Reports
2026, Vol. 6, No. 2, pp. 33–39
https://doi.org/10.11648/j.reports.20260602.12

Research Article

Yield Performance and Adaptability of Improved Fenugreek (Trigonella Foenum-graecum L.) Varieties in Buno Bedele Zone, Southwestern Ethiopia

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Abstract

Fenugreek (*Trigonella foenum-graecum* L.) is a multi-purpose spice and medicinal crop with substantial nutritional, pharmaceutical, and industrial significance. Despite its potential, varietal adaptability remains poorly documented in diverse agro-ecologies of Southwestern Ethiopia. A field experiment was conducted during the 2023-2024 main cropping season in the Buno Bedele Zone to identify adaptable and high-yielding fenugreek varieties. Five improved varieties were evaluated using a Randomized Complete Block Design (RCBD) with three replications across representative environments. Analysis of variance (ANOVA) revealed that the main effects of variety and environment significantly ($P < 0.01$) influenced phenological parameters, growth traits, and yield components. However, the variety-by-environment interaction was non-significant for all traits, indicating that the varieties exhibited a consistent performance across the study environments. The highest mean seed yield (1.43 t ha^{-1}) was recorded from the Ebissa variety, which was statistically superior to other varieties, followed by Burka (1.20 t ha^{-1}). In contrast, the lowest yield (0.79 t ha^{-1}) was observed in the Hundaol variety. Based on their superior biological performance and consistent yield across environments, Ebissa and Burka are recommended for large-scale on-farm demonstration and subsequent promotion to smallholder farmers in the Buno Bedele Zone and similar agro-ecologies.

Keywords

Adaptability, Ebissa, Fenugreek, Seed Yield, Varietal Performance

1. Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is an annual self-pollinating herb of the Fabaceae family, widely recognized for its versatile culinary, pharmaceutical, and industrial applications [1, 2]. Globally, its cultivation is concentrated in India, Argentina, Egypt, Morocco, Ethiopia, and Lebanon [3]. Beyond its economic value, fenugreek serves as a vital component in sustainable cropping systems due to its capacity for atmospheric nitrogen fixation, which enhances soil fertility [4]. In Ethiopia, the crop is predominantly grown in the highland plateaus (1800-2300 m asl) characterized by cool season subtropical climates.

Despite its socio-economic importance, fenugreek productivity in Ethiopia remains significantly low. While the global average yield ranges between 1.5 and 2.2 t ha^{-1}, productivity

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Received: 15 June 2026; **Accepted:** 1 July 2026; **Published:** 22 July 2026

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in Africa fluctuates between 0.6 and 0.8 t ha^{-1} due to limited genetic diversity and suboptimal agronomic management [5]. National estimates in Ethiopia are even lower (0.4 to 0.6 t ha^{-1}), a trend attributed to inadequate extension services and the slow adoption of improved agricultural technologies [6]. In the Buno Bedele Zone, productivity is further constrained to approximately 0.3-0.5 t ha^{-1}, primarily due to declining soil fertility and the persistent use of low-yielding local landraces [5].

The distribution of fenugreek in Ethiopia mirrors that of other cool-season legumes, such as faba bean and field pea, with primary concentration in the high-altitude highlands [6] and [7]. Although the crop covers over 24,400 hectares nationally with an annual production of approximately 45,626 tons [5], smallholder farmers in the Buno Bedele Zone continue to experience annual yield declines. Among the various biotic and abiotic constraints, the lack of site-specific, improved, and adaptable varieties remains the most critical bottleneck.

Although the Sinana Agricultural Research Center (SARC) officially released the variety Ebissa in 2012 with a broad national adaptability mandate, the original multi-environment testing framework primarily targeted the semi-arid and bimodal highland agro-ecologies of Southeastern Ethiopia, completely excluding the unique high-rainfall, sub-humid, and highly acidic Nitisol frameworks of the Buno Bedele Zone. Because wide adaptation attributes often break down under complex localized soil acidity pressures and unique bimodal distribution dynamics in Southwestern Ethiopia, moving directly into a Pre-Extension Demonstration (PED) without prior site-specific verification would present severe economic risks for smallholder farmers. Therefore, initiating this robust ecological adaptation test was critically required to scientifically baseline and verify the stability of Ebissa and other improved genotypes under these unrepresented western sub-humid conditions before investing in wide-scale promotion. Consequently, this study was initiated to evaluate and identify high-yielding and stable improved fenugreek varieties suitable for the Buno Bedele Zone and similar agro-ecologies in Southwestern Ethiopia.

