EFFECT OF NITROGEN RATES ON YIELD COMPONENTS AND QUALITY OF LINSEED (*Linum usitatissimum* L.) VARIETIES UNDER IRRIGATION IN ANGOLELA TERA DISTRICT, CENTRAL HIGHLANDS OF ETHIOPIA

M.Sc. THESIS

SINTAYEHU TENAYE

AUGUST 2022

DEBRE BERHAN, ETHIOPIA

EFFECT OF NITROGEN RATES ON YIELD COMPONENTS AND QUALITY OF LINSEED (*Linum usitatissimum* L.) VARIETIES UNDER IRRIGATION IN ANGOLELA TERA DISTRICT, CENTRAL HIGHLANDS OF ETHIOPIA

A Thesis Submitted to the Department of Plant Sciences
College of Agriculture and Natural Resources Sciences, College of Post Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agronomy

Sintayehu Tenaye

Major Advisor: Fresew Belete (Ph.D.)
Co- Advisor: Mitiku Ashenafi (Ph.D. candidate)

August 2022
Debre Berhan, Ethiopia

COLLEGE OF GRADUATE STUDIES

COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES

DEBRE BERHAN UNIVERSITY

ADVISOR'S APPROVAL SHEET

(Submission sheet- 1)

This is to certify that the thesis entitled "**Effect of nitrogen rates on yield components and quality of linseed (*Linum usitatissimum* L.) varieties under irrigation in Angolela Tera District, Central highland of Ethiopia"** submitted in partial fulfillment of the requirements for the degree of master with specialization in agronomy, the graduate program of plant science, college of agriculture and natural resource science, Debre Berhan University and is a record of original research carried out by **Sintayehu Tenaye, PGR/206/11,** under my supervision.

The assistance and help received during the course of this investigation have been acknowledged. Therefore, I recommended that it to be accepted as fulfilling the requirement and hence hereby can submit the thesis to the department.

Fresew Belete (Ph.D.)	________________	____________
Name of major advisor	**Signature**	**Date**
Mitiku Ashenafi (Ph.D. candidate)	________________	____________
Name of co-advisor	**Signature**	**Date**

COLLEGE OF GRADUATE STUDIES

COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES

DEBRE BERHAN UNIVERSITY

EXAMINERS' APPROVAL SHEET

(Submission sheet-2)

We, the undersigned members of the Board of Examiners of the final open defense by having read and evaluated his/her thesis entitled: **"Effect of nitrogen rates on yield components and quality of linseed (*Linum usitatissimum* L.) varieties under irrigation in Angolela Tera District, Central highland of Ethiopia**" and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the Master's degree in **plant sciences with a specialization in Agronomy.**

______________________	___________	____________
Name of Major Advisor	Signature	Date
______________________	___________	____________
Name of Internal Examiner	Signature	Date
______________________	___________	____________
Name of External Examiner	Signature	Date
______________________	___________	____________
Associate Dean, College Res/CS & post graduate	Signature	Date
______________________	___________	____________
Dean, College of Graduate Studies (CGS)	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the College of Graduate Studies (CGS) through the Department Graduate Committee (DGC) of the candidates.

Stamp of CGS Date______________

DEBRE BERHAN UNIVERSITY

COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES

DEPARTMENT OF PLANT SCIENCES

FINAL THESIS APPROVAL FORM

(Submission sheet -3)

As members of the Board of Examiners of the final masters open defense, we certify that we have read and evaluated the thesis prepared by **Sintayehu Tenaye** under the title: **"Effect of nitrogen rates on yield components and quality of linseed (*Linum usitatissimum* L.) varieties under irrigation in Angolela Tera District, Central highland of Ethiopia**", and recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in **Plant Sciences** with a specialization in **Agronomy**.

________________________ ____________ ______________

Name of Internal Examiner Signature Date

________________________ _____________ ______________

Name of External Examiner Signature Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the CGS through the DGC of the candidates department.
Thesis approved by:

________________________ _____________ _______________

DGC (Department of Graduate Committee) Signature Date

Certification of the Final Thesis

I hereby certify that all the corrections and recommendations suggested by the board of examiners are incorporated in to the final thesis.

____---
--by

______________________________ ____________ _____________

Name of the Designate Signature Date
Stamp of CGS Date---------------
N.B: Use this form to submit the thesis with ----------------suggested by the examining board.

DEDICATION

It is my great pleasure to dedicate this thesis to my beloved mother, Mrs. Birke Tenaye and my brother Mr. Mesfin Tenaye, for their endless love, constant encouragement and support throughout my thesis progress.

STATEMENT OF THE AUTHOR

I, **Sintayehu Tenaye,** hereby declare that this thesis is my genuine work and that all sources of materials used for this thesis have been profoundly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for a Master of Science (M.Sc.) at Debre Berhan University and it has been deposited at the university library to be made available for users under the rules of the library. I intensely declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Brief quotations from this thesis are allowable without special permission, provided that an accurate acknowledgment of the source is made. Requests for permission for extended quotations from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the School of Graduate Studies when in his judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author and advisors of this thesis.

Name: Sintayehu Tenaye Endemetu **Signature: ---------------------**

Place: College of Agriculture and Natural Resource Sciences, Debre Berhan University.

Date of Submission: August 2014 E.C

BIOGRAPHICAL SKETCH

The author, Mrs. Sintayehu Tenaye was born on November 28th, 1995 in Leshete District, Jamma Woreda, and South Wollo Zone of Amhara National Regional State, Ethiopia. She attended her primary education at Elishama primary school; secondary and preparatory education at Degollo general secondary and preparatory school in 2010-2013 G.C. After passing the Ethiopian General Secondary Education Certificate Examination (EGSECE), she joined Debre Berhan University in 2014 and graduated with the degree of Bachelor of Science in Plant Sciences in July 2017. Then, she was employed at Debre Berhan University as a Graduate Assistant in 2017. After two years of work, she joined the School of Graduate Studies at Debre Berhan University to pursue her studies leading to the degree of Master of Sciences in Agronomy.

ACKNOWLEDGEMENT

Above all, I would like to express my sincere thanks to the Almighty God for his love, benevolence, forgiveness, generosity and for keeping my spirits up even in the most difficult times. My deepest thanks goes to Fresew Belete (Ph.D.) my major advisor, for his sustained and educative guidance, unreserved advice, suggestions and collaboration, constructive comments, exemplary support and professional involvement, which immensely contributed to the accomplishment from proposal preparation to the complete write-up of this thesis. I also extend my heart-felt thanks to Mitiku Ashenafi (Ph.D. candidate) my co-advisor, for his support during the preparation of the proposal, important comments during the field research and for writing the thesis.

I would like to thank Debre Berhan University for creating a learning environment in terms of training and land provision for my research and also the Ministry of Science and Higher Education for supporting me with research funds. I wish to express my thanks to Holleta Agricultural Research Center and its staff for their cooperation in giving linseed seeds and Addis Ababa National Soil Testing Center for soil laboratory analysis.

I would also like to express my gratitude to all my friends: Dr. Bizuayehu Desta, Netsanet Tena, Dr. Fikrey Tesfay, Getahun Alemayehu, Aemro Birhanu, Abreham Kefelew, Tsegaye Debasu, Nigus Mequanint and all the other people who helped me in one way or the other in completing this research work. I'd also like express to my heartfelt gratitude and deepest appreciation to all my families for their incredible morale support and encouragement to continue my studies.

ABBREVIATIONS AND ACRONYMS

ALA	Alpha Linoleic Acid
ANOVA	Analysis of variance
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
cmol kg^{-1}	centimoles per kilogram
CSA	Central Statistical Agency
DAP	Di Ammonium Phosphate
DBARC	Debre Berhan Agricultural Research Center
DMRT	Duncan’s Multiple Range Test
dS m^{-1}	deciSiemens per meter
EC	Electrical Conductivity
EU	European Union
FAO	Food and Agricultural Organization
FAO-STAT	Food and Agricultural Organization Statistics
kg ha^{-1}	kilogram per hectare
LSD	Least Significant Difference
m.a.s.l	meters above sea level
OC	Organic Carbon
PPM	Part Per Million
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
t ha^{-1}	tone per hectare
U.S.A	United States of America

TABLES OF CONTENTS

Contents **Page**

TABLE OF CONTENTS *(CONTINUED)*

TABLE OF CONTENTS *(CONTINUED)*

LIST OF TABLES

Tables **Page**

LIST OF FIGURES

Figures **Page**

LIST OF TABLES IN THE APPENDICES

Appendix Tables **Page**

EFFECT OF NITROGEN RATES ON YIELD COMPONENTS AND QUALITY OF LINSEED (*Linum usitatissimum* L.) VARIETIES UNDER IRRIGATION IN ANGOLELA TERA DISTRICT, CENTRAL HIGHLANDS OF ETHIOPIA

By:

Sintayehu Tenaye (B.Sc.), Debre Berhan University, Ethiopia

Advisors: Fresew Belete (Ph.D.), Debre Berhan University, Ethiopia

Mitiku Ashenafi (Ph.D. candidate), Debre Berhan University, Ethiopia

ABSTRACT

Linseed (Linum usitatissimum L.) is one of the most important oilseed crops in the central highlands of Ethiopia. However, its productivity is low mainly due to inappropriate use of nitrogen fertilizer and lack of improved varieties. Hence, a field experiment was conducted during 2021 under irrigation in the demonstration farm of Debre Berhan university, Chacha, Angolela Tera District, to evaluate the effects of four nitrogen rates (0, 11.5, 23, and 34.5 kg ha^{-1}) and three linseed varieties (Kulumsa-1, Tolle and Bekoji-14) on growth, yield and quality of linseed. The experiment was conducted using a randomized complete block design in a factorial arrangement with three replications. The results revealed that linseed varieties significantly influenced all phenological, growth, yield and quality parameters while nitrogen rate affected all parameters except plant population and fatty acid composition. The interaction effects of nitrogen rates and linseed varieties were highly significant (P<0.001) in relation to days to flowering and maturity, plant height, branch height, number of capsules plant^{-1}, thousand seed weight, total dry biomass yield, seed yield, straw yield, harvest index, percent oil content and oil yield. The application of N at a rate of 11.5 kg ha^{-1} to Bekoji-14 variety increased plant height (89.07 cm), number of capsules per pant (37.87), thousand seed weight (7.16 g) and seed yield (2200.99 kg ha^{-1}) by 30.16%, 9.83%, 40.94% and 40.68% as compared to Bekoji-14 variety with no nitrogen application. According to the results of partial budget analysis, the application of N at a rate of 11.5 kg ha^{-1} on the Bekoji-14 variety was economically beneficial as compared to the other treatments as it produced the highest net benefit (118,625.70 ETB ha^{-1}) with a MRR value (9591.96). In addition, correlation analysis revealed that seed yield is positively and significantly correlated with plant height, number of capsules per plant, number of seeds per *capsule, aboveground dry biomass yield, straw yield, harvest index and oil yield but it is negatively correlated with percent oil content. Hence, it can be concluded that the application of N at a rate of 11.5 kg ha*$^{-1}$ *on Bekoji-14 variety could be recommended to enhance seed yield and quality of linseed in the study area and other similar agro-ecologies. However, as this is a one-season experiment at one location, a similar experiment has to be repeated over multiple locations and seasons in the district to reach a conclusive result.*

Keywords: Linseed, nitrogen, quality, varieties and yield

1. INTRODUCTION

Linseed (*Linum usitatissimum* L.) is one of the oldest oilseeds cultivated for food and fiber. It is used for oil production and in the food industries because of its nutritional qualities, essential polyunsaturated fatty acids and rich supply of soluble dietary fiber (Mohammad *et al*., 2010). It is a food and cash crop that generates revenue both in local and export markets. Industrial oil is an important ingredient in the manufacture of paints, varnishes and linoleum (Morris, 2005). Overall linseed plays a role in the treatment of cancer, arthritis and cardio logical diseases (Thompson *et al*., 2005). There is also a growing demand in the world market for linseed due to its numerous health benefits, especially in Europe (Wijnands *et al*., 2007).

The need for linseed has been increasing every year throughout the world as it contributes for the production of fiber in addition to its need for oil extraction and production of seed. The current worldwide acreage of linseed is 3.27 million hectares with a total annual production of 3.18 million tones and productivity of 975.10 kg ha^{-1} (FAOSTAT, 2020). Linseed is one of the widely grown economically important species, cultivated in many countries and production share of important countries like Russia (23%), Canada (19.8%), Kazakhastan (19.2%), China (12.4%), USA (7.5%), India (4.3%), Ukraine (3.2%), Ethiopia (3.0%), UK (1.6%), France (1.5%), Sweden (0.6%), Argentina (0.6%), Brazil (0.4%), Belgium (0.3%), Poland (0.3%) and others (2.3%) of the world (FAOSTAT, 2020).

Linseed has long history of cultivation by smallholder farmers, exclusively for its oil in the traditional agriculture of Ethiopia (Hiruy and Nigussie, 1988). It is a major oilseed crop produced in the South Eastern and Central Highlands of Ethiopia followed by Noug. It is the second major after Noug and the third major after Noug and sesame in the Oromia region and Ethiopia, respectively (CSA, 2016). In Ethiopia, linseed shares a total area coverage of 0.62% ha (79044.51 ha) with a total production of 3233448.8 quintals and the productivity of 4.09 t ha^{-1} which is certainly low as compared to the national average yield (11.16 t ha^{-1}) (CSA, 2017). Such low productivity in central highland of Ethiopia is due to various biotic and abiotic stresses, including low soil fertility, lack of improved varieties resistant to major diseases, insect pests and unavailability of improved agronomic practices (Abebe Delesa and Adane Chofere, 2016). Among those its productivity and oil quality can be improved through the use of optimal nitrogen fertilizer and identification of the most suitable varieties (Alemu *et al.*, 2020). The Ethiopian edible oil sector produces approximately 20,000 tons of edible oil annually; while domestic demand is estimated at 200,000 tons. Consequently, Ethiopia imports up to 160,000 tons of edible oil annually and this figure is increasing every year (PPPO, 2009).

Linseed grows under cool conditions, on clean, firm and smooth seedbed (Mridula *et al*., 2013). In Ethiopia the crop performs best in altitudes ranging from 2200-2800 m.a.s.l; but it is also produced in areas as low as 1200 m.a.s.l and as high as 3420 m.a.s.l (Hiruy and Nigussie, 1988). It is widely cultivated in the high elevations area of Arsi, Bale, Shewa, Gojam, Gonder, Wollo and Wellega (Getinet and Nigussie, 1997).

Nitrogen fertilizer is critical for increasing linseed crop productivity. According to Hiruy and Nigussie (1992), 23 kg N ha^{-1} is the blanket recommendation for linseed production in the country. However, the amount of fertilizer recommended for crops should be depending on the soil fertility status and nutrient utilization efficiency of the crops and the ultimate goal of economic yield. The increasing nitrogen significantly increases plant height, number of capsules $plant^{-1}$, 1000-seed weight and seed yield ha^{-1} (Soethe *et al*., 2013). However, applying high nitrogen rate beyond 46 kg ha^{-1} increases vegetative growth, disease susceptibility and lodging (Girma Taddese and Sintayehu Tenaye, 2018). Nitrogen fertilizer application has minimal effect on oil contents and fatty acid profiles (Lilian *et al*., 2015).

In addition to nitrogen, improved varieties are also important factors for determining the yield and quality of linseed. Improved linseed varieties have better productivity and standard oil content compared to the local genotypes (Worku *et al.*, 2012). Using improved varieties gave 2.2-3 t ha^{-1} in research fields and some model farmers managed to produce as high as 2.0-2.5 t ha^{-1} and an average of 38.6% oil content when supported with an improved seed of linseed, (Adugna *et al.*, 2004; KARC, 2012; Mulusew *et al.*, 2013). However, their genetic potential is affected due to variation in agro-ecology, poor soil fertility and poor crop management practices (Alemu *et al*., 2020). Oil content and its fatty acids composition are the main parameters for linseed when evaluating nutrition quality. Linseed oil consists mainly of linolenic, linoleic, oleic, palmitic and stearic acids. In order to reach high linseed oil yield and quality, it is necessary to understand the factors of influence (Barbara *et al*., 2020).

The usage of improved seeds is one of the most efficient ways of raising crop production, but in Ethiopia less than 10 percent of farmers use improved seeds. The linseed variety influences the quality of the seeds, and respective varieties must be chosen to improve the linseed product quality (Klein *et al*., 2016). However, recently there has been increased interest in breeding and growing linseed cultivars which can be harvested for both seed and oil (Easson and Molloy, 2000).

Despite the wide values of linseed in terms of nutritional, industrial, and export earnings; its average productivity in Ethiopia is very low as compared to its worldwide productivity which can be attributed to several reasons. The reason why the productivity is low in Ethiopia is due to limited information available on linseed; developed agronomic management guideline that can guarantee high and good quality linseed yield especially on the recently released varieties, weed competition and its limited response to inputs. On the other hand, low soil fertility also limit the productivity of linseed in the country mainly accounted for removal of surface soil by erosion, nutrients removal by crops from the soil, complete removal of plant residue from farmland, and lack of crop rotation system on the farmland resulting in lower crop yield (Abay Ayalew, 2016; Belay Yebo, 2015).

Mostly, farmers in the Amhara region suffer from low soil fertility including macro nutrients especially nitrogen (Agricultural Transformation Agency, 2016). In addition, farmers in the study area grow linseed without application of fertilizer. According to Abebe *et al*. (2011) nearly 89% of the farmer's do not apply organic or inorganic fertilizers for the production of linseed crop. Therefore, there is an urgent need to increase the productivity of linseed to narrow the present yield gap due to lack of proper use of nitrogen fertilizer rate and improved varieties by developing high yielding varieties and optimal nitrogen application. A character which has higher range of genetic variability, high heritability and high genetic advance would be an effective to improve economic yields and quality (Aytac and Kinaci, 2009). The application of optimum nitrogen fertilizer and selection of variety may fill the yield reduction gaps. Moreover, there is little information on the response of linseed varieties to nitrogen fertilization to optimize yield and quality in Angolela Tera District. Therefore this study was carried out to address the response of linseed varieties to different rates of nitrogen fertilizer.

1.1. Objectives of the Study

1.1.1. General objective

- To determine the interaction effect of nitrogen fertilizer rates and varieties on yield components and quality of linseed (*Linum usitatissimum* L.) under irrigation.

1.1.2. Specific objectives

- To determine the rate of nitrogen fertilizer application that may result in the optimum yield with preferable linseed quality.
- To evaluate the influence of varietal differences on growth, yield and quality of linseed.
- To determine the economically feasible nitrogen fertilizer rates for linseed production in the study area.

2. LITERATURE REVIEW

2.1. Origin and Distribution

Linseed appears to have evolved from a wild form of flax (*Linum Bienne* Mill) due to the similar morphological and genetic characteristics in both species (Genser and Morris, 2003). It is thought to have originated from the Indian subcontinent due to the presence of the greatest biological diversity within the genus *Linum* in this geographical area (Genser and Morris, 2003). It was among the first domesticated plants. The origin of linseed (*Linum usitatissimum* L.), which is one of the oldest of cultivated plants is uncertain. However, it is generally accepted that linseed has originated from -Fertile Crescent- an area east to Mediterranean Sea towards India (Anonymous, 2010) and was probably first domesticated there. It is supposed to have originated in the four centers of origin, viz. Central Asiatic Centre, Near Eastern Centre, Mediterranean Centre and Abyssinian Centre and distributed over the continent including Ethiopia.

2.2. Taxonomy, Morphology and Phenology

The genus *Linum* is the largest in the family *Linaceae*. Linseed cultivars belong to the species *Linum usitatissimum*. Linseed (*Linum usitatissimum* L.) is an erect annual herbaceous plant 30-120 cm, in height with slender glabrous, grayish green stem. They are relatively taller in height with straight culms, less number of secondary branches towards the top of the stem (Gill, 1987). These plants generally produce fewer capsules and smaller seeds. Fruit is small round smooth globular capsule of 5-9 mm diameter. In most of the varieties, the capsule is of indehiscent type. Flaxseed is predominantly self-pollinating (Tadesse *et al*., 2010). Wind pollination is not seen because the pollens are relatively heavy and sticky (Anonymous, 2010).

There are dual-purpose cultivars, which are grown for both seed and fiber (Easson and Molloy, 2000). The life cycle of the plant ranges from 90 to 150 days depends on the variety and soil fertility level (Diederichsen and Richards, 2003). Seed maturity occurs 30-60 days after flowering. Plant height varies between 20 and 100 cm depending on cultivar and growing conditions (Freer, 1993). The plant has a distinct main stem, which produces branches and has a tap root, which branches freely (Diepenbrock and Iwersen, 1989). The stem of the plant can be divided into two components: the bark (outside the vascular cambium) and the core (inside the vascular cambium). Flowers are borne on small branches and are self-pollinated.

