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Original article – Thematic Issue

Assessing qualitative and phenotypic trait diversity in Ethiopian enset [*Ensete ventricosum* (Welw.) Cheesman] landraces

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Summary

Introduction – **Enset [*Ensete ventricosum* (Welw.) Cheesman] is one of the major indigenous crops in Ethiopia providing food for over 20% of the population.** *Materials and methods* – **A total of 286 enset landraces sourced from six different regions of Ethiopia were evaluated for seven qualitative and phenotypic traits (maturity time, colour of leaf lamina, upper- and under-side colour of the petiole and leaf midrib, and leaf tip edge colour) at the Areka Agricultural Research Centre in south-western Ethiopia, to determine the extent and pattern of morphological and phenotypic variations. Percentage frequency for the seven traits and classes of the qualitative and phenotypic traits were calculated. The Shannon-Weaver diversity index (H') was computed using the class frequencies to assess the diversity for each trait for all landraces.** *Results and discussion* – **All qualitative traits showed a wide range of variation across the assessed landraces. The Shannon-Weaver diversity index (H') for all sampled germplasm ranged from 0.50 to 0.89, with a mean of 0.73. Analysis of variance for the Shannon-Weaver diversity index (H') revealed highly significant ($P<0.01$) differences between regions for all traits. Cluster analysis grouped the landraces into four clusters. Under-side (abaxial) and upper-side (adaxial) petiole colour and under-side midrib colour were the main traits for grouping the landraces into respective clusters.** *Conclusion* – **The present findings revealed that there is high genetic diversity in the Ethiopian enset landraces even though the extent of this diversity differed according to the region of collection. Generally, considerable variations important for enset improvement work have been observed, and regions with the highest diversity for some traits have been pinpointed for possible future *in situ* or *ex situ* germplasm conservation work.**

Keywords
enset, Ethiopia, germplasm management, morphological diversity, phenotypic traits

Résumé

Évaluation de la diversité des traits qualitatifs et phénotypiques dans les races locales d'ensète [*Ensete ventricosum* (Welw.) Cheesman] en Ethiopie.

Introduction – **L'ensète [*Ensete ventricosum* (Welw.) Cheesman] est l'une des principales cultures indigènes en Éthiopie, fournissant de la nourriture à plus de 20% de la population.** *Matériel et méthodes* – **Un total de 286 races locales d'ensète provenant de six régions différentes d'Éthiopie ont été évaluées pour sept caractères qualitatifs et phénotypiques (durée de maturité, couleur de la lame du limbe de la feuille, couleur de la face supérieure et inférieure du pétiole et de la nervure médiane de la feuille, et couleur de la pointe du feuillage) au centre de recherche agricole d'Areka, dans le sud-ouest de l'Éthiopie, afin de déterminer l'ampleur et le schéma des variations morphologiques et phénotypiques. La fréquence en pourcentage des sept caractères et les classes des caractères qualitatifs et phénotypiques ont été calculées. L'indice de diversité de Shannon-Weaver (H') a été calculé à l'aide des fréquences de classe afin d'évaluer la diversité de chaque caractère pour toutes les races locales.** *Résultats et discussion* – **Tous les traits qualitatifs ont présenté une large gamme de variations parmi les races locales évaluées. L'indice de diversité**

Significance of this study

What is already known on this subject?
- Enset landrace diversity provides resilience and food security despite challenging environmental conditions.

What are the new findings?
- A high genetic diversity exists in the Ethiopian enset landraces even though the extent of this diversity differed according to region of collection and altitude ranges.

What is the expected impact on horticulture?
- The presence of considerable qualitative and phenotypic trait diversity should be exploited in the genetic improvement of the crop for higher yields and income, taking farmer preferences duly into account.

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de Shannon-Weaver (H') pour tout le matériel génétique échantillonné a varié de 0,50 à 0,89, avec une moyenne de 0,73. L'analyse de variance pour l'indice de diversité de Shannon-Weaver (H') a révélé des différences hautement significatives ($P < 0,01$) entre les régions pour tous les caractères. L'analyse en grappes a regroupé les races locales en quatre grappes. La couleur du pétiole sous la face inférieure (abaxiale) et supérieure (la face postérieure) (adaxiale) et la couleur de la nervure médiane sous la face inférieure ont été les principales caractéristiques permettant de regrouper les races locales en grappes respectives. *Conclusion* **– Il existe une grande diversité génétique dans les races locales d'ensète éthiopiennes, même si l'étendue de cette diversité diffère selon les régions de collecte. En règle générale, des variations considérables ont été observées, qui ont leur importance pour l'amélioration génétique des ensètes. De plus, les régions présentant la plus grande diversité pour certains caractères ont été identifiées pour de futurs travaux de conservation du matériel génétique *in situ* ou *ex situ*.**

Mots-clés
ensète, Ethiopie, diversité morphologique, gestion du germoplasme, traits phénotypiques

Introduction

Enset [*Ensete ventricosum* (Welw.) Cheesman] is a diploid plant species ($2n=2x=18$) in the *Musaceae* family. Wild *Ensete ventricosum* can be found in most countries along the Rift valley in East, Central and Southern Africa (Simmonds, 1962). Next to *Ensete ventricosum*, there are six or seven other wild species in the genus *Ensete* which are distributed in Africa and Asia (Simmonds, 1962; Pursglove, 1972). The crop looks like a banana plant, but is taller and more stout or robust than banana. Enset produces a bunch, but fruits are inedible as they are full of large seeds, hence the name 'false banana' (Pijls *et al*., 1995). *Ensete ventricosum* is the only species in the genus *Ensete* that is cultivated, and this occurs solely in smallholder farming systems in southern and southwestern Ethiopia (Westphal, 1975; Brandt *et al*., 1997).

A large portion of the enset germplasm from Ethiopia has been collected from different parts of the country and established in an *ex situ* gene bank at the Areka Agricultural Research Centre in southwestern Ethiopia (Yeshitla and Yemataw, 2012). The value of a gene bank strongly depends on the information generated through morphological characterization and evaluation of genetic diversity through assessments of different traits (Blair *et al*., 2010). This information could then feed into breeding efforts (Bhullar *et al*., 2009; Freitas *et al*., 2010).

Numerous efforts at phenotypic characterization have been made to provide enset breeders with detailed information for parent plant selection (Taboge, 1997; Welde-Michael *et al*., 2008; Yemataw *et al*., 2012; Bekele *et al*., 2013; Yeshitla, 2014). However, the extent and patterns of phenotypic variation that might exist among and within the landraces collected in various regions of the large enset growing belt have not been qualitatively assessed using the Shannon-Weaver diversity index.

Enset-producing farmers use morphological characters (midrib, petiole and leaf colour) and plant growth attributes (vigour and maturity time) to distinguish enset cultivars (Negash, 2001; Yemataw *et al*., 2014, 2016). This study aimed to provide useful knowledge for breeders and agronomists, by using qualitative and phenotypic traits to estimate the level of variation that exists across enset landraces grown in southern Ethiopia. The main objectives of the study were to estimate the extent of morphological/phenotypic diversity among enset landraces based on qualitative and phenotypic trait data, and to assess regional patterns of this phenotypic diversity.

