**Performance Evaluation of Improved Tef Varieties for Grain Yield and Yield Related Traits at Koga Irrigation Schemes in Amhara Region, Northwestern Ethiopia**

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**Abstract**

*The most significant and strategically essential cereal crop in Ethiopia is tef, which is also the least productive due to its reliance on rainfall. The tef improvement research strategy was totally focused on the rain-fed system, which is insufficient to meet the rising local and international demand. The country should produce more tef in order to close the gap between supply and demand. Finding alternative tef producing methods is therefore becoming compulsory. The study was conducted to evaluate the grain yield performances of improved tef varieties under irrigation. Twenty-eight improved varieties and one local variety were evaluated at Koga irrigation schemes for two years (2015/16 to 2016/17) using a randomized complete block design with three replications. Flooding was the method used to irrigate each plot. Individual-year analysis of variance and the combined analysis of variance over years indicated a significant difference among the tested varieties in grain yield and other measured parameters. Wide variations were observed among the tested varieties for all measured parameters, including days to heading (47 to 61 days), days to maturity (90 to 107 days), grain filling period (37 to 54 days), plant height (71 to 102 cm), panicle length (31 to 43 cm), dry shoot biomass (3.5 to 8.1 1 t ha-1), grain yield (1.1 to 2.62 1 t ha-1), harvest index (23 to 53%), and lodging index (1.3 to 4.6). Gibe recorded the highest grain yield (2.62 t ha-1), while Enatit recorded the lowest (1.1 t ha-1). Based on their overall better mean performances for grain yield and yield components, varieties including Gibe, Quncho, Laketch and Gemechis have been recommended for large-scale production under the irrigated farming system.*

**Keywords***:* Correlation, Demand and Supply,Flood irrigation, Rain-fed

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](#_ENREF_24)). 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](#_ENREF_7)).

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([World Bank, 2006](#_ENREF_37)). 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](#_ENREF_37)). Proper land and water utilization, assisted by modern irrigation, is capable of intensifying agricultural production ([Tewodros, 2018](#_ENREF_35)). [Ahmed (2019](#_ENREF_1)) 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 and Almaw, 2021](#_ENREF_33)).

Tef [*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](#_ENREF_28)). It is indigenous to Ethiopia, and it has been cultivated for thousands of years in the Ethiopian highlands ([Assefa *et al.*, 2015](#_ENREF_3)). It is the most important and strategic cereal crop in Ethiopia ([Bokole *et al.,* 2023](#_ENREF_12)), 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](#_ENREF_17)). Tef, the world’s tiniest whole flour grain, measuring 1-1.7 mm in length and 0.6-1 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 ([Akanbi *et al.*, 2011](#_ENREF_2)). The crop is mainly produced in the Oromia, Amhara, and Southern Nations, Nationalities, and Peoples' (SNNP) regions, which account for 6,100,987.75, 4,586,325.71, and 1,102,915.09 hectares of land ([ESS, 2022](#_ENREF_17)). Tef 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](#_ENREF_17)). 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](#_ENREF_17)). In Ethiopia, tef 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](#_ENREF_6)).

Tef is receiving global attention among the cash crops and has been attracting an export market due to its nutritional and health-related benefits ([Provost and Jobson, 2014](#_ENREF_31)), especially due to the absence of gluten, a cause for celiac disease, in its grain ([Fikadu *et al.,* 2019](#_ENREF_20)). Most Ethiopian farmers are motivated to cultivate tef because of its relative merits over the other cereals with respect to husbandry, utilization, and economic benefits ([Assefa and Chanyalew, 2018](#_ENREF_4)). Moreover, tef has a much higher content of fiber, minerals, vitamins, and bioactive phenolic compounds than most other cereals ([Gebremariam *et al.,* 2014](#_ENREF_22)). These merits of the crop have brought a golden opportunity for Ethiopia to export tef grain and earn foreign currency.

