Seed Systems of Ethiopia. *International Journal of Research in Agricultural Sciences*. Volume 5, Issue 6, ISSN (Online): 2348 – 3997.

Black, C.A., Evans, D.D., and Dinauer, R.C.1965. Methods of soil analysis. (Madison, WI: *American Society of Agronomy*, Vol. 9, pp. 653-708).

BoFED (Bureau of Finance and Economic Development). 2010. Development indicators of Amhara Region. Bahir Dar.

Bosch, A.D.S. and Currah, L., 2002. Agronomy of Onions. pp. 187-224. In: Rabinowitch, H.D. and Currah, L. Alliums Crop Sciences: Recent Advance. CABI Publishing.

Bosekeng, G. 2012. Response of onion (*Allium cepa* L.) to sowing date and plant population. MSc Thesis, University of Free State, Bloemfontein. Sciences in Soil Sciences, 4 (5): 95-100.

Boyhan, G., Granbeery, D. and Kelley T. 2001. Onion production guide. The University of Georgia College of Agricultural and Environmental Science Bulletin, 1198.

Brady, N. C. and Weil, R. R., 2002.The nature and properties of soils.13th (ed.), Pearson Education Asia. Delhi, India. 960p.

Brewster, J. L. 1982. Growth, dry matter partition and radiation interception in an over wintered bulb onion crop. *Annals of Botany*, 49**:** 609-617.

Brewster, JL., 1994. Onions and other vegetable Alliums. Crop Production Science in Horticulture, CABI Publishing, Wallingford, UK. 236 -321 pp

Brewster, J. L. 1997. Onions and garlic. In the physiology of vegetable crops, Wien, H.C. (ed.), CAB International, Wallingford, UK. pp. 581-619.

Brewster, J. L. 2002. Onion and garlic. pp. 581-620. *In*: H. C. Wien (eds.), *the physiology of vegetable crops*. CABI Publishing, Wallingford bullition No. 35, Natrual Resource Institute, London. 232p.

Brewster, J.L. 2008. Onions and other vegetable alliums, ^{2}nd edition. CAB International, Wallingford, United Kingdom. 289p.

Caneppele, M.A.B., R.F.D.A., Allvarenga, G.M., Junior, C.J.H. and Cardoso,A.A. 1995. Influence of packaging, environment and storage period on seed quality in onion (*Allium cepa* L.). Revista Brassileriade Sementes, 17: 249-257.

Chapman, H. D. 1965. Cation exchange capacity by ammonium saturation. In: Black, C. A., L. E., Ensminger and F. E. Clarks (Eds.). Method of soil analysis pp. 891-901.American Society of Agronomy. Madison Wisconsin, USA.

Chillot Yirga and R.M Hassan., 2010. Social Costes and incentives for optimal control of soil nutrient depletion in the central highland of Ethiopia. Agricultural system, 103; 153-160

Chowdhury SH, Ali Hossain MS, Ahmed MA, Hoque MM. 2004. Effect of boron and sulphur on yield and quality of onion seed. Bangladesh J. Agric. Sci. 22:179- 184.

CIMMYT .1988. From Agronomic Data to Farmer Recommendations. An Economic Training Manual. Completely Revised Edition. CIMMYT, Mexico, D. F., Mexico.79 p

Conn KE, Lutton JS, Rosenberger SA (eds). 2012. Onion disease guide: a practical guide for seedsmen, growers and agricultural advisors. [s.l.]: Seminis Vegetable Seeds, Inc.

Coolong TW, Coolong WM, Randle L. 2008. Wicker structural and chemical differences in the cell wall regions in relation to scale firmness of three onion (*Allium cepa* L.) selections at harvest and during storage. *Journal of Food Science and Agriculture* 88:1277–1286.

Corgan, J., M. Wall, C. Cramer, Sammra, T., Lewis, B. and Schroeder, J. 2000. Bulb onion cultural and management. *Agricultural Experiment Station Circular*, 563: 1-16.

CSA. 2021. The federal democratic republic of Ethiopia central statistical agency agricultural sample survey. Statistical bulletins. Addis Ababa, Ethiopia.

CSA .2022. The federal democratic republic of Ethiopia central statistical agency agricultural sample survey. Statistical bulletins. Addis Ababa, Ethiopia.

CSSE (Crop Science Society of Ethiopia). 2006. Farmers' participatory onion seed production in the Central Rift Valley of Ethiopia: achievement, constraints and its implication for the national seed system. Conference summary, The Conference of the Crop Science Society of Ethiopia, Addis Abeba, Ethiopia.

Cumo, CE .2015. Onion. In: Foods that Changed History: How Foods Shaped Civilization from the Ancient World to the Present. ABC-CLIO LLC (American Bibliographic Center, CLIO Press). pp. 248–50.

Cuocola, L. and Barbieri, G. 1988. The effect of nitrogenfertilization and plant density on seed yield of onion (*Allium cepa* L.). *Rivista di Agronomia.*, 22 (3) : 195-202.

Currah, L. and Msika, L. 1994, Cheap methods of storing small quantities of onion seeds without refrigeration. Onion Newsletter for the Tropics, 6: 61-62.

Dahlgren, R.M., Clifford, H.T., and P.F. Yeo.1985. Families of the Monocotyledons. Springer Verlg, Berlin, 193p.

David R. and Albert D.1986. Specific Leaf Weight: Daily Trends in an Alfalfa Field. *Journal of Forage and Grain:* http://hdl.handle.net/10150/200533.

Dawar, N.M., Wazir, F.K., Dawar, M.D. and Dawar, S.H. 2007. Effect of planting density on growth and yield of onion varieties under climatic conditions of Peshawar. *Sarhad Journal of Agriculture*, 23 (4): 912-918.

Debashis M, MaityTK, Basu AK .2017. Response of Quality Seed Production of Onion (*Allium Cepa* L.) to Different Levels of Nitrogen and Potassium Application. Research Journal of Chemical and Environmental Sciences 5(2):38-45.

Debashis, M., P. Santra, T. K. Maity and A. K. Basu. 2016. Quality seed production of onion (*Allium cepa* L.) cv.Sukhsagar as influenced by bulb size and date of planting.*Agri. Res . Tech.*, 2(3) : 1-6.

Dhin Islam Md., Md.Yunus Miah, Mohammed Zia Uddin Kamal and Nishat Farhana. 2018. Effects of micronutrient and spacing on growth and chlorophyll content of rice. *International Journal of Environment, Agriculture and Biotechnology*. Vol-3, Issue -5,

Doijode, S. D. 1995. Effect of silica gel and storage con-tainers on viability and vigour in onion. *Seed Res*., 18: 163-165.

Dong, X., P. Nyren, B. Patton, B. Kreft, and A. Nyren. 2011. How does cattle grazing affect the growth of grass leaves? *Applied Ecology and Environmental Research* 9: 311–331.

Dornhoff, G.M. and R.M. Shibles. 1970. Varietal differences in net photosynthesis of soybean leaves. Crop Sci. 10: 42-45.

East Amhara Meteorological Service Center annual report (EAMSC) 2019. Kombolcha, Ethiopia.

Ethiopian Investment Agency (EIA) 2012. Investment Opportunity Profile for the Production Fruits and Vegetables in Ethiopia. Addis Ababa, Ethiopia.

El-Aweel, M.A.T. and A.A. Ghobashi .1999. Seed production in onion as influenced by dates of planting in the Sultanate of Oman. *Assiut, J. of Agric. Sci.*, 30: 43-53.

El-Helaly, M.A. and S.S. Karam .2012. Influence of Planting Date on the Production and Quality of Onion Seeds. *Journal of Horticultural Science & Ornamental Plants* 4 (3**):**275-279.

Epstein, E.; Bloom, A.J. 2005. Mineral nutrition of plants: principles and perspectives. Sunderland: Sinauer Associates. pp. 400.

