

Diversity of Qualitative Traits and Eco-Geographical Distribution of Ex-situ Finger Millet Collections

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Abstract

A total of 200 finger millet genotypes, collected from various regions and altitudes in Ethiopia, along with some introductions from Eritrea, Zambia, and Zimbabwe, were planted alongside two improved varieties to evaluate genetic diversity for qualitative traits. This experiment, conducted using a 10 x 20 lattice design at Maiaini during the 2019 and 2020 cropping seasons, utilized descriptors from the International Plant Genetic Resource Institute (IPGRI). Observations indicated that traits such as non-seed persistence, erect ear shape, purple glume color, and black seed color were commonly found across all regions, altitude classes, and countries of origin. Shannon diversity analysis revealed high diversity indices for genotypes from Zambia and Zimbabwe ($H' = 0.90 \pm 0.05$), with Benishangul Gumuz exhibiting the highest regional diversity for seed pericarp persistence and glume color ($H' = 0.99$). Significant differences ($P \leq 0.05$) were found in seed pericarp persistence and highly significant differences ($P \leq 0.01$) in seed color between countries, while other traits showed no significant differences. Regionally, seed color exhibited significant differences ($P \leq 0.05$), with other traits showing non-significant variations. These findings emphasize the substantial genetic diversity in finger millet, the significance of farmer preferences, and the potential for further research and conservation. Understanding the geographical distribution of economically important traits and overall diversity is crucial for effectively utilizing these genetic resources to enhance productivity and environmental resilience in this vital crop..

1. INTRODUCTION

Finger millet (*Eleusine coracana* L. Gaertn) ($2n = 4x = 36$) is an important small grain cereal for food security and subsistence farming in eastern and southern Africa, valued for its high nutritional and cultural values (Dida et al., 2008). It plays a key role in traditional low-input cereal-based farming systems (Wolie and Dessalegn, 2011) and is also widely cultivated in Southern Asia, particularly in India, Myanmar, Sri Lanka, Bhutan, and China (Upadhyaya et al., 2004). Renowned for its superior nutritional quality compared to most cultivated cereals, finger millet is rich in protein, fiber, and minerals, most importantly calcium and iron, which greatly help in alleviating malnutrition and anemia in countries where it is dietary staple (Babu et al., 2006). The crop thrives in diverse agro-ecological zones and various environmental conditions, including dry and rain-fed areas, making it more adaptable than other tropical cereals. It is principally grown by small-holder farmers and is often regarded a poor man's food (Kumar et al., 2019).

In finger millet and most related wild species, morphological descriptors that include observable traits are commonly used in diversity studies. These descriptors, which include qualitative and quantitative traits, are vital for racial differentiation and varietal identification (Kumar et al., 2019). Therefore diverse genetic resources in qualitative traits among finger millet genotypes like in seed color, panicle shape, perishable ability, lodging susceptibility, growth habit and glumes (ear) color are very crucial for the genetic advancement of finger millet, for their effective use in the crop improvement programmes (Tesfaye and Mengistu, 2017). In addition, qualitative traits are useful criteria for characterization of germplasm accessions, as they are stable expression. Further, if qualitative characters show association with yield components, it can serve as a marker in selection process (Das et al., 2017). Genetic resource conservation is aided by evaluating the genetic diversity of finger millet qualitative features across origin

countries and altitude classes (Brhane et al., 2022). It contributes to the identification and conservation of distinct genetic traits found in various eco-geographical regions. The creation of core subsets of finger millet germplasm and an understanding of the crop's population structure are made possible by the research of genetic diversity across eco-geographical locations and designing successful breeding programs and conservation efforts requires knowledge of this kind. The primary objective of this research study was to investigate the pattern of genetic diversity among 200 finger millet accessions, categorized by their countries of origin and altitudinal class. These genotypes were collected from various regions of Ethiopia and three other African countries, representing different agro-ecological zones and conserved ex situ in the gene banks of the Ethiopian Biodiversity Institute (EBI). Understanding this diversity is essential for developing core germplasm subsets, elucidating population structures, and designing effective breeding and conservation programs.

1.1. General Objective

- To assess the diversity and distribution of qualitative traits in finger millet genotypes across various countries of origin and altitude classes

1.2. Specific objectives

- To estimate the level of diversity and identify the most important qualitative traits that contribute considerable variability across different countries of origin and altitude classes.
- To evaluate the associations between qualitative traits and altitude classes in finger millets collected from different countries.
- To Identify and document the variations in qualitative traits among different finger millet genotypes.

2. MATERIALS AND METHODS

2.1. Experimental site

One of the potential finger millet growing area in the Tigray region is Maiaini, which is found in North-western zone of the Tigray region was identified and selected for genotypes evaluation during 2019 and 2020 planting seasons. This site is known for its suitability for finger millet production and serve as ideal site for evaluating and characterizing new finger millet genotypes and other cereal crops like sorghum (Tsehaye *et al.*, 2006).

Maiaini is geographically located in the Tselemti district of Tigray, 85 km from Shire town, at 14°16'N latitude, 38°12'E longitude, and an elevation of 1450 m.a.s.l. It is bordered by Asgede Tsimbla, Welkait, Tanqua Abregelle districts, and the Amara region to the north, west, east and south, respectively. The mean minimum and maximum annual temperature of the area is 16°C (November–January) and 38°C (February–May), respectively. Some of the major crops grown in the area include sorghum, finger millet, maize, chickpea and sesame (Gebregergs, 2020). The mean annual temperature ranged from 18.6 to 32.0 and 19.5 to 32.7°C for Maiaini, during 2019 and 2020 growing seasons, respectively. Further, the mean

annual rainfall ranged from 1301.0 to 1685.1 and 1482.2 to 2095.0 mm during 2019 and 2020 growing seasons, respectively. The soil type at was verti-cambisol with a pH of 6.2.

