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# Yield and Agronomic Performance of Improved Teff [Eragrostis tef (Zucc.) Trotter)] Varieties at Koga Irrigation Schemes in Mecha district, Northwestern Ethiopia

Atinkut Fentahun*, Sewagegne Tariku, Atalay Fentahun

Adet Agricaltural Research Center, Amhara Regional Agricultural Research Institute (ARARI), P.O.Box 08, Bahir Dar, Ethiopia.

*Corresponding author e-mail: atinkut947@gmail.com

**Abstract**

*Teff is the key and strategically crucial cereal crop in Ethiopia, yet its total production is constrained due to its heavy reliance on rainfall. The teff improvement research strategy was totally focused on the rain-fed system. The only rain-fed production system is insufficient to meet the rising local and international demand. The Country should increase teff production in order to close the gap between supply and demand. Finding alternative teff producing methods is therefore becoming compulsory. The study was aimed at evaluating the agronomic and grain yield performance of improved teff varieties that were released to be rain-fed while being irrigated. Twenty-eight improved varieties and one local cultivar were evaluated at Koga irrigation schemes for two years (2016 to 2017) using a randomized complete block design with three replications. Flooding was the method used to irrigate each plot. Individual-year analysis of variance, as well as the combined analysis of variance over years, indicated a significant difference among the tested varieties in grain yield and all other measured parameters. The significant variations among the tested varieties for all measured parameters in both years indicated that the tested varieties were diverse. Gibe recorded the highest grain yield (2.62 t ha$^{-1}$), while Simada recorded the lowest (1.41 t ha$^{-1}$). Based on their overall better mean performances for grain yield and yield components, varieties including Gibe, and Quncho have been recommended for large-scale production under the irrigated farming system. As a future direction for teff breeding research under irrigation, recommendations on frequency and method of irrigation, amount of water to be irrigated, and other agronomic practices are of paramount importance.*

**Keywords**: Demand and supply; grain yield; irrigation; rain-fed; teff

## 1. Introduction

Ethiopia's food supply and economy in general are largely dependent on rain-fed agriculture. Hence, irrigation development is vital to minimize the risk of crop failure and sustain agricultural production (Gebul, 2021). Irrigation is an essential option to improve the livelihood of communities, mainly in areas where there is subsistence rain-fed agriculture and is affected by an inconsistent rainfall pattern (Balew *et al.*, 2021). Hydrological variability has been linked to a 25% rise in poverty rates and is projected by the (World Bank, 2006) to have cost the Ethiopian economy more than one-third of its growth potential.

Irrigation not only eliminates the possibility that yields will be limited by drought but also allows a crop to be harvested during the dry season, when radiation is highest and insect and disease pressure is lowest. As a result, the expansion of irrigated agriculture has been identified as one of the key strategies to delink economic performance from rainfall and is thought to play a pivotal role in reaching the country's broader development vision (World Bank, 2006). Proper land and water utilization, assisted by modern irrigation, is capable of intensifying agricultural production (Tewodros, 2018). Ahmed (2019) also reported irrigation as an agricultural intensification that plays a key role in increasing agricultural production and productivity. Ethiopia has 5.3 million hectares of irrigable potential land, and the governments of Ethiopia have followed the development of small-scale irrigation. Still, only 5 to 10% of this potential land is irrigated, which produces less than 3% of the total food production of the country (Shitu andAlmaw, 2021).

*Teff* [*Eragrostis tef* (Zucc) Trotter] is an allo-tetraploid (2n=4x=40), small cereal grain crop that belongs to the family Poacea, sub-family Eragrostoideae, tribe Eragrostidae and genus Eragrostis (Ketema, 1997). It is indigenous to Ethiopia, and it has been cultivated for thousands of years in the Ethiopian highlands (Assefa *et al.*, 2015). It is the most important and strategic cereal crop in Ethiopia (Bokole *et al.,* 2023), having wide area coverage, high total production, and serving as a staple food. It is the most important small cereal crop in Ethiopia, which ranks first in terms of area coverage and second in terms of total production next to maize (ESS, 2022). *Teff*, the world's tiniest whole flour grain, measuring 1-1.7 mm in length and 0.6-1.7 mm in diameter, with an average seed weight of 0.3-0.4 gm for 1000 seeds and 150 seeds required to equal one seed of wheat (Adebowale *et al.,*2011).

The crop is an indigenous cereal crop in Ethiopia and is mainly produced in the Oromia, Amhara, and Southern Nations, Nationalities, and Peoples' (SNNP) regions, which account for 1,519,814.74, 1,177,078.03, and 211,639.30 hectares of land (ESS, 2022). *Teff* is the most widely cultivated food crop in Ethiopia, accounting for around one-third of the total acreage (29.3%) and one-fifth of the gross grain production (19.3%) of all cereals cultivated in the country (ESS, 2022). It takes up more than 2.9 million hectares (29.3 percent of the cereals crop area), which is higher than any of the other major cereals crops, such as maize (25.6%), sorghum (13.5%), and wheat (18.7%) (ESS, 2022). In Ethiopia, *teff* is annually cultivated by over 6 million smallholder farmers, and it is the staple food for more than 50 million people (Assefa *et al.*, 2017), but its productivity is very low as compared to other cereal crops.

In the Amhara National Regional State (ANRS), *teff's* productivity (1.92 $t\ ha^{-1}$) is similar to the national average. This region is one of the major teff-growing regions in the country. This region accounted for about 40.14% of the area and 40.15% of the *teff* production in Ethiopia. Over 1.177 million hectares of land were put under *teff* production, and a sum of over 2.254 million tons was harvested during the 2021/22 rainy season. West Gojam 121,411.77 hectares of land were put under teff production with productivity averages of 2.1 $t\ ha^{-1}$ (ESS, 2022). In spite of this, both the regional and national average yields are very low as compared to other cereals grown in Ethiopia (ESS, 2022).

The most important bottlenecks constraining the productivity and production of *teff* in Ethiopia are: i) low yield potential of farmers' varieties under widespread cultivation; ii) susceptibility to lodging, particularly under growth and yield-promoting conducive growing conditions; iii) biotic and abiotic stresses such as drought; iv) the culture and labor-intensive nature of the *teff* husbandry; v) inadequate research investment in the improvement of the crop, as it lacks global attention due to the localized importance of the crop, coupled with limited national attention; and vi) a weak seed and extension system (Barretto *et al.*, 2021).