Materials and methods

Description of the study site

Enset, originally sourced from six enset-growing regions (Dawro, Gamo Gofa, Gurage, Kembaa and Hadiya, Sidama and Wolayita), were evaluated at the Areka Agricultural Research Center, Ethiopia which hosts the coordination of the National Enset Improvement Program and is situated in the heart of one of the major enset-producing areas of the country. The six regions, located in the southcentral part of Ethiopia, are characterized by enset-dominated highland production systems. There are nevertheless altitude range differences between the study regions (Table 1). Although differences exists in grown landraces, farmers use similar selection criteria across the regions (on average 48% are morphological trait criteria; 36% food type [*e.g.*, kocho, bulla, amicho] and 11% food quality) (Yemataw *et al*., 2016). The Areka Agricultural Research Center is located at 7°09'N latitude and 37°47'E longitude at an elevation range of 1,750 to 1,800 m a.s.l. The soil is a silt-loam type with a pH of 4.8 to 5.6 and low to medium organic matter content (2.65–5.67%). The total amount of rainfall for the study period (2012–2017) was 1,539 mm, and minimum and maximum mean temperatures were 14.5 °C and 25.8 °C, respectively. The weather conditions were within the normal range for the growth and development of the enset crop in the study area.

Table 1. Number of enset landraces according to the region where the germplasm was collected and the altitude of the collection site.

Collection region/ altitude class	Altitude range (m a.s.l.)	Total number of landraces
Region		
Dawro	550–3,000	54
Gamo Gofa	600–3,300	45
Gurage	1,600–3,000	37
Kembata and Hadiya	1,400–2,980	73
Sidama	1,600–2,700	41
Wolayita	1,500–2,800	36
Altitude class		
A (≤2,000 m a.s.l.)		34
B (2,001–2,400 m a.s.l.)		115
C (2,401–2,800 m a.s.l.)		118
D (>2,800 m a.s.l.)		19

Plant materials

Two hundred and eighty-six enset landraces (*i.e.*, farmers' varieties), sourced from six different enset-growing regions in Ethiopia (Figure 1) and established at the Areka Agricultural Research Center, were used in this study. Germplasm collection site (6 sites) and altitude information

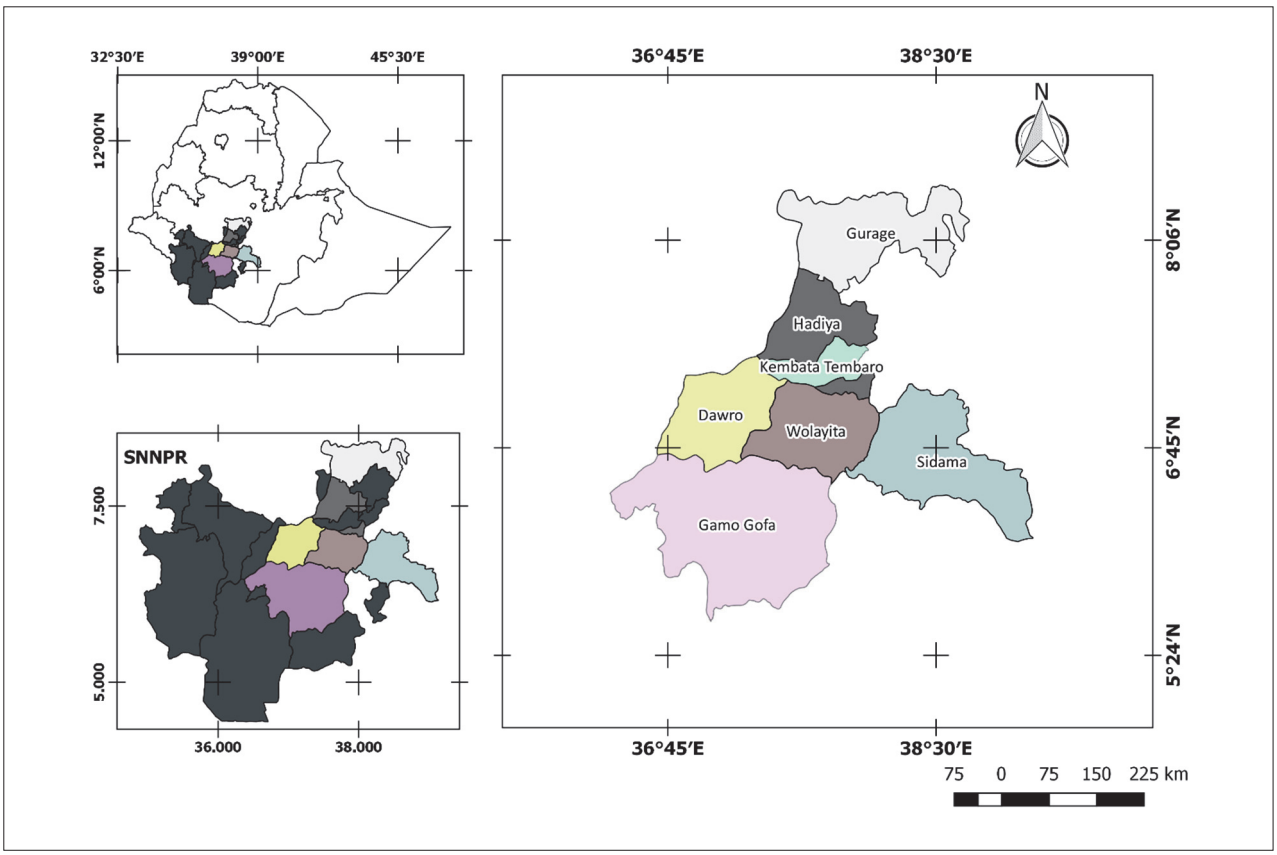

Figure 1. Map of Ethiopia and SNNP Regional State showing the test enset landrace collection regions (Dawro, Gamo Gofa, Gurage, Kembata and Hadiya, Sidama and Wolayita).

(4 altitude ranges) are provided in Table 1. The landraces were not evenly distributed among the collection sites, and the sampling process was dependent on the cropping conditions that prevailed in the collection regions. Detailed passport data of the enset landraces including the regions and altitudes of collection and the vernacular names have been summarized in Supplementary Table 1.

Agro-morphological and phenotypic traits

Two 3-year old enset plants obtained from a single mother plant (through macro-propagation) were assessed per landrace. Data were collected for seven morphological and phenotypic traits, namely maturity time (*i.e.*, number of years from transplanting up to harvesting), upper-side (adaxial) midrib colour, under-side (abaxial) midrib colour, upper-side petiole colour, under-side petiole colour, leaf lamina colour and leaf tip edge colour (Table 2). The Munsell colour chart was used for characterization (Munsell Colour, 1977; Anonymous, 1996, 2007). The number of phenotypic classes used for the Shannon-Weaver diversity index differed for each trait (Table 2).

Data analysis

Diversity index estimation

Percentage frequency for the seven traits and classes of the qualitative and phenotypic traits were calculated. The Shannon-Weaver diversity index (H') was computed using the class frequencies to assess the diversity for each trait for all enset landraces. The Shannon-Weaver diversity index (H) as described by Perry and McIntosh (1991) is given as:

$$H = \sum_{i=1}^{n} pi \ln(pi)$$

where n is the number of classes for a trait and pi is the proportion of the total number of landraces in the i^{th} class. H was estimated for each trait, within each region of origin, and altitude range. Each value of H was standardized by conversion to a relative diversity index (H') by division by $H_{max} = \ln(n)$ to express the values of H' in the range of 0–1.

$$H' = H/H_{max}$$

The diversity index was ranked as high ($H' \geq 0.60$), intermediate ($0.40 \leq H' \leq 0.60$) or low ($0.10 \leq H' \leq 0.40$) according to Eticha *et al.* (2005). Mean squares of H' values of enset landraces collected in different geographical regions and altitude ranges were also assessed.

