RESPONSE OF MAIZE (*Zea mays* L.) HYBRIDS TO PLANT DENSITY IN NONO DISTRICT, WEST SHOWA ZONE, ETHIOPIA

MSc THESIS

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We hereby certify that we have read and evaluated this Thesis entitled “**Response of Maize (*Zea mays* L.) Hybrids to Plant Density in Nono District, West Showa Zone, Ethiopia**” prepared under our guidance by Abera Workineh Shemete. We recommend that the Thesis shall be submitted as fulfilling the requirements for the award of a M.Sc. degree in Agronomy.

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As members of the Board of Examiners of the Master of Science Thesis open defense examination, we have read and evaluated this Thesis prepared by Abera Workineh Shemete and examined the candidate. We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (M.Sc.) in Agronomy.

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Final approval and acceptance of the Thesis is contingent upon the submission of its final copy to the Council of Postgraduate Program (CPGS) through the candidate’s department or school graduate committee (DGC or SGC).

DEDICATION

So affectionately, I dedicate this thesis to my wife, Nono Woreda Agricultural offices and Experts for all their enormous and unreserved contributions towards my entire life and academic success.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of the thesis. Any scholarly matter that is included in the thesis has been recognition through citation. This Thesis is submitted in partial fulfillments of the requirements for Master Science degree in Agronomy at Wolkite University. The Thesis is deposited in the Wolkite University Library and is made available to borrowers under the rules of the library. I solemnly declare that this thesis has not been submitted to any institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this thesis may be made without special permission provided that accurate and complete acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this Thesis in whole or in part may be granted by the Head of the Department when in his or her judgment the proposed use of material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author of the Thesis.

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BIOGRAPHICAL SKETCH

Abera Workineh Shemete, the author, was born on February 7th, 1983 in the West Showa zone of the Oromia region. He attended his elementary school (grades 1-6) at Tulu Silmi General Primary School from 1992 to 1997, grade 7-8 education at Shenen Primary School from 1998 to 1999, his high school education (grades 9–10) at Shenen High School from 2001 to 2002, and his secondary and preparatory education (grades 11–12) at Ambo Seinioer High School in Ambo Town from 2003 to 2005. He next enrolled in Ambo University College, where he graduated in March 2000EC with a BSc. in Crop production (2008GC). He was then hired by the Nono District Department of Agronomy, Office of Agriculture and Natural Resources, where he worked for ten years until joining the School of Graduate Studies at Wolkite University in 2019 to pursue his studies leading to the Degree of Master Science (MSc.) in Agronomy.

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ACRONMYS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
BRC	Bako Research Center
CIMMYT	International Centre for Maize and Wheat Improvement
CSA	Central Statistical Agency
EIAR	Ethiopian Institute of Agricultural Research
ESA	Eastern and Sothern Africa
FAOSTAT	Statistical database of the Food and Agriculture of the United Nations
MoANR	Ministry of Agriculture and Natural Resource
NPSB	Nitrogen, Phosphorus, Sulfur and Boron
PHSE	Pioneer Hybrid Seed Ethiopia
SAS	Statistical Analysis System
SSA	Sub-Saharan Africa

Response of Maize (*Zea mays* L.) Hybrids to Plant Density in Nono District, West Showa Zone, Ethiopia

ABSTRACT

To increase maize yield in a positive environment, it's important to suit the planting density and cultivar. Field research were carried out in 2021 under rain-fed conditions in Nono district of West Shewa zone in two locations (Silk Amba and Jiru Gemechu), to decide the effects of plant density levels on maize hybrids reproduction, growth, yield and yield components. The study included four maize hybrids (BH540, BH546, Damote and Limu) and three planting densities (44,444, 53333 and 67,667 plants ha^{-1}*) in a randomized complete block design in a factorial arrangement with 3 replications. Results revealed that location (Loc) had significantly (*$P \leq 0.05$*) influenced most measured phenological, growth, yield and yield components of maize. Across environments hybrids significantly (P_< 0.05) affected all measured parameters. Planting density had additionally affected a few growth, yield and yield components of maize drastically . Across environments, the lowest grain yield (7.88* ha^{-1}*) was observed from BH540 (oldest hybrid). No significant yield increase observed beyond 53,333 plats* ha^{-1}*, and recommended to be the superior planting density for the maize hybrids included on this study in the district. Compared to the district's existing suggested planting density of 44,444 plants* ha^{-1}*, planting density of 53,333 plants* ha^{-1} *produced greater than nine quintals* ha^{-1} *yield advantage. At both locations, BH540 and BH546 both had comparable outcomes. On the other hand, Pioneer hybrids, Damote and Limu resulted the highest yield of 12 and 12.32 t* ha^{-1} *respectively at Silk Amba, whereas, at Jiru Gemechu, the highest yield was recorded from Limu (10.64 t* ha^{-1}*) hybrid and was also corresponding to BH546 (9.31 t* ha^{-1}*) and Damote (9.99 t* ha^{-1}*) suggested differential response of hybrids in different environments as a result of Loc x H interaction. This study provided further evidence that the growth and yield of maize are significantly influenced via environment, genotype, plant population, and interactions. It also made the point that optimizing planting density to match the high-quality performing variety should be taken into account as new varieties are delivered and advocated particularly environments.*

Keywords: Cultivar, environment, growth, grain yield, plant density

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1. INTRODUCTION

Maize (*Zea mays L.*) plays a critical role in meeting the high food demand and is globally one of the most widely cultivated crops (FAOSTAT, 2018). In Ethiopia, maize ranks second in area coverage after *tef* (*Eragrotis tef*) but contributes the highest grain yield from cereal crops. Due to its versatile nature, maize is growing under diverse agro-ecologies and socioeconomic conditions (Tsedeke Abate *et al*., 2017) with great potential to feed over 100 million people in the country (Dagne Wegary *et al*., 2019). Currently, maize has already expanded to new production areas where maize production was not well known in the past (such as west and east Gojam), yet with better productivity (Tesfaye Balemi *et al*., 2019). Furthermore, maize has also steadily growing to new agroecologies such as the highlands of Ethiopia, previously known for production of major pulse crops and small cereals (Demissew Abakemal *et al*., 2013) following the release of suitable highland varieties (Gudeta Nepir *et al*., 2011).

The use of inappropriate maize agronomic practices could contribute to maize yield gaps. Among agronomic practices, plant population and row spacing which determine the plant final yield are among the key factors known to have a strong influence on maize grain yield (Haarhoff and Swanepoel, 2018), but this relationship is greatly variable (Assefa *et al*., 2016) and can be affected by an array of factors including rainfall, tillage system, fertilization, and soil type (Haarhoff and Swanepoel, 2018) and genotype (Sangoi *et al*., 2002). For example in Ethiopia from the available agronomic recommendation for maize, optimum plant density (Tesfa *et al*., 2011; 2019) is among the most key determinants agronomic recommendations for maize productivity. Targeting the right plant density for a certain environment is therefore a crucial factor to maximize yield for that given environment (Lacasa *et al*., 2020).

Plant density below the optimal will have more resources per plant with greater individual plant growth but in a population-scale the overall yield will be lower than when the canopy is at the optimal number of plants, maximizing light capture and canopy growth (Lacasa *et al*., 2020). In contrast, high planting density above the optimum will have a negative consequence by increasing intraspecific competition, reducing the available resources per plant, and in some situations increasing plant barrenness (Echarte *et al*., 2000). Variable maize grain yield responses to alterations in plant populations is common (Milander *et al*., 2016; Amelong *et al*., 2017). Interactions between plant genotype, environment and plant population can also affect maize grain yield (DeBruin *et al*., 2017). Previous studies under Ethiopian condition also revealed that maize yields significantly varied with plant population (Gobeze *et al*., 2012; Getahun *et al*., 2018).

To this end, in West Shewa zone of Oromia region, Nono district, farmers grow a number of improved maize hybrid varieties including Limu, BH661, BH660, BH540, Damote and others. The recommended planting density (75 cm x 30 cm) has not changed despite the development and introduction of stress tolerant maize varieties in the district. However, the present planting density may not be optimal for all types of hybrids due to genetic differences with respect to tolerance to planting density. Matching maize hybrids to planting density is required as new hybrids may require different optimum crop-management practices including optimum planting density. Therefore, information on how maize hybrids respond to a given plant density in a given environment to get an optimum yield should be studied and determined. Therefore, this study was conducted with the following objectives:

General objective

- To Study the Response of Maize (*Zea mays* L.) Hybrids to Planting Density on Yield and Yield Components in Nono District, West Showa Zone, Ethiopia

2. LITERATUR REVIEW

2.1. Maize and its Importance

Maize (*Zea mays* L.) is a member of the grass family *Gramineae (Poaceae)* and one of the oldest cultivated crops (Sleper and Poehlman, 2006). It is the primary food grain in Mexico, Central America, the Andean region of South America, and eastern and southern Africa (Sleper and Poehlman, 2006). The crop is grown at latitudes varying from the equator to 50° north and south, from sea level to over 3 000 meters elevation, under conditions ranging from heavy rainfall to semi-arid, from cool to very hot climates with growing cycles ranging from 3 to 13 months (Dowswell *et al*., 1996). To date, maize is widely cultivated in most parts of the world, over a wide range of environmental variables signifying its global and regional importance to millions of people who rely on the crop in pursuit of food security and livelihoods.

Maize is the third most important cereal crops widely grown throughout the world after wheat and rice. It is the most widely cultivated crop and one of the few crops that have profound effects on the livelihoods of people in sub-Saharan Africa (SSA) (Kindie *et al*., 2016). It is an important source of carbohydrates and protein in the diet in almost half of the calories and protein consumed in Eastern and Southern Africa (ESA) (Bekele *et al*., 2011) with 36 million hectare harvested annually (Tsedeke *et al*., 2017). In ESA, it covers 53% of the total land occupied by cereal crops (FAOSTAT, 2018).

2.2. Maize Production Status in Ethiopia

Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions (Tsedeke *et al*., 2017). It is grown mainly during the main growing season known as *meher*, which relies on May-September rainfall (Dawit *et al*., 2014). Maize has expanded rapidly (in terms of both area and production) and yield has also shown an increasing trend. About 70% of maize production concentrates in Oromia and Amhara regions (Dawit *et al*., 2014). Following the significant increase in maize productivity as a result of the good investment in improved seeds and chemical fertilizers to increase maize production and productivity, maize had a positive impact on poverty reduction in many parts of the country (Tsedeke *et al*., 2017). Maize has already expanded to new areas where maize production was not well known in the past (such as west and east Gojam), yet with better productivity. Maize has also expanded to new agro ecologies such as the highlands of Ethiopia following the release of suitable highland varieties such as BH660, Jibat and Wonchi (Gudeta *et al*., 2011).