Ethiopian Agricultural Research Organization (EARO) 2004. Directory of Released Crop Varieties & Their Recommended Cultural Practices, Addis Ababa.

Ethiopian Institute of Agricultural Research (EIAR) 2022. "Onion Seed Production: Current Status and Future Prospects in Ethiopia." [Online]. Available:

http://www.eiar.gov.et/documents/26626/97b10/onion-seed.pdf/6fae284e-f2e2-48c1-9413-0d55c2cbb57b

EthioSIS. 2014. Soil Fertility and Fertilizer recommendation Atlas of Tigray Region.Ministry of Agriculture (MoA) and Agricultural Transformation Agency (ATA).

Fageria, N. K. 2003. Plant tissue test for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice.Commun. Soil Sci. Plant Anal. 34:259–270.

Farghali, M.A. 1995. Effect of planting date and clipping of mother bulb on seed yield of onion under Assiut conditions. *Assiut J. Agric. Sci*., 26: 81-91.

FAO, 2023. Production, Crops, Onion, Area harvested, Yield, Production. http://www.fao.org/faostat/en/#data/QC [accessed 12/11/2023]

FAOSTAT, 2021. Crops. Retrieved from http://www.fao.org/faostat/en/#data/QC

FAO. 2017. Production year book. Food and Agriculture Organization

Farooqui MA, Naruka IS, Rathore SS, Singh PP, Shaktawat RPS, 2009. Effect of nitrogen and sulphur levels on growth and yield of garlic (*Allium sativum* L.). In: *As J Food Ag-Ind. pp. S18-23. Special Issue.*

Fekadu M,. 2019. Evaluation of Different Organic and Inorganic Fertilizer Rates on Yield and Quality of Onion (*Allium cepa* L.) at Dugda District Arsi Zone, Ethiopia. *Journal of Soil Sciences and Environmental Management*, 10(6), 69-**78.**

Francisco das C. Gonçalves1, Leilson C. Grangeiro1, Valdivia de F. L. de Sousa1, Jandeilson P. dos Santos1, Francisco I. de Souza1 & Luiz R. R. da Silva1, 2019. Yield and quality of densely cultivated onion cultivars as function of nitrogen fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental. 23 (11): 847-851.

Fritsch, R.M. and N.Friesen, 2002. Evolution, domestication and taxonomy.pp. 5-30. *In: Allium* crop science: Recent advances,H.D.Rabinowitch,and L.Currah,eds.,CABI Publ.,Wallingford,UK.

GBIF (2023). *Allium cepa L*. https://www.gbif.org/species/2857697 [accessed 23.11.2023]

Gebremedhn Gebretsadkan, Yohanes Gebremicael, Kiros Asgele, Eyasu Abebe, Weldegerima Gebrelibanos, Yrgalem Tsehaye. 2018. Enhancing Productivity and Production of Onion (*Allium cepa L.*) Through the use of Improved Varieties at North Western Zoze of Tigray,Ethiopia. *International Journal of Environment, Agriculture and Biotechnology (IJEAB***).** *Vol-3, Issue-3 , May-June- 2018. http://dx.doi.org/10.22161/ijeab/3.3.6*

Gemechis, A.O. 2017. Optimization of Productivity and Quality of Irrigated tomato (*Solanum lycopersicum* L.) by Smallholders in the Central Rifty Valley area of Oromia, Ethiopia. PhD Thesis, Wageningen University, Wageningen, The Netherlands, with summary in English, 262 pp.

Gessesew WS, Woldetsadik K, Mohammed W. 2015. Onion (*Allium cepa* L.) Bulb Traits as Affected by Nitrogen Fertilizer Rates and Intra-Row Spacing under Irrigation in Gode, South-Eastern Ethiopia. *Journal of Horticulture* 2: 160. doi:10.4172/2376-0354.1000160.

Getachew A .2014. Effect of plant spacing and NP fertilizer levels on growth, seed yield and seed quality of onion (*Allium cepa*L.) at Shewa Robit, M.Sc Thesis presented to Haramaya University, Northern Ethiopia P 29.

Geremew Awas, Teshome Abdisa, Kasaye Tolesa and Amenti Chali. 2010. Effect of intra- row spacing on yield of three onion (*Allium cepa* L.) varieties at Adami Tulu Agricultural Research Center (Mid rift valley of Ethiopia). *Journal of Horticulture and Forestry,* 2(1): 007-011.

Ghaffoor A, Jilani MS, Khaliq G, Waseem K. 2003. Effect of different NPK levels on the growth and yield of three onion (*Allium cepa* L.) varieties. Asian J. Plant Sci. 2(3):342-346.

Gomez, K.A. and Gomez, A.A. 1984. Statistical procedures for Agicultural Research. An international rice research institute book. New york.

Greeley, CO. 2011. US National Onion Association, "History of onions" Retrieved 23 January 2017.

Greenwood, D. J., D. A. Stones and A. Barnes. 2001. Root development of vegetable crops. Plant Soil, 68: 75-96.

Guesh Tekle., 2015. Growth, Yield, and Quality of Onion (*Allium Cepa* L.) As Influenced By Intra-Row Spacing and Nitrogen Fertilizer Levels in Central Zone of Tigray, Northern Ethiopia.

Habtamu Tegen, Minuyelet Jembere, Esmelealem Mihiretu and Alebachew Enyew. 2016. Influences of inter and intra row spacing on yield, yield component and morphological characteristics of onion (*Allium cepa* L.) at Western Amhara region. *African Journal of Agricultural Research.*

Hania, U. 2012. Response of onion to different micronutrients (Doctoral dissertation).

Hanlet, P, 1990. Taxonomy, Evolution and History. pp.1-26.In:Onions and Allied crops, H.D.Rabinowitch,and J.L.Brewster,eds.,CRC Press Inc,Boca Raton,Florida,USA.

Hansch, R. Mendel, R.R. 2009. Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Current Opinion on Plant Biology*, 12: 259-66.

Hasan M. M, Fahim A., M. Y. Rafii, Faruq G., and M. A. Latif. 2013. Effect of sulphur on growth, yield and yield attributes in onion (A*llium cepa* L.). Asian Journal of crop science. AJCS 7(9):1416-1422 (2013).

Helen Teshome, Ashenafi Woldeselassie and Tibebu Simon, 2015. Seed Yield and Quality of Onion (*Allium Cepa* L.) Seed as Influenced by Bulb Treatment and Spacing patterns at Larena, Southern Ethiopia ISSN 2224-3186 (Paper) ISSN 2225-0921.

Hirose, T., T. Werger, and K. Pamé. 1988. "A method for the measurement of specific leaf weight in a network of venation." Journal of Experimental Botany 39 (12): 1603-1612

Horky, J. 1988. Long term storage of vegetable seeds at room temperature in different wrapping materials. Sbornik, Zabradnictivi, 15: 257-269.

Hussain, S.W., M. Ishtiaq and S.A. Hussain .2001. Effects of different bulb sizes and planting dates on green leaf production of onion (*Allium cepa* L.). J. Biol. Sci., 8:433-439.

Islam, K.S. 2002. Control of growth cycle of onion for high yield and quality seed production. PhD. Thesis, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Islam and M.F. Mondal. 2005. Effects of planting date and GA3 on growth, yield and quality of onion seeds grown from sets. J. Bangladesh Agril. Univ. 3(1):7-12.

ISTA.1985. International rules for seed testing. Seed Science and Technology 13: 299-335.

Joosten, F., Boselie, D., Bekele Wolde and Lemma Dessalegn. 2011. Exporting Fruit and Vegetables from Ethiopia: Assessment of Development Potentials and Investment Options in the Export-oriented Fruit and Vegetable Sector, Ethiopia-Netherlands Horticulture Partnership Program. Jones, H.A.and l.k. Mann, 1963. *Onions and their Allies*, Leonard HillLtd, London.286p.

