

Evaluation of Phenotypic Diversity and Genetic Parameters in Nepalese Finger Millet (*Eleusine Coracana* L. Gaertn) Landraces

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EVALUATION OF PHENOTYPIC DIVERSITY AND GENETIC PARAMETERS IN NEPALESE FINGER MILLET (*Eleusine coracana* L. Gaertn) LANDRACES

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Abstract

Finger millet (*Eleusine coracana* L. Gaertn) is a climate-resilient cereal, recognized as a future smart crop for enhancing food and nutritional security. This study focuses on assessing the phenotypic diversity and genetic parameters of germplasms at the National Agricultural Genetic Resources Centre, Lalitpur, Nepal. 33 finger millet accessions, collected from 14 districts, were characterized under an augmented design with two replications. Twenty-one quantitative and six qualitative traits were recorded following the IBPGRI descriptor. Shannon-Weaver diversity indices showed high diversity (0.6-0.95) for all quantitative traits, whereas up to 0.98 for qualitative traits. Principal component analysis explained 43.78% of the variation in the first two components, resulting from phenological and leaf morphological traits, along with grain yield. Cluster analysis grouped accessions into four clusters based on 8 quantitative traits, suggesting broad genetic divergence. Estimates of genetic variability showed a higher phenotypic coefficient of variation for all traits than the genotypic coefficient of variation. Higher heritability with greater GAM was estimated for traits like finger length, phenological traits, and number of leaves per plant, indicating the influence of additive gene action and effective selection potential. Phenotypic path analysis identified flag leaf blade width, thousand seed weight, finger length, flag leaf blade length, and productive tillers as key traits associated with the grain yield. Accessions CO14422 and CO11943 were identified as early-maturing, while CO11696 and CO13039 exhibited superior yield potential. These findings provide valuable insights for selecting diverse and high-performing genotypes to enhance breeding programs for finger millet improvement in Nepal.

Keywords: Phenotypic diversity, Characterization, Genetic variability, Heritability

1. INTRODUCTION

Finger millet (*Eleusine coracana* L. Gaertn) is a significant minor cereal crop and a part of the Chloridoidea subfamily among the grass family Poaceae. It is an allotetraploid ($2n = 4x = 36$) crop with a genome size of 1,593 Mb (Goron & Raizada 2015). Globally, it is the fourth most cultivated cereal crop, followed by pearl millet, sorghum, proso millet, and foxtail millet. In Nepal, it holds the fourth rank in terms of production and area, with 3,10,846.8 metric tons and 2,27,934 hectares, respectively (MoALD 2024). The domestication of the finger millet was set out 5000 years ago from the primary center of diversity, i.e., eastern African highlands, which later made its way to India as a secondary center of diversity, marking diversification 3000 years ago (Hilu et al. 1979). The cultivated species *E. coracana* subsp. *coracana* was developed through the domestication of *E. coracana* subsp. *africana* and possesses a tetraploid chromosome structure (AABB), with cytogenetic and isozyme analyses indicating *E. indica* (AA) as one of the genomic donors, while the second donor remains unidentified (BB) (Devarumath et al. 2005). There is high diversity of finger millet in the hills of Nepal, delineating that out of 15 species in the world, *E. coracana*, *E. indica*, and *E. aegyptica* are found in Nepal (Kandel et al. 2019).

Finger millet is considered a “Future smart crop” because it adapts highly to drought and other biotic & abiotic stresses. Being a climate-resilient crop, it has high potential for improving nutrition and food security, addressing the major issues of climate change in the agricultural production sector. It is commonly used in Nepal as dhindo, roti, and raksi (traditionally fermented liquors), which maintains the diversity of genotypes grown specifically for each purpose. The millet gene pools found in Nepal have great nutritional importance along with tolerance to cold, drought, and pests (Bhatta et al. 2017). The nutritive content of finger millet comprises carbohydrate (72.6%), protein (7.7%), crude fiber (3.6%), fat (1.5%), ash (2.7%), calcium (344 mg%), phosphorus (250 mg%), and iron (6.3 mg%) (Gull et al. 2014). Finger millet is the richest source of calcium and iron, which helps prevent the deficiencies causing bone and teeth disorders. Due to its high potential for food and nutritional security, its demand is increasing and shifting from underutilized crops to high-value crops, mainly due to extruded and bakery products (Kandel et al. 2020). In the context of food security, assessment of phenotypic diversity of finger millet plays a pivotal role as the resulting forecast states that the yields of major crops such as rice, wheat, maize, and soybean are decreasing due to climate change, posing a threat to food production and security in densely populated and arid regions of the world (Wright & Devos 2024).

It has been found cultivated in a wide range of environments from tropical to sub-tropical and altitudes ranging from 85 masl (Bara district) to the highest of 3150 masl (Humla district) in Nepal (Amgai et al. 2004; Ghimire et al. 2020). Due to its adaptability to harsh climates and minimum inputs, it has been cultivated in almost all districts of Nepal except Kapilvastu, Banke, and Bardiya. Recently published data from the Ministry of Agriculture and Livestock Development (MoALD 2024) shows that the major production districts are Khotang, Sindhuupalchok, Okhaldhunga, Kaski, Gorkha, and Syangja with 38,367 mt, 23,693 mt, 19,378 mt, 14,252 mt, 13,664 mt, and 13,622 mt, respectively,

with overall national production of 3,10,846.76 t. In the global context, the production of finger millet is 31.59 million tons and 13.13 million tons in Africa (FAO 2023). In Nepal, various agricultural cultivation practices are implemented across agro-ecological zones, encompassing sole cropping, mixed cropping, intercropping, and relay cropping practices. It is predominantly cultivated as a sole crop, succeeded by paddy or wheat in the Terai region, while barley, wheat, potato, or buckwheat are cultivated in the mountainous areas. Concurrently, it is also cultivated as a mixed crop, intercropped, or utilized in relay cropping alongside cereal crops (Gyawali 2021).

Landraces are genetically diversified and locally adapted crop varieties that possess a historical and distinct identity and exhibit a great adaptation to biotic and abiotic stresses (Villa et al. 2005). Finger millet landraces are abundant in East Africa and South Asia regions, having significant variation in traits such as drought tolerance, disease tolerance, high nutritive content, particularly calcium and iron. These centers of diversity hold valuable genetic resources and variability of finger millet and are preserved in global gene banks. More than 40,000 accessions are protected by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), among which a large proportion are present in Asia and African countries (Harlan 1971). Nepal has preserved 1086 accessions of finger millet at NAGRC, Khumaltar, Nepal (Genebank 2023).

The phenotypic diversity of the various accessions collected from different parts of Nepal can be utilized for the selection and development of varieties for different regions, respective of the specific features of the accessions. The availability of genetic diversity is a prerequisite for genetic improvement of a crop. Characterization serves as a fundamental methodology for evaluating the data of the collected accessions, which is crucial for their effective application in plant breeding initiatives. Thus, this study aims to provide information about the phenotypic diversity of landraces of Nepal that can help in forming strategies and policies for food and nutritional security.

2. MATERIALS AND METHODS

2.1 Experimental Site and Design

A total of 33 finger millet accessions, obtained from 14 different districts of Nepal, were subjected to characterization at the National Agriculture Genetic Resources Center (NAGRC), Lalitpur, Nepal (Table 1). The NAGRC is situated at an elevation of 1368 meters above sea level, with geographic coordinates of 27°40'N latitude and 085°20'E longitude. The research was carried out during the winter season of 2022. The experimental plots were characterized by black loamy soil, and the accessions were subjected to an augmented replicated block design to facilitate agro-morphological characterization, with two replications. An augmented randomized block design (AUD) was adopted, wherein treatments were randomized across plots measuring 3 m × 1 m.