*Teff* is receiving global attention among the cash crops and has been attracting an export market due to its nutritional and health-related benefits (Provost andJobson, 2014), especially due to the absence of gluten, a cause for celiac disease, in its grain (Fikadu *et al.,* 2019). Most Ethiopian farmers are motivated to cultivate *teff* because of its relative merits over the other cereals with respect to husbandry, utilization, and economic benefits (Assefa and Chanyalew, 2018). Moreover, *teff* has a much higher content of fiber, minerals, vitamins, and bioactive phenolic compounds than most other cereals (Gebremariam *et al.,* 2014). These merits of the crop have brought a golden opportunity for Ethiopia to export *teff* grain and earn foreign currency.

However, *teff* is known to be a rain-fed crop in Ethiopia and is produced only once a year, resulting in low productivity that has created a wider gap between the ever-increasing demand (both in the country and abroad) and supply (Belachew *et al.*, 2022). As a result, the ever-increasing price of *teff* grain has created hardships for many Ethiopian families, who are forced to switch to other cereals as substitutes. This needs to bridge the gap through enhancing the production and productivity of *teff* using different options. One of the options is producing *teff* under irrigation. These days, farmers have become aware of the merits of *teff* production under irrigation through learning by doing. They have started *teff* production under irrigation by themselves. Accordingly, 11,072 hectares of land have been covered by *teff* under irrigation in different regions of the country, which ranks 3rd in area coverage next to maize (38,115 ha) and sorghum (11,923 ha) (ESS, 2022). Farmers are reporting that they are getting much higher yields from irrigated *teff* as compared to the rain-fed one. The reasons suggested by farmers are as follows: (i) unlike that of the rain-fed production in irrigated *teff*, water is available for the crop at the right time and amount that helps the crop to express its genetic potential, (ii) no untimely rainfall that causes crop shattering, (iii) no hail damage that makes the crop to be lodged, (iv) no serious pest occurrence, and (v) no extended rainfall that delays harvesting, which brings yield penalty (personal communication). A maximum *teff* grain production of 3.3 t $ha^{-1}$was reported by (Yihun *et al.,* 2013) under irrigation, while *teff* was not under any water stress. *Teff* grain yield and dry aboveground biomass decreased by 69% and 36%, respectively, when the amount of irrigation water was decreased by 50% (Hilemicael and Alamirew, 2017).The value of per-hectare crop production under irrigated conditions is about twice that of under rain-fed settings (Ahmed, 2019). Gebretsadkan (2016) also noted that the highest grain yield was obtained under full irrigation and the lowest grain yield was obtained under rain-fed conditions. Realizing the ever-increasing demand as well as raising the price of *teff* in the country and the huge potential of *teff* grain as a source of foreign currency, the government of Ethiopia has designed a strategy to boost *teff* production using the underutilized big irrigation potential of the country besides rain-fed production. As a result, local demand will be satisfied at reasonable prices, and the country will earn foreign exchange through the export of *teff* grain.

So far, *teff* breeding research in the country has been totally focused on the rain-fed production system, through which a number of varieties have been released in the country. However, the performances of these varieties under irrigation are not yet evaluated. Therefore, this study was conducted to evaluate their agronomic and grain yield performances for improved *teff* varieties under irrigation.

## 2. Materials and Methods

### 2.1.Description of the study area

A field experiment was conducted at koga irrigation schemes in the Lake Tana basin under Mecha district, south of the Amhara Region, Ethiopia (Figure 1). The study was conducted from the end of December to April for two consecutive years (2015/16 and 2016/17). Geographically, the Koga experimental site is located at 37°7'29.72" Easting Longitude and 11°20'57.85" Northing Latitude at an altitude of 1953 meters above sea level (masl). Koga irrigation scheme is located 41 km to the west of Bahir Dar city and 543 km to the north of the capital city, Addis Ababa (Tewabe *et al.,* 2022). The average maximum and minimum temperature of the site during the course of the study ranged from 29.6 to 33.0 °C and from 7.7 to 13.2 °C, respectively. There was no rainfall recorded during the course of the study. The soil type of the site is nitosols; however, it is strongly acidic, which is below PH 5.5 (Kebede, 2016) indicated that soil acidity is one of the major environmental constraints facing *teff* production.

### 2.2.Planting materials used for the Experiment

Twenty-eight *teff* varieties that have been released for rain-fed production systems under late and early maturing groups, plus one local cultivar. National and regional released varieties were included (Table 1). The materials have been selected, some from the old and recently released varieties based on seed accessibility.

### 2.3.Experimental design and treatment management

The treatments were laid out using a randomized complete block design with three replications in a plot size of 4 m² (10 rows of 2 m length and 0.2 m apart). The experimental plots were fertilized with Urea and Diammonium Phosphate (DAP) at the rate of 40/60 $N/P_2O_5$ per hectare. The whole DAP was applied at planting but Urea was top dressed at the tillering stage. Seed at a rate of 10 kg $ha^{-1}$ was drilled in a row. Irrigation was applied on average every three-day interval for the first initial stage, a seven-day interval at the vegetative stage, and a fifteen-day interval after heading to early maturity with the flood irrigation method. All other relevant agronomic practices were applied as deemed necessary.