2.3. Plant Density and Maize Productivity

Keeping plant density in optimum range is an important agronomic practice determining grain yields and yield components of maize crop (Tenaw *et al*., 2001; Sangoi, 2000; Abuzar *et al*., 2011). Lower plant density can explain up to 33% of the maize grain yield variation (Nafziger, 1994). Studies showed that maize yields significantly varied with plant population (Gobeze *et al*., 2012; Getahun *et al.*, 2018) and the same results were observed by Tesfaye *et al*. (2019) in a joint survey conducted by EIAR and CIMMYT where a positive relationship between grain yield and plant density as well as number of cobs and plant density. Both very low and very high plant population, however, reduced maize grain yield (Getahun *et al*., 2018). Getahun *et al*. (2018) observed that low plant population resulted in 18% of the maize grain yield reduction at Assosa, in Ethiopia. Increasing plant population beyond the optimum resulted in reduced grain yield and Tokatlidis and Koutroubas (2004) ascribes such reduction in grain yield to increased barrenness of plants as a result of the adverse effect of high plant population on the interval of pollen shading and silking creating non-synchronization and hence results in low yield.

2.4. Effect of Plant Density on Maize Yield and Yield Components

Plant population has a strong influence on maize grain yield (Van Roekel and Coulter, 2011), however, this relationship is highly variable (Assefa *et al*., 2016) and can be affected by factors such as rainfall, tillage system, fertilization, and soil type (Haarhoff and Swanepoel, 2018). Several studies indicated the effect of plant density/population affect the growth, phenology, yield and yield components of maize (Nik *et al*., 2011; Assefa *et al*., 2016; Bernhard and Below, 2020). Hybrids response to increasing plant population also varied (Assefa *et al*., 2016; Bernhard and Below, 2020) indicating existence of variability among hybrids in response to the population variation and suggests existence of interaction effect.

Study by Nik *et al*. (2011) grain yield, 1000-grains weight, biologic yield, harvest index varied with hybrids and population. Recently, an evaluation of genetic, environment, and management interactions concluded that responses to plant population depend on genetic and environmental conditions (Assefa *et al*., 2016). Recent study by Kamara *et al*. (2020), reported increased plant density resulted in higher grain yields, total dry matter, ears m^{-2}, and number of grains m^{-2} at 88,888 than at 53,333 plants ha^{-1} across environments. However, the magnitude of increases in yield when plant density was increased to 88,888 plants ha^{-1} was, however, higher for the new hybrids than for the old commercial hybrids.

2.5. Maize Hybrids Response to Planting Density

Interactions between plant genotype and plant population can also affect maize grain yield, with a recent study conducted by DeBruin *et al*. (2017) finding a positive relationship between maize grain yields and plant population in modern hybrids, but a contrasting response in older hybrids. Modern hybrids possess the ability to withstand greater stress attributable to high population densities than older hybrids, which in turn enables producers to establish higher plant populations, leading to higher yields per unit area (Duvick, 1997). The agronomic practices implemented in a production system should allow the selected germplasm to react positively to the increased plant populations when favorable environmental conditions occur (Haegele *et al*., 2014) while also being tolerant to increased plant-to-plant competition under suboptimal growing conditions (Tokatlidis and Koutroubas, 2004). High densities are required for maximum yield potential, but optimum density differs among hybrids and across seasons (Fasoula and Tollenaar, 2005).

2.6 . Major maize growing Agro-ecologies in Ethiopia

Maize is produced under diverse ecological conditions in different parts of the country. The reasons for such large adoption and expansion of maize cultivation in Ethiopia include: The maize agro-ecologies in Ethiopia can be broadly divided into six major categories (MOA, 2005), including Moist and Semi-moist mid-altitudes (1700–2000 m above sea level; 1000–1200 mm rainfall), Moist upper mid-altitudes(2000– 2400 m; >1200 mm), Dry mid-altitudes (1000–1600 m; 650–900 mm), Moist lower mid-altitudes (900–1500 m; 900–1200 mm), Moist lowlands . Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socio-economic conditions grown mainly during the main growing season known as meher, which relies on May-September rainfall (Tesfay B et al ., 2019) . Maize has expanded rapidly (in terms of both area and production) and yield has also shown an increasing trend. Following the significant increase in maize productivity as a result of the good investment in improved seeds and chemical fertilizers to increase maize production and productivity, maize had a positive impact on poverty reduction in many parts of the country. Maize has already expanded to new areas where maize production was not well known in the past (such as west and east Gojam), yet with better productivity (Tesfay B et al ., 2019) .

2.7. Maize Varieties in Ethiopia

Discussions of agriculture and rural development in Ethiopia inevitably lead to the subject of seed. Through a combination of modern science and modest changes in farmer cultivation practices, improved seed can yield remarkable abundance for small-scale farmers in Ethiopia (Ethiopian seed Association ,2014) . The development of improved maize variety in Ethiopia focuses on the improvement of two types of maize varieties: hybrids and open pollinated maize varieties. Hybrids are superior in yield potential compared to open pollinated maize varieties. Even if open pollinated maize mostly provided lower yield than hybrids, they can provide comparable yield as hybrid under reduced input utilization (Emmanuel et al, 2014; Thembinkosi, 2010) and farmers can save their seed to use for more than three years. In addition to these open pollinated maize varieties are easier to develop than hybrids and their seed production is relatively simple and inexpensive (CIMMYT, 1999).

This abundance can contribute to greater production and productivity in the agricultural sector while also addressing the country’s food security and poverty reduction challenges (Alamu D at el .,2008) **.** Open pollinated maize varieties are the best choice to small scale farmers which cannot afford the cost of hybrids, cultivating maize in low potential environment and cannot pay for inputs such as fertilizers and pesticides, in the deficiency of adapted hybrids and absence of enough hybrid seed for timely planting (Emmanuel et al., 2014; Kutka, 2011; Thembinkosi Nyathi, 2010). SARE (2004) reported that maize producers’ interest in growing open pollinated maize has increased due to four main reasons:- economic considerations, grain quality, self reliance, and independence from agricultural conglomerates.

Open pollinated maize varieties are one of the best options for farmers who cannot afford the cost of hybrids, cultivating maize in low potential environments and cannot pay for inputs such as fertilizers and pesticides. Maize is currently grown across 13 agro-ecological zones which together cover about 90 percent of the country. Maize cultivation is also a largely smallholder phenomenon in Ethiopia. The small-scale farmers that comprise some 80 percent of Ethiopia's population are both the primary producers and consumers of maize in Ethiopia.

Maize cultivation is also a largely small holder phenomenon in Ethiopia. The small-scale farmers that comprise some 80 percent of Ethiopia's population are both the primary producers and consumers of maize in Ethiopia . In support of the growing popularity of maize, an extensive maize seed industry has emerged in Ethiopia over the last several decades . Seed industry players include public sector research organizations and extension services; market-actors such as private breeders, seed companies, stockiest, and trade associations civil society actors such as non-governmental, farmer and community-based organizations and farmers themselves (Mwangi at el., 2008). The recent introduction of several new maize varieties in Ethiopia illustrates the potential importance of this seed industry and the contribution of improved maize varieties to Ethiopia's agricultural sector. These varieties were specifically adapted to the semiarid agro-ecologies of Ethiopia's Rift Valley, an area comprising the central part of the country and characterized by lowland to intermediate agro-ecologies with access to relatively greater irrigation than other parts of the country. Their potentially significant impact on yields and output has been demonstrated through extensive field trials (Gudeta et al ., 2011) .

2.8 .Response of Maize Varieties to Environment

Environmental effects have been shown to have effects on grain yield and thus yield components as well. Water and temperature have specifically been shown to affect yield through yield components. Available N is not considered to be an environmental factor but it is related as it moves with water in the soil and the plant. Environment varies across growing seasons and thus causes yield components to vary due to multiple and interactive environmental factors (Haegele et al., 2014) . Maize an important cereal of the world, ranked 1st in seed yield production and can grow in areas where annual precipitation exceeds 600mm.

Despite modern agriculture is concerned with yield and nutritional quality of crop but environment does play its role for production of the varieties (Akwal at el., 2010) .

Maize an important cereal of the world, ranked 1st in seed yield production and can grow in areas where annual precipitation exceeds 600mm. Despite modern agriculture is concerned with yield and nutritional quality of crop but environment does play its role for production of the varieties (Akwal at el., 2010) . Optimum plants with sufficient inputs might play significant role in production due to efficient utilization of resources e.g. light, CO_2 and water etc. Assuming biotic and abiotic stresses constant, dry matter yield is equal to amount of radiation absorbed by the canopy . Light interception by crop canopy is function of dry matter productivity where leaf contributes more than 80% . Leaf area development at different nodal position is therefore important parameter to take in consideration of crop yield and yield components. Temperature also affects grain fill of maize as it has an effect on the rate and duration of kernel growth and final kernel weight. Extreme temperatures of 15°C and 35°C during grain fill have been found to be similarly detrimental to kernel growth and reduce kernel weight. These effects were more severe during early grain fill then during late grain fill (Jones et al., 1984). The opposite effects were observed when higher temperatures occurred in the same time period and thus lower yields were attained.

3. MATERIAL AND METHODS

3.1. Description of the Study Areas

Two field experiments were conducted during the *Belg* cropping season 2021 at farmer's fields (Silkamba and Jiru Gemechu) in Nono district, West Shewa zone, Oromia region. Nono district is located at latitude $37^0$59 E and longitude $8.20.3^0$N at an altitude range of 1500 to 1950 m.a.s.l. The district has two major Agro-ecological zones, with 70.59% Kola and 29.41 % Wayne Dega (Nono Woreda Agricultural office 2011). The district was known for its potential for maize production. The district receives mean annual rainfall that ranges from 900 to 1100 ml. The mean annual minimum and maximum temperature is 14 ºCe and 24 ºCe respectively. The experimental site was carried out at two different locations whith low and mid altitudes .

Silk Amba is situated in Nono woreda, 223 kilometers from Addis Abeba and 70 kilometers to the southwest of Ambo town. It is located at an elevation of 1850 masl, with an annual temperature of 15 °C, and receives 1950 ml of precipitation each year (Nono Woreda Agricultural Office 2005). The predominant soil type in the area is loam soil. Jiru Gamachu, which has an annual temperature of 22 °C, an annual rainfall of 900 ml, and an elevation of 1572 masl, is situated 239 km from Addis Abeba and 16 km from Silk Amba town. The predominant soil type in the area is also loam.

3.2. Experimental Materials

For the experiment, four hybrid maize varieties with varying maturities were used: Limu and Damote from the Pioneer Seed Company, and BH540 and BH546 from the Bako Research Center. Limu and Damote are both late in maturing (165–180 days), while BH540 and BH546 both have a medium maturation period (145 days) (MoANR, 2016). Additional description of the hybrid maize varieties used is presented in Table1.