2.2. Plant materials

A total of 200 finger millet accessions, (hereafter genotypes) collected from different regions of Ethiopia and other African countries (Eritrea, Zambia, and Zimbabwe), were obtained from the Ethiopian Institute of Biodiversity (Table 1.). These genotypes span altitudes from 1000 to 2380 m.a.s.l, representing Ethiopia’s agro-ecological zones for finger millet cultivation. Two improved varieties, Mereb-1 and Tekeze-1 released from Aksum and Maitsebri agricultural research centers, were used as checks to evaluate the qualitative traits in the accessions. The accessions source, collection region, and altitude are displayed in Table 1. The study materials were not directly collected by the authors from the field. The identity of the accessions was based on its records and associated information provided by Ethiopian Biodiversity Institute (EBI). The accession numbers of the materials evaluated in this study is maintained and have been retained in our research records. No voucher specimen was deposited in a publicly accessible herbarium for this study.

Table 1
Number of finger millet genotypes collected from different African countries/regions and altitudinal classes.

No	Country	Altitude class (m.a.s.l.)				# of genotypes
		Region	≤ 1500	1501–2000	≥ 2001	
1	Ethiopia	Tigray	2	30	19	51
2	Ethiopia	Oromiya	2	9	10	21
3	Ethiopia	Amara	2	16	7	25
4	Ethiopia	Benishangul Gumuz	2	3	0	5
Total			8	58	36	102
5	Eritrea		0	30	0	30
6	Zambia		11	8	0	19
7	Zimbabwe		49	0	0	49
Sub-total			68	96	36	200
Released varieties			2			2
Grand total						202

2.3. Experimental design and layout

The genotypes were arranged using an alpha lattice design, consisting of 10 incomplete blocks (20 x 10) and replicated twice. Each genotype was planted in 7.5 m² plots, with two rows measuring 5 m in length. The inter-row spacing was set at 0.75 m, and the intra-row spacing was 0.1 m. The spacing between plots and replications were 0.5 and 1m, respectively. Seeds were sown along the rows at rate of 11.25 g/plot, equivalent to 15 kg/ha⁻¹, and later thinned to maintain the 0.1 m spacing between plants. Each experimental plot received a uniform basal dose of DAP fertilizer (100 kg/ ha) at the time of planting and Urea (100 kg/ha) in three stages: at planting, one month after planting, and at grain filling stage. Weeding and other management practices were uniformly applied across all experimental plots as per crop recommendations.

2.4. Data collection

Data on five qualitative traits (ear shape, finger branching, seed color, glume color, and pericarp persistence) were collected from 5 randomly selected individual plants per genotype (Table .2). The traits were assessed according to the International Plant Genetic Resources Institute (IPBGR, 1985) descriptor list for finger millet. Besides, color chart and visual examination using a 10× magnifying lens were used (Munsell, 1970).

Table 2
Phenotypic classes of the qualitative characters used for diversity study

Traits	No. of class	Code	classes
Ear shape	5	1	droopy
		2	Open
		3	Semi-compact
		4	Compact
		5	Fist-like
Finger branching	2	1	Present
		2	absent
Seed color	5	1	Black
		2	Red
		3	White
		4	Brown
		5	Orange
Glume (Ear) color:	4	1	Yellow-green
		2	Light-green
		3	Purple
		4	White
Pericarp persistent	3	1	Persistent
		2	Partially persistent
		3	Not persistent

The collection sites for each of the 200 genotypes, along with the two check varieties, were classified into the major agro-ecological zones of Ethiopia based on altitude. Of these, 70 genotypes, including the check varieties, were collected from areas at or below 1500 m.a.s.l., classified as lowland; 96 genotypes were from altitudes between 1501–2000 m.a.s.l., categorized as intermediate; and 36 genotypes were originally collected from 2001 m.a.s.l. and above, classified as highland. According to Ayana and Bekele (1998), the highland zones are mainly characterized by fertile soils and dense populations, the intermediate zones have good agricultural potential often with mixed farming systems, while the lowland zones tend to be more arid often facing challenges like drought.

2.5. Statistical analysis

The genotypes were stratified by country of origin, region, and altitudinal class. Trait frequency percentages were calculated using SPSS software packages v 20 (SPSS, Chicago, IL, USA), and chi-square tests were carried out using MINITAB software version 19 to test deviations from expected values. The Shannon-Weaver diversity index (H') was estimated and used to measure the phenotypic diversity among the genotypes for the studied traits. The index (H') was estimated on the frequency data as described by Hutcheson (1970) as follows:

$$H' = - \sum_{i=1}^n \frac{p_i \ln p_i}{\ln n}$$

Where **n** is the number of phenotypic classes for a character and **P_i** is the proportion of total entries (N) in the **ith** class.

Descriptive statistics (**mean and standard error**) were estimated using PAST software, a one-way ANOVA tested differences in H' across classifications (Table .2). The chi-square analysis was carried out to test deviations from the overall mean for countries of origin, regions, and altitude classes.

3. RESULTS

3.1. Frequency distribution of qualitative traits by country

The variation in pericarp persistence revealed the predominance of non-persistent types in genotypes collected from all countries, except Zimbabwe, which recorded higher frequency of partially persistent seeds (43%). Across regions in Ethiopia, no persistent type was observed in samples from Benishangul Gumuz (Table 4). The open type ear shape was predominant across all countries, with Ethiopia showing the highest frequency at 54%, followed by Eritrea (47%), Zimbabwe (36%), and Zambia (35%). In Ethiopia, droopy and semi-compact ear shapes were also common, while the fist-like ear shape was rare in Ethiopian (3%) and Zambian (7%) samples. This type was not observed in Eritrea, and droopy was the least frequent in Zimbabwe (Table 3).