2.3. Ecological Requirements of the Crop

Linseed thrives best in regions with temperate climates with moderate warmth, high humidity and well-drained medium-heavy soils (Worku *et al.*, 2015). It requires moderate to cool temperatures and adequate moisture during the growing season for optimum seed yield and quality. Good yield can be achieved with a temperature range of 10-30 ^{0}C, and a mid-day relative humidity of 60-70%, and a rainfall of 150-200 mm distributed over the growing periods (Abebe and Adane, 2019). Its production is optimal on well-drained, medium heavy soils, especially silty loam, clay loam, and silty clays (Braidek, 1975). However, high temperatures in the absence of drought decreases seed set and reduces yield (Cross *et al.*, 2003). In addition to this cool climate also results in high oil and low protein content in seed (Bernacchia *et al.*, 2014). In order to reach high linseed yield, oil yield and quality, it is necessary to understand the factors of influence and it climatic requirement.

2.4. Production Status of Linseed in Ethiopia

Linseed was grown in 47 countries in 2004 with the seed production of 1.903 million metric tons (Smith and Jimmerson 2005). Canada has the highest area and production of flax in the world followed by China, USA, India and EU. In 2006, Canada produced 1.014 million tons of flax seed from an area of about 800 thousand hectares (Statistics Canada, 2006).

Linseed is being cultivated in Egypt, Europe and India since pre-historic times. The important linseed growing countries are India, Russia, Canada, Argentina, and the U.S.A. Productivity of Asian region (608 kg ha^{-1}) is approximately 60% of the world productivity of 1006 kg ha^{-1} (Anonymous, 2011a). India is the second largest (21.21%) linseed growing country in the world in terms of area of cultivation after Canada. Production wise, India ranks 4th (8.20%) in the world after Canada (40.51%), China (18.68%) and the USA (10.89%) (Srivastava, 2009). But as per Food and Agricultural Organization Statistical data (FAO-STAT, 2007), India ranks 3rd (9%) in the world‘s top 20 linseed producing countries. Linseed is distributed and produced in different parts of the world such as Canada, India, China, Kazakhstan, Russia, United States, Ethiopia and

Europe (Adugna, 2007). Among those Ethiopia is seventh in linseed production in the world with total share of 3.5% of linseed production (FAO, 2017).

At present, linseed is cultivated in about 3.420 ha with the contribution of 1.537 tons to the annual oilseed production of our country and the yield being 449 kg ha^{-1} is far below the world production of 21.23 tons from 21.12 ha with productivity of 1006 kg ha^{-1} (Anonymous, 2011a). However, the greatest challenges of linseed production in central highland of Ethiopia include poor usage and shortage of improved varieties, poor soil fertility management and unavailability of improved agronomic practices (Abebe and Adane, 2016). The production of linseed in Ethiopia in 2016/17 was about 87,911.655 tons from 80,353.74 ha with an average productivity of 1.094 t ha^{-1} (CSA, 2017).

Ethiopia is one the 5th major producer of linseed in the world after Canada, China, USA and India. In Africa Ethiopia is the first producer. This is mainly produced in central highland of the nation (Delesa *et al*., 2010). Linseed has a long history of cultivation by smallholder farmers and the second most important oil crops next to Noug, exclusively for its oil in the traditional agriculture of Ethiopia (Delesa *et al*., 2010). About 25% of the total land allocated for oil crop production in Oromia region was covered by linseed (CSA, 2019). Even though the production area of linseed is the second largest next to Noug, its productivity is still low as compared to its potential productivity.

2.5. Economic Importance of Linseed

Linseed occupies an important position in world market because of its multiple trade use. It is a valuable crop and every part of the plant has specific economic importance (Pandey and Dayal, 2003).

2.5.1. Human consumption and functional food

Linseed was being used as a food source and natural laxative dating back as far as the ancient Greeks and Egyptians. It was also being used as a food in Asia and Africa (Berglund, 2002). The unique and diverse properties of linseed are reviving interest in this crop. In 2005, approximately 200 new food and personal care products were introduced in the US market containing flax or flax ingredients (Morris, 2007), which suggests that linseed based products have the highest growth potentials in functional food industry.

Due to the presence of higher concentration of health promoting omega-3 fatty acids (alpha-linolenic acid), which lowers cholesterol level and imparts cardio vascular benefits, many linseed based recipes have been standardized. The crushed seeds/flour is used for value addition and for making various nutritious food preparations (Chauhan *et al*., 2009). But the linseed oil is not edible due to the laxative properties of the mucilage in the seed coat and presence of higher level of linolenic acid which causes rancidity and emits pungent flavors on oxidation. So on a very small scale, it is used for edible purpose as seed breads, bagels and fried food stuff by a small segment of people (Anonymous, 2006).

Functional or nutraceuticals are foods that claimed to have health-promoting or disease-prevention properties in addition to basic nutritional properties in the food. While a complete assessment of the research on linseed as a functional food is beyond the scope of this article, readers are directed to (Bloedon and Szapary, 2004; Fitzpatrick, 2007). It helps to reduce cardiovascular diseases by altering the ω-3 fatty acid content of cell membranes by improving blood lipids and endothelial function and also by exerting antioxidant effects (Bloedon and Szapary, 2004).

2.5.2. Animal feed

The quantity of hull in linseed meal is about 38%, twice the level in canola or soybean meals (Agriculture and Agri-Food Canada, 1997). Linseed oil is also used in mixed pet diets, including dogs, cats and horses. The essential fatty acids (ALA and LA) present in linseed contribute to a lustrous coat, help prevent dry skin and dandruff, and also help in reducing digestive and skin problems in animals.

2.5.3. Fertilizer

Linseed oil cake is one of the best nitrogenous fertilizer among oilcakes with respect to nitrogen, phosphorus and potassium (4.7% N, 11.7% P_2O_5, and 1.3% K_2O) contribution to soil (Anonymous, 2011b). It provides slow and steady nourishment, stimulation, protection from soil nematodes (particularly Meloidogyne javanica) and insects. So it also improves yields and quality of product like taste, flavor and amino acid composition etc. Moreover, it can also be used as a manure to prevent soil from unwanted microbes due to its germicidal properties by improving plant health and thereby gives greater resistance to infection (Anonymous, 2011b).

2.6. Factor Affecting Linseed Production in Ethiopia

Crop production is concerned with the exploitation of plant morphological or structural and plant physiological or functional responses with a soil and atmospheric environment to produce a high yield per unit area of land. Plants are cultured in different environments where they are exposed to various climate and soil conditions with a direct repercussion on the seed filling and its final composition (Westcott and Muir, 2003; Lafond *et al.*, 2008; Kirkhus *et al.*, 2013). In fact, several factors comprising temperature, rainfall, light, drought, ozone exposure, nitrogen deprivation, fertilizers may influence the nutritional quality of oilseeds especially lin*s*eed (Baldini *et al*., 2002; Flagella *et al.*, 2002; Rahimi *et al.*, 2011; Tripathi and Agrawal, 2013). Numerous works have reported the environmental effects on yield, oil content, fatty acids composition and phospholipids in oilseed plants (linseed, sesame, sunflower) (Zubr and Matthaus, 2002; Tripathi and Agrawal, 2013).

Seed quality and yield of linseed are known to be influenced by genotype, growing season, geographic location and agronomic practices associated with crop production including soil management, cultivation, weeding and watering (Wilcox and Shibles, 2001). Weather conditions like temperature and rainfall regime could also have an important effect on the yield and quality of produced seeds (Anastasiua *et al*., 2016). Environmental conditions influence crop growth and development, which are the most vital factors in reducing crop productivity (Franklin *et al*., 2010). Continental temperate climate influences a higher content of polyunsaturated fatty acid (ALA) and lower content of oleic acid (monounsaturated fatty acid) in comparison to crops from Mediterranean and subtropical regions (Klein *et al*., 2016). Oil content is higher when linseed grows at lower temperatures. It has a rather high demand for water 400 to 450 mm in the growth period (140 days). Genetic and environmental factors such as soil and climate can also influence linseed seed yield, oil content and the fatty acid composition of seed oil (Angelini *et al*., 2014; Bernacchia *et al.*, 2014; Elayan Sohair *et al*., 2015). The linseed variety influences the quality of the seeds, and respective varieties must be chosen to improve the linseed product and quality (Klein *et al*., 2016).

2.7. Effect of Nitrogen Fertilizer on Yield Components and Quality of Linseed

Nitrogen is often the most important plant nutrients, which affect the amount of protein, protoplasm and chlorophyll formed, consequently increases cell size, leaf area and photosynthetic activity. Nitrogen is also essential element of bio-molecules such as amino acids, proteins, nucleic acids and enzymes. It stimulates growth, expansion of the crop canopy and interception of solar radiation (Eckert, 2010).

2.7.1. Effect on yield and yield components

Nitrogen is an essential mineral nutrient for crop growth and yield (Xu *et al.*, 2012). Nitrogen application rates have increased rapidly and excessive quantities of nitrogen fertilizers have been used to enhance crop yields. However, Excessive nitrogen application could lead to soil acidification as well as worsen the soil environment thus, ultimately has a negative impact on linseed growth and yield (Guo *et al*., 2010; Schroder *et al*., 2011). Zhao *et al*. (2014) found that the application of lower nitrogen rates sustained high yields compared with higher nitrogen rates. Yield reductions in crops with high nitrogen fertilization are primarily caused by physiological disorders associated with excessive uptake of nitrogen and soil degradation (Qiao *et al*., 2012). Although, optimum nitrogen rates are affected by many factors, studies have shown that a moderate reduction in nitrogen inputs does not lead to a decrease in crop yield (Luo *et al*., 2018) but, conversely, improved nitrogen use efficiency (Zhang *et al*., 2015a). Excessive nitrogen fertilization has caused low nitrogen use efficiencies and serious environmental problems (Cui *et al*., 2016; Zhu *et al*., 2016). Therefore, rational nitrogen fertilization strategies must be considered for achieving high crop production and sustainable agro-ecosystem. The amount of fertilizers that a crop needs depends on many factors including climate conditions, plant species and cultivar, and soil fertility levels (Casa *et al*., 1999).

The suitable fertilizing program is necessary for optimizing linseed cultivation and its qualitative and quantitative characteristics (Dordas, 2010). Besides genotype and other environmental factors, plant nutrition and adequate levels of nutrient elements is prerequisite for maximum yield. Surveys show that there is an increase of about 50% in food production due to use of chemical fertilizers (Aliari, 2006). Linseed yield is also increased by increasing nitrogen application (Hussain and Zedan, 2008). Excess nitrogen application results in reduction of seed yield by promoting vegetative growth (Ibrahim *et al.*, 2010).

Lafond *et al*. (2003) and Soethe *et al*. (2013) also reported that nitrogen levels affect plant height, number of capsules plant^{-1}, 1000-seed weight and seed yield ha^{-1}.The experiments of Hocking *et al.* (1997) did not show a significant effect of increasing nitrogen rates on seed yield of linseed, while Dordas (2010) is of opinion that the nitrogen nutrition status of plants is one of more important nutritional factors that determine the level of yield components. Regarding plant production, effects of nitrogen fertilizers is higher than other fertilizers; however the efficiency of this fertilizer is low and frequently resulted in lodging and environmental pollution (Marschner, 1995). Linseed has also diverse and conflicting responses to nitrogen. Several reports indicated that it has a favorable response to nitrogen (Hocking, 1995; Tanwar *et al.*, 2011; Reta, 2015) especially when soil nitrogen was low (Marchenkov *et al.*, 2003). In addition, Ashfaq *et al*. (2001) found that the highest seed yield and yield components were obtained with 20 kg ha^{-1} nitrogen application. However, Grant *et al.* (2004) claim that too high rates of mineral fertilizers, in particular nitrogen fertilizers, can cause excessive branching of plants, which promotes their lodging and reduction in yield.

2.7.2. Effect on quality

Many researchers have decided that using nitrogen fertilizer in suitable needed level could improve quality of flax, including Zimmermann *et al.* (2006), Lafond *et al*. (2008), Dordas (2010), El-Nagdy *et al*. (2010), Rahimi *et al*. (2011), Homayouni *et al*. (2013) and Soethe *et al*. (2013). The effectiveness of mineral fertilization of linseed is still little known and, there is still no explanation for the effect of this factor on the biological determinants of yield potential and its quality (Zając, 2005). Independently of cultivar linseed fertilized with nitrogen at rates of 60 and 80 kg N ha^{-1}, compared to a rate of 40 kg N ha^{-1}, was characterized by significantly higher plant density per unit area as well as better productivity per plant and per crop. While other authors reported that linseed has a poor response to nitrogen in turn nitrogen had no effect on oil content (Leilah, 1993). These variable responses to nitrogen could be due to initial soil nitrogen level, soil moisture and growing seasons (Genene *et al*., 2006).

2.8. Effect of Variety on Yield Components and Quality of Linseed

Sowing the suitable varieties is important factor to enhance growth, yields and its components and quality parameters of linseed. Many investigators indicating that there are significant differences due to flax genotypes in growth, yield, yield components and quality traits due to the differences in genetic structure and their interaction with environmental conditions that prevailing during the growing season (Rahimi and Nourmohamadi, 2010 and Abd El-Mohsen *et al*., 2013). Al-Doori (2012) and Bakry *et al*. (2012) also showed that flax crop genotypes significantly differed for all studied yield, its component and quality parameters.

2.8.1. Effect on yield components

Many studies stated that flax genotypes can successfully grow under newly reclaimed soil conditions for improving their seed yield (Kandil *et al*., 2008; Bakry, 2009; El-Seidy *et al.*, 2015; Nawar *et al*., 2017; Emam, 2019). The highest numbers of capsules plant^{-1}, 1000-seed weight, seed yield and oil yield ha^{-1} was produced from strain genotype. Wadan (2013) reported that the two tested cultivars (Sakha 1 and Sakha 2) exhibited significant differences for almost yield traits. Gallardo *et al*. (2014) indicated that significant differences among flax genotypes were found for all studied characters. The best seed yields were observed in Prointa Lucero and Carape INTA varieties. Bakry *et al*. (2015) reported that Sakha-2 variety significantly surpassed Amon variety in plant height, technical length, seed yield per plant, straw yield per plant, 1000 seed weight, seed yield per fed, straw yield per fed, While, Amon variety surpassed Sakha-2 in fruiting zone length, number of capsules per plant. Many investigators also found statistical differences among flax genotypes related to straw, and seed yield per unit area (Khalifa *et al.*, 2011; Bakry *et al*., 2012; Homayouni *et al*., 2013; Gallardo *et al*., 2014; Bakry *et al*., 2015; El-Shafey *et al*., 2016; Sadi *et al*., 2017; Emam, 2019).

Yechalew Sileshi *et al.* (2019) showed that the highest plant height was recorded from Bekoji-14 (101.6 cm) and the shortest from BILTSTAR (83 cm). The highest number of seeds per capsule was obtained from CI-1652 (7.6), while the lowest number of seeds per capsule was obtained from Bekoji-14 (5.3). Similarly, the maximum amount of yield was observed for varieties BILTSTAR (2.06 t ha^{-1}) and minimum for varieties Chilalo (1.55 t ha^{-1}). Linseed varieties showed significant effects for the seed yield variable. Other authors, Choi *et al.* (2012) found that varieties produce the highest linseed yields due to their genetic compatibility with the growing agro-ecology. Abebe Delesa and Adane Chofere (2019) reported that Yadanno produced better seed yield (2246 kg ha^{-1}) than the standard check Kulumsa-1 (1772 kg ha^{-1}) across locations. Yadanno was 26.7% high yielder than the standard check (Kulumsa-1) and 44.5% high yielder than the local check (Belay-96).

2.8.2. Effect on quality

A significant effect of cultivars on oil yield and fatty acid composition were observed. Variety remains the principal factor affecting oil yield, percent oil content and fatty acid content of linseeds. Oil content in linseeds was reported between 30 to 50% of the dry weight containing 40 to 66% of C18:3 with a level highly dependent on the genetic variation between linseed genotypes (Adugna *et al*., 2004). As for other plant species, the linseed cultivars tend to maintain their rank in regard to oil content and fatty acid composition whatever the culture conditions (Ghamkhar *et al*., 2010, and Rahimi *et al*., 2011). Thus, the linseed genotype variability is specifically exploited to identify common molecular markers linked to oil content and fatty acids in order to establish efficient strategies for marker-assisted breeding of linseed (Chandrawati *et al*., 2014; Soto-Cerda *et al*., 2014). By contrast, varieties showed ´ no significant differences among them, with oil yield between 728 kg ha^{-1} and 842 kg ha^{-1}. Abebe Delesa and Adane Chofere (2019) reported that Yadanno had 30% oil yield and 2.4% oil content advantage over Kulumsa-1. Likewise, it had 55% oil yield and 7.1% oil content advantage over the local check. In agreement with Lafond *et al*. (2008) oil yield showed a significant response to varieties, decreasing from 844.75 kg ha^{-1} to 644.35 kg ha^{-1}. Concentrations of oleic and linolenic acids showed no significant differences between cultivars, the average for the cultivars under study being 30.19 g 100 g^{-1} and 47.96 g 100 g^{-1}, respectively. Varieties also showed to have an effect on palmitic, stearic and linoleic fatty acid composition.

2.9. Combined Effect of Nitrogen and Varieties on Yield Components and Quality of Linseed

The interaction effect of nitrogen and varieties significantly influenced seed yield and quality of linseed. Different varieties of linseed may respond differently in growth and yield to similar levels of nitrogen fertilizer rates (Weiss, 2000) owing to differences in nutrient uptake and use efficiency. Thus, the same recommended rates may not be optimal for enhancing the productivity of all cultivars (Mengel and Kirkby, 2001).

2.9.1. Effect on yield component

Since over and under application of nitrogen fertilizer affects crop performance and also the environment greatly, there should be appropriate recommendation depending on the environmental conditions of different regions and the cultivars (Ziadi *et al*., 2007; Gholizadeh *et al*., 2009). The introduction of high yielding linseed varieties accompanied with improved production technology packages like optimum N fertilization could markedly increase the production and productivity per a given hectare. Alemu *et al*. (2020) reported that the highest seed yields (1508 and 1423 kg ha^{-1}) were recorded from the 46 kg N ha^{-1} and 34.5 kg N ha^{-1} with Jeldu variety, respectively. However, the minimum seed yield was recorded from no nitrogen application with Kulumsa-1 (781.9 kg ha^{-1}), Bekoji-14 (833 kg ha^{-1}) and Jeldu (1040 kg ha^{-1}).

2.9.2. Effect on quality

Alemu *et al*. (2020) revealed that application of 23 kg N ha^{-1} had about 92.8% more than the yield advantage than the control treatment. This increase in quality could be the synergetic effect of nitrogen fertilizer and the suitability of the improved linseed variety to the growing agro-ecology. The average quality can be higher if a proper amount of nitrogen fertilizer is applied in accordance with linseed varieties. Similarly, Reta (2015) reported that nitrogen fertilizer level and improved varieties had a synergetic effect on oil quality of linseed.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted at Angolela Tera district, on demonstration site of Debre Berhan University, North Shewa Zone of Amhara National Regional State, Central Highland of Ethiopia in 2021 under irrigation. Angolela Tera district was located 112 km away from Addis Ababa and at a latitude and longitude of 9°15’0’’N 39°15’0’’E/ 9°35’0’’N 39°40’0’’E, respectively (Fig 1). The altitude of the study area was 2774 m.a.s.l. The mean annual minimum and maximum temperature of the district were 6.5 ^{0}C and 18 ^{0}C, respectively. The annual rain fall of the district was 1114 mm (DBARC, 2014). It encompasses agro ecologies of *dega*, *woina dega* and *kola* agro-climatic zones with a proportion of 85%, 13% and 2% respectively. Ethio GIS soil shape-files (2004) showed that the main soil types were Eutric Cambisols, Eutric Vertisols and Eutric Leptosols. The study area is generally suitable for cereal crops, pulses and oil crops including wheat, barley, bean, and linseed production.