Jurgiel-Malecka G, Gibczynska M, Nawrocka-Pezik M., 2015. Comparison of chemical composition of selected cultivars of white, yellow and red onions. *Bulgarian Journal of Agricultural Science.*21: 736–741.

Jyotindra N Patel, N Sasidharan, Sudeshna Chakraborty, Bhushan Aher, Kalyani Kumari,Indrapratap Thakare and Gayatri Limbachiya. 2013. Effect of Different Storage Materials and Storage Periods on the Germination of Onion Seeds *(Allium cepa* L.). *Research Journal of Agricultural Sciences*, 3(6): 1180-1182.

Kabir, Z., K.M.M. Hossain, A.I. Khan and M.S. Islam. 1994. Effect of different fertilizer on the yield of potato.1st National Workshop on Tuber Crops. TCRC, BARI, Joydebpur, Gazipur. pp. 81-90.

Kandoliya, U.K.,Bodar, N.P., Bajaniya,V.K., Bhadja N.V. and Golakiya, B.A, 2015. Determination of nutritional value and antioxidant from bulbs of different onion (*Allium cepa*) variety: A comparative study. *International Journal of Current Microbiology and Appliedsciences*.4 (1): 635-641.

Kassie, M., Jaleta, M., and Marenya, P. 2013. Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania. Technological Forecasting and Social Change, 80(3), 525-540.

Kelley, W.T. and D.M. Granberry. 2000. Dry bulb onions. Commercial vegetable production. Circular 801.The University of Georgia Agriculture and Environmental Sciences, Cooperative Extension Service, Georgia, USA.

Khalid MK. 2019. Mineral nutrient management for onion bulb crops – a review. The Journal of Horticultural Science and Biotechnology pp. 2380-4084.

Khan H, Iqbal M, Ghaffoor A, Waseem K. 2002. Effect of various plant spacing and different nitrogen levels on the growth and yield of onion. *Online Journal of Biological Sciences* 2: 545–547.

Khatemenla, V.B. Singh, Trudy Tengse A. Sangma1 and C.S. Maiti, 2018. Effect of Zinc and Boron on Growth, Yield and Quality of Onion (*Allium cepa* L.) cv. Agrifound Dark Red. *International Journal of Current Microbiology and Applied Sciences.* ISSN: 2319-7706 Volume 7 Number 04 https://doi.org/10.20546/ijcmas.2018.704.413.

Kihara, J., Nziguheba, G., Zingore, S., Coulibaly, A., and Esilaba, A. 2010. Understanding variability in crop response to fertilizer and amendments in sub-Saharan Africa. Agronomy Journal, 102(2), 446-458**.**

Khodadadi, M. 2009. Effects of motheral bulb size, plant density and planting date on the yield and yield components of onion Ghole Ghese variety. Abhar Islamic Azad Univ. Pub., Iran, 28p.

Khokhar, K. M., S. I. Hussain, T. Mahmood, Hidayatullah and M. H. Bhatti. 2001. Effect of set size on bulb yield, maturity and bolting in local and exotic cultivars of onion during autumn season. *Sarhad J.Agri*c. 17: 355-358.

Kołota E, Adamczewska-Sowińska K, Uklańska-Pusz C. 2013. Response of Japanese bunching onion (*Allium fistulosum* L.) to nitrogen fertilization. *Acta Scientiarum Polonorum Hortorum Cultus* 12: 51–61.

Koshiba, T; Kobayashi, M; Matoh, T. 2009. "Boron deficiency". Plant Signal Behav. 4: 557–8. PMC 2688312 . PMID 19816136. doi:10.1093/pcp/pcn184.

Kubsa A., Desalegne P and Verschoor R., SNV. 2006. Analysis of livelihood strategies for Arba Minch, Ethiopia, Awassa.

Kuhl, J. C., Cheung, F., Yuan, Q., Martin, W., Zewdie, Y., McCallum, J., & Town, C. D. 2001. A unique set of 11,008 onion expressed sequence tags reveals expressed sequence and genomic differences between the monocot orders asparagales and poales. Plant Cell, 13(7), 1699-1713

Kumari, P, S. Kumar, A., Tadava, T.P., BanerjeE, M.K. and Dahiya, O.S. 2001. Efficacy of various containers in maintaining seed quality of onion (*Allium cepa* L.) Agriculture Research. New Series, 22 (2): 171-176.

Lawande K. E., 2001. Onion, In: K. V. Peter, Ed., Handbook of Herbs and Spices, Woodhead Publishing, Oxford.

Lambers, H., and H. Poorter. 1992. Inherent variation in growth rate between higher plants: A search for physiological causes and ecological consequences. *Advances in Ecology Research* 23: 187–261.

Lambers, H., Chapin III, F.S., and Pons, T.L. Plant Physiological Ecology. Springer, 2008.

Lemma Desalegn and Shimeles Aklilu. 2003. Research Experiences in Onion production Research Report No 55, Ethiopia Agricultural Research Organization, Addis Ababa, Ethiopia.

Lemma D., Yayeh Z., E. Hearth, Getachew T. and Asfaw G. 1994. Variety development on vegetables. In: E. Hearth, and Lemma D. eds. proceeding of the Second National Horticultural Workshop of Ethiopia pp.276-287.

Lemma, D., 1998. Seed production guideline for tomatoes, onion and hot pepper. Institute of Agricultural Research (IAR), Addis Ababa, Ethiopia.

Limeneh Demis Fikre, Hussien Mohammed Beshir and Fekadu Gebretensay Mengistu. 2019. Influence of Nitrogen and Phosphorus fertilizer Rates on Seed Yield, Yield Components and Quality of Onion (*Allium cepa* L.) at Kulumsa in Arsi Zone, South East Ethiopia. *African Journal of Agricultural Research.* Vol. 14(33), pp. 1795-1808.

Maguire, J.D. 1962. Speed of germination-aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2:176-177.

Maji, A. 2013. Integrated Nutrient Management for Sustainable Crop Production and Soil Fertility. *International Journal of Scientific and Research Publications*, 3(7), 1-8.

Malik, Y.S., N. Singh and B.K. Nehra,1999. Effect of planting time, bulb cut pinching of bolt treatment on yield and quality of onion seed. Vegetable Sci. 26:143-145.

Manohar CM, Xua J, Murayyan A, Neethirajan S, Shi J. 2017. Antioxidant activity of polyphenols from Ontario grown onion varieties using pressurized low polarity water technology. J Funct Foods 31:52–62.

Maria, M. and H. Roman, 2009. Effect of bulb size on selected morphological characteristics of seed stalks, seed yield and quality of onion (*Allium cepa* L.) seeds. Folia Horticulturae, 21(1):27-38.

Marschner H. 1995. Mineral nutrition of higher plants. 2nd ed. New York: Academic Press.

May, D, M. 1993. Moisture Stress to maximize Processing tomato Yield and fruit Quality. *Acta Horticulturae,* 335: 547-552.

Mbulelo Ncayiyana, Martin M Maboko and Isa Bertling. 2018. Yield and nutritional quality of different short-day onion cultivars as affected by nitrogen application. *South African Journal of Plant and Soil 2018, 35(3): 215–221*.

McGrath, J. M., & Pritts, M. P. (2016). Onions. In J. Prohens & F. Nuez (Eds.), Handbook of Plant Breeding: Vegetables I. Springer, Cham. doi: 10.1007/978-3-319-25973-2_6

Mehri S, Forodi BR,Kashi AK. 2015. Influence of planting date on some morphological characteristic and seed production in onion (*Allium cepa* L.) cultivars. Agric Sci Dev. 4 (2):19–21.

Melkamu Alemayehu, FentahunTesfa, Solomon Bizuayehu and Belayneh Ayele, 2015. Amhara Region Horticultural Development Strategy 2015 - 2020.