Finger branching was observed in two phenotypic classes (present and absent) across all countries with minor proportional differences. For this trait, Zambia and Ethiopia exhibited slightly higher frequencies of the present type, which accounted for 55% and 51%, respectively, while Eritrea and Zimbabwe were dominated by the absent type (Table 3). The four phenotypic classes of ear (glume) color were observed in all countries, with purple being the most frequent, followed by white, except in Zimbabwe, where yellow-green was the most dominant. Eritrea and Zambia had the highest frequencies of purple glumes (42%), while light-green was least frequent color in all countries of origin (Table 3). A high proportion of black-seeded finger millet genotypes was observed in Eritrea (54%) and Ethiopia (46%). In Zambia, both black- and red-seeded were equally dominant at 32%, followed by orange seed type. In contrast, Zimbabwe's genotypes were predominantly red-seeded (43%), followed by orange (30%) and Black (19%).

Table 3

Percentage distribution of five major qualitative traits among 200 genotypes collected from African countries, four Ethiopian finger millet-producing regional states, and two standard check varieties.

Country	No.	Pericarp persistence			Glumes color				Seed Color				
		P	PAP	NP	YG	LG	PP	WT	BK	RD	WT	BN	OG
Ethiopia	104	11	37	52	21	12	40	27	46	28	10	6	10
Eritrea	30	19	31	50	18	8	42	32	54	35	2	2	7
Zambia	19	23	33	44	13	4	42	41	32	32	12	0	24
Zimbabwe	49	24	43	33	29	12	34	25	19	43	4	4	30
Total	202	16	38	46	22	11	39	28	39	33	8	4	16
Country	No	Finger branch		Ear Shape									
		PT	AB	DR	OP	SM	CM	FL					
Ethiopia	104	51	49	21	54	15	7	3					
Eritrea	30	49	51	23	47	23	7	0					
Zambia	19	55	45	19	35	18	21	7					
Zimbabwe	49	48	52	10	36	17	24	14					
Total	202	50	50	18	47	17	12	6					
P = persistent, PAP = partially persistent, NP = not persistent, YG = yellow green, LG = light- green, PP = purple, WT = white, BK =black, RD = red, BN = brown, OG = orange, PT = present, AB = absent, DR = droopy, OP = open, SM =semi-compact, CM = compact, FL = fist-like													

Table 4

Percentage distribution of five major qualitative traits among 200 genotypes collected from four Ethiopian finger millet producing regional states and two standard check varieties.

Region/Ethiopia	No.	Pericarp persistence			Glumes color				Seed Color				
		P	PAP	NP	YG	LG	PP	WT	BK	RD	WT	BN	OG
Amara regional state	25	11	43	46	24	10	46	20	50	31	11	2	6
Benishangul gumuz regional state	5	0	44	56	28	16	36	20	52	24	12	4	8
Oromiya regional state	21	18	35	47	12	11	45	32	35	34	19	6	6
Tigray regional state	53	8	35	57	22	13	36	29	48	24	6	9	13
total	104	11	38	52	21	12	40	27	46	28	10	6	10
Region/Ethiopia	No.	Finger branch		Ear Shape									
		PT	AB	DR	OP	SM	CM	FL					
Amara regional state	25	56	44	16	54	17	9	4					
Benishangul gumuz regional state	5	60	40	16	48	20	16	0					
Oromiya regional state	21	53	47	7	46	25	15	7					
Tigray regional state	53	46	54	30	58	9	2	1					
total	104	51	49	22	54	15	6	3					

Table 5

Percentage proportion of five major qualitative traits among 200 finger millet genotypes and two standard checks across three altitude classes.

Altitude	No.	Pericarp persistence			Glumes color				Seed Color				
		P	PAP	NP	YG	LG	PP	WT	BK	RD	WT	BN	OG
≤ 1500	70	23	40	37	25	9	36	30	23	40	6	3	28
1501–2000	96	13	36	51	19	11	41	29	48	30	8	5	9
≥ 2001	36	12	35	53	22	14	40	24	48	27	11	6	9
Total	202	16	37	46	22	11	39	29	39	33	8	5	16
Altitude	No	Finger Branching		Ear Shape									
		PT	AB	DR	OP	SM	CM	FL					
≤ 1500	70	51	49	13	43	14	20	10					
1501–2000	96	48	52	22	44	20	10	4					
≥ 2001	36	54	46	21	62	12	5	0					
Total	202	50	50	18	47	17	12	6					
P = persistent, PAP = partially persistent, NP = not persistent, YG = yellow green, LG = light- green, PP = purple, WT = white, BK =black, RD = red, BN = brown, OG = orange, PT = present, AB = absent, DR = droopy, OP = open, SM =semi-compact, CM = compact, FL = fist-like													

All five seed color types were recorded in samples from all countries, except for brown seed color, which was absent in the Zambia collections (Table 3). The chi-square test showed significant ($p \leq 0.05$), highly significant ($p \leq 0.01$), and non-significant deviations for the five qualitative traits among countries compared to expectations (Table 6).

The observed and expected frequencies for finger branching across all countries were similar, with no significant deviations. In contrast, highly significant deviations were observed for seed pericarp persistence, glume color, seed color, and ear shape in Ethiopia and Eritrea. In Zambia, a high deviation was observed only for glume and seed color traits. In contrast, finger branching and ear shape did not exhibit significant deviations from expectations in Zimbabwe.

3.2. Regional Distribution of Traits

Table 4 presents the regional frequency distributions of five traits. Regionally, the most notable result for pericarp persistence was to the predominance of non-persistent types across all regions, followed by partially persistent types. Persistent types were generally less frequent across regions, with none observed in Benishangul Gumuz region. The distribution of glume color showed proportionate patterns

throughout regions, with 12 out of 25 (46%) in Amhara, 10 out of 21 (45%) in Oromiya, 2 out of 5 (36%) in Benishangul Gumuz, and 19 out of 53 (36%) in Tigray having mostly purple glumes. The pattern of seed color in the regions was similar with the countries of origin, with black-seeded types being more frequent, followed by red seed types; while brown seed type was less frequent. The predominant phenotypic classes for finger branching and ear shape were largely observed in most regions, except for Tigray, where the open type was more common. The chi-square test showed significant regional differences in seed pericarp persistence and seed color, while Tigray and Amara regions showed highly significant differences in ear shape (Table 6).