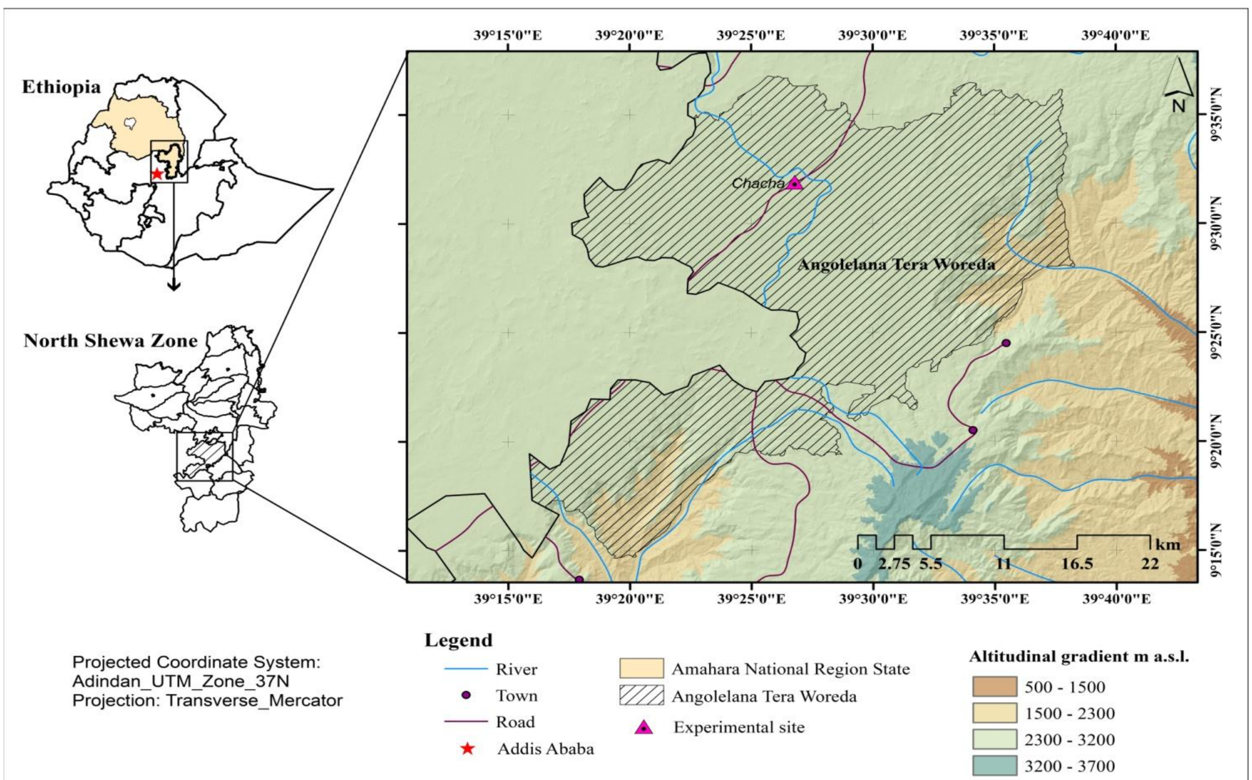

Figure 1. Map of the study area.

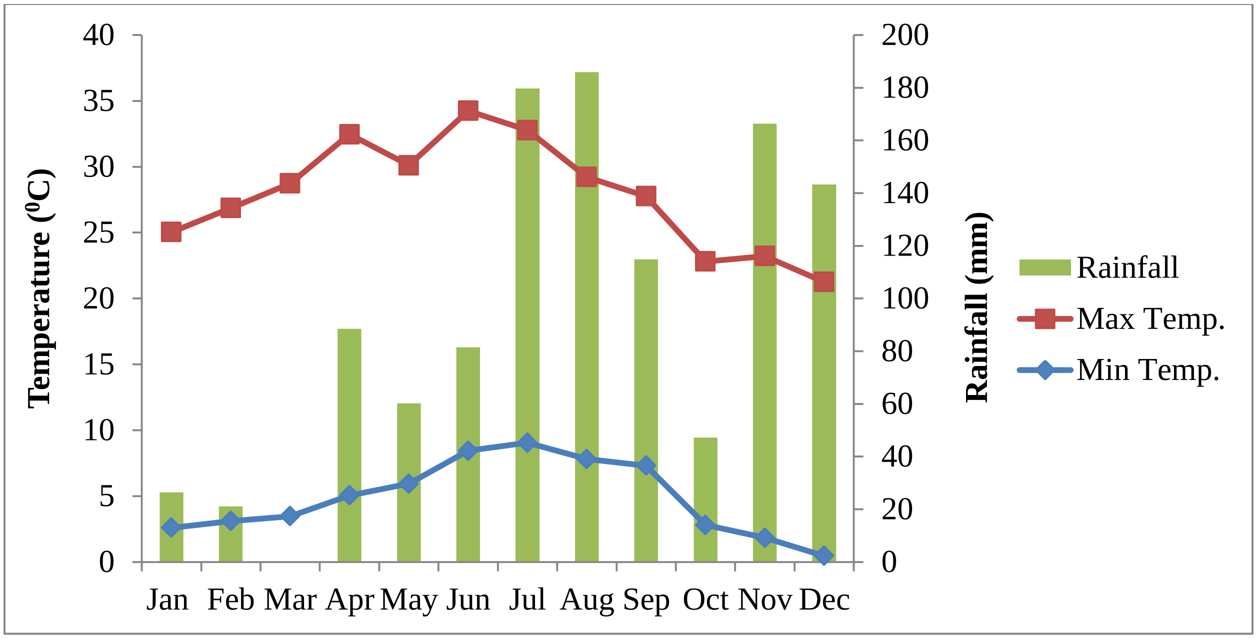

Figure 2. Monthly rainfall (mm), maximum and minimum temperature (^{0}C) during crop growing season in the study area

3.2. Description of the Experimental Materials

3.2.1. Plant and fertilizer materials

Three linseed varieties namely Kulumsa-1, Tolle and Bekoji-14, which are adapted to the agro-ecology of the area, were used for the study. The varieties were obtained from Holleta Agricultural Research Center. Urea (46% N) and TSP (46% P_2O_5) were used as a source of fertilizer for the study and obtained from Debre Berhan University and Debrezeit Agricultural Research Center (DZARC), respectively.

Table 1. Description of linseed varieties used for the experiment

No	Varieties	Year of release	Breeder	Oil content (%)	Seed color
1	Kulumsa-1	2006	KARC	37.1	Brown
2	Tolle	2004	HARC	36.0	Brown
3	Bekoji-14	2014	HARC	38.03	Brown

Source: Ministry of Agriculture and Natural Resource, 2016.

3.3. Treatments and Experimental Design

The treatments consisted of a total of twelve treatments four rates of nitrogen (0 kg, 11.5 kg, 23 kg and 34.5 kg ha^{-1}) and three varieties of linseed (namely; Kulumsa-1, Tolle and Bekoji-14). The experiment was laid out using RCBD in a factorial arrangement with three replications. The plots had 4 m^2 plot size and the spacing between plots and blocks were 0.5 and 1 m, respectively. Each plot had 8 rows which were spaced 20 cm apart. Therefore, the net plot area that was used for data collection consisted of 6 rows (1.2 m) each 2.1 m in length (2.52 m^2) and the total area for the experiment was 6.8 m × 35.5 m =241.4 m^2.

3.4. Experimental Procedures

Land preparation was started in January 2021 and the experimental land was prepared by plowing. Fine seedbeds were prepared; plots and rows were made across each plot. After the layout, the plots were leveled manually; under the specifications of the design, each treatment was assigned randomly to the plots within a block. The linseed plants in the two outer most rows on both sides of a plot as well as 0.2 m on each end of central rows were considered as border effect and not considered for data collection.

All linseed varieties were drilled at the rate of 25 kg ha^{-1}. Different rates of Urea 0 kg, 25 kg, 50 kg and 75 kg ha^{-1} according to the treatment and all the phosphorus (50 kg ha^{-1}) in the form of TSP was applied at the time of sowing to all plots uniformly. All other management practices such as watering and weeding were applied for the crop at the appropriate time to facilitate root, vegetative growth, and capsule formation of the tested crop. Furrow Irrigation was done accordingly as per the knowledge and experience of local farmers till the test crop was harvested. No insecticide or fungicide was applied as there was no incidence of insect pests or diseases.

3.5. Soil Sampling and Analysis

Soil samples were collected in a zigzag pattern from ten sampling spots of the prepared experimental field at a depth of 0-30 cm using an augur before sowing. The soil samples collected were made into one kg composite sample. The composite soil sample was dried, crushed with pestle and mortar and allowed to pass through a 2 mm sieve and prepared for analysis of some selected physical and chemical properties. The selected physical and chemical properties include organic carbon, total nitrogen, available phosphorus, available potassium, soil pH, electrical conductivity, cation exchange capacity and soil texture and were analyzed at Addis Ababa National Soil Testing Centre.

Organic carbon (OC) content was determined by the volumetric method (Walkley and Black, 1934). Total nitrogen (N) was analyzed by the Kjeldahl digestion method using sulfuric acid (Jackson, 1967). The available phosphorus (P) was determined by using the Olsen method as described by Olsen *et al.* (1954). The pH of the soil was estimated in the supernatant suspension of 1:2.5 soil and distilled water mixture by using a glass electrode pH meter. While cation exchange capacity (CEC) and available potassium (K) content were determined by the ammonium acetate method. Particle size distribution or textural class was done by the hydrometer method (FAO, 2008).

3.6. Data Collected

3.6.1. Phenological parameters

Days to 50% flowering (days): Determined as the number of days from sowing to the time when the linseed plants were flowered 50% based on visual observation.

Days to 90% maturity (days): Determined as the number of days from sowing to the time when the plants were reached 90% maturity based on visual observation. It was indicated by threshing of seed from the capsules when pressed between the forefinger and thumb.

3.6.2. Growth parameters

Plant height (cm): The plant height was measured at physiological maturity from the soil surface to the top parts of the plant of ten-randomly selected plants from the central unit area. The total measured plant height was summed together and divided by the number of plants to get the height per plant.

Branch height (cm): The height of the longest branch was measured from the cotyledon node to the tip parts of the branch of ten randomly selected plants and the average was taken by dividing the summed height per plant number.

3.6.3. Yield parameters

Stand **count (count):** The total number of plant stands per m^2 was counted after the plant branches and the data was recorded for further analysis.

Number of branches (No): The mean number of branches produced per plant was counted from ten randomly selected plants at the physiological maturity stage.

Number of capsules per plant (No): The total number of capsules per plant was counted from ten randomly selected plants and the average was taken for further analysis.

Number of seeds per capsule (No): The number of seeds was counted from the top, middle and bottom capsules of the ten randomly selected plants and the average was calculated by dividing by the total number of capsules and used for further analysis.

Thousand seed weight (g): It was determined based on the weight of 1000 seeds sampled from the bulk seed yield of each treatment by counting and their weight taken with an electronic sensitive balance and adjusted at 7% seed moisture content.

Above-ground dry biomass yield (kg ha^{-1}): The whole plant parts, including leaves, stems, and seeds from the net plot area were harvested at maturity, and after drying the biomass was measured. The complete drying was determined by obtaining constant weight.

Seed yield (kg ha^{-1}): Seed yield was measured from the harvested central unit areas of 2.52 m^2. Seeds were cleaned following harvesting and threshing and weighed using electronic sensitive balance, and adjusted to 7% moisture content.

Straw yield (kg ha^{-1}): Straw yield was calculated as the difference between total above-ground biomass and seed yield.

Harvest index (%): Harvest index was calculated by the ratio between seed yield and above-ground total biomass and expressed as percentage.

$$HI = \frac{Total\ seed\ yield}{Total\ above\ ground\ biomass} \times 100\%$$

3.6.4. Quality Parameters

Percent oil content (%): It was calculated as the proportion of oil in the seed to total oven-dried seed weight as determined by a nuclear magnetic resonance spectrometer (NMRS). In this experiment, 25 g of seeds were prepared and dried in an oven for two and half hours at 130 ^{0}C, and cooled for 30 minutes. Then oil contents of seeds were determined using nuclear magnetic resonance (NMR) in Holleta Agricultural Research Center Food and Nutrition Laboratory.

Oil yield (kg ha^{-1}): The amount of oil in kilogram per hectare was obtained by multiplying the seed yield per hectare by the corresponding seed oil percentage obtained from the oil content analysis and divided by one hundred (Legesse, 2010).

$$Oil\ yield = \frac{seed\ yield\ (kg/\ ha) \times percent\ oil\ content\ (\%)}{100}$$

Fatty acid profile analysis: It was analyzed using near-infrared reflectance spectroscopy (NIRS) to determine the percent of fatty acids composition (Palmitic acid, Stearic acid, Oleic acid, Linoleic acid, Linolenic acid). The near-infrared spectra was corrected with a monochromator (FOSS NIR system 500) by scanning at 1108-2492 nm spectra range with an 8 nm step and all spectra and reference data were recorded and managed with the Win ISI version II software (infra soft international port Matilda, PA, USA) (HARC, 2021).

3.7. Partial Budget Analysis

Partial budget analysis was made using the prevailing inputs at planting and for outputs at the time the crop was harvested. Partial budget analysis was estimated for the average yield of the different treatment combinations. Current prices of linseed and urea were used for the analysis. The potential response of crops towards the added fertilizer and the price of fertilizers during planting ultimately determine the economic feasibility of fertilizer application (CIMMYT, 1988). A treatment was considered worth to farmers when its minimum acceptable rate of return (MRR) is 100% (CIMMYT, 1988), which is suggested to be economically profitable. The partial budget analysis recommended by CIMMYT (1988) procedure was applied as follows:

Average yield (AVY) (kg ha^{-1}): It is the average yield of each treatment was converted to kilogram per hectare.

Adjusted yield (AJY): The adjusted yield for treatment is the average yield adjusted downward by 10% to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment.

$$AJY = AVY - (AVY \times 0.10)$$

Gross field benefit (GFB): The gross field benefit for each treatment was calculated by multiplying the field gate price that farmers receive for the crop when they sell it by an adjusted yield.

$$GFB = AJY \times \textit{field gate price}$$

Total variable costs (TVC): This is the sum of all the costs that vary for a particular treatment. **Net benefits (NB):** This was calculated by subtracting the total variable costs from the gross field benefit for each treatment.

$$NB = GFB - TVC$$

Dominance analysis (D): It was carried out by first listing the treatments in order of increasing costs that vary. Any treatment that has net benefits that are less or equal to those of treatment with lower costs that vary is dominated.

Marginal rate of return (MRR): It was computed by dividing the change in net benefits with the change in total variable costs multiplied by a hundred and expressed as a percentage.

$$MRR = \frac{change\ in\ NB}{Change\ TVC} X\ 100\%$$

Where; MRR= Marginal rate of return, NB= change in net benefit, TVC= change in total variable cost.

Following these procedures, economically the best nitrogen rate with the best variety was selected for linseed production in the study area.

3.8. Data Analysis

The collected data were subjected to statistical analysis. Analysis of variance (ANOVA) was carried out using SAS version 9.3 statistical software programs. Comparisons among treatment mean with a significant difference for measured and scored characters were made using Duncan's Multiple Range Test (DMRT) at a 5% level of significance (SAS Institute, 2012). Moreover, correlation analysis for some selected parameters was conducted for growth, yield and quality of linseed varieties using a person's correlation coefficient.

4. RESULTS AND DISCUSSION

4.1. Soil Physico-Chemical Properties of the Experimental Site before Sowing

Soil analysis for specific parameters relevant to the current study was carried out at Addis Ababa National Soil Testing Center. The proportion of sand, silt and clay in the soil of the experimental site was 21%, 31% and 48%, respectively (Table 2). Thus, the texture of the soil was clay. The texture properties of the soil influence water holding capacity, water intake rates, aeration, root penetration and soil fertility. The pH of the soil was 5.9 which were moderately acidic. This indicates that the soil reaction of the experimental sites is suitable for optimum growth and yield of most crops. According to Adugna Wakijra (2007), linseed will not perform well on soils with pH less than 5.0 or above 7.0, which show that the crop is sensitive to both soil acidity and alkalinity. The CEC of the soil was 55.65 cmol (+) kg^{-1} which was very high (Landon, 1991), this indicates that the soil has relatively high capacity to hold nutrient cation and supply to the crop. According to Landon (1991), CEC of the soils greater than 40 cmol (+) kg^{-1} is rated as very high and 25-40 cmol (+) kg^{-1} as high and CEC of soil from 15-25, 5-15 and <5 cmol (+) kg^{-1} of soil are classified as medium, low, and very low, respectively.

The total nitrogen content of the soil (0.25%) was medium which means fertilizer addition may increase growth and yield of linseed. Hazelton and Murphy (2007) described the N content of soil less than 0.15% as low, from 0.15-0.25% medium and greater than 0.25% as high. The organic carbon and organic matter analysis indicated that the experimental field had 3.80% organic carbon and 6.54% organic matter both of them was medium as per Booker (1991). Organic matter plays a key role in soil aggregate formation which reduces soil bulk density and compaction. As a result, it increases the soil water holding capacity. The available P content of the soil was 6.39 ppm. According to Olsen *et al*. (1954), the available P of the soil is low (6.39 ppm). Olsen *et al*. (1954) showed that in irrigated areas phosphorus content of soil classified as <12 ppm was low, 12-17 ppm marginal, 18-25 ppm adequate and >25 ppm was high.

The exchangeable K was 0.844 cmol (+) K kg which was low. The exchangeable K expressed as a percentage of CEC of the soils was considered to assess the response to potash fertilizers. A value greater than 2 cmol (+) K kg indicates a fairly good supply and the response to potash fertilizer is unlikely and <2 cmol (+) kg is low (Frinck, 1962). Potassium was one of the three primary nutrients, apparently its sufficient presence production. Also, the soil had no salinity problem as the electrical conductivity of soils was about 0.093 dS m^{-1}. Hazelton and Murphy (2007) described that the soil salinity effect below 2.0 dS m^{-1} is mostly negligible for most crops.

Table 2. Soil physic-chemical properties of the experimental site before sowing at Angolela Tera district of north Shewa during growing season of 2021

Soil parameters	Value	Rating	References
Sand (%)	21%		
Silt (%)	31%		
Clay (%)	48%		
Textural class	clay		Tekalign (1991)
pH	5.9	Lightly acidic	Motsara and Roy (2008)
CEC (cmol (+) kg)	55.65	very high	Hazelton and Murphy (2007)
EC (ds m^{-1})	0.093	good	Hazelton and Murphy (2007)
Total N (%)	0.25	medium	Goronski *et al*. (2010)
Available K(mg kg^{-1})	120	low	Frinck (1962)
Available P (ppm)	6.39	low	Olsen (1954)
Organic carbon (%)	3.80	medium	Booker (1991)
Organic matter (%)	6.54	medium	Booker (1991)

4.2. Phenological Parameters

4.2.1. Days to flowering

The analysis of variance revealed that days to flowering was significantly ($P<0.001$) affected by the main and interaction effect of nitrogen rates and varieties (Appendix Table 1). Tolle variety at 34.5 kg N ha^{-1} (84.00 days) delayed days to 50% flowering which was statistically similar to Bekoji-14 and Kulumsa-1 varieties at 34.5 kg N ha^{-1}. The delay in days to flowering due to the application of nitrogen at a rate of 34.5 kg ha^{-1} was 9 days and 13.37 days as compared to the application of nitrogen at a rate of 23 kg ha^{-1} on Bekoji-14 and 0 kg ha^{-1} on Kulumsa-1 variety, respectively. In general, application of the highest rate of N fertilizer delays maturity of all the tested varieties (Table 3).

The delay in days to flowering by the increased amount of nitrogen fertilizer on all varieties might be due to the rate of net photosynthesis and efficiency of assimilate partitioning to the vegetative parts and the vigorous vegetative growth due to the increased rate of nitrogen application. This in turn delays days to flowering.

Similarly, Manthar *et al*. (2022) reported that the flowering initiation took the maximum number of days (74.33) in linseed variety Pr-75, relatively lesser number of days to initiate flowering (70.00) were observed in variety Pr-83. Furthermore, Raja *et al*. (2007) reported that higher nitrogen application could boost vegetative growth resulting in late flower formation. Haruna (2011) and Bareja (2011) also mentioned that flowering is delayed with increasing nitrogen from lower to higher levels and the genetic makeup of sesame varieties can change plant growth stages (flowering stage). Contrary to the present finding, Fathy *et al*. (2009) reported that sesame cultivar was the latest in flowering date especially under the high nitrogen fertilizer rates.

