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Research Article

Inclusive Technology Performance Evaluation in the Production of Teff (*Eragrostis tef* (Zucc.) Trotter)

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Different management practices likely to enhance teff production are used in Ethiopia, however, evidence on their relative performance is little studied or unavailable. This on-farm experiment was conducted to assess the performance of different management practices for teff productivity, profitability, and acceptability in subtropical districts of North East Amhara. Four trial treatments (viz., IKIM, IBIM, LBIM, and LBFM) were laid out in an unreplicated simple block considering farmers as replication during the main cropping seasons of 2019 and 2020. Tukey's (HSD) test following one-way ANOVA, partial budget analysis, and weighted matrix ranking were used to explain the significance level, profitability, and preference traits, respectively. Results presented a significant ($p \leq 0.01$) treatment difference across districts in days to maturity, grain, and biomass yields. Among treatments, IKIM had short maturity days at Sekota (94), Dehana (105), and Lasta (95) districts. The grain yields were on average 1.75 ton ha^{-1}, 1.45 ton ha^{-1}, and 1.63 ton ha^{-1} at Sekota, Dehana, and Lasta districts, respectively. The lowest grain yields of 0.70 ton ha^{-1}, 0.58 ton ha^{-1}, and 0.63 ton ha^{-1} were recorded from LBFM. Despite the higher total variable costs, IKIM was gainful having 51400 ETB, 40579 ETB, and 46928 ETB net benefits at Sekota, Dehana, and Lasta districts, respectively. The MRR showed that a marginal profit of 13.77, 9.76, and 9.23 ETB was gained per each 1.00 ETB investment for shifting the practice (LBFM to IKIM). Therefore, we recommend IKIM as best management practice for consistent teff production in similar agroecological conditions.

1. Introduction

Teff [*Eragrostis tef* (Zucc.) Trotter] is a panicle-bearing cereal crop adaptable to a wide range of environments is originated in Ethiopia [1]. Its flour is used to make "injera" (i.e. pancake-like soft and flatbread found in everyday food dishes in Ethiopia), porridge as well as alcoholic beverages [2]. As it is a gluten-free cereal, favored by gluten-intolerant consumers. It is preferred also for utilization because of its better milling efficiency, baking returns, and quality "injera" [3]. The straw is also an important feed source for livestock over other cereal straws in Ethiopia [1]. Teff is produced by 43% of total farmers in Ethiopia and takes the highest share of crop production both in area and volume of production [4]. Annually, 3 million hectares of land (32% of the total farmland) is covered by teff, and 5.2 million tonnes of grain (21% of the production volume) is produced in Ethiopia [5]. Among cereal crops, teff is the farmers' main source of income in Ethiopia since its grain and biomass yield had higher market demand and prices [6].

Teff is also the leading crop in the Amhara region both in area coverage and volume of production [4]. The 1.5 ton ha^{-1} regional productivity is higher than that of the national average (<1.5 ton ha^{-1}) [7]. In North East Amhara, where the current study was conducted, teff production has got 1st and 2nd ranks in area coverage and production volume, respectively [8]. Despite this fact, the average productivity of teff (<1.4 ton ha^{-1}) in the study area is considerably below the national and regional average [9]. The low productivity is, however, due to a lack of high-yielding varieties, lack of improved agronomic practices, and use of traditional production methods as well as low input utilization, exacerbated by soil fertility decline and erratic rainfall distribution [4]. Based on the production problems mentioned above, agricultural research centers in Ethiopia have been conducting several trials to develop better-yielding teff varieties [2, 5]. Improved teff verities (viz., *Korra* and *Bosset*) with their recommended production practices (teff technologies, hereafter) were found to be promising in the study areas [7].

The farmers usually sow teff by broadcast using high seed density (>25 kg ha^{-1}) to increase seed establishment and the technical easiness of sowing [2]. This method, however increases seed cost, causes interplant competition, and decreases the resource use efficiency of the plant [10]. In conventional teff cultivation, seedbed preparation involves several tillage operations (3–5 times) and using oxen as a source of power for ploughing and soil compaction exposes farmers to higher costs of broadcast sowing [11]. Besides, row sowing has several advantages over broadcast sowing through increasing efficient use of resources, facilitating ease of the practice of farm activities, and better tillering capacity [2]. Row sowing is recommended for better teff production although the adoption rates are still low due to higher labour costs [1]. Among the production methods of teff, improved management practices using improved varieties, optimum tillage, row sowing, recommended fertilizer, and seed rates could improve the growth and yield of the crop [3]. Different teff production practices recommended at national level were not accepted by the local farmers because they were suggested based on biological traits which divest the farmers' participation and their social values [6, 7]. In recent scenarios, however, participatory research relieved to assess new technologies at farmers' real circumstances [10].