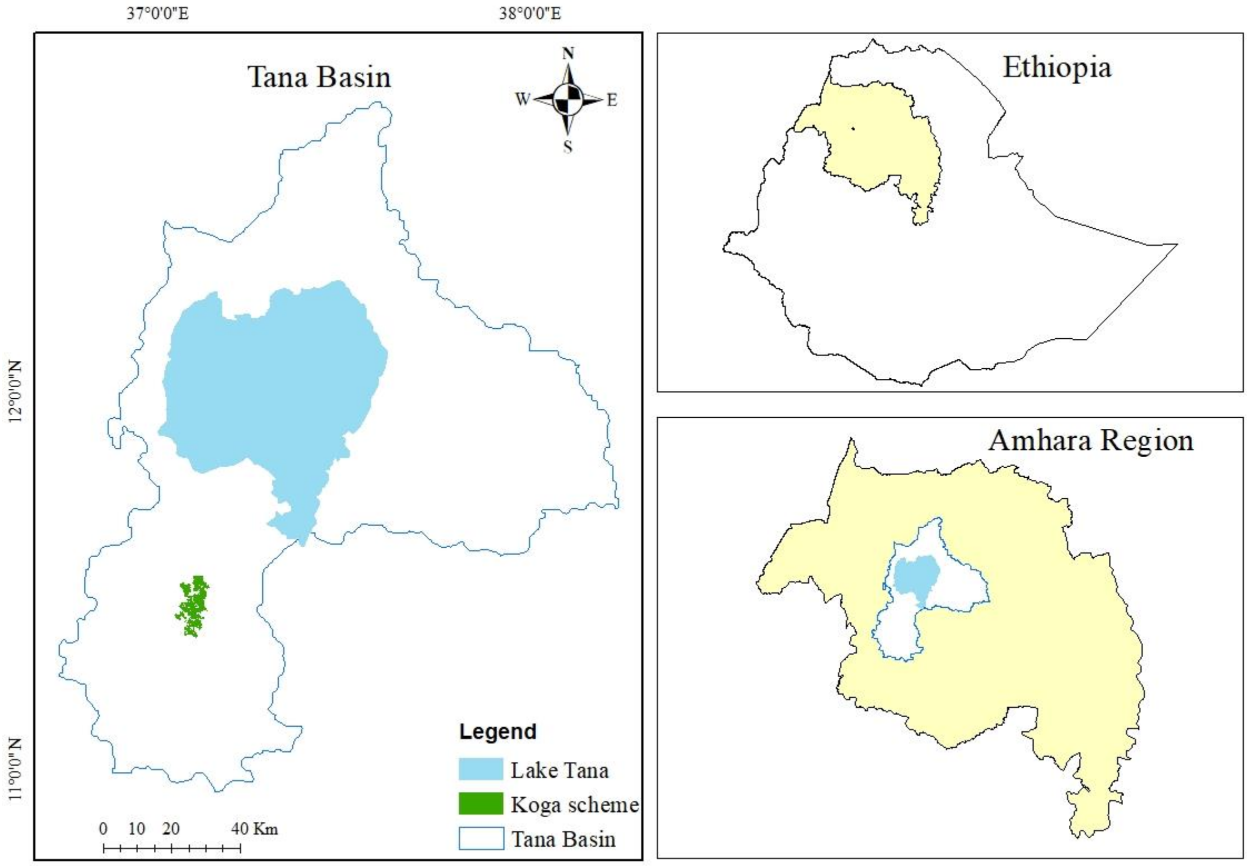


Figure 1. Map of the study site

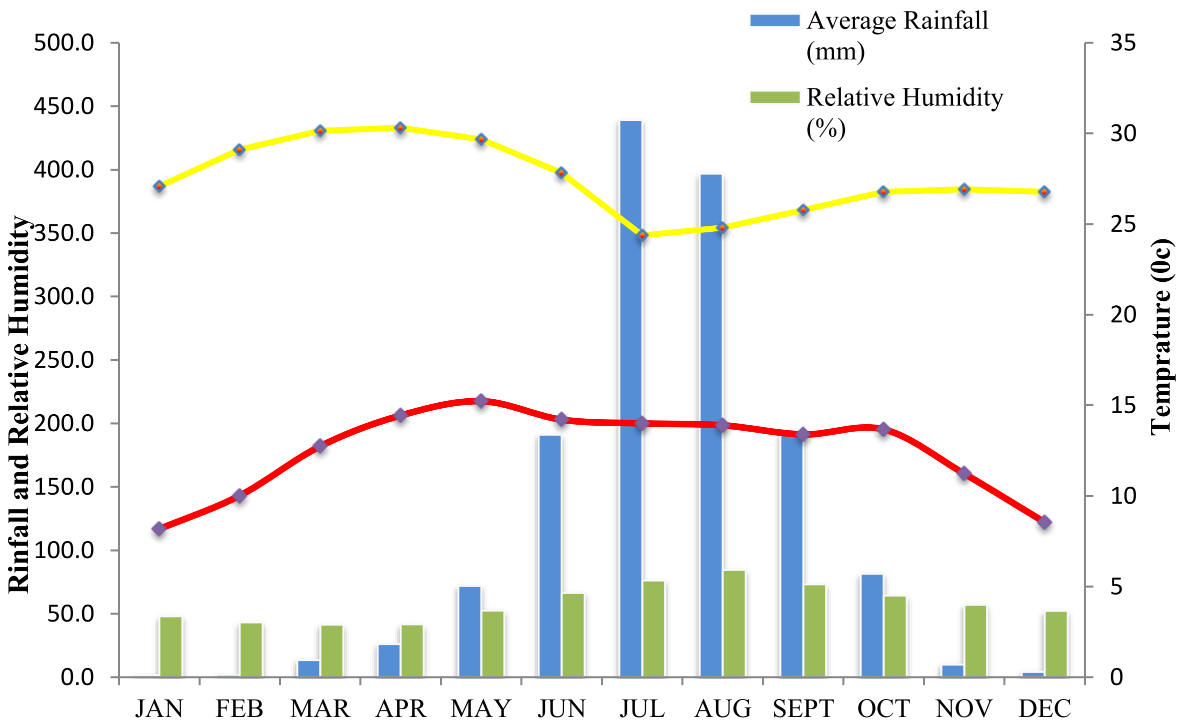


Figure 2. Meteorological data
Source: National meteorological Agency Bahir- Dar branch (2000-2017).