Statistical analysis

Hierarchical cluster analyses, using the Minitab statistical program (MINI, 2000), were used to examine the aggregation patterns/dendrogram of the 286 enset landraces. The grouping of all enset landraces into clusters was done on basis of their morphological traits. Trait data were pre-standardized to mean zero and unity variance to minimize biases due to differences in the scales of measurement (Sneath and Sokal, 1973). The clustering method used was average linkage with Euclidean distance measure. Links between division of enset landraces in the various clusters and geographical region and altitude range where a specific landrace was collected were assessed.

Table 2. Descriptors used for estimating qualitative and phenotypic trait diversity in 286 enset landraces, linked classes for each trait, and the proportion (%) of occurrence of a class per trait.

Phenotypic/ qualitative trait#	Observed classes		Proportion (%)
MT	(1)	Early maturing (<4 years)	14.7
	(2)	Intermediate (4–6 years)	61.9
	(3)	Late maturing(>6 years)	23.4
UPMID	(1)	Light-to-medium green with black patches and black stripes	29.0
	(2)	Light-to-medium green with red streaks and red stripes	23.4
	(3)	Light-to-medium green with tinges of red	1.0
	(4)	Red with green lines	1.4
	(5)	Red-purple with green lines	9.4
	(6)	Purple with green lines and black spots	1.7
	(7)	Pink with green lines	1.7
	(8)	Orange-red with green lines	0.7
	(9)	Rusty-brown with green lines	22.7
	(10)	Red-purple with green lines	8.7
UNDMID	(1)	Light-to-medium green with black patches and black streaks	16.1
	(2)	Light to medium green with red streaks and red stripes	5.2
	(3)	Light to medium green with tinges of red	2.1
	(4)	Green-yellow	1.0
	(5)	Red with green lines	7.3
	(6)	Red-purple with green lines	1.0
	(7)	Purple-brown with green lines and black spots	0.3
	(8)	Pink with green lines with tinges of red	1.0
	(9)	Beige-pink with green lines	2.1
	(10)	Orange-red with green lines	57.7
	(11)	Rusty-brown with green lines	4.9
	(12)	Ivory with green lines	1.0
UPPET	(1)	Light-to-medium green with black patches and black streaks	32.9
	(2)	Light-to-medium green with red streaks and red stripes	19.2
	(3)	Red with green lines	1.4
	(4)	Red-purple with green lines	0.7
	(5)	Rusty-brown with green lines	20.6
	(6)	Orange-red with green lines	1.4
	(7)	Purple-brown with green lines and black spots	16.1
	(8)	Pink with black patches to green lines	3.5
	(9)	Red with black patches	4.2
UNDPET	(1)	Light-to-medium green with black patches and black streaks	2.8
	(2)	Light-to-medium green with brown stripes	29.7
	(3)	Light-to-medium green with red streaks and red stripes	4.5
	(4)	Brown with black patches and green lines	1.7
	(5)	Black with green lines	5.9
	(6)	Orange-red	2.1
	(7)	Red with green lines	9.1
	(8)	Purple with black patches and green lines	4.5
	(9)	Pink with black patches and green lines	0.7
	(10)	Red with black patches	32.9
	(11)	Red-purple with green lines and black patches	1.7
	(12)	Rusty-brown with green lines	3.5
	(13)	Ivory with green lines with tinges of red	0.7
LFCL	(1)	Light-green	69.6
	(2)	Medium-green	30.4
LTECL	(1)	Light-green to green	17.8
	(2)	Black	1.7
	(3)	Brown	80.5

#MT = maturity time, UPMID = upper-side midrib colour, UNDMID = under-side midrib colour, UPPET = upper-side petiole colour, UNDPET = under-side petiole colour, LFCL = leaf lamina colour, LTECL = leaf tip edge colour.

Results and discussion

Frequency distribution

Results of the current study demonstrate wide variations between the 286 enset landraces for the studied traits (Table 2). Frequency distribution for maturity time shows that 62% of landraces fall in the intermediate group of maturity period (4–5 years). Three types of upper-side midrib colour predominate across the enset landraces, namely light-to-medium green with black patches, and black stripes (29%), light-to-medium green with red streaks and red stripes (23%), and rusty-brown with green lines (23%). Two types of under-side midrib colour stood out, namely orange-red with green lines, and light-to-medium green with black patches and black streaks, covering 74% of landraces. A wide range of upper-side petiole colours were observed, including green, red, red-purple, rusty-brown, orange-red and purple, in combination with streaks, spots and patches. However, light-to-medium green with black patches and black streaks (33%), rusty-brown with green lines (21%), and light-to-medium green with red streaks and red stripes (19%) were predominant. Under-side petiole colour showed a relatively high frequency for red with black patches (33%), followed by light-to-medium green with brown stripes (30%) and red with green lines (9%) (Table 2; Figure 2). These results are in agreement with Yeshitla (2014) who reported that the most predominant upper- and under-side enset petiole colour were light-to-medium green with spots/patches. The majority of assessed enset landraces had light-green leaf laminas (70%), while the leaf tip edge colour was predominantly brown (81%).

The frequency distribution for the seven traits according to site of enset landrace collection is shown in Table 3. The highest frequency was consistently observed for intermediate maturity time (1) (4–5 years) across all six collection regions. The frequency distribution of the upper-side midrib colour showed highest percentage of light-to-medium green with red streak and red stripes (2) in Kembata and Hadiya, Wolayita and Sidama. The upper-side midrib colour type light-to-medium green with red streaks and red stripes (2) was not observed in Dawro and Gurage. However, light-to-medium green with black patches and black stripes (1) and rusty-brown with green lines (9) were mainly observed at these two latter sites. The distribution of under-side midrib colour classes in all six regions revealed a greater abundance of orange-red with green lines (10), while the proportion of other classes was relatively low. The upper-side petiole colour of enset landrace populations from Dawro, Gamo Gofa and Gurage was predominantly light-to-medium green with black patches and black streaks (1) (respectively 70, 60 and 54%) followed by purple-brown with green lines and black spots (7) (respectively 26, 29 and 46%). Enset landraces from Kembata and Hadiya, Wolayita and Sidama displayed a high proportion of light-to-medium green with red streaks and red stripes (2) followed by rusty-brown with green lines (5). A wide variety of under-side petiole colour was observed for the enset landraces from Kembata and Hadiya, Wolayita and Sidama. Farmers of these regions grow different enset landraces in the same plot of land and distinguish different enset landraces mainly through under-side petiole and midrib colour (Negash, 2001; Yematawet al., 2014).

