Journal of Tropical Crop Science Vol. 12 No. 1, February 2025
www.j-tropical-crops.com

Received 27/06/2024; Revised 11/12/2024; Accepted 25/02/2025
https://doi.org/10.29244/jtcs.12.01.246-253

Participatory Evaluation and Promotion of Tef Production Technologies for Moisture Deficit Areas of Simada District in Amhara Region, Ethiopia

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Abstract

Tef (*Eragrostis tef* Zucc. Trotter) is a small cereal crop resilient to adverse climatic and soil conditions and possesses desirable storage properties. It provides high-quality food and grows under marginal conditions which are not unsuitable for other cereal crops. Although tef is a major cultivated crop in the Simada district, demonstration and adoption of improved tef varieties and agronomic practices are very limited. Therefore, the study was initiated to select and promote the higher grain yielding tef varieties with agronomic practices and create awareness to farmers and end users. The activity was conducted on six farmers' fields in the Simada district in the 2019 and 2020 cropping seasons. Early maturing tef released varieties, namely "Hiber-1", "Boset", and "Tseday" (Cr-37), and local tef varieties were used for the study in a plot area of 10m by 10m for each variety across sites. Farmers and researchers selected the "Hiber-1" tef variety due to agronomic traits and grain yield performance. "Hiber-1" was ranked 1st by farmers in both the Vertisol and Nitisol areas. It showed 31%, 28.4%, and 25.1% grain yield advantage over "Boset", "Tseday", and the local varieties respectively. In addition, the rank correlation of farmers' rank and grain yield rank of the varieties showed a strong positive correlation. Therefore, the "Hiber-1" tef variety should be scaled out in the Simada district and areas with similar agro-ecologies in Amhara Region and Ethiopia..

Keywords: adoption, early maturing, farmers' preference traits, grain yield, rank correlation

Introduction

Tef (*Eragrostis tef* Zucc. Trotter) is an important crop agriculturally, nutritionally, and economically in Ethiopia. It is cultivated in arid, moist tropics, subtropics, and temperate areas. In general, Tef is widely adaptable to different agro-ecologies; in particular, it is tolerant to moisture deficit, water-logged Vertisol areas, soil acidity, and cold-prone areas which are not more productive to other cereal crops (Assefa al., 2015). Tef is grown in different seasons and farming practices such as under rainfed (main season and spring), double cropping after potato in high rainfall highland areas, and recently under irrigation conditions. Farmers prefer to grow tef due to their resilience to stress conditions and suitability for double cropping (Seyfu, 1997). Therefore, tef area coverage in Ethiopia is ranked 1st (about 3 million hectares) compared to other cereal crops (CSA, 2022); it is a staple small cereal crop in Ethiopia used to prepare diverse food (Seyfu, 1997), gluten-free, stable starch with a higher content of iron, calcium, essential amino acids (lysine), and good mineral content than other cereal crops (Melak,1966). Tef is a source of foreign currency to Ethiopia through the "Injera" export, where exporters can earn about 38 million dollars per year (Fortune, 2022).

Improved tef technologies' productivity is higher than the national average tef productivity (1.88 $t.ha^{-1}$) (CSA, 2022). Improved tef technologies comprise tef varieties, agronomic practices, and pest management, which are limiting factors of adoption. Among 58 tef-released varieties, about 10 tef varieties are released for moisture deficit areas in Ethiopia (EAA, 2023). Although, in the Simada district, tef is a major cultivated crop and represents a moisture deficit area in the region, Farmers grow local tef varieties with poor agronomic practices. Therefore, considering the grain yield performance of improved tef varieties under moisture deficit conditions and lack of adoption of improved tef technologies in the Simada district, the study was vital to promote the tef technologies to farmers and tef producers.

The participation of farmers and stakeholders in tef technology evaluation is very limited, which

Received 27/06/2024; Revised 11/12/2024; Accepted 25/02/2025
https://doi.org/10.29244/jtcs.12.01.246-253

negatively affects the adaptability, acceptance, and diffusion of improved technologies to farmers and end users (Chiara et al., 2017; Sewagegn et al., 2023 and Misganaw and Zina, 2020). Farmers' and stakeholders' participation in technology evaluation is relevant to alleviating their concerns on the technologies to select well-adapted and preferred (demand-led) varieties and to create awareness, skills, and knowledge of diversities in the future breeding program (Dawit et al., 2024 and Molla et al., 2023) and to reduce time and resources wasted for technology diffusion. Therefore, the study was initiated with the objectives of selecting and promoting the higher grain yielding tef varieties with improved agronomic practices and creating awareness among farmers and end users.