Table 1. Description of Finger Millet Landraces

S.N.	Accession name	Local Name	District
1	CO 13408	Seto Ursi Kodo	Kaski
2	CO 12230	Mudke Kodo	Tanahun
3	CO 13407	Mudke Kodo	Kaski
4	CO 12298	Rato Kodo	Tanahun
5	CO 11694	Local Kodo	Nuwakot
6	CO 10980	Nanga Katuwa Kodo	Ramechhap
7	CO 11695	Seto Kodo	Nuwakot
8	NGRCO 5049	Kavre Kodo - 1	Kavre
9	CO 12435	Local Kodo	Tanahun
10	CO 13048	Larkane Kodo	Nawalpur
11	CO 11708	Kartike Kodo	Dhading
12	CO 13344	Khairo Kalo Kodo	Dhankuta
13	CO 13026	Mudke Kodo	Nawalpur
14	CO 13324	Pangdure Kodo	Dhankuta
15	CO 11701	Chaure Kodo	Rasuwa
16	CO 10047	Bhotange Kodo	Udayapur
17	CO 12460	Dudhe Kodo	Tanahun
18	CO 13039	Kartike Kodo	Nawalpur
19	CO 12712	Local Kodo	Solukhumbu
20	CO 13252	Mudke Kodo	Dhankuta
21	CO 11943	Ghar Kodo	Mugu
22	CO 13308	Dalle Kodo	Dhankuta
23	CO 14422	Rato Kodo	Jumla
24	CO 11702	Dalle Kodo	Rasuwa
25	CO 11714	Local Kodo	Makwanpur
26	CO 12722	Nanga Katuwa Kodo	Solukhumbu
27	CO 13519	Rato Kodo	Nuwakot
28	CO 11696	Seto Kodo	Tanahun
29	CO 12246	Local Kodo	Makwanpur
30	CO 11711	Local Kodo	Makwanpur
31	NGRCO 5050	Kavre Kodo-2	Kavre
32	CO 13343	Seto Kodo	Dhankuta
33	CO 12327	Seto Kodo	Tanahun

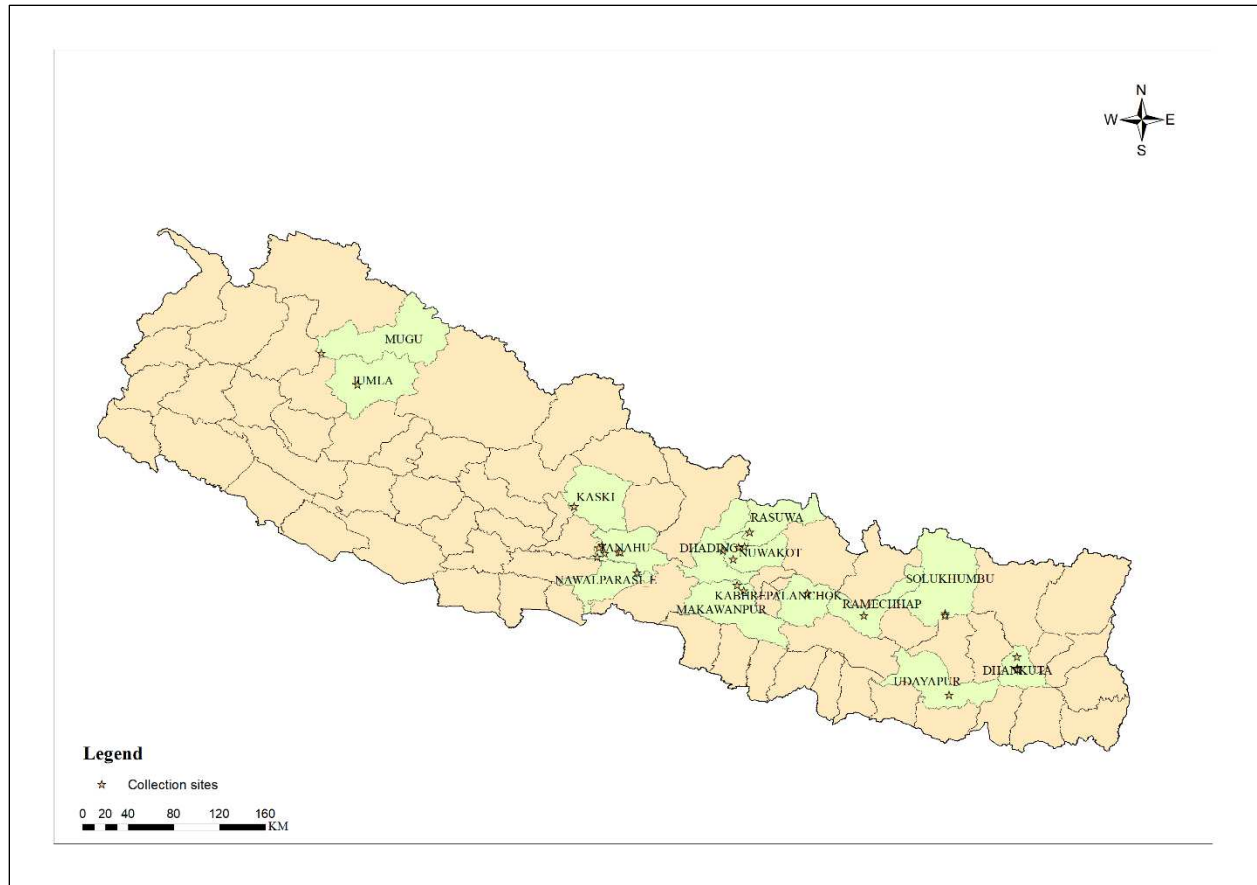


Figure 1. Collection sites of 33 finger millet landraces

2.2 Data collection and analysis

Morphological data of 21 quantitative traits and 6 qualitative traits were recorded using the standard descriptors of IBPGR (IPGRI 1985). The qualitative characteristics were recorded in accordance with the assessment of descriptor states, whereas the quantitative characteristics were determined through measurement and counting (Supp. Data: Table 1 & Table 2). The data were taken from 5 randomly selected plants and seeds in the field and the seed lab, respectively.

The data obtained were entered into Microsoft Excel for statistical analysis. The combined mean of the respective quantitative data was used for descriptive statistics, including minimum, maximum, mean, standard deviation, and coefficient of variation, as well as inferential statistics, i.e., multivariate analysis in R Studio software. Shannon-Weaver diversity index (H') was calculated for both quantitative and qualitative traits with Microsoft Excel (Eticha et al. 2005).

$$\text{Diversity index } (H') = \left[\sum \left(\frac{n}{N} \right) \times \left\{ \log_2 \left(\frac{n}{N} \right) \times (-1) \right\} \right] / \log_2 \kappa$$

Where n represents the frequency of a phenotypic trait class, N is the total number of observations for a particular trait, and κ denotes the number of phenotypic classes.