2. Materials and Methods

2.1. Description of the Experimental Sites

The experiments were conducted for two consecutive years (2023-2024) across three representative districts in the Buno Bedele Zone, Southwestern Oromia, Ethiopia. The study sites Gechi, Dabo Hana, and Chora were purposively selected to represent the diverse agro-ecological conditions of the major fenugreek-growing areas in the zone. The experimental sites are situated within an altitude range of 1750 to 2150 meters above sea level (m asl). Geographically, the target zone is situated between latitudes 7°54′30″N to 8°13′00″N and longitudes 36°17′15″E to 36°30′47″E, with a central coordinate point around 8°05′N. The region is characterized by a sub-humid tropical climate with a reliable bimodal annual rainfall framework ranging from 1200 to 1750 mm. The thermal regime of the target zone is moderately warm, with the mean minimum temperature averaging 14 ℃ and the mean maximum temperature reaching 27 ℃. The soils at all experimental sites are predominantly well-drained Nitisols, which are typical for the southwestern Ethiopian highlands.

2.2. Experimental Materials and Design

The experimental materials comprised five improved fenugreek varieties and one local check (Table 1). The improved varieties (Ebissa, Burka, Argane, and Hundaol) were sourced from the Sinana Agricultural Research Center (SARC) based on their potential adaptability and yield performance. The field trials were laid out in a Randomized Complete Block Design (RCBD) with three replications at each location. Each plot had a gross area of 4.8 m^2 (2.4 m × 2 m), comprising eight rows with a 30 cm inter-row spacing and an intra-row fageenya of 10 cm. Sowing was done at a seed rate of 15 kg ha^{-1}. To minimize border effects, data were harvested strictly from the four central rows.

Table 1. *Agronomic description of the evaluated fenugreek varieties.*

Varieties	Releasing Year	Breeder/Source	Agro-ecology (m asl)	Specific Features
Ebissa	2012	SARC/IQQO	1800-2600	High yielding, widely adapted
Burka	2016	SARC/IQQO	1800-2600	Late maturing, high yield
Argane	2021	SARC/IQQO	1800-2600	Recent release, adaptable
Hundaol	2006	SARC/IQQO	1800-2600	Early maturing
Local Check	-	Farmer’s seed	1800-2400	Local landrace

2.3. Agronomic Management and Procedures

All agronomic practices, including deep plowing, harrowing, leveling, and cultivation, were carried out uniformly across all experimental units. Fertilizer application was executed strictly based on regional guidelines, applying a standard rate of 100 kg ha^{-1} of NPSB (18.9% N, 37.7% P_2O_5, 6.95% S, 0.1% B) at planting, supplemented with a split application of 50 kg ha^{-1} of Urea (46% N) during the vegetative growth phase [8].

2.4. Data Collection and Statistical Analysis

Phenological traits such as days to flowering, days to maturity, and seed yield (t ha^{-1}) were recorded on a plot basis. In contrast, growth and yield components, including plant height (cm), number of branches per plant, pods per plant, and seeds per pod, were recorded from ten randomly selected plants within the net plot. Disease reactions were also monitored. Data were subjected to Analysis of Variance (ANOVA) using SAS software (version 9.3) following the procedures of Gomez and Gomez (1984). Mean separation was performed using the Least Significant Difference (LSD) test at a 5% probability level.

3. Results and Discussion

3.1. Analysis of Variance

The combined analysis of variance (ANOVA) revealed highly significant (P < 0.01) differences among the tested varieties and environments for the majority of the traits (Table 2). However, the variety-by-environment interaction effects were statistically non-significant for the majority of the parameters, including days to flowering, days to maturity, plant height, and seed yield. This trend indicates a highly consistent agronomic performance of the varieties across the tested sub-humid environments of the Buno Bedele Zone (Table 2).