3.3. Altitudinal Distribution of Traits

Among the 202 genotypes studied (Table 5), 28 out of 70 (40%) were classified as partially persistent types at altitudes below 1500 m.a.s.l., with traits such as purple glume (36%), red seeds (40%), finger branching (51%), and open ear shapes (43%). In this altitude class, non-persistent pericarp, white glumes, black seeds, and compact ear shapes were also observed. For the 96 genotypes collected from altitudes between 1501 and 2000 m.a.s.l., notable traits included non-persistent pericarp (51%), purple glumes (41%), black seeds (48%), absence of finger branching (52%), and open ear shapes (44%). The remaining 36 genotypes from altitudes of ≥ 2001 m.a.s.l. showed non-persistent pericarp (53%), purple glumes (40%), black seeds (48%), open ear shapes (62%), and finger branching (54%). The study noted that purple glumes and open ear shapes were consistent across altitudinal ranges, with higher dominance of purple glumes in the intermediate range and an increasing trend of open ear shapes with altitude (Table 5). Significant differences were found for all traits except finger branching (Table 6).

Table 6

Chi-square values for five qualitative traits across different countries, regions and altitude ranges.

	Qualitative traits				
	PP	GC	SC	FB	ES
country	$\backslash \text{varvec}x^2$	$\backslash \text{varvec}x^2$	$\backslash \text{varvec}x^2$	$\backslash \text{varvec}x^2$	$\backslash \text{varvec}x^2$
Ethiopia	137.40**	85.98**	293.3**	0.069ns	30.53**
Eritrea	20.52**	40.56**	166.8**	0.027ns	15.36**
Zambia	6.34*	43.15**	35.16**	0.85ns	3.8*
Zimbabwe	13.53**	27.34**	136.65**	0.33ns	1.18ns
$\backslash \text{varvec}x^2$	38.93**	27.2**	137.81**	1.26ns	7.53ns
region					
Amara	27.66**	34.00**	104.56**	1.8ns	8.71**
Benishangul	13.04**	2.36ns	18.8**	1ns	1.96ns
Oromia	13.03**	32.56**	44.38**	0.47ns	1.61ns
Tigray	93.11**	29.99**	150.38**	1.66ns	20.11**
$\backslash \text{varvec}x^2$	14.24*	12.45*	25.70**	4.86ns	1.98ns
altitude					
≤ 1500	17.90**	56.08**	163.29**	0.29ns	7.73**
1501–2000	103.09**	98.28**	334.52**	1.01ns	23.41**
≥ 2001	47.1**	27.2**	110.44**	1.42ns	15.02**
x^2	26.45**	10.02NS	103.09**	2.7ns	2.6ns
a) PP = Pericarp persistence, GC = Ear (glumes) color, SC = Seed color, FB = finger branching, ES = Ear shape,					
b) * Significant at 5% level; ** significant at 1% level; otherwise n.s, non-significant;					
c) x^2 , chi-square					

3.4. Shannon-Weaver diversity index (H') analysis

The Shannon-Weaver diversity index (H') analysis revealed notable variations in diversity among the countries of collection. The highest diversity for seed pericarp persistence was observed in Zimbabwe and Zambia (0.98), while the lowest was in Ethiopia (0.86), with an overall mean of 0.94. Glume color diversity was high across all countries of origin, though Zambia showed a relatively lower diversity estimate (0.82) compared to Zimbabwe (0.96), Ethiopia (0.94), and Eritrea (0.90). Genotypes collected from the studied countries demonstrated larger phenotypic diversity for seed color and ear shape (Table 7), with moderate differences between countries. Zambia had the highest diversity for both seed color (0.97) and ear shape (0.95), while Eritrea and Ethiopia demonstrated lower diversity indices (0.65 for SC and 0.77 for ES, respectively). Besides, Ethiopian and Zimbabwean genotypes exhibited intermediate diversity for seed color (Table 7). In contrast, the diversity for finger branching was low across all countries, likely due to the balanced proportions of phenotype classes for this trait. However, a high diversity index for ear shape (0.77–0.94) was calculated in all countries (Table 7).

Within Ethiopia, relatively high H' values were observed for all traits across regions. Pericarp persistence had H' values ranged from 0.82 in Tigray to 0.99 in Benishangul Gumuz. The highest H' values across regions were recorded for glume color and ear shape. Similar to the country-level analysis, finger branching showed low H' across all regions. According to Table 8, the pooled H' values across traits ranged from 0.85 for seed color to 0.94 for glumes color across countries, and from 0.78 for ear shape to 0.95 for glumes color across regions. This indicates a rich phenotypic variation in genotypes from various countries, regions, and altitudes, with H' values generally exceeding 0.78 across all traits.

Table 7

Estimation of Shannon-Weaver diversity indices (H') and standard error of mean ($\pm$ SE) for five qualitative traits in finger millet genotypes categorized by countries of origin, regions, and altitude ranges.