The phenotypic and genotypic coefficients of variance of each trait were computed with the formula (Wolie et al. 2013),

$$\text{Phenotypic coefficient of variance (PCV)} = \left[\frac{\sigma_p}{\bar{X}} \right] \times 100$$

$$\text{Genotypic coefficient of variance (GCV)} = \left[\frac{\sigma_g}{\bar{X}} \right] \times 100$$

Where σ_p = phenotypic standard deviation, σ_g = genotypic standard deviation, and $\bar{X}$ = mean value of each trait.

While, broad-sense heritability and genetic advance of traits were computed by following the formula (Wolie et al. 2013),

Heritability (h^2) = $[\sigma_g^2/\sigma_p^2] \times 100$

Genetic advance = $(k) \cdot (\sigma_p) \cdot (h^2)$

Genetic advance as a mean = $[GA/\bar{X}] \times 100$

Where σ_g^2 = genotypic variance, σ_p^2 = phenotypic variance, k = selection differential (2.06, at 5% selection intensity)

3. RESULTS

3.1 Descriptive statistics and diversity indices of quantitative traits

For descriptive statistics, range, mean, standard error of mean, standard deviation, and coefficient of variation were computed (Table 2). The coefficient of variation ranged from 8.57% (Culm thickness) to 26.51% (number of grains per spike). Among vegetative traits, productive tillers and plant height showed greater variation, with the coefficient of variation of 23.16% and 21.1% respectively. The length of ear exertion ranged from 5.27 to 27.72 cm, and plant height ranged from 79.13 cm to 216.81 cm, with an overall mean of 13.67 cm to 103.9 cm, respectively. The length of the leaf blade ranged from 29.56 cm to 42.2 cm, with a mean of 35.53 cm, while its width varied between 0.92 cm to 2.15 cm. On average, the accessions had 12 leaves per plant, while the minimum and maximum numbers of leaves recorded were 7 and 16, respectively. The early maturing accessions showed first heading at 59 days after sowing, and 96 days by late maturing accessions, with an average productive tiller of 4, 6.75 cm finger length, and 103.9 cm plant height. Among these accessions, 80% of maturity was observed from 103 to 164 days, with an average of 142 days. A wide range of variation was observed in the trait: number of grains per spike, ranging from 1286 to 5030.6, yielding an average of 2.82 t/ha and 7 fingers per head.

Table 2. Descriptive statistics of quantitative traits

S.N.	Variables	Min	Max	Mean	Std. Dev	CV (%)
1	Days to first heading	59	96	78.38±1.56	8.94	11.40
2	Days to 50% heading	65	107	87.91±1.59	9.11	10.36
3	Days to 80% maturity	103	164	142.44±2.41	13.84	9.72
4	Blade length of flag leaf (cm)	20.52	31.42	26.00±0.4	2.31	8.87
5	Blade width of flag leaf (cm)	0.77	1.23	0.97±0.02	0.10	10.64
6	Leaf blade length (cm)	29.56	42.2	35.53±0.58	3.36	9.45
7	Leaf blade width (cm)	0.92	2.15	1.21±0.04	0.25	20.27
8	Leaf sheath length (cm)	6.37	11.22	9.65±0.19	1.09	11.28
9	Leaf sheath diameter (mm)	4.63	7.156	5.77±0.12	0.68	11.81
10	Leaf number per plant	6.80	16.20	11.97±0.35	2.01	16.79
11	Productive tillers	1.70	4.80	3.28±0.13	0.76	23.16
12	Ear exertion (cm)	5.27	27.72	13.67±0.61	3.53	25.83
13	Culm thickness(mm)	4.90	7.021	5.76±0.09	0.49	8.57
14	Finger length (cm)	4.64	10.94	6.75±0.28	1.63	24.15
15	Finger width (cm)	0.73	1.40	1.05±0.02	0.10	9.56
16	Plant height (cm)	79.13	216.81	103.90±3.82	21.92	21.10
17	Finger number per head	5.60	8.90	6.71±0.13	0.75	11.13
18	Number of grains per spike	1286	5030.6	2414.06±111.39	639.90	26.51
19	Thousand-grain weight (gm)	2.36	3.53	2.80±0.05	0.30	10.63
20	Fresh straw yield per plot (t/ha)	8.28	27.05	20.58±0.73	4.18	20.33
21	Grain yield per plot (t/ha)	1.45	4.40	2.82±0.13	0.73	25.88

Min. = Minimum, Max. = Maximum, Std. Dev = Standard Deviation, CV = Coefficient of Variation, H' = Shannon-Weaver diversity index

Shannon-Weaver diversity index ranged from 0.60 (leaf blade width) to 0.95 (productive tillers), with an overall index of 0.81, which showed a high level of diversity among the landraces (Figure 2). The diversity indices of quantitative traits depicted a copious amount of variation among the studied traits of finger millet landraces. A very high diversity was found in productive tillers (0.95), leaf sheath diameter (0.91), leaf blade length (0.91), days to first heading (0.90), blade width of flag leaf (0.88), fresh straw yield (0.87), blade length of flag leaf (0.85), days to 80% maturity (0.84), grain yield per plot (0.84), culm thickness (0.83) and days to 50% heading (0.81), indicating a wider variability. Meanwhile, the remaining traits, ear exertion, number of grains per spike, finger number per head, thousand-grain weight, finger length, finger width, leaf number per plant, leaf blade width, and plant height had high diversity indices ranging from 0.6 to 0.79.

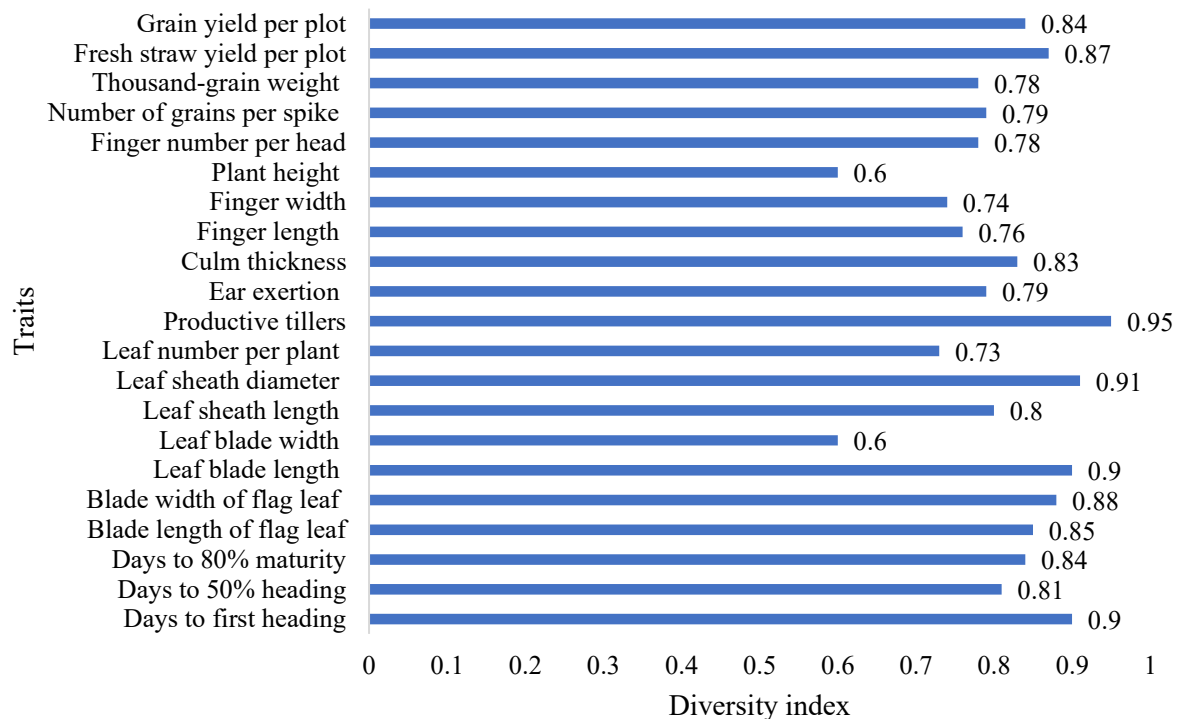


Figure 2. Diversity indices of quantitative traits of studied finger millet landraces

