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Effect of Different Zinc Fertilization Rates on the Agronomic and Grain Quality Traits of Tef (*Eeragrostic tef* (Zucc.) Trotter) Varieties in Northern Ethiopia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Although tef is a major crop in Ethiopia, its grain yield is often low due to insufficient application of Zinc fertilizer. This experiment was conducted during the 2019/2020 main cropping season to evaluate the agronomic, yield, and grain quality responses of tef varieties to different Zinc fertilizer rates. The experiment was arranged in a split-plot design with five treatments: 4, 6, 8, and 10 kg $^{-1}$ Zn, including a control, applied as subplots for three tef varieties (flagot, Local [Zezew], and Quncho), with three replications. Results showed that Zinc rates, the varieties, and their interactions have significantly affected all the traits. The highest grain yield (2442 Kg ha^{-1}) was obtained from the

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Quncho variety treated with 6 Kg ha-^{1} Zn. The highest grain Zn (42.50 mg kg^{-1}), and Fe (738.4 mg kg^{-1}) contents were recorded from flagot tef variety treated with10kg Zn ha-^{1}. Therefore, farmers in the target area are advised to apply 6 kg and 10kg Zn ha^{-1} to enhance tef productivity and grain Zn & Fe content.

Keywords: Zinc; variety; yield formation; quality.

1. INTRODUCTION

Tef (*Eragrostis tef* (Zucc.) Trotter) is an annual crop with a growth cycle of 2 to 5 months, predominantly cultivated as a staple food crop in Ethiopia [1, 2]. Ethiopia is the center of origin and diversity of cultivated tef [3]. It's a tropical crop and C_4-cycle photosynthetic pathway. Tef is an allotetraploid species with 2n = 4x = 40 chromosomes, and its flowers open in the morning (7–9 AM) in response to light and temperature. It is predominantly self-pollinating but with a very low degree of outcrossing (up to 1%). The crop has a large crown, numerous tillers, and a shallow, diverse root system. While most cultivars have erect stems, some exhibit bending or elbowing growth habits. Tef holds considerable economic importance in Ethiopia. Nationally, it accounts for 24% of the total cultivated area and 17.29% of the total grain production, with an average productivity of 16.64qt ha^{-1}. In the Tigray region, tef is grown on approximately 167,584.33 hectares, with an average yield of 14.38 qt ha^{-1} [4]. Tef is healthy crop & superior in nutritional quality. The grain of tef is a good source of carbohydrate, fiber, iron, calcium and zinc and a good source of essential amino acids than other cereal grains, including wheat, barley and sorghum [5,6]. It is most made into injera & straw provides an excellent nutritional product in contrast to other animal feed and is also utilized to reinforce mud or plasters used in the construction of buildings [5,7].

The soil fertility map of agricultural lands has been developed by EthioSIS to identify nutrients that may limit crop productivity and to develop balanced fertilization in Ethiopia [8]. Accordingly, widespread Zn deficiency in soils of Tigray Region was [9] Zinc deficiency is also a global problem in human nutrition associated with cereal-based diets, while low soil Zn often limits crop production and crop grain quality [10]. There is an interest from the government of Ethiopia for use of Zn containing fertilizers such as NPSZn to increase crop yields and quality. Farmers in Ethiopia have started using fertilizers containing Zn. In Tigray Region, farmers are encouraged through the extension system to apply fertilizer containing Zn at a rate of 100 kg ha^{-1} replacing Di-ammonium phosphate (DAP) for all crops. The Zn content in NPSZn fertilizer is 2.2 kg. The recommended target of Zn concentration in crop grains for human nutrition is 40-60 mg kg^{-1} [10]. Fertilizers containing Zn might also improve the productivity and quality of cereals and concentration of Zn in tef grain. Zinc fertilizers are commonly applied to many crops around the world. The most common sources are $ZnSO_4$ and ZnO, but other inorganic products and sources such as chelates and natural organic complexes also are used. It is used in the formation of chlorophyll and some carbohydrates and is used in the conversion of starches to sugars. Zinc also helps plant tissue withstand cold temperatures. Zinc is essential in the formation of auxins, which help with growth regulation and stem elongation. In zinc deficient plants stunted growth and small leaves are the most distinct visible symptoms and result from the disturbance in the auxin metabolism [11] mentioned that if zinc contents are lower, zinc deficiency can cause a 50 to 70% reduction in photosynthesis, decreased protein production, loss of membrane integrity and reduced yield. Hence, there are limited studies investigating the effects of fertilizers containing Zn and their effects on yields and grain Zn concentration (quality) on types of tef varieties.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This research was conducted at Axum Agricultural Research Center (AxRC) during 2020 main cropping season, at the Ahform substation, is positioned at longitude 390 04'40.2'' and latitude 140, 6'28.015'', with an elevation of 2200 meters above sea level. The average annual rainfall in this area ranged from 500 to 700 mm, with daily average minimum and maximum temperatures of 20°C and 30°C, respectively.