Table 3. Interaction effect of nitrogen rates and linseed varieties on days to flowering and maturity

Nitrogen rates (kg ha^{-1})	Varieties	DTF(days)	DTM(days)
0	Kulumsa-1	70.67^{f}	126.33^{c}
	Tolle	78.33^{cd}	132.33^{ab}
	Bekoji-14	73.67^{ef}	126.33^{c}
11.5	Kulumsa-1	71.33^{ef}	124.00^{cd}
	Tolle	79.00^{bc}	132.33^{ab}
	Bekoji-14	70.67^{f}	123.00^{d}
23	Kulumsa-1	74.67^{de}	129.67^{b}
	Tolle	82.67^{ab}	132.33^{ab}
	Bekoji-14	75.00^{de}	129.67^{b}
34.5	Kulumsa-1	82.33^{a-c}	135.00^{a}
	Tolle	84.00^{a}	135.00^{a}
	Bekoji-14	82.33^{ab}	133.33^{a}
CV (%)		2.56	1.40

Treatment means followed by the same letter(s) are not significantly different. Where: CV= coefficient of variation; DTF= days to flowering; DTM= days to maturity;

4.2.2. Days to 90% physiological maturity

Days to maturity were significantly ($P<0.001$) affected by the main and interaction effect of nitrogen rates and varieties (Appendix Table 1). The application of nitrogen at a rate of 34.5 kg ha^{-1} on all varieties delayed days to maturity (135 days) which was statistically similar to Tolle variety at the application of 0, 11.5 and 23 kg N ha^{-1} while Bekoji-14 and Kulumsa-1 mature earlier in response to the application of 11.5 kg N ha^{-1} (Table 3). The delay in days to physiological maturity due to the application of 34.5 kg N ha^{-1} on all varieties was 12 days and 13 days as compared to the application of 11.5 kg N ha^{-1} on the Kulumsa-1 and Bekoji-14 variety, respectively.

The increased number of days required to reach physiological maturity in response to increased rates of nitrogen fertilizer on all varieties might be attributed to the enhanced availability of nitrogen in the soil and its increased uptake by the linseed varieties, which may have resulted in a more luxurious vegetative growth that might have resulted in delayed physiological maturity.

Similarly, Kutcher *et al.* (2005a) found delayed maturity in response to increasing rate of nitrogen in canola. The present study also revealed that, the application of nitrogen had no effect on the physiological maturity of Tolle variety, but on the other varieties application of nitrogen had a significant role in determining the days to physiological maturity. This might be due to the genetic difference between varieties. On the contrary, Reta Dargie *et al*. (2020) reported that application of nitrogen had no significant effect on days to physiological maturity on linseed crop. In agreement with the present study, Engin *et al.* (2010) reported a significant difference in days to 90% maturity among linseed varieties. Manthar *et al*. (2022) also reported that linseed variety Pr-75 took the maximum number of days (108.33) to reach physiological maturity while the lowest number of days required for physiological maturity was obtained from pr-84 variety (100 days).

4.3. Growth Parameters

4.3.1. Plant height

Plant height was significantly ($P<0.001$) affected by the main and interaction effect of nitrogen rates and varieties (Appendix Table 1). The highest plant height (89.07 cm) was recorded from the application of 11.5 N kg ha^{-1} on Bekoji-14 variety which was statistically similar with the application of 23 kg N ha^{-1} on Bekoji-14 variety and 11.5 kg N ha^{-1} on Kulumsa-1 variety. However the lowest plant height (68.43 cm) was obtained from Tolle variety without N application (Table 4). The increased in plant height due to the application of 11.5 N kg ha^{-1} on Bekoji-14 variety was 30.16% as compared to Tolle variety without nitrogen application.

The increase in plant height due to the increasing nitrogen rate (0 to 11.5 kg ha^{-1}) and genotypic difference might be due to vigorous growth of the plant and the genotypic character of the tested varieties. In addition, the optimum nitrogen rate increased length of the internodes which ultimately resulted in progressive increase in plant height as well as the medium amount of total nitrogen in the soil resulted in increased plant height.

In agreement with the present study, Tasew Derese and Muhammed Sitote (2020) reported that variety Bekoji-14 showed the highest plant height (88.94 cm) and yadenno showed the shortest plant height (81.06 cm). On the contrary, Lilian (2016) reported that plant height was not significantly influenced by the interaction of different nitrogen rate and lined varieties. Shahab-u *et al*. (2015) revealed that plant height of sesame increased on S-17 variety at optimum level of nitrogen application. Abdus Salam *et al.* (2020) also stated that the tallest plant height of sesame (83.14 cm) was found in 18.4 kg urea ha^{-1} and the shortest plant height (73.96 cm) was observed in control (no nitrogen) treatment. The author also, reported that the highest plant height of sesame (90.32 cm) was obtained in Binatil-3 variety fertilized with 55 kg N ha^{-1} and the lowest (72.90 cm) was recorded in BARI Til-3 variety along with 0 kg N ha^{-1}.

Table 4. Interaction effect of nitrogen rates and linseed varieties on plant height and branch height

Nitrogen rate (kg ha^{-1})	Varieties	PH (cm)	BH (cm)
0	Kulumsa-1	72.27^{f-h}	62.40^{de}
	Tolle	68.43^{h}	57.73^{e}
	Bekoji-14	73.63^{fg}	64.57^{cd}
11.5	Kulumsa-1	84.20^{bc}	74.67^{ab}
	Tolle	71.07^{gh}	61.87^{de}
	Bekoji-14	89.07^{a}	79.67^{a}
23	Kulumsa-1	84.93^{a-c}	73.33^{b}
	Tolle	78.73^{de}	65.57^{cd}
	Bekoji-14	86.90^{ab}	79.77^{a}
34.5	Kulumsa-1	74.97^{e-g}	64.67^{cd}
	Tolle	80.47^{cd}	69.70^{bc}
	Bekoji-14	76.07^{d-f}	66.23^{cd}
CV (%)		3.25	4.70

Treatment means followed by the same letter(s) are not significantly different. Where; CV= coefficient of variation; PH= Plant height; BH= Branch height;

4.3.2. Branch height

Branch height was significantly ($P<0.001$) affected by the main and interaction effect of nitrogen rates and varieties (Appendix Table 1). The highest branch height (79.77 cm) was recorded from the application of 23 kg N ha^{-1} on Bekoji-14 variety which was statistically similar with application of 11.5 kg ha^{-1} N on Kulumsa-1 and Bekoji-14 varieties. However, the lowest branch height (57.73 cm) was obtained from Tolle variety without nitrogen application (Table 4). The increase in branch height due to the application of 23 kg N ha^{-1} on Bekoji-14 variety was 38.18% as compared to Tolle variety without nitrogen application. The increase in branch height due to the increasing nitrogen rate (0 to 23 kg ha^{-1}) might be due to the vigorous growth of the plant that ultimately led to the increased branch height and the genotypic character difference between the cultivars.

In agreement with this study, Abd Eldaiem (2015) stated that Giza-10 cultivar of flax at 33.5 kg N ha^{-1} surpassed other studied genotypes (Sakha 2 and Strain 22) without nitrogen application in branch height. El-Saeed (2020) recorded the highest technical stem length or branch height (76.68) from Sakha-3 flax variety fertilized with 50 kg N ha^{-1} while the lowest was obtained from Giza 11 variety fertilized with low level fertilizer. Enaney Tigabu *et al*. (2020) also reported that Abasena sesame variety produced the highest branch height (65.66 cm) while the lowest branch height (46 cm) was obtained from Tate followed by Mehando-80 variety (48 cm).

4.4. Yield and yield components

4.4.1. Stand count

Stand count is one of the most important factors on which grain yield and other yield contributing attributes of crops are dependent. The analysis of variance revealed that stand count was significantly ($P<0.05$) affected by the main effect of variety. However, the main effect of nitrogen rates and their interaction did not significantly affect this parameter (Appendix Table 2).

The highest number of plants per m^2 (1121.67) was obtained from Kulumsa-1 variety (1166.67) which was statistically similar with Bekoji-14 variety (1121.67). However, Tolle variety (1035) recorded the lowest number of plant stands per m^2 (Table 5). The difference in number of plant stands per m^2 among the tested varieties could mainly be imputed to the potential difference in genetic structure constitution, their abilities responses to the environmental conditions and the germination capacity of those tested varieties.

Similarly, Andruszczak *et al*. (2015) reported that Szafir linseed variety had highest number of plants per meter square over variety Oliwin. These results confirm the findings of Genene Gezu *et al*. (2006) who reported no significant differences in stand count per square meter in response to different rates of nitrogen fertilizers on linseed. On the contrary, Pankaji and Badiyala (2016) revealed that plant stand per square meter was significantly affected by the main effect of nitrogen rate while not influenced by the main effect of linseed variety.

Table 5. Main effect of nitrogen rates and linseed varieties on plant population and number of branches per plant

N rate (kg ha^{-1})	PP	NB
0	1046.33	2.92^{b}
11.5	1159.33	3.32^{a}
23	1171.22	3.37^{a}
34.5	1055.44	3.19^{ab}
Varieties		
Kulumsa-1	1166.67^{a}	3.08^{b}
Tolle	1035.92^{b}	2.89^{b}
Bekoji-14	1121.67^{ab}	3.63^{a}
CV	11.1	10.09

Treatment means followed by the same letter (s) are not significantly different at P=0.05. Where; CV= coefficient of variation; PP= plant population; NB= number of branches.

4.4.2. Number of branches per plant

The analysis of variance revealed that number of branches was significantly (P<0.05) affected by the main effect of nitrogen rates and (P<0.001) varieties. However, the interaction effect did not significantly affect this parameter (Appendix Table 2). The application of N fertilizer at a rate of 23 kg ha^{-1} produced the highest number of branches (3.37) which was statistically similar with the application of 11.5 kg N ha^{-1} and 34.5 kg N ha^{-1}. However, the lowest number of branches (2.92) was obtained from the control treatment (Table 5).

The higher number of branches produced due to the application of nitrogen might be due to the increased number of leaves per plant and optimum level of nitrogen fertilizer application which enhanced the number of branches per plant. The application of nitrogen fertilizer beyond 23 kg N ha^{-1} decreased number of branches per plant due to lodging effect.

Similarly, Abebe Delesa and Adane Choferie (2016) reported that the application of 23 kg N produced more number of branches (2.5) per plant on linseed followed by the application of 11.5 kg ha^{-1} than other treatments. In contrary with this finding, Reta Dargie (2020) reported that the main effect of nitrogen had no significant effect on number of branches per plant on linseed crop. In addition, Genene Gezu *et al*. (2006) reported that nitrogen rate had no significance effect on number of branches per plant of linseed crop. Abdus Salam (2020) also described that the application of 36.8 N kg ha^{-1} produced the highest number of branches $plant^{-1}$ of sesame (2.68) whereas the lowest number of branches $plant^{-1}$ (1.31) was recorded from no nitrogen application (control plot).

As to the variety difference, the highest number of branches per plant (3.63) was obtained from Bekoji-14 variety while Tolle variety produced the lowest number of branches per plant (2.84) which was statistically similar with Kulumsa-1 variety (Table 5). The difference in number of branches per plant among tested varieties could be due to the genotypic character difference that caused a difference in the rate of photosynthesis and assimilate production that resulted in variation in vegetative growth. In addition, Bekoji-14 variety was more responsive to environmental conditions and invested towards stimulating the growth of lateral buds and then an increasing the number of branches.

Similarly, Bhagyalaxmi *et al*. (2022) reported that linseed variety RLC-148 produced significantly maximum number of branches over variety LSL-93. Andruszczak *et al*. (2015) reported that Szafir linseed variety had the highest number of branches per plant over variety Oliwin. In addition, Gaikwad *et al*. (2020) reported that the highest and the lowest number of branches per plant (5.40) was obtained from lined variety ll-93 and NL-260, respectively.

4.4.3. Number of capsules per plant

The number of capsules per plant was significantly ($p<0.001$) affected by the main and interaction effect of nitrogen rates and varieties (Appendix Table 2). The highest number of capsules per plant (37.87) was obtained from variety Bekoji-14 in response to the application of 11.5 kg N ha^{-1} while the lowest number of capsules per plant (18.47) was recorded from variety Tolle in response to the application of 34.5 kg N ha^{-1} (Table 6).

The higher number of capsules per plant with the increase in nitrogen (0-11.5 kg ha^{-1}) rates might be ascribed to the vigorous vegetative growth and branching of linseed varieties and the medium total nitrogen within the soil of the experimental site. This indicates that nitrogen is an important factor on distribution of photosynthetic assimilates between vegetative and reproductive organs which mean more availability of nitrogen resulting in enhanced vegetative growth, leading to improved fruiting and thereby increase number of capsules per plant. However, excessively high applications of nitrogen fertilizer beyond 11.5 kg ha^{-1} reduced number of capsules per plant can cause problems because rank crop growth results in lodging and poor capsule production in linseed.

In agreement with this study, El-Saeed (2020) reported that Giza 11 variety of flax received at 30 kg N ha^{-1} produced the highest number of capsules per plant. Tasew Derese and Muhammed Sitote (2020) reported that the maximum number of capsules per plant observed in Kuma linseed variety (39.38) followed by Yadenno (37.05) and the minimum number of capsules per plant were observed in Kassa-2 (18.83). Sharief *et al*. (2005) who have reported that nitrogen application significantly increased the number of capsules per plant of flax. Furthermore, Sisay Berhanu *et al*. (2016) revealed that the Barsan sesame variety recorded the highest number of capsules $plant^{-1}$ (46.07) at 46 kg N ha^{-1} and the lowest number of capsules recorded from Mehado-80 variety (10.87 $plant^{-1}$) without nitrogen application. Mesfin *et al.* (2019) also reported that significant differences among sesame varieties and nitrogen rates for number of capsules per plant.

Table 6. Interaction effect of nitrogen rates and linseed varieties on number of capsules per plant and thousand seed weight

Nitrogen rate (kg ha^{-1})	Varieties	NCPP	TSW
0	Kulumsa-1	31.93^{bc}	5.98^{bc}
	Tolle	19.10^{g}	5.08^{d}
	Bekoji-14	25.63^{d-f}	6.12^{bc}
11.5	Kulumsa-1	26.23^{de}	6.47^{b}
	Tolle	24.97^{d-f}	5.73^{c}
	Bekoji-14	37.87^{a}	7.16^{a}
23	Kulumsa-1	29.27^{cd}	6.53^{ab}
	Tolle	22.27^{e-g}	6.39^{bc}
	Bekoji-14	36.03^{ab}	6.66^{ab}
34.5	Kulumsa-1	20.60^{fg}	6.22^{bc}
	Tolle	18.47^{g}	6.42^{b}
	Bekoji-14	19.20^{g}	6.07^{bc}
CV (%)		10.99	5.69

Treatment means followed by the same letter(s) are not significantly different. Where: CV= Coefficient of variation; NCPP=Number of capsule per plant; TSW=Thousand seed weight;

4.4.4. Thousand seed weight

Thousand seed weight was significantly ($p<0.001$) affected by the main and interaction effect of nitrogen fertilizer rate and varieties (Appendix Table 2). The highest thousand seed weight (7.16 g) was recorded from the application of 11.5 kg N ha^{-1} on Bekoji-14 variety which was statistically similar with the application of 23 kg N ha^{-1} on kulumsa-1 and Bekoji-14 varieties. However, the lowest thousand seed weight (5.08 g) was obtained from Tolle variety without nitrogen application (Table 6).

The highest thousand seed weight attributed to the optimum application of nitrogen and genotypic difference might be attributed to the positive effect of nitrogen on biomass production of plants during their vegetative growth which later encouraged enlargement of seed size than those plants with no nitrogen application. Also the soil analysis of the experimental site of current study showed medium nitrogen content so the increasing in nitrogen beyond 11.5 kg ha^{-1} resulted in decreased thousand seed weight due to vigorous vegetative growth lead to lodging.

Similarly, Sisay Berhanu *et al*. (2016) reported that Barsan variety had the highest thousand seed weight at a rate of 46 kg N ha^{-1} and the lowest thousand seed weight was obtained from Adi variety grown in no nitrogen application. In addition, Shahab-u *et al.* (2015) revealed that thousand seed weight of sesame increased at 70 kg N ha^{-1} on S-17 variety while the lowest thousand seed weight of sesame obtained from Pr-125 variety at 0 kg N ha^{-1}. In agreement with this, Ashfaq *et al*. (2001) also reported that the increasing rate of nitrogen application and genetic difference significantly vary the mean seed weight.

4.4.5. Number of seeds per capsule

Number of seeds per capsule was significantly ($p<0.01$) affected by the main effect of nitrogen rate and ($P<0.05$) variety. However, the interaction effect did not significantly affect this parameter (Appendix Table 2). The highest number of seeds per capsule (8.45) was recorded from the application of 23 kg N ha^{-1} which was statistically similar with the application of 11.5 kg N ha^{-1} while the lowest number of seeds per capsule (8.07) was recorded by the application of 34.5 kg N ha^{-1} which was statistically similar with the control treatment (Table 7). This indicates increasing the rate of nitrogen beyond 23 kg N ha^{-1} significantly decreased number of seed per capsule. The highest number of seeds per capsule with the optimum rate of nitrogen application might be due to the sufficient amount of assimilates production that was favored by optimum vegetative growth and the moderate total nitrogen with in the soil. This in turn caused increased number of seeds.

Similarly, Abdus Salam (2020) described that the highest number of seeds capsule^{-1} of sesame (58.91) was recorded from the application of 36.8 kg N ha^{-1} whereas the lowest number of seeds capsule^{-1} (39.81) was found from the control treatment. In contrary with this result, Teshome Gutu and Alemayehu Debasa (2021) revealed that number of seeds per capsule of linseed was not affected by main effect of nitrogen fertilizer rates. Paul and Savithri (2003) and Mekonnen *et al.* (2016) also reported that the application of 36.8 kg N ha^{-1} produced the highest number of seeds capsule^{-1}. In addition, Malik *et al.* (2003) recorded the higher significance difference among nitrogen levels for number of seeds per capsule on sesame.

With regard to varietal effect, the highest number of seeds per capsule (8.37) was obtained from Bekoji-14 variety but statistically similar with Kulumsa-1 variety (8.23). However, Tolle variety produced the lowest (8.09) number of seeds per capsule (Table 7). The difference in number of seeds per capsule among varieties could be due to their genotypic difference.

Similarly, Tasew Derese and Muhammed Sitote (2020) also stated that the maximum number of seeds per capsule was observed in Kuma linseed variety (8.83), followed by Yadenno (8.61) and the minimum number of seeds per capsule were observed in Kassa-2 (7.33). In addition, Yechalew Sileshi (2019) reported that the highest number of number of seeds per capsules of linseed was obtained from variety CI-1652 (7.6), while the lowest number of seeds per capsule was obtained from Bekoji-14 variety (5.3). Andruszczak *et al*. (2015) also reported that Oliwin linseed variety had the highest number of branches per plant over variety Szafir.

Table 7. Main effect of nitrogen rates and linseed varieties on number of seeds per capsule

Nitrogen rate (kg ha^{-1})	NSPC
0	8.11^{b}
11.5	8.29^{ab}
23	8.45^{a}
34.5	8.07^{b}
Varieties	
Kulumsa-1	8.23^{ab}
Tolle	8.09^{b}
Bekoji-14	8.37^{a}
CV	2.76

Treatment means followed by the same letter(s) are not significantly different. Where: CV= coefficient of variation; NSPC= number of seeds per capsule

4.4.6. Above-ground dry biomass yield

The analysis of variance revealed that total dry biomass yield was significantly ($p<0.001$) affected by the main and interaction effect of nitrogen fertilizer rate and linseed varieties (Appendix Table 3). The highest biomass yield (9391.5 kg ha^{-1}) was recorded from the application of 34.5 kg N ha^{-1} on Kulumsa-1 variety which was in parity with Bekoji-14 variety at

11.5, 23 and 34.5 kg N ha^{-1} application while the lowest biomass yield (5562.2 kg ha^{-1}) was obtained from Tolle variety grown without N application (Table 8).

The highest above-ground dry biomass yield due to higher nitrogen rate and genotypic character difference might be attributed to the availability of nitrogen to the plant increased and it caused increased plant height, number of capsules per plant, branching and dry matter accumulation. Thus, ultimately contribute to the increment of above-ground biomass and also the suitable characters of tested varieties contribute for biomass increment.

Similarly, Sisay Berhanu *et al*. (2016) reported that the highest dry biomass yield was obtained by the application of 92 N kg ha^{-1} on Mehado-80 sesame variety (8.82 t ha^{-1}). However, Adi variety grown without nitrogen application produced the lowest dry biomass yield. Furthermore, Shehu *et al*. (2009) also obtained a significant increase in total dry biomass yield of sesame varieties with increasing nitrogen application rates. Leleu (2000) observed that plant height, number of leaves, leaf area, fresh and dry weight of shoot and number of flowers of canola increased in response to the increasing rate of nitrogen application.