3.2 Frequency distribution and diversity indices of qualitative traits

The major characteristics observed among the accessions were intermediate spikelet density (85%), intermediate ear size (61%), less pigmentation (58%), light-brown grain color (55%), and semi-compact ear shape (52%) with no spikelet shattering (Figure 3). The four distinct grain colors were observed, namely light brown (55%), purple brown (18%), white (15%), and copper brown (12%) (Figure 4). Similarly, ear shape was also found to be distributed into four classes, i.e., open (24%), semi-compact (52%), compact (12%), and droopy (12%).

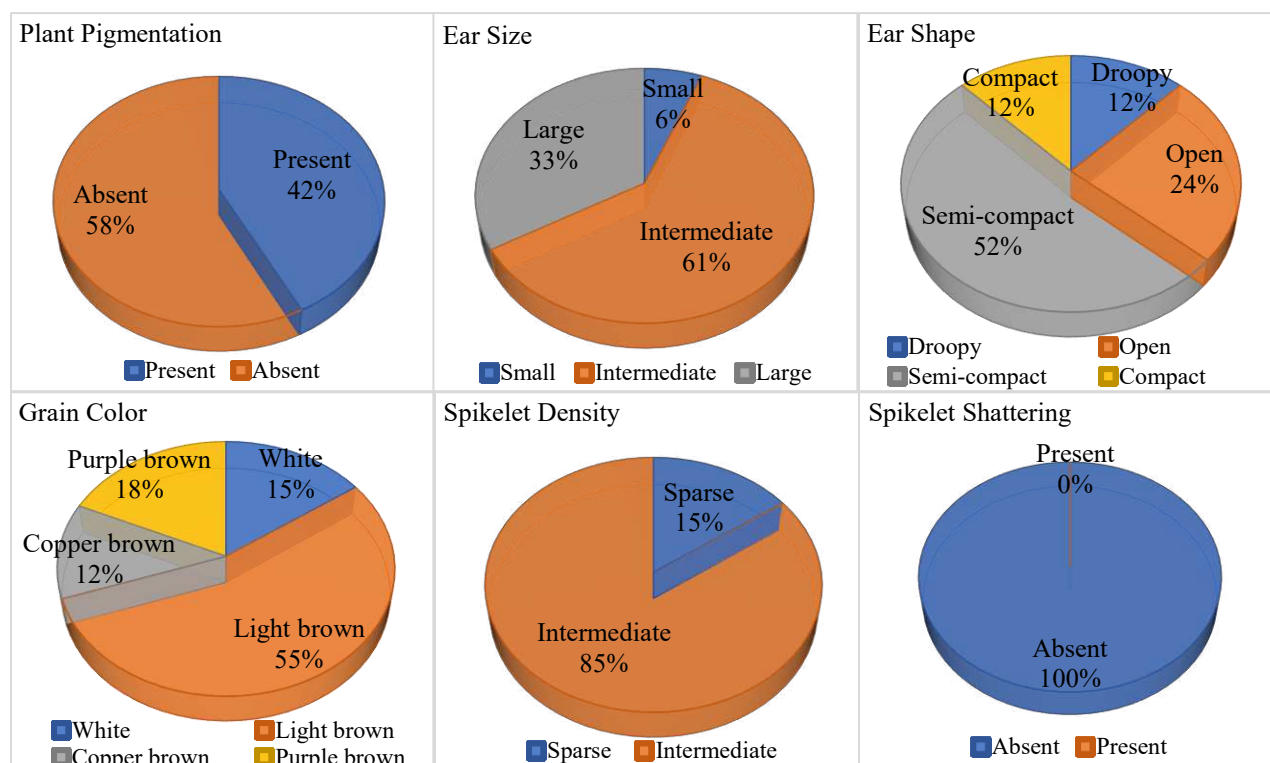


Figure 3. Distribution of finger millet landraces among 6 qualitative traits



Figure 4. Distribution of Seed color of finger millet landraces

Based on the estimation of the Shannon-Weaver diversity index (H') represented in Figure 5, it was found that the diversity of qualitative traits varied from low to high diversity (0-0.98) in the finger millet landraces. A high diversity index (H') was found in the plant pigmentation (0.98), ear shape (0.86), grain color (0.85), and ear size (0.76), whereas low diversity was observed in spikelet density (0.39).

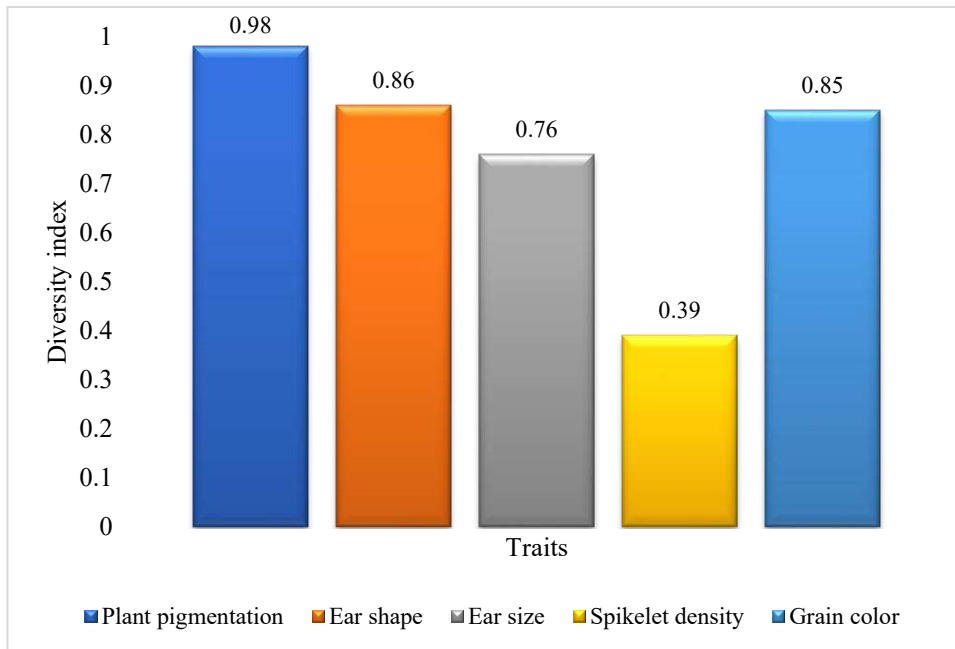


Figure 5. Diversity indices of qualitative traits

3.3 Principal Component Analysis

The phenotypic variations due to the various traits studied among 33 accessions were examined through principal component analysis. The following scree plot explained 10 principal components, showing 88.8% of the total variability (Figure 6). The first principal component contributed 30.7% of the total variability with an eigenvalue of 6.45, which is mostly influenced by the traits like days to 50% heading, days to first heading, days to 80% heading, and number of leaves per plant, whereas blade width of flag leaf and grain yield were found to be the least contributing traits in it. In addition, the second principal component explained 13.1% of the total variability with an eigenvalue of 2.75, majorly influenced by flag leaf blade length, flag leaf blade width, fresh straw yield per plot, leaf blade length, grain yield, and productive tillers.