Country	Qualitative traits					
	PP	GC	SC	FB	ES	Mean $\pm$ SD
Ethiopia	0.86	0.94	0.84	0.69	0.77	0.85 $\pm$ 0.04
Eritrea	0.94	0.90	0.65	0.70	0.88	0.84 $\pm$ 0.05
Zambia	0.98	0.82	0.97	0.69	0.95	0.90 $\pm$ 0.05
Zimbabwe	0.98	0.96	0.81	0.69	0.94	0.89 $\pm$ 0.05
Mean	0.94	0.91	0.82	0.69	0.89	
Region/Ethiopia	Qualitative traits					
	PP	GC	SC	FB	ES	Mean $\pm$ SD
Amara regional state	0.89	0.91	0.74	0.69	0.80	0.84 $\pm$ 0.05
Benishangul gumuz regional state	0.99	0.99	0.84	0.69	0.95	0.88 $\pm$ 0.05
Oromiya regional state	0.95	0.90	0.87	0.70	0.86	0.85 $\pm$ 0.04
Tigray regional state	0.82	0.96	0.84	0.69	0.63	0.82 $\pm$ 0.06
Mean	0.91	0.95	0.82	0.69	0.81	
altitude	Qualitative traits					
	PP	GC	SC	FB	ES	Mean $\pm$ SD
≤ 1500	0.98	0.93	0.84	0.69	0.91	0.89 $\pm$ 0.05
1501–2000	0.89	0.93	0.80	0.69	0.86	0.86 $\pm$ 0.05
≥ 2001	0.87	0.95	0.83	0.69	0.75	0.84 $\pm$ 0.04
Mean	0.89	0.94	0.82	0.69	0.84	
PP = Pericarp persistence, GC = Ear (glumes) color, SC = Seed color, FB = finger branching, ES = ear shape						

Table 8

Estimation of mean Shannon-Weaver diversity indices (H') and standard error of mean ($\pm$ SE) of the 5 qualitative traits of finger millet collections pooled over countries, regions and altitude.

Pooled data	PP	GC	SC	FB	ES	Mean $\pm$ SD
country	0.93	0.94	0.85	0.92	0.87	0.90 $\pm$ 0.02
altitude	0.93	0.94	0.85	0.86	0.87	0.89 $\pm$ 0.02
region	0.87	0.95	0.85	0.91	0.78	0.87 $\pm$ 0.03

3.5. Analysis of diversity

The one-way analysis of variance (ANOVA) for the non-normalized diversity index (H') of individual qualitative traits is presented in Table 9. Seed pericarp persistent and seed color were the only traits that revealed significant ($P \leq 0.05$) and highly significant ($P \leq 0.01$) differences between countries, respectively. However, the other traits revealed no significant differences across countries.

Table 9

Mean squares for variations across country, region and altitude classes from the one-way ANOVA of the diversity index (H') for individual traits.

Traits	Between			Between genotypes within		
	Country	Region	Altitude	Country	Region	Altitude
	(df = 3)	(df = 3)	(df = 2)	(df = 198)	(df = 198)	(df = 199)
PP	0.003*	0.006	0.003	0.048*	0.051*	0.048*
GC	0.004	0.003	0.000	0.065*	0.059*	0.065*
SC	0.017**	0.003*	0.000	0.074*	0.087*	0.074*
FB	0.000	0.000	0.000	0.072*	0.025*	0.072*
ES	0.001	0.000	0.001	0.093*	0.057*	0.093*
* significant at 0.05**significant at 0.01, df = degree of freedom						

PP = Pericarp persistence, GC = Ear (glumes) color, SC = Seed color, FB = finger branching, ES = ear shape

As interpreted above, traits with a high diversity index (H') value offer ample opportunities for genetic improvement of finger millet through exploitation of these traits in breeding improvement.

Finger millet genotypes across various altitude ranges displayed high mean Shannon diversity (H') values for pericarp persistence ($H' = 0.98$) and glume color ($H' = 0.95$), while lower diversities were observed for finger branching ($H' = 0.69$) and seed color ($H' = 0.80$). There was a noticeable decrease in polymorphism for pericarp persistence and ear shape with increasing altitude, with H' values dropping from 0.98 to 0.87 and from 0.91 to 0.75, respectively, between lower altitudes (≤ 1500 m.a.s.l.) and higher altitudes (≥ 2001 m.a.s.l.) (Table 7). Genotypes from altitudes above 2001 m.a.s.l. exhibited higher diversity for glume color

($H' = 0.95$), while higher H' values for seed color ($H' = 0.84$) and ear shape ($H' = 0.91$) were more prevalent at lower altitudes ≤ 1500 m.a.s.l (Table 7). Seed color diversity was lower at altitudes between 1501–2000 m.a.s.l. In contrast, finger branching ($H' = 0.69$) showed consistent diversity across all altitude ranges, indicating this trait is relatively unaffected by altitude changes.

4. DISCUSSION

4.1 Distributions of Finger Millet Qualitative Traits across Countries, Regions in Ethiopia, and Attitude Ranges

Finger millet's adaptability to a wide range of agro-ecological zones enables it to be cultivated in different African countries and by farmers across a wide range of altitudinals. In the present study, the 202 African finger millet genotypes, including the check varieties (merb-1 and Tekeze-1), showed high diversity for seed pericarp persistence after harvesting. Genotypes with non-persistent seed pericarp were more abundant across the countries of origin and regions, except in Zimbabwe, where partially persistent types were more dominant. In terms of altitude, genotypes collected from lowland areas (≤ 1500 m.a.s.l.) were dominated by partially persistent seed pericarp, while those collected from altitudes between 1501–2000m.a.s.l and ≥ 2001 m.a.s.l. were mostly characterized by intermediate, non-persistent seed pericarp types (Tables 3, 4, and 5). This pattern suggests that farmers prefer non-persistent finger millet genotypes, as these genotypes are easier to thresh compared to those with persistent seed pericarp, which are more challenging due to tightly bound seed coats (Tsehay and Kebebew, 2002; Yemane, 2016). Likewise, Kumar et al. (2019) reported that non-persistent types were dominant in finger millet germplasm collected from Utrakhand Hills, constituting (76.08%) of the total population. In contrast, Bezawele et al. (2007) found persistent pericarp types predominating (91%) in the Tigray region. The same study showed that the partially persistence seed type dominate in most finger millet growing regions of Ethiopia with the non-persistence type was common in sampled from Gojam, Welega and Gamo Gofa. The widespread presence of non-persistent types in this study could potentially help in the development varieties with improved threshability and processing ease. Genotypes collected from regions such as Benishangul Gumuz and Tigray in Ethiopia, and from Eritrea, could be considered enter of concentration for this trait.