Materials and Methods

Description of the Study Area

The experiment was conducted at Simada district in the South Gondar Zone of Amhara Region of Ethiopia during the 2019 and 2020 main cropping seasons. Simada is far from 774 km north of Addis Ababa and 209 km southeast of Bahir Dar. It is located at 11° 29'59.99'' N latitude and 38° 14' 60'' with elevations ranging from 1196 to 3525 m above sea level, and the district is divided into three climatic zones: middle altitude (40%), highland (10%), and lowland (50%) (Meseret, 2012). During the growing seasons, the Simada district rainfall and temperature ranged from 736 to 770 mm and 13-15°C, respectively. It has high rainfall for the two months of summer with less or no rainfall during other months of the year. Nevertheless, the wet season extends mostly from mid-June to the beginning of September. The main soil types in Simada are Nitisol and Vertisol, accounting for about 75% and 25% of the total area, respectively (Marye, 2011). Almost all the population living in the district is dependent on mixed farming. The district's total area is 132,373.9 km^2 according to the Simada District Agricultural Office.

Description of Tef Varieties for the Study

Four tef varieties, three early maturing released tef varieties for moisture deficit areas, and one local tef variety were used for the technology evaluation study. The description of the released tef varieties is listed in Table 1.

Site Selection and FREG Establishment

The participatory evaluation and demonstration were conducted in the Simada district of the South Gondar Zone. The two administrative units, or kebeles, were selected based on their tef area coverage and potential for production. Farmer's Research and Extension group (FREG) was established which consist of 25 (5 female) farmers to execute participatory technology evaluation and demonstration of tef varieties with improved agronomic practices. FREG consists of a multidisciplinary team of researchers, extension workers, agricultural experts, administrative managers, farmers, and other pertinent actors to conduct the study on farmers' fields on selected host farmers (Bedru et al., 2009). Among the FREG members, a total of six (6) interested host farmers were selected both at Nitisol and Vertisol sites because tef is cultivated on two soil types in the district.

Research Design and Agronomic Practices

Three different tef varieties, "Hiber-1", "Boset", and Tsedey, along with local check, were used for the study. The trial was carried out on the host farmers' field. Each variety was planted side by side on equal-sized plots (10 m x 10 m) replicated by the number of host farmers. The trail was planted at six farmers' fields, of which three at Nitisol and three at Vertisol per kebele, for two years in the 2019 and 2020 cropping seasons. The seed rate was 0.01 $t.ha^{-1}$ with row planting method by drilling the seeds for Nitisol and 0.015 $t.ha^{-1}$ with a broadcasting method for Vertisol. Spacing between rows was 20 cm for row planting. NPS fertilizer was applied at the rate of 0.158 $t.ha^{-}$

Table 1. Description of early maturing tef varieties used for the study [1)]

Variety	Pedigree	Releasing center	Release year	Altitude (m.a.s.l)	Rainfall (mm)	Maturity date
"Hiber-1"	DZ-01-974*P1222988	ADARC	2017	1200-2000	500-1000	93-114
"Boset"	DZ-Cr-409/RIL50d	DZARC	2012	1500-1750	500-900	75-86
"Tseday"	DZ-Cr-37	DZARC	1984	1500-2200	150-200	82-90
Local variety	-	-	-	-	-	-

Notes: [1)] Ethiopian Agricultural Authority (2023). ADARC is Adet Agricultural Research Center, DZARC is Debre Zeit Agricultural Research Center.

Received 27/06/2024; Revised 11/12/2024; Accepted 25/02/2025
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^{1} and 0.11 t.ha^{-1} for Nitisol and Vertisol, respectively. Urea fertilizer was applied at 0.022 t.ha^{-1} and 0.135 t.ha^{-1} for Nitisol and Vertisol, respectively. All NPS was applied at planting, whereas Urea was applied 1/3 at planting and 2/3 at the tillering stage for Vertisol and all Urea at tillering for Nitisol. The fertilizing system was in a row and broadcast for Nitisol and Vertisol, respectively. Weeding was done two to three times depending on the weed infestations.