However, tef is known to be a rain-fed crop in Ethiopia and is produced only once a year, resulting in low productivity in which the supply does not meet the demand ([Bazie *et al.*, 2025](#_ENREF_8)). As a result, the ever-increasing price of tef 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 tef using different options. One of the options is producing tef under irrigation. These days, farmers have become aware of the merits of tef production under irrigation through learning by doing. They have started tef production under irrigation by themselves. Accordingly, 11,072 hectares of land have been covered by tef 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](#_ENREF_17)). Farmers are reporting that they are getting much higher yields from irrigated tef 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 tef, 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 tef grain production of 3.3 t ha-1 was reported by [Yihun *et al.,* (2013](#_ENREF_39)) under irrigation, without water stress. Tef 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](#_ENREF_26)). The value of per-hectare crop production under irrigated conditions is about twice that of under rain-fed settings ([Ahmed, 2019](#_ENREF_1)). [Gebretsadkan (2016](#_ENREF_23)) 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 tef in the country and the huge potential of tef grain as a source of foreign currency, the government of Ethiopia has designed a strategy to boost tef 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 tef grain.

So far, tef 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, lack of improved tef varieties for irrigation farming system is one of the problems that need to be addressed. Therefore, this study was conducted to evaluate the grain yield performances of improved tef varieties under irrigation.

1. **MATERIALS AND METHODS**
	1. **The study area description**

A field experiment was conducted at Koga irrigation schemes (Figure 1) in the Lake Tana basin under Mecha district, south of the Amhara Region, Ethiopia. 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. 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](#_ENREF_34)). 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](#_ENREF_27)) indicated that soil acidity is one of the major environmental constraints facing tef production.



Figure 1. Map of the study site

* 1. **Planting materials and trial management**

Twenty-eight tef varieties that have been released for rain-fed production systems under late and early maturing groups, plus one local variety (Table 1), were evaluated in a randomized complete block design (RCBD) with three replications in a plot size of 4 m2 (10 rows of 2 m length and 0.2 m row space). Fertilizers (UREA as a source of N and DAP as a source of P) were applied at a rate of 40 kg ha-1 N and 60 kg ha-1 P2O5. The whole amount of DAP and half of UREA were applied at planting, while the remaining UREA was applied at tillering. Seed at a rate of 10 kg ha-1 was drilled in a row. Irrigation was applied averagely every three-day interval for the initial stage, a seven-day interval at the vegetative stage, and a fifteen-day interval after heading to early maturity through flood irrigation method. All other relevant agronomic practices were applied as deemed necessary.

Table 1. List of tef varieties used in the study

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| No | Variety | Year of release  | Maturity group  | No | Variety | Year of release  | Maturity group  |
| 1 | Enatit  | 1970 | Late set | 16 | Ambo toke | 2000 | Late set |
| 2 | Asgori | 1979 | Late set | 17 | Gamechis | 2007 | Early set |
| 3 | Walankomi | 1978 | Late set | 18 | Genete | 2005 | Early set |
| 4 | Magna | 1978 | Late set | 19 | Zobel | 2005 | Early set |
| 5 | Menagasha | 1982 | Late set | 20 | Mechere | 2007 | Early set |
| 6 | Gibe | 1993 | Late set | 21 | Laketch | 2009 | Early set |
| 7 | Dukem | 1995 | Late set | 22 | Etsub | 2008 | Late set |
| 8 | Quncho | 2006 | Late set | 23 | Dima | 205 | Late set |
| 9 | Tseday  | 1984 | Early set | 24 | Guduru | 2006 | Late set |
| 10 | kayt-ena | 2002 | Early set | 25 | Kena | 2008 | Late set |
| 11 | Kora | 2014 | Late set | 26 | Ajora | 2004 | Early set |
| 12 | Simada | 2009 | Early set | 27 | Degatef | 2005 | Late set |
| 13 | Boset | 2012 | Early set | 28 | Worekiyu | 2014 | Early set |
| 14 | Gimbichu | 2005 | Late set | 29 | Local check | ------ |  |
| 15 | Holeta key | 1999 | Late set |  |  |  |  |