Table 1. Descriptions of the twenty-eight *teff* varieties were used for the experiment

| No | Variety | Years of release | Center | Area of adaptation | | Maturity (days) | Productivity | |
|---|---|---|---|---|---|---|---|---|
| | | | | Altitude (m) | Rainfall (mm) | | on station | On farm |
| 1 | Enatit | 1970 | DebreZeit | 2200-2500 | 300-700 | 85-100 | 2.4-3.2 | 2.0-2.4 |
| 2 | Asgori | 1979 | DebreZeit | 2200-2500 | 300-700 | 80-130 | 2.2-2.8 | 1.8-2.2 |
| 3 | Walankomi | 1978 | DebreZeit | 1800-2500 | 400-700 | 90-130 | 2.4-3.0 | 2.0-2.4 |
| 4 | Magna | 1978 | DebreZeit | 1800-2500 | 700-1200 | 80-113 | 1.8-2.4 | 1.6-2.0 |
| 5 | Menagasha | 1982 | DebreZeit | 2200-2500 | 400-700 | 95-140 | 1.8-2.4 | 1.8-2.2 |
| 6 | Gibe | 1993 | DebreZeit | 1900-2600 | 300-700 | 114-126 | 2.0-2.6 | 1.6-2.2 |
| 7 | Dukem | 1995 | DebreZeit | 1600-2200 | 150-700 | 75-137 | 2.4-3.4 | 2.0-2.7 |
| 8 | Quncho | 2006 | DebreZeit | 1800-2500 | 800-1200 | 86-151 | 2.0-3.2 | 1.8-2.6 |
| 9 | Tseday | 1984 | DebreZeit | 1800-2700 | 300-700 | 82-90 | 1.8-2.5 | 1.4-2.1 |
| 10 | Kay Tena | 2002 | DebreZeit | 1600-1900 | 300-500 | 84-93 | 1.7-2.4 | 1.6-2.2 |
| 11 | Kora | 2014 | DebreZeit | 1700-2400 | 700-120 | 105-120 | 2.5-2.8 | 1.8-2.2 |
| 12 | Simada | 2009 | DebreZeit | 1300-1750 | 300-700 | 75-87 | 2.0-2.8 | 1.6-2.4 |
| 13 | Boset | 2012 | DebreZeit | 1300-1750 | 300-700 | 82-90 | 2.3-2.0 | 2.0-2.8 |
| 14 | Gimbichu | 2005 | DebreZeit | 2000-2500 | 1000-1200 | 118-137 | 1.8 | 1.6 |
| 15 | Holeta key | 1999 | Holeta | 1900-2700 | 700-800 | 76-118 | 21 | - |
| 16 | Ambo toke | 2000 | Holeta | 2200-2300 | 700-800 | 125-140 | 3.6 | 2.7 |
| 17 | Gamechis | 2007 | Melekasa | 1450-1695 | 690-965 | 62-83 | 2.4 | 1.3-2.0 |
| 18 | Genete | 2005 | Sirinka | 1450-1850 | 660-1025 | 78-85 | 2.2 | 1.6 |
| 19 | Zobel | 2005 | Sirinka | 1450-1850 | 660-1025 | 78-85 | 2.1 | 1.5 |
| 20 | Mechere | 2007 | Sirinka | 1450-1850 | 660-1025 | 79 | 2.1 | 1.8 |
| 21 | Laketch | 2009 | Sirinka | 1450-1850 | 660-1025 | 90 | 2.24 | 1.3-1.8 |
| 22 | Etsub | 2008 | Adet | 1800-2600 | 1230 | 92-127 | 1.9-2.7 | 1.6-2.2 |
| 23 | Dima | 205 | Adet | 2000-2600 | >600 | 105 | 2.5 | 1.7 |
| 24 | Guduru | 2006 | Bako | 1850-2500 | 1000-1200 | 110-134 | 1.5-2.7 | 1.3-2.0 |
| 25 | Kena | 2008 | Bako | 1850-2400 | 1000-1200 | 132 | 15-23 | 1.4-2.0 |
| 26 | Ajora | 2004 | Areka | 1600-2200 | 900-1200 | 85-110 | 1.8 | 1.1 |
| 27 | Degatef | 2005 | DebreZeit | 1800-2500 | 997-1200 | 112-123 | 1.8-2.8 | 1.6-2.0 |
| 28 | Worekiyu | 2014 | Sirinka | 1450-2220 | 505-1025 | 94 | 2.2 | - |

Source: Ministry of agriculture in variety registration booklets (from1970-2014)

### 2.4.Data collection and management

Data were collected on a plant and plot basis. Five randomly selected plants were taken from the central five rows for plant-based parameters. The entire ten rows in the plot were used for plot-based data scoring.

#### 2.4.1. Plot based data

Data on a plot basis were taken based on all plants in the central rows of each plot, leaving one border row from each side of the plots. Days to heading and maturity, grain-filling period, lodging index, dry biomass, grain yield, and harvest index were recorded on a whole-plot basis as follows.

Days to 50% panicle emergence: Number of days taken from seedling emergence to the appearance of the tips (about 5 cm) of the panicles on 50% of the plants in a plot. *Teff* panicles emerge without showing the booting stage, which is unlike the other small cereals like wheat and barley but similar to that in rice.

Days to 85% maturity: Number of days taken from seedling emergence to 85% of the plants reaching physiological maturity stage (as evidenced by eyeball judgment of the plant stands when the straw color of the vegetative parts changed from green to yellow).

Days to grain filling period: This is computed as the difference between the days to panicle emergence and that to maturity.

Shoot dry biomass: The dry weight of all the central row plants, including tillers, harvested at the level of the ground before threshing.

Grain yield: The dry weight in grams of grains for all the central row plants, including tillers, harvested at the level of the ground after threshing and converted to kg/ha.

Harvest index (Ratio): The ratio of grain yield to the total biomass multiplied by 100.

$$\text{Harvest Index} = \frac{\text{Grain yield}}{\text{Above ground biomass}} \times 100$$

Lodging Index: The value recorded following the method of Caldicott and Nuttall (1979), who defined lodging index as the product sum of each scale or degree of lodging (0-5) and their respective percentage divided by five, where 0 value is fully upright (90$^o$), 1 = 0-15$^o$ lodging, 2=15-30$^o$ lodging, 3 = 30-45$^o$ lodging, 4 = 45-60$^o$ lodging and 5 = 60-90$^o$lodging and the plants become completely flat.

Lodging Index=sum of (lodging score × their respective % of area lodged)/5

Data on diseases and insects were not collected because both diseases and insect pests did not appear during the course of the study.

2.4.2. plant based data

Five random samples of plants were tagged on the main shoot from the central rows of each plot at the early tillering stage, and all individual plant-related data were assessed on these ten random samples of plants. The mean values of the five random samples of plants were considered to estimate the performance of each genotype and for the analysis of different traits of each plot (Assefa *et al.,* 2002).

The individual plant traits were assessed as follows:

Plant height (cm): The length of the plant in centimeters from ground level to the tip of the panicle at maturity.

