

Nutritional and anti-nutritional potentials and variability among selected finger millet (*Eleusine coracana* subsp. *coracana*) landraces of Tigray, northern Ethiopia

Tesfakiros Semere

tesfish.24@gmail.com

Mekelle University

Lijalem Tareke

Mekelle University

Ashenafi Teklay

Mekelle University

Etsay Mesele

Mekelle University

Melaku Mekonen Kasegn

Mekelle University

Haregot Fisseha

Mekelle University

Girmay Mekonen

Mekelle University

Birhanu Kahsay

Mekelle University

Lijalem Gebrewahid Embaye

Mekelle University

Wendm Yigzaw

Mekelle University

Hailay Mehari Gebremedhin

Mekelle University

Negash Aregay Weldekidan

Mekelle University

Yemane Tsehaye

Mekelle University

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Abstract

Finger millet is one of the staple food crops used for different end-uses in Tigray, northern Ethiopia. However, limited research attention has been given to its nutritional and anti-nutritional profiling. Thus, this research was conducted to assess the potential and variability in protein, starch, minerals, flavonoid, tannin, and antioxidant activities among selected finger millet landraces. Protein and starch were analyzed using an infrared spectrophotometer, whereas mineral elements were estimated using an atomic absorption spectrophotometer. Antioxidant activity was analyzed using ferric-reducing antioxidant power and phosphomolybdenum assays. The result revealed significant variation among the landraces for all the evaluated nutritional and anti-nutritional components. Respectively, protein and starch contents ranged from 8.79 to 11.05% and 70.30 to 76.17%. Extensive variations were observed for Fe (93.56–742.59), Zn (14.76–30.13), Cu (8.29–13.11), Mn (88.40–201.303), and Cr (2.54–6.58) as measured in mg/100g. High variabilities for total flavonoid (4–33.88 mg CE/g) and tannin (0.76–2.70 mg CE/100 g) were also observed. Ferric reducing antioxidant power (15.55–57.06 mg AAE/g), and total antioxidant activity (7.78–20.59 mg BHTe/g) were also highly variable among the samples. Multivariate analysis revealed three distinct groups of the tested landraces. The rich genetic diversity in the nutritional and anti-nutritional attributes may be an opportunity for breeding for grain quality improvements of finger millet that, in turn, helps in addressing malnutrition.

1. Introduction

Finger millet (*Eleusine coracana* L. Gaertn.), a member of the Poaceae (Gramineae) family, is one of the most important food cereals in sub-Saharan Africa and south Asia [1]. It is a food security crop with a high impact on poor Africans as a source of energy and gluten-free protein. It is a potential future crop because of its adaptability to environmental fluctuations and high nutritional value [2]. The high nutritive value of finger millet, coupled with its ability to thrive under poor soil fertility and low rainfall conditions, makes it a climate-smart crop.

The occurrence of the wild progenitor *E. africana* [3] in the fields of finger millet in Ethiopia, including Tigray, and the associated indigenous knowledge on its cultivation and utilization could suggest Ethiopia as a possible place of domestication for this crop. Besides, Hilu et al. [4] noted that the oldest domesticated finger millet occurs in the archaeological records of Ethiopia, dating back around 5000 years. In Ethiopia, finger millet is a very important cereal crop, particularly in the drought-prone lowland areas. It often occupies important niches, thrives in the risky and fragile conditions of rural communities, and is ideal in marginal lands due to its resilience to various stresses. In the major finger millet-growing areas of the country, it thrives relatively well in drier years and serves as an important crop during times of famine [5]. The wide topographical and climatic distribution in Ethiopia is an indication for a remarkable genetic diversity among crop species, including finger millet. This crop is considered one of Ethiopia's ancient and indigenous crops, traditionally used to make Ethiopian flat bread ("enjera"), porridge, and undistilled local beer (referred to as "swa" in Tigrigna or "tela" in Amharic).

Finger millet is higher in protein, fat, and minerals than rice, maize, or sorghum. The main protein fraction (eleusinins), is of high biological value and contains good amounts of tryptophan, cystine, methionine, and total aromatic amino acids, which are deficient in most cereals [6] (National Research Council, 1996). The richness in dietary fiber, calcium, polyphenol, and protein content in millets makes them unique among the cereals [7]. Millets are very good sources of carbohydrates, micronutrients, and phytochemicals. The grain is particularly a good option for individuals with celiac disease as it is gluten-free and easy to digest [8]. Bioactive compounds

such as tannins, anthocyanins, flavonoids, and minerals obtained from cereal grains are associated with a wide range of human health benefits, including oxidative stress-related disorders, lipid-lowering, antibacterial, antiviral, anti-inflammatory, and anticancer properties [9, 10].

Finger millet is one of the predominant stable food crops in the Tigray region of northern Ethiopia [5] and is primarily grown by small-scale farmers in the central and northwestern zones. Despite its being diverse and stable food crop used for different end-uses, such as enjera and Swa in Tigray, information on nutritional and anti-nutritional profiling and variability among the different landraces is limited. This makes it crucial to profile the nutritional and anti-nutritional components of finger millet landraces. Hence, the objective of this study was to determine the amount and variations of protein, starch, minerals, flavonoid, tannins, and antioxidant activities of selected finger millet landraces. This will serve as a benchmark for the nutritional improvement of finger millet.

2. Materials and Methods

2.1. Plant materials

Twelve finger millet samples were collected in situ (on-farm) from different areas of Tigray, northern Ethiopia. The names of the 12 finger millet landraces, along with some of their descriptions, are listed in Table 1.

Table 1
List of the 12 finger millet landraces used in the study with their end-uses

No.	Landrace name	Preferred end-use
1	Abat	Swa/Enjera
2	Fejer 1	Enjera
3	Fejegl原因	Enjera/Swa
4	Keyih Dagusha	Enjera
5	ZerE-Gebreslassie	Enjera
6	TsaEda Dagusha 1	Enjera/Swa
7	Akoma	Swa/Enjera
8	ZerE-Tesfay	Swa/Enjera
9	ZerE-Welkayt	Enjera/popping
10	Fenjel	Enjera/Swa
11	TsaEda Dagusha 2	Enjera/Swa
12	Fejer 2	Swa/Enjera

2.2. Sample preparation and extraction

The collected seed samples were cleaned and kept for further analysis. The samples were then ground into a fine powder using an electric grinder (FM100 model, China), and an extract was prepared by dissolving 10 g of

the fine powder in 100 ml of methanol. The contents were kept in an orbital shaker for 8 hours at room temperature. Thereafter, each extract was filtered using Whatman No. 1 filter paper and evaporated to dryness under vacuum at 40 °C using a rotary evaporator (Buchi, 3000 series, Switzerland). The resulting extracts were kept in a sealed glass bottle at -20 °C for further analysis, including total tannin content, total flavonoid content and antioxidant activities.