4.4.7. Straw yield

Straw yield was significantly affected by the main and interaction effect of nitrogen fertilizer rate and varieties (Appendix Table 3). The highest straw yield (7545.6 kg ha^{-1}) was recorded from the application of 34.5 kg N ha^{-1} on Kulumsa-1 variety which was statistically similar with the application of 23 kg N ha^{-1} on Bekoji-14 variety while the lowest straw yield (3997.7 kg ha^{-1}) was recorded by Tolle variety without N application (Table 8).

The increase in straw yield due to the application of higher nitrogen fertilizer and genotypic character difference might be nitrogen was responsible for increased number of leaves/plant and leaf-area index, causing higher photosynthesis, assimilation rate, metabolic activity and cell-division, which were responsible for the significant increase in the growth characters, yield attributes and thus ultimately increase the straw yields. The highest straw yield in Kulumsa-1 under highest nitrogen rate variety was ascribed to its highest number of plant stand per meter square.

Similarly, Omar and Ash-Shormillesy (2006) and Andruszczak *et al*. (2015) also found that straw yield was significantly affected by flax cultivars and nitrogen fertilizer rates. Furthermore, El-Hariri *et al.* (2004) found that there were large differences in straw yield attributes among flax genotypes.

Table 8. Interaction effect of nitrogen rate and variety on total dry biomass yield, straw yield, seed yield and harvest index

Nitrogen rate (kg ha^{-1})	Varieties	ADBY (kg ha^{-1})	StY (kg ha^{-1})	SY (kg ha^{-1})	HI (%)
0	Kulumsa-1	6349.2^{e}	4609.2^{fg}	1740.05^{f}	21.78^{g}
	Tolle	5562.2^{f}	3997.7^{g}	1564.52^{g}	19.66^{h}
	Bekoji-14	6613.8^{de}	4821.5^{ef}	1792.31^{ef}	22.60^{g}
11.5	Kulumsa-1	7275.1^{cd}	5152.3^{d-f}	2122.79^{ab}	27.23^{c-e}
	Tolle	7010.6^{cd}	5390.9^{c-e}	1619.66^{g}	24.41^{f}
	Bekoji-14	8862.4^{a}	6661.4^{b}	2200.99^{a}	28.20^{bc}
23	Kulumsa-1	8068.8^{b}	5927.6^{c}	2141.36^{ab}	28.96^{ab}
	Tolle	7275.1^{cd}	5261.9^{c-f}	2013.17^{c}	26.17^{e}
	Bekoji-14	9127.0^{a}	6969.7^{ab}	2157.25^{ab}	29.62^{a}
34.5	Kulumsa-1	9391.5^{a}	7545.6^{a}	1845.98^{de}	26.09^{e}
	Tolle	7672.0^{bc}	5577.2^{cd}	2094.71^{b}	27.67^{b-d}
	Bekoji-14	8730.2^{a}	6817.5^{b}	1912.63^{d}	26.55^{de}
CV		4.79	6.49	2.39	3.03

Treatment means followed by the same letter(s) are not significantly different. Where: CV= coefficient of variation; ADBY=above-ground dry biomass yield; StY=straw yield; SY=seed yield; HI=harvest index;

4.4.8. Seed yield

The analysis of variance revealed that seed yield was significantly ($p<0.001$) affected by the main and interaction effect of nitrogen fertilizer rate and varieties (Appendix Table 3). The highest seed yield (2200.99 kg ha^{-1}) was recorded from the application of 11.5 kg N ha^{-1} on Bekoji-14 variety which was statistically similar with the application of 11.5 kg N ha^{-1} on Kulumsa-1 variety and 23 kg N ha^{-1} on Kulumsa-1 and Bekoji-14 varieties. However, the lowest seed yield (1564.52 kg ha^{-1}) was obtained from Tolle variety without N application (Table 8).

The increase in seed yield due to the application of nitrogen fertilizer and the genotypic makeup difference might be related to the synergetic effect of nitrogen fertilizer and the suitability of the improved linseed variety to the growing agro-ecology and the favorable effect of optimum nitrogen fertilizer levels on yield attributing characters as well as the moderate amount of total nitrogen in the soil analysis result, which finally resulted in higher seed yield. However, Grant *et al*. (1999) claim that too high rates of mineral fertilizers, in particular nitrogen fertilizers, can cause excessive branching of plants, which promotes their lodging and reduction in yield.

Similarly, Alemu *et al*. (2020) reported that the highest seed yield (1508 kg ha^{-1}) was recorded from the application of 34.5 kg N ha^{-1} with Jeldu variety of linseed while the minimum seed yield (781.9 kg ha^{-1}) was recorded from no nitrogen application with Kulumsa-1 variety. In line with this, Reta (2015) reported that nitrogen fertilizer level on improved varieties had a positive effect on seed yield of linseed. Bastia and Mohanty (2001) also described that high yielding varieties of linseed respond well to moderate dose of fertilizers. In addition, Hussain *et al.* (2009) reported that the application of recommended dose of fertilizers would be helpful in realizing yield potential of the linseed varieties. Lafond *et al*. (2008) and Laza and Pop (2012) also found variations in seed yields and its related traits among flax cultivars and nitrogen fertilizer rates.

4.4.9. Harvest index

Harvest index was significantly ($p<0.001$) affected by the main and interaction effect of nitrogen fertilizer rate and varieties (Appendix Table 3). The highest harvest index (29.62%) was recorded from the application of 23 kg N ha^{-1} on Bekoji-14 variety which was statistically similar with the application of 23 kg N ha^{-1} on kulumsa-1 variety while the lowest harvest index (19.66%) was recorded by Tolle variety without nitrogen application (Table 8). The higher harvest index attributed to the increased amount of nitrogen rate and genotypic efficiency difference might be related to variation in biomass yield and seed yield, which could be evidenced by significant linear relationship of these parameters with harvest index.

Similarly, El-Saeed *et al*. (2020) also described that the highest harvest index (16.48%) was obtained from Giza 11 linseed variety when received 30 kg N ha^{-1} while Sakha 3 cultivar with no nitrogen application gave the lowest harvest index (10.10%). Sisay Berhanu *et al.* (2016) demonstrated that the highest harvest index of sesame (24%) was recorded from Barsan variety at 46 kg N ha^{-1} whereas the lowest (9%) was recorded by Barsan variety with no nitrogen application. In addition, Dereje (2012) reported a significant variation in harvest index among sesame varieties due to a difference in nitrogen rate application.

4.5. Quality Parameters

4.5.1. Percent oil content

The analysis of variance indicated that percent oil content was significantly ($P<0.001$) affected by the main and interaction effect of nitrogen fertilizer rate and varieties. The highest percent oil content (37.5%) was recorded from Kulumsa-1 variety without nitrogen application which was statistically similar with the application of 23 kg N ha^{-1} on Bekoji-14 variety, 11.5 kg N ha^{-1} on kulumsa-1 variety, Bekoji-14 variety with no nitrogen application and 23 kg N ha^{-1} on Kulumsa-1 variety. However, the lowest percent oil content (34.87%) was obtained from Tolle variety fertilized with 34.5 kg N ha^{-1} (Table 9). In general, increasing rate of nitrogen to the highest rate decreased the percent oil of linseed varieties tested.

The reduction in oil content of all the varieties at higher supply of nitrogen rate might be due to the conversion of more carbohydrate into protein and thus the amount of synthesized carbohydrates left for conversion into fats are relatively low. Moreover, it could be due to the dilution effect of oil in heavier seeds produced under higher nitrogen.

In agreement with this, Tanwar *et al*. (2011) obtained the highest oil content from lowest dose of nitrogen levels and Kulumsa-1 variety. Similarly, Rahimi *et al.* (2011) found that up to 50 kg ha^{-1} of N fertilizer had no effect on linseed oil content. On the contrary, Ibrahim (2009) reported that increasing N fertilization of linseed from 107-179 kg ha^{-1} led to increased oil content. Some studies on the oil contents of linseed varieties have reported the mean values ranging from 23-45.7% (El-Beltagi *et al.*, 2007; Diederichsen and Fu 2008, Bayrak *et al.*, 2010; El-Beltagi *et al.*, 2011). The oil contents of the tested varieties in the present study also fell within this range (34.87-37.50%). Moreover, Nykter and Kymäläinen (2006) also reported that the linseed oil content ranged from 26-45% depending on the cultivars and growing agro-ecology. Furthermore, Pali and Mehta (2014) also stated that linseed has high oil content (20-40%) depending on the varieties.

Table 9. Interaction effect of nitrogen rates and varieties on percent oil content and oil yield

Nitrogen rate (kg ha^{-1})	Varieties	POC (%)	OY (kg ha^{-1})
0	Kulumsa-1	37.50^{a}	652.50^{d}
	Tolle	36.73^{bc}	578.37^{e}
	Bekoji-14	36.97^{ab}	653.37^{d}
11.5	Kulumsa-1	37.07^{ab}	786.83^{a}
	Tolle	36.17^{b-d}	585.77^{e}
	Bekoji-14	36.10^{b-d}	794.93^{a}
23	Kulumsa-1	36.75^{a-c}	786.93^{a}
	Tolle	35.38^{de}	712.30^{bc}
	Bekoji-14	37.08^{ab}	800.03^{a}
34.5	Kulumsa-1	35.36^{de}	653.00^{d}
	Tolle	34.87^{e}	730.43^{b}
	Bekoji-14	35.90^{cd}	686.67^{cd}
CV (%)		1.44	2.98

Treatment means followed by the same letter(s) are not significantly different. Where: CV= coefficient of variation; POC= percent oil content; OY= oil yield;

4.5.2. Oil yield

Seed oil yield was significantly (P<0.001) affected by the main and interaction effect of nitrogen fertilizer rate and varieties. The highest seed oil yield (800.03 kg ha^{-1}) was recorded from Bekoji-14 variety at 23 N kg ha^{-1} which was statistically similar with the application of 11.5 N kg ha^{-1} on Bekoji-14 variety, 23 and 11.5 N kg ha^{-1} on Kulumsa-1 variety while the lowest oil yield (578.37 kg ha^{-1}) was obtained from the application of 0 and 11.5 kg N ha^{-1} on Tolle variety (Table 9). This indicates Bekoji-14 and Kulumsa-1 varieties produced a higher seed oil yield when supplied with the optimum rate of nitrogen as compared to Tolle variety at these N rates.

The increase in oil yield due to the application of optimum nitrogen rate for all the varieties might be related to moderate nitrogen increase the number of capsules per plant and thereby the seed yield thus, ultimately increase in oil yield. However, nitrogen rate beyond 23 kg ha^{-1} decreased seed yield due to lodging effect and thereby decrease oil yield due to positive correlation between seed and oil yield.

This result agreed with Ozer *et al.* (2004) and Aglave *et al.* (2009) who found increased oil yield of linseed in response to increasing rate of nitrogen. Cheema *et al.* (2001) and Poonia (2003) also reported the role of nitrogen fertilizer to enhance the seed and oil yields of linseed. The present study is also in line with the report of Sana *et al.* (2003) who studied significant variations in oil yield among sesame varieties.

4.5.3. Fatty acid composition

The fatty acids profiles for the studied varieties, produced under different nitrogen rates are shown in Table 10. Linseed oil consists mainly of palmitic, stearic, oleic, linoleic, and α-linolenic acids. The main fatty acid is α-linolenic acid, an omega-3 tri-unsaturated fatty acid ranging from 47.36% to 53.01% (Barbara *et al*., 2020).

4.5.3.1. Palmitic acid

The analysis of variance showed that the palmitic fatty acid composition of linseed was significantly ($P<0.05$) influenced by the main effect of varieties. However the main effect of nitrogen rates and their interaction doesn't affect this parameter (Appendix Table 4). The highest palmitic acid was recorded from Bekoji-14 variety (6.14%) which was statistically similar with Kulumsa-1 variety (5.85%) while the minimum was obtained from Tolle variety (5.44%) (Table 10). This difference in palmitic fatty acid could be attributed due to the genetic variability of tested linseed varieties.

Similarly, Alemu *et al*. (2020) reported that the maximum (6.1%) and minimum (5.6%) of palmitic fatty acid composition of linseed were obtained from Jeldu and Kulumsa-1 varieties, respectively. This also indicated how genetic makeup of varieties played a significant role in determining the fatty acid composition in linseed. Gabiana (2005) also reported that nitrogen rate had no significant effect on palmitic fatty acid of linseed. The present finding was in agreement with Pali and Mehta (2014) who reported that the range of palmitic fatty acid in linseed ranged from 5.0 to 9.9%.

4.5.3.2. Stearic acid

The analysis of variance showed that the stearic fatty acid composition of linseed was significantly (P<0.05) influenced by the main effect of varieties. However the main effect of nitrogen rates and their interaction doesn't affect this parameter (Appendix Table 4). The highest stearic acid was recorded from Bekoji-14 variety (4.27%) which was statistically similar with Kulumsa-1 variety (3.78%) while the minimum was obtained from Tolle variety (3.45%) (Table 10). The difference in percent of stearic fatty acid composition might be due to variation in the genotypic characteristics of linseed varieties.

Similarly, Gambus *et al.* (2003) reported that linseed oil contains from 4 to 5.4% stearic acid. In addition, Pali and Mehta (2014) also revealed that stearic fatty acid composition of linseed ranged from 1.3 to 7.6% depending on varieties and soil fertility level. Hence, the result of this study is in line with the range of stearic fatty acids of other studies. Gabiana (2005) also reported that nitrogen rate had no significant effect on stearic fatty acid of linseed. On the contrary, Alemu *et al*. (2020) revealed that the stearic fatty acid composition of linseed was not influenced by the main effect of linseed varieties.

Table 10. Main effect of nitrogen rates and linseed varieties on palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid

N rate (kg ha^{-1})	PA	SA	OA	LA	LCA
0	5.76	3.66	16.66	13.41	34.37
11.5	5.78	3.68	16.74	13.44	34.39
23	6.14	4.04	17.15	13.81	34.92
34.5	5.57	3.95	17.17	13.11	34.34
Varieties					
Kulumsa-1	5.85^{ab}	3.78^{ab}	17.09^{ab}	13.51^{ab}	34.63^{ab}
Tolle	5.44^{b}	3.45^{b}	16.45^{b}	13.06^{b}	34.09^{b}
Bekoji-14	6.14^{a}	4.27^{a}	17.25^{a}	13.76^{a}	34.81^{a}
CV (%)	10.38	20.83	4.57	4.48	1.99

Treatment means followed by the same letter(s) are not significantly different. Where: CV= coefficient of variation; PA= palmitic acid; SA= stearic acid; OA= oleic acid; LA= linoleic acid and LCA= linolenic acid.

4.5.3.3. Oleic acid

The analysis of variance revealed that the oleic fatty acid composition of linseed was significantly ($P<0.05$) affected by the main factor of varieties However, the main effect of nitrogen rate and their interaction doesn't affect this parameter (Appendix Table 4). The highest (17.25%) percent of oleic fatty acid composition of linseed were obtained from Bekoji-14 variety which was statistically similar with Kulumsa-1 variety and the minimum was obtained from Tolle variety (16.45%) (Table 10**).** The varietal difference in oleic fatty acid composition could be due to the difference in their inherent characteristics.

Similarly, Alemu *et al*. (2020) reported that the highest (19.6 %) and the lowest (18.6 %) percent of oleic fatty acid composition of linseed were obtained from Jeldu and Bekoji-14 varieties, respectively. Pali and Mehta (2014) also reported that the oleic fatty acid content in linseed genotypes differs and ranged from 13.3 - 35%.

As nitrogen level increased from zero to the highest level, it increased percent of oleic fatty acid significantly but there was no significance difference statistically. Similarly, Gabiana (2005) also reported that nitrogen rate had no significant effect on oleic fatty acid content of linseed. On the contrary, Klimek *et al.,* (2013) who reported that increasing the levels of mineral fertilizer increased the content of oleic fatty acids.

4.5.3.4. Linoleic acid

The analysis of variance indicated that percent of linoleic fatty acid composition of linseed was significantly ($P<0.05$) influenced by the main effect of varieties while nitrogen rates and the interaction of main factors didn't affected linoleic fatty acid composition (Appendix Table 4). The highest (13.76%) of linoleic fatty acid composition of linseed was obtained from Bekoji-14 variety which was statistically similar with Kulumsa-1 variety and the minimum was obtained from Tolle variety (13.06%) (Table 10**).** The difference in linoleic acid content among varieties might be due to their difference in their genetic makeup. The result of this study was in agreement with Hosseinian (2004) who reported that the content of linoleic fatty acid of linseed ranged from 11.18 - 16.13%. Similarly, Pali and Mehta (2014) reported that the values of linoleic acids ranged 10.4 - 20.9 % for linseed. On the contrary, Alemu *et al*. (2020) revealed that the linoleic fatty acid composition of linseed was not influenced by the main effect of linseed varieties and Gabiana (2005) also reported that nitrogen rate had significant effect on linoleic fatty acid of linseed.

4.5.3.5. Linolenic acid

The analysis of variance revealed that the linolenic fatty acid composition of linseed was significantly ($P<0.001$) influenced by the main factors of varieties while nitrogen fertilizer levels and their interaction doesn’t influenced this parameter (Appendix Table 4). The highest (34.81%) of linolenic fatty acid composition of linseed were obtained from Bekoji-14 variety which was statistically similar with Kulumsa-1 variety and the minimum was obtained from Tolle variety (34.09%) (Table 10). This variation also might be ascribed to their genetic makeup difference. Similarly, Pali and Mehta (2014) reported that the values of alpha-linolenic acids in linseed range (33.1 to 63.1%) depend on the cultivars. On the contrary, Alemu *et al*. (2020) recorded that the linoleic fatty acid composition of linseed was not affected by the main effect of linseed varieties and Gabiana (2005) also reported that nitrogen rate had significant effect on linolenic fatty acid of linseed.

4.6. Partial Budget Analysis

Partial budget is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. It is the process of examining only those costs, returns and resource need that change with a proposed adjustment. A partial budget is a way of calculating the total costs that vary and the net benefits of each treatment (CIMMYT, 1988).

From the result of the present study, the average yield of twelve treatment combinations was obtained. According to CIMMYT (1988), the average yield was adjusted down wards by 10%. This is for the reason researchers have assumed that using the same treatments the yields from the experimental plots and farmers’ fields are different, thus average yields should be adjusted downward. Based on this, the recommended level of 10% was calculated for all twelve treatment combinations to get the adjusted yield.

Furthermore, to obtain the gross field benefits, it is essential to know the field price value of one kg of linseed during harvesting time. Then adjusted yield was multiplied by field price to obtain gross field benefit. For different treatment combinations, the total costs and net benefits were calculated. The cost of this experiment includes the cost of Urea and labour for fertilizer application. The purchasing price of Urea was 18.00 birr kg^{-1} and the cost for daily labour during the season was 150 Birr per day. The field price of linseed during the harvesting season was 60 birr kg^{-1}. Finally to obtain net benefit all the total variable costs were subtracted from gross field benefit.

Hence, to recommend the present result for producers, it is necessary to estimate the minimum rate of return acceptable to producers in the recommendation domain. The results of the partial budget analysis revealed that the Bekoji-14 variety at 11.5 kg ha^{-1} N had the highest net benefit with net benefit (118,625.7 ETB ha^{-1}) and MRR of (9591.96) (Table 11). Therefore, the application of nitrogen at a rate of 11.5 on the Bekoji-14 variety was recommended for linseed production in the study area. This showed that fertilizer has a major role on a crop yield and preferable quality and hence optimum nitrogen rate with best performed variety is important to obtain maximum net profit.