Training of Farmers and Stakeholders

Training on production and management practices was provided to farmers and stakeholders both theoretically and practically. It was given to 49 farmers (13 female) and 17 extension workers (7 female) in the 2019 cropping season, while 52 farmers (15 female) and 15 extension workers (6 female) in the 2020 cropping season. The training was given by a multidisciplinary team of researchers comprising breeders, pathologists, agronomists, and extension researchers. The training focused on sowing, agronomic practices, integrated disease and pest control/management, post-harvest management, food processing, and seed dissemination mechanisms. The following table illustrates the number of farmers, DAs, and experts who participated in the training.

Technology Evaluation and Demonstration Methods

The evaluation and demonstration of the technologies were implemented in host farmers' fields to create awareness about the technology. FRGs, development agents, and experts at different growth stages of the crop were involved in the evaluation and demonstration. The activity was jointly monitored by FRGs, researchers, experts, and development agents.

Data Collection and Analysis

During the span of the activity, the yield of the crop and farmers' preference toward the crop was collected through supervision and organizing mini field day by researchers and development agents of the respective kebele. The biological data grain yield (t.ha^{-1}) was collected on 1 m by 1 m areas with three replications per plot across sites. Social data (farmers' preference traits and experts' opinions/feedback) were collected during monitoring, technology evaluation, and field days.

The quantitative data were analyzed by using average and frequency distribution, while qualitative data were described or narrated qualitatively; farmers' preferences were analyzed using the pair-wise ranking method based on their own evaluation and selection criteria. Hence, based on each criterion, the varieties were selected by direct scoring methods (1= the best, 4 = the poorest). The sum of the preference value (score x weight) of each of the varieties in all criteria was used to determine the final acceptability rank of the varieties in each location. Spearman's rank correlation coefficient, "rs," can be used to evaluate the degree of selection of varieties by farmers using reference traits with the actual value of measured attributes. Hence, Spearman's rank correlation was calculated to see whether farmers' preferences matched actual yield.
Spearman's rank correlation coefficient r_s is defined as follows:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

Where N - denotes the number of individuals or phenomena ranked (number of varieties in this case); d - denotes the difference in the ranks assigned to the same individual or phenomenon (actual yield rank minus farmers preference rank).

Results and Discussion

Preference and Ranking of Traits by Farmers

Farmers' preference traits were relatively similar across soil types. However, ranks of traits were different across soil types. Earliness was ranked 1st at Nitisol whereas it was ranked 4th at Vertisol. Tillering capacity was ranked 1st at Vertisol, whereas it was ranked 2nd at Nitisol, as depicted in Tables 3 and 4. It might be due to farmers understanding the moisture-holding capacity of soil types. The study

Table 2. Training of farmers and other stakeholders

	Participants					
	Experts (DA + SMS)			Farmers		
Year	Male	Female	Total	Male	Female	Total
2019	10	7	17	36	13	49
2020	9	6	15	37	15	52
Total	19	13	32	73	28	101

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https://doi.org/10.29244/jtcs.12.01.246-253

was in line with Sewagegn et al. (2023), Shumet and Teklemariam (2023), Damtie et al. (2022), and Chiara et al. (2017) reports, showing that farmers' selection criteria and ranks were very diverse and different within and across agro-ecologies.

Matrix Ranking of Tef Varieties

The variety "Hiber-1" was ranked 1st in both soil types, and "Boset" and local variety were ranked last at Vertisol and Nitisol, respectively, which is presented in Tables 6 and 8. The matrix ranking of each criterion varied in early maturing tef varieties and across soil types. Although the newly released "Hiber-1" rank varies in each criterion, the weighted rank of the "Hiber-1" was ranked 1st, followed by "Tseday" (Cr-37) and local varieties, both ranked 2nd and "Boset," which was ranked 4th at Nitisol (Table 5 and 6). Similarly, at Vertisol, the weighted rank of the "Hiber-1" was ranked 1st, followed by "Tseday" (Cr-37), "Boset", and

Table 3. Pair-wise ranking of preference traits by farmers on Vertisol in the Simada district