2.3. Determination of protein and starch

Protein and starch contents of the finger millet samples were analyzed using near-infrared spectrophotometers [11]. A sample of 100 g of pure finger millet seeds from each landrace were placed in a sample cup for scanning of the whole seeds. The samples were scanned twice, and the average values of protein and starch were recorded.

2.4. Estimation of mineral elements

The contents of mineral elements in the finger millet landraces, including iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), and chromium (Cr), were estimated using an atomic absorption spectrophotometer (Varian AA240FS) as described by Melash and Mengistu [12]. A dried seed sample of each landrace was ground to a fine powder, with 2 g of the powder placed in the ashing vessel and ashing was done at 550 °C. the resulting ash was then dissolved in a mixture of HCl-H₂O (1:1) to complete the ashing process. Subsequently, the samples were subjected to mineral analysis using an atomic absorption spectrophotometer equipped with an air-acetylene flame. The estimated concentrations of minerals were recorded in milligrams per 100 grams (mg/100g) of the sample.

2.5. Determination of Total Flavonoid Content (TFC)

The TFC of the samples was estimated according to the method of Quettier et al. [13]. The methanol extract (1 mg/ml) was first diluted with 1.25 ml of distilled water and then 75 µl of NaNO₂ was added to the mixture. Subsequently, AlCl₃ (150 µl; 10%) and NaOH (1 ml; 1M) were added separately to the mixture following a 5-minute interval. The absorbance of the resulting pink colored solution was then measured at 415 nm against a blank sample (methanol extract without AlCl₃). The measurement was performed twice, and the average absorbance was recorded. TFC was determined using a standard curve of catechin (1–40 µg/ml), and the values were calculated as milligrams of catechin equivalent per gram of dried extract (mg CE/g).

2.6. Determination of Total Tannin Content (TTC)

The TTC was determined according to the method described by Chew et al. [14]. A volume of 0.5 ml of undiluted crude extract (1 mg/ml) was mixed with 3 ml of vanillin reagent (4% w/v, in absolute methanol), followed by an addition of 1.5 ml of concentrated HCl. The mixture was then kept at room temperature for 15 minutes in a dark environment. Blank was prepared by replacing the 0.5 ml of undiluted crude extract with 0.5 ml of deionized water. The absorbance of the mixture was measured at 500 nm against a blank using a spectrophotometer. The measurement was performed twice and the average absorbance was recorded. Catechin (1–40 µg/ml) was used to calibre the standard curve and the results were expressed as milligrams of catechin equivalent per 100 g of dry weight sample (mg CE/100g).

2.7. Determination of Ferric Reducing Antioxidant Power

The ferric-reducing antioxidant power (FRAP) assay was performed as described by Desalegn [15]. A solution of sample extract (1 mg/ml) was mixed with sodium phosphate buffer (2.5 ml, 0.2 M, pH 6.6) and potassium ferricyanide (2.5 ml, 1% w/v). The mixture was incubated at 50 °C for 20 minutes, followed by the addition of trichloroacetic acid (2.5 ml, 10% w/v) and centrifugation at 3000 rpm for 5 min. Subsequently, 2.5 ml of the supernatant solution was mixed with 2.5 ml of distilled water and 0.5 ml of FeCl₃ (0.1% w/v). the resulting solution was incubated at room temperature in the dark for 30 minutes, and the absorbance was measured at 700 nm using a spectrophotometer. The measurement was performed twice and the average absorbance was recorded. The ferric reducing power capacities of the sample extracts were depicted graphically by plotting absorbance against concentration. The antioxidant activity was quantified in milligrams of ascorbic acid equivalents per gram of dried extract (mg AAE/g) based on the L-ascorbic acid calibration curve.

2.8. Determination of Total Antioxidant Capacity

The total antioxidant activities (TAC) of the samples were determined using a phosphomolybdenum assay according to the method of Prieto et al. [16] with some modifications. A 0.3 ml sample extract was mixed with 2.5 ml of phosphomolybdenum reagent (0.6 mM sulfuric acid, 28 mM sodium sulfate, and 4 mM ammonium molybdate, all mixed in 250 ml of distilled water). The absorbance of the reaction mixture was measured at 695 nm using a spectrophotometer. The total antioxidant capacity was quantified as milligrams butylated hydroxytoluene equivalent per gram of dried extract (mg BHTE/g).

2.9. Statistical data analysis

The results obtained from the two replicates of all parameters were reported as mean values $\pm$ standard error of mean. Pearson's correlation coefficients were used to assess associations among the nutritional attributes. Cluster analysis was conducted on the standardized data using the Ward Linkage method and Squared Euclidean Distance measure in MINITAB v21. Principal component analysis (PCA) was performed using a correlation matrix to define the existing pattern of variation among populations using Past4.0 software.

3. Results

3.1. Protein, starch, and mineral contents

The current study revealed that there were highly significant ($p < 0.001$) differences in protein, starch, and mineral contents among the twelve finger millet landraces. The protein content ranged from 8.79 to 11.05%, with a mean value of 9.72% (Table 3). Protein content similarity was observed among the finger millet landraces with similar local names, but variability was seen in others. For example, the protein content of finger millet landraces like Fejer (9.45–10.31%) and TsaEda Dagusha (8.97–9.53%) was variable (Table 2). Higher protein content was found in ZerE-G/slassie with a value of 11.05%, followed by Fejer 1 and Fenjel with similar protein contents of 10.30%, whereas lower protein content was found in ZerE-Tesfay (8.79%), followed by TsaEda Dagusha 2 (8.97%). The starch content in the landraces ranged from 70.30 to 76.17% (Table 3), with Akoma having the highest (76.17%) starch content followed by Abat (74.05%) (Table 2). The lowest starch content (70.30%) was found in Fejer 2, followed by Fejeglay, with a value of 71.36%. As is shown in protein, similarity in starch content was also observed among landraces with the same local names; for example, the starch content of Fejer was within the range of 70.3 and 71.87%.