Table 1. Description of maize hybrid varieties used for the study

Name of Variety	Year of release	Rain fall requirement	Altitude (m)	Maturity	Yield (qt ha^{-1})	Breeder
BH540	1995	1000-1200	1600-2200	145	80-90	BRC
BH546	2013	1000-1200	1600 – 2200	145	93-103	BRC
Limu (P3812W)	2012	1000-1900	1200-2000	180	80-100	PHSE
Damote (P3506W)	2015	900-1800	800-1800	165	60-80	PHSE

Medium 120-150 and late 160-180 days (Tesfaye et al., 2020). BRC; Bako Research Center and PHSE; Pioneer Hybrid seed Ethiopia. Source: (MoANR, 2016)

3.3. Treatments and Experimental Design

The treatments was consist factorial combinations of three planting populations (44 444; 53 333; 66667 plants ha $^{-1}$) and four widely cultivated commercial maize hybrids (BH540, BH546, Limu and Damote) arranged in 3 x 4 factorial combination in randomized complete block design (RCBD) replicated three times. The spacing between plots and adjacent replication were maintained at 1.5 m and 1 m, respectively. For the first (44, 444 plants ha^{-1}) and second plant population (53, 333 plant ha^{-1}), a spacing of 75 cm x 30 cm and 75 cm x 25 cm was used to achieve the desired plant population, respectively . For the third (66,667 plants ha $^{-1}$) a spacing of 75 cm x 40 cm with two seeds placed 5 cm apart was used. Each plot consisted of a gross area of six 3m long rows (4.5m x 3m = 13.5m^{2}). At each location, the central four rows of each plot (a net plot area of 9 m^{2}) were used for data collection.

Table 2. Treatment combinations used for the study

S/No.	Variety	Plant density (plants ha^{-1})	Treatment combination
1	BH540	44,444	BH540 at 44,444 plants ha^{-1}
2	BH540	53, 333	BH540 at 53,333 plants ha^{-1}
3	BH540	66,667	BH540 at 66,667plants ha^{-1}
4	BH546	44,444	BH546 at 44,444 plants ha^{-1}
5	BH546	53, 333	BH546 at 53,333 plants ha^{-1}
6	BH546	66,667	BH546 at 66,667plants ha^{-1}
7	Limu	44,444	Limu at 44,444 plants ha-1
8	Limu	53, 333	Limu at 53,333 plants ha-1
9	Limu	66,667	Limu at 66,667plants ha^{-1}
10	Damote	44,444	Damote at 44,444 plants ha^{-1}
11	Damote	53, 333	Damote at 53,333 plants ha^{-1}
12	Damote	66,667	Damote at 66,667plants ha^{-1}

3.4. Experimental Procedures and Field Management

The land was prepared at each testing site (Silk Amba and Jiru Gemechu) by plowing it three times with oxen followed by leveling it in April 2021. Planting was carried out on May 24 and May 27 at Jiru Gemechu and Silk Amba sites, respectively. During planting, each site received a basal fertilizer treatment of recommended full dose blended NPSB fertilizer (200 kg NPSB ha^{-1}). Additionally, at both sites, the recommended nitrogen rate in the form of urea (250 kg^{-1}) was applied uniformly in two bands: half of it after 30 days after planting and the remaining half after 60 days. At both research sites, every other aspect of cultural practices were applied consistently to every experimental plot. At the vegetative stage of the maize plant in both locations, Stem Borer and Fall Army Worm were observed. As a result, Ethiozinon 60% EC (Diazoni) insecticide applied at the recommended rate of 1-2 L/ha diluted in 1000 liter volume of water. At each site, harvesting was done from the central rows of each experimental plot when the crops reached physiological maturity (plant turned to yellowish, ear husk turned into the brown and appearance of black layer at the base of each kernel).

3.5. Soil Sampling and Analysis

At each site prior to planting, soil samples were taken using auger randomly to depth of 0– 20 cm by walking the field in “W” pattern from 10 spots and composites sample prepared for each. Composited samples used for physico-chemical analysis of the experimental sites at. Laboratory analysis was conducted at Wolkite Sample testing and Soil Fertility Improvement Center testing laboratory. Composite soil sample were air dried and analyzed for the determination of soil texture, soil pH, organic matter content, total nitrogen, available phosphorus and cation exchange capacity (CEC). Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos., 1962). The pH of the soil was measured in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter (Rhoades at el., 1982). Organic carbon (%) was determined by method as described by Walkley and Black , (1934). Total nitrogen was measured using Kjedahl method as described by (Bremner and Mulvaney, 1982). CEC in cmol (+) kg^{-1} soil was determined by ammonium acetate method.

3.6. Data Collection and Measurements

At each location, observations based on plot and plant base were made for each experimental plot from the net plot area of each as follows:

Day to anthesis (DA): measured by counting the number of days from planting to the date when 50% of the plants in a plot had shed pollen.

Days to silking (DS) :- measured by counting the number of days from planting to the date when 50% of the plants in a plot had emerged silks.

Anthesis silking interval (ASI) :- was computed as the difference between DS and DA.

Days to physiological Maturity (DPM): was recorded as the number of days from planting to the formation of a black layer at the point of attachment of the kernel with the cob by 75% of the maize plants in the net plot.

Plant height (PH):- measured as the distance from the base of the plant to the height of the first tassel branch and taken from ten randomly selected plants from the central rows of each plot after flowering (measured two weeks after pollen shed).

Ear height (EH):- measured as the distance from the base of the plant to the node bearing the upper ear after flowering and taken from five randomly selected plants from the central rows of each plot after flowering (measured two weeks after pollen shed).

Number of ears per plant (EPP): determined by dividing the total number of ears harvested from the central rows of each plot by number of plants in the plot at harvest. An ear was counted if it had at least one fully developed grain.

Number of rows per ear (RPE):- was recorded as the average number of kernel rows per ear from the five randomly sampled ears harvested from the central three rows of each plot.

Number of kernels per row (KPR): recorded as the average number of kernels per row from the five randomly taken ears during harvesting.

Ear length (EL) (mm): was measured as length of the ear from the base to tip, like ear diameter, an average of five ears was used.

Ear diameter (ED) (mm): measured using Vernier caliper from five randomly selected ears from all harvested ears of each plot (net plot). It was measured at the mid-way along the ear length as average of the five randomly selected ears.

Field weight (FWT): It was recorded as the weighted in kg of all dehusked ears (cobs) in the plot (from net plot area) at harvesting.

Moisture percentage (MOIST):- To determine grain moisture content (%), five representative cobs were selected, dehusked and shelled. The moisture content of the grains was then measured with digital moisture tester (Model PM-450, Kett Electric Laboratory) in the field.

Thousand Kernel weight (TKW): was determined by counting 1000 seeds from a bulk of each experimental plot and weighed in grams after the moisture was adjusted to 12.5%.

Total above ground biomass yield (TBY) (t ha^{-1}):-plants were harvested from the net plot area(9m$^{2)}$, weighed using field balance (Salter Model-235), and recorded biomass yield at harvested .

Grain yield (GY) (tha^{-1}):- was determined on field weight basis (ears weighted in kg) from the net plot area, adjusted to 12.5% moisture content, and 80% shelling percentage was assumed for estimating the grain yield and converted to t ha^{-1}.

To determine grain moisture content (%), five representative cobs were selected and grains removed from their cobs. The moisture content of the grains was measured with digital moisture tester (Model PM-450, Kett Electric Laboratory) using the following formula (Badu-Apra et al., 2021). Grain yield (t/ha) = [Fresh ear weight (kg/plot) × 10 × (100 − MC) × 0.8)/((100 − adjusted Moisture content) × Plot Area]

Harvest index (HI): was determined as the ratio of grain yield to total above ground biomass and multiplied by 100% at harvest in Kilo gram from each plot (Huehn, 1993).

$$\mathrm{HI\%} = \frac{\text{Grain yield}}{\text{Total above ground biomass}} \times 100$$

3.7. Statistical Data Analysis

At each location, analysis of Variance (ANOVA) was conducted using the PROC GLM procedure of SAS SAS version 9.3 (SAS Institute, 2014) for all measured traits. When traits mean square found significant, combined analysis of variance was performed using the PROC MIXED procedure of SAS with RANDOM statement with TEST option after performing test of homogeneity of error variances using Minitab version 17 software. In the combined ANOVA, maize hybrids and plant populations were considered as fixed effects, while location (Loc), replication (Rep), Rep nested within Loc and all interactions with these effects were considered random effects. Significant treatment means were separated by Fisher's protected least significant difference (LSD) test at P = 0.05. Pearson's correlation analysis between grain yield and other measured parameters was conducted using Minitab version 17 software.

4. RESULT AND DISCUSSION

4.1. Soil Physico-Chemical Properties of Study Sites

Table 3 shows the analysis of the laboratory analysis of the experimental sites for certain soil physical and chemical characteristics. The results demonstrate that the soil textural class for both Silk Amba and Jiru Gemechu is loam soil. Silk Amba and Jiru Gemechu had pH values of 6.7 and 6.4%, respectively. According to Tisdale et al. (2002), soil pH values of <_ 3.5, 3.5-4.4, 4.5-5, 5.1-5.5, 5.6-6, 6.1-6.5, and 6.6-7.3 were each described as being either extremely acidic, very strongly acidic, strongly acidic, moderately acidic, likely acidic, and neutral. Accordingly, both the experimental sites are neutral . The normal soil pH for maize production is known to be between 5 and 8 (Martin, 1993), the current pH result at both sites indicate suitability for maize production . It was evident from the results that both sites had low levels of organic carbon according to Landon's (1991) rating. Similarly, according to the rating of a similar author, the status of total nitrogen in both sites has been shown to be low.

Table 3. Selected physico-chemical properties of the experimental sites

Site	OM%	TN%	pH, H_2O	CEC (meq/100gsoil)	Texture			
					%Sand	%Clay	%Silt	Textural Class
Silk Amba	5.24	0.262	6.7	33.6	40	23	37	Loam
Jiruu Gamechu	5.58	0.279	6.4	49.4	36	19	45	Loam

Note : OM (organic matter), TN (total nitrogen), pH (potential of hydrogen),CEC (cation exchange capacity)

4.2. Crop phenology and Growth Parameters

4.2.1. Days to anthesis, silking, and physiological maturity

Examining the days to anthesis (DA), silking (DS), and maturity (DM) across locations, it was revealed that there was a noticeable effect of location ($P \leq 0.05$) and variety ($P \leq 0.01$) (Appendix Table 1). Location by hybrid interactions were significant (($P \leq 0.05$) for DS and DM but not for DA ($P > 0.05$) (Appendix Table 1). Besides, interaction of hybrid by plant population, location x hybrid, and location x hybrid x population revealed non- significant effect for DA, DS and DM (Appendix Table 1).

Effect of location and variety on days to anthesis

The longest days to anthesis was observed at Silk Amba site than Jiru Gemechu (Figure 1). The higher elevation, and the prevailing rainfall during the growing season at Silk Amba might contributed to the delay in days to anthesis than Jiru Gemechu, located at lower altitude and received low rainfall. Temperature variation at the study locations might also contributed in the variation to days to anthesis.

Mean values of hybrids indicated that, Damote took maximum days (90.55 days) to anthesis (male flowering) followed by BH54, while hybrids BH540 and Limu took minimum days to anthesis (87.83 and 88.72 days). The variation observed among maize hybrids for days to anthesis could be attributed to inherent genetic variation. Consistent to the present study, Abubakar and Manga (2017) reported variability of maize for days to flowering in ten maize genotypes. In to this finding, previous study by Ajayo *et al*. (2021) in ten early and late maize genotypes revealed varied response of maize genotypes for days to flowering and anthesis. Furthermore previous studies also documented significant effect of hybrids to days to anthesis, silking and anthesis silking interval across environments (Dagne et al., 2011; 2014; Berhanu et al., 2017; Addisalem et al., 2019).