Table 11. Summary of partial budget and marginal rate of return analysis for production of linseed varieties influenced by nitrogen fertilizer rates

N rate (kg ha^{-1})	Varieties	Av Y (kg ha^{-1})	Ad Y (kg ha^{-1})	TVC (ETB ha^{-1})	Ad TVC(ETB ha^{-1})	GFB (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	Kulumsa-1	1740.05	1566.04	0	0	93,962.40	93962.40	
11.5	Kulumsa-1	2122.79	1910.51	207	227.7	114,630.60	114,402.90	D
23	Kulumsa-1	2141.36	1927.22	414	455.4	115,633.20	115,177.80	D
34.5	Kulumsa-1	1845.98	1661.38	621	683.1	99,682.80	98,999.70	D
0	Tolle	1564.52	1408.10	0	0	84,486.00	84,486.00	-
11.5	Tolle	1619.66	1457.69	207	227.7	87,461.40	87,233.70	D
23	Tolle	2013.17	1811.85	414	455.4	108,711.00	108,255.60	D
34.5	Tolle	2094.71	1885.24	621	683.1	113,114.00	112,430.90	D
0	Bekoji-14	1792.31	1613.08	0	0	96,784.8.00	96,784.80	-
11.5	Bekoji-14	2200.99	1980.89	207	227.7	118,853.40	118,625.70	9591.96
23	Bekoji-14	2157.25	1941.52	414	455.4	116,491.20	116,035.80	D
34.5	Bekoji-14	1912.63	1721.37	621	683.1	103,282.20	102,599.10	D

Av Y= average yield; Ad Y= adjusted yield; TVC= total variable cost; Ad TVC= adjusted total variable cost; GFB= growth field benefit; NB= net benefit; MRR= marginal rate of return; D= dominated treatment; Purchasing price of urea fertilizer= 18.00 Eth-Birr kg^{-1}; purchasing price of linseed= 60 Eth-Birr kg^{-1}; Labour cost = 150 Eth-Birr per man per day.

4.7. Correlation of Seed Yield and Some Related Parameters

The correlation coefficient estimates the degree of association of different linseed yield, yield components and quality parameters among themselves. The correlation coefficient was calculated for the different response variables which help to show how the growth characters and yield components affected the growth, yield and quality of linseed.

Thus, it was observed that the total seed yield was highly significantly and positively correlated with plant population (r=0.44**), plant height (r=0.84**), branch height (r=0.81***), number of branch (r=0.53***), thousand seed weight (r=0.67***), above-ground dry biomass yield (r=0.64***), straw yield (r=0.51**), harvest index (r=0.81***), oil yield (r=0.98***) and significantly correlated with number of capsules per plant (r=0.37*) and number of seed per capsule (r=0.35*) (Table 12). This indicated that the increased growth of plant height, number of capsules per plant and number of seeds per capsule increased the yield and quality of linseed varieties. Similarly, Kumar and Paul (2016) indicated that seed yield of linseed had significant and positive association with plant height, biological yield, straw yield, and 1000-seed weight. In addition, Kant *et al.* (2008) also reported significant and positive correlation of seed yield of linseed with number of capsules per plant, number of seeds per capsule, aerial dry biomass, harvest index, thousand seed weight and oil yield. In addition, fatty acid profile component was positively and highly significantly correlated with each other.

However, seed yield was negatively and non-significantly associated with days to flowering (r=-0.13^{ns}) and percent oil content (r=-0.08^{ns}) while it is negatively and significantly correlated with days to maturity (-0.33*). The negative correlation between seed yield and percent oil content could be due to the decrease in seed oil content as seed yield increased with application of nitrogen fertilizer. Percent oil content was negatively and highly significantly correlated with day to flowering (r=-0.68***) and day to physiological maturity (r=-0.51**). Similarly Kaur and Paul (2020) showed that significant negative correlation was observed for days to flowering with oil content and days to maturity with oil content of linseed. This association indicates nitrogen fertilization had noticeably contributed to enhancing the yield and quality of linseed varieties. Finally, the effective yield improvement of linseed would be achieved through the characters which have significant and positive correlation with yield and other economic traits.

Table 12. Correlation analysis of phenological, growth, yield and quality parameter of linseed varieties as influenced by nitrogen fertilizer rates

Par.	DF	DM	PP	PH	BH	NT	NCPP	NSPC	TSW	ADBY	SY
DF	1.00										
DM	0.79***	1.00									
PP	-0.22ns	-0.32ns	1.00								
PH	-0.19ns	-0.35*	0.42**	1.00							
BH	-0.22ns	-0.38*	0.42**	0.96***	1.00						
NT	-0.16ns	-0.34*	0.67***	0.54***	0.60***	1.00					
NCPP	-0.63***	-0.63***	0.38*	0.38*	0.48***	0.38*	1.00				
NSPC	-0.21ns	-0.38*	0.24ns	0.24ns	0.48***	0.24ns	0.54***	1.00			
TSW	-0.21ns	-0.30ns	0.46**	0.73***	0.70***	0.61***	0.51***	0.46**	1.00		
ADBY	0.24ns	0.67ns	0.26ns	0.54***	0.56***	0.41**	0.19ns	0.31ns	0.53***	1.00	
SY	-0.13ns	-0.33*	0.44**	0.84***	0.81***	0.53***	0.37*	0.35*	0.67***	0.64***	1.00
StY	0.29ns	0.15ns	0.20ns	0.43**	0.46**	0.35*	0.13ns	0.28ns	0.46**	0.99***	0.51**
HI	0.10ns	-0.03ns	0.39*	0.81***	0.78***	0.43**	0.32ns	0.38*	0.71***	0.74***	0.81***
POC	-0.68***	-0.51**	0.36*	-0.07ns	0.03ns	0.19ns	0.45**	0.05ns	-0.07ns	-0.26ns	-0.08ns
OY	-0.27ns	-0.44**	0.52***	0.82***	0.81***	0.58***	0.47**	0.36*	0.66***	0.58***	0.98***
PA	-0.10ns	-0.32*	0.32ns	0.45*	0.45*	-0.51**	0.29ns	0.40*	0.32ns	0.39*	0.45*
SA	0.13ns	-0.16ns	0.18ns	0.42*	0.46*	0.37*	-0.02ns	0.19ns	0.26ns	0.44*	0.38*
OA	-0.14ns	-0.08ns	0.19ns	0.34*	0.36*	0.35*	-0.05ns	0.06ns	0.28ns	0.54***	0.40*
LA	-0.15ns	-0.32*	0.31*	0.43**	0.48**	0.39*	0.34*	0.44**	0.29ns	0.36*	0.40*
LCA	-0.02ns	-0.19ns	0.22ns	0.53***	0.55***	0.29ns	0.57ns	0.32ns	0.30ns	0.43*	0.47**

Correlation (*continued*)

Par.	STY	HI	POC	OY	PA	SA	OA	LA	LCA
STY	1.00								
HI	0.65^{***}	1.00							
POC	-0.27^{ns}	-0.25^{ns}	1.00						
OY	0.45^{**}	0.78^{***}	0.13^{ns}	1.00					
PA	0.35^{*}	0.28^{ns}	0.09^{ns}	0.46^{*}	1.00				
SA	0.41^{*}	0.28^{ns}	-0.11^{ns}	0.36^{*}	0.83^{***}	1.00			
OA	0.52^{**}	0.30^{ns}	-0.15^{ns}	0.37^{*}	0.71^{***}	0.88^{***}	1.00		
LA	0.32^{ns}	0.25^{ns}	0.13^{ns}	0.42^{*}	0.97^{***}	0.70^{***}	0.59^{***}	1.00	
LCA	0.39^{*}	0.34^{*}	-0.06^{ns}	0.46^{**}	0.92^{***}	0.85^{***}	0.74^{***}	0.90^{***}	1.00

Where: Par= parameter; DF= days to flowering; DM= days to maturity; PP= plant population; PH= plant height; BH= branch height; NB= number of branches; NCPP= number of capsules per plant; TSW= thousand seed weight; NSPC= number of seeds per capsule; TDBY= total dry biomass yield; StY= straw yield; SY= seed yield; HI= harvest index; POC= percent oil content; OY= oil yield; PA= palmitic acid; SA= stearic acid; OA= oleic acid; LA= linoleic acid; LCA= linolineic acid

5. SUMMARY, CONCLUSION AND RECOMMENDATION

Linseed is the most widely cultivated oil crops in Ethiopia and the country was one of the leading producers and exporters in the world. In Ethiopia, it is used as cash crop, export commodity, raw material for industries and as source of employment opportunity. Also it is the major export commodity of oil seed crops that generate foreign currency. The increment in linseed production and productivity can be related with different growth factors. Among those the use of appropriate agronomic management is an undoubted contribution to increased linseed yield and quality. Although several constraints are associated with linseed production including improper agronomic practice used by farmers, lack of improved seed varieties, moisture stress, poor crop management practices including proper nitrogen fertilizer application are the major problems. Hence, appropriate nitrogen fertilizer rates and improved varieties are the key agronomic practices which affect yield and quality of linseed.

Therefore, a field experiment was conducted during the 2021 main cropping season at Angolela Tera District demonstration site of Debre Berhan University to evaluate the effect of nitrogen fertilizer rates on growth, yield and quality of linseed (*Linum usitatisimum* L.) varieties. The treatments consisted of four rates of N fertilizer (0, 11.5, 23, and 34.5 kg ha^{-1}) and three linseed varieties (Kulumsa-1, Tolle and Bekoji-14). The experiment was laid out using a randomized complete block design in a factorial arrangement with three replications.

The analysis of variance revealed that phenological, growth, yield and quality parameters responded differently to varieties and nitrogen fertilizer rates. Plant population and fatty acid profile was significantly influenced by the main effect of varieties alone. While number of branches and number of seeds per capsule were significantly influenced by the main effect of nitrogen rates and varieties.

However, days to flowering, days to maturity, plant height, branch height, number of capsules per plant, thousand seed weight, above-ground dry biomass yield, seed yield, straw yield, harvest index, percent oil content and oil yield was significantly influenced by the interaction effect of nitrogen fertilizer rates and linseed varieties.

Plants grown at the higher rates of nitrogen application (34.5 kg ha^{-1}) required higher number of days to flower and mature. Similarly, difference in linseed varieties resulted in difference flowering and maturity period. Significantly more number of branches and higher number of seeds per capsule were obtained by the application of nitrogen at a rate of 23 and 11.5 kg ha^{-1}, respectively. Likewise, more number of branches and higher number of seeds per capsule were obtained from Bekoji-14 variety.

However, the increase in nitrogen fertilizer application from 0 kg ha^{-1} to 23 kg ha^{-1} resulted in an increment in plant height, number of capsules per plant, thousand seed weight, and seed yield but further increase in nitrogen fertilizer showed statistically similar trend. This might be due to the medium amount of nitrogen in the soil and further application of nitrogen fertilizer at higher rate might not lead to show an increasing trend. The application of nitrogen fertilizer at a rate of 11.5 kg ha^{-1} on Bekoji-14 variety resulted in a higher value of yield and yield components as compared to other treatment combinations. Thus, variety Bekoji-14 exhibited superiority over other varieties.

The partial budget analysis revealed that the highest net benefit of Birr (118,625.7 ETB ha^{-1}) was recorded from the combination of Bekoji-14 variety at 11.5 kg ha^{-1} N with a MRR value 9591.96%. Based on this finding it could be concluded that Bekoji-14 varieties at nitrogen rate of 11.5 kg ha^{-1} is the optimum to be adopted for linseed production and economic feasibility around the experimental area and similar agro-ecologies. However, as the experiment was done for only one season and single location, it has to be repeated over seasons and locations and it is essential to demonstrate high yielder and best quality linseed varieties with optimum nitrogen application to the farmer for production through extension and demonstrations.

6. REFERENCES

Abay Ayalew. 2016. Assessment of soil fertility status of different types of soils in selected areas of Southern Ethiopia. *Journal of Natural sciences Research*, 6(1): 2224-3186.

Abd Eldaiem, M. 2015. Response of some flax genotypes under different plant densities. *Journal of Plant Production*, Mansoura University, 6 (7): 1247-1261.

Abd El-Mohsen, A., Amany, M. Abdallah, C., Gamalat, O. and Mahmoud, K. 2013. Optimizing and describing the influence of planting dates and seeding rates on flax cultivars under Middle Egypt region conditions. *World Essays Journal*, 1(4): 142-152.

Abdus Salam, Akhi Khatun and Abdul Kader. 2020. Effect of levels of nitrogen on the growth and yield of sesame (*Sesamum indicum* L.) cultivars. *Journal of Bangladesh Agricultural University*, 18(4): 949-955.

Abebe Delesa and Adane Choferie. 2016. Response of linseed (*Linum usitatissimum* L.) to fertilizer application and weeds control in South-Eastern Highlands of Ethiopia. *Journal of Cereals and Oilseeds*, 7(5): 44-54.

Abebe Delesa and Adane Choferie. 2019. Outstanding performance of recently released linseed (*Linum usitatissimum* L.) variety Yadanno and other linseed lines in South Eastern Highlands of Ethiopia. *Journal of Biology, Agriculture and Healthcare*, ISSN 2225-093 (Online), DOI: 9(7): 2224-3208.

Abebe, D., Berhane, A., Workiye, T. and Adane, C. 2011. Prevalence of weeds in linseed fields and farmers cultural practices in producing linseed. Oilseeds: engine for economic development. Ethiopian Institute of Agricultural Research, Addis Ababa. Pp. 299-302.

Adugna Wakjira (2007). Linseed (*Linum usitatissimum* L.) in: van der Vossen H.A.M. and Mikilamo G.S. (Eds.) Plant Resources of Tropical Africa 14.Vegetable oils PROTA Foundation, Wageningen, Netherlands/BackhuysPublishers, Leiden, Nether lands pp. 108-115.

Adugna, W, Labuschagne, M. and Hugo, A. 2004. Variability in oil content and fatty acid composition of Ethiopian and introduced cultivars of linseed. *Journal of the Science of Food and Agriculture,* 84: 601-607.

Aglave, B., Kalegore, N., Chavan, M. and Jagtap, P. 2009. Performance of rained rabi sunflower under varied cropping sequence and nitrogen levels. *Journal of Soils and Crops*, 19(2): 265-268.

Agriculture and Agri-Food Canada. 1997. Flaxseed: Situation and outlook, bi-weekly bulletin, market analysis division, policy branch, agriculture and agri-food Canada, 10: p. 22, Winnipeg, MB.

Al-Doori, S. 2012. Influence of sowing dates on growth, yield and quality of some flax (*Linum usitatissimum* L.) genotypes. *College of Basic Education Research Journal*, 12(1): 733-746.

Alemu, D., Temesgen, D. and Habtamu, A. 2020. Effect of nitrogen fertilizer rates on seed yield and oil quality of linseed (*Linum usitatissimum* L.) varieties in Welmera District, central highland of Ethiopia. *Journal of Science and Sustainable Development*, 8(2): 62-73.

Aliari, H. 2006. Agronomy and physiology of oil seeds. Amidi Publications, Iran. (In Farsi).

Anastasiua, A., Chira, N., Banub, I., Ionescuc, N., Stana, R. and Roscaaa, S. 2016. Oil productivity of seven Romanian linseed varieties as affected by weather conditions. *Industrial Crops and Products*, 86: 219-230.

Andruszczak, S., Gawlik-Dziki, U., Kraska, P., Kwiecińska-Poppe, E., Różyło, K. and Pałys, E. 2015. Yield and quality traits of two linseed (*Linum usitatissimum* L.) cultivars as affected by some agronomic factors. *Plant Soil Environment,* 61 (6): 247-252.

Angelini, L., Tavarini, S., Antichi, D., Foschi, L. and Mazzoncini, M. 2014. On-farm evaluation of seed yield and oil quality of linseed (*Linum usitatissimum* L.) in Inland areas of Tuscany, Central Italy. *Italian Journal of Agronomy*, 11.

Anonymous. 2006. Annual group meeting on linseed and safflower., souvenir, directorate of research, university of agriculture and technology, Narendra Nagar, Kumarganj, Faizabad, Uttar Pradesh.

Anonymous. 2010. *Linum usitatissimum* L. (linseed/ flax): An assessment of the risks of adventitious GM presence in UK conventional seed, GM inspectorate, food and environment research agency, department of environment, food and rural affairs, Sand Hutton.

Anonymous. 2011a. Annual progress report, all India coordinated research project on linseed (ICRP), Hyderabad, p. 261.

Anonymous. 2011b. National fertilizers from oilcakes and oil meals, the solvent extractors association of India, Indian oil meals fertilizers from nature, Nariman Point, Mumbai.

Ashfaq, A., Mahboob, A., Abdi, H., Ehsanull, A. and Musaddique, M. 2001. Genotypic response of sesame to nitrogen and phosphorus application. Department of Agronomy, University of Agriculture, Faisalabad. *Pakistan Journal of Agricultural Science*, 38: 12-15.

ATA (Agricultural Transformation Agency). 2016. Soil fertility status and fertilizer recommendation, atlas for Amhara Regional State, Ethiopia, Addis Ababa.

Bakry, A. 2009. Effect of seeding rate on yield and quality traits of some flax (*Linum usitatissimum* L.) varieties grown in newly reclaimed sandy soil. Ph.D. Thesis. Cairo University. Egypt.

Bakry, A., Nofal, O. and Zeidan, M. 2012. Agronomic characteristics of three flax varieties as affected by some sources of potassium fertilization under newly reclaimed sandy soil conditions. *Australian Journal of Basic and Applied Sciences*, 6(4): 77-81.

Bakry, B., Nofal, O., Zeidan, M. and Hozayn, M. 2015. Potassium and zinc in relation to improve flax varieties yield and yield components as grown under sandy soil conditions. *Journal of Agricultural Science*, 6: 152-158.

Bakry, B., Tawfik, M., Mekki, B. and Zeidan, M. 2012. Yield and yield components of three flax (*Linum usitatissimum* L.) cultivars in response to foliar application with Zinc, Manganese and Iron under newly reclaimed sandy soil conditions. *American-Eurasian Journal of Agricultural and Environmental Science*, 12 (8): 1075-1080.

Baldini, M., Giovanardi, R., Tahmasebi-Enferadi, S. and Vannozzi, G. 2002. Effects of water regime on fatty acid accumulation and final fatty acid composition in the oil of standard and high oleic sunflower hybrids. *Italian Journal of Agronomy,* 6: 119-126.

Barbara, C., Saša, S., Aleš, H. and Anita, K. 2020. Impact of linseed variety, location and production year on seed yield, oil content and its composition. *Agronomy,* 10: 1770.

Bareja, B. 2011. Topography and soil, abiotic factors affecting crop growth, development and productivity. *Crops Review*. *https://www cropsreview.com/abiotic-factors.html.*

Bastia, D. and Mohanty, S. 2001. Response of linseed varieties to fertility levels under rain fed conditions. *Indian Journal of Agronomy,* 46: 343-345.

Bayrak, A., Kiralan, M., Ipek, A., Arslan, N., Cosge, B. and Khawar, K. 2010. Fatty acid compositions of linseed (*Linum usitatissimum* L.) genotypes of different origin cultivated in Turkey. *Biotechnology and Biotechnological Equipment*, 24: 1836-1842.

Belay Yebo. 2015. Integrated soil fertility management for better crop production in Ethiopia, *International Journal of soil science*, 10(1): 1-16.

Berglund, D. 2002. Flax: New uses and demands. In: Janick, J. and Whipkey, A. (eds.), Trends in new crops and new uses. ASHS Press, Alexandria, VA, USA, Pp. 358-360.

Bernacchia, R., Preti, R. and Vinci, G. 2014, Chemical composition and health benefits of flaxseed. *Austin Journal of Nutrition and Food Sciences,* 2: 1045.

Bhagyalaxmi, Asewar, B. and Asra, N. 2021. Response of different linseed (*Linum usitatissimum* L.) varieties to fertilizer levels. *The Pharma Innovation Journal*, 2022; 11(1): xx-xx.

Bloedon, L. and Szapary, P. 2004. Flaxseed and cardiovascular risk. *Nutrition Reviews*, 62: 18-27.

Booker. 1991. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics.

Braidek, J.G., 1975. Agronomic considerations in flax production. In: Harapiak, J. (Ed.), oil seed and pulse crops in Western Canada: A Symposium. Western co-operative fertilizers, calgary, Alberta, pp. 279-285.

Casa, R., Russell, G., Cascio, B. and Rossini, F. 1999. Environmental effects on linseed (*Linum usitatissimum* L.) yield and growth of flax at different stand densities. *European Journal of Agronomy*, 11: 267-278.

Chandrawati, R., Maurya, F., Singh, P., Ranada, S. and Yadav, H. 2014. Diversity analysis in India genotypes of linseed (*Linum usitatissimum* L.) using Amplified Fragment Length Polymorphism markers. Pp. 171-178.

Chauhan, M., Singh, S. and Singh, A. 2009. Post-harvest uses of linseed. *Journal of Human Ecology*, 28 (3): 217-219.

Cheema, M., Malik, M., Hussain, A., Shah, S. and Basra, S. 2001. Effect of time and rate of nitrogen and phosphorus application on the growth and the seed and oil yields of canola (*Brassica napus* L.). *Journal of Agronomy and Crop Sci*ence, 186: 103-110.

Choi, H., Park, S. and Kim, S. 2012. "Effect of seeding time on fatty acid composition, oil contents and seeds yield in flax," *Korean Journal of Plant Resources,* 5(6): 700-706.