In addition, the performance and economic advantage of improved management practices of teff are not compared with traditional practices in North East Amhara [8]. Since the use of improved management practices in teff cultivation is new to the study area, the farmers' acceptability and preference parameters are little studied yet. Therefore, in this study, we hypothesized that the use of improved teff variety with optimum tillage, row sowing, recommended fertilizer and seed rates, and optimum weeding as a package would improve teff yield at a reasonable cost of production. The specific objective was to assess the effect of different management practices on yield, acceptability, and economics of teff cultivation. The study outputs finally would enhance demand-driven teff production technology adoption in the potential subtropical areas of North East Amhara.

2. Materials and Methods

2.1. Description of the Study Areas. On-farm participatory evaluation trial was conducted during the main production seasons (2019–2020) at three districts (viz., Sekota, Dehana, and Lasta) of the North East Amhara region [11]. Sekota is located between 12°23′ and 13°16′ N latitudes and 38°44′ and 39°21′ E longitudes. Its altitude varies from 1340 to 2200 meters above sea level (m. a. s. l), while the average annual temperature ranges from 16 to 27°C [10]. The annual rainfall ranges between 700 and 1386 mm, but the mean annual rainfall is 774.2 mm which falls usually from early July to mid-September [12]. The rainfall distribution pattern is erratic and uneven. Black sandy, loam, and clay soil are the main soil types of the district [8]. Dehana district is found at an altitude of 2140 m. a. s. l at 12°35″ N latitude and 38°75″ E longitude, respectively with an average annual rainfall of 882 mm. It has a black (vertisol) soil type with an annual rainfall of 895.2 mm [11]. Lasta district is located at 12°03 N latitude and 39°23 E longitude at an altitude of 2400 m. a. s. l having a mean annual rainfall of 895.2 mm. The soil type of the district is mainly black, sandy, and loam. The average annual temperature of Sekota, Dahana, and Lasta districts were 26.5, 26.0, and 26.2°C, respectively. The main crops grown in the study area are teff, wheat, barley, faba bean, and sorghum [13].

2.2. Sampling Method (Procedure). The sample districts were purposefully selected from the mid-altitudeteff-producing areas of the North East Amhara region [14]. The farmers' research and extension group (FREG, hereafter) was organized in each district containing 10 couple members (farmers with their spouses) for teff production technology evaluation [15]. The members were selected purposively to exemplify the diverse social segments of the community. Earlier to the actual experiment, a strong linkage between multidisciplinary teams (expert-farmer-researchers) was created to share duties in the experimentation stages. From three trial districts, 18 (6 females) experts and 60 (30 females) farmers as FREG members were provided theoretical and practical training on the agronomic practices of each treatment.

2.3. Treatments and Experimental Design. The experiment was conducted during the 2019 and 2020 main cropping seasons to evaluate four teff production practices at three districts ($4 \times 3 = 12$ treatments). Four farmers from FREG members per district were selected to host the trial using farmers as replications. The treatments were laid out in an unreplicated simple block with a plot area of 100 m^2, having a 0.5 m distance from the border and 1 m space between plots [14]. Trial plots were free of cost to farmers while other costs were covered by the study center. Keeping the package components constant, the improved teff varieties were compared with the local variety to display changes due to the varietal differences [8]. On the other hand, keeping variety constant, the local variety was managed under improved management and farmers' conventional practice to show the changes attained through full package application [10]. The treatment combination and experimental setup were arranged in the following order:

(1) Improved "*Korra*" teff variety + improved management practices (IKIM),

(2) Improved "*Bosset*" teff variety + improved management practices (IBIM),

(3) Local "*Burssa*" teff variety + improved management practices (LBIM), and

(4) Local "*Burssa*" teff variety + farmers' existing management practices (LBFM).

In this study, improved management practice comprises full production package components, i.e. sowing teff varieties in a row with recommended spacing, seed, and fertilizer rates under optimum land preparation and two times hand weeding [15].

2.4. Crop Management Practices. Since the study used a participatory approach, researchers, farmers, and district-level experts participated in plot and layout preparation, sowing, fertilizing, field management, and evaluation stages [5]. Land preparation and weeding were done with human labor as the plots were too small to use cattle and chemicals, respectively. The trial plots were plowed 3 times and leveled mechanically before the sowing dates (10 July 2019 and 10 July 2020). Treatments under improved management were planted in a row using a 15 kg ha^{-1} seed rate. Fertilizers were applied at the rate of 100 and 50 kg ha^{-1} for DAP (Diammonium Phosphate) and urea, respectively [14]. The spacing was 1.0 m and 0.2 m between the plot and row, respectively. The fertilizer was placed along the furrows in the row-sowing plots. All the DAP and half of the urea were applied at sowing, while the remaining urea was applied 30 days later after sowing. Treatments under farmers' practice were sown in broadcast at 25 kg ha^{-1} seed rate without fertilizer. Hand weeding was used to remove weeds twice at 30 and 60 days after sowing [16].