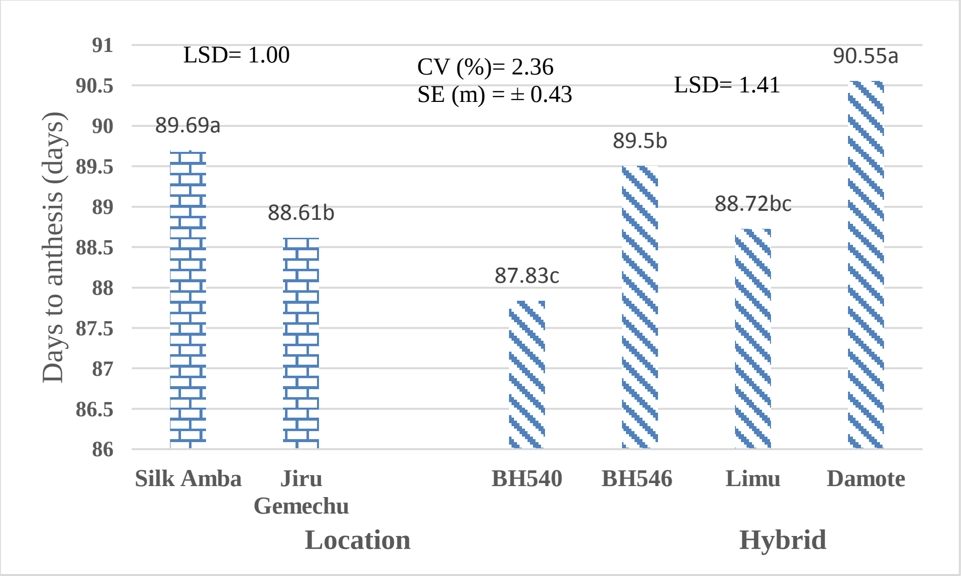

Figure 1. Effect of location and hybrid on days to anthesis

Effect of hybrid by location interaction on days to silking and anthesis silking-interval

Table 4. depicts hybrid by location interaction effect on days to silking (DS) and anthesis silking-interval(ASI). The interaction of hybrid by location on DS and ASI indicated performance of hybrids were not consistent across environments . The longest DS(97.44 days) was observed at Silk Amba by hybrids BH546, Damote and Limu. All the test hybrids at Jiru Gemechu did not significantly varied for DS. The lowest DS (93.22 days) was observed at Jiru Gemechu from hybrid Damote, and was not statistically different from the rest hybrids. In agreement with the present findings, Dagne et al. (2014) and Addisalem et al. (209) reported significant hybrid by environment interaction for maize hybrids for days to silking.

Similarly ASI of maize was significantly affected by the interaction of hybrids and locations. The shortest ASI(1.27 days) was noted from Damote at Jiru Gemechu, and was statistically at par with hybrids BH540 at both locations. In contrast the maximum ASI (1.42 days) was noted from Silk Amba site from BH546, which was statistically not different from all hybrids at both locations with the exception of Damote hybrid at Jiru Gemechu site. Higher ASI indicated less synchrony between male and female flowering, while shorter ASI indicates high synchrony between female and male flowering. Accordingly, higher DS at Silk Amba for BH546 hybrid and Damote resulted for wider ASI (not desirable). In contrast, shortest DS at

Jiru Gemechu from hybrid Damote resulted in the shortest ASI days, and preferred one and resulted in higher synchrony between male and female flowering. Generally the ASI observed in this study is shorter among hybrids at each location as it was less pronounced in modern maize hybrids (Kamara et al., 2006). Significant hybrid by location interaction for ASI for maize hybrids has been also reported previously (Dagne et al., 2014; Addisalem et al., 2019).

Table 4. Interaction effect of hybrid and location on days to silking and anthesis silking interval

Hybrid	Location	Days to silking	Anthesis-silking interval
BH540	Silk Amba	92.89c	1.35ab
	Jiru Gemechu	92.33c	1.34ab
BH546	Silk Amba	97.44a	1.42a
	Jiru Gemechu	94.11bc	1.36a
Limu	Silk Amba	96.22ab	1.40a
	Jiru Gemechu	93.67bc	1.38a
Damote	Silk Amba	97.44a	1.41a
	Jiru Gemechu	93.22c	1.27b
LSD (5%)		1.67	0.05
CV (%)		1.86	4.1

Means followed by the same letter in a column are not significantly different at $P > 0.05$

Effect of location on days to maturity and ear height

Location significantly affected days to maturity and ear height of maize hybrids (Figure 2.). Accordingly, Silk Amba site resulted in delayed maturity than Jiru Gemechu. Likewise, Silk Amba resulted in the highest (134 cm) ear height of maize compared to Jiru Gemechu. The significant differences between locations for days to maturity and ear height (Figure 2) might have arisen from the differences in weather conditions (temperature, rainfall, elevation) that prevailed during the evaluation of the trial at these locations. The two test locations, namely Silk Amba and Jiru Gemechu, differed markedly in rainfall, across years, contributing to the observed differences for these traits in these locations. In agreement with the present findings Kamara et al. (2020) reported significant effect of location growth, yield and yield components of maize hybrids. Addisalem et al. (2019) also reported significant effect of location on ear height and other traits of maize hybrids tested at Ambo and Bako.

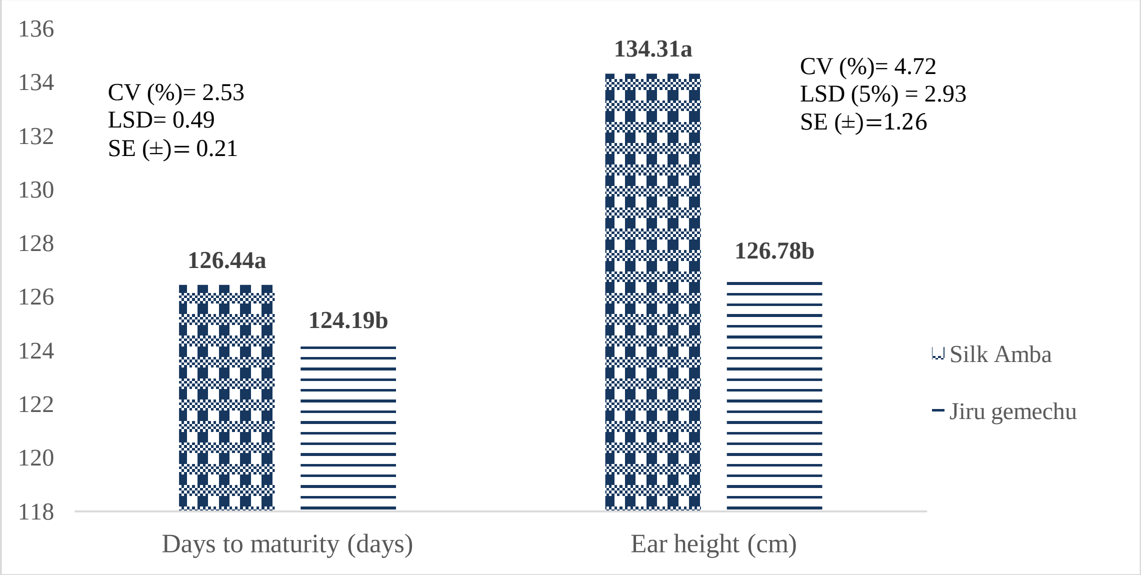

Figure 2. Effect of location on days to maturity and ear height

Effect of plant density on days to maturity, plant and ear heights

Days to physiological maturity, plant height and ear height significantly affected by plant density (Table 5). Days to maturity, took earlier at 44, 444 and 53,333 plants ha^{-1}. The highest plant density resulted in delayed to physiological maturity and was statistically not different than plant population at 53, 333 plants ha^{-1} (Table 5). Plant density also affected plant height significantly. Accordingly, the highest plant height (257.7 cm) was observed at the highest plant population ha^{-1}, while the lowest (250.92 cm) was observed at the lowest plant population (Table 5). Likewise, the highest ear height (134.22 cm) was observed at the highest plant population (66,667plants h-^{1}) and the lowest plant population resulted in the lowest ear height (44,444 plant h-^{1}) and was also statistically at par with ear height at 53,333 plant population ha^{-1}. Generally in this study, both plant and ear height increased with increased planting density from 44,444 to 66,667 plants ha^{-1}. Previous studies on plant population effect on maize hybrids also reported significant effect of plant population on physiological development including days to maturity, and growth traits like plant and ear height under varied plant populations in different agro-environments (Abubakar and Manga, 2017; Omar et al., 2022).

Effect of hybrid on maturity, plant and ear heights

The hybrids differed in days to maturity, plant and ear heights across locations(Table 5) . Days to physiological maturity ranged from 124.33 days (BH540) to 125.83 days (BH546 and Damote). Hybrids BH546, Limu and Damote resulted in the delayed to physiological maturity, but did not resulted in significant mean variation for the trait. Inherent characteristics of the hybrids might contributed for variation in days to maturity, but most conversely, BH540 took significantly earlier days to physiological maturity than the rest hybrids. Plant height among the hybrids ranged from 243.41cm (BH546) cm to 264. 41- cm (Damote). Hybrid Damote resulted in the highest plant height and was not however, statistically different from Limu variety . In contrast, the lowest plant height was recorded form BH540, and was statistically at par with hybrid BH546 (Table 5). Ear height ranged from 127.11 cm (BH546) to 133.69 cm (Limu). The highest ear height was observed from hybrid Limu, and statistically not different than BH540 hybrid. In contrast, the shortest plant height was recorded from hybrid BH546, and was also not significantly different from hybrid Damote. Variations in maize hybrids for growth parameters recorded in the current study is in agreement with previous studies on maize hybrids in Ethiopia that included Limu and BH546 hybrids in their study (Tesfaye et al.,2020). Similarly, existence of hybrids variability to maturity and growth characters have also been reported (Jan et al., 2007; Dagne et al., 2014; Abubakar and Manga, 2017; Fromme et al., 2019; Omar et al., 2022).

Table 5. Effect of plant population and hybrid on days to maturity, plant and height

Treatments	Traits		
Plant density ha^{-1}	Days to maturity	Plant height	Ear height
44,444	124.92b	250.92b	127.33b
53, 333	125.29ab	255.84a	130.07b
66,667	125.75a	257.70a	134.22a
LSD (5%)	0.6	4.71	3.59
Hybrid			
BH540	124.33b	248.34b	133.24a
BH546	125.83a	243.41b	127.11b
Limu	125.27a	264.81a	133.69a
Damote	125.83a	262.72a	128.13b
LSD (5%)	0.69	5.44	4.14
CV (%)	2.53	3.18	4.72

Means followed by the same letter in a column are not significantly different at P > 0.05

4.3. Ear parameters

4.3.1. Number of ears per plant

Combined ANOVA revealed highly significant ($P \leq 0.01$) effect of location, hybrid and plant density on number of ears per plant. However, none of the second and third order interaction effects were significant ($P > 0.05$) for the same trait (Appendix Table 2).