Mishu, H.M., Ahmed, F., Rafii, M.Y., Golam, F. and Latif, M.A. 2013. Effect of sulphur on growth, yield and yield attributes in onion (Allium cepa L.). *Australian Journal of Crop Science*, 7(9), p.1416.

Mitra J, Shrivastava SL, Rao PS. 2012. Onion dehydration: a review. *Journal of Food Science and Technology* 49: 267–277.

Mohammed A, Mohammed W. 2017. Soil Fertility Status and the Effect of Inorganic Fertilizer on Yield and Yield Components of Onion (*Allium cepa* L.) at Gubalafto District, North Wollo, Amhara Region, *Ethiopia. Journal of Agricultural Science*, 9(3), 121-132.

Mohammed, A.E, Gaafar, M. E. 2015. Some Quality Characters of Six Sudanese Onion Cultivars. *International Journal of Research in Agricultural Sciences*,2 (2): 2348 – 3997.

Mohsen K. and H. Davoud. 2012. The effects of planting date and motheral bulb size on quantitative and Qualitative seed traits of onion red rey variety. *International Journal of Agriculture: Research and Review*, 2 (4): 324-327.

Mekonnen A, 2020. Effect of Variable Fertilizer Rates on Yield and Quality of Onion (*Allium cepa* L.) in Northwestern Ethiopia. *Journal of Soil Science and Environmental Management*, 11(2), 9-15**.**

Mollah, M. R. A., M. A. Ali, M. Ahmad, M. K. Hassan and M. J.Alam, 2015. Effect of bulb size on the yield and quality of true seeds of onion. *European J. Biotech Biosci*., 3(7) :23-27.

Mondal, M. F., 1980. Effect of time of planting of onion bulbs on the yield and quality of seeds. *Bangladesh J. Agric*., 5(3): 131-134.

Mondal, M.F., Brewster, J.L. Morris, G.E.L and Butler, H.A. 1986. Bulb development in onion (*Allium cepa* L.). Effects of the size of adjacent plants. Shading by neutral and leaf filters, irrigation and nitrogen regime and the relationship between the red and far red spectral ratio in the canopy and leaf area index. *Annuals of Botany*, 58: 207-219.

Monteith, J.L. 1977. Climate and the Efficiency of Crop Production in Britain. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 281(980),

Mordor Intelligence. 2021. Onion Seeds Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021-2026). Retrieved from https://www.mordorintelligence.com/industry-reports/onion-seeds-market

Mosleh, U. 2008. Effect of mother bulb size and planting time on growth, bulb and seed yield of onion. *Bangladesh J. Agril. Res*. 33 (3): 531-537.

Mostafa, A.K. 1983. Studies on some factors affecting pollination and seed production in onion. PhD.Thesis, Fac.of Agric. Mansoura Univ., p: 129.

Mota CL, Luciano C, Dias A, Barroca MJ, Guiné RPF. 2010: Convective drying of onion: kinetics and nutritional evaluation. *Food Bioproduct Process* 88: 115–123.

Motsara, M. R. and Roy, R. N. 2008. Guide to laboratory establishment for plant nutrient analysis. FAO fertilizer and plant nutrition bulletin, 19: p: 17-219.

Mozumder SN, Moniruzzaman M, Halim MA. 2007. Effect of N, K and S on the yield and storability of transplanted onion (*Allium cepa* L.) in the hilly region. J. Agric. Rural Dev. 5(1&2):58-63.

Muluneh B. E. Alli M. Amsalu N., 2019. Effects of Different Level of Nitrogen Fertilizer Application on Growth, Yield, Quality and Storage Life of Onion (*Allium cepa* L.) at Jimma, South Western Ethiopia. *Journal of Natural Sciences Research*.9 (10).

Muluneh Bekele Etana, Mosissa Chewaka Aga, Bikila Ollika Fufa. 2019. Major Onion (*Allium cepa* L.) Production Challenges in Ethiopia: A Review. Journal of Biology, Agriculture and Healthcare. ISSN 2225-093X (Online) DOI: 10.7176/JBAH Vol.9, No.7.

Muluneh Bekele. 2018. Effects of different levels of potassium fertilization on yield, quality and storage life of onion (*Allium cepa* L.) at Jimma, Southwestern Ethiopia. *Journal of Food Science Nutrition. Volume 1 Issue 2.*

Muluneh Nigatu, Melkamu Alemayheu, Amare H/Sillassie. 2018. Optimum rate of NPS fertilizer for economical production of irrigated onion (*Allium cepa* L) in Dembyia District of Amhara Region, Ethiopia. *Ethiop. J. Sci. & Technol. 11(2) 113 - 127, 2018.*

Muktadir, M. S., A. M. Farooque, M. A. Rahim and M. M. Hossain, 2001. Yield and quality of onion seed as influenced by the planting time and bulb size. *Bangladesh J. Seed Sci. Technol,* 5(): 47–52.

Mumtaz Khan L, M. Javed Iqbal, M. Abbas, H. Raza, R. Waseem and Arshad Ali. 2004. Loss of Vigour and Viability in Aged Onion (*Allium cepa* L.) Seeds. International Journal OF Agriculture & Biology. *Institute of Horticultural Sciences, University of Agriculture, Faisalabad–38040, Pakistan.*

Myint M. M., Sutkhet Nakasathien and Ed Sarobol. 2011. Responses of Specific Leaf Weight, Biomass and Seed Yield of Soybean to Nitrogen Starter Rate and Plant Density. *Kasetsart Journal - Natural Science.* 45: 1 – 11.

Nandpuri KS, Madan SPA, Singh A, Singh S.1990. Effect of various doses of nitrogen and Phosphorus on Onion seed production. Pp. 92. In: Currah, L. and F. J. Proctor, (eds). Onion in tropical regions National Resources Institute Bulletin. No. 35, UK.

Nasreen S and Huq SMI. 2005. Effect of sulphur fertilization on yield, sulphur content and uptake by onion. *Indian J. Agril. Res*., 39(2): 122-127.

Nasreen, m. M. Haque, m. A. Hossain and a. T. M. Farid4. 2007. Nutrient uptake and yield of onion as influenced by nitrogen and sulphur fertilization. *Bangladesh J. Agril. Res. 32(3) : 413-420.*

National Onion Research Program (NORP). 2021. Ethiopian Onion Seed System. Retrieved from https://www.ethiopianonion.com/seed-system

Nayar, S. K., & Dahling, P. S. 2007. Onion seed production and handling. In E. B. Kurst-Swanger & D. A. Relf (Eds.), The Onion Book: A Master's Treatise on Onion Improvement and Production (pp. 244-258). AVI Publishing, Westport.

Negasi Tekeste, Nigussie Dechassa, Kebede Woldetsadik, Lemma Dessalegne and Abuhay Takele.2018.Influence of Nitrogen and Phosphorus Application on Bulb Yield and Yield Components of Onion (*Allium Cepa* L.).*The Open Agriculture Journal.p1-13.*

Nehra BK, Pandita ML, Kirti S, Sing K. 1988. Cultural and nutritional studies in relation to seed production in onion (*Allium cepa* L.). *Haryana J Hortic Sci*. 17: 106-10.

Nigussie, A., Kissi, E., Misganaw, M., and Ambushe, A. 2012. Fertilizer types and application rates on nutrient concentrations, uptake and yield of onion (*Allium cepa* L.) in vertisol. *African Journal of Agricultural Research*, 7(39), 5407-5416.

Nikus, O. and Mulugeta, F. 2010. Onion Seed Production Techniques. A Manual for Extension Agents and Seed Producers.FAO.Crop Diversification & Marketing Development Project. Asella, Ethiopia.

Ndor E, Dauda NS, Chammang HB. 2012. Effect of germination media and seed size on germination and seedling vigour of fluted pumpkin (Telferia occidentalis) Hook. F *Int J Agric Sci* ISSN: 2167-0447 vol.2 (3), pp. 113-115.