The concentration of Fe ranged from 93.56 mg/100g to 742.59 mg/100g (Table 3). Among the landraces, Fejer 1 had the highest Fe concentration (742.59 mg/100g), followed by Keyih Dagusha (639.80 mg/100g). TsaEda Dagusha 1 and Fenjel had the lowest Fe values with 93.56 and 130.91 mg/100g, respectively (Table 2). Zinc concentrations were highest in the landrace Fejer 1 (30.13 mg/100g) and lowest in ZerE-Tesfay (14.76 mg/100g). The highest level of Cu concentration (13.11 mg/100g) was found in landrace ZerE-Welkayt, while the lowest (8.29 mg/100g) was found in landrace Abat. The highest Mn (201.3 mg/100 g) and Cr (6.58 mg/100g) were recorded from the landraces ZerE-Gebreslassie and ZerE-Welkayt, respectively. The minimum concentrations of Mn (88.4 mg/100g) and Cr (2.54 mg/100g) were, however, recorded by Landarces ZerE-Tesfay and Fejer 2, respectively.

Table 2
The value of protein, starch, and minerals for all the 12 finger millet landraces

No	Landrace name	Protein (%)	Starch (%)	Fe (mg/100g)	Zn (mg/100g)	Cu (mg/100g)	Mn (mg/100g)	Cr (mg/100g)
1	Abat	9.64	74.05	204.14	29.87	8.29	141.77	3.74
2	Fejer 1	10.31	71.87	742.59	30.14	11.38	154.14	3.96
3	Fejeglay	10.16	71.36	547.18	29.69	10.65	152.42	4.67
4	Keyih Dagusha	9.22	72.69	639.80	22.70	11.13	182.05	5.88
5	ZerE-G/slassie	11.05	72.51	176.59	28.85	12.35	201.27	2.84
6	TsaEda Dagusha 1	9.63	73.47	93.56	16.68	8.88	109.87	2.88
7	Akoma	9.38	76.17	289.15	24.75	12.15	169.44	4.87
8	ZerE-Tesfay	8.79	72.16	563.80	14.76	10.15	88.37	3.01
9	ZerE-Welkayt	9.72	72.77	406.47	19.64	13.11	119.57	6.58
10	Fenjel	10.30	72.13	130.91	17.40	10.51	164.43	4.80
11	TsaEda Dagusha 2	8.97	73.23	559.06	21.07	12.54	99.41	4.95
12	Fejer 2	9.45	70.30	219.45	16.78	8.71	113.08	2.54

Table 3
Descriptive statistics for nutritional and anti-nutritional traits of finger millet landraces

Variable	Min	Max	Mean	SD	t-test
Protein (%)	8.79	11.05	9.72	0.64	0.000
Starch (%)	70.30	76.17	72.73	1.47	0.000
Fe (mg/100g)	93.56	742.59	381.1	222.40	0.000
Zn (mg/100g)	14.76	30.13	22.69	5.82	0.000
Cu (mg/100g)	8.29	13.11	10.82	1.59	0.000
Mn (mg/100g)	88.40	201.30	141.3	35.30	0.000
Cr (mg/100g)	2.54	6.58	4.225	1.28	0.000
Flavonoid (mg CAE/100g)	4.00	33.88	15.20	9.41	0.000
Tannin (mg CAE/g)	0.76	2.70	1.92	0.66	0.000
FRAP (mg AAE/g)	15.55	57.06	28.92	13.72	0.000
TAC (mg BHTE/g)	7.78	20.59	13.53	4.26	0.000
<i>Min = minimum, Max = maximum, SD = Standard deviation, Fe = Iron, Zn = Zinc, Cu = Copper, Mn = Manganese, Cr = Chromium FRAP = Ferric Reducing Antioxidant Power, TAC = Total Antioxidant Capacity</i>					

3.2. Variability in Flavonoid, Tannin, and antioxidant activities

The finger millet landraces analyzed in this study displayed flavonoid levels ranging from 3.99 to 33.87 mg CAE/100 g, with a mean value of 15.20 mg CAE/100 g (Table 3). The landraces Keyih Dagusha (33.87 mg CAE/100 g) and ZerE-Welkayt (3.99 mg CAE/100 g) exhibited the highest and lowest flavonoid content, respectively (Table 4). Next to Keyih Dagusha, ZerE-Tersfay scored a higher flavonoid content with 29.26 mg CAE/100 g (Fig. 1).

Table 4
The value of flavonoid, tannin, and antioxidant activities for all the 12 finger millet landraces

No	Landrace name	Flavonoid (mg CAE/100g)	Tannin (mg CAE/g)	FRAP (mg AAE/g)	TAC (mg BHTE/g)
1	Abat	18.185	2.62	16.88	9.67
2	Fejer 1	14.91	1.975	23.13	9.605
3	Fejeglay	20.235	1.125	37.03	19.48
4	Keyih Dagusha	33.875	2.7	57.065	20.595
5	ZerE-G/slassie	10.055	0.92	26.635	17.305
6	TsaEda Dagusha 1	6.78	2.245	15.835	10.125
7	Akoma	7.895	0.755	16.7	11.71
8	ZerE-Tesfay	29.255	1.97	51.115	14.77
9	ZerE-Welkayt	3.995	2.565	15.55	7.775
10	Fenjel	9.015	1.94	25.5	10.885
11	TsaEda Dagusha 2	7.96	1.895	27.765	13.275
12	Fejer 2	20.265	2.34	33.835	17.14

Tannin content of the finger millet landraces ranged from 0.76 to 2.7 mg CAE/g, with a mean of 1.92 mg CAE/g (Table 3). Among the 12 landraces, Keyih Dagusha, Abat, ZerE-Welkayt, and Fejer 2 showed the highest levels of total tannin content with 2.7, 2.62, 2.56, and 2.34 mg CAE/g, respectively (Table 4). The lowest amount of total tannin content was observed in Akoma (0.76 mg CAE/g), followed by ZerE-G/slassie (0.92 mg CAE/g) (Fig. 2).