Effect of location, hybrid and plant density on number of ears per plant

Planting environment significantly affected number of ears per plant (Figure 3). The highest number of ears per plant was recorded at Silk Amba (1.21) site than Jiru Gemechu (1.11). The prevailing environmental condition at Silk Amba might contributed to increased growth and development and resulted in more number of ears per plant than the other environment. The variations in weather and soil characteristics that prevailed during the experimentation period at these locations may have contributed to the large differences in the number of ears per plant between the locations. The rainfall variation between years at the two test sites, Silk Amba and Jiru Gemechu, might explain the observed variations in the number of ears per plant and other features observed. In accordance with the current study, substantial effect of location on the number of ears per plant in maize hybrids have been reported in previous studies (Dagne et al., 2014; Addisalem M et al., 2019; Kamara et al., 2020; Alamu et al., 2022).

Maize hybrids also responded differently across environments for number of ears per plant (Figure 3). Hybrid Damote had the maximum number of ears per plant (1.25) and was statistically comparable to BH546 and Limu hybrids, whereas BH540 had the lowest number of ears per plant (1.01) (Figure 3). The modern hybrids (BH546, Limu and Damote) showed more ears on each plant than the older one (BH540) did. In agreement, Cui et al. (2022) and Kamara et al. (2020) both noted that new maize hybrids had more ears per plant than older varieties do.

Plant density significantly affected number of ears per plant on maize (Figure 3). The lowest plant density(44,444 plants ha^{-1}) yielded the maximum number of ears per plant (1.31), whereas the highest plant density (66,667 plants ha^{-1}) yielded the lowest (1.04) number of ears per plant (Figure 3). In the current study, the number of ears per plant decreased as plant density increased, and was in agreement with previous studies (Jan et al., 2007; Fromme et al., 2019; He et al., 2022; Andrea et al., 2022) where higher ear prolificacy in low-density crops.

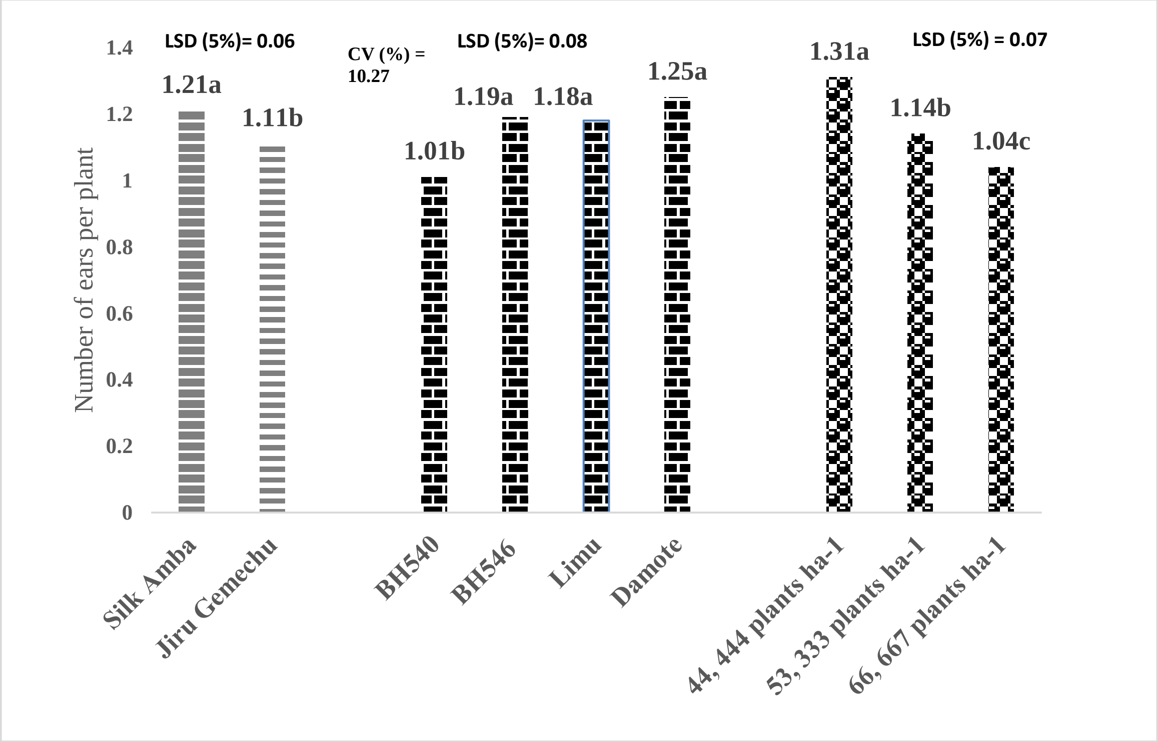

Figure 3. Effect of location, hybrid and plant density on number of ears per plant on maize

4.3.2. Ear diameter and ear length

The mean square showed that the main effects of location and hybrid significantly ($P < 0.01$) affected (Appendix Table 2) ear diameter (ED). The interaction effect of location by hybrid also significantly ($P < 0.05$) affected ear diameter. However, the main effect of plant density and the rest two and three way interaction effects failed to significantly affect ear diameter (Appendix table 2). With regard to ear length (EL), mean square for combined ANOVA showed that only the main effect of hybrid significantly ($P < 0.01$) affected EL of maize. Other main effects and all interaction effects did not significantly affected ear length (Appendix Table 2).

Interaction effect of location by hybrid on ear diameter

Figure 4 shows the interaction effect of location by hybrid on ear diameter (ED). Ear diameter ranged from 46.56 mm at Jiru Gemechu from BH540 hybrid to 50.76 mm at the same location from BH546. In the current study, the environment in the two settings significantly affected ED for BH540 (Figure 4). The ear diameter of other maize hybrids, however, was not impacted by the environment, suggesting that the new hybrids performed consistently for ear diameter in both locations. Significant effect of environments on ear diameter and other ear characteristics has been reported previously (Mousavi *et al*., 2020; Andayani *et al*., 2020).

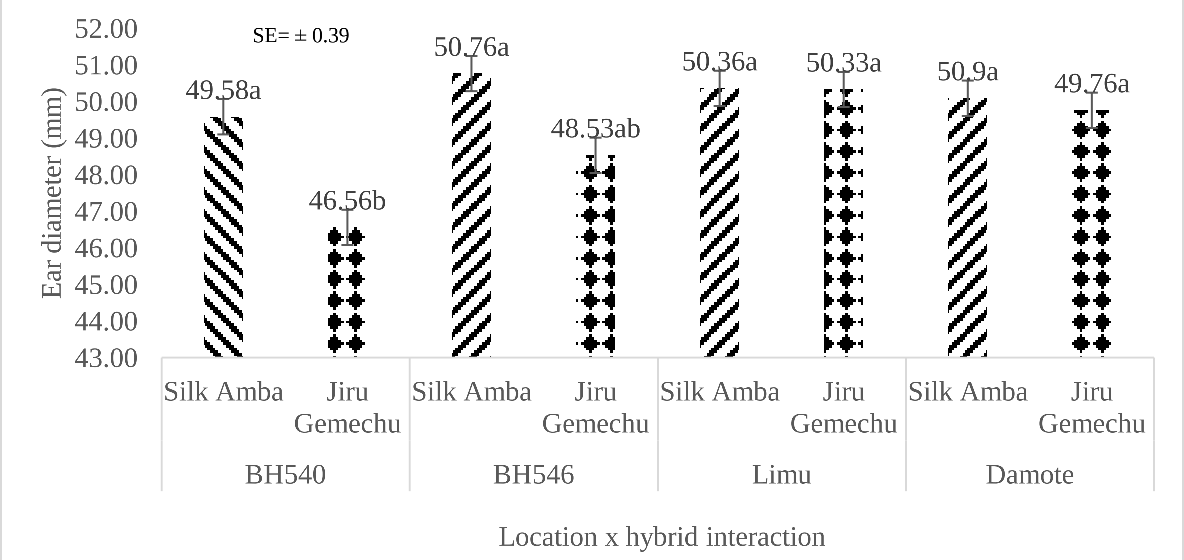

Figure 4. Interaction effect of location and hybrid on maize ear diameter

Effect of hybrid on ear length

The effect of hybrid on maize ear length is presented in Table 6. Hybrid BH540, recorded the shortest ear length, less number of kernel rows per ear and number of kernels per row (Table 6). The longest ear length (18.47 cm) was recorded from Limu hybrid. However, hybrids BH540, BH546 and Damote did not significantly different in ear length. The narrowest ear diameter was obtained from the oldest hybrid (BH540), while the widest ear diameter was recorded from Limu and was statically at par with Damote and BH546 (Table 6). Existence of genetic variations for ear length among the hybrids could be the culprit for differences in ear length variability. Variations to maize hybrids for ear length have been reported in Ethiopia for varieties adapted in mid altitude environments (Tasisa and Teshome , 2019) and for low land maize varieties (Mekuannet , 2020).

4.3.3. Kernel characteristics

Across environments, mean squares for number of kernel rows per ear (KRPE) and number of kernels per row (KPR) significantly (P < 0.001) affected by hybrids. However, the main effects of location and plant density and all interactions did not significantly affected these traits (Appendix Table 2). Significant effect of hybrid on KRPE and KPR suggested that these traits are governed by genetic make of the hybrids.

The least number of kernel rows per ear (12.82) was recorded from BH540, and the highest(14.73) from BH546 which was not significantly different than Limu. With regard to kernel number per row, the lowest (35.42) was recorded from BH540, and the highest(39.25) was obtained from Limu. However, BH546 and Damote did not significantly vary in KPR (Table 6). Mekuannet , (2020) observed hybrid variability for kernels per ear in low land maize varieties in earlier studies, which is consistent with the findings of the current study.

Table 6. Ear length, kernel rows per ear and number of kernels per row as influenced by maize hybrids

Hybrid	Ear length(cm)	Kernel row per ear	Kernel per row
BH540	15.77b	12.82c	35.42c
BH546	16.86b	14.73a	37.37b
Limu	18.47a	14.4a	39.25a
Damote	16.39b	13.64b	37.77b
LSD (5%)	1.59	0.4722	1.3405
CV (%)	14.0	5.05	5.33

LSD, least significant difference at 5% probability level. Means followed by the same letter in a column are not significantly different at P > 0.05

4.4. Grain Yield and Yield Components

4.4.1. Grain yield

Combined analysis of variance depicted that the main effects of location, hybrid and population were significant ($P \leq 0.05$) for grain yield (Appendix Table 3). In addition, location by hybrid interaction significantly influenced grain yield. However, all the rest two way or three way interaction did not significantly ($P > 0.05$) influenced grain yield.