Olalusi A. 2014. Hot air drying and quality of red and white varieties of onion (*Allium cepa*). *Journal of Agricultural Chemistry and Environment* 3: 13–19.

Olsen, S.R. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate.

Orzolek, M 2010, *Factors affecting pungency in sweet onions*, media release, 9 December, Penn State Ectention, College of Agricultural Sciences, viewed 27 August 2014.

Padma, V., and Reddy, M.B. 2002. Storage of brinjal seed under ambient conditions at two moisture levels. *Journal of Research. Angrau*, 30 (2): 6-10.

Pandey, D.K., 1996. A suitable liquid preservative for enhancing longevity of orthodox seeds. Sci. Hortic., 66: 1–8.

Patel JN, N Sasidharan, C Sudeshna, A Bhushan, Kalyani Kumari, I Thakare and L Gayatri, 2012. Effect of different storage materials and storage periods on the germination of onion seeds (*Allium cepa* L.) *Research Journal of Agricultural Sciences*, **3**(6): 1180-1182.

Patel, C. A. Babariya, Jyoti Sondarva, K. H. Ribadiya and V. J. Bhatiya. 2017. Effect of storage conditions, packing materials and seed treatments on viability and seedling vigour of onion (*Allium cepa* L.) seeds. *Journal of Applied and Natural Science* 9 (2): 1054 – 1067.

Patil, J.G., Shelar, V.R. and S.K.Shinde,1993. Effect of irrigation intensity on seed yield and components of seed in onion seed crop in India. *Onion Newsletter for the Tropics*, 4:40-42.

Paul, J. K. Halder B. C and Khan. M. A. 2007. Effects of Boron and Sulphur on the Growth and Yield of Onion. *J. Sci. technol. (Dinajpur)* Vol. 5: 60-66, ISSN 1994-0386

Power, M.S. Gedam, V.B., Rametke, J.R., Rudragouda. 2008. Influence of organic manures on yield, nutrient uptake and change in physico-chemical properties of soil after harvest of groundnut. Crop Research, 36,111-114.

Prats PA, Munoz de Con L, Fundora MZ. 1996. Influence of onion bulb size and its locality of origin of seed yield. Onion Newsletter for the Tropics 7:25-32.

Quadir, M.A. and Boulton, A. 2005. Yield and maturity of new released red onion cultivars in New South Wales. *Acta Horticulture*, 694: 117-119.

Rabinowitch, H.D.and J.L. Brewster. 1990. Onions and Allied crops. Vol. I. Botany, physiology and Genetics. CRS Press. USA. p320.

Radford,P.J,1967. Growth analysis formulae-their use and abuse crop sci.7:171-175.

Raemaekers, H. R. 2001. Crop Production in Tropical Africa.DGIC Ministry of Foreign affairs, External Trade and International co-operation, Brussels, Belgium.pp 455.

Randle, W.M. 2000. Increasing nitrogen concentration in hydroponic solutions affects onion flavour and bulb quality. *Journal of the American Society for Horticultural Science*, 125: 254-259.

Rasmussen, D. C. 1963. Quantitative Relations between Growth and Yield in Crop Plants. Agronomy Journal, 55(6), 503-506.

Rizk, F.A. Shaheen, A.M. Abd El-Samad, E.H. and Sawan, O.M. 2012. Effect of different nitrogen plus phosphorus and sulphur fertilizer levels on growth, yield and quality of onion (*AIlium cepa* L.). *Journal of Applied Science Research*, 8(7):3353-3361.

Robert Solow, 1956. Technical Change and the Aggregate Production Function. Absolute growth rate. https://www.investopedia.com/terms/n/neoclassical-growth-theory.asp#citation-3

Rodo, A. B. and J. Marcos-Filho, 2003. Onion seed vigor in relation to plant growth and yield. Hortic. Bras. 21: 220-226.

Sahee, P., Kar, D.K., Das, B.C. and Das, S.K. 1994. Influence of initial moisture level of storability of tomato seeds. Seed Tech News, 24: 27.

SARC. 2009. Sirinka Agricultural Research Center progress report. Sirinka, Ethiopia.

SAS-Institute. 2008. SAS 9.4 copyright 2002–2008. Cary, NC: SAS Institute Inc.

Salo, T., T. Suojala and M. Kallela. 2002. The effect of fertigation on yield and nutrient uptake of cabbage, carrot and onion. Acta Horticulture, 571: 253-241.

Saud, S., Yajun, C., Razaq, M., Luqman, M., Fahad, S., Abdullah, M. and Sadiq, A. 2013. Effect of potash levels and row spacing on onion yield. *Journal of Biology Agriculture and Health care*, 3(16): 2013-2118.

Saxena, O.P., Singh, G., Pakeeraiah, H. and Pandey, N.1987, Seed deterioration studies in some vegetable seeds. Acta Horticulture, 215: 39-44.

Saxena, O.P.1994. Physiological and biochemical changes in relation to storage in some crop seeds. Seed Tech News, 29: 24.

Schwimmer, S. and W.J. Weston. 1961. Enzymatic development of pyruvic acid in onion as a measure of pungency. J. Agr. Food Chem. 9:301.

Sedigheh Mehri, Bahram Rostam Forodi, Abdol-Karim Kashi. 2015. Influence of Planting Date on Some Morphological Characteristic and Seed Production in Onion (*Allium cepa* L.*)* Cultivars. Agriculture Science Developments Vol (4), No (2).

Shaheen AM, MonaM, AbdelM, Aisha AM, Fatma AR. 2007. Natural and chemical phosphorus fertilizers as affected onion plant growth, bulb yield and its some physical and chemical properties. Australia journal of basic and applied science, Insect Publication 1(4):519-524.

Shamima Nasreen, S.M. Imamul Haq and Altab Hossain. 2003. Sulphur Effects on Growth Responces and yield of onion. Asian Journal of Plant Sciences 2(12): 897- 902.

Sharangi AB, Sahu PK. Effect of Placement and Dose of Phosphatic Fertilizers on Onion. J Plant Nutr 2009; 32(11): 1901-13. [http://dx.doi.org/10.1080/01904160903242383].

Shelar, V.R., Patil, R.B. and Gawade, N.D. 1992. Onion seed viability influenced by different storage containers. Onion Newsletter for the Tropics, 4: 39-42.

Shiberu, T.and Mahammed, A. 2014. The Importance and management option of onion thrips, Thrips tabaci (L.) (Thysanoptera: Thripidae) in Ethiopia: *A Review. Journal of Horticulture*, p.1-6.

Shimelis, H., Lemma, B., and Haji, J. 2012. Onion (*Allium cepa* L.) based cropping systems in Ethiopia: Influence on yield and yield components of succeeding crops. *Journal of Agriculture and Rural Development in the Tropics and Subtropics,* 113(2), 147-**157.** Retrieved from https://www.jarts.info/index.php/jarts/article/view/2012060481223

Shukla SK, and Warsi AS. 2000. Effect of sulphur and micronutrients on growth, nutrient content and yield of wheat (*Triticumaestivum*L.). *Indian J. Agri. Res*. 34:203-205.

Simon T, M Tora, A Shumbulo and S Urkato, 2015. The effect of variety, nitrogen and phosphorus fertilization on growth and bulb yield of onion (*Allium cepa* L.) at Wolaita, Southern Ethiopia. *J Biol, Agric Healthcare,* 4: 90-92.

Sinclair P. 1989. Physiology of the onion. Australian Onion Grower, 6: 7-9.

Singh, S.P. 2001. Seed production of commercial vegetables. Agrotech Publishing Academy. New Delhi. 186p.

Singh NP, Singh RA. 2002. Scientific crop production, X press Graphics, Delih- 28, 1st ed, India.

Sorensen JN, Grevsen K. 2010. Sprouting in bulb onions (*Allium cepa*L.) as influenced by nitrogen and water stress. *The Journal of Horticultural Science and Biotechnology* 76:501-506.