Source([EAA, 2022](#_ENREF_16)**)**

* 1. **Data collection**

Data on days to heading (from planting to when 50% of the plants in a plot reached heading stage), days to maturity (from planting to when 85% of the plants in a plot reached maturity stage), grain filling period (determined by subtracting the number of days to heading from the number of days to maturity), plant height (measured in centimeters as the distance from the base of the plant to the tip of the longest panicle), panicle length (measured in centimeters as the distance from the base of the panicle to the tip of the longest panicle), above-ground dry biomass, (includes both the straw and the grain measured in kg plot-1), grain yield (dry seed measured in kg plot-1) and harvest index (determined by dividing the grain yield to above-ground dry biomass and expressed in percent) and lodging index (0-5 scale), were collected. Data on diseases and insects were not collected; both diseases and insect pests did not appear during the course of the study.

* 1. **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](#_ENREF_32)), and the correlation among parameters was done using R software version 4.3.2 ([Olivoto andLúcio, 2020](#_ENREF_30)). Duncan’s Multiple Range Tested was used for mean separation.

1. **RESULTS AND DISCUSSION**
	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. 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 [Fikre *et al.,* (2020](#_ENREF_21)) and [Birhanu *et al.*, (2020](#_ENREF_14)) under irrigation; [Worku and Fentie (2024](#_ENREF_36)) and [Ferede *et al.,* (2024](#_ENREF_18)) under rain-fed conditions.