Effect of plant density on maize grain yield

In modern maize hybrids, field yield increases with plant density until a maximum population is reached, in line with the growing surroundings and after this maximum field yield declines (Greveniotis et al., 2019). On research, the lowest grain yield (9.2 t ha^{-1}) was found at the lowest plant population(44,444 plants ha^{-1}) , whilst the highest plant population resulted within the maximum grain yield (10.27 t ha-1). However, there was no apparent yield distinction between the plant populace at 53,333 plants consistent with hectare and the highest plant population (figure 5). Grain yield typically expanded appreciably whilst plant population improved from 44, 444 to 53,333 plants per hectare, but did now not increase significantly after 53, 333 plant population, indicating that 53,333 plants per hectare was the most excellent population in this study for optimum grain yield.

Similarly to changing growth and developmental styles and carbohydrate production, stand density also has an effect on plant architecture. At low densities, maximum maize varieties do now not tiller efficiently and quite often produce only one ear per plant (Abuzar et al., 2011). If the plant density is just too high, it's going to actually lead to interplant competition as a way to increase crowding stress and reduce grain yield (Sangoi, 2001; Tollenaar et al., 2006; Yan et al., 2017; Fromme et al., 2019). It seems that plant density of 53,333 plants ha^{-1} are required for optimum yield in Nono district. It together with this observation, in advance investigations determined a considerable effect of plant population on maize grain yield (Jan et al., 2007; Fromme et al., 2019; He et al., 2022; Omar et al., 2022).

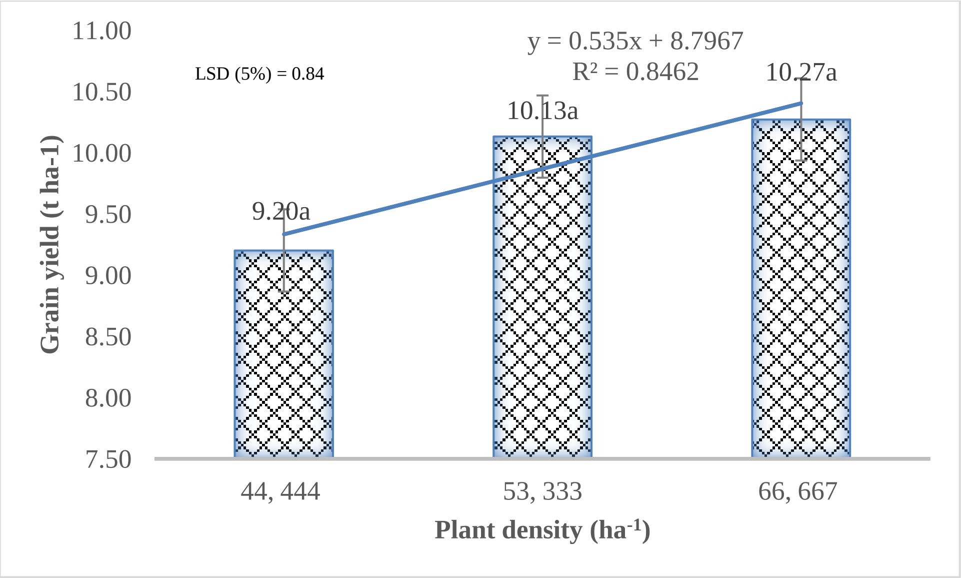

Figure 5. Effect of plant density on grain yield of maize hybrid

Effect of location by hybrid interaction on maize grain yield

The effect of location by hybrid interaction on maize grain yield indicated that hybrids performance were inconsistent across the tested locations. The maximum grain yield was produced by hybrid Damote at Silk Amba (12.32 t ha^{-1}), which was comparable to Limu hybrid at the same location. The Damote variety outperformed BH540 in Jiru Gemechu by 36%, while the Limu variety outperformed BH540 at Silk Amba by 25.94%. The lowest grain yield at Jiru Gemechu was observed from hybrid BH540, which was statistically equivalent to BH546. At Silk Amba, hybrid BH546 resulted in comparable grain yield to Limu and Damote hybrids (Figure 6). Generally at both locations the pioneer hybrids resulted in higher grain yield compared to hybrids released from Bako Agricultural Research Center. Significant effect of maize hybrid by location interaction have also been reported (Dagne *et al*., 2011 Berhanu et al., 2017; Addisalem *et al*., 2019; Azrai *et al*., 2022). In contrast, Tariku et al. (2022) reported non-significant location by variety interaction on maize varieties released for low land environments of Ethiopia. The variations among previous results might be due to variations in hybrids and locations used for the study.

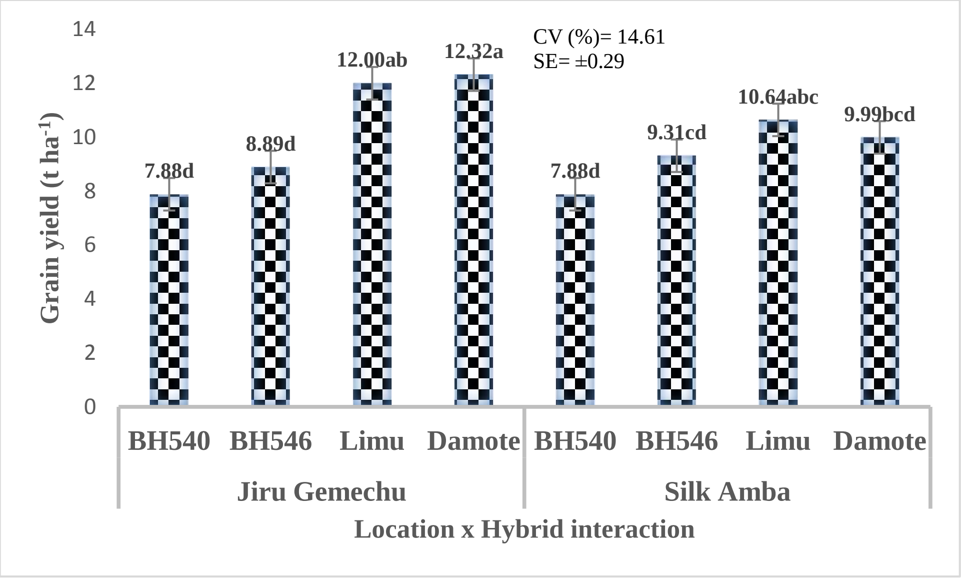

Figure 6. Location by hybrid interaction effect on maize grain yield

4.4.2. Thousand kernel weight

The analysis of variance result of the effect of location, hybrid and plant density on thousand kernel weight (TKW) is presented in Appendix Table 3. The mean squares for location, hybrid and hybrid by location interaction, location by plant density interaction had significant ($P \leq 0.05$) effect on TKW. However, there were no significant ($P > 0.05$) plant density, location by hybrid by plant density interaction effect on TKW.

Effect of location by hybrid, and location by plant density interaction on thousand kernel weight

Interaction effect of location by plant density and location by hybrid is indicated in Table 7. The weight of the thousand kernels varied from 500.79 to 417.75 grams. The maximum TKW was recorded at Silk Amba from a plant density of 53,333 ha^{-1}, and the lowest TKW was recorded at Jiru Gemechu from the smallest plant density (44,444 plants ha^{-1}) (Table 7). However, the three plant densities did not produced a noticeably different TKW at Silk Amba or Jiru Gemechu. In general, TKW increased at both sites as the plant population increased from 44,444 to 53,333 plants ha^{-1}, but decreased at the biggest plant population. This decrease in TKW at the highest plant population may be due to increased interplant competition for resources like space, light, water, nutrients, and other growth factors that affect final kernel weight. The results are in line with previous discoveries (Abuzar et al., 2011; Greveniotis *et al*., 2019; Mian et al., 2021) that population had a considerable impact on 1000 grain weight in maize. Greater plant competition slowed the 1000-grain weight in closer spacing. High plant densities might make the growing ear less able to get water, nitrogen, and photosynthate. Additionally, Zamir et al. (2011) reviewed the evidence and found that a high plant population decreased reproductive growth and grain filling due to competition for nutrients, light, and air.

The interaction of hybrids with the environment was considerable for TKW (Table 7), and the results indicated inconsistent hybrid performance for TKW across the two locations. At Silk Amba, hybrid BH540 had the highest TKW, while hybrid Damote had the highest TKW at Jiru Gemechu. At Silk Amba, however, hybrids BH540 and BH 546 as well as hybrids

BH546, Limu and Damote, did not significantly differ in TKW. At Jiru Gemechu, the four hybrids did not statistically differ from one another. According to previous research, hybrids have exhibited a variety of responses to many environmental factors regarding ear properties, such as thousand grain weight on maize (Greveniotis et al., 2019). Statistically significant variations in maize hybrids for thousand grain weight were also noted by Duvick (2005) and Mekuannet and Kiya (2020).

Table 7. Thousand kernel weight (gm) as affected by Location × Plant density and Location x Hybrid interaction

Treatments	**Silk Amba**	**Jiru Gemechu**
Plant density ha^{-1}		
44, 444	482.59ab	417.75d
53, 333	500.79a	448.25bcd
66, 667	477.91abc	436.92cd
CV (%)	7.63	
SE	35.14	
Hybrid		
BH540	543.54a	435.78c
BH546	501.66ab	406.22c
Limu	447.42bc	436.67c
Damote	455.77bc	458.56bc
CV (%)	7.63	
SE	35.14	

Means with the same letters in a column are not significantly differently ($P > 0.05$)

4.4.3. Harvest index

The harvest index represents the proportion of plant dry biomass allocated into grains. The combined analysis of variance displayed that the main effect hybrid and interaction effect of location by plant density were significant for harvest index. However, the main effects of location, population and the rest second and third order interaction were not significantly affected HI (Appendix Table 3).

Effect of hybrid on harvest index

The main effect of hybrid on harvest index of maize is presented in Figure 7. The maximum harvest index was obtained from hybrid Damote and did not differ significantly from Lumu and BH540. On the other hand, hybrid BH540 had the lowest harvest index (Figure 7). The discrepancies that occurred among hybrids for the harvest index could be attributed to variations in hybrid morphology and the variations in partitioning of assimilates into sinks among hybrids. According to Liu et al. (2020), hybrids differed in the maize harvest index. Nevertheless, Mujtaba et al. (2003) found no significant differences in harvest index among maize hybrids included in the study.