2.2 Experimental Design and Management

The experiment was conducted using a split plot design with five treatments 4, 6, 8 & 10 kg ha^{-1} ZnO including the control. These were applied as subplots within three tef varieties (Local [Zezew], Flagot and Quncho), with three replications. Each plot measured 2m x 2m, containing 10 rows with 20 cm inter-row spacing. Plot, main plot, and replication spacing was 0.5 cm, 1 m, and 1.5 m, respectively. The recommended tef seed rate of 10 kg ha^{-1} [12] was used, and blended fertilizer (NPSB) was applied at a rate of 100 kg ha^{-1}, as reported by [2]. Although N fertilizer was applied Split application where half dose was applied just after germination and the application of the remaining dose was done two weeks later after the first dose application. All other agronomic crop husbandry practices were applied uniformly to all plots.

2.3 Data Collection

Data were collected on 11 agronomic traits from the eight middle rows of each plot leaving the two rows as borders. Assessments depending on the trait were made both on individual plants and on a plot basis.

2.3.1 Phenological traits

Days to 50% heading and Days to 90% maturity were recorded when 50% of the plant per plot headed and 90% of the plants reached physiological maturity.

2.3.2 Agronomic traits

Plant height (PH), Number of productive tillers, Panicle length (cm), grain yield (kgha^{-1}) and aboveground biomass (kgha^{-1}) were collected per plot using appropriate methods. The harvest index was calculated as a ratio of grain yield to the biomass yield.

2.3.3 Quality traits

Estimation of Zinc & Iron (mg/kg) content: Grain micronutrient (Zn & Fe) was determined using 1g dry and ground plant material transfer quantitatively into a beaker and by adding 10 mL (2:1 ratio) nitric acid-per chloric acid mixture and allowing to stand overnight or until the vigorous reaction phase is over using 150 °C temperature for 1-hour digest. Temperature was slowly increased to 235 °C until all traces of *HNO3* disappeared, then analyzed by the equipment of an Atomic Observation Spectrometer (AAS) at Ezana Analytical Laboratory;2

2.4 Data Analysis

All the collected data were subjected to statistical analysis using GenStat 18th Edition statistical software. For traits that showed significant response to either the main or the interaction effects, a mean comparison was performed using the least significance difference (LSD) at a 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Response of Tef Phonological Traits to Rates of Zinc Fertilizer

3.1.1 Days to 50% heading

The V×Zn interaction has a significant ($p<0.01$) effect on days to heading. The longest (58.34 days) day to heading was recorded for the Quncho variety treated with 10 kg ha^{-1} Zn while the shortest (46.05 days) days to heading was recorded for the local variety treated with control. (Table 1). This result indicated that higher amount of Zn fertilizer might have contributed to the delayed number days to heading the effect of zn rates on heading dates of tef was reported previously [13].

3.1.2 Days to 90% physiological maturity

The days to maturity of the varieties showed a significant ($P<0.01$) variation under the different Zn fertilizer rates, showing that the interaction effect is strong. A delayed maturity (101 days) was recorded from the Quncho variety that received 10 kg ha^{-1} Zn treatments while the earliest (83days) maturity was recorded for the local variety without any fertilization this result showed brown–seeded color are early maturing than white-seeded (Table 1). Mehoni et al. [13] who Saied that the fertilizer blended in different proportions of N, P, S, Fe and Zn and higher amount of Zn and urea might have contributed to the delayed number days to maturity of tef. The delayed maturity time might be associated with prolonged period for the vegetative developmental stage and might increase the chance of lodging and susceptibility to diseases and pests.

3.2 Effect of V×Zn on Agronomic Traits

3.2.1 Plant height

The V×Zn interaction significantly ($p<0.01$) affected the height of the various varieties. The tallest (127.8cm) was recorded for the Quncho variety treated with 8kg ha^{-1} Zn fertilizer whereas the shortest (83.1cm) height was recorded for the local with zero fertilizer.

(Table 1). Similar results were reported by other scholars for various crops [14–15]. Reported that Plant height increased 4.8 and 23.1% by utilization of Zn at the stem elongation and also at the stemming and grain filling stages, respectively and added Zn significantly increased plant height via increasing internodes distances. Haileselassie et al., [16] Contradictory for this current study.

Table 1. The mean value for the Interaction effect of Zn fertilizer rates and tef varieties on phenology, morphology, yield and yield component of tef.