Table 2. Mean performance of commercial tef 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  | 58abcd | 100a | 42abcdef | 83ijk | 35abc | 6.5fhij | 2.1de | 32def |
| 2 | Asgori | 58abcd | 95f | 37f | 77mn | 29fg | 6.4ijk | 2.2cd | 33cde |
| 3 | Welankomi | 58abcd | 100a | 42abcdef | 90cd | 34bc | 7.0b | 2.1de | 30fgh |
| 4 | Magna | 57bcde | 100a | 43abcde | 89de | 31df | 5.6p | 1.9fg | 35bc |
| 5 | Menagasha | 58abcd | 99ab | 41cdef | 86fgh | 31def | 5.9no | 1.8gh | 29ghi |
| 6 | Gibe | 56cdef | 100a | 44abcd | 87efg | 31def | 6.8bcdef | 2.6a | 32def |
| 7 | Dukem | 61a | 99ab | 38ef | 92c | 36ab | 7.0b | 2.2cd | 31efg |
| 8 | Quncho | 60ab | 99ab | 39def | 99a | 37a | 5.9no | 2.2cd | 32def |
| 9 | Tseday  | 54ef | 92gh | 38ef | 73op | 29fg | 5.0q | 1.6i | 32def |
| 10 | Kaytena | 55def | 95f | 40cdef | 79lm | 30fg | 6.1lmn | 1.9fg | 30fgh |
| 11 | Kora | 59abc | 96bef | 37f | 96b | 34bc | 6.7befgh | 2.3bc | 35bc |
| 12 | Simada | 47g | 90h | 43abcde | 71p | 26hj | 4.7r | 2.0ef | 43a |
| 13 | Boset | 53f | 92gh | 39def | 79lm | 28gh | 5.8op | 2.0ef | 34bcd |
| 14 | Gimbichu | 56cdef | 101a | 45abc | 82jk | 31def | 6.3jkl | 1.9fg | 30fgh |
| 15 | Holeta key | 55def | 94fg | 39def | 79lm | 28ghi | 6.6fghi | 2.2cd | 32def |
| 16 | Ambo toke | 58abcd | 99ab | 41cdef | 82jk | 29fg | 6.8bcdef | 2.4b | 34bcd |
| 17 | Gamechis | 54ef | 96bcef | 42abcdef | 86fgh | 30fg | 7.0bc | 2.4b | 34bcd |
| 18 | Genete | 57bcde | 98abcde | 41acdef | 89de | 33cd | 7.0bcd | 2.3bc | 33cde |
| 19 | Zobel | 58abcd | 99abc | 41abcdef | 83ijk | 31def | 6.0mno | 2.1de | 33bcd |
| 20 | Mechere | 55def | 98abcde | 43abcde | 84hij | 33cd | 6.6efghi | 2.3bc | 35bc |
| 21 | Laketch | 60ab | 100a | 40cdef | 87efg | 31def | 6.9bcde | 2.4b | 30fgh |
| 22 | Etsub | 60ab | 99abcd | 39def | 92c | 35abc | 6.9bcde | 2.2cd | 31efg |
| 23 | Dima | 58abcd | 99abcd | 41abcdef | 75no | 26hijk | 5.2q | 1.4j | 27ij |
| 24 | Guduru | 58abcd | 99abcd | 41abcdef | 100a | 36ab | 6.8bcdefg | 1.7hi | 31efg |
| 25 | Kena | 61a | 101a | 40cdef | 88def | 30fg | 5.9no | 1.7hi | 33cde |
| 26 | Ajora | 53f | 99abcd | 46a | 81kl | 30fg | 6.1lmn | 2.0ef | 28hij |
| 27 | Degatef | 56cdef | 101a | 45abc | 87efg | 33cd | 7.4a | 2.1de | 36b |
| 28 | Worekiyu | 54ef | 100a | 46a | 85ghi | 33cde | 6.2klm | 2.2cd | 36b |
| 29 | Local check | 60ab | 100a | 40cdef | 73op | 24j | 6.7bcefgh | 1.8gh | 26j |
|  | Mean | 57 | 98 | 41 | 85 | 31.2 | 6.3 | 2.1 | 32 |
|  | SEM (+) | 1.5 | 1.28 | 2.08 | 1.13 | 0.97 | 0.13 | 0.08 | 1.0 |
|  | CV (%) | 4 | 1.7 | 6 | 6 | 9 | 15 | 13 | 16 |

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 SEM=standard error of the mean, CV= Coefficient of variance