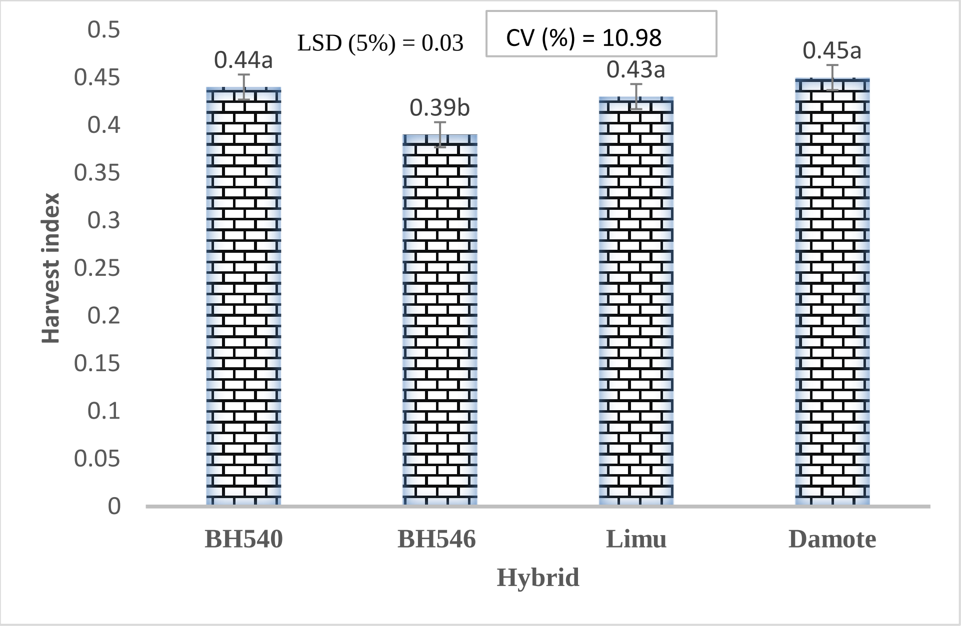

Figure 7. Effect of hybrid on harvest index

Effect of location by plant density interaction on harvest index

The analysis of variance showed that the harvest index of maize was significantly affected by the interaction effect of location by plant density (Figure 8) . Jiru Gemechu had the highest harvest index (0.46) at with 53,333 plants ha^{-1}, and the lowest harvest index(0.4) , at 66,667 plants ha^{-1} (Figure 9). There were no notable variations among plant populations at Silk Amba for harvest index. At Jiru Gemechu, the harvest index tended to rise with rising plant population, but it fell after 53,333 plant population ha^{-1}. In agreement Ion et al. (2015) reported significant effect of location by plant density interaction on maize on harvest index.

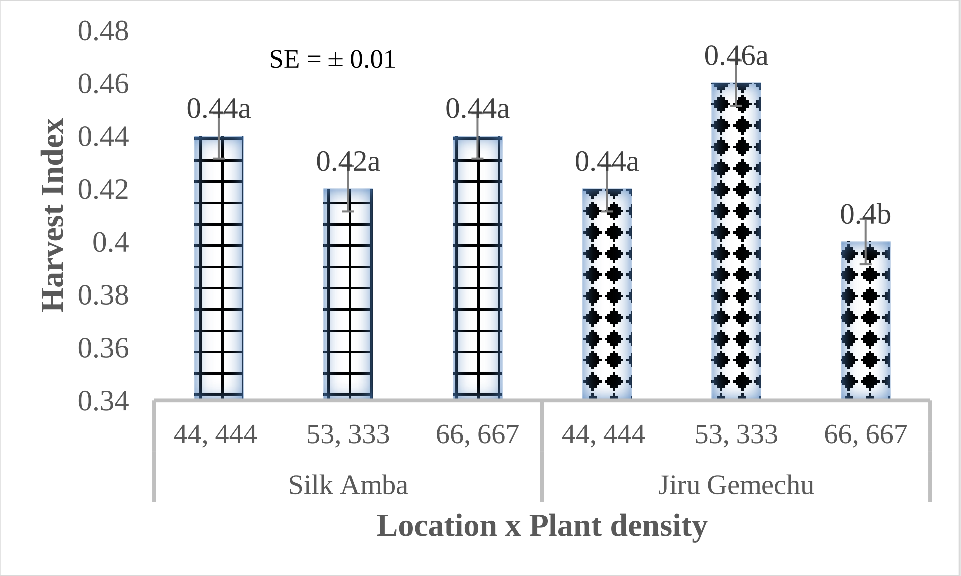

Figure 8. Effect of location by plant density interaction on harvest index of maize

4.4.4. Total biological yield

Combined ANOVA for total biomass yield (TBY) revealed that the main effects of hybrid, density and interaction effects of location × hybrid were significant ($P \leq 0.05$). However, non-significant effect of location, interactions of hybrid × plant density, location × density and the three-way interaction (location × hybrid × plant density) on TBY (Appendix Table 3).

Effect of location by hybrid interaction on total biological yield

The total biomass yield (TBY) ranged from 13.02 to 17.37 t ha^{-1}. The lowest TBY(11.61) was observed at Silk Amba from BH540, while the maximum(17.38) was observed from Jiru Gemechu from Limu hybrid (Figure 9). Older hybrid (BH540) recorded the highest TBY than recently released hybrids. He et al. (2021) also noted that newer hybrids had greater sink capacities than older hybrids.

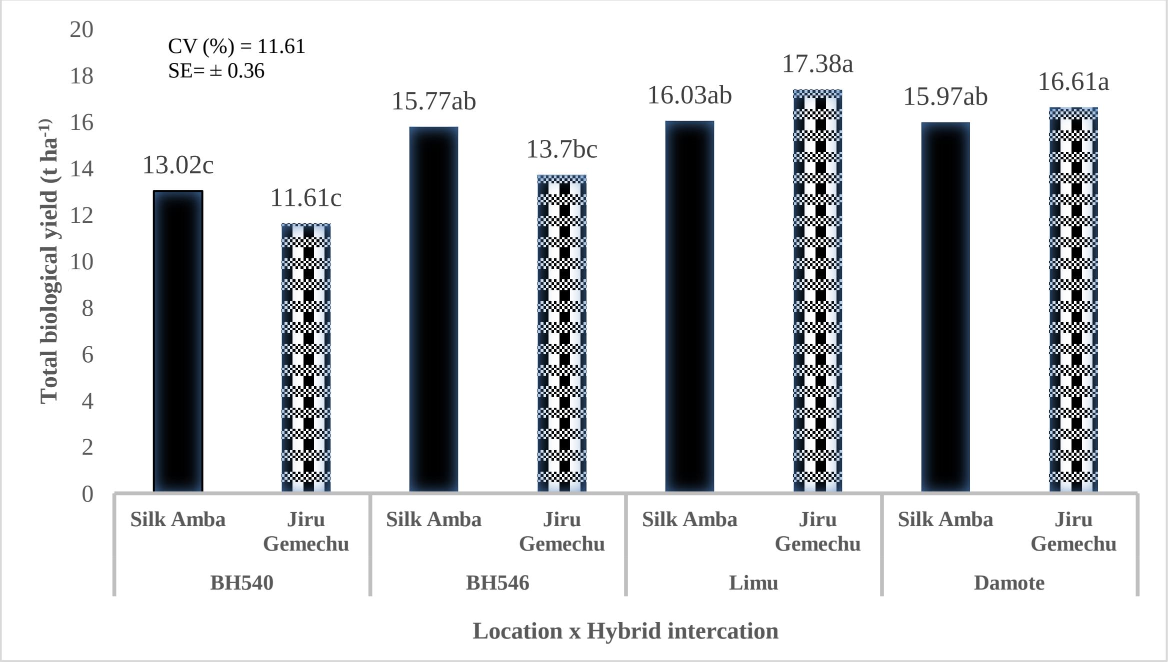

Figure 9. Interaction effect of location by hybrid on total biological yield of maize

Effect plant density on total biological yield

Total biomass yield varied significantly with planting density (Figure 10). Aboveground biomass accumulation increased with the increase in planting density (Figure 10), with the highest value recorded at the highest planting density (66,667 plants ha^{-1}). Biomass yield accumulation increased from 44,444 to 66,667 plants ha^{-1}. The lowest TBY was recorded from the lowest plant density, and was statistically not different from plant density 53,333 plants ha^{-1}. In the current study, the largest plant density (66,667 plants ha^{-1}) produced 10.8% more TBY than the lowest plant density (44,444 plants ha^{-1}) . Despite increased in planting density increased TBY, increased TBY decrease photosynthetic characteristics which resulted in decline in yield and resource use efficiency at the highest planting density beyond the optimum as suggested by Zhang et al. (2021).

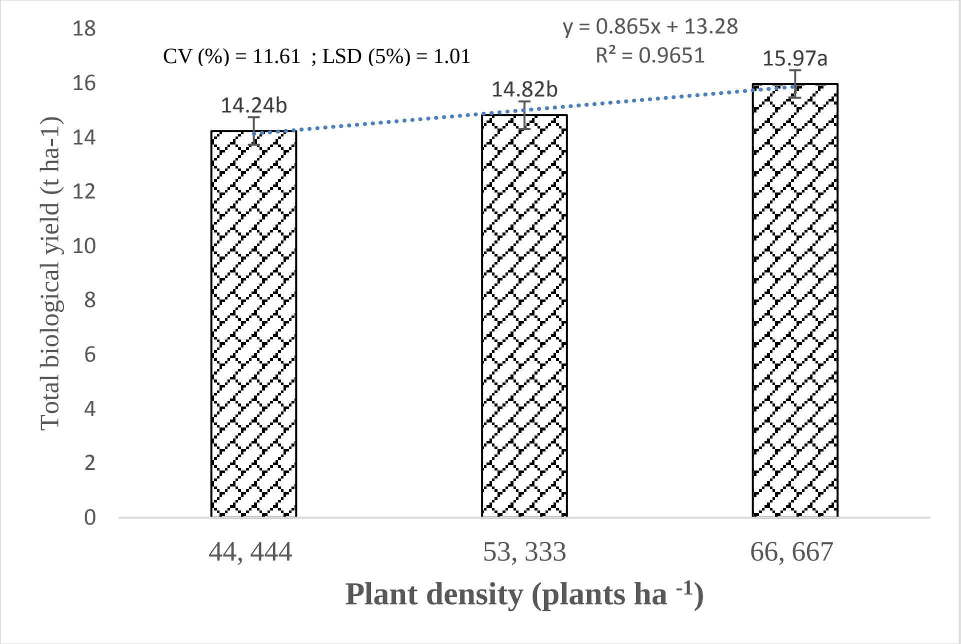

Figure 10. Effect of plant density on total biological yield of maize

4.5. Correlation Analysis

Parsons's correlation coefficients for paired traits for phenology, growth, yield and yield characteristics are presented in Table 8. Grain yield significantly and positively correlated with days to anthesis ($P < 0.05$), plant height ($P < 0.01$), days to maturity ($P < 0.05$), number of kernels per row ($P < 0.01$), thousand kernel weight ($P < 0.01$), total biomass yield ($P < 0.01$) (Table 8). This suggests that, grain yield was positively influenced by the product of numerous intricate morphological and physiological processes. The observed relationship between grain yield and the other traits under investigation implies that the characteristics of the growth, morphological, and yield components significantly influenced maize production across environments in this study. These parameters can be enhanced, resulting in an increase in the grain yield of maize, by optimizing the planting density and appropriate maize variety. Previous studies also confirmed correlation of morphological, growth and yield components to grain yield in maize (Sibonginkosi et al., 2019; Tesfaye et al., 2020).