3.2. Phenological Parameters

The results exhibited significant varietal variation in flowering and maturity periods. The local check recorded the earliest flowering and maturity, whereas Hundaol was the latest-maturing variety (Table 4). These variations are primarily attributed to the inherent genetic constitution of the genotypes. Similar findings were reported by [9] and [10] who observed significant phenological differences among fenugreek genotypes. Furthermore, studies by [11] and [12] corroborated that maturity duration in fenugreek is significantly influenced by varietal characteristics.

Table 2. *Combined mean square values for phenological and yield components of Fenugreek varieties (2023-2024).*

Source of Variation	DF	DTF	DTM	PH	NBPP	NPP	SY
Replication	2	414.98ns	210.0ns	159.60ns	8.84ns	0.40ns	22.98ns
Variety (V)	4	892.78**	1535.0**	342.60**	156.44**	154.18**	220.33**
Location (L)	2	328.54**	310.0**	2.50ns	165.67**	93.10**	207.52**
Year (Y)	1	2.50*	722.50**	122.50ns	250.00**	202.50**	303.97**
V × L	8	0.01ns	0.01ns	0.01ns	0.01**	0.01ns	0.04ns
V × Y	4	0.04ns	0.01ns	0.01ns	0.17ns	4.38ns	0.05ns
V × Y × L	10	33.50**	2.00ns	30.50ns	3.50ns	1.50ns	7.94ns
Error	58	7.59	20.34	43.53	5.74	4.51	3.81

Key: DF: Degree of Freedom; DTF: Days to Flowering; DTM: Days to Maturity; PH: Plant Height; NBPP: Number of Branches per Plant; NPP: Number of Pods per Plant; SY: Seed Yield; ns: Non-significant; *: Significant (P < 0.05); **: Highly significant (P < 0.01).

3.3. Performance of Phenology, Growth, and Yield-Related Traits

3.3.1. Days to Flowering and Maturity

The combined analysis of variance revealed highly significant (P < 0.01) differences among fenugreek varieties for phenological parameters (Table 2). The local cultivar exhibited the shortest vegetative phase, flowering in 73.83 days, while Hundaol was the latest to flower (97.67 days). Similarly, the local variety reached physiological maturity significantly earlier (107.67 days) compared to Hundaol, which was the latest-maturing variety (124.33 days) (Table 4). These variations are primarily attributed to the inherent genetic constitution of the varieties and their differential responses to environmental stimuli. These findings align with [1] and [13], who observed that early flowering is often positively correlated with early maturity in fenugreek genotypes.

3.3.2. Plant Height (cm)

Varietal effects on plant height were highly significant (P < 0.01), whereas the environmental influence was non-significant (Table 2). This suggests that plant height is largely under genetic control rather than environmental modulation in the study area. The tallest plants (29.00 cm) were recorded for the Burka variety, while Argane produced the shortest plants (20.67 cm) (Table 4). These results are in conformity with [14] and [10], who reported significant genotypic variations in fenugreek plant architecture.

3.3.3. Number of Primary Branches and Pods Per Plant

The number of primary branches and pods per plant were highly significantly (P < 0.01) influenced by both variety and environment (Table 2). The mean number of pods per plant ranged from 20.03 (Local check) to 16.19 (Argane). Varietal differences in these traits reflect the genetic potential of genotypes for resource acquisition and dry matter partitioning. These findings are consistent with [15] and [13] who documented significant genotypic variations for these critical yield components.

3.3.4. Number of Seeds Per Pod

Significant (P < 0.01) varietal and environmental effects were observed for the number of seeds per pod (Table 2). The highest seed count per pod (13.83) was recorded for the Ebissa variety, while Hundaol produced the minimum (6.33) (Table 4). This variation is a result of genetic factors inherent to each genotype. Similar results were reported by [16] and [15].

3.3.5. Disease Reaction

Powdery mildew was the predominant biotic constraint observed during the experimental period. Most varieties exhibited moderate resistance, and no high susceptibility was recorded. This indicates a favorable genetic background for disease tolerance among the tested improved varieties. These observations align with [17], who identified powdery mildew as a major challenge for fenugreek production in Southwestern Ethiopia.