Table 3. Mean performance of commercial tef 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  | 58ab | 107a | 49cde | 95cd | 41bc | 4.6k | 1.1l | 26q |
| 2 | Asgori | 55bcde | 104bcd | 49cde | 81m | 36efg | 8.1a | 1.9fg | 23r |
| 3 | Welankomi | 55bcde | 103cde | 48def | 98b | 39cde | 7.3bc | 1.9fg | 26q |
| 4 | Magna | 55bcde | 103cde | 48def | 88hi | 36efg | 6.1e | 1.9fg | 35g |
| 5 | Menagasha | 55bcde | 104bcd | 49cde | 94de | 39cde | 7.1c | 1.9fg | 28op |
| 6 | Gibe | 54cdef | 105abc | 51bc | 89gh | 38cdef | 5.3ij | 2.6a | 53a |
| 7 | Dukem | 57abc | 102def | 45gh | 96c | 38cdef | 6.0ef | 1.7hi | 28op |
| 8 | Quncho | 57abc | 102def | 45gh | 93e | 41bc | 5.8fg | 2.6a | 49c |
| 9 | Tseday  | 50ghi | 100f | 50bcd | 85k | 37def | 5.3ij | 2.1de | 46d |
| 10 | Kaytena | 53defg | 103cde | 50bcd | 94de | 39cde | 6.6d | 2.0ef | 30lmn |
| 11 | Kora | 57abc | 106ab | 49cde | 101a | 43ab | 4.8k | 1.9fg | 40f |
| 12 | Simada | 48i | 100f | 52ab | 73o | 35fg | 4.8k | 1.3k | 28op |
| 13 | Boset | 49hi | 101ef | 52ab | 81m | 38cdef | 5.6gh | 2.2cd | 40f |
| 14 | Gimbichu | 59a | 106ab | 47efg | 88hi | 36efg | 5.5hi | 1.9fg | 51b |
| 15 | Holeta key | 52efgh | 101ef | 49cde | 81m | 39cde | 6.0ef | 1.8gh | 29no |
| 16 | Ambo toke | 54cdef | 103cde | 49cde | 94de | 38cdef | 7.1c | 2.0ef | 28op |
| 17 | Gamechis | 51fghi | 105abc | 54a | 87ij | 39cde | 7.1c | 2.3bc | 31klm |
| 18 | Genete | 53defg | 101ef | 48def | 91f | 35fg | 6.1e | 2.0ef | 33jkl |
| 19 | Zobel | 54cdef | 104bcd | 50bcd | 83l | 39cde | 6.6d | 2.4b | 34ghi |
| 20 | Mechere | 53defg | 101ef | 48def | 96c | 43ab | 5.8fg | 2.1de | 35g |
| 21 | Laketch | 57abc | 105abc | 48def | 102a | 38cdef | 6.0ef | 2.28bcd | 35g |
| 22 | Etsub | 56abcd | 103cde | 47efg | 95cd | 38cdef | 6.1e | 2.1de | 34gh |
| 23 | Dima | 56abcd | 103cde | 47efg | 87ij | 40cd | 7.5b | 2.2cd | 30lmn |
| 24 | Guduru | 58ab | 101ef | 43h | 98b | 34g | 6.6d | 2.0ef | 29mno |
| 25 | Kena | 56abcd | 105abc | 49cde | 86jk | 34g | 5.3ij | 1.5j | 31klm |
| 26 | Ajora | 50ghi | 101ef | 51bc | 83l | 37defg | 5.5hi | 1.6ij | 29mno |
| 27 | Degatef | 57abc | 103cde | 46fg | 76n | 40cd | 3.5l | 1.5j | 43e |
| 28 | Worekiyu | 59a | 106ab | 48def | 90fg | 36efg | 5.6gh | 1.9fg | 33hij |
| 29 | Local check | 57abc | 106ab | 49cde | 81m | 36efg | 5.1j | 1.7hi | 33hij |
|  | Mean | 55 | 103.3 | 48.6 | 89 | 38.1 | 5.9 | 1.9 | 35 |
|  | SEM (+) | 1.63 | 0.98 | 1.03 | 0.81 | 1.3 | 0.11 | 0.08 | 0.8 |
|  | CV (%) | 4 | 1.7 | 6 | 6 | 9 | 15 | 13 | 16 |

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, SEM=standard error of the mean, CV= Coefficient of variance

* 1. **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](#_ENREF_15)), who reported significant variation among tef 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 (47 to 61 days), days to maturity (90 to 107 days), grain filling period (37 to 54 days), plant height (71 to 102 cm), panicle length (31 to 43 cm), dry shoot biomass (3.5 to 8.1 t ha-1), grain yield (1.1 to 2.62 t ha-1), harvest index (23 to 53%), and lodging index (1.3 to 4.6 based on a 0 to 5 scale) (Table 3). ([Fikre *et al.*, 2020](#_ENREF_21)) and ([Birhanu *et al.*, 2020](#_ENREF_11)) indicated that tef is diverse in different important traits under irrigation. In agreement with the results of the present study, [Belete and Admasu (2021](#_ENREF_10)) and [Assefa *et al.,* (2015](#_ENREF_3)) also reported that wide ranges of variations were observed among the released tef 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 (2.4 t ha-1) and Laketch and Gemechis (2.34 t ha-1). The lowest grain yield (1.1 t ha-1) was recorded by Enatit. In this study, a grain yield advantage of up to 48% over the local variety was observed. The significant grain yield advantage of improved varieties over the local variety observed in this study can be a driving force to expand tef production under irrigation using improved varieties. Similarly, [Birhanu *et al.,* (2020](#_ENREF_11)) and ([Yazachew *et al.*, 2021](#_ENREF_38)) identified Gibe as the highest yielder, which gave 3.0 and 2.6 t ha⁻¹ respectively, at Dembia district and [Yihun *et al.,* (2013](#_ENREF_39)) reported that the quncho variety gave about 3.3 t ha⁻¹ under irrigation conditions.