The antioxidant activities showed a highly significant difference ($P < 0.001$) among the landraces (Table 3). The landraces displayed a wide range of ferric-reducing antioxidant power, with values ranging from 15.55 to 57.06 mg AAE/g. Keyih Dagusha exhibited the highest ferric-reducing antioxidant power (57.06 mg AAE/g), followed by ZerE-Tesfay (51.12 mg AAE/g) and Fejeglay (37.03 mg AAE/g) (Table 4). In contrast, ZerE-Welkayt (15.55 mg AAE/g), Tsaeda Dagusha 1 (15.84 mg AAE/g), Akoma (16.70 mg AAE/g), and Abat (16.88 mg AAE/g) exhibited the lowest ferric-reducing antioxidant power among the landraces.

Strongest and weakest total antioxidant capacity were also found in landraces Keyih Dagusha (20.56 mg BHTE/g) and ZerE-Welkayt (7.78 mg BHTE/g), respectively. Next to Keyih Dagusha, the three finger millet landraces with the highest total antioxidant activity were Fejeglay (19.48 mg BHTE/g), ZerE-G/slassie (17.31 mg BHTE/g), and Fejer 2 (17.14 mg BHTE/g) (Table 4). On the other hand, landraces Fejer 1 (9.61 mg BHTE/g) and Abat (9.67 mg BHTE/g) were among the landraces that exhibited the weakest total antioxidant activity (Fig. 3).

3.3. Grouping and ordination of genotypes

3.3.1. Cluster analysis

The result shows that the twelve finger millet landraces were clustered into three groups (Fig. 4). Respectively, clusters I, II, and III consist of 6, 3, and 3 landraces. High variability was observed in cluster means for all traits (Table 5). Genotypes under cluster I are characterized by their lower contents of Fe, flavonoids, and antioxidants (FRAP and TAC), but higher levels of starch and Cr. Those in cluster II have the highest protein and mineral contents (Fe, Zn, Cu, and Mn) with moderate levels of phenolics and antioxidant activities. Genotypes in cluster III have the lowest amount of mineral contents (Zn, Cu, and Mn) but the highest phenolics (flavonoid and tannin) and antioxidant activities.

Table 5
Mean of finger millet nutritional and anti-nutritional traits of the three clusters

Mean of nutritional traits											
Cluster	Protein	Starch	Fe	Zn	Cu	Mn	Cr	TFC	TTC	FRAP	TAC
I	9.61	73.64	280.50	21.57	10.91	134.10	4.64	8.97	2.00	19.71	10.57
II	10.51	71.91	489	29.56	11.46	169.30	3.82	15.07	1.34	28.93	15.46
III	9.15	71.72	474	18.08	9.99	127.80	3.81	27.80	2.34	47.34	17.50

3.3.2. Principal component analysis

Out of the 12 principal components (PCs), the first three PCs contributed much of the variability with eigenvalues greater than unity and cumulatively accounted for 72.30% of the total variation among the landraces. Thus, these three PCs were considered important for this study, but the first two component scores were plotted to aid visualization of the overall variability among the samples (Fig. 5). The three PCs explained 30.45, 23.83, and 18.02% of the total variability for the evaluated traits, respectively (Table 6). The result of PCA revealed that the nutritional traits showed different patterns of contribution to the overall variability among the landraces. In PC 1, flavonoid, ferric reducing antioxidant power, Fe, and total antioxidant capacity had a higher contribution with positive loading, whereas protein and starch had a higher contribution in the negative direction. On the other hand, mineral elements like Mn, Zn, and total antioxidant capacity greatly contributed to the positive loading for the variability in PC 2.

Table 6
Principal component matrix showing eigenvalues, total variance, and cumulative variance for the 12 nutritional traits of finger millet landraces

Traits	PC1	PC2	PC3
Flavonoid	0.88	0.29	-0.08
Tannin	0.44	-0.53	0.17
FRAP	0.89	0.37	0.06
TAC	0.60	0.62	-0.23
Fe	0.47	0.41	0.59
Zn	-0.37	0.68	-0.07
Cu	-0.36	0.45	0.66
Mn	-0.35	0.78	-0.17
Cr	-0.13	0.20	0.84
protein	-0.55	0.50	-0.49
Starch	-0.54	-0.11	0.37
Eigenvalue	3.35	2.62	1.98
Total variance (%)	30.45	23.83	18.02
Commutative variance (%)	30.45	54.28	72.30

4. Discussion

4.1. Variability in protein, starch and mineral contents

In the present study, the variability in protein content among the 12 landraces of finger millet may be due to the genetics of the landraces and agroecological conditions. The highest protein content found in this study (11.05%) exceeds the protein content reported in a previous study by Nakarani et al. [17], which was between 6.7 and 8.0%. Various studies have also revealed significant variations in protein content among finger millet landraces that ranged from 6.7–12.3% [18], 6.3–10.5% [19], 3.55–18.20% [20], and 10–14.6% [21]. Protein is the second major component of finger millet in terms of nutritional content [22], suggesting its potential as an alternative protein source in diets and/or as a supplement, especially for rural communities. The starch content is known as an important determinant of grain yield and quality [23], with the great variability in starch content indicating genetic differences among finger millet landraces and environmental effects. Such a wide variability aligns with findings from previous studies [24]. The starch content range observed in the current study (70.3–76.17%) surpasses the range reported by Nirmala et al. [25], which was between 59.4 and 70.2%. The high-protein and high-starch finger millet landraces could be targeted for the development of complementary food products to enrich the nutritional profile of finger millet-based food products. In addition, plant breeders may also consider these landraces as potential starting materials for improving grain quality in finger millet.