Table 3. *Combined mean phenological and yield-related parameters of Fenugreek varieties (2023-2024).*

Varieties	DTF (days)	DTM (days)	PH (cm)	NBPP (no.)	NPPP (no.)	NSPP (no.)	PM (%)
Burka	77.67d	112.67c	29.00a	8.83b	10.67b	10.26b	30 MR
Ebissa	82.67c	119.33b	28.00a	12.50a	15.70a	13.83a	30 MR
Argane	91.00b	131.00b	20.67b	7.17b	11.33a	11.33b	30 MR
Hundaol	97.67a	124.33b	21.67b	7.17b	6.33c	9.15b	30 MR
Local	73.83d	107.67c	25.30a	4.50c	11.13a	10.18b	30 MR
LSD (0.05)	3.32	5.12	7.35	2.77	2.63	0.32	
CV (%)	3.37	3.60	25.87	28.84	20.65	12.17	
P-Value	**	**	*	**	**	**	

Key: DTF: Days to Flowering; DTM: Days to Maturity; PH: Plant Height; NBPP: Number of Branches per Plant; NPPP: Number of Pods per Plant; NSPP: Number of Seeds per Pod; PM: Powdery Mildew; MR: Moderate Resistance; LSD: Least Significant Difference; CV: Coefficient of Variation; *: Significant; **: Highly Significant.

3.4. Seed Yield Performance Across Locations and Years

The combined analysis of variance revealed highly significant (P < 0.01) effects of variety and environment on seed yield (Table 2). Varietal seed yield across the six environments (three locations × two years) ranged from 0.79 t ha^{-1} to 1.43 t ha^{-1} (Table 3). The variety Ebissa consistently demonstrated superior yield performance across all environments, achieving a grand mean yield of 1.43 t ha^{-1}, followed by Burka (1.20 t ha^{-1}). These varieties provided a yield advantage of 68.24% and 41.18%, respectively, over the local check (0.85 t ha^{-1}).

The non-significant variety-by-environment interaction for seed yield suggests that these varieties exhibited broad adaptation across the high-rainfall highlands of the Buno Bedele

Zone. These findings are in agreement with [10], who highlighted the significant impact of genotype selection on fenugreek productivity. Furthermore, the strong positive correlation between seed yield and yield components (r = 0.83** to 0.94**) observed in this study (Table 5) confirms that the superior performance of Ebissa and Burka is attributed to their enhanced capacity for branch and pod development.

Table 4. *Combined mean seed yield (t ha^{-1}) of fenugreek varieties tested during the 2023-2024 cropping seasons at Dabo Hana, Gechi, and Chora districts.*

Varieties	Dabo Hana			Gechi			Chora			Over all Combined	YA (%)
	2023	2024	Combined	2023	2024	Combined	2023	2024	combined		
Burka	0.89b	1.32a	1.14a	1.1a	1.34a	1.22a	1.28a	1.22a	1.25a	1.2a	41.18
Ebissa	1.3a	1.44a	1.37a	1.4a	1.55a	1.48a	1.54a	1.34a	1.44a	1.43a	68.24
Argane	0.64b	0.87b	0.76b	0.93b	1.16a	1.05a	0.67b	1.1a	0.89b	0.9b	
Hundaol	0.58b	0.78b	0.68b	0.73b	0.82b	0.78b	0.71b	1.13a	0.92b	0.79b	
Local	0.76b	0.81b	0.79b	0.82b	0.94b	0.88b	0.78b	0.98b	0.88b	0.85b	
LSD (0.05)	0.39	0.44	0.26	0.41	0.54	0.46	0.41	0.34	0.26	0.31	
CV (%)	26.95	23.12	10.65	24.28	20.17	26.24	18.17	18.17	18.17	16.29	
P-Value	**	**	**	**	**	**	**	**	**	**	

Key: YA (%) = Yield Advantage over the local check, LSD (0.05) = Least Significant Difference, CV (%) = Coefficient of Variation, ** = Highly Significant (P < 0.01).