2.5. Data Collection and Analysis. This study used a mixed study approach, i.e. quantitative and qualitative study methods. The quantitative agronomic data, input costs, and output incomes of each treatment were collected at the plot level and converted into standard measurement units. Focus group discussions (FGDs) and participatory selection techniques were used to collect the farmers' preferences and entire feedback qualitatively.

2.5.1. Quantitative Agronomic Data. The quantitative agronomic data such as days to maturity, grain, and biomass yields of each treatment were collected at trial plots. Descriptive statistics tools and different indices of yield gaps [12, 16] were worked out to show plot level variations across treatments using equations (1)–(3). One-way analysis of variance (ANOVA) was used to analyze mean variations among treatments employing an appropriate statistical package, SPSS (version-20). However, results from one-way ANOVA do not indicate differences within the treatment groups, study districts, and the magnitude of existing variations. It is thus compulsory to conduct postanalysis following a one-way ANOVA analysis [17]. Since the homogeneity of variance assumption is satisfied (i.e. equal variances assumed), Tukey (HSD) test from the General Linear Model (GLM) is applied for significant variables [11]. The data of indicative scores of sites for the four agronomic records were standardized and sample variance (S^2) was calculated as equation (4).

$$\mathrm{TG} = Y_d - Y_a. \tag{1}$$

$$\mathrm{VG} = Y_d - Y_l. \tag{2}$$

$$\mathrm{TI} = \frac{Y_d - Y_a}{Y_p} \times 100, \tag{3}$$

where, Y_p = potential yield, Y_d = yield of improved varieties with improved management , Y_l = yield of local cultivar under improved management, Y_a = yield of local cultivar under conventional practice, TG = technological gap, VG = varietal gap, and TI = technological index [8, 17]

$$S^2 = \frac{\sum(\mathbf{Xi} - \mathbf{X})^2}{\mathbf{n - 1}}, \tag{4}$$

where, S^2 = sample variance, Σ = sum, x_i = term in dataset, x = sample mean, n = sample size.

2.5.2. Partial Budget Analysis. The costs of seeds, fertilizers, and labour for different agronomic practices were collected as variable input costs, while income from grain and straw yields was used as outputs [8]. The average labour cost was quantified as man-day by recording the time to complete each activity (ploughing, line making, sowing, and weeding) per treatment assuming that 1 day = 8 hours of work in Ethiopia [12]. The total variable cost (TVC) was calculated as the sum of the costs of inputs. The adjusted grain and straw yields of teff were multiplied by the farm gate selling prices to provide income of outputs. Partial-budget analysis was performed using input costs and output incomes of each treatment [13]. Sensitivity analysis was calculated assuming that grain and straw yields of teff and their selling prices were reduced by 10% [15]. All costs and income were calculated using Ethiopian Birr (ETB) on hectare bases as the average of two seasons. The gross benefit was calculated as the sum of income from selling the grain and straw yields of teff, while the net benefit (NB) was the difference between gross benefit and total variable cost. Using TVC, the treatments were arranged in ascending order then treatments with higher NB and lower TVC were selected for further analysis, but the rest were considered as dominated treatments [10]. The marginal rate of return (MRR) was calculated as the ratio of change in NB and TVC of consecutive treatments (equation (5)). Treatments having MRR < 50%, were considered as nonprofitable, because the acceptable minimum rate of return (AMRR) that farmers expect to earn from new technology is agreed to be between 50 and 100% [17]. The remaining treatments were ranked by NB, and the one ranked first, was selected as the most economically feasible production practice.

$$\mathrm{MRR} = \frac{\Delta \mathrm{NB}}{\Delta \mathrm{TVC}} \times 100, \tag{5}$$

where, ΔNB = change in net benefit, ΔTVC = change in total variable input costs, and MRR = marginal rate of return [12].

2.5.3. Farmers' Preference and Evaluation. Having a higher yield or greater net benefit from any production practice is not a guarantee for farmers' sustainable technology adoption

[6]. Assessment of farmers' feedback, preference, and acceptability of treatments through a participatory approach was hence vital to triangulate and support results from the measured agronomic data with farmers' qualitative perception. Sex-disaggregated farmers in each FREG were allowed to visit trial sites, then brainstormed to identify their evaluation criteria for teff production technology selection [18]. After several round-way visits and discussions, the farmers identified common selection attributes. Grain yield, earliness, spike length, vegetative performance, biomass yield, and tolerance to pests were thus given 6, 5, 4, 3, 2, and 1 weight values, respectively [14]. Using the scoring method, the farmers were asked to compare treatments, then scores were counted to provide 1st, 2nd, 3rd, 4th, 5th, and 6th ranks. To summarize the liking evaluation, the weighted matrix ranking (sum of score ∗ weight) method was used to provide final treatment ranks, hence the lowest sum was ranked first [13]. Finally, Spearman's rank correlation equation (6) was employed to analyze the degree of coincidence between the actual measured attributes rank and farmers' preference rank [10].