Finger branching, an important yield-related trait (Malambane and Jaisil, 2015; Dasanayake, 2017; Kumar et al., 2019; Benkaddour, 2023), showed varying frequencies across countries of origin. In Ethiopia and Zambia, genotypes with branching type were more common, while in Eritrea and Zimbabwe, non-branching types predominated. Regionally, genotypes collected from Amara, Benishangul Gumuz, and Oromia were more likely to be branching, while those from Tigray were mostly non-branching type. Despite some studies, such as Dasanayaka and Kaluthanthri (2017), who found lack of significant variability for branching in 42 finger millet genotypes, the phenotypic variation observed in this study presents a promising opportunity for finger millet breeders to develop high-yielding varieties by selecting for branching traits in larger populations.

Seed color variation was depicted among the 202 genotypes collected from different altitudinal ranges and African countries (Tables 3, 4, and 5). Overall, black was the dominant seed color (39%), followed by red (33%) and orange (16%), while white (8%) and brown (4%) colors were less infrequent. All types of seed colors appeared across all countries, regions, and altitudes, although brown seed color was absent in Zambian collections (Table 3). In Ethiopia, brown seed color followed by orange color was rare compared to the other colors, with similar frequency trend observed across altitude ranges (Table 4). Bezawele et al. (2007) also reported the rarity of white colored seeds in Welega finger millet collections. On the other hand, Malambane and Jaisil (2015) reported the dominance of brown seed color in their finger millet collections. The differences in seed color might be related to the yielding potential of the genotypes, with dark-colored (black) varieties often being more resilient to climate change and higher-yielding (Bezawele et al., 2007; Reddy et al., 2009). Seed color also affects the market value, as black-seeded varieties typically fetch higher market prices than white or red varieties (Kebede et al., 2019). Seed color is one of the most important trait for quality and market acceptance, with farmers often using seed color for variety identification and even associating it with palatability, with lighter colors believed to be more palatable than darker ones (Malambane and Jaisil, 2015). The abundance of black and red seeds might reflect farmers' preference for these types, as black grain is used to make local drinks (e.g., 'Siwa', 'Tella', and 'Ferso' in Tigrigna, Amharic, and Afan Oromo languages, respectively) while red seeds are mainly preferred for making the local flat bread (injera), though both require fertile, well-drained soil (Yemane et al., 2006).

Finger millet farmers mostly divide their varieties mainly into five phenotypic classes based on ear shape. This trait is also important for differentiating pearl millet varieties (Upadhyaya et al., 2017). The frequency distribution of ear shape indicated that open-shaped panicles were most common across the studied countries. Overall, 47% of the genotypes had open panicles, followed by 18% droopy, 17% semi-compact, 12% compact, and 6% fist-like shapes (Table 3), with similar trends obtained across all regions and altitude ranges (Tables 4 and 5). These results align with Abdi et al. (2002), who reported that about 59% of their sorghum collections were open-panicle types. In addition, Dasanayaka¹ and Kaluthanthri (2017) found four ear shape categories in their 42 finger millet study: semi-compact (68.0%), compact (19.0%), open (10.4%), and flat-like (2.6%). Tsehaye and Kebebew (2002) also reported higher frequencies of semi-compact and compact types of finger millets in the Gamogofa, Illubabor, and Welega regions of Ethiopia. Overall, the present study suggests that countries, regions, and altitude ranges with better distribution of phenotypic classes across various traits exhibit better diversity, which is important for improving finger millet varieties.

4.2. Estimation diversity

The diverse distribution of finger millet types across different countries, regions, and altitudinal ranges contributes significantly to the phenotypic diversity of finger millet populations. This variation highlights the importance of these areas for *in situ* conservation of finger millet germplasm, representing the genetic diversity of African countries. According to Bezawele et al (2007), the Shannon-Weaver diversity index (H') for seed pericarp persistence ranged from 0.60 to 0.99. Lule et al. (2012) reported the highest diversity for ear shape in Eritrea ($H' = 0.485$) and the lowest in Zimbabwe ($H' = 0.302$). The diversity index (H')

estimates across the three altitudinal classes showed varying degrees of polymorphism for most traits, indicating a broad range of variation within the genotypes (Derbew et al., 2013).

Qualitative traits are less influenced by environmental factors and tend to show high diversity due to genetic differences, making them important for successfully identifying desirable genotypes. Research by Devaliya et al. (2018) confirmed that genotypic variation exists among finger millet genotypes for qualitative traits, with variation documented across different countries of origin, collection regions, and altitude ranges by various scholars (Abubakar et al., 2019; Kumar et al., 2019; Bezawele et al., 2007; Tsehaye and Kebebew, 2002). Additionally, Lule et al., (2012) reported that the highest diversity index was found at lower altitudes (among farmer varieties), followed by diversity within regions, among regions or countries, and within altitudes, with the least similarity observed among different altitudes. This suggests that intensive genetic collection and *in situ* genetic conservation efforts should focus more at lower altitudes. Furthermore, studies by Lule et al. (2012), Sapkota et al. (2016), and Yadav et al. (2018) emphasize the broad genetic variation observed among finger millet genotypes, highlighting the importance of this diversity for effective collection, conservation, and sustainable improvement of breeding programs. This information is vital for genetic exploitation and further research.