Finger millet landraces exhibit significant variation in the mineral element composition of their grains. Factors such as environmental conditions, soil nutrient availability, genetic variations, and other variables could all contribute to this variability [22, 26, 27]. The growing environment may have an impact on the uptake, translocation, and accumulation of mineral elements [12]. Similar to the current study, variability in mineral contents among different finger millet genotypes was reported in previous studies [21, 23, 28, 29]. One of the best ways to address severe malnutrition issues is through biofortification, which increases the density and availability of micronutrients [30]. As a result, the high mineral concentration investigated in the finger millet landraces studied could be a promising resource for biofortification. Specific landraces such as Fejer 1 and Keyih dagusha, which are rich in Fe and Zn, could be beneficial for individuals with micronutrient deficiencies. In general, landraces with improved mineral elements could serve as valuable breeding material to create new and nutritionally rich varieties, or could be consumed directly as whole grains to meet daily micronutrient requirements.

4.2. Variability in phenolic compounds and antioxidant activities

The finger millet landraces in the current study exhibited a wide range of flavonoid content, as indicated by previous studies that found levels ranging from 24.33 to 84.50 mg/100g [22], 101.3–115.8 mgCE/100g [31], and 2.75–39.36 mg/100g [32]. The observed variation in flavonoid content among the different landraces could be attributed to the genetic factors and various agro-climatic conditions. Flavonoids play a vital role in plant development by regulating auxin transport. This flavonoids found in diets offer several abenefits, such as anti-diabetic properties [31], acting as radical scavengers [33], anti-inflammatory properties [34], and anti-tumorigenic effects [35]. According to the reports of the National Research Council [6] and Kumar et al. [36], finger millet is recognized as one of the most nutritious crops among the major food grains, containing high-quality minerals (calcium and iron) and amino acids (methionine) and providing 8–10 times more calcium than wheat or rice. On the other hand, finger millet grain contains various anti-nutritional factors and phenolic compounds such as tannin, oxalate, and phytate [37–39].

The findings of the present study regarding the total tannin content are in agreement with the findings of Owheruo et al. [40], who found a mean tannin content of 1.64 mg/g in raw millet flour. Other studies [20, 41, 42] have reported higher amount of tannin content in finger millet genotypes compared to the current findings. The variations in tannin content among the different landraces may be attributed to differences in genotypes and environmental conditions [42]. The presence of tannins in some finger millet cultivars could have agronomic significance, providing tolerance to biotic stresses such as molds and birds. On the contrary, when consumed by human being, the presence of tannin in finger millet can negatively affect digestibility, nutrient utilization, and mineral absorption [43–45]. Plant extracts contain antioxidants that play a role in reducing molybdenum (VI) to molybdenum (V) and ferric ion (Fe^{3+}) to ferrous (Fe^{2+}). since the value is based on the reduction of ions in the presence of antioxidants, the higher reducing values observed in the finger millet landrace of Keyih Dagusha (a local name to mean red finger millet) implies it possesses a higher antioxidant capacity [46]. As a result, finger millet can be utilized as a natural antioxidant against free radicals and other physiological or pathological abnormalities.

4.3. Clustering and principal component analysis

Cluster analysis helps to facilitate future identification and selection of the best parents for nutritional improvement of crops, such as finger millet. The wide range of cluster means in this study suggests an extensive

genetic diversity among the planting materials for the studied nutritional and anti-nutritional traits.

PCA was conducted to reduce the number of variables into a few correlated components that can explain much of the variability and to estimate the relative importance and contribution of each nutritional and anti-nutritional trait to the total variance. The sign of the loading indicates the direction of the relationship between the components and the variables [47]. The biplot generated from the PCA results clearly shows the associations and differences among the landraces and targeted traits. The distinctiveness of characters that appear less than a 90° angle apart are positively correlated, whereas those that are more than 90° apart show a negative correlation and those that have a 90° between them do not show any correlation [48].

Programs aimed at improving finger millet could benefit from the large genetic variability in the nutritional and anti-nutritional composition of landraces, which remained dispersed throughout the four quadrants. Comparatively speaking, landraces in close proximity tend to have similar nutritional qualities, while those further apart exhibit different qualities. Landraces that are distant from their origin are separated from the rest due to their unique nutritional and anti-nutritional characteristics. Selecting these landraces as potential parent materials would therefore aid in successful crossing of a particular finger millet variety with improved nutritional attributes. The length of the vector represents the strength of the trait in grouping the landraces. Landraces positioned in the direction of the vector arrows show high values for the trait, while those on the other side of the arrows indicate a small values.

5. Conclusion

In conclusion, the current study highlights the diverse nutritional and anti-nutritional attributes of finger millet that could contribute to food and nutrition security. As a result, finger millet has the potential to serve as one of the main stable cereal crops throughout Tigray, instead of being localized to specific locations. It can also partially substitute other common cereals in marginal areas because its stress tolerance ability. The landraces with superior nutritional profiles such as ZerE-G/slassie for protein, and Akoma for starch can serve as potential resources for enhancing grain quality in finger millet and developing new food products. The rich genetic diversity in the nutritional and anti-nutritional attributes may provide some novel genes for enhanced grain quality in finger millet, underscoring the importance of conserving and utilizing the genetic resources of finger millet. Finally, the findings of the present study will serve as a benchmark in designing biofortification and/or breeding for improved nutritional quality traits in finger millet.

Declarations

Author Contribution

Material preparation, data collection, and analysis were performed by T.S., L.T., and Y.T. The first draft of the manuscript was written by T.S, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