Frequency distribution across the four altitude groups also revealed that the intermediate maturity group (2) consistently scored highest (Table 4). The most abundant upper-side midrib colour across all altitude groups was light-to-medium green with black patches and black stripes (1). The distribution of under-side midrib colour classes at all altitude ranges revealed a greater abundance of orange-red with green lines (10), while the proportion of other classes was relatively low. This reveals that orange-red with

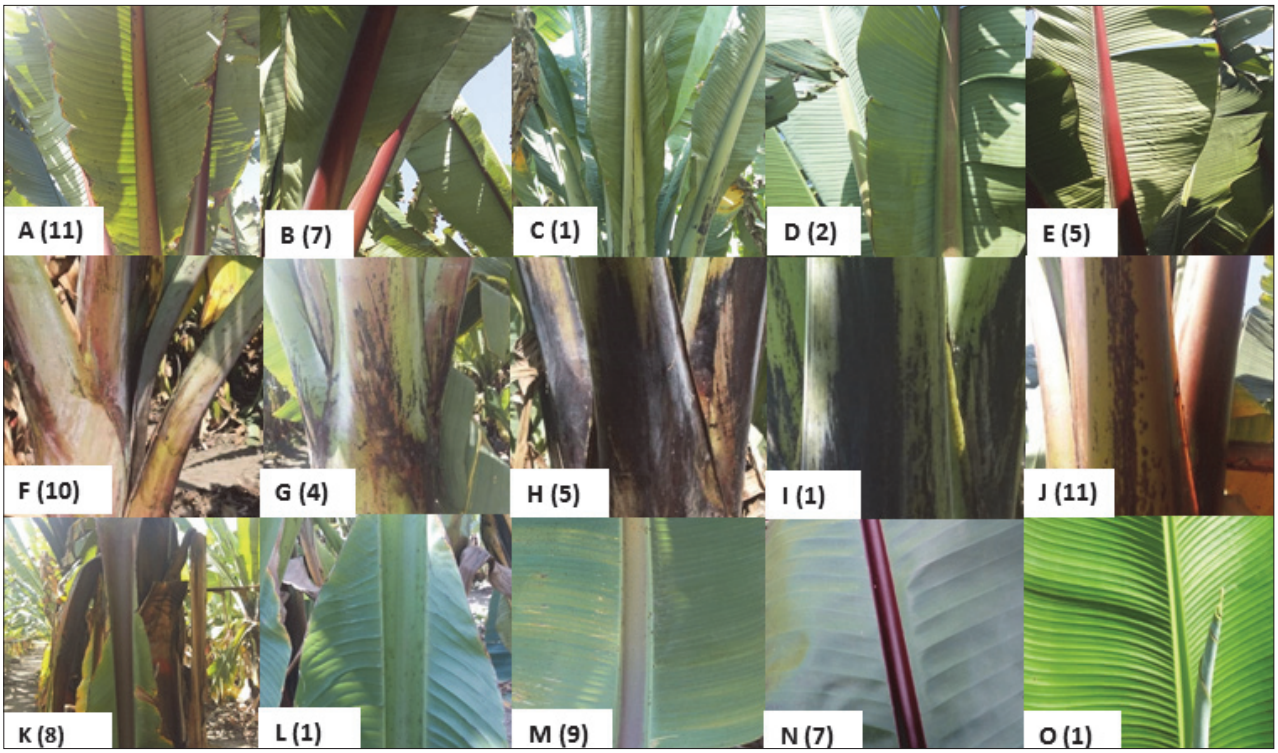

Figure 2. A-E: Examples of morphological variation in under-side midrib colour; F-J: Examples of morphological variation in under-side petiole colour; and K-O: Examples of morphological variation in upper-side midrib colour. Class number (see Table 2) for each qualitative/phenotypic trait is listed between brackets.

Table 3. Frequency distribution (%) for different classes of seven traits according to enset landrace collection site.

Site of enset landrace collection	Phenotypic/ qualitative trait#	Observed phenotypic class*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Kembata and Hadiya	MT	17.9	**65.7**	16.4	-	-	-	-	-	-	-	-	-	-
	UPMID	4.1	**50.7**	1.4	0	2.75	2.75	2.7	2.7	13.7	19.2	-	-	-
	UNDMID	11	5.5	6.8	2.7	9.6	1.4	1.4	1.4	0	**54.8**	5.4	0	-
	UPPET	6.8	**49.3**	1.4	0	**23.3**	0	0	8.2	11	-	-	-	-
	UNDPET	2.74	**21.9**	4.1	2.7	4.1	0	5.5	9.6	1.4	**39.7**	1.4	6.86	0
	LFCL	**100**	0	-	-	-	-	-	-	-	-	-	-	-
	LTECL	1.4	4.1	**94.5**	-	-	-	-	-	-	-	-	-	
Dawro	MT	13.0	**51.9**	**35.1**	-	-	-	-	-	-	-	-	-	-
	UPMID	**46.3**	0	0	0	22.2	0	0	0	**27.8**	3.7	-	-	-
	UNDMID	14.8	1.9	0	0	5.6	0	0	0	0	**74**	3.7	0	-
	UPPET	**70.4**	0	0	0	3.7	0	**25.9**	0	0	-	-	-	-
	UNDPET	3.7	**25.9**	0	0	0	0	7.4	0	0	**57.4**	5.6	0	0
	LFCL	**51.9**	**48.1**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	**22.2**	0	**77.8**	-	-	-	-	-	-	-	-	-	-
Gamo Gofa	MT	4.4	**53.4**	**42.2**	-	-	-	-	-	-	-	-	-	-
	UPMID	**42.2**	2.2	0	0	20	6.7	0	0	**28.9**	0	-	-	-
	UNDMID	**31.1**	0	0	0	0	0	0	0	6.7	**60**	2.2	0	-
	UPPET	**60**	0	0	0	8.9	0	**28.9**	0	2.2	-	-	-	-
	UNDPET	0	**60**	0	0	0	8.9	17.8	4.4	0	8.9	0	0	0
	LFCL	**73.3**	**26.7**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	**35.6**	0	**64.4**	-	-	-	-	-	-	-	-	-	-
Wolayita	MT	19.4	**61.2**	19.4	-	-	-	-	-	-	-	-	-	-
	UPMID	**33.3**	**36.1**	2.8	5.5	2.8	0	2.8	0	11.1	5.6	-	-	-
	UNDMID	8.3	11.1	2.8	2.8	16.7	5.6	0	0	5.6	**38.9**	8.2	0	-
	UPPET	5.6	**22.2**	5.5	0	**50**	2.8	5.6	2.8	5.5	-	-	-	-
	UNDPET	2.8	13.9	5.5	8.3	16.7	2.8	8.3	5.55	0	**30.6**	0	5.55	0
	LFCL	**88.9**	11.1	-	-	-	-	-	-	-	-	-	-	-
	LTECL	5.6	0	**94.4**	-	-	-	-	-	-	-	-	-	-
Sidama	MT	**24.4**	**61**	14.6	-	-	-	-	-	-	-	-	-	-
	UPMID	19.5	**39**	2.4	4.9	2.4	0	4.9	0	9.8	17.1	-	-	-
	UNDMID	12.2	14.6	0	0	4.9	0	0	4.9	2.4	**43.9**	9.8	7.3	-
	UPPET	4.9	**26.8**	2.4	4.9	**43.9**	7.4	0	7.3	2.4	-	-	-	-
	UNDPET	0	**24.4**	17.1	0	19.5	0	7.32	2.44	0	14.6	2.44	7.3	4.9
	LFCL	**61**	**39**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	**26.8**	4.9	**68.3**	-	-	-	-	-	-	-	-	-	-
Gurage	MT	8.1	**81.1**	10.8	-	-	-	-	-	-	-	-	-	-
	UPMID	**43.2**	0	0	0	5.4	0	0	0	**51.4**	0	-	-	-
	UNDMID	**21.6**	0	0	0	8.1	0	0	0	0	**70.3**	0	0	-
	UPPET	**54.1**	0	0	0	0	0	**45.9**	0	0	-	-	-	-
	UNDPET	8.11	**35.1**	2.73	0	0	2.7	10.8	2.73	2.72	**35.1**	0	0	0
	LFCL	**43.2**	**56.8**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	**24.3**	0	**75.7**	-	-	-	-	-	-	-	-	-	-

'-' is for classes that do not exist for a specific trait.