4.3. Statistical significance of Traits

The variation in qualitative traits like seed pericarp persistent, glume color, finger branching, and ear shape did not show statistical significance across the collection regions in Ethiopia. However, seed color displayed significant variation between regions, though no significant differences were found across altitude ranges. On the other hand, the real diversity was observed at the genotype level, where statistical differences were observed between genotypes within classification variables (Table 9). Previous studies by Bekele (1984), Negassa (1986), and Bechere et al. (1996) on Ethiopian wheat, as well as Tsehaye and Kebebew (2002) on finger millet, Geleta and Labuschagne (2005) on sorghum, Mengistu et al. (2015) on durum wheat, Addisu et al. (2018) on barley, Kefyalew et al. (2000) on tef, and Workeye (2002) on chickpea have all reported high diversity within regions. Across the collection of origin and altitude ranges, all these traits showed highly significant differences ($P < 0.001$) among the farmers' varieties of the aforementioned crops.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Effective use of genetic resources requires an understanding of the diversity and geographic distribution of economically important traits. This study found significant variation in five qualitative traits among 202 finger millet genotypes from various nations and elevations. Common traits observed included black seed color, purple glume color, open ear shape, and non-persistent seed pericarp. In Zambia, both black and red seed colors were equally prevalent, while partially persistent seed pericarp and red seed color were more prevalent in Zimbabwe and lower elevations (≤ 1500 m.a.s.l.). Genotypes from Eritrea and Zimbabwe lacked finger branching, while those from Ethiopia and Zambia displayed higher frequencies of this trait.

Finger branching was more common in all regions except Tigray. The Shannon diversity index proved to be an essential tool for assessing trait diversity among genotypes, especially when taking into account their altitude range and region of origin. The study showed a significant degree of variability in qualitative traits such as ear shape, glume color, seed color, and seed pericarp persistence, emphasizing the importance of conserving the genetic diversity of these traits in their natural habitats for future breeding initiatives and environmental adaptation. Qualitative traits, therefore, serve as valuable criteria for characterizing germplasm genotypes and can potentially be used as a marker in the selection process if correlated with yield components.

5.2. Recommendations

The genetic variation observed in African finger millet genotypes offers significant opportunities for selecting and developing varieties suitable for Tigray's diverse agro-climatic conditions. The findings of the study underscore the importance of the diversity found in traits such as seed pericarp persistence, glume color, seed color, ear shape, and grain number, particularly among samples from Ethiopia and Eritrea. This diversity indicates the crop's potential for adaptation and resilience to environmental challenges, highlighting its importance for future breeding and adaptation strategies.

Declarations

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contribution

Dr. Fikre Hagos conducted the experiment, collected and entered data in excel sheet and overall write up of the manuscript. Yemane Dr.Tsahaye and Dr.Dejene K. Mengistu designed the research proposal and provided overall supervision of the research work, guided data analysis, contributed to the interpretation of results, improved grammatical issue and provided constructive suggestions for clarity and organization of the work.

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Data Availability

The datasets generated and analyzed during the current study on diversity of qualitative Traits and all necessarily information regarding the study materials like accession code number, collection of country, region, zone, wereda and altitude are available from the corresponding author upon reasonable request.

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References

1. Abdi, A., Bekele, E., Asfaw, Z. & Teshome, A. Patterns of morphological variation of sorghum (*Sorghum bicolor* (L.) Moench) landraces in qualitative characters in North Shewa and South Welo, Ethiopia. *Hereditas* **172**, 161–172 (2002).
2. Abubakar, A., Falusi, O. A., Adebola, M. O. & Daudu, O. A. Y. Genetic diversity studies for morphological traits in pearl millet (*Pennisetum glaucum* L.) landraces of Northern Nigeria. *GSC Biol. Pharm. Sci.* **7** (2), 060–070 (2019).
3. Addisu, F., Fantahun, W. & Shumet, T. Qualitative traits variation in barley (*Hordeum vulgare* L.) landraces from the Southern highlands of Ethiopia. *Int. J. Biodivers. Conserv.* **10** (5), 258–264 (2018).
4. Ayana, A. & Bekele, E. Geographical patterns of morphological variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Ethiopia and Eritrea : qualitative characters. *Hereditas* **129**, 195–205 (1998).
5. Babu, B. K. et al. Assessment of genetic diversity among finger millet (*Eleusine coracana* L. Gaertn) accession using molecular markers. *Genetic Res. Crop Evol.* **54**, 339–404 (2006).
6. Bechere, E., Belay, G., Mitiku, D. & Merker, A. Phenotypic diversity of tetraploid wheat landraces from northern and north-central regions of Ethiopia. *Hereditas* **124** (2), 165–172 (1996).
7. Bekele, E. Analysis of regional patterns of phenotypic diversity in the Ethiopian tetraploid and hexaploid wheats. *Hereditas* **100**, 131–154 (1984).
8. Benkaddour, R. *Characterization of Some Turkish Faba Bean (Vicia faba L.) Genotypes for Agro-morphological Traits.* **7**(1); 116–134. (2023).
9. Bezawele, K., Sripichitt, P., Wongyai, W. & Hongtrakul, V. Phenotypic diversity of Ethiopian finger millet [*Eleusine coracana* (L.) Gaertn] in relation to geographical regions as an aid to germplasm collection and conservation strategy. *Kasetsart J. - Nat. Sci.* **41** (1), 7–16 (2007).
10. Brhane, H. et al. Novel GBS-Based SNP Markers for Finger Millet and Their Use in Genetic Diversity Analyses. *Front. Genet.* **13**, 1–17 (2022).