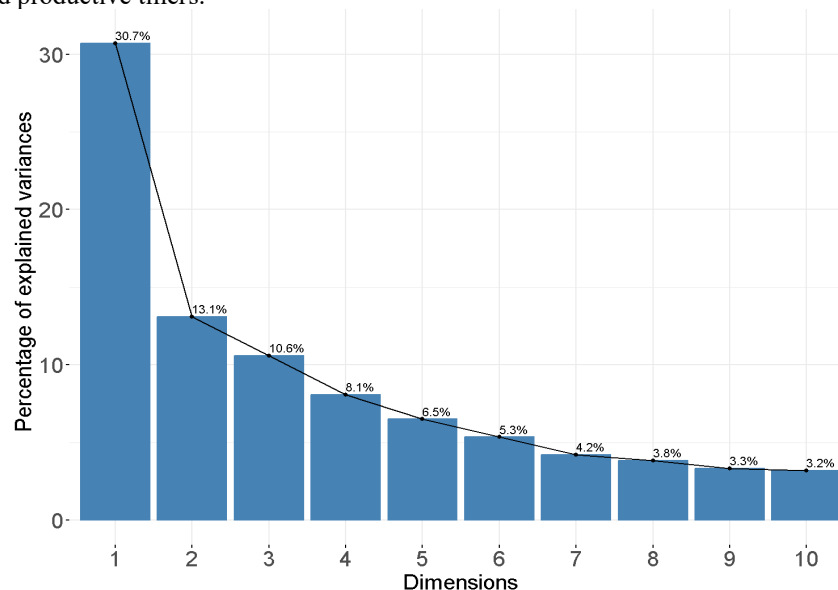


Figure 6. Scree plot of principal components

The third principal component (PC-3) explained 10.58% of the total variance, with major contributions from finger

number per head, grain yield, length of the finger, culm thickness, plant height, and width of the finger. The fourth principal component (PC-4) accounted for 8.09% of the variance, primarily influenced by leaf sheath diameter, leaf blade width, thousand-seed weight, and finger length. Similarly, the fifth component (PC-5) explained 6.50% of the variance, with substantial contributions from leaf sheath diameter, leaf blade width, thousand-seed weight, culm thickness, and finger length. Likewise, the sixth principal component (PC-6) accounted for 5.34% of the total variance, with key contributions from plant height, leaf blade width, grain yield, thousand-seed weight, and ear exertion.

Table 3. Principal component analysis for twenty-one quantitative characters of finger millet landraces

Dimensions	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6
Eigenvalue	6.45	2.75	2.22	1.70	1.37	1.12
Variance (%)	30.69	13.09	10.58	8.09	6.50	5.34
Cumulative variance (%)	30.69	43.78	54.36	62.45	68.95	74.30
Variables	Coefficient vectors					
Days to first heading	-0.363	0.055	-0.116	0.076	0.082	0.089
Days to 50% heading	-0.370	0.070	-0.088	0.041	0.056	0.017
Days to 80% heading	-0.350	0.008	-0.066	0.015	0.039	-0.131
Blade length of flag leaf (cm)	0.102	0.475	-0.026	0.043	-0.308	-0.069
Blade width of flag leaf (cm)	0.018	0.473	-0.004	0.171	-0.105	0.008
Leaf blade length (cm)	0.200	0.318	-0.049	-0.134	0.070	0.113
Leaf blade width (cm)	0.099	-0.008	-0.185	-0.475	0.015	-0.411
Leaf sheath length (cm)	0.280	0.086	-0.138	0.008	0.117	-0.136
Leaf sheath diameter (mm)	0.124	-0.044	-0.136	0.571	0.095	0.074
Leaf number per plant	-0.326	0.082	-0.195	-0.054	0.134	0.137
Productive tillers	-0.205	0	-0.089	-0.058	0.248	-0.184
Ear exertion (cm)	0.246	0.250	-0.055	-0.036	0.094	0.367
Culm thickness(mm)	-0.189	0.022	-0.322	0.290	-0.132	-0.025
Finger length (cm)	-0.244	0.068	0.334	0.226	-0.085	0.190
Finger width (cm)	0.242	-0.055	-0.222	0.171	0.292	-0.010
Plant height (cm)	0.078	-0.019	0.277	-0.146	0.487	0.476
Finger number per head	0.049	-0.081	-0.541	0.026	0.268	0.044
Number of grains per spike	0.200	0.213	-0.175	0.158	-0.180	0.066
Thousand grain weight (g)	0.126	-0.168	0.168	0.379	0.318	-0.388
Fresh straw yield per plot (t/ha)	-0.164	0.368	-0.021	-0.100	0.414	-0.085
Grain yield per plot(t/ha)	0.026	0.268	0.396	0.137	0.208	-0.388

The magnitude of the coefficient, irrespective of the sign, indicates the effectiveness of the selection of corresponding traits in discriminating the landraces. The results of PCA suggested that traits, viz., days to 50% heading, days to first heading, number of leaves per plant, flag leaf blade length, plant height, days to 80% maturity, grain yield, fresh straw yield per plot, thousand seed weight, number of fingers per plant, and finger length were the principal discriminatory characteristics of the Nepalese finger millet landraces.

3.4 Hierarchical cluster dendrogram

A hierarchical cluster dendrogram was constructed to study the similarity among various finger millet landraces based on specific characteristics using the average (UPGMA) clustering method based on the Euclidean distance. The cluster analysis categorized 33 finger millet accessions into four clusters utilizing the standardized mean of eight quantitative traits (Figure 7). Clusters are differentiated with different colors, presenting red and blue as the highest number of accessions (15), followed by green (2) and purple (1). Among the four clusters, cluster III contained two accessions

(CO11943 and CO14422) that showed early phenological traits and a larger number of fingers per plant (Table 4). In contrast, clusters I and IV showed late phenological traits with more productive tillers and finger length, respectively. Cluster II was found to be the group of most of the intermediate traits, except for grain yield, which was the highest.