$$r_s = 1 - \frac{6\sum \mathbf{d}^2}{\mathbf{n}\left(\mathbf{n}^2 - 1\right)}, \tag{6}$$

where, r_s = correlation coefficient, Σ = sum, d = rank difference given to similar phenomenon, n = number of ranked phenomenon

3. Results and Discussion

3.1. Performance of Yield and Related Traits of Teff. The results revealed that there was a statistically significant difference ($p \leq 0.01$) among the four treatments in days to maturity, grain, and biomass yields in all trial districts (Table 1). Among the experimental treatments, IKIM and IBIM had relatively short maturity days than LBIM and LBFM across districts. Average maturity days of 94, 105, and 95 were recorded in common for IKIM and IBIM, whereas 97, 108, and 97 were for LBIM and LBFM at Sekota, Dehana, and Lasta districts, respectively (Table 2). As displayed in Table 3, the difference in days to maturity among IKIM and IBIM, as well as LBIM and LBFM was statistically insignificant. In terms of yield, IKIM was the best with average grain yields of 1.75 ton ha^{-1}, 1.45 ton ha^{-1}, and 1.63 ton ha^{-1} at Sekota, Dehana, and Lasta districts, respectively. Its biomass yields were on average 3.40 ton ha^{-1}, 2.95 ton ha^{-1}, and 3.15 ton ha^{-1} at three districts in the given order. Following IKIM, IBIM was the second highest treatment in grain and biomass yields across the three districts, despite the statistically insignificant difference between them (Table 3). Besides, the lowest average grain (biomass) yields of 0.70 (1.20) ton ha^{-1}, 0.58 (1.30) ton ha^{-1}, and 0.63 (1.20) ton ha^{-1} were obtained from LBFM at Sekota, Dehana, and Lasta districts, respectively (Table 2). Therefore, the improved varieties under improved management (IKIM and IBIM) significantly ($p \leq 0.05$) outyielded the local cultivar under improved management (LBIM) and conventional practice (LBFM) in all districts. The IKIM, IBIM, and LBIM treatments had insignificant biomass yield differences in Sekota district (Table 3).

The significant ($p \leq 0.05$) yield deviation among similar treatments across districts was witnessed may be due to the agroecological variations of the trial sites. But, a significant ($p < 0.01$) yield variation between experimental treatments was probably attributed to the efficient use of production package components like improved teff variety, sufficient seed and fertilizer rates, proper tillage, and weeding frequency. This finding is in agreement with [19], who identified that a substantial grain and biomass yield difference among different teff production practices is significantly associated with proper utilization of yield-improving production package components like improved teff varieties, optimum tillage and weeding, row sowing, suggested seed, and fertilization rate. The finding also agrees with [4] who confirmed that the higher yield record of teff usually correlates with reducing the impact of yield-limiting factors through the efficient use of modern production inputs of teff.

On the other hand, the varietal gap analysis was done to show the yield variation due to varietal differences, keeping the improved management practice constant for all treatments [12]. The result revealed that the improved "*Korra*" teff variety under IKIM, had 69.9%, 70.6%, and 50.9% yield advantages over local "*Burssa*" teff variety under LBIM at Sekota, Dehana, and Lasta districts, respectively. The technological gap analysis was calculated to show variations due to changes in teff variety and production management practices [8]. The use of IKIM thus had 150, 153.5, and 158.7% yield advantages over LBFM at Sekota, Dehana, and Lasta districts, respectively (Table 2). The yield penalty of LBFM was therefore due to gaps in using improved teff variety with its recommended production package components. From the varietal and technological gap analysis results, the study underscores a possibility of increasing teff yield nearly by fold shifting from conventional production practice (LBFM) to the improved way of production practices (IKIM). This finding is in line with[20], who strongly underlines the benefits of improved technologies under small-scale teff production context, which is noticeable through increasing the farm outputs and income that are vital to advance the living standard of local communities.

In addition, despite the consistently higher yield of IKIM in all districts, the technological index proved that 50%, 42.4%, and 47.6% yield gaps provide an agronomic potential for teff production improvement in Sekota, Dehana, and Lasta districts, respectively (Table 1). These yield gaps hence would be bridged using improved teff varieties with their production package components at a sufficient level. The finding agrees that the low technological index unfolds the likelihood of repeating the yield potential of improved technology in farmers' real context [21]. Finally, the study result demonstrated that among the experimental treatments, IKIM was significantly ($p \leq 0.05$) the best-performing treatment in terms of days to maturity, as well as grain and biomass yields across all districts.

Table 1: Statistical difference between treatments on agronomic traits across districts.