Soubeih Kh. A. A. 2018. Effect of fertilizer Packages and polymers on onion yield and quality under Bahariya Oasis conditions. *Middle East Journal of Agriculture Research. 7(4): 1769-1785.*

Tadesse, M., Negash, A., and Derbew, B. 2019. Challenges and Opportunities of Onion Seed Production in Ethiopia. *International Journal of Agronomy*, 2019, 5980748.

Takhtajan, A. 1997. Diversity and Classification of Flowering Plants. Columbia University Press, New York,643 pp

Tamrat T . 2006. Effect of nitrogen and phosphorous application on seed yield and nutrient uptake of onion (*Allium cepa* var. cepa). MSc. Thesis, Haramaya University, Ethiopia pp. 1-81.

Tegbew.W. 2011. Yield and Yield Components of Onion (*Allium cepa* L.) Cultivars as influenced by population density. MSc. Thesis submitted to the school of graduate studies of Haramaya University, Ethiopia.

Tekalign, T. 2009. Fertilizer use optimization for major crops in Ethiopia. *Soil Science Society of America Journal, 73(4), 1287-1296.*

Tekalign, T., Geremew, A., Asfaw, A., & Fikre, A. 2018. Challenges and opportunities of onion (Allium cepa L.) seed production in Ethiopia: A review. *Journal of Horticulture and Forestry,* 10(1), 16-23.

Tekle G, F Belay and S Chernet. 2020. Effect of different planting time on seed yield and quality of onion (*Allium cepa* L.) in tigrai region, Northern Ethiopia. *Int J Agri Biosci*, 9(5): 216-220.

Tesfaye, M., Belew, D., Dessalegn,Y. 2018. Effect of planting time on growth, yield components, seed yield and quality of onion (*Allium cepa* L.) at Tehuledere district, northeastern Ethiopia. *Agric & Food Secur* **7**, 28 .https://doi.org/10.1186/s40066-018-0178-0

Tibebu S, Melese T, Abrham S, and Samuel U. 2014. The effect of variety,nitrogen and phosphorous fertilization on growth and bulb yield of onion (*Allium cepa* L.) at Wolaita, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare 4:90-92.*

Tindal, H.D, 1983. Vegetables in the tropics. The Macmillan Press Ltd, Hong Kong.

UD-Deen, M.M. 2008. Effect of mother bulb size and planting time on growth, bulb and seed yield of onion. Bangladesh J. Agric. Res., 33:531-537.

Vazquez-Oderiz ML, Vazquez-Blanco ME, Lopez-Hernandez J,Simal-Lozano J, Romero-Rodrıguez MA. 1994. Simultaneous determination of organic acids and vitamin C in green beans by liquid chromatography. *Journal of AOAC International* 77:1056–1059.

Walkley, A. J. and Black, I. A. 1934. Estimation of soil organic carbon by the chronic acid titration method. Soil Science 37: 29-38.

Weldemariam S., Kebede W., Wassu M. 2015. Growth Parameters of Onion (*Allium cepa* L.) as Affected by Nitrogen Fertilizer Rates and Intra-row Spacing Under Irrigation in Gode, South-Eastern Ethiopia. *Journal of Agriculture, Forestry and Fisheries.* 4(6): 239-245.

Wonya, T., and Assefa, E. 2015. Assessment on the Knowledge and Perception of Smallholder Farmers on Use of Inorganic Fertilizers: The Case of Chencha and Arbegona Woredas in Gamo Goffa Zone, Southern Ethiopia. International Journal of Innovation and Applied Studies, 11(4), 972-979.

Yemane Kahsay, Derbew Belew and Fetien Abay. 2013. Effect of intra-row spacing on yield and quality of some onion varieties (*Allium cepa* L.) at Aksum, Northern Ethiopia. *African Journal of Plant Science*, 7(12): 613-622.

Yohannes K., Belew D., Debela A., 2013. Effect of farmyard manure and nitrogen fertilizer rates on growth, yield and yield components of onion (*Allium cepa* L.) at Jimma southwest *Ethiopia.Asian Journal of Plant Sciences,* 2013, vol. 12. No. 6/8. 228-234 ref. 28.

Yohannes A. 1987. Current activities, recommendation and future strategies of onion research in Ethiopia. p. 358-370. In: Burba, J.L. and C.R. Galmarini, (eds), 1994. Proceedings of the 19th National crop improvement conference. Addis Ababa, Ethiopia, 22-26, April 1988, Institute of Agricultural Research.

Zeleke and Derso, (2015). Production and management of major vegetable crops in Ethiopia. pp: 32-51. Ethiopian Institute of Agricultural Research. Addis Abeba, Ethiopia.

8. BIOGRAPHY

The author, Teshome Ashagrie Guangul, was born in Amhara regional state, North Wollo zone, Habru district, at Sirinka town on November 10, 1973, to his father, Mr. Ashagrie Guangul, and his mother, Mrs. Bizu Desalegn. He attended elementary and junior secondary school in Sirinka Kutaye and Woldia town, respectively. He attended his high school education at Woldia Senior Secondary School (9–10) and Jimma Jrien Senior Secondary School (11–12). After the completion of his high school education, he joined Jimma College of Agriculture, now Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), and graduated with a Diploma in General Agriculture in 2000. Immediately after graduation, he was recruited by Wadla Woreda Co-operative office, assigned to work as a market study expert, and served for five months. Then, in 2001, he was employed at Sirinka Agricultural Research Center, Kobo Sub-center, and served as a technical assistant and farm manager. In 2004, the author joined JUCAVM to study his BSc and graduated with a Bachelor of Science degree in Horticulture in 2008. After graduation, he worked as an assistant researcher in the Department of Horticulture at Sirinka Agricultural Research Center (SARC). Then,in September 2011, he rejoined the School of Graduate Studies at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) to pursue his MSc in Horticulture (Vegetable Science) and obtained MSc degree in Horticulture (Vegetable Science) in November 2014. Right after graduation, he joined his Research Center (SARC) and served as an associate researcher in vegetable crops and as a coordinator of the crop research directorate for two and a half years. In October 2016, he rejoined the School of Graduate Studies at Jimma University College of Agriculture and Veterinary Medicine to pursue his PhD studies in horticulture. Currently, the author is married and a father of three daughters and one son.

9. BIBILOGRAPHY

List of publications

Teshome Ashagrie, Derbew Belew and Amsalu Nebiyu, 2021. Influence of planting date and bulb size on yield and quality of onion (*Allium cepa* L.) seed production, *Cogent Food & Agriculture*, 7:1, 1908656, DOI: 10.1080/23311932.2021.1908656

Ashagrie, T., Belew, D., and Nebiyu, A., 2023. Effects of Blended Fertilizer Rate and Variety on Yield and Quality of Onion (*Allium cepa* L.) Seed production in Northeastern Amhara, Ethiopia. *Abyssinia Journal of Science and Technology*, 8(1), 11-20.

Teshome Ashagrie, Derbew Belew, Sentayehu Alamerew andnd Yehenew Getachew, 2014. Effects of Planting Time and Mother Bulb Size on Onion (*Allium cepa* L.) Seed Yield and Quality at Kobo Woreda, Northern Ethiopia. *International Journal of Agricultural Research, 9: 231-241*.