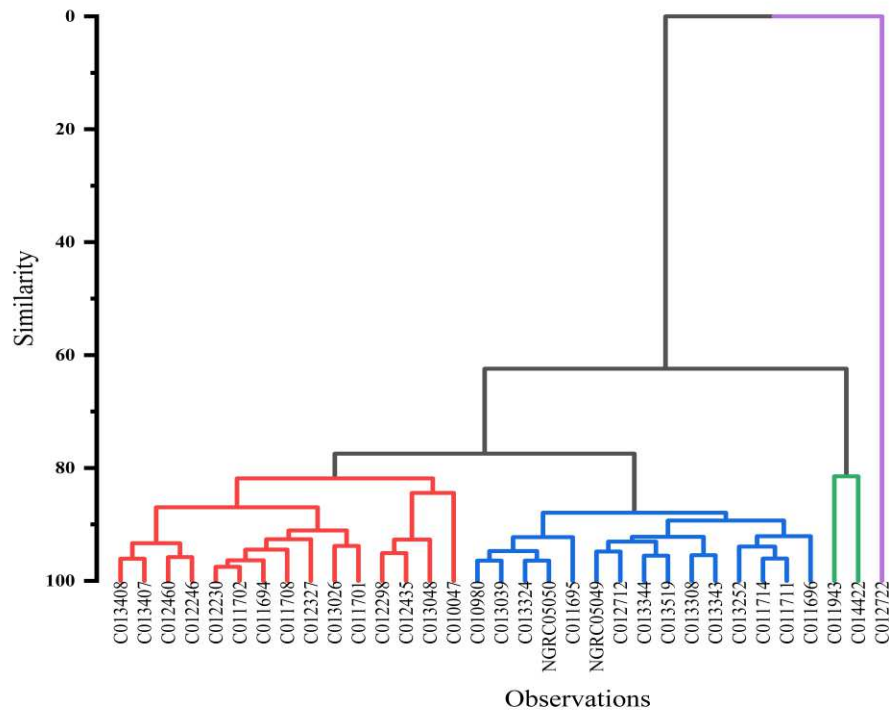


Figure 7. Hierarchical cluster dendrogram of finger millet landraces

Table 4. Cluster mean table

Clusters	I	II	III	IV
Accessions	15	15	2	1
Days to 50% heading	95.87	82.93	67	85
Days to 80% maturity	154.10	135.20	110	141
Productive tillers	3.55	3.22	1.85	3.2
Finger length (cm)	6.97	6.65	4.68	9.05
Plant height (cm)	96.27	103.38	108.66	216.81
Number of fingers per plant	6.92	6.48	7.35	5.80
Thousand-seed weight (g)	2.70	2.88	2.86	3.00
Grain yield (t/ha)	2.52	3.26	1.72	3.06

Table 5. Cluster centroid distance

	Cluster-I	Cluster-II	Cluster-III	Cluster-IV
Cluster-I	0.00	24.00	54.23	121.76
Cluster-II	24.00	0.00	30.42	113.62
Cluster-III	54.23	30.42	0.00	114.05
Cluster-IV	121.76	113.62	114.05	0.00

3.5 Path analysis:

Path coefficient analysis was executed to inspect the direct and indirect, and total linear effects of yield-attributing characters on the total yield. For path coefficient analysis, 19 traits were used as independent variables, while grain yield was used as the dependent variable. The traits related to the vegetative parameters, reproductive parameters, and seed-related traits are used to show the total linear effect on the total yield, which is presented in Table 6. The total direct and indirect linear coefficient estimated positive effect on the overall yield by the traits: flag leaf blade width (0.276), thousand seed weight (0.254), finger length (0.234), flag leaf blade length (0.228), productive tillers (0.221), leaf blade length (0.12), plant height (0.112), ear exertion (0.101), leaf sheath length (0.047) and grain per spike (0.026) whereas the remaining traits showed negative effects. This model explains the 57.41% variation in the total yield, and the rest of the variation 42.59% was explained by environmental factors.

Table 6. Phenotypic path analysis

	DTFH	DTFPH	DTEPM	FLBL	FLBW	LBL	LBW	LSH	LSD	LNPP	PT	EXT	CT	FL	FW	PH	FPP	GPS	THSW	linear
DTFH	-1.060	-0.212	0.624	-0.021	0.003	0.042	0.055	0.093	-0.013	0.370	0.261	-	-	0.117	-	0.047	-	0.040	-0.096	-
												0.192	0.192		0.012		0.007			0.153
DTFPH	-1.016	-0.221	0.653	-0.021	0.004	0.044	0.048	0.092	-0.016	0.362	0.258	-	-	0.116	-	0.055	0.004	0.039	-0.103	-
												0.210	0.178		0.014					0.105
DTEPM	-0.919	-0.200	0.720	-0.030	-0.010	0.044	0.022	0.074	-0.019	0.340	0.236	-	-	0.107	-	0.050	0.025	0.032	-0.068	-
												0.242	0.198		0.013					0.047
FLBL	0.159	0.032	-0.151	0.142	0.058	-0.063	-0.015	-0.033	0.001	-	0.042	0.141	0.029	-	0.001	0.046	0.022	-	-0.056	0.228
										0.073				0.003				0.050		
FLBW	-0.037	-0.009	-0.081	0.095	0.086	-0.031	0.020	-0.022	0.004	0.034	0.100	0.127	-	0.035	-	0.026	0.009	-	-0.031	0.276
													0.026		0.001			0.023		
LBL	0.383	0.082	-0.268	0.075	0.023	-0.117	-0.018	-0.058	0.003	-	0.001	0.203	0.123	-	0.009	-	-	-	-0.024	0.120
										0.137				0.086		0.033	0.005	0.037		
LBW	0.316	0.057	-0.088	0.011	-0.009	-0.011	-0.184	-0.036	-0.016	-	-	0.041	0.061	-	0.002	0.008	-	-	-0.032	-
										0.061	0.001			0.099			0.047	0.010		0.098
LSH	0.658	0.136	-0.358	0.031	0.013	-0.045	-0.045	-0.150	0.010	-	-	0.199	0.060	-	0.012	-	-	-	0.120	0.047
										0.174	0.175			0.125		0.027	0.042	0.052		
LSD	0.202	0.049	-0.191	0.002	0.005	-0.005	0.041	-0.021	0.071	-	-	0.069	-	-	0.009	0.017	-	-	0.144	-
										0.115	0.128		0.042	0.020			0.059	0.038		0.010
LNPP	-0.895	-0.183	0.559	-0.024	0.007	0.037	0.026	0.059	-0.019	0.438	0.229	-	-	0.085	-	0.019	-	0.032	-0.146	-
												0.163	0.200		0.011		0.030			0.180
PT	-0.509	-0.105	0.312	0.011	0.016	0.000	0.000	0.048	-0.017	0.184	0.544	-	-	0.061	-	0.015	-	0.018	-0.102	0.221
												0.080	0.166		0.004		0.006			
EXT	0.492	0.112	-0.422	0.048	0.027	-0.058	-0.018	-0.072	0.012	-	-	0.413	0.075	-	0.011	-	-	-	-0.032	0.101
										0.173	0.105			0.075		0.068	0.018	0.048		
CT	-0.495	-0.096	0.346	-0.010	0.005	0.035	0.027	0.022	0.007	0.213	0.219	-	-	0.067	-	0.092	-	0.003	-0.078	-
												0.075	0.411		0.001		0.041			0.169
FL	-0.527	-0.109	0.328	-0.002	0.013	0.043	0.077	0.079	-0.006	0.158	0.141	-	-	0.236	-	-	0.093	0.037	-0.030	0.234
												0.132	0.117		0.014	0.034				
FW	0.464	0.115	-0.347	0.007	-0.003	-0.039	-0.012	-0.068	0.024	-	-	0.162	0.021	-	0.027	-	-	-	0.125	-
										0.180	0.072			0.122		0.027	0.084	0.024		0.033
PH	0.204	0.050	-0.149	-0.027	-0.009	-0.016	0.006	-0.016	-0.005	-	-	0.115	0.155	0.033	0.003	-	0.026	0.001	0.051	0.112
										0.035	0.033					0.243				
FPP	-0.037	0.005	-0.085	-0.015	-0.004	-0.003	-0.041	-0.030	0.020	0.061	0.016	0.036	-	-	0.011	0.029	-	-	-0.004	-
													0.080	0.103			0.213	0.011		0.446
GPS	0.398	0.080	-0.214	0.066	0.018	-0.040	-0.017	-0.073	0.025	-	-	0.183	0.013	-	0.006	0.003	-	-	0.006	0.026
										0.129	0.090			0.080			0.021	0.108		
THSW	0.262	0.059	-0.127	-0.021	-0.007	0.007	0.015	-0.046	0.026	-	-	-	0.083	-	0.009	-	0.002	-	0.387	0.254
										0.166	0.143	0.034		0.018		0.032		0.002		