Table 8. Pearson correlation of Phenological, growth, yield and yield components of maize

	DA	DS	PH	EH	DM	EPP	ED	EL	KPR	RPE	TKW	TBY	HI	GY
DA														
DS	0.80***													
PH	0.33	0.23												
EH	-0.22	-0.30	0.42											
DM	0.90**	0.92***	0.25	-0.19										
EPP	0.11	0.26	0.04	-0.66*	0.09									
ED	0.53	0.27	0.13	-0.13	0.50	-0.28								
EL	-0.25	0.18	0.34	0.11	-0.03	0.50	-0.47							
KPR	0.31	0.57	0.58	-0.03	0.47	0.37	0.23	0.63*						
RPE	0.21	0.7**	-0.04	-0.39	0.50	0.44	0.11	0.54	0.67*					
TKW	-0.54	-0.77**	-0.44	0.05	-0.75**	-0.25	-0.37	-0.44	-0.8**	-0.74**				
TBM	0.63*	0.75**	0.73**	0.10	0.75**	0.14	0.33	0.42	0.82**	0.49	-0.85**			
HI	-0.06	-0.47	0.53	0.30	-0.34	0.05	0.07	-0.11	-0.07	-0.55	0.18	-0.04		
GY	0.57	0.59*	0.87**	0.18	0.61*	0.20	0.34	0.41	0.80**	0.36	0.78**	0.93**	0.28	

*Significant at the P <0.05 probability level; **Significant at *P* < 0.01 probability level; ***Significant at the *P* < 0.001 probability level. DA, days to anthesis; DS, days to silking; PH, plant height; EH, ear height; DM, days to physiological maturity; EPP; number of ears per plant; EL, ear length; ED; ear diameter; RPE, number of rows per ear; KPR, number of kernels per row; TKW; thousand kernel weight; TBY, total aboveground yield; HI, harvest index; GY, grain yield

5. SUMMARY AND CONCLUSION

In Ethiopia, maize has taken on a key position in the country's diet, surpassing teff, sorghum, and wheat by more than 50% each in terms of total national annual production. In comparison to the other grains, maize is a less expensive source of calories, and it now accounts for the majority of calories consumed and produced in the nation. Despite the large area coverage, multiple advantages, and high yielding potential, the national average yield is low due to a variety of biotic and abiotic factors, including a lack of improved and adapted varieties for the target agro-ecological zones, poor agronomic practices, such as non-optimal plant population (spacing), low soil fertility, and others.

It is crucial to match the best maize hybrids with the optimum plant density in a particular production environment as plant population density has a significant impact on the vegetative and reproductive development and final yield of maize. Field studies were carried out in the Nono District of the West Showa Zone at two locations, namely Silk Amba and Jiru Gemechu, during the 2021 cropping season to study the response of maize hybrids to planting density on growth, yield and yield components in Nono District, West Showa Zone, Ethiopia. The study treatments comprised of four maize hybrids (BH540, BH546, Limu and Damote) and three planting densities (44,444, 53,333 and 67,667 plants ha^{-1}) in factorial arrangement replicated three times.

Results across environments revealed that location significantly affected almost all measured traits. The variations in prevailing altitude, rainfall and temperature at Silk Amba and Jiru Gemechu significantly affected the measured parameters response in the two locations. On the other hand, plant density significantly affected days to maturity, plant height, and ear height, number of ears per plant, grain yield and total above ground biomass. Interaction of hybrid by plant density did not resulted in any significant difference in all measured traits. Location x hybrid interaction significantly affected days to silking, anthesis silking interval, ear diameter, thousand kernel weight and grain yield. Location by density interactions mean squares significantly ($P < 0.05$) affected only thousand kernel weight and harvest index. However, the three-way interaction of location x hybrid x plant density did not significantly ($P > 0.05$) affected all the measured traits in this study.

The Silk Amba site took more days than Jiru Gemechu to reach anthesis (male flowering). The maize hybrid Damote had the longest days to anthesis of all the hybrids, whereas BH540 had anthesis earlier than the other hybrids. At the Silk Amba site, the hybrids Damote and BH546 both needed the longest days to reach silking (female flowering). Maize hybrid Damote at Jiru Gemechu and hybrid BH540 at both locations produced the shortest anthesis silking intervals (ASI). Silk Amba location increased the number of days needed for maturity and also recorded the highest ear height than Jiru Gemechu. Hybrids BH546, Limu and Damote resulted in delayed maturity than BH540. In comparison to the Bako hybrids, BH540 and BH546 the Pioneer hybrids Damote and Limu obtained the maximum plant height. At Silk Amba, the highest ear per plant was recorded. Among the hybrids, the lowest ear per plant was obtained from BH540, the other hybrids did not significantly varied for ear per plant .

An inverse relationship between plant density and earperplan was found, with the highest ear perplant (1.31) and lowest earperplant (1.01) being obtained from the lowest plant density and highest plant density respectively. The narrowest ear diameter was found in BH540, while the biggest ear diameter was found in BH546 hybrid at Silk Amba. The longest (18.47 cm) ear length was recorded from hybrid Limu, while the lowest was observed from BH540. More number of kernel rows per ear (KRPE) and number of kernels per row (KPR) was recorded from hybrids BH546 and Limu respectively. Grain yield showed an increasing trend from the lowest (44,444 plants ha^{-1}) to the highest plant densities (66,667 plants ha^{-1}), but above 53,333 plants ha^{-1}, no significant yield increase was seen, suggesting that 53,333 plants ha^{-1} was the optimum plant population across all study sites; this plant density also produced a higher yield advantage than the lowest plant density (> 9 q ha^{-1}).

Currently in Nono district of West Showa zone, the plant density recommendation used by farmers for maize is 75 cm x 30 cm (44,444 plants ha^{-1}). However, this study confirmed that 53,33 plants ha^{-1}, across the two locations resulted in more than 9 quintals maize yield per hectare than the current practice in the district, and suggested that the planting spacing used in the district need further studies. The lowest grain yield was observed from BH540 consistently

(7.88 t ha^{-1}) at both sites. Bako hybrids, BH540 and BH546 performed similarly at both Silk Amba and Jiru Gemechu sites. On the other hand, both pioneer hybrids, Damote and Limu resulted the highest yield of 12 and 12.32 t ha^{-1} respectively at Silk Amba, whereas, at Jiru Gemechu, the highest yield was recorded from Limu (10.64 t ha^{-1}) hybrid and was also comparable to BH546 (9.31 t ha^{-1}) and Damote (9.99 t ha^{-1}). From the study it was also noted that older hybrid (BH540) performed poorly in grain yield and other traits across environments than the new hybrids.

Generally in this study, the growth, phenology, yield, and yield-related characteristics of maize in this study were affected by hybrid, planting density, and their interactions. Although the hybrids in this study are all recommended for mid-altitude farming ecologies, their performance differs because of genetic, environmental factors including planting density, and their interaction. Lastly, in order to maximize maize grain output, which requires the best maize hybrid with the appropriate plant populations, this study can be utilized as a baseline for reviewing the current planting density in the study area.

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APPENDIX TABLES

Appendix Table 1. Mean squares for combined analysis of variance for days to anthesis, days to silking, anthesis-silking interval, days to maturity, plant height and ear height across two locations, Silk Amba and Jiru Gemechu in 2021

Source of variation	df	DA (days)	DS (days)	ASI (days)	DM (days)	PH (cm)	EH (cm)
Location (Loc)	1	21.12*	128.00***	0.05***	91.13**	239.076	1018.50***
Rep/Loc	4	8.19	9.33*	0.004	7.69***	26.6172	10.13
Hybrid (H)	3	24.08**	35.89***	0.01**	9.01***	2006.17***	208.67**
Density (D)	2	9.6	5.79	0.001	4.18*	294.11*	288.93**
H*D	6	1.73	0.85	0.001	0.51	31.85	55.24
Loc*H	3	4.5	11.00*	0.02**	2.35	13.9	46.69
Loc*D	2	7.13	1.125	0.003	0.13	15.22	90.44
Loc*H*D	6	2.88	3.74	0.001	0.9	13.54	41.29
Error	44	4.42	3.11	0.003	1.06	65.61	38.05
CV (%)		2.36	1.86	4.07	2.53	3.18	4.72
Mean		89.15	94.67	1.37	125.32	254.82	130.54
SE (m)		0.43	0.36	0.01	0.21	1.65	1.26

*Significant at the $P < 0.05$ probability level; **Significant at $P < 0.01$ probability level; ***Significant at the $P < 0.001$ probability level. DA, days to anthesis; DS, days to silking; ASI, anthesis-silking interval; DM, days to physiological maturity; PH, plant height; EH, ear height

Appendix Table 2. Mean squares combined analysis of variance for ears per plant, ear length, ear width, and kernel rows per ear and kernels per row across two locations, Silk Amba and Jiru Gemechu in 2021

Source of variation	df	EPP (#)	EL (cm)	ED (mm)	KRPE (#)	KPR (#)
Location (Loc)	1	0.15**	2.49	27.38**	0.01	1.28
Rep /Loc	4	0.07**	4.16	14.81**	0.64	6.95
Hybrid (H)	3	0.15***	23.99**	17.79**	13.02***	44.86***
Density (D)	2	0.44***	9.91	4.33	0.99	0.2
Hybrid*D	6	0.021	6.00	6.29	0.30	5.43
Loc*H	3	0.021	6.13	12.14*	0.60	3.67
Loc*D	2	0.001	7.43	0.21	0.25	2.11
Loc*H*D	6	0.009	5.27	1.82	0.2	4.38
Error	44	0.014	5.57	3.6	0.49	3.98
CV (%)		10.27	14	3.83	5.05	5.33
Mean		1.163	16.8	49.49	13.9	37.46
SE (m)		0.02	0.48	0.39	0.14	0.41

*Significant at the $P < 0.05$ probability level; **Significant at $P < 0.01$ probability level; ***Significant at the $P < 0.001$ probability level. EPP, ears per plant; EL, ear length; ED, ear diameter; KRPE, number of kernel rows per ear; KPR, number of kernels per row

Appendix Table 3. Mean squares for combined analysis of variance for thousand kernel weight, grain yield, harvest index and total biological yield across two locations, Silk Amba and Jiru Gemechu in 2021

Source of variation	df	TKW (gm)	GY (t h a^{-1})	HI	TBY (t ha^{-1})
Location (Loc)	1	50165.28***	12.09*	0.001	2.49
Rep/Loc	4	1743.32	3.69	0.003	5.03
Hybrid (H)	3	7470.07**	49.93***	0.01**	71.03***
Density (D)	2	421.64	8.16*	0.001	18.57**
H*D	6	706.23	1.5	0.003	2.44
Loc*H	3	14545.19***	7.14*	0.002	11.84*
Loc*D	2	4184.11*	1.75	0.01*	3.08
Loc*H*D	6	1133.22	2.05	0.004	1.84
Error	44	1235.2	2.08	0.002	3.04
CV (%)		7.63	14.61	10.98	11.61
Mean		460.70	9.86	0.4383	15.01
SE (m)		7.17	0.29	0.01	0.36

*Significant at the P <0.05 probability level; **Significant at *P* < 0.01 probability level; ***Significant at the *P* < 0.001 probability level. TKW, thousand kernel weight; GY, grain yield;; HI, harvest index; TBY, total biological yield

Appendix Figure 1. Field layout

Appendix Figure 2.Field management

Appendix Figure 3. Fertilizer application

Appendix Figure 4 Maize hybrids at vegetative stage

Appendix Figure 5. Maize hybrid varieties

Appendix Figure 6. Maize performance before flowering

Appendix Figure 7. Field measurements