Tadesse Wudu, Teshome Ashagrie and Berhan Kelemu, 2023. Participatory tomato (*Lycopersicon esculentum* Mill) variety selection and evaluation for production in Eastern Amhara regional state. *International Journal of Horticulture and Food Science 2023; 5(1): 35-40*

List of abstracts and Posters presented in Conference/ Workshops

Teshome Ashagrie, Derbew Belew and Amsalu Nebiyu, 2022. Effects of Blended Fertilizer Rate and Variety on Yield and Quality of Onion (*Allium cepa* L.) Seed production in Northeastern Amhara, Ethiopia. *10th Annual National Research Conference, 12-14 May, Sodo, Ethiopia*

Teshome Ashagrie, Derbew Belew and Amsalu Nebiyu, 2022. Evaluation of Packaging Material Type and Storage Period on Onion (*Allium cepa* L.) Seed Quality. *Amhara Annual Regional Agricultural Research Review Workshop, 7-12 March, Bahir Dar, Ethiopia.*

Teshome Ashagrie and Berhan Gashaw, 2018. Effect of Planting Date and Varieties on Onion (*Allium cepa* L.) Seed Production Potential at Kobo. *Proceeding of the 9th and 10th Annual Regional Conference on Completed Crop Research Activities, 9-20 March 2015 and 13-16 March 2017, Bahir Dar, Ethiopia*

Solomon Kassaye and Teshome Ashagrie, 2014. Performance of Dessert and Cooking Type Banana Varieties at Jari, South wollo. *Proceedings of the first workshop on Agricultural water management research & Development in Amhara Region 28-30 March, Bahir Dar, Ethiopia*

Teshome Ashagrie, Derbew Belew and Sentayehu Alamerew, 2014. Effects of Planting Time and Mother Bulb Size on Onion (*Allium cepa* L.) Seed Yield and Quality at Kobo Woreda, Northern Ethiopia. *Proceedings of the 6th and 7th Annual Regional Conference on completed Crops Research Activities*. February, 2014. Bair Dar, Ethiopia.

Solomon Kassaye and Teshome Ashagrie, 2014. Performances of of Dessert Type Banana in Eeastern Amhara. *Proceedings of the 6th and 7th Annual Regional Conference on completed Crops Research Activities.* February, 2014. Bahir Dar, Ethiopia.

APPENDICES

Appendix Table 1. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Kobo and Woramit

Source of variation	DF	Variables			
		Number of leaves per plant	Leaf length	Crop growth rate	Speccific leaf weight
		Mean Square			
LOC	1	103.629**	4142.643**	0.074^{ns}	160.716**
VA	1	35.620**	140.146**	0.001^{ns}	82.309**
LOC*VA	1	3.563*	21.100**	0.473**	47.867**
FR	6	2.637**	111.317**	0.043^{ns}	177.032**
LOC*FR	6	0.871^{ns}	13.091**	0.141**	140.410**
VA*FR	6	2.295**	10.025**	0.211**	20.921**
LOC*VA*FR	6	2.766**	6.609*	0.106*	36.256**
Error	54	0.569	2.259	0.03151235	4.767
*=Significance ns= non significance					

Appendix Table 2. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Kobo

Source of variation	DF	Variebles			
		Specific leaf area	Absolute growth rate	Net assimilation rate	Harvest index
		Mean square			
VA	1	0.00007^{ns}	0.526*	0.828**	220.344*
FR	6	0.001**	0.124^{ns}	0.229**	151.289^{ns}
VA*FR	6	0.0004**	0.344*	0.171*	146.761^{ns}
Error	28	0.00008	0.103	0.036	28.193
*=Significance ns= non significance					

Appendix Table 3. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Woramit

Source of variation	DF	Variables			
		Specific leaf Area	Absolute growth rate	Net Assimilation rate	Harvest index
		Mean square			
VA	1	0.004**	0.533*	0.094ns	58.552ns
FR	6	0.003**	0.335**	1.689*	68.067ns
VA*FR	6	0.0009*	0.476**	0.580ns	6.401ns
Error	28	0.0003	0.061	0.397	30.248

*=Significance ns= non significance

Appendix Table 4. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Kobo

Source of variation	DF	Variables		
		Buln neck thickness	Bulb length	Bulb dry weight
		Mean squares		
VA	1	0.079*	0.400*	3010.746**
FR	6	0.066*	0.049ns	313.794ns
VA*FR	6	0.032ns	0.151ns	703.223*
Error	28	0.019	0.083	194.784

*=Significance ns= non significance

Appendix Table 5. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Woramit

Source of variation	DF	Variables		
		Buln neck thickness	Bulb length	Bulb dry weight
		Mean squares		
VA	1	0.027ns	0.400*	296.537**
FR	6	0.059**	0.049ns	442.163ns
VA*FR	6	0.017ns	0.151ns	1234.849*
Error	28	0.012	0.083	210.242

*=Significance ns= non significance

Appendix Table 6. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Kobo and Woramit

Source of variation	DF	Variables				
		Bulb diameter (cm)	Mean bulb weight(g)	Marketable bulb yield ton ha^{-1}	Unmarketable bulb yield ton ha^{-1}	Total bulb yield ton ha^{-1}
		Mean squares				
LOC	1	0.379^{*}	67.322^{ns}	2303.714^{**}	62.229^{**}	3120.762^{**}
VA	1	0.128^{ns}	257.950^{*}	115.034^{**}	24.429^{**}	244.122^{**}
LOC*VA	1	0.547^{*}	855.048^{**}	183.934^{**}	7.381^{**}	266.430^{**}
FR	6	0.162^{ns}	357.930^{**}	82.285^{**}	0.977^{*}	88.166^{**}
LOC*FR	6	0.165^{ns}	232.886^{**}	69.261^{**}	1.444^{**}	73.072^{**}
VA*FR	6	0.057^{ns}	299.559^{**}	31.733^{**}	1.264^{**}	36.111^{**}
LOC*VA*FR	6	0.286^{*}	194.503^{*}	14.896^{**}	1.541^{**}	18.641^{**}
Error	54	0.093	53.124	1.217	0.303	1.721

*=Significance ns= non significance

Appendix Table 7. Analysis of variance for the influence of blended fertilizer rate and onion varieties on different variables at Kobo and Woramit

Source of variation	DF	Variables		
		Total soluble solid(TSS)	Total titratable acidity(TTA)	Vitamin C
		Mean square		
LOC	1	13.705^{**}	0.0006^{ns}	69.579^{**}
VA	1	19.267^{**}	0.004^{**}	5.559^{ns}
LOC*VA	1	0.477^{**}	0.004^{**}	15.817^{*}
FR	6	8.434^{**}	0.005^{**}	49.467^{**}
LOC*FR	6	1.742^{**}	0.006^{**}	27.363^{**}
VA*FR	6	5.386^{**}	0.005^{**}	47.209^{**}
LOC*VA*FR	6	5.838^{**}	0.003^{**}	49.314^{**}
Error	54	0.0013	0.0002^{**}	2.587

*=Significance ns= non significance

Appendix Table 8. Analysis of variance for the influence of blended fertilizer rate and onion varieties on pyruvic acid (pungency) at Kobo and Woramit

Source of variation	DF	Kobo	Woramit
		Variable	
		Pyruvic acid (pungency)	
		Mean squares	
VA		0.017**	0.00009ns
FR		0.004**	0.008**
VA*FR		0.019**	0.002ns
Error		0.0002	0.0009

*=Significance ns= non significance

Appendix Table 9. Analysis of variance for the effect of blended fertilizer rate and onion varieties on different variables at Kobo and Libso

Source of variation	DF	Variables			
		Number of leaves per plant	50% bolting date	50% flowering date	Flower stalk height
		Mean squares			
VA	1	1296.428**	8540.583**	18128.048**	3653.762**
FR	6	21.075**	19.429**	3.179ns	19.218**
VA*FR	6	12.789*	16.167**	5.908ns	29.289**
Error	70	5.205	2.574	5.438	4.633

*=Significance ns= non significance

Appendix Table 10. Analysis of variance for the effect of blended fertilizer rate and onion varieties on flower stalk diameter at Kobo and Libso

Source of variation	DF	Kobo	Libso
		Parameter	
		Flower stalk diameter	
		Mean squares	
VA		0.041*	0.089*
FR		0.003ns	0.007ns
VA*FR		0.005ns	0.002ns
Error		0.005	0.016