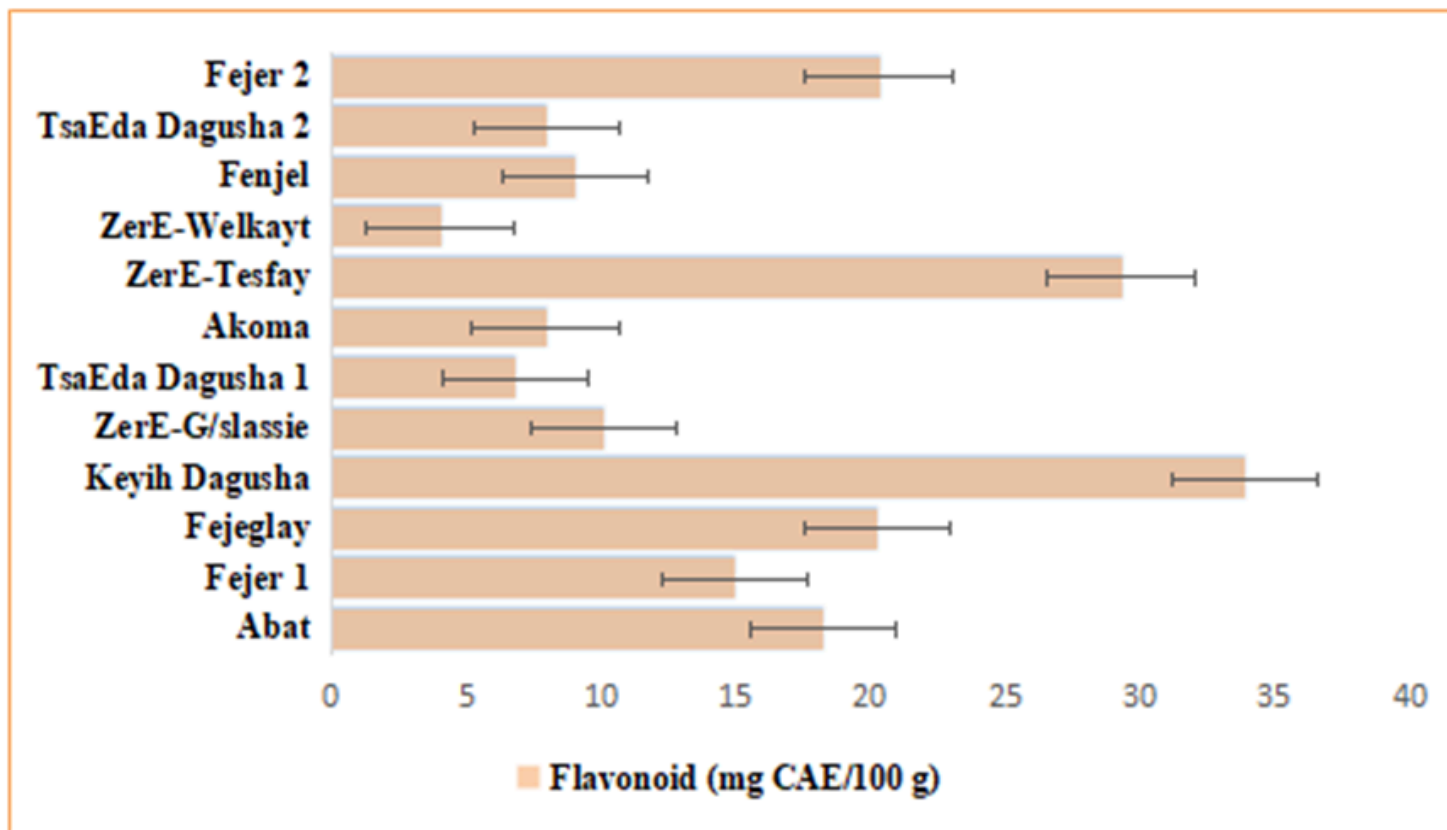


Figure 1

Variability for total flavonoid contents among 12 finger millet landraces

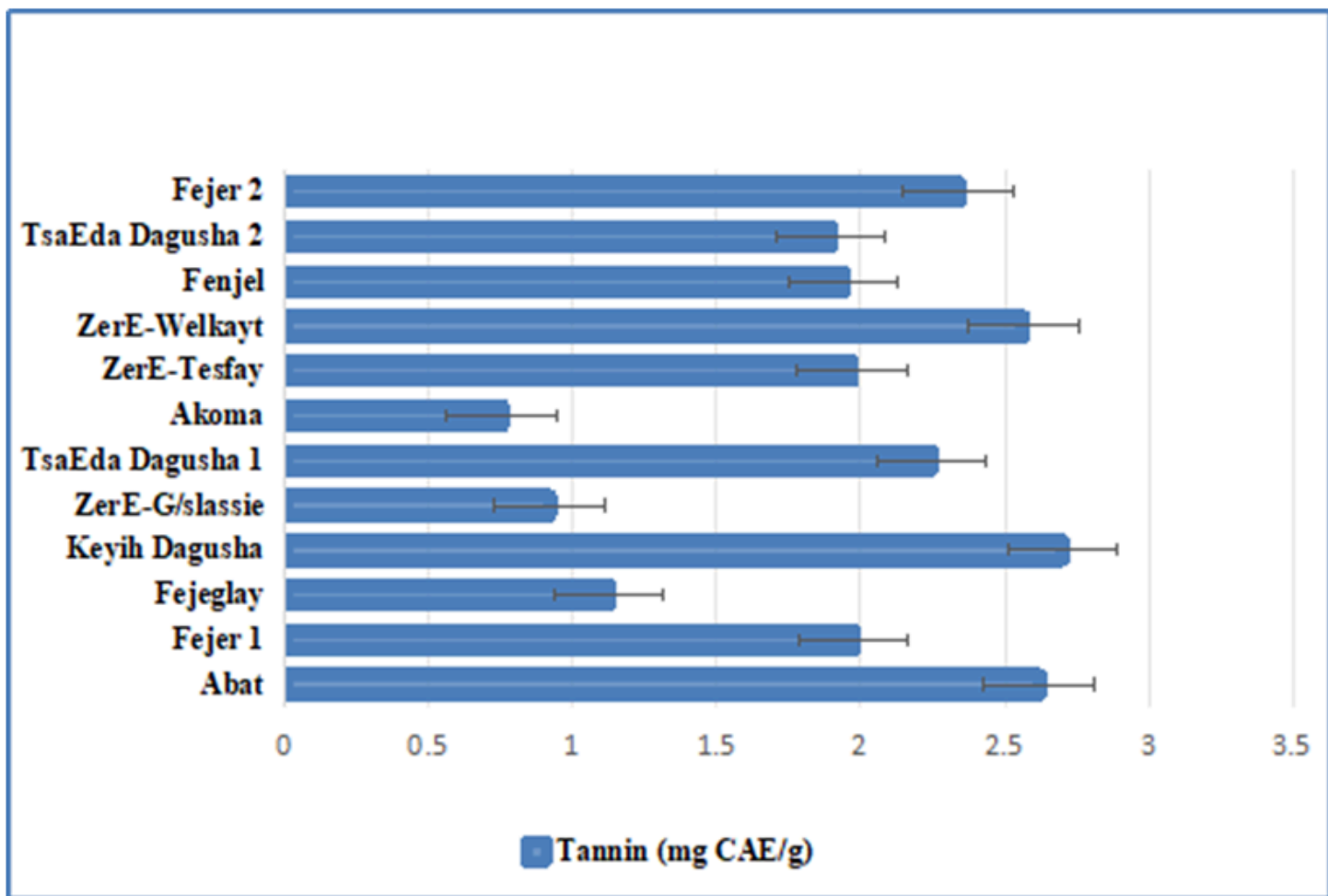


Figure 2

Variability for total flavonoid contents among 12 finger millet landraces