Panicle length (cm): Length in centimeters from the node where the first panicle branch starts to the tip of the panicle at maturity.

### 2.5. Data analysis

Analysis of variance and combined analysis of variance for grain and related traits were carried out to show the presence of significant differences among varieties for each year separately and across years as a randomized complete block design procedure using the PROC GLM model of the SAS computer program SAS version 9.4 (SAS, 2013), and the correlation among parameters was done using R software version 4.3.2 (Olivoto andLúcio, 2020). Mean separation was carried out using the least significant difference (LSD) at a 5% level of significance.

## 3. Results and Discussion

### 3.1.Analysis of variance of individual year data

The results of the analysis of variance for each year showed a statistically significant difference among the varieties for all measured parameters (Tables 2 and 3). The significant variations among the tested varieties for all measured parameters in both years indicated that the tested varieties were diverse. Such considerable trait variations would provide a good opportunity for grain yield selection and improvement (Bakala *et al.,* 2018). Almost all of the tested varieties showed performance differences for each measured parameter between years. A significant year-over-year variation was observed for all measured parameters (Table 4). Fluctuations in climatic conditions and fluctuations in the water supply to the experimental plots, soil acidity status, and, above all, the amount, type, and frequency of irrigation are proposed as the sources of year variance. Similar significant year variation studies are reported by (Birhanu *et al.*, 2020) and (Girma Degife *et al.,* 2019) under irrigation. Similarly, Worku and Fentie (2024) and Ferede *et al.,* (2024) also reported under rain-fed conditions.

Table 2. Mean performance of commercial *teff* varieties for grain yield and other agronomic parameters as evaluated under irrigation at Koga during 2015/16 off season

| No | Varieties | DTH | DTM | GFP | PH | PL | DSB | GY | HI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Enatit | 58 | 100 | 42 | 83 | 35 | 6.5 | 2.1 | 32 |
| 2 | Asgori | 58 | 95 | 37 | 77 | 29 | 6.4 | 2.2 | 33 |
| 3 | Welankomi | 58 | 100 | 42 | 90 | 34 | 7.0 | 2.1 | 30 |
| 4 | Magna | 57 | 100 | 43 | 89 | 31 | 5.6 | 1.9 | 35 |
| 5 | Menagasha | 58 | 99 | 41 | 86 | 31 | 5.9 | 1.8 | 29 |
| 6 | Gibe | 56 | 100 | 44 | 87 | 31 | 6.8 | 2.6 | 32 |
| 7 | Dukem | 61 | 99 | 38 | 92 | 36 | 7.0 | 2.2 | 31 |
| 8 | Quncho | 60 | 99 | 39 | 99 | 37 | 5.9 | 1.9 | 32 |
| 9 | Tseday | 54 | 92 | 38 | 73 | 29 | 5.0 | 1.6 | 32 |
| 10 | Kaytena | 55 | 95 | 40 | 79 | 30 | 6.1 | 1.9 | 30 |
| 11 | Kora | 59 | 96 | 37 | 96 | 34 | 6.7 | 2.3 | 35 |
| 12 | Simada | 47 | 90 | 43 | 71 | 26 | 4.7 | 2.0 | 43 |
| 13 | Boset | 53 | 92 | 39 | 79 | 28 | 5.8 | 2.0 | 34 |
| 14 | Gimbichu | 56 | 101 | 45 | 82 | 31 | 6.3 | 1.9 | 30 |
| 15 | Holeta key | 55 | 94 | 39 | 79 | 28 | 6.6 | 2.2 | 32 |
| 16 | Ambo toke | 58 | 99 | 41 | 82 | 29 | 6.8 | 2.4 | 34 |
| 17 | Gamechis | 54 | 96 | 42 | 86 | 30 | 7.0 | 2.4 | 34 |
| 18 | Genete | 57 | 98 | 41 | 89 | 33 | 7.0 | 2.3 | 33 |
| 19 | Zobel | 58 | 99 | 41 | 83 | 31 | 6.0 | 2.1 | 34 |
| 20 | Mechere | 55 | 98 | 43 | 84 | 33 | 6.6 | 2.3 | 35 |
| 21 | Laketch | 60 | 100 | 40 | 87 | 31 | 6.9 | 2.1 | 30 |
| 22 | Etsub | 60 | 99 | 39 | 92 | 35 | 6.9 | 2.2 | 31 |
| 23 | Dima | 58 | 99 | 41 | 75 | 26 | 5.2 | 1.4 | 27 |
| 24 | Guduru | 58 | 99 | 41 | 100 | 36 | 6.8 | 1.7 | 31 |
| 25 | Kena | 61 | 101 | 40 | 88 | 30 | 5.9 | 1.7 | 33 |
| 26 | Ajora | 53 | 99 | 46 | 81 | 30 | 6.1 | 2.0 | 28 |
| 27 | Degatef | 56 | 101 | 45 | 87 | 33 | 7.4 | 2.1 | 36 |
| 28 | Worekiyu | 54 | 100 | 46 | 85 | 33 | 6.2 | 2.2 | 36 |
| 29 | Localcheck | 60 | 100 | 40 | 73 | 24 | 6.7 | 1.8 | 26 |
| | Mean | 57 | 98 | 41 | 85 | 31 | 6.0 | 2.0 | 32 |
| | CV (%) | 4 | 1.7 | 6 | 6 | 9 | 15 | 13 | 16 |
| | LSD (5%) | 2.2 | 1.8 | 3.2 | 9.6 | 4.5 | 1.5 | 0.2 | 6 |

Note: DTH= days to heading, DTM=days to maturity, GFP= grain filling period, PH=plant height, Pl=panicle length, DSB=dray shoot biomass, GY= grain yield, HI= harvest index