#MT = maturity time, UPMID = upper-side midrib colour, UNDMID = under-side midrib colour, UPPET = upper-side petiole colour, UNDPET = under-side petiole colour, LFCL = leaf lamina colour, LTECL = leaf tip edge colour.

* See Table 2 for the observed classes per trait.

Table 4. Frequency distribution (%) for different classes of seven phenotypic/qualitative traits in enset according to altitude ranges.

Altitude ranges (m a.s.l.)	Phenotypic/ Qualitative trait#	Observed phenotypic class*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
≤2,000	MT	**23.5**	**64.7**	11.8	-	-	-	-	-	-	-	-	-	-
	UPMID	**35.4**	**26.5**	0	2.9	2.9	2.9	2.9	0	17.7	8.8	-	-	-
	UNDMID	**20.6**	11.8	0	0	11.8	2.9	2.9	0	8.8	**41.2**	0	0	-
	UPPET	**32.4**	**20.6**	0	2.9	**20.6**	5.9	14.7	2.9	0	-	-	-	-
	UNDPET	0	**38.3**	11.8	2.9	8.8	8.8	8.8	0	0	14.8	2.9	2.9	0
	LFCL	**70.6**	**29.4**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	**35.3**	2.9	**61.8**	-	-	-	-	-	-	-	-	-	-
2,001–2,400	MT	14.8	**60**	**25.2**	-	-	-	-	-	-	-	-	-	-
	UPMID	**25.3**	**24.3**	1.7	1.7	9.6	1.7	1.7	0.9	**25.3**	7.8	-	-	-
	UNDMID	9.6	7.7	3.5	0.9	7	0.9	0	0.9	0.9	**60**	7	1.6	-
	UPPET	**27**	**21.7**	0.9	0.9	**25.1**	0.9	15.7	2.6	5.2	-	-	-	-
	UNDPET	2.6	**25.2**	4.3	1.7	7.1	0.9	13	5.2	0.9	**32.2**	1.7	3.5	1.7
	LFCL	**73**	**27**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	12.1	0.9	**87**	-	-	-	-	-	-	-	-	-	-
2,401–2,800	MT	14.4	**59.3**	**26.3**	-	-	-	-	-	-	-	-	-	-
	UPMID	**26.3**	**25.4**	0.8	0.8	11.1	1.7	1.7	0.8	20.3	11.1	-	-	-
	UNDMID	19.5	1.7	1.7	1.7	5.1	0.8	0	1.7	1.7	**60.2**	5.1	0.8	-
	UPPET	**31.4**	19.5	2.5	0	19.5	0.8	16.1	5.1	5.1	-	-	-	-
	UNDPET	2.5	**28.8**	3.4	1.7	5.1	1.7	5.9	5.1	0.8	**39.1**	1.7	4.2	0
	LFCL	**68.6**	**31.4**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	16.1	2.5	**81.4**	-	-	-	-	-	-	-	-	-	-
>2,800 m	MT	**36.8**	**63.2**	0	-	-	-	-	-	-	-	-	-	-
	UPMID	**57.9**	0	0	0	10.5	0	0	0	**31.6**	0	-	-	-
	UNDMID	**26.3**	0	0	0	15.8	0	0	0	0	**57.9**	0	0	-
	UPPET	**78.9**	0	0	0	0	0	**21.1**	0	0	-	-	-	-
	UNDPET	10.5	**47.4**	0	0	0	0	5.3	5.3	0	**31.5**	0	0	0
	LFCL	**52.6**	**47.4**	-	-	-	-	-	-	-	-	-	-	-
	LTECL	**31.6**	0	**68.4**	-	-	-	-	-	-	-	-	-	-

#, *: see Tables 2 and 3.

green lines as under-side midrib colour is widely distributed across the enset landraces in the whole study region. Light-to-medium green with black patches and black streaks (1) was the predominant upper-side petiole colour of enset landrace populations at all four altitude ranges. These results are in agreement with Taboge (1997) who studied morphological traits of enset landraces in two regions (Wolayita and Kembata and Hadiya) in southern Ethiopia. The under-side petiole colours were mainly light-to-medium green with brown stripes (2) and red with black patches (10) across the four altitude ranges.

Across the six geographical regions and four altitude ranges, there were two classes observed for upper-side leaf lamina colour and the most frequent was light green (1) (Tables 3 and 4). The predominant occurrence of light-green leaf laminas in enset was also reported by Taboge (1997) and Yeshitla (2014). These authors used similar enset landrace qualitative and phenotypic trait diversity assessment methods. The most frequent leaf tip edge colour was brown (3) across regions and altitude ranges. These results also agree with Yeshitla (2014) who reported that the most predominant leaf tip edge colour in enset was brown-purple.

Estimates and analysis of qualitative trait diversity

The extent of diversity estimated using the Shannon-Weaver diversity index (H') and its partitioning within and between collection sites are shown in Table 5. The seven traits differed in amount of variation. The overall average diversity (H') across landraces was 0.73, varying from 0.50 (leaf tip edge colour) to 0.89 (leaf lamina colour). Leaf tip edge colour and under-side midrib colour were relatively monomorphic, while under-side petiole colour, upper-side midrib colour, and upper-side petiole colour had an intermediate diversity.

The phenotypic diversity estimates based on the Shannon-Weaver diversity index (H') for the different collection regions are shown in Table 6. Enset landraces from the Kembata and Hadiya regions showed the highest H' values (Table 6) for maturity time, under-side petiole colour, upper-side midrib colour and under-side midrib colour. The highest degree of diversity in the Wolayita-sourced landraces was recorded for days to maturity, under-side petiole colour and under-side midrib colour. Enset landraces from Gamo Gofa exhibited the highest diversity index for maturity time and leaf lamina colour. The lowest mean diversity index values for the seven traits were obtained for the Dawro-sourced enset landraces.

Table 5. Estimates of the Shannon-Weaver diversity index (H') according to within and between enset landrace collection site for various qualitative traits assessed on 286 enset landraces. H' = diversity index for each trait calculated from the entire dataset; H_{cl} = average (arithmetical) diversity index of each trait for the six localities; H_{cl}/H' = proportion of diversity within locality and $(H' - H_{cl})/H'$ = proportion of diversity between localities in relation to the total variation.

Traits#	H'	H'_{cl}	H'_{cl}/H'	$(H' - H_{cl})/H'$
MT	**0.86**	0.80	0.93	0.07
UPMID	0.76	0.59	0.78	0.22
UNDMID	0.59	0.52	0.88	0.12
UPPET	0.78	0.52	0.66	0.33
UNDPET	0.74	0.63	0.85	0.15
LFCL	**0.89**	0.71	0.80	0.20
LFTCOL	0.50	0.45	0.90	0.10
Average	0.73	0.60	0.83	0.17

#: see Table 3.