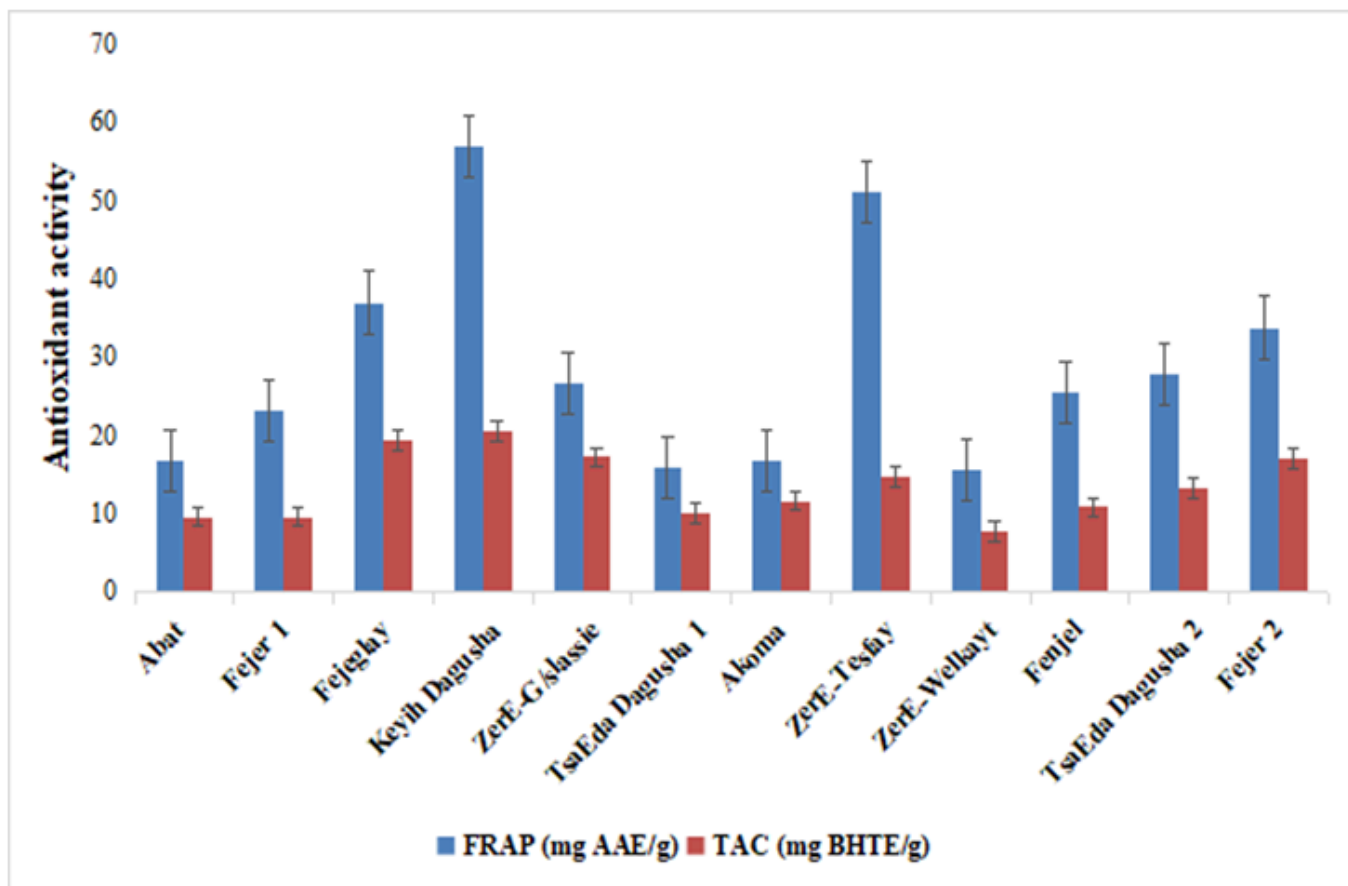


Figure 3

Variability for antioxidant capacities among 12 finger millet landraces

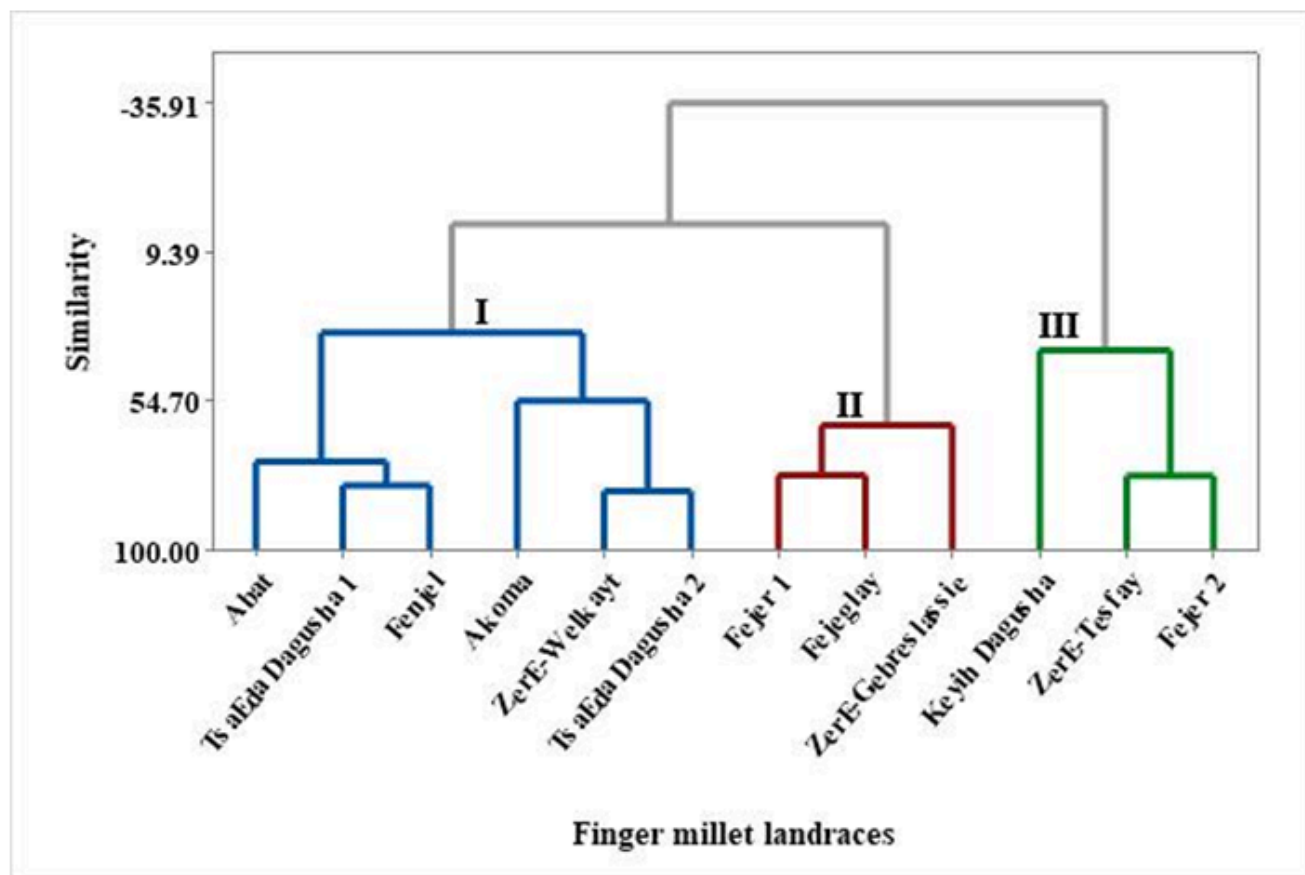


Figure 4