Parameters	SV	Sekota					Dehana					Lasta				
		SSQ	d*f*	MS	*F*	Sig.	SSQ	d*f*	MS	*F*	Sig.	SSQ	d*f*	MS	*F*	Sig.
Grain yield	Treatments	261.25	3	87.08	44.49	***	162.69	3	54.23	96.41	***	226.19	3	75.39	97.81	***
	Errors	23.50	12	1.958			6.75	12	0.56			9.25	12	0.77		
	Total	284.75	15				169.44	15				235.44	15			
Biomass yield	Treatments	1110.06	3	370.02	19.27	***	740.63	3	246.88	30.19	***	704.55	3	234.85	24.68	***
	Errors	230.36	12	19.19			98.13	12	8.18			114.19	12	9.52		
	Total	1340.44	15				838.75	15				818.74	15			
Days to maturity	Treatments	16.00	3	5.333	16.00	***	49.00	3	16.33	19.60	***	64.00	3	21.33	64.00	***
	Errors	4.00	12	0.333			10.00	12	0.83			4.00	12	0.33		
	Total	20.00	15				59.00	15				68.00	15			

Note. SV (source of variation), SSQ (sum of squares), MS (mean square), d*f* (degree of freedom), *F* (statistical value of ANOVA), Sig. (significant difference); *** is the level of significance at 0.1%.

Table 2: The performance of yield and yield-related attributes of experimental treatments across districts.

Districts	Treatments	Days to maturity	Average yield (ton ha^{-1})		Yield range index (ton ha^{-1})		Varietal gap		Technological gap		Technology index (%)
			Grain	Biomass	Grain	Biomass	(ton ha^{-1})	%	(ton ha^{-1})	%	
Sekota	IKIM	94	1.75	3.40	1.70–1.80	2.85–4.05	0.72	69.9	1.05	150	50.0
	IBIM	94	1.48	3.00	1.30–1.75	2.70–3.55	0.45	43.7	0.78	111.4	43.3
	LBIM	97	1.03	2.55	0.80–1.20	2.05–3.20					
	LBFM	97	0.70	1.20	0.60–0.80	1.00–1.40					
Dehana	IKIM	105	1.45	2.95	1.40–1.50	2.75–3.40	0.60	70.6	0.89	153.5	42.4
	IBIM	105	1.05	2.75	1.00–1.10	2.40–2.90	0.20	23.5	0.47	81.1	26.1
	LBIM	108	0.85	2.20	0.75–0.95	1.45–2.50					
	LBFM	108	0.58	1.30	0.50–0.70	1.10–1.40					
Lasta	IKIM	95	1.63	3.15	1.55–1.70	2.70–3.00	0.55	50.9	1.00	158.7	47.6
	IBIM	95	1.40	2.80	1.30–1.50	2.40–3.00	0.32	29.6	0.77	122.3	42.8
	LBIM	97	1.08	1.95	1.00–1.20	1.20–2.40					
	LBFM	97	0.63	1.20	0.50–0.75	1.00–1.30					

Note. The potential yield of *Korra* and *Bosset* teff technologies are 2.1 ton ha^{-1} and 1.8 ton ha^{-1}, respectively [9]; IKIM (Improved "*Korra*" teff variety + improved management practices), IBIM (Improved "*Bosset*" teff variety + improved management practices), LBIM (Local "*Burssa*" teff variety + improved management practices), LBFM (Local "*Burssa*" teff variety + farmers' existing management practices).

Table 3: Tukey (HSD) test following one-way ANOVA to identify significantly consistent treatment across districts.

Parameters	Pair of treatments	Sekota			Dehana			Lasta		
		MD	SDE	THSD	MD	SDE	THSD	MD	SDE	THSD
Grain yield	IKIM - IBIM	2.7500	0.9895	0.069	4.000***	0.5303	0.000	2.250**	0.6208	0.016
	IKIM - LBIM	7.2500***	0.9895	0.000	6.000***	0.5303	0.000	5.500***	0.6208	0.000
	IKIM - LBFM	10.500***	0.9895	0.000	8.750***	0.5303	0.000	10.00***	0.6208	0.000
	IBIM - LBIM	4.5000***	0.9895	0.003	2.000**	0.5303	0.012	3.250***	0.6208	0.001
	IBIM - LBFM	7.750***	0.9895	0.000	4.750***	0.5303	0.000	7.750***	0.6208	0.000
	LBIM - LBFM	3.2500**	0.9895	0.029	2.750***	0.5303	0.001	4.500***	0.6208	0.000
Biomass yield	IKIM - IBIM	3.3750	3.0982	0.702	0.000	0.6455	1.000	1.625	2.1814	0.877
	IKIM - LBIM	8.000	3.0982	0.096	−3.500***	0.6455	0.001	9.375***	2.1812	0.005
	IKIM -LBFM	21.875***	3.0982	0.000	−3.500***	0.6455	0.001	16.63***	2.1812	0.000
	IBIM - LBM	4.6250	3.0982	0.471	7.375**	2.0220	0.015	7.750**	2.1812	0.018
	IBIM - LBFM	18.500***	3.0982	0.000	14.125***	2.0220	0.000	15.00***	2.1812	0.000
	LBIM -LBFM	13.875***	3.0982	0.004	6.750**	2.0220	0.026	7.2500**	2.1812	0.027
Days to maturity	IKIM - IBIM	0.000	0.4082	1.000	0.000	0.6455	1.000	0.000	0.4082	1.000
	IKIM - LBIM	−2.000***	0.4082	0.002	−3.500***	0.6455	0.001	−4.000***	0.4083	0.000
	IKIM - LBFM	−2.000***	0.4082	0.002	−3.500***	0.6455	0.001	−4.000***	0.4083	0.000
	IBIM - LBIM	−2.000***	0.4082	0.002	−3.500***	0.6455	0.001	−4.000***	0.4085	0.000
	IBIM - LBFM	−2.000***	0.4082	0.002	−3.500***	0.6455	0.001	−4.000***	0.4082	0.000
	LBIM -LBFM	0.000	0.4082	1.000	0.0000	0.6455	1.000	0.000	0.4082	1.000