DTFH = Days to first heading, DTFPH = Days to 50% heading, DTEPM = Days to 80% heading, FLBL = Blade length of flag leaf, FLBW = Blade width of flag leaf, LBL = Leaf blade length, LBW = Leaf blade width, LSH = Leaf sheath length, LSD = Leaf sheath diameter, LNPP = Leaf number per plant, PT = Productive tillers, EXT = Ear exertion, CT = Culm thickness, FL = Finger length, FW = Finger width, PH = Plant height, FPP = Finger number per head, GPS = Number of grain per spike, THSW = 1000 grain weight

3.6 Estimation of heritability and genetic advance

Genetic variation inherent within various finger millet landraces under this study was assessed by calculating components of variation, such as genotypic coefficient of variance (GCV), phenotypic coefficient of variance (PCV), broad-sense heritability (h_{bs}^2), and genetic advance as a mean (GAM). The range of variation is categorized as per Sivasubramanjan & Menon (1973) into three classes: low (<10%), moderate (10-20%), and high (>20%). All the traits assessed under this study exhibited a higher phenotypic coefficient of variation (PCV) than genotypic coefficient of variation (GCV). The phenotypic coefficient of variation ranged from 10.35% for days to 80% maturity to 33.01% for number of grains per spike, while the genotypic coefficient of variation ranged from 5.77% for flag leaf blade length to 22.56% for finger length.

Heritability is the measurement of the total heritable amount of genetic variation in a trait that expresses the accuracy of phenotypic value. Heritability estimates of the traits showed an appreciable difference between the variables, ranging from 0.08 to 0.91 (Table 7). Highest heritability was reported for the traits: days to first heading, days to 50% heading, finger length, days to 80% maturity, and number of leaves per plant, with respective values 0.91, 0.91, 0.77, 0.76, and 0.62. Productive tillers, on the other hand, showed the least value for heritability, being very distinct from other traits. Likewise, finger length, grain yield, number of leaves per plant, and days to first heading were found to have the highest genetic advance of all the traits. Prioritizing high-heritability traits with strong genetic gain can help develop improved finger millet varieties with better yield and adaptability.

Table 7. Estimation of genetic parameters

Variables	GCV	PCV	Heritability (h_{bs}^2)	GAM (%)
Days to the first heading	11.09	11.58	0.91	21.89
Days to 50% heading	10.11	10.56	0.91	19.93
Days to 80% maturity	9.04	10.35	0.76	16.28
Flag leaf blade length (cm)	5.77	11.13	0.26	6.17
Leaf blade length (cm)	7.67	10.94	0.49	11.07
Leaf sheath length (cm)	9.87	12.53	0.62	16.01
Number of leaves per plant	14.73	18.63	0.62	23.99
Productive tillers	9.25	31.41	0.08	5.16
Ear exertion (cm)	16.5	32.57	0.25	17.23
Finger length (cm)	22.56	25.62	0.77	40.95
Finger width (cm)	6.02	12.11	0.24	6.16
Plant height (cm)	10.98	27.73	0.15	8.96
Number of fingers per plant	8.2	13.43	0.37	10.32
Grain per spike	17.76	33.01	0.28	19.68
Thousand seed (g) weight	8.75	12.2	0.51	12.94
Fresh straw yield per plot (t/ha)	14.87	24.6	0.36	18.51
Grain yield (t/ha)	19.46	30.99	0.39	25.17

GCV = Genotypic coefficient of variance, PCV = Phenotypic coefficient of variance, h_{bs}^2 = heritability, GAM = Genetic advance as a mean

3.7 Elite lines:

Out of 33 accessions collected from 23 districts around Nepal, six accessions were selected as elite lines based on early maturity and high grain yield. CO14422 and CO11943 were found to be the earliest maturing accessions, taking 103 and 117 days to mature, collected from Jumla and Mugu districts, respectively. Meanwhile, NGRC05050 (4.4t/ha), CO11696 (3.85t/ha), and CO13039 (3.75t/ha) were promising landraces with higher grain yield at NAGRC, Lalitpur, collected from Kavre, Tanahun, and Kavre districts, respectively. These accessions could be regarded as valuable genetic resources that help in developing finger millet varieties.

Table 8. Elite lines

S. N	Specific trait	Landraces
1	Earlier days to 80% maturity	CO14422(103), CO11943(117)
2	Grain yield (t/ha)	NGRC05050 (4.4), CO11696 (3.85), CO13039(3.75)

4. DISCUSSION

In breeding programs, evaluating genetic resources and their diversity enhances understanding of population divergence, with morphological traits serving as a viable alternative to molecular methods, illustrated by the phenotypic variation among accessions. The utilization of diversity for breeding purposes and the selection of superior lines for the development of finger millet varieties have not gained much importance in Nepal, which plays a major role in food sustainability. Nepal, as a second center of diversity, had only 70 accessions preserved at the core collection developed by ICRISAT (Gairhe et al. 2021; Ghimire et al. 2023), and further studies, like characterization, have to be given more priority to assess the information about landraces for the advancement of crop improvement. In this study, a total of 33 finger millet landraces were characterized, and a wide variation was observed through multivariate analysis.

Descriptive statistics of both quantitative and qualitative traits showed a greater diversity among 33 accessions studied at NAGRC, Lalitpur. Accession CO14422 reached 80% maturity earlier at 103 days, followed by CO11943 (117) and CO11696 (129) with an overall mean of 142 days. In contrast, late maturing accessions were CO12435 (164), CO13048 (164), and CO12298 (163) with a range of 103 to 164 days. These findings were similar to the results of global accessions, i.e., 96 to 165 days (Bharathi 2011), suggesting that the presence of early maturing germplasm could be beneficial in breeding programs for drought-prone environments. The variation in days to 80% maturity may be due to its specific genetic factors and farmers' mediated selection over time for early-maturing landraces to overcome the cold and drought stress. Early-maturing accessions are found preserved in Jumla and other high-altitude regions of Nepal, which can be exploited to develop early-maturing lines by crossing with accessions having desirable traits, such as high yield, disease resistance, etc. The height of accessions (79-216 cm) was found to have greater variability compared to 84-143 cm in a global collection (Backiyalakshmi et al. 2021), and low variability compared to 55-240cm East African accessions (Reddy et al. 2009), which may be due to broader ecological sampling and greater genetic diversity in their study. CO12722 was the tallest of all the accessions, having 216.8cm, followed by CO11943 (116.7) and CO13252 (115.3 cm), which provides a significant contribution in fodder and straw yield, whereas shorter height tends to be more lodging tolerant. The average grain yield of 2.82 t/ha was observed, wherein NGRC05050, CO11696, CO13039, and NGRC05049 exhibited superior production levels. These observations differ from those presented by Ghimire et al. (2023), which may be attributed to variations in geographical conditions and genetic factors. These accessions exhibited early maturation and higher yield, which may be the result of escaping environmental stress and enhancing grain filling and yield. Similar results for quantitative traits like days to heading, leaf sheath length, productive tillers, leaf blade width, and finger length were found from the previous study, out of 537 accessions carried out at NAGRC, Lalitpur (Bhattarai et al. 2014). The high diversity observed under this study provides a resource for creating region-specific varieties.