Criteria	Early maturity (EM)	Panicle morphology (PM)	Tillering capacity (TC)	White seed color (SC)	Plant height (PH)	Total score	Rank
Early maturity	X	PM	TC	SC	EM	1	4
Panicle morphology		X	TC	SC	PM	2	3
Tillering capacity			X	TC	TC	4	1
White seed color				X	SC	3	2
Plant height					X	0	5

Table 4. Pair-wise ranking of preference traits by farmers on Nitisol in the Simada districts

Criteria	Early maturity (EM)	Tillering capacity (TC)	White seed color (SC)	Panicle length (PL)	Plant height (PH)	Total	Rank
Early maturity	X	EM	EM	EM	EM	4	1
Tillering capacity		X	TC	TC	TC	3	2
White seed color			X	SC	SC	2	3
Panicle length				X	PL	1	4
Plant height					X	0	5

Figer 1. Variety selection on the demonstration site at Simada districts in 2020 cropping season.

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https://doi.org/10.29244/jtcs.12.01.246-253

the local varieties, which were ranked 2nd, 3rd, and 4th, respectively (Table 7 and 8). The study was in line with Shumet and Teklemariam (2023), Mohammed et al. (2022), and Zerihun et al. (2012) who reported that farmers are knowledgeable and efficient in identifying the best genotypes for their specific environment.

Ranking of Tef Varieties by "Injera" Quality

"Injera" quality is the first selection criteria for farmers and end users for home consumption and market. Farmers have indigenous knowledge that they expect higher "Injera" production and good "Injera" quality parameters such as flour weight and stickiness/water holding capacity of tef flour. Farmers were drowning out the physical and sensory quality preferences of "Injera", such as seed color, appearance, glossiness, softness, and thickness (Table 10). Farmers ranked "Injera" appearance (locally called the Injera eye) was ranked 1st, followed by glossiness, softness, thickness, and color (Tables 9, 10, and 11). The study

Table 5. Ranking of the varieties based on the preference traits on Nitisol in the Simada district

Preference traits	Rank of varieties by farmers' score			
	"Boset"	"Tseday"	"Hiber-1"	Local check
Early maturity	19(1)	43(3)	59(4)	29(2)
Tillering capacity	43(3)	55 (4)	24(1)	30(2)
White seed color	21(1)	40(3)	29(2)	60(4)
Panicle length	42(3)	60(4)	15(1)	33(2)
Plant height	44(1)	15(1)	15(1)	32(3)

Table 6. Weighted matrix ranking of the tef varieties on Nitisol in the Simada district

Variety	Weighted score of the tef varieties					Total score	Rank
	Early maturity (1)	Tillering capacity (2)	White seed color (3)	Panicle length (4)	Plant height (5)		
"Boset"	1	6	3	12	20	42	4
"Tseday"	3	8	9	16	5	41	2
"Hiber-1"	4	2	6	4	5	21	1
Local variety	2	4	12	8	15	41	2

Table 7. Ranking of tef varieties based on the preference traits on Vertisol in the Simada district

Criteria	Variety rank by traits			
	"Boset"	"Tseday"	"Hiber-1"	Local check
Tillering capacity	22(2)	33(3)	12(1)	36(4)
White seed color	22(3)	18(1)	20(2)	40(4)
Longer panicle length	21(2)	32(3)	10(1)	38(4)
Early maturity	24(3)	18(2)	40(4)	17(1)
Plant height	21(2)	21(2)	10(1)	38(4)

Table 8. Weighted matrix ranking of tef varieties on Vertisol in the Simada district

Variety	Criteria with their weights					Total	Rank
	Tillering capacity (1)	White seed color (2)	Panicle morphology (3)	Early maturity (4)	Plant height (5)		
"Boset"	2	6	6	12	10	36	3
"Tseday"	3	2	9	8	10	32	2
"Hiber-1"	1	4	3	16	5	29	1
Local variety	4	8	12	4	20	48	4

Received 27/06/2024; Revised 11/12/2024; Accepted 25/02/2025
https://doi.org/10.29244/jtcs.12.01.246-253

was in line with Chiara et al. (2017) and Sewagegn et al. (2023), who reported which farmers have the Indigenous knowledge to identify the crop genotypes for their consumption and agroecology.