Note. MD (mean difference), SDE (Standard error), THSD (Tukey's honestly significant difference), IKIM (Improved "*Korra*" teff variety + improved management practices), IBIM (Improved "*Bosset*" teff variety + improved management practices), LBIM (Local "*Burssa*" teff variety + improved management practices), LBFM (Local "*Burssa*" teff variety + farmers' existing management practices); **, *** are statistically significant levels at 1% and 0.1%, respectively.

3.2. Economic Estimation and Profitability. Using total variable costs and output incomes, the profitability of each trial treatments was calculated on a hectare basis [15]. Among the trial treatments, LBFM had the lowest total variable cost at Sekota (3420 ETB), Dehana (3300 ETB), and Lasta (3415 ETB) districts. However, IKIM had the higher gross benefit at Sekota (57150 ETB), Dehana (46410 ETB), and Lasta (52708 ETB) districts. In terms of net benefit, IKIM had on average 51400 ETB, 40579 ETB, and 46928 ETB at Sekota, Dehana, and Lasta districts, respectively (Table 4). The improved teff production technology (IKIM) provided the highest net benefit over the rest of treatments across districts. The result demonstrates that all treatments were profitable in all trial districts despite the net benefit is highly variable across treatments and districts. Therefore, IKIM was extremely profitable than other treatments, but LBFM was the least in all districts. The finding is in agreement with [20], who described that maximizing the gross margin and net profit per each defined output level is the ultimate goal of farmers expected from the financial investments in farm inputs.

On the other hand, a dominant treatment logically has the lowest net benefit at the same and/or higher total variable cost among trial treatments. The IBIM was thus rejected from further analysis because of its lower net benefit at higher variable input cost in Lasta district. Similarly, LBFM was eliminated for its punishing net benefit than other treatments in all districts. The finding is in line with [18] who described that attaining higher yields from different teff production practices does not mean financially profitable unless the output income exceeds the cost of production inputs.

The MRR comparison, on the other hand, indicated that for each 1.00 ETB investment to move from the local teff production practice to the improved one (LBFM to IKIM), the farmers can obtain 13.77, 9.76, and 9.23 ETB net profit after covering the cost in Sekota, Dehana, and Lasta districts, respectively. Keeping teff variety constant, and using the improved management practices (shifting from LBFM to LBIM), hence, provided 4.51 ETB, 3.51 ETB, and 3.02 ETB net income at Sekota, Dehana, and Lasta districts, respectively (Table 4). This result underlined that the farmers would be profitable even by transforming from an existing management practice in all districts. The sensitivity analysis showed that by keeping the output price of teff constant but increasing its input price by 894, 695, and 812%, the IKIM would have a positive return at Sekota, Dehana, and Lasta districts, respectively.

3.3. Farmers' Preference Traits and Evaluation. In the study, six preference parameters were identified and weighted by farmers to compare and select the best teff production technology among the trial treatments. The weighted ranking matrix result presented that among trial teff production technologies, IKIM followed by IBIM, LBIM and LBFM were the first, second, third, and fourth choices of farmers by the overall preference attributes across districts (Table 5). Attaining the farmers' preference is a key parameter for enhanced technology uptake by local farm households. Involving the farmers' preference attributes in the process of crop production technology development is inevitable for sustainable technology adoption [22]. Likewise, field days involving main stakeholders were held at the physiological maturity stage to make inclusive treatment evaluation. Hence, among teff production technologies, IKIM was preferred by participant farmers for its good vegetative performance and early maturity in all districts. They were also highly interested to use the new

Table 4: Partial budget analysis and profitability of experimental treatments across districts.