CIMMYT. 1988. from Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition, Mexico.

Cross, R., Mckay, S., McHughen, A. and Bonham-Smith, P. 2003. Heat stress effects on reproduction and seed set in *Linum usitatissimum* L. (flax). *Plant Cell Environment*. 26, 1013-1020.

CSA (Central Statistical Agency of Ethiopia). 2016. Agricultural sample survey report on area and production of crops. Central Statistical Agency of Ethiopia. Stat. Bul., 1.

CSA (Central Statistical Agency of Ethiopia). 2017. Agricultural samples survey 2017/18. Report on area and Production of crops, central statistics authority, Addis Ababa, Ethiopia.

CSA (Central Statistical Agency). 2019. Agricultural Sample Survey Report on Area and Production of Major Crops, 1: Pp. 21-22.

Cui, P., Fan, F., Yin, C., Song, A., Huang, P., Tang, Y. and *et al*. 2016. Long-term organic and inorganic fertilization alters temperature sensitivity of potential nitrous oxide emissions and associated microbes. *Soil Biology and Biochemistry*, 93: 131-141.

DBARC (Debre Berhan Agricultural Research Center). 2014. Monthly Rainfall (Mm), Monthly Minimum and Maximum Temperature (^{0}C) recorded from 2012-2021. Debre Berhan, Ethiopia.

Delesa, A., Choferie, A. and Aka, E. 2010. Registration of Kulumsa-1 linseed (*Linum usitatissimum* L.) variety. *East African Journal of Science*, 4 (2): 123-127.

Dereje Agizie. 2012. Effect of plant density on yield and yield related traits of sesame (*Sesamum indicum* L.) varieties at Woyto river basin, southern Ethiopia. MSc. thesis, Haramaya University, Ethiopia.

Diederichsen, A. and Fu, Y. 2008. Flax genetic diversity as the raw material for future success. *International Conference on Flax and Other Best Plants*, ID.51: Pp. 271-280.

Diederichsen, A. and Richards, M. 2003. Cultivation of flax and the genus *Linum* L. Taxonomy and germplasm collection. In A.D. Muir and N. D. Westcott (eds). Flax -The genus *Linum.* Taylor and Francis. London.

Diepenbrock, W. and Iwersen, D. 1989. Yield development of ten linseed (*Linum usitatissimum* L.) varieties. *Plant Research Development.* 30: 104-125.

Dordas, C. 2010. Variation of physiological determinants of yield in linseed in response to nitrogen fertilization. *Industrial Crops and Products*, 31: 455-465.

Easson, D. and Molloy, R. 2000. A study of the plant, fiber and seed development in flax and linseed (*Linum usitatissimum* L.) grown at a range of seed rates. *Journal of Agricultural Science*, Cambridge 135: 361-369.

Eckert, D. 2010. Efficient fertilizer use- Nitrogen. Pp. 1-19.

Elayan Sohair, E., Abdallah Amany, M., Naguib, A. and Mahmoud Doaa, I. 2015. Effect of sowing date on yield, fiber and seed quality of eight flax genotypes. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 15: 886-895.

El-Beltagi, H., Salama, Z. and El-Hariri, D. 2007. Evaluation of the fatty acids profile and the content of some secondary metabolites in seeds of different flax cultivars (*Linum usitatissimum* L.). *General and Applied Plant Physiology*, 33: 187-202.

El-Beltagi, H., Salama, Z. and El-Hariri, D. 2011. Variations in oil and some phytochemical contents in flaxseed cultivars (*Linum usitatissimum* L.). *Electronic Journal of Environmental, Agricultural and Food Chemistry*, 10: 2711-2721.

El-Hariri, D., Hassanein, M., El-Sweify, and Amna, H. 2004. Evaluation of some flax genotypes, straw yield, yield components and technological characters. *Journal of Natural Fibers*, 1(2): 1-12.

El-Nagdy, G., Dalia, M., Nassar, A., Eman, A., El-Kady, B., Gelan, S. and ElYamanee, A. 2010. Response of flax plant (*Linum usitatissimum* L.) to treatments with mineral and bio-fertilizers from nitrogen and phosphorus. *Journal of American Science*, 6(10): 207-217.

El-Saeed, M., El-Gedwy, M., Gaber, Y., Hammam, M., Salah, A., Allam, H., Saber, H., Mostafa A., Khaled, S. and El-Shimy, S. 2020. Straw, Seed Yield and Quality of Three *Linum usitatissimum* L. Cultivars in Relation to Nitrogen Fertilizer Rate and Plant Density. *Asian Journal of Advances in Agricultural Research*, 14(4): 8-29.

El-Seidy, E., El-Refaey, R., Abou-Zaied, A., Abd El-Razek, U. and Rashwan, E. 2015. Effect of different mineral and biological nitrogenous fertilizers combinations on seed yield and its components of some flax (*Linum usitatissimum* L.) genotypes. *Global Journal of Agriculture, Food Sciences research*, 2(3): 180-198.

El-Shafey, Amina, I., Hassan and Sanaa, S. 2016. Impact of ascorbic and folic acids foliar application on yield, growth and its attributes of flax cultivars. *Alexandria Journal of Agricultural Sciences,* 61(2): 61-72.

Emam, S. 2019. Cultivars response of flax (*Linum usitatissimum* L.) to different nitrogen sources in dry environment. *Egyptian Journal of Agronomy,* 41(2): 119-131.

Enaney Tigabu, Amare Girma and Khan A. 2020. Evaluation of Sesame (*Sesamum indicum* L.) Varieties for Seed and Oil Yield sat Omo Kuraz, Southern Ethiopia. *Journal of Biology, Agriculture and Health care:* 10 (8): 2224-3208.

Engin, Y., Emre, K., Seymu, F. and Bulent, U. 2010. Assessment of selection criteria in sesame by using correlation coefficients, path and factor analyses. *Australian Journal of Crop Science,* 4: 598-602.

Ethio GIS Soil Shape Files. 2004.

FAO (Food and Agricultural Organization). 2017. FAOSTAT database: Agricultural crops. The Food and Agriculture Organization of the United Nations, USA.

FAO-STAT (2007): Food and Agriculture Organisation Statistical Databases. FAO, Rome, Italy.

FAOSTAT. 2020. Available online at http://fenix.fao.org/faostat/internal/en/#data/QC.

Fathy, S. El-Nakhlawy, B., Mohamed, A. and Shaheen, G. 2009. Response of seed yield, yield components and oil content to the sesame cultivar and nitrogen fertilizer rate diversity. *Metrology, Environment and Arid Land Agricultural Science,* 20(2): 21-31.

Frinck, A. 1962. Kalium status of some Sudam clay Soils. Plant and Soil, 16: Pp. 293-309

Fitzpatrick, K. 2007. Innovation in Western Canadian functional food. *Cereal Foods World,* 52: 289-290.

Flagella, Z., Rotunno, T., Tarantino, E., Di Caterina, R. and De Caro, A. 2002. Changes in seed yield and oil fatty acid composition of high oleic sunflower (*Helianthus annuus* L.) hybrids in relation to the sowing date and the water regime. *European Journal of Agronomy,* 17: 221-230.

Food and Agriculture Organization of the United Nations (2008). FAO fertilizer and plant nutrition bulletin: Guide to laboratory establishment for plant nutrient analysis, FAO, Rome, Italy. 203p.

Franklin, P., Gardner, R., Pearce, B. and Mitchell, R. 2010. Physiology of crop plants; Scientific Press: Christchurch, New Zealand, p. 336.

Freer, J. 1993. Linseed husbandry, a UK perspective. *Journal of Industrial Crops and Products* 1: 211-217.

Gabiana, C. 2005. Response of linseed (*Linum usitatissimum* L.) to irrigation, nitrogen and plant population. Master of Applied Science thesis, Lincoln University.

Gaikwad, S., Suryavanshi, V., Bhusari, S and Misal, A. 2020. Effect of fertilizers on growth and yield of linseed (*Linum usitatissimum* L.) varieties. *The Pharma Innovation Journal*, 9(10): 127-131.

Gallardo, M., JoséMilisich, H., Drago, S. and González, R. 2014. Effect of cultivars and planting date on yield, oil content, and fatty acid profile of flax (*Linum usitatissimum* L.) varieties. *International Journal of Agronomy*, 2014: 1-7.

Gambus, H. and Zajac, T. 2003. Chemical composition of linseed with different Journal of Science and Sustainable Development (JSSD), 2020, 8(2), 62-73 ISSN: 2304-2702 (print) colour of bran layer. *Polish Journal of Food and Nutrition Sciences*, 12: 67-70.

Genene Gezu, Habtamu Seboka, Kedir Nefo, Tilahun Geleto, Ashinie Bogale. 2006. Response of linseed to nitrogen and phosphorus fertilizers in the highlands of Bale, South-eastern Ethiopia. Sebil. Proceedings of the 12th Annual Conference of the Crop Science Society of Ethiopia, 22-24 May 2006, Addis Ababa, Ethiopia. 12:117-125.

Genser, A. and Morris, N. 2003. History of cultivation and uses of flaxseed. In A. D. Muir and N. D. Westcott (Eds). Flax - The genus *Linum*. Taylor and Francis. London.

Getinet, A. and Nigussie, A. 1997. Highland Oil Crops: A three decade research experience in Ethiopia. Research Report No. 30. Institute of Agricultural Research, Addis Ababa, Ethiopia.

Ghamkhar, K., Croser, J., Aryamanesh, N., Campbell, M., Kon'kova, N. and Clive, F. 2010. Camelina (*Camelina sativa* L.) as an alternative oilseed: Molecular and Eco geographic analyses. 53: Pp. 558-567.

Gholizadeh, A., Amin, M., Anuar, A. and Aimrun, W. 2009. Evaluation of leaf total nitrogen content for nitrogen management in a Malaysian paddy field by using soil plant analysis development chlorophyll meter. *American Journal of Agricultural and Biological Sciences*, 4(4): 278-282.

Gill, K. 1987: Linseed (*Linum usitatisimum* L.). Indian Council of Agricultural Research, New Delhi.

Girma Tadesse and Sintayehu Tenaye. 2018. Effect of nitrogen on flax (*Linum usitatissimum* L.) fiber yield at Debre Berhan area, Ethiopia. *Forestry Research and Engineering International Journal*, 2(5): 284-286.

Goronski, J., Beer, U., Johnson, M. and Jocelyn, C. 2010. Improving and preparing soil for growing linseed in Gloucester and surrounding areas. The Gloucester Project Inc., (1): 2-12. www.theglocesterproject.org.au.

Grant, D., Monreal, M., Irving, B., McLaren, D. and Mohr, R. 2004. The role of P fertility and mycorrhizae in linseed production. Pp. 213-218. In 2004 Great Plains Soil Fertility Conference Proceedings. Schlegel, A. ed. March 2-3, 2004, Denver CO. Phosphate and Potash Inst., Brookings.

Guo, J., Liu, X., Zhang, Y., Shen, J., Han, W., Zhang, W. and *et al.* 2010. Significant acidification in major Chinese croplands. *Science*, 327: 1008-1010.

Haruna, I. 2011. Dry matter partitioning and grain yield potential in sesame (*Sesamum indicum* L.) as influenced by poultry manure, nitrogen and phosphorus at Samaru, Nigeria. *Journal of Agricultural Technology*, 7(6): 1571-1577.

Hazelton, P. and Murphy, B. 2007. Interpreting soil test results: What do all the numbers mean? CSIRO Publishing. 2nd ed. Australia. Pp. 59-90.

Hiruy, B. and Nigusie, A. 1988. Verification of improved linseed production practices on farmers' fields. In Oil crops: sunflower, linseed and sesame. Proceedings of the fourth oil crops network workshop, Njoro, Kenya.

Hiruy, B. and Nigusie, A. 1992. Verification of improved linseed production practices on farmers' fields. Proceedings of the 4th oil crops network workshop. Njoro, Kenya. Pp. 92-95.

Hocking, P. 1995. Critical nitrate-nitrogen and total nitrogen concentrations for vegetative growth and seed yield of Linola (edible-oil linseed) as affected by plant age. *Australian Journal of Experimental Agriculture*, 35:239-246.

Hocking, P., Kirkegaard, J., Angus, J., Gibson, A. and Koetz, E. 1997. Comparison of canola, Indian mustard and Linola in two contrasting environments. I. Effects of nitrogen fertilizer on dry-matter production, seed yield and seed quality. *Field Crops Research*, 49: 107-125.

Holleta Agricultural Research Centre (HARC). 2021. Holleta, Ethiopia

Homayouni, G., Souri, M. and Zarein, M. 2013. Effects of zinc and nitrogen on yield components of five flax genotypes. Global Journal of Science Frontier Research Chemistry, 13(5): 20-24.

Hosseinian, F., Rowland, G., Bhirud, P., Dyck, J. and Tyler, R. 2004. Chemical composition, physico-chemical and hydrogenation characteristics of high-palmitic acid Solin (low-linolenic acid flaxseed) oil. *Journal of American Oil Chemistry,* 81(2): 185-188.

Hussain, K., Malik, Y., Srivastava, R. and Pandey, R. 2009. Production technology and industrial uses of dual purpose linseed (*Linum usitatissimum*): An overview. *Indian Journal of Agronomy,* 54: 374-379.

Hussein, M. and Zedan, S. 2008. Yield and quality of two flax varieties as affected by foliar spraying with potassium rates and nitrogen levels under sandy soil condition. *Journal of Agricultural Sciences,* Mansoura University, 33: 3937-3952.

Ibrahim, H. 2009. Effect of sowing date and N-fertilizer rates on seed yield, some yield components and oil content in flax. *Alexandria Journal of Agricultural Research*. 54(1): 19-28.

Ibrahim, M., Hassan, A., Arshad, M. and Tanveer, A. 2010. Variation in root growth and nutrient element of wheat and rice: effect of rate and type of organic materials. *Soil Environment*, 29: 47-52.

Jackson, M. 1967. Soil chemical analysis. New Delhi, Prentice Hall of India Private Limited, New Delhi, Pp. 326-338.

Kandil, A., Hoballah, A., El-Hariri, D., Zeidan, M. and Bakry, A. 2008. Effect of seeding rate on yield and quality traits of some flax (*Linum usitatissmum* L.) varieties grown in newly reclaimed sandy soils. *Egyptian Journal of Applied and Agricultural Research*, 1(1): 69-81.

Kant, R., Chauhan, M., Srivastava, R. and Maurya, K. 2008. Correlation and path coefficient analysis of seed yield and yield components of linseed (*Linum usitatissimum* L.). *International Journal of Plant Science,* 3: 323-325.

Kaur, N. and Paul, S. 2020. Correlation and path coefficient analysis for seed yield and fiber traits in linseed (*Linum usitatissimum* L.). *International Journal of Current Microbiology and Applied Sciences, 9*(2): 66-75.

Khalifa, R., Manal, F., Bakry, A. and Zeidan, M. 2011. Response of some flax varieties to micro-nutrients foliar application under newly reclaimed sandy soil. Australian Journal of Basic and Applied Sciences, 5(8): 1328-1334.

Kirkhus, B., Lundon, A., Haugen, J., Vogt, G., Borge, G. and Henriksen, B. 2013. Effects of environmental factors on edible oil quality of organically grown camelina (*Camelina sativa* L.*). Journal of Agricultural and Food Chemistry*, 61: 3179-3185.

Klein, J., Zikeli, S., Claupein, W. and Gruber, S. 2016. Linseed (*Linum usitatissimum*) as an Oil Crop in Organic Farming: Abiotic Impacts on Seed Ingredients and Yield. *Organic Agriculture*, 7:1-19.

Klimek, Kopyra, A., Zając, T. and Rębilas, K. 2013. A mathematical model for the evaluation of cooperation and competition effects in intercrops. *European Journal of Agronomy*, 51: 9-17.

Kulumsa Agricultural Research Center (KARC). 2012. Highland Oil Crops Research Project Report, Pp. 25.

Kumar, N. and Paul, S. 2016. Selection criteria of linseed genotypes for seed yield traits through correlation, path coefficient and principal component analysis. *Journal of Animal and Plant Sciences*, 26(6): 1688-1695.

Kutcher, H., Malhi, S. and Gill, K. 2005a. Topography and management of nitrogen and fungicide affects diseases and productivity of canola. *Agronomy Journal*, 97: 533-541.

Lafond, G., Grant, C., Johnston, A., McAndrew, D. and May, W. 2003. Management of nitrogen and phosphorus fertilizer in no-till flax. *Canadian Journal of Plant Sciences*, 83: 681-688.

Lafond, G., Irvine, B., Johnston, A., May, W., McAndrew, D., Shirtliffe, S. and Stevenson, F. 2008. Impact of agronomic factors on seed yield formation and quality in flax. *Canadian Journal of Plant Sciences*, 88(3): 485-500.

Landon, J. 1991. Booker tropical soil manual: A Handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Long man scientific and technical, Essex, New York. p. 474.

Laza, A. and Pop, G. 2012. The influence of fertilization and seeding density on flax oil production quality. *Research Journal of Agricultural Science*, 44(4): 1-7.

Legesse Burako. 2010. Genetic diversity study of linseed genotypes on acidic soil at Bedi trial site, Central Highland of Ethiopia, MSc. Thesis. Addis Ababa University, Addis Ababa.

Leilah, A. 1993. Evaluation of yield and its components of flax cultivars under different nitrogen fertilizer levels. *Journal of Agricultural Science*, 18(2): 313-321.

Leleu, O., Vuylsteker, C., Tetu, J., Degande, D., Champoliver, L. and Rambour, S. 2000. Effect of two contrasted nitrogen fertilization on rapeseed growth and nitrate metabolism. *Plant Physiology and Biochemistry* (Paris), 38: 639-645.

Lilian, W. 2016. The influence of cultivars, nitrogen supply, location and water stress on performance and oil quality of linseed (*Linum usitatissimum* L.) in Kenya. Jomo Kenyatta University of Agriculture and Technology, PhD. Thesis.

Lilian, W., Arnold, N., Peter W., Stephen M. and Kenneth O. 2015. Oil content and fatty acid composition of five linseed varieties grown in two agro-ecological locations of Kenya. *Journal of Agriculture and Environmental Sciences,* 4(2): 186-194.

Luo, Z., Liu, H., Li, W., Zhao, Q., Dai, J., Tian, L. and *et al*. 2018. Effects of reduced nitrogen rate on cotton yield and nitrogen use efficiency as mediated by application mode or plant density. *Field Crop Research*, 218: 150-157.

Malik, M., Saleem, M., Cheema, M. and Ahmad, S. 2003. Influence of different nitrogen levels on productivity of sesame (*Sesamum indicum* L.) under varying planting patterns.

Manthar Ali, Abdul Haleem, Kamran Razzaque, Babar Sultan, Fateh Muhammad and Ayaz Latif. 2022. Comparative evaluation of linseed varieties under environmental conditions of Tandojam Pakistan. *Pure Applied Biology*, 11(1):92-99.

Marchenkov, A., Rozhmina, T. Uschapovsky, L. and Muir, A. 2003. Cultivation of flax. In A. Muir and N. Westcott (Eds). Flax - The genus *Linum*. Taylorand Francis, London.

Marschner, H. 1995. Function of mineral nutrients: macronutrients. In: Mineral Nutrition of Higher Plants, Academic Press, Orland, and FL. Pp. 195-267.

Mekonnen, S., Sharma, J. and Dechassa, N. 2016. Effects of nitrogen fertilizer rates on yield and yield components of sesame (*Sesamum indicum* L.) varieties under irrigation in Gode, South-Eastern Ethiopia. *International Journal of Plant Breeding and Crop Science;* 3(1): 71-78.

Mengel, K. and Kirkby, E. 2001. Principles of plant nutrition. 5^{th} ed., Kluwer Academic Publishers, Netherlands.

Mesfin, H., Yechalew, S., Behailu, A. and Abush, T. 2019. Linseed (*Linum usitatissimum* L.) variety adaptation at south western Ethiopia. *International Journal of Forestry and Horticulture (IJFH)*, 5(4): 41-45.

MoANR (Ministry of Agriculture and Natural Resource). 2016. Addis Ababa, Ethiopia

Mohammad, A., Saeidi, G. and Arzani, A. 2010. Genetic analysis of some agronomic traits in flax (*Linum usitatissimum* L.). *Australian Journal of Crop Sciences*, 4: 343-352.

Morris, D. 2005. Flax -a health and nutrition primer. Flax Council of Canada.

Morris, H. 2007. Flax: A health and nutrition primer. Flax Council of Canada, Winnipeg, Canada, p. 140.