In the study, the longest time (107 days) and shortest time (90 days) for maturity were recorded by varieties Enatit and Simada, 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](#_ENREF_14)) noted that tef exhibits large phonologic plasticity depending on the growing conditions and genotype. The longest (102 cm) and the shortest (71 cm) plant heights were recorded by Laketch and Simada, respectively. Regarding the harvest index, the highest (53%) and the lowest (23%) were recorded by Gibe and Asgori, respectively; similar studies were reported by [Girma (2019](#_ENREF_25)) under irrigation. 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](#_ENREF_19)).

Table 4. Combined mean performance of commercial tef varieties for grain yield and other agronomic parameters as evaluated under irrigation at Koga (2015/16-2016/17) off season

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No | Varieties | DTH | DTM | GFP | PH | PL | DSB | GY | HI | LI |
| 1 | Enatit  | 58ab | 104a | 46abcde | 89def | 40a | 5.6no | 1.6 n | 28.1no | 1.6il |
| 2 | Asgori | 57abcd | 100fg | 43fgh | 79n | 33efghi | 7.3a | 2.05fgh | 28.3no | 2.3gh |
| 3 | Welankomi | 57abcd | 102abcd | 45cdef | 94c | 37bc | 7.2ab | 2.0ghi | 28.0o | 3.0cd |
| 4 | Magna | 56bcde | 102abcd | 46abcde | 89def | 34efghi | 5.85kl | 1.9ijk | 35.0e | 1.6ijl |
| 5 | Menagasha | 57abcd | 102abcd | 45cdef | 90d | 35de | 6.5ef | 1.85jkl | 28.5mno | 2.6dg |
| 6 | Gibe | 55cdef | 103ab | 48ab | 88fgh | 35de | 6.1ij | 2.6a | 42.5a | 2.0hi |
| 7 | Dukem | 59a | 101cdef | 42gh | 94c | 37bc | 6.5ef | 1.95hij | 29.8klm | 1.6ijkl |
| 8 | Quncho | 59a | 101cdef | 42gh | 96b | 39a | 5.85kl | 2.4b | 40.6b | 3.0cde |
| 9 | Tseday  | 52gh | 96ij | 44efgh | 79n | 33efghi | 5.2 p | 1.85jkl | 38.9c | 2.6deg |
| 10 | Kaytena | 54defg | 99gh | 45cdef | 87h | 35de | 6.4fg | 1.95hij | 30.2kl | 1.3l |
| 11 | Kora | 58ab | 101cdef | 43fgh | 989a | 39a | 5.8klm | 2.1efg | 37.5d | 4.6a |
| 12 | Simada | 48i | 95j | 48ab | 72p | 31kl | 4.8q | 1.65mn | 34.7e | 3.3c |
| 13 | Boset | 51h | 97ij | 46abcde | 80mn | 33eghi | 5.7lmn | 2.1efg | 36.8d | 1.6ijkl |
| 14 | Gimbichu | 58ab | 104a | 46abcde | 85i | 34efghi | 5.9jk | 1.9ijk | 40.6b | 4.0b |
| 15 | Holeta key | 54efgh | 98hi | 44efgh | 80mn | 34efghi | 6.1hi | 2.0ghi | 30.6jkl | 2.3gh |
| 16 | Ambo toke | 56bcde | 101cdef | 45cdef | 88fgh | 34efghi | 7.0c | 2.2de | 31.2ijk | 2.3gh |
| 17 | Gamechis | 53fgh | 101cdef | 48ab | 87h | 35de | 7.1bc | 2.34bc | 33.2fgh | 3.0cdef |
| 18 | Genete | 55cdef | 100efg | 45cdef | 90d | 34efghi | 6.6de | 2.15def | 32.3hi | 1.3l |
| 19 | Zobel | 56bcde | 102abcd | 46abcde | 83j | 35de | 6.3gh | 2.25cd | 33.9efg | 2.6defg |
| 20 | Mechere | 54defg | 100efg | 46abcde | 90d | 38abc | 6.2ghi | 2.2de | 35.1e | 1.6ijkl |
| 21 | Laketch | 59a | 103abc | 44efgh | 95bc | 35de | 6.3gh | 2.34bc | 32.6ghi | 1.3l |
| 22 | Etsub | 58ab | 101cdef | 43fgh | 94c | 37bc | 6.5ef | 2.15def | 32.7gh | 2.0hij |
| 23 | Dima | 57abc | 101cdef | 44efgh | 81klm | 33efghi | 6.4fg | 1.8kl | 28.6mno | 1.6ijkl |
| 24 | Guduru | 58ab | 100efg | 42gh | 99a | 35de | 6.7d | 1.85jkl | 30.1kl | 1.6ijkl |
| 25 | Kena | 59a | 103ab | 45cdef | 87gh | 32jk | 5.6mno | 1.6n | 31.9hij | 2.0hijk |
| 26 | Ajora | 52gh | 100efg | 49a | 82jk | 34efghi | 5.8kl | 1.8kl | 28.5mno | 1.3l |
| 27 | Degatef | 57abc | 102abcd | 46abcde | 82jk | 37bc | 5.5o | 1.8kl | 39.6bc | 1.3l |
| 28 | Worekiyu | 57abc | 104a | 47abcd | 88fgh | 35de | 5.9jk | 2.05fgh | 34.4ef | 2.3gh |
| 29 | Localcheck | 59a | 103ab | 45cdef | 77o | 30l | 5.9jk | 1.75lm | 29.6lmn | 2.3gh |
|  | Mean | 56.0 | 101 | 45 | 87 | 35 | 6.1 | 2.0 | 33 | 2.2 |
|  | CV (%) | 5.8 | 0.7 | 7.6 | 8.7 | 8.5 | 19.2 | 19.3 | 20.4 | 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, CV= Coefficient of variance