Table 3. Mean performance of commercial *teff* varieties for grain yield and other agronomic parameters as evaluated under irrigation at Koga during 2016/17 off season

| No | Varieties | DTH | DTM | GFP | PH | PL | DSB | GY | HI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Enatit | 58 | 107 | 49 | 95 | 41 | 4.6 | 1.1 | 26 |
| 2 | Asgori | 55 | 104 | 49 | 81 | 36 | 8.1 | 1.9 | 23 |
| 3 | Welankomi | 55 | 103 | 48 | 98 | 39 | 7.3 | 1.9 | 26 |
| 4 | Magna | 55 | 103 | 48 | 88 | 36 | 6.1 | 1.9 | 35 |
| 5 | Menagasha | 55 | 104 | 49 | 94 | 39 | 7.1 | 1.9 | 28 |
| 6 | Gibe | 54 | 105 | 51 | 88 | 38 | 5.3 | 2.6 | 53 |
| 7 | Dukem | 57 | 102 | 45 | 96 | 38 | 6.0 | 1.7 | 28 |
| 8 | Quncho | 57 | 102 | 45 | 93 | 41 | 5.8 | 2.6 | 49 |
| 9 | Tseday | 50 | 100 | 50 | 85 | 37 | 5.3 | 2.1 | 46 |
| 10 | Kaytena | 53 | 103 | 50 | 94 | 39 | 6.6 | 2.0 | 31 |
| 11 | Kora | 57 | 106 | 49 | 101 | 43 | 4.8 | 1.9 | 40 |
| 12 | Simada | 48 | 100 | 52 | 72 | 35 | 4.8 | 1.3 | 28 |
| 13 | Boset | 49 | 101 | 52 | 81 | 38 | 5.6 | 2.2 | 40 |
| 14 | Gimbichu | 59 | 106 | 47 | 88 | 36 | 5.5 | 1.9 | 51 |
| 15 | Holeta key | 52 | 101 | 49 | 81 | 39 | 6.0 | 1.8 | 29 |
| 16 | Ambo toke | 54 | 103 | 49 | 94 | 38 | 7.1 | 2.0 | 28 |
| 17 | Gamechis | 51 | 105 | 54 | 87 | 39 | 7.1 | 2.3 | 31 |
| 18 | Genete | 53 | 101 | 48 | 91 | 35 | 6.1 | 2.0 | 32 |
| 19 | Zobel | 54 | 104 | 50 | 83 | 39 | 6.6 | 2.3 | 34 |
| 20 | Mechere | 53 | 101 | 48 | 96 | 43 | 5.8 | 2.1 | 35 |
| 21 | Laketch | 57 | 105 | 48 | 102 | 38 | 6.0 | 2.1 | 35 |
| 22 | Etsub | 56 | 103 | 47 | 95 | 38 | 6.1 | 2.1 | 34 |
| 23 | Dima | 56 | 103 | 47 | 87 | 40 | 7.5 | 2.2 | 30 |
| 24 | Guduru | 58 | 101 | 43 | 98 | 34 | 6.6 | 2.0 | 29 |
| 25 | Kena | 56 | 105 | 49 | 86 | 34 | 5.3 | 1.5 | 31 |
| 26 | Ajora | 50 | 101 | 51 | 83 | 37 | 5.5 | 1.6 | 29 |
| 27 | Degatef | 57 | 103 | 46 | 76 | 40 | 3.5 | 1.5 | 73 |
| 28 | Worekiyu | 59 | 107 | 48 | 90 | 36 | 5.6 | 1.9 | 33 |
| 29 | Localcheck | 57 | 106 | 49 | 81 | 36 | 5.1 | 1.7 | 33 |
| | Mean | 55 | 103 | 48 | 89 | 38 | 6.0 | 1.9 | 35 |
| | CV (%) | 4.8 | 2.7 | 4 | 10 | 10 | 12 | 15 | 20 |
| | LSD (5%) | 3.4 | 2.6 | 2.9 | 15 | 6.2 | 1.7 | 0.4 | 17 |

Note: DTH= days to heading, DTM=days to maturity, GFP= grain filling period, PH=plant height, Pl=panicle length, DSB=dray shoot biomass, GY= grain yield, HI= harvest index

**3.2.Combined analysis of variance**

The results of the combined analysis of variance over years showed statistically significant differences among the tested varieties for all measured parameters, including days to heading, days to maturity, grain filling period, plant height, panicle length, dry shoot biomass, grain yield, harvest index, and lodging index (Table 4). The results of the present study are in agreement with (Dutamo *et al.*, 2020), who reported significant variation among *teff* varieties for different traits.. The study indicated that the tested varieties showed better performances both in grain yield and agronomic traits under irrigated conditions.

Wide variations were observed among the tested varieties for all measured parameters, including days to heading (49 to 62 days), days to maturity (99 to 105 days), grain filling period (39 to 53.3 days), plant height (63.3 to 100.2 cm), panicle length (26.5 to 40.9 cm), dry shoot biomass (5.1 to 8.9 t $ha^{-1}$), grain yield (1.41 to 2.62 t $ha^{-1}$), harvest index (27 to 51%), and lodging index (1.6 to 4.6 based on a 0 to 5 scale) (Table 3). (Fikre *et al.*, 2020) and (Birhanu *et al.,* 2020) indicated that *teff* is diverse in different important traits under irrigation. In agreement with the results of the present study, Belete and Admasu (2021) and Assefa *et al.,* (2015) also reported that wide ranges of variations were observed among the released *teff* varieties for grain yield and other agronomic traits under rain-fed conditions. Among the tested varieties, the highest grain yield (2.62 t $ha^{-1}$) was recorded by Gibe, followed by Quncho (2.38 t $ha^{-1}$) and Laketch and Gemechis (2.34 t $ha^{-1}$). The lowest grain yield (1.41 t $ha^{-1}$) was recorded by Simada. In this study, a grain yield advantage of up to 32% over the local cultivar was observed. Farmers in a few areas of the country have started *teff* production under irrigation; however, they use local cultivars, which are poor in productivity. The significant grain yield advantage of improved varieties over the local cultivar observed in this study can be a driving force to expand *teff* production under irrigation using improved varieties. Similarly, Birhanu *et al.,* (2020) identified Gibe as the highest yielder, which gave 3.0 t $ha^{-1}$, and Yihun *et al.,* (2013) reported that the quncho variety gave about 3.3 t $ha^{-1}$ under irrigation conditions.