11. Dasanayaka¹, N. & Kaluthanthri, D. V. S. Genetic Variability Characterization Of Some Ex Situ Conserved Finger Millet (*Eleusine Coracana* (L.) Gaertn. Subsp. *Coracana*) Germplasm Accessions In Sri Lanka using Qualitative Morphological Markers. *Int. J. Adv. Res. (IJAR)*. **5** (5), 1381–1389 (2017).
12. Dasanayake, P. N. Characterization of Some ex situ Conserved Finger Millet (*Eleusine coracana* (L.)) Germplasm Accessions in Sri Lanka. *Int. J. Multidisciplinary Stud.* **3** (2), 141 (2017).
13. Derbew, S., Mohammed, H. & Urage, E. Phenotypic Diversity for Qualitative Characters of Barley (*Hordeum Vulgare* (L.)) Landrace Collections from Southern Ethiopia. *Int. J. Sci. Res. (IJSR)*. **2** (9), 34–40 (2013).
14. Devaliya, S. D., Singh, M., Intawala, C. G. & Bhagora, R. N. Genetic Variability Studies in Finger Millet (*Eleusine coracana* (L.) Gaertn. *Int. J. Pure App Biosci.* **6** (1), 1007–1011 (2018).
15. Dida, M. M., Wanyera, N., Dunn, H., Bennetzen, M. L., Devos, K. M. & J. L., & Population Structure and Diversity in Finger Millet (*Eleusine coracana*) Germplasm. *Genet. Resour. Crop Evol.* **1** (2), 131–141 (2008).
16. Geleta, N. & Labuschagne, M. T. Qualitative traits variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from eastern highlands of Ethiopia. *Biodivers. Conserv.* **14**, 3055–3064 (2005).
17. Hutcheson, K. A test for comparing diversities based on the shannon formula. *J. Theor. Biol.* **29** (1), 151–154 (1970).
18. IPBGR. *Descriptors for finger millet* (p. 20). (1985).
19. Kebede, D. et al. Genotype by Environment Interaction and Grain Yield Stability of Ethiopian Black Seeded Finger millet Genotypes. *Afr. Crop Sci. J.* **27** (2), 281–294 (2019).
20. Kefyalew, T., Tefera, H., Assefa, K. & Ayele, M. Phenotypic diversity for qualitative and phenological characters in germplasm collection of tef (*Eragrostis tef*). *Genet. Resou Crop Evol.* **47**, 73–80 (2000).
21. Kumar, A., Chawla, H. S., Jeena, A. S. & hit, R. Morphological Characterization of Finger Millet Germplasm Collected from Uttrakhand Hills for Qualitative Traits. *Int. J. Curr. Microbiol. Appl. Sci.* **8** (09), 2105–2109 (2019).
22. Lule, D., Tesfaye, K., Fetene, M. & de Villiers, S. Inheritance and Association of Quantitative Traits in Finger Millet (*Eleusine coracana* Subsp. *Coracana*) Landraces Collected from Eastern and South Eastern Africa. *Int. J. Genet.* **2** (2), 12–21 (2012).
23. Malambane, G. & Jaisil, P. Morphological variability for qualitative and quantitative traits in finger millet (*Eleusine coracana* L. Gaertn). *J. Adv. Agric.* **5** (1), 528–537 (2015).
24. Mengistu, D. K., Kiros, A. Y. & Pè, M. E. Phenotypic diversity in Ethiopian durum wheat (*Triticum turgidum* var. *durum*) landraces. *Crop J.* **3** (3), 190–199 (2015).
25. Munsell. *The Munsell Book of Colour: Matte Collection*; 1–48. (1970).
26. Negassa, M. Patterns of Diversity of Ethiopian Wheats (*Triticum* spp.) and a Gene Center for Quality Breeding. *Plant. Breed.* **97**, 147–162 (1986).
27. Reddy, V. G., Upadhyaya, H. D., Godwa, C. L. L. & Singh, S. Characterization of eastern African finger millet germplasm for qualitative and quantitative characters at ICRISAT.SAT. e *J.* **7** (1), 1–9 (2009).

28. Sapkota, M., Pandey, M. P., Thapa, D. B., Yadav, M. K. & Ghimire, S. Diversity Assessment Of Foxtail Millet (*Setaria Italica* L. Beauv) Accessions Collected From Different Locations Of Nepal. *Int. J. Appl. Sci. Biotechnol. (IJASBT)*. **4** (4), 483–488 (2016).
29. Tesfaye, K. & Mengistu, S. Phenotypic characterization of Ethiopian finger millet accessions (*Eleusine coracana* (L.) Gaertn), for their agronomically important traits. *Acta Universitatis Sapientiae Agric. Environ.* **9** (1), 107–118 (2017).
30. Tsehay, Y. & Kebebew, F. Morphological diversity and geographic distribution of adaptive traits in finger millet [*Poaceae*] populations from Ethiopia. *Ethiop. J. Biol. Sci.* **1**, 37–62 (2002).
31. Wolie, A. & Dessalegn, T. Correlation and path coefficient analyses of some yield related traits in finger millet (*Eleusine analyses of some yield related traits in finger millet (Eleusine coracana coracana (L.)Gaertn.) germplasms in northwest Ethiopia. (L.)Gaertn.) germplasms in northwest Ethiopia. Afr. J. Agric. Res.* **6** (22), 5099–5105 (2011).
32. Upadhyaya, H. D., Gowda, C. L. L., Pundir, R. P. S., Reddy, V. G. & Singh, S. Development of core subset of finger millet germplasm using geographical origin and data on 14 quantitative traits. *Genetic Resource Crop Evol.* **53**, 679–685 (2004).
33. Upadhyaya, R. K. N., M, I. A., Kumar, V. M. K. G., Ramachandran, S. & Received Geographical distribution of traits and diversity in the world collection of pearl millet [*Pennisetum glaucum* (L.) R. Br., synonym : *Cenchrus americanus* (L.) Morrone] landraces conserved at the ICRISAT genebank. *Genet. Resour. Crop Evol.* **64** (6), 1365–1381 (2017).
34. Workeye, F. Morphological and Biochemical Diversity in Chickpea (*Cicer arietinum* L.) Landraces of Ethiopia. M.Sc. thesis. Addis Ababa University; Addis Ababa (2002).
35. Yadav, R. K., Adhikari, A. R., Gautam, S., Ghimire, K. H., J, R. D. &, & Diversity sourcing of foxtail millet through diversity assessment and on-farm evaluation. *Cogent Food Agric.* **4**, 1–17 (2018).
36. Yemane, T. Establishing A Core Collection Of Finger Millet (*Eleusine coracana* [L.] Gaertn.) Ex Situ Holdings Of The. Ethiopian Genebank. *J. Drylands.* **6** (2), 519–530 (2016).