Cost-benefit items	Sekota				Dehana				Lasta			
	IKIM	IBIM	LBIM	LBFM	IKIM	IBIM	LBIM	LBFM	IKIM	IBIM	LBIM	LBFM
Mean grain yield (ton ha^{-1})	1.75	1.475	1.025	0.7	1.45	1.05	0.85	0.575	1.608	1.309	1.134	0.892
Adjusted grain yield (ton ha^{-1})	1.58	1.33	0.92	0.63	1.31	0.95	0.77	0.52	1.45	1.18	1.02	0.80
Mean biomass yield (ton ha^{-1})	3.4	3	2.55	1.2	2.95	2.75	2.2	1.3	3.15	2.8	1.95	1.2
Adjusted biomass (ton ha^{-1})	3.1	2.7	2.3	1.1	2.65	2.48	1.98	1.17	2.84	2.52	1.76	1.1
Gross benefit (ETB ha^{-1})	57,150	48,460	34,040	22,740	46,410	35,276	28,556	19,084	52,708	43,144	36,792	28,520
Seed cost (ETB ha^{-1})	3400	3400	3100	3100	3400	3400	3000	3000	3400	3400	3100	3100
Fertilizer cost (ETB ha^{-1})	1450	1450	1450	—	1500	1500	1500	—	1450	1450	1450	—
Management cost (ETB ha^{-1})	900	880	920	320	940	925	900	300	930	950	925	315
Total variable cost (ETB ha^{-1})	5,750	5,730	5,470	3,420	5,840	5,825	5,400	3,300	5,780	5,800	5,475	3,415
Net benefit (ETB ha^{-1})	51,400	42,730	28,570	19,320	40,570	29,451	23,156	15,784	46,928	37,344	31,317	25,105
MRR (%)	1,377	1,013	451.2	*R*	975.8	501.6	351	*R*	922.7	*D*	301.5	*R*
Sensitivity analysis (%)	894	746	522	—	695	506	429	—	812	—	572	—

Note. The prices of fertilizer = 14.5 ETB kg^{-1}; improved (local) seeds = 34 (30) ETB kg^{-1}; grain yield = 34 ETB kg^{-1}; biomass yield price = 1.2 ETB kg^{-1}; labor wage = 60 man/day; IKIM (Improved "*Korra*" teff variety + improved management practices), IBIM (Improved "*Bosset*" teff variety + improved management practices), LBIM (Local "*Burssa*" teff variety + improved management practices), LBFM (Local "*Burssa*" teff variety + farmers' existing management practices); ETB = Ethiopian Birr; *R* (rejected); *D* (dominated).

Table 5: Farmers' preference attributes and ranking matrix results of treatments across districts.

Weighted parameters	$S*W$	Sekota				Dehana				Lasta			
		IKIM	IBIM	LBIM	LBFM	IKIM	IBIM	LBIM	LBFM	IKIM	IBIM	LBIM	LBFM
Grain yield	S	1	2	3	4	1	2	3	4	1	2	3	4
	W	6	6	6	6	6	6	6	6	6	6	6	6
	$S*W$	6	12	18	24	6	12	18	24	6	12	18	24
Early maturity (earliness)	S	1	2	3	4	1	2	3	4	1	2	3	4
	W	5	5	5	5	5	5	5	5	5	5	5	5
	$S*W$	5	10	15	20	5	10	15	20	5	10	15	20
Spike length	S	1	2	3	4	1	2	3	4	1	2	3	4
	W	4	4	4	4	4	4	4	4	4	4	4	4
	$S*W$	4	8	12	16	4	8	12	16	4	8	12	16
Vegetative performance	S	1	2	3	4	1	2	3	4	1	2	3	4
	W	3	3	3	3	3	3	3	3	3	3	3	3
	$S*W$	3	6	9	12	3	6	9	12	3	6	9	12
Biomass yield	S	1	2	3	4	1	2	3	4	1	2	3	4
	W	2	2	2	2	2	2	2	2	2	2	2	2
	$S*W$	2	4	6	8	2	4	6	8	2	4	6	8
Tolerance to pest	S	1	2	3	4	1	2	3	4	1	2	3	4
	W	1	1	1	1	1	1	1	1	1	1	1	1
	$S*W$	1	2	3	4	1	2	3	4	1	2	3	4
$\sum(S^*W)$		21	42	63	84	21	42	63	84	21	42	63	84
Rank		1	2	3	4	1	2	3	4	1	2	3	4

Note. IKIM (Improved "*Korra*" teff variety + improved management practices), IBIM (Improved "*Bosset*" teff variety + improved management practices), LBIM (Local "*Burssa*" teff variety + improved management practices), LBFM (Local "*Burssa*" teff variety + farmers' existing management practices); *S*: Score, *W*: Weight, value description (1 = very good, 2 = good, 3 = enough, 4 = poor).

technology in the future. This result is consistent with [11], who intensely argued that making scale-wide evaluation using field days is vital for farmers to use the technology sustainably, and then to recommend for other eligible nearby farmers. Spearman's rank correlation test also revealed a complete (100%) coincidence between the farmers' preference rank and the actual grain yield, biomass yield, and earliness traits rank (Table 6). The degree of coincidence between farmer given ranks and actual value ranks of the major technology attributes should be above 80% for sustainable adoption of any new crop technology [8, 11].