In the study, the longest time (105 days) and shortest time (99 days) for maturity were recorded by varieties Kena and Kora, respectively. However, in contrast to the rain-fed conditions, most of the tested varieties showed plasticity in days to maturity under irrigated conditions. Varieties in the early-maturing group showed a tendency to be late, while varieties in the late-maturing group showed a tendency to be early (Table 4). This might be due to the varietal reaction differences between the environmental variations.Chanyalew *et al.* (2019) noted that *teff* exhibits large phonologic plasticity depending on the growing conditions and genotype. The longest (102.2 cm) and the shortest (63.3 cm) plant heights were recorded by Guduru and Simada, respectively. Regarding the harvest index, the highest (51%) and the lowest (27%) were recorded by Degatef and Guduru, respectively; similar studies were reported by Girma (2019) under irrigation. However, the grain yield of Degatef was found to be lower than the grain yield of many of the tested varieties with a lower harvest index than Degatef, indicating that the highest harvest index value may not be a guarantee for a variety to have a higher grain yield. The combined analysis of variance over years also showed that genotype-by-year interaction (G*Y) was significant for all measured parameters, indicating the change in ranking among the varieties for the measured parameters over the years. These findings are in line with Ferede *et al.* (2024).

Table 4. Combined mean performance of commercial *teff* varieties for grain yield and other agronomic parameters as evaluated under irrigation at Koga (2015-2016) off season

| No | Varieties | DTH | DTM | GFP | PH | PL | DSB | GY | HI | LI |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Enatit | 60.5 | 103 | 42.5 | 94.9 | 38.8 | 8.9 | $1.76^{bc}$ | 29.2 | 1.6 |
| 2 | Asgori | 56.6 | 102 | 45.3 | 78.8 | 33.0 | 8.8 | $2.09^{abc}$ | 28.3 | 3.6 |
| 3 | Welankomi | 55.0 | 102 | 47.0 | 93.4 | 37.3 | 7.7 | $1.86^{bc}$ | 28.1 | 3.0 |
| 4 | Magna | 55.0 | 102 | 47.0 | 92.9 | 34.0 | 8.7 | $2.21^{ab}$ | 35.1 | 1.6 |
| 5 | Menagasha | 54.3 | 102 | 47.6 | 92.9 | 37.7 | 7.9 | $2.29^{ab}$ | 28.7 | 2.6 |
| 6 | Gibe | 49.6 | 103 | 53.3 | 88.5 | 36.5 | 8.3 | $2.62^{a}$ | 49.5 | 2.0 |
| 7 | Dukem | 58.3 | 101 | 43.0 | 95.6 | 36.9 | 8.0 | $2.19^{ab}$ | 30.0 | 1.6 |
| 8 | Quncho | 62.0 | 101 | 39.3 | 95.1 | 39.5 | 7.0 | $2.38^{ab}$ | 41.0 | 3.0 |
| 9 | Tseday | 50.0 | 101 | 51.0 | 80.1 | 33.0 | 6.7 | $2.23^{ab}$ | 39.6 | 2.6 |
| 10 | Kaytena | 57.0 | 101 | 44.0 | 86.1 | 35.0 | 7.5 | $2.12^{ab}$ | 30.7 | 1.3 |
| 11 | Kora | 60.6 | 99 | 39.0 | 98.1 | 40.4 | 6.3 | $1.92^{bc}$ | 38.3 | 4.6 |
| 12 | Simada | 49.0 | 100 | 51.0 | 63.3 | 26.5 | 5.1 | $1.41^{c}$ | 36.4 | 3.3 |
| 13 | Boset | 49.3 | 100 | 51.3 | 76.4 | 30.8 | 6.0 | $2.12^{ab}$ | 37.6 | 1.6 |
| 14 | Gimbichu | 57.6 | 102 | 44.6 | 86.4 | 36.5 | 5.9 | $1.82^{bc}$ | 41.0 | 4.0 |
| 15 | Holeta key | 61.0 | 102 | 41.0 | 71.9 | 30.8 | 5.9 | $1.76^{bc}$ | 31.1 | 2.3 |
| 16 | Ambo toke | 56.6 | 102 | 45.6 | 88.7 | 36.9 | 7.9 | $2.11^{ab}$ | 31.1 | 2.3 |
| 17 | Gamechis | 59.6 | 101 | 42.0 | 93.9 | 37.7 | 7.9 | $2.34^{ab}$ | 32.7 | 3.0 |
| 18 | Genete | 53.6 | 101 | 48.0 | 85.8 | 36.8 | 7.6 | $1.95^{abc}$ | 32.9 | 1.3 |
| 19 | Zobel | 58.0 | 101 | 43.6 | 86.9 | 34.3 | 7.3 | $2.12^{ab}$ | 34.6 | 2.6 |
| 20 | Mechere | 53.3 | 101 | 48.0 | 88.7 | 35.6 | 6.5 | $2.01^{abc}$ | 35.7 | 1.6 |
| 21 | Laketch | 58.0 | 101 | 43.3 | 98.3 | 38.3 | 6.8 | $2.34^{ab}$ | 32.9 | 1.3 |
| 22 | Etsub | 58.3 | 101 | 43.3 | 93.9 | 37.6 | 7.1 | $2.18^{ab}$ | 32.7 | 2.0 |
| 23 | Dima | 58.0 | 102 | 44.3 | 83.5 | 33.6 | 8.4 | $2.32^{ab}$ | 28.9 | 1.6 |
| 24 | Guduru | 58.6 | 102 | 43.3 | 100.2 | 40.9 | 7.2 | $1.96^{abc}$ | 27.2 | 1.6 |
| 25 | Kena | 58.0 | 105 | 47.0 | 86.8 | 34.1 | 7.3 | $1.86^{bc}$ | 31.2 | 2.0 |
| 26 | Ajora | 52.0 | 100 | 48.3 | 81.4 | 33.2 | 6.5 | $1.82^{bc}$ | 31.6 | 1.3 |
| 27 | Degatef | 55.6 | 103 | 47.3 | 84.1 | 36.2 | 7.5 | $2.04^{abc}$ | 51.0 | 1.3 |
| 28 | Worekiyu | 53.0 | 102 | 49.3 | 88.0 | 37.3 | 8.1 | $2.24^{ab}$ | 34.6 | 2.3 |
| 29 | Localcheck | 62.0 | 101 | 39.6 | 80.1 | 32.0 | 7.5 | $1.99^{abc}$ | 29.9 | 2.3 |
| | Mean | 56.2 | 101 | 45.5 | 87.4 | 35.6 | 7.3 | 2.07 | 34.2 | 2.2 |
| | CV (%) | 5.8 | 0.7 | 7.6 | 8.7 | 8.5 | 20.2 | 22.3 | 21.4 | 27 |
| | Genotype (G) | ** | ** | ** | ** | ** | ** | * | * | ** |
| | Year (Y) | ** | ** | ** | ** | ** | ** | * | * | ** |
| | G*Y | ** | * | ** | ** | * | ** | * | * | ** |