3.5. Correlation Analysis

Correlation analysis among the tested fenugreek varieties revealed strong and positive associations between seed yield and its primary contributing components (Table 5). Specifically, a highly significant and positive phenotypic correlation was observed between the number of branches per plant and the number of pods per plant (r = 0.71**), number of seeds per pod (r = 0.68**), and overall seed yield (r = 0.83**). These results indicate that genotypes with a higher branching capacity tend to produce more reproductive structures, leading to enhanced productivity.

Furthermore, a robust positive association was identified between the number of pods per plant and both the number of seeds per pod (r = 0.81**) and seed yield (r = 0.89**). Most notably, the number of seeds per pod exhibited the strongest positive correlation with seed yield per hectare (r = 0.94**), suggesting it is the most critical determinant of yield in the study area. These strong inter-relationships imply that selection based on branches, pods per plant, and seeds per pod would be highly effective for the simultaneous improvement of seed yield in fenugreek. These findings are consistent with the reports of [13] and [15] who emphasized the importance of yield components as reliable selection criteria for fenugreek improvement.

Table 5. *Correlation coefficients for mean agronomic traits of Fenugreek grown Gechi, Didessa and Chora districts during 2023-2024 cropping season.*

Parameters	DF	DM	PH	NBPP	NPPP	NSPP	SY
DF	1						
DM	0.81**	1					
PH	0.02ns	0.08ns	1				
NBPP	0.39*	0.36*	0.18**	1			
NPPP	0.32*	0.33*	0.02ns	0.71**	1		

Parameters	DF	DM	PH	NBPP	NPPP	NSPP	SY
NSPP	0.43**	0.53*	0.54**	0.68**	0.81**	1	
SY	0.57**	0.46*	0.45**	0.83**	0.89**	0.94**	1

Key: DF = Days to Flowering, DM = Days to Maturity, PH = Plant Height, NBPP = Number of Branches per Plant, NPPP = Number of Pods per Plant, NSPP = Number of Seeds per Pod, SY = Seed Yield, ns = Non-significant, * = Significant ($P < 0.05$), ** = Highly significant ($P < 0.01$).

4. Conclusion and Recommendation

The present study evaluated the adaptability and yield performance of five improved fenugreek varieties across the high-rainfall highlands of the Buno Bedele Zone. The results indicated significant varietal differences in phenological, growth, and yield parameters. The variety Ebissa demonstrated outstanding performance, achieving the highest grand mean seed yield of 1.43 t ha^{-1}, which represents a 68.24% yield advantage over the local landrace. This was followed by the variety Burka (1.20 t ha^{-1}), with a 41.18% yield advantage. The non-significant variety-by-environment interaction suggests that these varieties are stable and well-adapted to the agro-ecological conditions of the study area. Based on their superior yield potential and consistent performance, Ebissa and Burka are strongly recommended for large-scale adoption and promotion to smallholder farmers in the Buno Bedele Zone and similar agro-ecologies of Southwestern Ethiopia. Furthermore, subsequent on-farm demonstrations are suggested to familiarize farmers with these high-yielding varieties to enhance productivity and household food security.

Abbreviations

ANOVA	Analysis of Variance
BeARC	Bedele Agricultural Research Center
IQQO	Oromia Agricultural Research Institute (IQQO)
LSD	List Significance Difference

Acknowledgments

The authors would like to express their sincere gratitude to the Oromia Agricultural Research Institute (IQQO) for providing the necessary financial support for this study. We are also indebted to the Bedele Agricultural Research Center (BeARC) for facilitating the research activities and the Sinana Agricultural Research Center (SARC) for providing the experimental seeds. Finally, the Horticultural and Spice Crops Research Team of the Bedele Agricultural Research Center is highly acknowledged for their professional commitment to trial management, rigorous data collection, and assistance in data analyses.

Author Contributions

Alemayehu Abdeta: Conceptualization, Data curation, Formal Analysis, Methodology, Project administration, Software, Supervision, Writing – original draft, Writing – review & editing

Tolasa Tamiru: Conceptualization, Methodology, Software, Writing – review & editing

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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