Table 6: The correlation between measured agronomic traits rank and farmers' preference ranks among treatments across districts.

Districts	Treatments	Grain (ton ha^{-1})	Ranks A	Ranks F	d^2	Biomass (ton ha^{-1})	Ranks A	Ranks F	d^2	Days to maturity	Earliness rank A	Earliness rank F	d^2
Sekota	IKIM	17.5	1^{st}	1^{st}	$(1-1)^2$	34.0	1^{st}	1^{st}	$(1-1)^2$	95	1st	1st	$(1-1)^2$
	IBIM	14.8	2^{nd}	2^{nd}	$(2-2)^2$	30.0	2^{nd}	2^{nd}	$(2-2)^2$	95	2nd	2nd	$(2-2)^2$
	LBIM	10.3	3^{rd}	3^{rd}	$(3-3)^2$	25.5	3^{rd}	3^{rd}	$(3-3)^2$	95	3rd	3rd	$(3-3)^2$
	LBFM	7.0	4^{th}	4^{th}	$(4-4)^2$	12.0	4^{th}	4^{th}	$(4-4)^2$	95	4th	4th	$(4-4)^2$
			$r_s = 1$ (100%)				$r_s = 1$ (100%)				$r_s = 1$ (100%)		
Dehana	IKIM	14.5	1^{st}	1^{st}	$(1-1)^2$	31.0	1^{st}	1^{st}	$(1-1)^2$	95	1st	1st	$(1-1)^2$
	IBIM	10.5	2^{nd}	2^{nd}	$(2-2)^2$	27.0	2^{nd}	2^{nd}	$(2-2)^2$	95	2nd	2nd	$(2-2)^2$
	LBIM	8.5	3^{rd}	3^{rd}	$(3-3)^2$	20.0	3^{rd}	3^{rd}	$(3-3)^2$	95	3rd	3rd	$(3-3)^2$
	LBFM	5.8	4^{th}	4^{th}	$(4-4)^2$	13.0	4^{th}	4^{th}	$(4-4)^2$	95	4th	4th	$(4-4)^2$
			$r_s = 1$ (100%)				$r_s = 1$ (100%)				$r_s = 1$ (100%)		
Lasta	IKIM	16.25	1^{st}	1^{st}	$(1-1)^2$	28.4	1^{st}	1^{st}	$(1-1)^2$	94	1st	1st	$(1-1)^2$
	IBIM	14.0	2^{nd}	2^{nd}	$(2-2)^2$	26.8	2^{nd}	2^{nd}	$(2-2)^2$	94	2nd	2nd	$(2-2)^2$
	LBIM	10.8	3^{rd}	3^{rd}	$(3-3)^2$	19.0	3^{rd}	3^{rd}	$(3-3)^2$	98	3rd	3rd	$(3-3)^2$
	LBFM	6.3	4^{th}	4^{th}	$(4-4)^2$	11.8	4^{th}	4^{th}	$(4-4)^2$	98	4th	4th	$(4-4)^2$
			$r_s = 1$ (100%)				$r_s = 1$ (100%)				$r_s = 1$ (100%)		

Note. A (actual), *F* (farmers'), r_s (correlation coefficient), and *d* (difference in ranks assigned to the same phenomenon); IKIM (Improved "*Korra*" teff variety + improved management practices), IBIM (Improved "*Bosset*" teff variety + improved management practices), LBIM (Local "*Burssa*" teff variety + improved management practices), LBFM (Local "*Burssa*" teff variety + farmers' existing management practices).

4. Conclusion

The study assessed the performances of four teff management practices through stakeholder participation to select the best and most consistent practices for sustainable teff production and adoption. The overall evaluation result hence revealed that among trial treatments, the improved teff varieties with improved management practices (IKIM and IBIM) significantly outyielded local variety under improved and farmers' existing management (LBIM and LBFM). More specifically, IKIM was the most performing and preferred practice in terms of grain yield, biomass yield, and earliness across districts. Economically, it was also more profitable than other treatments having a higher net benefit even at higher total variable input costs in all districts. The preference matrix ranking again demonstrated that IKIM, followed by IBIM and LBIM were 1^{st}, 2^{nd}, and 3^{rd} choices of farmers by overall selection attributes, respectively. Therefore, the farmers' preference ranks of grain yield, biomass yield, and earliness for IKIM have entirely coincided with the actual measured agronomic ranks. As a result, IKIM as the best practice is suggested for better and consistent teff production in subtropical areas of North East Amhara and other similar agroecologies.

Data Availability

The data of this study will be available on reasonable request to the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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