Note: *, ** significant at 5% and 1% level of probability, respectively, DTH= days to heading, DTM=days to maturity, GFP= grain filling period, PH=plant height, Pl=panicle length, DSB=dray shoot biomass, GY= grain yield, HI= harvest index, LI= lodging index

## 3.3. Association of grain yield with yield and yield related traits

Yield is the result of the sum of agronomic and phonological traits resulting from the interaction of genetic and environmental factors Ferede *et al.* (2024). Therefore, it is important to identify the association of genetic and phonological traits with yield. Studies of correlations among different traits enable the determination of the level and magnitude of the components that affect a character. Positive and negative values were obtained, and negative values indicated that as one parameter increased, the other parameter decreased, whereas parameters with positive values showed that as one parameter increased, the other parameter also increased or vice versa (Zewdu *et al.*, 2024).

Results of analysis of correlation among parameters showed that grain yield had positive correlation with plant height, panicle length and dry shoot biomass (Fig. 3). But dry biomass contribute the highest correlation (r=0.53) to grain yield followed by plant height (r=0.47) and panicle length (0.41). The result of this study is in line with the reports of (Assefa *et al.*, 2022). A strong positive correlation coefficient among grain yield, dry shoot biomass, and plant height had a direct contribution to yield and was used to improve grain yield productivity. Likewise, Bekana *et al.* (2022) reported a high direct effect of above-ground dry shoot biomass on grain yield. However, the lodging index has been negatively correlated with grain yield (Fig. 3). Lodging can cause decreases in grain yield and quality by reducing leaf photosynthesis and assimilate accumulation because of decreased light interception. Similarly, (Lule andMengistu, 2014) reported a negative association between the lodging index and grain yield. On the contrary, (Chanyalew, 2010) reported that lodging showed a positive and significant correlation with grain yield. Generally, lodging is a serious problem that could result in a significant economic loss in Ethiopia. Lodging under natural conditions could cause up to 22% total *teff* grain yield loss, 35% of 1000-kernel weight, and 51% of grain yield per panicle (Chanyalew *et al.,* 2019).

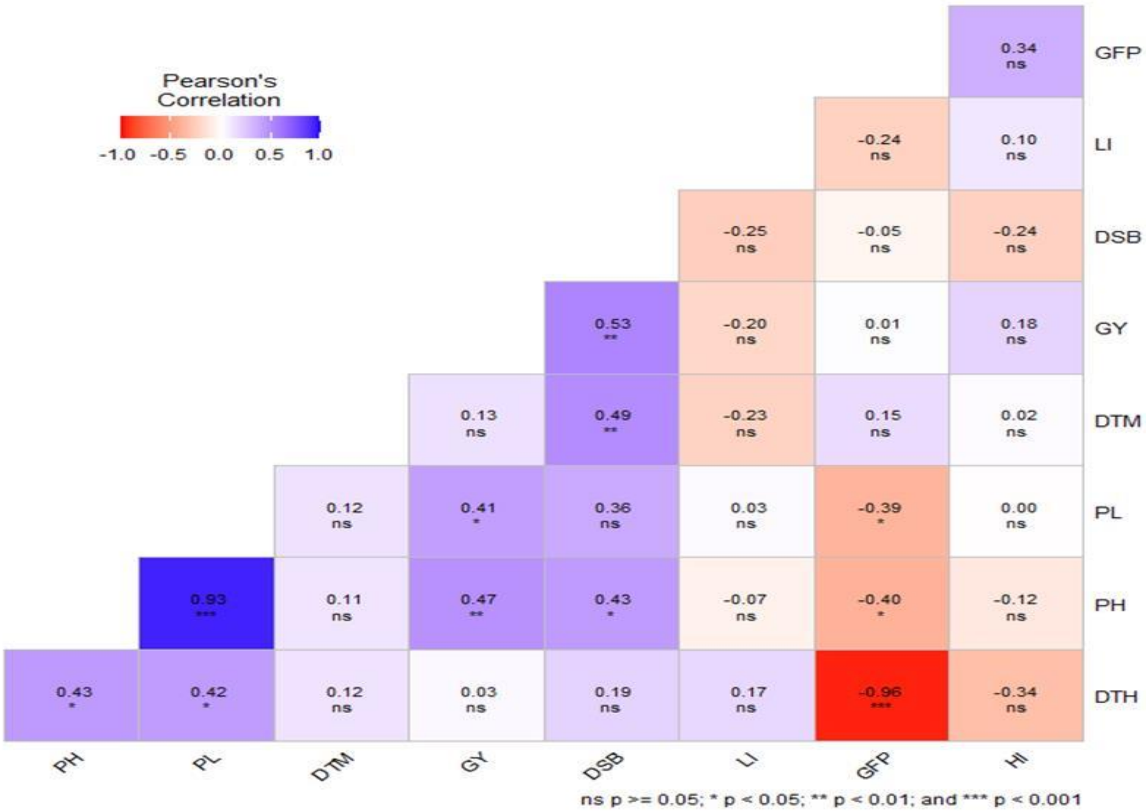


Figure 3. Association of grain yield with yield and yield related traits

## 4. Conclusion and Recommendation

Wide and statistically significant differences were observed among the tested varieties for all measured parameters, which can lead to selecting and recommending the promising ones for wide production under the irrigated farming system. The promising results learned from the study should be used as a driving force to start *teff* breeding research activities under irrigation so that *teff* productivity and production will be enhanced and the gap between demand and supply for *teff* can be reduced. As there were no agronomic recommendations for *teff* under irrigation, the study was done by adopting the rain-fed recommendations. However, as the rain-fed farming system is quite different from the irrigated farming system, agronomic recommendations, including water amount, type, and frequency of irrigation, are future directions. Based on their overall better mean performances for grain yield and yield components, varieties including DZ-Cr-255 (Gibe), and DZ-Cr-387/RIL355 (Quncho) have been recommended for large-scale production under the irrigated farming system.

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**Conflict of interest**

The authors have not declared any conflict of interest.

**Data availability**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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