TRT Va*Zn	HD	MD	PH	Pl	TI N	BY	GY	HI
1 1	47.59 bcde	84.15 a	83.1 j	33.20 h	8.77 bcd	5149 k	1468 cde	0.28 a
1 2	46.55 ab	83.36 a	86.7 i	36.30 f	9.03 b	6094 i	1337 f	0.22 bc
1 3	46.72 abc	84.02 a	86.6 i	31.50 j	7.2 e	5638 j	1168 gh	0.21 cd
1 4	46.38 ab	84.52 a	83.7 j	33.67 h	8.6 bcd	7969 ef	1809 b	0.23 b
1 5	46.05ab	84.02 a	88.8 h	33.77 h	7.33 e	8438 cd	1848 b	0.22 bc
2 1	50.78 ij	83.37 a	94.3f	35.37 g	11.22 a	7656 fg	1178 gh	0.15 gh
2 2	49.63 fhij	83.66 a	99.7 e	36.30 f	9.1 b	8281 de	1146 h	0.14 h
2 3	48.97 efgh	83 a	93.9 f	37.10 e	6.8ef	7266 ef	1399 def	0.19 de
2 4	50.3 ij	83.66 a	90.7 g	35.70 fg	8.7 bcd	7969 ef	1303 f	0.16 fg
2 5	49.47 fghi	83 a	94.5 f	32.30 i	8.9 b	7500 gh	1282 fg	0.17 f
3 1	56.96 kl	101 b	126.4 ab	42.70 d	5.13 g	8750 bc	1406 ij	0.15gh
3 2	57.34 klm	101 b	125.4 bc	48.00 a	5.83 fg	9531 a	1336 ef	0.155 fgh
3 3	58 lmn	101 b	123.2 d	44.50 c	7.83 cde	8945 b	2442 a	0.27 a
3 4	57 kl	101 b	127.6 a	44.90 c	6.85 ef	9062 b	1599 c	0.19 g
3 5	58.34 mn	101 b	123.9 cd	46.20 b	7.73 de	8438 cd	1599 c	0.19 g
CV%	1.0	0.3	0.8	0.8	5.6	2.7	4.8	4.8
LSD (5%)	1.42	1.21	1.59	0.69	1.06	357.5	132.70	0.017
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

DH50%; day of 50% heeding, DM90%; day of 90% maturity, PH; Plant height), Number of Effective tillers (NET), Panicle length (PL, cm), Grain yield (GY kg ha^{-1}), Biological yield (BY kgha-1), Harvest index (HI) and V1; local, V2; flagot, V3;Quncho and Z1=control, Z2=4kgZn ha^{-1}, Z3=6kgZn ha^{-1}, Z4=8kgZn ha^{-1} and Z5=10kgZn ha^{-1}.

Table 2. The Mean value for Interaction effect of Zn fertilizer rates and tef varieties on quality traits of tef at Ahforom site

Traits (varieties*rate of zinc)	Zn (mg kg^{-1})	Fe (mg kg^{-1})
local*control	36.20 f	347.5c
local*4kg	27.30 m	196.8 k
local *6kg	30.60 l	255.4 f
local *8kg	30.50l	253.6 f
local *10kg	42.50 a	738.4 a
Flagot * control	32.07 j	286.9 e
Flagot *4kg	37.20 d	209.5 i
Flagot *6kg	37.00 e	206.1 j
Flagot *8kg	31.60 k	355.9 b
Flagot *10kg	39.60 b	246.6 g
Quncho*control	32.30 i	158.2 m
Quncho *4kg	33.10 h	162.3 l
Quncho *6kg	38.60 c	236.9 h
Quncho *8kg	32.30 i	300.1 d
Quncho *10kg	34.10 g	194.7 k
LSD(0.05)	0.1747	3.465
CV (%)	0.3	0.6
P-value	<.001	<.001

Fe; iron (Zn) zinc grain concentration v1; local,v2; flagot,v3Quncho Z1=control, Z2=4kgZn, Z3=6kgZn, Z4=8kgZn and Z5=10kgZn

3.2.2 Panicle lengths (cm)

These traits were under significant ($p<0.01$) influence of the V×Zn interaction effects (Table 1). The longest panicle length (48cm) was recorded for Quncho variety treated with 4 kg ha^{-1} Zn. On the other hand, the shortest panicle length (31.50 cm) was recorded for the local treated with 6kg ha^{-1} Zn. Various previous studies Contradictory for this study there was no significant interaction effect of Zn fertilizer and soil for either panicle length or plant height of tef b/c Low soil organic carbon, total nitrogen, clay content, both available and total Zn and other related poor physical and biological soil properties might have contributed for the lowest growth of tef [16] and [17] on rice.

3.2.3 Number of Effective Tiller (NET)

As presented for the other traits, the V×Zn interaction significantly ($p<0.01$) affected the number of tef productive tillers. Many NETs (11 per plant) were recorded for flagot variety treated with no Zn application while only 5 tillers per plant were recorded for the Quncho variety with no fertilizer (Table 1). These results are in line to the findings made by [18] reported that application of zinc has a very little effect on total numbers of tillers produced on wheat.