Correlation Analysis of Grain Yield and Farmers Rank of Varieties

The grain yield advantage of "Hiber-1" over "Boset", "Tseday" (Cr-37), and the local variety was 31%, 28.4%, and 25.1%, respectively (Table 12). During the study, there was a moisture deficit at the grain-filling growth stage. Two varieties, "Hiber-1" and a local variety, stayed green during the stress, whereas "Boset" and "Tseday" went to forced maturity. As a result, "Hiber-1", followed by the local variety, performed higher grain yield than "Boset" and "Tseday". The Rank correlation at Nitisol showed a positive, strong correlation (R=0.9). In contrast, at Vertisol, it showed a positive medium correlation (r= 0.4) between varieties grain yield rank and varieties weighted rank by farmers (Table 13). The study was in line with Mahmoud et al. (2014), Molla et al. (2023), and Shumet and Teklemariam (2023) reports there was a significant positive correlation between the farmers' rank and the grain yield rank of the varieties.

Table 9. Pair-wise ranking of tef "Injera" quality parameters by farmers

Criteria	Softness (SF)	Appearance (A)	Thickness (TK)	Glossiness (G)	White color (WC)	Total score	Rank
Softness	X	A	TK	G	SF	1	4
Appearance		X	A	A	A	4	1
Thickness			X	G	TK	2	3
Glossiness				X	G	3	2
White color					X	0	5

Table 10. Ranking of tef varieties based on the "Injera" quality parameters

Criteria	Varieties			
	"Boset"	"Tseday"	"Hiber-1"	Local
Softness (SF)	14(4)	22(4)	21(4)	23(4)
Appearance/"Injera" Eye	9(1)	16(1)	23(1)	31(1)
Thickness (TK)	18(3)	23(3)	22(3)	15(3)
Glossiness/attractiveness	9(2)	22(2)	19(2)	29(2)
White Color (WC)	9(5)	19(5)	19(5)	29(5)

Table 11. Weighted matrix ranking of tef varieties using "Injera" quality parameters

Variety	Weighted score of "Injera" quality by farmers						
	Softness	Appearance	Thickness	Attractiveness	White Color	Score	Rank
"Boset"	56	16	69	44	95	280	1
"Tseday"	88	16	69	44	95	312	3
"Hiber-1"	84	23	66	36	95	304	2
Local variety	92	31	45	58	145	371	4

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Table 12. Grain yield (t.ha^{-1}) performance of tef varieties across sites

Varieties	Soil types					Grain yield advantage over the local varieties (%)	Grain yield advantage over "Boset" (%)	Grain yield advantage over "Tseday" (%)
	Vertisol		Nitisol		Mean			
	Site 1*	Site 2	Site 3	Site 4*				
"Boset"	2.08	1.16	1.16	1.12	1.38	-4.5		
"Tseday"	1.61	1.74	0.87	1.41	1.41	-2.5		
"Hiber-1"	2.21	1.65	1.45	1.91	1.81	25.1	31	28.4
Local variety	1.71	1.39	1.28	1.39	1.44			

Notes: ***=** sites evaluated by farmers.

Table 13. Rank correlation between varieties' grain yield rank and weighted rank

Varieties	Vertisol			Nitisol		
	GYR	MRF	D^2	GYR	MRF	D^2
"Boset"	2	3	1	4	4	0
"Tseday"	4	2	4	2	2	0
"Hiber-1"	1	1	0	1	1	0
Local	3	4	1	3	2	1
$\sum d^2$			6			1
SRC =1-(6*$\sum d^2/(n^3-n)$)			0.4			0.9

Notes: GYR = grain yield rank, MRF = matrix ranking by farmers, SRC = Spearman rank correlation.

Conclusions

A significant correlation between farmers' rank and grain yield rank of tef varieties implies that the farmers can adequately evaluate and select higher grain-yielding tef varieties through agronomic traits. Therefore, the study indicated that farmers' participation in variety evaluation and popularization is vital to choosing the best-fit tef variety for their specific environment. "Hiber-1" was selected 1st by farmers in Vertisol and Nitisol areas. It also showed 31 %, 28.4%, and 25.1% grain yield advantages over "Boset," "Tseday," and the local varieties respectively. Therefore, the "Hiber-1" tef variety should be scaled out in the Simada district and areas with similar agro-ecologies.

Acknowledgment

The authors thank the Simada District Agricultural Office Manager, District and Kebele Agricultural Experts, and Farmers for supporting the establishment of FREG, field management, and data collection activities.

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