Dendrogram showing sorghum landraces clustered into different distinct groups

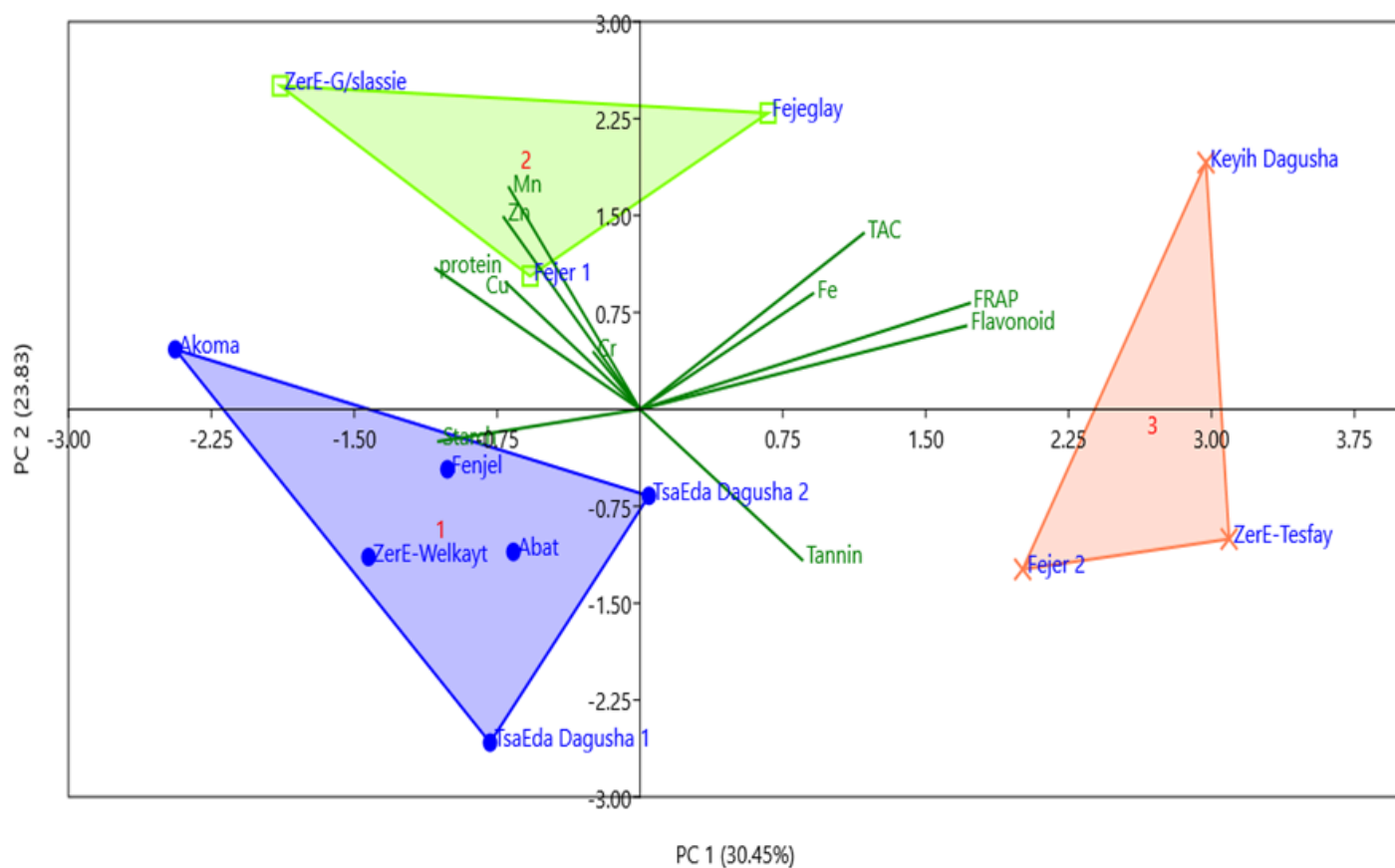


Figure 5

Biplot of the 12 finger millet landraces and nutritional traits for the first and second principal components