* 1. **Association of grain yield with 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](#_ENREF_18)). 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](#_ENREF_40)).

In the present study, plant height, dry shoot biomass, and panicle length showed a highly significant positive correlation with grain yield (Fig. 2). The result of this study is in line with the reports of [Ferede *et al.,* (2024](#_ENREF_18)) and ([Assefa *et al.*, 2022](#_ENREF_5)). A strong positive correlation coefficient among grain yield, dry shoot biomass, and plant height had a direct contribution to grain yield and was used to improve yield productivity. Likewise, [Bekana *et al.,* (2022](#_ENREF_9)) 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. 2). 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](#_ENREF_29)) reported a negative association between the lodging index and grain yield. On the contrary, [Chanyalew (2010](#_ENREF_13)) 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 tef grain yield loss, 35% of 1000-kernel weight, and 51% of grain yield per panicle ([Chanyalew *et al.*, 2019](#_ENREF_14)).

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Figure 2**.** Association of grain yield with yield and yield related traits

1. **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 different tef research activities under irrigation so that tef productivity and production will be enhanced and the gap between demand and supply for tef can be reduced. As there were no agronomic recommendations for tef 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 duties. Based on their overall better mean performances for grain yield and yield components, varieties including Gibe, Quncho, Laketch and Gemechis have been recommended for large-scale production under the irrigated farming system.

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