Table 6. Estimates of the Shannon-Weaver diversity Index (H') for seven traits in 286 enset landraces according to region/location of collection. Mean squares of H' for seven traits among locations and overall mean values per location are also presented.

Location of collection	Traits#							Mean ± se
	MT	UPMID	UNDMID	UPPET	UNDPET	LFCL	LFTPEDG	
Kembata and Hadiya	0.83	0.66	0.63	0.63	0.73	0.50	0.22	0.59 ± 0.07
Dawro	0.89	0.51	0.35	0.33	0.45	0.49	0.48	0.50 ± 0.07
Gamo Gofa	0.75	0.57	0.38	0.44	0.46	0.84	0.59	0.57 ± 0.06
Wolayita	0.84	0.69	0.74	0.69	0.79	0.50	0.20	0.63 ± 0.08
Sidama	0.81	0.73	0.69	0.72	0.76	0.96	0.69	0.76 ± 0.03
Gurage	**0.70**	0.37	0.32	0.31	0.61	0.99	0.50	0.54 ± 0.09
Mean squares of H' (df = 5)	0.20*	0.73*	1.55*	1.48*	1.08*	2.68*	1.87*	

#: see Table 3; df = degrees of freedom; * significant at P ≤ 0.01.

Table 7. Estimates of the Shannon-Weaver diversity Index (H') in 286 enset landraces according to altitude class. Mean squares of H' for seven traits among altitude class and overall mean values per altitude class are also presented.

Altitude class (m a.s.l.)	Traits#							Mean ± se
	MT	UPMID	UNDMID	UPPET	UNDPET	LFCL	LFTPEDG	
≤2,000	0.81	0.72	0.65	0.76	0.72	0.87	0.70	0.74 ± 0.03
2,001–2,400	0.88	0.77	0.58	0.77	0.76	0.84	0.38	0.71 ± 0.06
2,401–2,800	0.84	0.76	0.54	0.79	0.69	0.89	0.50	0.71 ± 0.05
>2,800	0.63	0.40	0.39	0.23	0.49	0.99	0.57	0.53 ± 0.09
Mean squares of H' (df = 3)	0.35*	0.78*	0.31*	1.78*	0.42*	0.14*	0.99*	

#: see Table 3; df = degrees of freedom; * significant at P ≤ 0.01.

At 2,001–2,400 m a.s.l., highest H' values were observed for maturity time, upper- and under-side petiole colour and upper-side midrib colour (Table 7). Leaf colour had the largest H' value at altitudes above 2,800 m a.s.l. On the other hand, under-side midrib colour and leaf tip edge colour had highest H' values in the altitude zone below 2,000 m a.s.l. The highest overall mean diversity index value was recorded for enset landraces obtained below 2,000 m a.s.l.

Analysis of variance for H' revealed highly significant ($p < 0.01$) differences among all regions, altitude classes and this for all traits (Tables 6 and 7). Similar phenotypic trait diversity among regions of origin and altitude groups have been noted in Ethiopian wheat (Bekele, 1984; Tesfaye *et al.*, 1991; Bechere *et al.*, 1996), barley (Engels, 1994; Demissie and Bjørnstad, 1996), sorghum (Ayana and Bekele, 1998, 1999) and tef (Assefa *et al.*, 2002) germplasm. Overall, the study showed substantial levels of diversity in the enset landrace landraces for most of the qualitative traits. From a conservation point of view, a special focus should be made on regions and altitude ranges which have exhibited the largest diversity values. Interestingly, these regions and altitude ranges correspond to major production zones and high/better performance regions of enset in Ethiopia (Yematawet *et al.*, 2016).

Table 8. Clustering of 286 enset landraces into four groups using seven phenotypic/qualitative traits.

Clusters	Enset landraces#	No. of landraces	Percentage of total population (*n* = 286 landraces)
Cluster I	1, 2, 5, 12, 15, 20, 21, 22, 24, 25, 26, 27, 29, 30, 34, 36, 37, 38, 42, 46, 48, 50, 51, 56, 59, 61, 66, 67, 68, 69, 71, 72, 75, 77, 80, 83, 84, 85, 87, 88, 89, 94, 95, 96, 99, 100, 103, 104, 107, 108, 109, 110, 113, 114, 118, 121, 122, 123, 125, 126, 127, 130, 132, 135, 145, 148, 152, 153, 154, 155, 159, 160, 164, 165, 166, 167, 171, 172, 182, 186, 189, 191, 195, 199, 202, 206, 212, 216, 220, 222, 227, 228, 229, 231, 233, 234, 240, 247, 248, 249, 252, 253, 255, 257, 258, 262, 270, 272, 273, 277, 278, 280, 281, 282, 283, 284, 286	117	40.9
Cluster II	3, 4, 6, 7, 11, 13, 16, 23, 32, 43, 44, 45, 47, 54, 55, 58, 64, 65, 74, 79, 86, 91, 97, 102, 106, 112, 117, 124, 128, 131, 133, 134, 137, 139, 140, 146, 147, 151, 156, 157, 163, 168, 173, 180, 181, 185, 187, 193, 194, 197, 198, 201, 208, 210, 211, 213, 214, 217, 221, 223, 226, 235, 243, 244, 245, 250, 259, 265, 266, 267, 268, 269, 275, 276	74	25.9
Cluster III	8, 9, 10, 14, 17, 19, 28, 33, 35, 39, 49, 52, 53, 60, 62, 76, 82, 90, 92, 93, 98, 105, 115, 120, 174, 177, 183, 184, 190, 192, 200, 203, 205, 207, 224, 238, 251, 254, 256	39	13.6
Cluster IV	18, 31, 40, 41, 57, 63 70, 73, 78, 81, 101, 111, 116, 119, 129, 136, 138, 141, 142, 143, 144, 149, 150, 158, 161, 162, 169, 170, 175, 176, 178, 179, 188, 196, 204, 209, 215, 218, 219, 225, 230, 232, 236, 237, 239, 241, 242, 246, 260, 261, 263, 264, 271, 274, 279, 285	56	19.6

#: Numbers refer to the code/ entry number of a landrace; see Supplementary Table 1 for details of each landrace.

Cluster analysis

The number of landraces that fall in each cluster were highest (117) in cluster I (C1) followed by CII (74), CIV (56) and CIII (39) (Table 8; Figure 3). Although cluster analysis grouped genotypes with high morphological similarity together, the clusters did not necessarily group enset landraces from specific regions. Ahmad *et al*. (2008) and Zubair *et al*. (2007) also reported a lack of association between morpho-agronomic traits and place of origin.