3.2.4 Biomass Yield (BY) and Grain Yield (GY)

Yield is an ultimate goal of crop production and the impact of production factors on these traits is critically observed. Our study found that both the BY and GY were under strong influence ($p<0.01$) of V×Zn interaction effects. The highest biomass yield (9531 kgha-1) and grain yield (2442 kg ha^{-1}) were recorded for the Quncho variety treated with 4 kg ha^{-1} Zn and 6 kg ha^{-1} Zn, respectively (Table 1). The lowest biological yield (5149kg ha^{-1}) recorded from local variety treated with no fertilizer application and lowest grain yield (1178 kg ha^{-1}) were recorded from flagot variety without any fertilization. Haileselassie et al., [16] also found similar results who observed there was a significant interaction effect of Zn fertilization and soil for biomass yield and grain yield of tef [17,19], also observed and found higher biological yield and grain yield with Zn foliar application on rice and wheat. Availability of micronutrients causes increase in the yield of crops. This increase of yield may be due to the abundant efficiency of enzyme activities which influence plant pigments because zinc is an important component of all classes of enzymes. 24% - 38% yield can be increased by the application of zinc as compared to controlled plots and Zinc may be endorsed increased photosynthesis, initial growth, nitrogen fixation which encourages biological yield. These finding are in line to results of [18].

3.2.5 Harvest index

Harvest index is a good indicator of assimilates accumulation into the final intended product. The HI ranged from 0.14 to 0.27 and significantly ($p<0.01$) affected by the V× Zn interaction effect. The largest (0.279) HI was obtained from Quncho variety treated with 6 kg ha^{-1} Zn while the lowest (0.14) HI was recorded from the flagot variety treated with 4kg ha^{-1} Zn (Table 1). Similar results were reported previously], [16] who reported on average Zn fertilizer increased significantly grain and harvest index of tef. the highest grain yield and harvest index of tef were recorded from the application of 100 kg NPSZn ha^{-1} + 4 kg Zn ha^{-1} with recorded increases of 3.6% and 7.6%, respectively, over the control.

3.3 V×Zn interaction Effects on Tef Grain Quality Traits

Improvement in grain quality traits is equally important as improvement in grain in crop improvement to achieve nutritional security. Some of the grain quality traits are influenced by agronomic management and the responses of varieties to the applied agronomic management. In this paper, we presented the effect of varieties' interaction with Zn rates on tef grain Zn and Fe concentration according to [20].

3.3.1 Grain Fe and Zn concentration

Micronutrient deficiency is a major contributor to malnutrition in Ethiopia especially in the northern part and improving their access through bio fortification is the main target of agronomic and breeding research. Our analysis revealed that the concentration of these micronutrients by the various tef varieties under different rates of Zn fertilizer treatment was significantly ($p<0.01$) different. These results support the finding made by [16] who reported that significant interaction effect of Zn fertilization and soil for grain quality or Zn concentration of tef. The highest (738 mg/kg) mean Fe concentration was recorded from the local variety treated with 10 kg ha^{-1} Zn. In comparison, the lowest (158.2 mg kg^{-1}) was recorded from the Quncho variety without Zn treatment (Table 2). Similarly, the highest (42.50 mg kg^{-1}) of grain Zn content was recorded from the local variety treated with 10 kg ha^{-1} Zn, and the lowest (27.30 mg kg^{-1}) content was also recorded from the same variety treated with 4 kg ha^{-1} Zn. The variation in Fe and Zn concentration by varieties under different fertilizer treatments by crops like tef and wheat was reported by various scholars [13,14,18,21]. The potential of brown -seeded tef varieties to concentrate more Fe and Zn compared to the improved white-seeded tef varieties was also reported by [22]. The increase in grain Zn content with foliar Zn application may be due to increase in plant growth and metabolism finding by [15]. The findings suggest that applied Zn is important to maintain sufficient yield and grain Fe and Zn concentration.

4. CONCLUSION

It could be inferred from the result that the response of tef varieties to the applied rates of zinc fertilizer was significantly high. The V×Zn interaction effect has affected all the studied agronomic and grain quality traits very significant. The improved variety, Quncho (whait -seeded clour) showed a better response to high rates of zinc fertilizer for yield and yield-related traits while the flagot variety (read (brown) seeded clour) concentrated more micronutrients with the highst rates of zinc fertilization. The read seed clour tef variety might extend its roots deeper into the root zone in search of nutrients than the improved varieties, which enabled it to accumulate more Fe and Zn when deprived of fertilizer application. This inference needs further verification. Application of 6 kg ha^{-1} Zn to the variety Quncho looks more yield and 10 kg ha^{-1} Zn to the variety flagot accumulate more Fe & Zn grain content than the other options and is recommended for this particular location. We recommend further research to ascertain our findings.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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