More than half of the accessions (54%) exhibited a light brown color, and Ravikumar & Seetharam (1993) mentioned that white and light pigmentation possess high protein content, while dark color grains with blast blast-tolerant. Furthermore, brown seed color has multifaceted utility, including bread and high malting quality for brewing purposes. All of the landraces collected were found to be non-shattering, and it is likely due to preferences and selection for low shattering. Non-shattering reduces the yield loss at the time of harvesting, resulting in greater yield and easy threshability (Li et al. 2006).

The Shannon-Weaver diversity index is primarily used to assess the diversity among quantitative and qualitative characteristics, examining both richness and evenness. An elevated diversity index for quantitative traits was recorded

for attributes such as productive tillers (0.95), followed closely by leaf sheath diameter (0.91), leaf blade length (0.91), and days to first heading (0.90) in our study. The diversity index for qualitative traits revealed plant pigmentation (0.98) as the most pronounced, followed by ear shape and grain color, corroborating the findings of Bastola et al. (2015), which may be attributable to oligogenic genetic mechanisms and environmental interactions with landraces.

Among the four clusters, accessions CO11943 and CO14422 from cluster III are early-maturity accessions with a high number of fingers per plant. These accessions can be used to develop early-maturing lines for environments experiencing chilling stress during the maturity period. Similarly, clusters II and IV can be leveraged to create high-yielding lines, as these accessions exhibit high grain yield and finger length, respectively. The cluster analysis of the accessions was closely related to the principal component analysis, which was used to study the variation of a larger number of variables by reducing the dimension. In this study, 30.69% of the total variation was exhibited by the first principal component, and the major contributing traits were days to 50% heading, days to first heading, days to 80% heading, and no. of leaves per plant for the evaluation of the studied finger millet landraces. Similar results for phenological traits were reported by Ghimire et. al. (2023).

Genetic parameters such as PCV, GCV, heritability, and GAM accompanied the quantification of the heritable portion among genotypes, and the difference between PCV and GCV indicates the presence of environmental effects on the expression of traits (Anuradha et al. 2020). Particularly, higher PCV values were observed for traits including number of grains per spike (33.01%), ear exertion (32.57%), productive tillers (31.41%), grain yield (30.99%), and fresh straw yield per plot (24.6%). Finger length was observed to have a higher GCV (22.56%) and GAM (40.95%), with heritability of 0.77, representing the trait governed by additive gene action, and similar results were obtained by Patel et al. (2024). The difference between PCV and GCV was smaller for phenological traits like days to 50% heading, days to first heading, and days to 80% maturity, suggesting that selection would be more effective for genetic improvement in these areas. The findings regarding productive tillers and grain yield correspond with Raut et al. (2024), whereas finger length aligns with the study by Ganapathy et al. (2011). Heritability alone may not serve as an effective selection tool due to its susceptibility to environmental influences. Consequently, traits with high heritability and high GAM are prioritized for further selection in breeding programs. Among the traits examined, days to first heading, finger length, and number of leaves per plant exhibited both high heritability and high GAM, indicating effective selection at the phenotypic level and a predominance of additive gene action.

5. CONCLUSION

This study revealed diverse variation among the landraces preserved in the Gene Bank, NAGRC, Lalitpur, collected from 14 districts, using the Shannon-Weaver diversity index for various quantitative and qualitative traits. CO14422 and CO11943 were the early-maturing landraces, while CO11696 and CO13039 showed the best performance for high-yielding landraces among the studied accessions preserved in NAGRC, Lalitpur. These accessions should be deployed in multi-location trials to evaluate their response to diverse environmental conditions and assess their suitability. Additionally, further molecular characterization is essential for identifying the specific genes associated with traits important for plant breeding to develop novel varieties.

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Supplementary data

Table 1. Descriptor of quantitative traits

S.N.	Variables	Unit	Description
1	Days to first heading	Days	From sowing to the stage when the first heading occurs
2	Days to 50% heading	Days	From sowing to the stage when 50% of the main tillers have mature ears
3	Days to 80% maturity	Days	From sowing to the stage when 80% of the main tillers have mature ears
4	Flag leaf blade length	cm	Measured from ligule to leaf tip at the flowering stage
5	Flag leaf blade width	cm	Measured across the center at the flowering stage
6	Leaf blade length	cm	Measured from the ligule to the tip of the fourth leaf blade from the top at the flowering stage
7	Leaf blade width	cm	Measured across the center of the fourth leaf blade from the top at the flowering stage
8	Leaf sheath length	cm	Measured from the node to the ligule of the flag leaf from the top at the flowering stage
9	Leaf-sheath diameter	mm	Measured the circumference at the middle of the leaf sheath
10	Leaf number per plant	Count	Number of leaves at the flowering stage
11	Productive tillers	Count	Number of basal tillers which bear mature ears
12	Ear exertion	cm	Exsertion of inflorescence at the dough stage
13	Culm thickness	mm	Diameter of internode between the third and fourth nodes from the top at the dough stage
14	Finger length	cm	From the base to the tip of the longest spike on the main tiller at the dough stage
15	Finger width	cm	Measured across the center of the longest spike at the dough stage
16	Plant height	cm	From ground level to the tip of the inflorescence at the dough stage
17	Finger number per head	Count	Number of fingers present in the main ear at the dough stage
18	Number of grains per spike	Count	Average number of seeds per spike from 5 typical spikes randomly selected from growing Landraces
19	Thousand seed weight	g	The weight of a random sample of 1000 seeds from the total harvest of an accession was expressed in grams
20	Biological yield	t/ha	
21	Grain yield	t/ha	Grain yield harvested from the net plot area and converted to t/ha

Table 2. Descriptor of qualitative traits

S.N.	Variables	Descriptor states
1	Plant pigmentation	Not pigmented (0), Pigmented (+)
2	Ear shape	Droopy (1), Open (2), Semi-compact (3), Compact (4)
3	Ear size	Small (3), Intermediate (5), Large (7)
4	Spikelet density	Sparse (3), Intermediate (5), Large (7)
5	Spikelet shattering	Absent (0), Present (+)
6	Grain color	White (1), Light-brown (2), Copper-brown (3), Purple-brown (4)

Table 3. Frequency distribution and Shannon-Weaver diversity of 6 qualitative traits

S.N.	Parameters	Descriptor states	Frequency(n)	Percentage (%)	H'
1.	Plant pigmentation	+ (Present)	14	42.42	0.98
		0 (Absent)	19	57.58	
2.	Ear shape	1 (Droopy)	4	12.12	0.86
		2 (Open)	8	24.24	
		3 (Semi-compact)	17	51.52	
		4 (Compact)	4	12.12	
3.	Ear size	3 (Small)	2	6.06	0.76
		5 (Intermediate)	20	60.61	
		7 (Large)	11	33.33	
4.	Spikelet density	3 (Sparse)	5	15.15	0.39
		5 (Intermediate)	28	84.85	
5.	Spikelet shattering	0 (Absent)	33	0	0
6.	Grain color	1 (White)	5	15.15	0.85
		2 (Light brown)	18	54.55	
		3 (Copper brown)	4	12.12	
		4 (Purple brown)	6	18.18	

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Datasheet.xlsx](#)