The first cluster included 117 genotypes which account

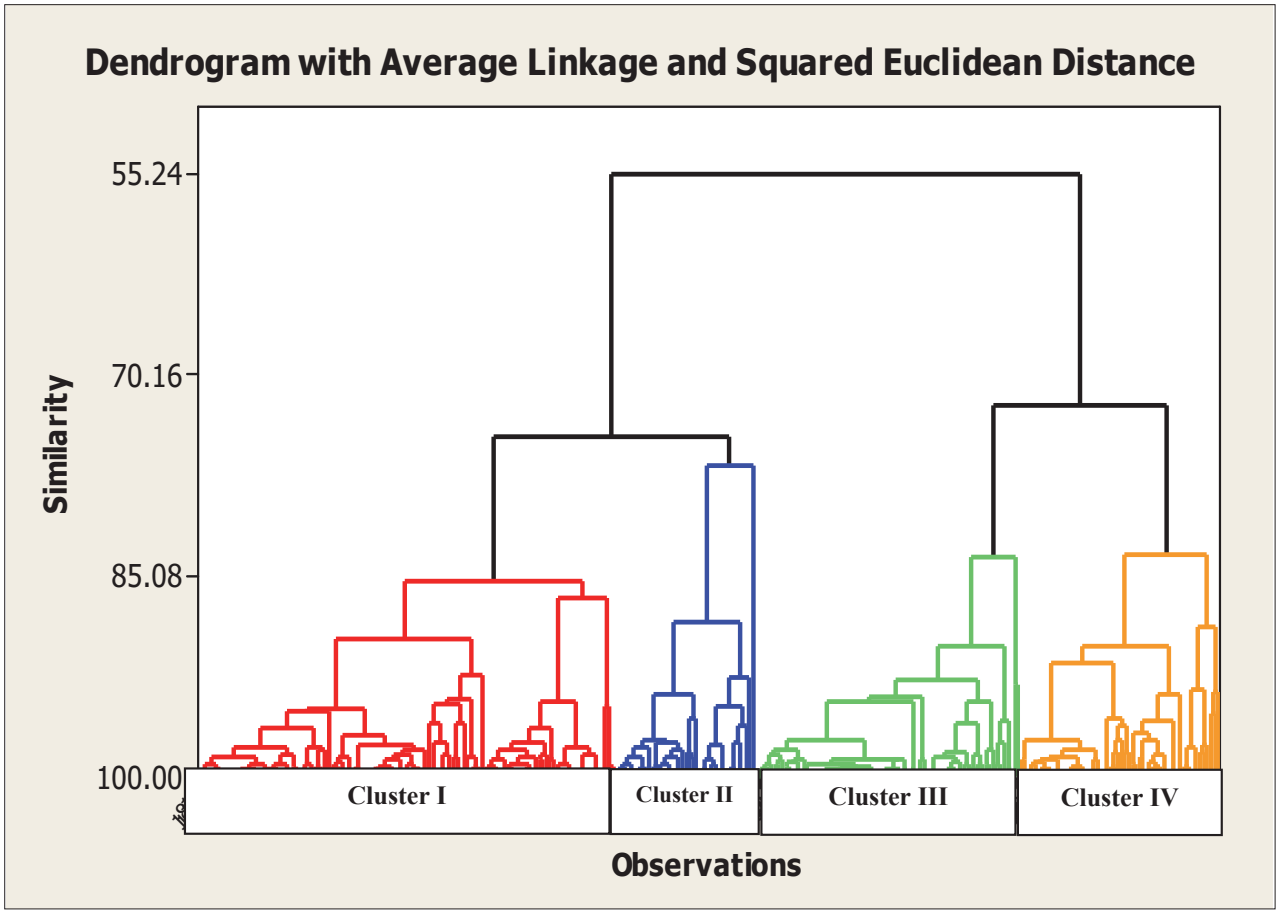

Figure 3. Dendrogram showing the clustering pattern of 286 enset landraces computed using data collected on seven qualitative/phenological traits.

Table 9. Distribution of the 286 enset landraces over four clusters according to region of origin and altitude class.

Regions or altitude class	Clusters				Total
	I	II	III	IV	
Regions					
Kembata and Hadya	32	18	15	8	73
Dawro	29	10	9	6	54
Gamo Gofa	17	14	-	14	45
Wolayita	8	11	10	7	36
Sidama	14	12	2	13	41
Gurage	17	9	3	8	37
Altitude class (in m a.s.l.)					
≤2,000	9	13	3	9	34
2,001–2,400	48	25	20	22	115
2,401–2,800	54	31	14	19	118
>2,800	6	5	2	6	19
Total	117	74	39	56	286

for 40.9% of the total experimental materials. Cluster I clearly showed the close relationship between landraces from the Kembata and Hadiya, Dawro, Gamo Gofa and Gurage regions (Table 9). Cluster II contained 74 landraces which account for 25.9% of the total experimental materials. A relatively large number of landraces in this cluster were from the Kembata and Hadiya (18) and Gamo Gofa (14) regions. Similarly, the contribution of altitude classes II (2,001–2,400 m a.s.l.) and III (2,401–2,800 m a.s.l.) for this cluster was also high. Cluster III contained 39 landraces of which the larger proportion was obtained from Kembata and Hadiya and from the 2,001–2,400 m a.s.l. altitude range. Cluster IV consisted of 56 landraces accounting for 19.6% of the total experimental materials. Landraces from the Gamo Gofa and Sidama regions and altitude class II (2,001–2,400 m a.s.l.) were included in this cluster.

Cluster analyses revealed that enset landraces from the same collection site do not necessarily fall in the same cluster, while landraces from different collection sites may cluster together. For example, although the geographical location of Sidama is distant from Gurage and from Kembata and Hadiya, landraces from these locations showed some level of similarity. This could be explained by the traditional exchange of planting materials over several centuries and sometimes long distances. In addition, farmers also often use same selection criteria across regions leading to similar phenotypes. Similar findings were reported by Ayana and Bekele (1998, 1999) on sorghum landraces where a clear cut differentiation of sorghum lines according to region of origin was not apparent.

The number of enset landraces grown at a given locality, their genetic (dis-)similarity and the geographical areas they occupy over time and space are influenced by enset germplasm introductions, conservation and exchange (Yemataw *et al*., 2017). Landraces of interest to farmers that were originally limited to a specific location might have spread out to large geographical regions due to frequent exchange of planting materials among farmers. In addition, similar selection criteria used by farmers of different regions might also have influenced enset diversity patterns and evolution (Yemataw *et al*., 2016). Traits like yield stability, resistance to biotic and abiotic stresses and low dependence on external inputs are often used as selection criteria by farmers (De Boef *et al*., 1996). Even if the original composition of enset landraces might have varied according to region, the crop might have also been forced to evolve, over the centuries, in the same direction by this type of "local breeding" for the same targets, driven by similar economic, social, cultural and ecological factors. These aspects could explain why enset landraces from different collection sites may cluster together.

Conclusion

A total of 286 enset landraces, sourced from six enset growing regions, were evaluated for seven traits to detect regional and altitude-linked diversity patterns. In general, the present findings revealed that there is high genetic diversity in the Ethiopian enset landraces even though the extent of this diversity differed according to region of collection and altitude ranges. The similarities and dissimilarities in agro-ecology across the enset growing belt of Ethiopia, in farmer selection criteria across enset regions, in socio-economic and cultural situations coupled with the long years of cultivation of the crop are major contributing factors to the currently observed phenotypic diversity. Results of this study also indicate that future enset germplasm collection and conservation strategies would need to focus on the wide range of enset growing regions and altitude zones, due to the observed cross-region and cross-altitude diversity. The presence of considerable qualitative and phenotypic trait diversity (in plant part colour and maturity time, which are important selection criteria for farmers) could be exploited in the genetic improvement of the crop, taking farmer preferences duly into account.