*=Significance ns= non significance

Appendix Table 11. Analysis of variance for the effect of blended fertilizer rate and onion varieties on different variables at Kobo and Libso

Source of variation	DF	Variables		
		Flower stalk per plant	Number of umbels per plant	Umbel diameter
		Mean squares		
VA	1	165.762**	152.012**	2.823**
FR	6	1.853*	2.269**	0.597**
VA*FR	6	2.623**	2.484**	0.358**
Error	70	0.609	0.574	0.080

*=Significance ns= non significance

Appendix Table 12. Analysis of variance for the effect of blended fertilizer rate and onion varieties on different variables at Kobo and Libso

Source of variation	DF	Variables		
		Number of seeds per umbel	Seed weight per umbel	Seed yield ton ha^{-1}
			Mean Squares	
LOC	1	8300.298*	15.429**	0.074**
VA	1	464880.964**	0.274ns	3.086**
LOC*VA	1	1710.012ns	14.417**	0.074**
FR	6	186825.222**	5.430**	0.954**
LOC*FR	6	3907.159*	1.202**	0.012ns
VA*FR	6	172430.437**	2.676**	0.126**
LOC*VA*FR	6	4268.929*	2.040**	0.036**
Error	54	1156.772	0.102	0.007

*=Significance ns= non significance

Appendix Table 13. Analysis of variance for the effect of blended fertilizer rate and onion varieties on germination percentage at Kobo and Libso

Source of variation	DF	Parameter
		Germination percentage
		Mean square
VA	1	490.583**
FR	6	308.769**
VA*FR	6	171.278**
Error	70	7.255

*=Significance ns= non significance

Appendix Table 14. Analysis of variance for the effect of blended fertilizer rate and onion varieties on different variables at Kobo and Libso

Source of variation	DF	Variables		
		Speed of germination	Seed vigor index I	Seed vigor index II
			Mean Square	
LOC	1	20.701**	4294.290*	251.680**
VA	1	15.003**	7942.408*	64.138**
LOC*VA	1	14.169**	801.052ns	38.679**
FR	6	1.699*	51159.962**	36.211**
LOC*FR	6	1.459*	4173.549**	16.181**
VA*FR	6	1.966*	11548.597**	14.576**
LOC*VA*FR	6	2.270*	6503.588**	61.184**
Error	54	0.639	1132.764	1.939**

*=Significance ns= non significance

Appendix Table 15. Analysis of variance for the influence of planting date and onion bulb size on number of flower stalks per plant at Kobo and Libso

Source of variation	DF	Variable
		Number of flower stalks per plant
		Mean Square
LOC	1	7.347**
BS	2	65.042**
LOC*BS	2	1.514ns
PD	3	6.718**
LOC*PD	3	0.569ns
BS*PD	6	0.356ns
LOC*BS*PD	6	1.236*
Error	46	0.519

*=Significance ns= non significance

Appendix Table 16. Analysis of variance for the influence of planting date and onion bulb size on different variables at Kobo and Libso

Source of variation	DF	Variables	
		Number of leaves per plant	50% flowering date
		Mean squares	
BS	2	1544.431**	11.931*
PD	3	102.167**	1031.051**
BS*PD	6	85.264**	77.801**
Error	60	7.650	2.197
*=Significance ns= non significance			

Appendix Table 17. Analysis of variance for the influence of planting date and onion bulb size on different variables at Kobo and Libso

Source of variation	DF	Variables		
		Umbel diameter	Number of seeds per umbel	Seed yield ton ha^{-1}
		Mean squares		
BS	2	1.587**	7691.764**	2.717**
PD	3	3.061**	443336.940**	1.038**
BS*PD	6	0.379**	24125.801**	0.035ns
Error	60	0.060	715.831	0.038
*=Significance ns= non significance				

Appendix Table 18. Analysis of variance for the influence of planting date and onion bulb size on seed weight per umbel at Kobo and Libso

Source of variation	DF	Kobo	Libso
		Variabel	
		Seed weight per umbel	
		Mean squares	
BS	2	0.088**	0.468**
PD	3	3.513**	19.659**
BS*PD	6	0.204**	0.576**
Error	24	0.009	0.036
*=Significance ns= non significance			

Appendix Table 19. Analysis of variance for the influence of planting date and onion bulb size on germination percentage at Kobo and Libso

Source of variation	DF	Variable
		Germination percentage
		Mean squares
BS	2	470.597**
PD	3	1041.606**
BS*PD	6	225.134**
Error	60	4.975
*=Significance ns= non significance		

Appendix Table 20. Analysis of variance for the influence of planting date and onion bulb size on Seed vigor index I at Kobo and Libso

Source of variation	DF	Variable
		Seed vigor index I
		Mean square
LOC	1	563479.587**
BS	2	155911.605**
LOC*BS	2	1052.389ns
PD	3	272281.675**
LOC*PD	3	46975.326**
BS*PD	6	65877.189**
LOC*BS*PD	6	7541.574**
Error	46	1473.703
*=Significance ns= non significance		

Appendix Table 21. Analysis of variance for the influence of planting date and onion bulb size on Seed vigor index II at Kobo and Libso

Source of variation	DF	Kobo	Libso
		Variable	
		Seed vigor index II	
		Mean squares	
BS	2	3.452ns	30.985**
PD	3	22.424ns	63.637**
BS*PD	6	44.245*	22.401**
Error	24	14.440	4.646
*=Significance		ns= non significance	

Appendix Table 22. Analysis of variance for the influence packaging material type and storage period on germination percentage,germination index and germination rate index at Sirinka

Source of variation	DF	Variables		
		Germination percentage	Germination index	Germination rate index
		Mean squares		
SP	1	3674.133**	6.256**	3.333^{ns}
PM	4	198.550**	0.446**	6.167*
SP*PM	4	116.050**	0.157*	1.167^{ns}
Error	20	4.333	0.041	2.722
*=Significance ns= non significance				

Appendix Table 23. Analysis of variance for the influence packaging material type and storage period on shoot and root length at Sirinka

Source of variation	DF	Variables	
		Shoot length	Root length
		Mean squares	
SP	1	5.208**	0.048^{ns}
PM	4	1.510**	0.065^{ns}
SP*PM	4	0.263^{ns}	0.036^{ns}
Error	20	0.104	0.300
*=Significance ns= non significance			

Appendix Table 24. Analysis of variance for the influence packaging material type and storage period seed vigor index I, seed vigor index II and field emergence percentage at Sirinka

Source of variation	DF	Variables		
		Seed vigor index I	Seed vigor index II	Field emergence percentage
		Mean squares		
SP	1	976396.961**	28.227**	235.200**
PM	4	79992.018**	2.239**	9.167^{ns}
SP*PM	4	29888.365**	0.975*	45.867**
Error	20	4435.393	0.294	5.567
*=Significance ns= non significance				

Appendix Figures

Onion bulb fertilizer rate and variety trial at Woramit and Kobo



A



B



C



D



E



F



G

Appendix figures 1. Onion bulb trial on blended fertilizer rate and variety from field to laboratory work (A-G).

Onion seed fertilizer rate and variety trial at Kobo and Libso



A



B



C



D

Appendix figures 2. Onion seed trial on blended fertilizer and variety from field to harvest work (A-D)

Onion seed trial on bulb size and planting date at Kobo and Libso



A



B



C



D



E

Appendix figures 3. Bulb size and planting date trial from bulb storage to umbel harvest (A – E)

Onion seed trial in different packaging types and storage periods



A (Glass jars)



B (Polythen bags)



C (Cloth bags)



D (Nylon sacks)



E (Aluminum bags)



F (storage shelf)



F (seed germination)

Appendix figures 4. Onion storage materials and seed germination (A – F)

Field day for onion seed trials



A



B



C

Appendix figures 5. Field day participant photos at Kobo (A –C)



Appendix figures 6. Onion seed produced during trial (bulked).