Motsara, M. and Roy, R. 2008. Guide to laboratory establishment for plant nutrient analysis. FAO fertilizer and plant nutrition bulletin 19. Rome. Pp. 204.

Mridula, D., Singh, K. and Barnwal, P. 2013. Development of omega-3 rich energy bar with flax seed. *Journal of Food Science Technology*, 50(5): 950-957.

Mulusew Fikere, Firew Mekbib and Adugna Wakjira. 2013. Seed oil diversity of Ethiopian linseed (*Linum usitatissimum* L.) landraces accessions and some exotic cultivars. *African Journal of Biochemistry Research*, 7(6): 76-85.

Nawar, A., Abou-zied, K. and Khalil, H. 2017. Impact of tillage intensity, NPK fertilization and weed control on seed yield and yield components of flax in newly reclaimed lands. Egyptian Journal of Agronomy, 39(2): 179-194.

Nykter, M. and Kymäläinen, H. 2006. Quality characteristics of edible linseed oil. *Agricultural and Food Science*, 15: 402- 413.

Olsen, S., Cole, F., Watanabe, D. and Dean, A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department Circular Agriculture, p. 939, USA.

Omar, A. and Ash-Shormillesy, S. 2006. Effect of seeding rate and nitrogen fertilization on the yield of flax. *Journal of Productivity and Development*, 11(2): 337-350.

Ozer, H., Polat, T. and Ozturk, E. 2004. Response of irrigated sunflower (*Helianthus annuus* L.) hybrids to fertilization, growth, yield and yield components. Turkey. *Plant Soil Environment,* 50(5): 205-211.

Pali, V. and Mehta, N. 2014. Evaluation of oil content and fatty acid compositions of flax (*Linum usitatissimum* L.) varieties of India. *Journal of Agricultural Science*, 6:198-207.

Pandey, R. and Dayal, R. 2003. Flax-Jute and Flax-Cotton blended fabric. *Asian Textile Journal*, 12(7): 5155.

Pankaj Chopra and D. Badiyala. 2016. Influence of nitrogen fertilization on performance of linseed (*Linum usitatissimum* L.) under *utera* system. *Himachal Journal of Agricultural Research* 42(1): 108-110.

Paul, I. and Savithri, K. 2003. Effect of bio-fertilizers vs. perfected chemical fertilization for sesame grown in summer rice fallow*, Journal of Tropical Agriculture,* 41: 47-49.

Poonia, K. 2003. Effect of planting geometry, nitrogen and sulphur on quality of sunflower (*Helianthus annuus* L.). *Annals of Agriculture Res*earch, 24(4): 828- 832.

PPPO (Public Private Partnership on Oilseeds). 2009. Improving the competitiveness of the Ethiopian edible oil sector-policy brief.

Qiao, J., Yang, L., Yan, T., Xue, F. and Zhao, D. 2012. Nitrogen fertilizer reduction in rice production for two consecutive years in the Taihu Lake area. *Agriculture, Ecosystems and Environment*, 146: 103-112.

Rahimi, M. and Nourmohamadi, G. 2010. The effect of different planting dates on yield of different medicinal flax cultivars. *Journal of New Agricultural Science* (*Modern Science of Sustainable Agriculture*), 6(19): 31-39.

Rahimi, M., Nourmohamadi, G., Ayneband, A., Afshar, E. and Moafpourian, G. 2011. Study of effect of planting date and nitrogen levels on yield, yield components and fatty acids of linseed (*Linum usitatissimu*m L.). *World Applied Sciences Journal,* 12: 59-67.

Rahimi, M., Zarei, M. and Arminian, A. 2011. Selection criteria of flax (*Linum usitatissimum* L.) for seed yield, yield components and biochemical compositions under various planting dates and nitrogen. *African Journal of Agricultural Research*, 6(13): 3167-3175.

Raja, A., Hattab, K., Gurusamy, L. and Suganya, S. 2007. Sulphur levels on nutrients uptake and yield of sesame varieties and nutrients availability. *International Journal of Soil Science,* 2(4): 278-285.

Reta Dargie, Tamiru Meleta and Kissi Wakweya. 2020. Effects of seeding rates and nitrogen fertilization on seed yield oil content and yield components of linseed (*Linum usitasissimum* L.) in the highlands of Bale. *American Journal of Plant Biology*, 5(3): 45-49.

Reta Dargie. 2015. Effect of nitrogen and sulfur fertilizer levels on growth, yield, and oil content of linseed (*Linum usitatissimum* L.) in Sinana, South-eastern Ethiopia, Haramaya University, Ethiopia.

Sadi, G., Burhan, K. and Muhammad, A. 2017. Biochemical characterization of four different genotypes of Flax (*Linum usitatissimum* L.) seeds. *Anatolian Journal of Botany*, 1(1): 12-17.

Sana, M., Ali, A., Malik, M., Saleem, M. and Rafiq, M. 2003. Comparative yield potential and contents of different canola caltivars (*Brassica napus* L.). *Pakistan Journal of Agronomy* 2: 1-7.

SAS Institute, Inc. 2012. The SAS System for Windows. Release 9.3; SAS Institute, Inc.

Schroder, J., Zhang, H., Girma, K., Raun, W., Penna, C. and Payton, M. 2011. Soil acidification from long-term use of nitrogen fertilizers on winter wheat. *Soil Science Society of American Journal*, 75: 957-964.

Shahab-u, D., Mahmoodah, B., Asif, N., Nazeer, A., Zahid, S., Fateh, M. and Shafeeque, A. 2015. Response of various sesame varieties under the influence of nitrogen and phosphorus doses. *American Journal of Plant Sciences,* 6: 405-412.

Sharief, A., EL-Hindi, M., EL-Moursy S., and Seadh, A. 2005. Response of two flax cultivars to N, P and K fertilizer levels. *Scientific Journal of King Faisal University* (Basic and Applied Sciences), 6(1): 127-144.

Shehu, H., Kwari, J. and Sandabe, M. 2009. Nitrogen, phosphorous and potassium nutrition of Sesame in Mubi, Nigeria. *Research Journal of Agronomy,* 3: 32-36.

Sisay Berhanu, Sharma, J. and Nigussie Dechassa 2016. Effects of nitrogen fertilizer rates on yield and yield components of sesame (*Sesamum indicum* L.) varieties under irrigation in Gode, South-Eastern Ethiopia. *International Journal of Plant Breeding and Crop Science*, 3(1): 071-078.

Smith, H. and Jimmerson, J. 2005. Briefing Agricultural Marketing Policy Center, Montana State University, MO, USA.

Soethe, G., Feiden, A., Bassegio, D., Santos, R., Souza, S. and Secco, D. 2013. Sources and rates of nitrogen in the cultivation of linseed. *African Journal of Agricultural Research*, 8 (19): 2249-2253.

Soto-Cerda, B., Duguid, S., Booker, H., Rowland, G., Dierderichsen, A. and Cloutier, S. 2014. Association mapping of seed quality traits using the Canadian flax (*Linum usitatissimum* L.) core collection. *Theoretical and Applied Genetics,* 127: 881-896.

Srivastava, R. 2009. Research and development strategies for Linseed in India. In: National Symposium on vegetable Oils Scenario: Approaches to Meet the Growing Demands, Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Pp. 29-31.

Statistics Canada. 2006. Production data of field and specialty crops.

Tadesse, T., Parven, A., Singh, H. and Weyessa, B. 2010. Estimates of Variability and Heritability in Linseed Germplasm. *International Journal of Sustainable Crop Production*, 5 (3): 8-16.

Tanwar, S., Zhang, L. and Teixeira, M. 2011. Adenomatous polyposis coli (APC) are essential for maintaining the integrity of the *Seminiferous epithelium. Molecular Endocrinology,* 25: 1725-1739.

Tasew Derese and Muhammed Sitote. 2020. Linseed Released Varieties Adaptation Trial at Sidama and Hadya Zones of Ethiopia. *Journal of Crop science and Technology,* 9(3): 2319-3395.

Tekalign Taddese. 1991. Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Teshome Gutu and Alemayehu Dabasa. 2021. Effect of NPS and Nitrogen Fertilizers on Growth, Yield and Yield Components of Linseed (*Linum usitatissimum L.*) at Western Oromia, Ethiopia. *International Journal of Applied Agricultural Sciences*, 7(3): 128-134.

Thompson, L., Chen, J., Li, W., Straaser, P and Goss, E. 2005. Dietary flaxseed alters tumor biological markers in post-menopausal breast cancer. *Clinical and Cancer Research*, 11: 3828-3835.

Tripathi, R. and Agrawal, S. 2013. Interactive effect of supplemented ultraviolet B and elevated ozone and seed yield and oil quality of two cultivars of linseed (*Linum usitatissimum* L.) carried out in open top chambers. *Journal of the Science of Food and Agriculture*, 93: 1016-1025.

Wadan, A. 2013. Optimizing and describing the influence of planting dates and seeding rates on flax cultivars under Middle Egypt region conditions. *Journal of Scientific Research and Reports*, 1(2): 28-39.

Walkley, A. and Black, C. 1934. Determination of organic matter in the soil by chromic acid digestion. *Soil Science,* 63: 251-264.

Weiss, E. 2000. Oil seed Crops. *2nd ed*. Blackwell Science, Inc., Malden, MA.

Westcott, N. and Muir, A. 2003. Chemical studies on the constituents of *Linum* sp. In: Muir A. and Westcott N. (Eds.). Flax: the genus *Linum*. New York (USA): Taylor and Francis, Pp: 55-73.

Wijnands, J., Biersteker, J. and Hiel, R. 2007. Oilseeds business opportunities in Ethiopia.

Wilcox, J. and Shibles, R. 2001. Interrelationships among seed quality attributes in soybean. *Crop Science*, 41: 11-14.

Worku, N., Heslop-Harrison, J. and Adugna, W. 2015. Diversity in 198 Ethiopian linseed (*Linum usitatissimum* L.) accessions based on morphological characterization and seed oil characteristics. *Genetic Resources and Crop Evolution*, 62: 1037-1053.

Worku, N., Zemede, A. and Haileselassie, Y. 2012. Linseed (*Linum usitatissimum* L.) ethno botany and its cultivation status in Ethiopia. *International Journal of Agriculture and Applied Science,* 4: 48-57.

Xu, G., Fan, X. and Miller, A. 2012. Plant nitrogen assimilation and use efficiency. *Annual Revised Plant Biology,* 63:153-182.

Yechalew Sileshi, Mesfin Hailemariam, Behailu Atero and Abush Tesfaye. 2019. Linseed (*Linum usitatissimum* L.) variety adaptation at south western Ethiopia. *International Journal of Forestry and Horticulture (IJFH),* 5 (4): 41-45.

Zając, T. 2005. Assimilation area and yielding of linseed cultivars depending on sowing density and mineral treatment. *Acta Agraria Silvestria series Silvestris,* 45: 65-76.

Zhang, X., Davidson, E., Mauzerall, D., Searchinger, T., Dumas, P. and Shen, Y. 2015a. Managing nitrogen for sustainable development. *Nature*, 528: 51-59.

Zhao, S., Qiu, S., Cao, C., Zheng, C., Zhou, W., and He, P. 2014. Responses of soil properties, microbial community and crop yields to various rates of nitrogen fertilization in a wheat-maize cropping system in north-central China. *Agricultural Ecosystem and Environment,* 194: 29-37.

Zhu, G., Peng, S., Huang, J., Cui, K., Nie, L., and Wang, F. 2016. Genetic improvements in rice yield and concomitant increases in radiation and nitrogen use efficiency in middle reaches of Yangtze River. *Scientific Reports*, 6: 210-249.

Ziadi, N., Gilles, B., Athyna, N., Cambouris, N., Nolin, M. and Annie, C. 2007. Relationship between phosphorous and nitrogen concentrations in corn. *Agronomy Journal,* 99: 833-841.

Zimmermann, R., Bauermann, U. and Morales, F. 2006. Effects of growing site and nitrogen fertilization on biomass production and lignin content of linseed (*Linum usitatissimum* L.). *Journal of Science and Food Agriculture*, 86: 415-419.

Zubr, J. and Matthaus, B. 2002. Effects of growth conditions on fatty acids and tocopherols in Camelina (*Camelina sativa)* oil. *Journal of Indian Crops Production*, 15: 155-162.

7. APPENDICES

Appendix Table 1. Mean square of analysis of variance for days to flowering, days to maturity, plant height and branch height of linseed varieties as influenced by nitrogen rates

Source of variation	DF	DTF (day)	DTM (day)	PH (cm)	BH (cm)
REP	2	13.44	19.53	72.03	90.49
N rate	3	160.84***	106.41***	256.22***	247.89***
Var	2	95.36***	85.36***	140.73**	236.11**
N*Var	6	69.91***	51.69***	135.66***	151.42***
Error	22	6.41	2.21	6.48	10.31
CV (%)		3.31	1.14	3.25	4.70

Where: DF =degree of freedom; REP =replications; Var =variety; N rate =nitrogen rate; N*Var= nitrogen rate and variety interaction; CV=coefficient of variation; DTF= days to flowering; DTM= days to maturity; PH= plant height; BH= branch height

Appendix Table 2. Mean square of analysis of variance for plant population, number of branches, number of capsules per plant, number of seeds per capsule and thousand seed weight of linseed varieties as influenced by nitrogen rates

Source of variation	DF	PP (count)	NB (count)	NCPP (count)	NSPC (count)	TSW (g)
REP	2	18517.33	0.27	79.79	0.01	0.20
N rate	3	39590.99ns	0.36*	201.71***	1.28**	1.18**
Var	2	52947.25*	1.74***	225.72***	1.24*	1.12**
N*Var	11	24527.52ns	0.32ns	131.54***	0.13ns	0.80***
Error	22	16859.70	0.10	8.13	0.24	0.13
CV (%)		11.72	10.09	10.99	2.76	7.30

Where: DF =Degree of Freedom; REP =replications; Var =Variety; N rate =Nitrogen rate; N*Var= Nitrogen rate and Variety interaction; CV=Coefficient of Variation; PP= Plant Population; NB= Number of Branches; NCPP= Number of Capsules per Plant; NSPC= Number of seeds per Capsule; TSW= Thousand Seed Weight; g= gram

Appendix Table 3. Mean square of analysis of variance for total dry biomass yield, straw yield, seed yield and harvest index of linseed varieties as influenced by nitrogen rates

Source of variation	DF	TDBY (kg ha^{-1})	StY (kg ha^{-1})	SY (kg ha^{-1})	HI (%)
REP	2	2236093.03	1352263.16	115823.20	0.41
N rate	3	10004322.17***	7551383.27***	7551385.27***	82.33***
Var	2	6445014.41***	4826189.46***	4826189.46***	16.05***
N*Var	11	4320007.25***	3462588.79***	145384.49***	28.01***
Error	22	134809.54	137985.86	2144.64	0.61
CV (%)		4.79	6.49	2.40	3.03

Where: DF =Degree of Freedom; REP =replications; Var =Variety; N rate =Nitrogen rate; N*Var= Nitrogen rate and Variety interaction; CV=Coefficient of Variation; TDBY= Total Dry Biomass Yield; StY= Straw Yield; SY= Seed Yield; HI= Harvest Index

Appendix Table 4. Mean square of analysis of variance for percent oil content, oil yield, palmitic acid, stearic acid, oleic acid, linoleic acid and linolenic acid of linseed varieties as influenced by nitrogen rates

Source of variation	DF	POC (%)	OY (kg ha^{-1})	PA (%)	SA (%)	OA (%)	LA (%)	LNA (%)
REP	2	1.42	17398.88	2.33	5.52	3.92	1.79	4.08
N rate	3	3.98***	30535.19***	0.52^{ns}	0.33^{ns}	0.66^{ns}	0.73^{ns}	1.69^{ns}
Var	2	2.10*	23122.43**	1.48*	2.02*	2.14*	1.51*	1.21*
N*Var	11	1.99***	19041.36***	0.46^{ns}	0.54^{ns}	0.64^{ns}	0.55^{ns}	0.56^{ns}
Error	22	0.27	437.94	0.26	0.64	0.57	0.30	0.47
CV (%)		1.44	2.98	10.38	14.96	4.28	4.48	1.99

Where: DF =degree of Freedom; REP =replications; Var =variety; N rate =nitrogen rate; N*Var= nitrogen rate and variety interaction; CV=coefficient of variation; POC= percent oil content; OY= oil yield; PA = palmitic acid; SA =stearic acid; OA = oleic acid; LA = linoleic acid; LNA = linolenic acid

Appendix Table 5. Mean monthly and annual rainfall (mm) at Angolelana Tera area (2012-2021)

	Month											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	ep	Oct	Nov	Dec
2012	0	0	10.55	89.65	0	42.19	184.57	221.48	116.02	0	0	0
2013	10.55	0	42.19	126.56	36.91	68.55	237.3	200.39	105.47	42.19	31.64	0
2014	0	26.37	47.46	94.92	89.65	47.46	152.93	142.38	137.11	52.73	5.27	0
2015	10.55	5.27	42.19	0	73.83	126.56	63.28	152.93	26.37	0	31.64	10.55
2016	42.19	36.91	36.91	205.66	105.47	15.82	200.39	147.66	142.38	36.91	15.82	5.27
2017	0	163.48	126.56	10.55	142.38	15.82	131.84	174.02	121.29	36.91	5.27	0
2018	0	42.19	15.82	152.93	15.82	94.92	126.56	205.66	36.91	52.73	58.01	0
2019	0	42.19	47.46	200.39	31.64	63.28	63.28	232.03	195.12	47.46	47.46	21.09
2020	0	15.82	58.01	237.3	105.47	52.73	184.57	258.4	94.92	31.64	10.55	5.27
2021	26.37	21.09	0	88.5	60.14	81.4	179.73	185.88	114.87	47.19	166.31	143.29

Appendix table 6. Mean monthly and annual maximum temperature (^{0}C) at Angolelana Tera area (2012-2021)

	Month											
year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	ep	Oct	Nov	Dec
2012	23.44	25.72	26.73	24.74	25.4	26.95	22.53	20.47	19.4	21.2	22.26	22.75
2013	26.25	26.21	27.19	24.39	24.35	24.59	21.25	19.25	19.34	19.22	20.01	21.34
2014	23.67	24.8	25.1	24.32	22.42	25.23	24.57	21.02	19.69	19.05	21.62	21.49
2015	22.75	25.06	25.19	25.99	26.3	24.84	23.27	23.22	23.25	22.72	22.84	23.25
2016	23.22	26.01	26.22	25.55	22.18	23.89	21.87	20.87	20.08	19.29	22.44	21.48
2017	24.33	25.03	23.94	24.26	22.08	24.82	23.05	22.85	20.03	20.39	21.18	22.6
2018	23.12	24.94	26.33	22.99	24.05	24.98	21.56	21.23	20.11	21.22	20.77	21.18
2019	24.06	24.64	26.28	22.15	24.84	25.44	23.4	22.69	20.64	19.23	20.23	22
2020	22.86	25.24	27	24.49	21.77	23.28	22.43	20.13	20.18	19.85	20.65	21.45
2021	22.45	23.75	25.26	27.41	24.18	25.81	23.73	21.41	20.45	20.01	21.39	20.79

Appendix table 7. Mean monthly and annual minimum temperature (^{0}C) at Angolelana Tera area (2012-2021)

	Month											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	ep	Oct	Nov	Dec
2012	2.66	3.09	3.64	7.75	8.15	8.83	7.81	8.65	8.12	1.23	3.45	3.19
2013	3.65	4.74	6.71	8.99	8.66	9.12	8.16	8.3	7.5	4.32	2.08	1.02
2014	3.73	5.26	6.96	7.17	8.26	8.51	9.19	9.58	6.61	4.25	3.26	1.72
2015	1.73	3.39	4.5	5.71	7.94	7.73	8.65	8.62	7.94	5.5	3.08	3.3
2016	5.65	3.94	7.55	8.99	9.06	8.48	8.68	7.5	8.58	3.12	0.23	0.05
2017	-0.11	4.16	5.99	5.66	9.22	9.27	9.18	9.22	7.76	5.17	2.14	-0.46
2018	1.99	2.04	4.34	8.03	7.48	9.43	8.75	8.43	5.8	3.76	2.12	2.84
2019	1.4	4.94	7.52	7.73	7.93	8.47	9.08	9.42	8.01	3.4	4.45	1.9
2020	4.11	5.38	7.99	7.94	8.31	9.6	8.23	8.19	8.3	3.3	1.23	2.21
2021	2.59	3.11	3.47	5.05	5.93	8.44	9.05	7.81	7.31	2.8	1.83	0.46