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Supplementary Table 1. Qualitative traits of the 286 enset landraces tested at Areka.

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
1	Abatmerza	Kembata and Hadiya	3	2.00	9	10	8	10	1	3
2	Abato	Kembata and Hadiya	2	1.00	9	10	9	10	1	3
3	Airo	Kembata and Hadiya	2	2.00	2	3	2	2	1	3
4	Ashura	Kembata and Hadiya	3	2.00	2	1	5	2	1	3
5	Astara	Kembata and Hadiya	2	3.00	10	10	2	10	1	3
6	Azenora	Kembata and Hadiya	3	1.00	2	4	2	5	1	3
7	Becherota	Kembata and Hadiya	3	2.00	2	1	2	2	2	2
8	Bedadeda	Kembata and Hadiya	2	3.00	2	10	2	10	1	3
9	Bedediet	Kembata and Hadiya	2	2.00	2	10	2	10	1	3
10	Beleka	Kembata and Hadiya	3	1.00	2	10	2	12	1	3
11	Bikamo	Kembata and Hadiya	2	2.00	2	2	5	2	1	3
12	Bikamo	Kembata and Hadiya	2	2.00	9	11	5	10	1	3
13	Bishato	Kembata and Hadiya	3	2.00	3	3	2	3	1	3
14	Boela	Kembata and Hadiya	2	1.00	2	10	2	10	1	3
15	Bossie	Kembata and Hadiya	3	2.00	7	10	2	10	2	3
16	Chereka	Kembata and Hadiya	3	2.00	2	4	8	4	1	3
17	Dengicho	Kembata and Hadiya	3	2.00	2	10	5	12	1	3
18	Denticho	Kembata and Hadiya	2	1.00	2	10	2	2	1	3
19	Digomerza	Kembata and Hadiya	3	1.00	2	10	5	10	1	3
20	Dirbo	Kembata and Hadiya	3	2.00	10	11	1	10	1	3
21	Disho	Kembata and Hadiya	3	3.00	10	10	9	9	1	3
22	Etinie	Kembata and Hadiya	3	3.00	10	10	5	10	1	3
23	Fechachie	Kembata and Hadiya	2	2.00	2	2	2	2	1	3
24	Ferchasa	Kembata and Hadiya	3	3.00	10	10	9	8	2	3
25	Ferezia	Kembata and Hadiya	2	2.00	6	10	2	10	1	3

Supplementary Table 1. (Continued).

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
26	Fugatesa	Kembata and Hadiya	3	1.00	10	10	8	10	1	3
27	Gimbo	Kembata and Hadiya	3	2.00	8	10	2	10	1	3
28	Ginjena	Kembata and Hadiya	2	2.00	2	5	2	10	1	3
29	Gishera	Kembata and Hadiya	3	2.00	9	10	9	10	1	3
30	Goemerrie	Kembata and Hadiya	3	2.00	5	10	8	4	1	3
31	Gotedirbo	Kembata and Hadiya	1	1.00	2	7	2	5	1	2
32	Gozeza	Kembata and Hadiya	3	3.00	2	1	2	2	1	3
33	Guarye	Kembata and Hadiya	2	1.00	2	3	2	10	1	3
34	Gulfe	Kembata and Hadiya	3	2.00	6	10	2	10	1	3
35	Gureza	Kembata and Hadiya	3	2.00	2	6	2	10	1	3
36	Hankuchie	Kembata and Hadiya	3	1.00	10	10	9	10	2	3
37	Hargamo	Kembata and Hadiya	2	2.00	9	11	5	10	1	3
38	Heilla	Kembata and Hadiya	2	2.00	10	10	5	7	1	3
39	Henuwa	Kembata and Hadiya	3	2.00	2	10	2	10	1	3
40	Hiniba	Kembata and Hadiya	2	2.00	2	10	2	2	1	3
41	Jegeda	Kembata and Hadiya	3	1.00	2	10	3	7	1	3
42	Keberichie	Kembata and Hadiya	2	2.00	9	11	5	7	1	3
43	Kembat	Kembata and Hadiya	3	2.00	2	1	1	1	1	1
44	Kerbo	Kembata and Hadiya	2	1.00	2	2	2	2	2	3
45	Kerkerie	Kembata and Hadiya	3	2.00	2	1	2	2	1	3
46	Keshkeshiya	Kembata and Hadiya	2	2.00	10	5	5	8	1	3
47	Kessiet	Kembata and Hadiya	3	2.00	2	1	5	2	1	2
48	Kinchie	Kembata and Hadiya	3	1.00	10	10	2	10	1	3
49	Korttie	Kembata and Hadiya	3	2.00	2	5	2	11	1	3
50	Lekaka	Kembata and Hadiya	2	3.00	10	10	2	12	1	3
51	Manduluka	Kembata and Hadiya	2	2.00	10	10	2	7	1	3
52	Mariya	Kembata and Hadiya	3	2.00	2	8	2	10	2	3
53	Menera	Kembata and Hadiya	3	2.00	1	5	5	10	1	3
54	Mesmesa	Kembata and Hadiya	3	3.00	2	1	9	2	1	3
55	Nechiwe	Kembata and Hadiya	3	2.00	2	3	5	3	1	3
56	Oniya	Kembata and Hadiya	3	2.00	5	10	5	8	1	3
57	Onjamo	Kembata and Hadiya	3	2.00	2	10	2	5	1	3
58	Ored	Kembata and Hadiya	3	2.00	2	1	5	2	1	3
59	Ososa	Kembata and Hadiya	2	2.00	8	10	2	12	1	3
60	Senkutie	Kembata and Hadiya	3	3.00	2	5	5	10	1	3
61	Sesikila	Kembata and Hadiya	3	3.00	10	10	2	10	1	3
62	Sessa	Kembata and Hadiya	1	2.00	1	5	1	10	1	3
63	Shelekie	Kembata and Hadiya	3	2.00	2	10	8	2	1	3
64	Tebuttie	Kembata and Hadiya	2	2.00	2	3	2	2	1	3
65	Tegaded	Kembata and Hadiya	3	3.00	1	2	2	3	2	3
66	Tesa	Kembata and Hadiya	3	2.00	7	10	2	10	1	3
67	Wechered	Kembata and Hadiya	3	2.00	9	10	5	8	1	3
68	Wellachie	Kembata and Hadiya	3	2.00	9	10	9	12	1	3
69	Wenadie	Kembata and Hadiya	3	2.00	10	5	1	8	1	3
70	Weshmeda	Kembata and Hadiya	3	3.00	2	10	2	1	2	3
71	Wohie	Kembata and Hadiya	2	2.00	9	10	1	8	1	3

Supplementary Table 1. (Continued).

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
72	Zebro	Kembata and Hadiya	2	2.00	9	10	9	8	1	3
73	Zeriyie	Kembata and Hadiya	2	2.00	2	10	8	2	1	3
74	Aeluwa	Dawro	2	2.00	1	5	1	2	2	3
75	Aguasa(ta)	Dawro	2	3.00	9	10	1	11	1	3
76	Akachiya	Dawro	2	2.00	1	10	1	10	1	3
77	Argema	Dawro	3	3.00	5	10	7	10	1	3
78	Ayina	Dawro	3	2.00	1	10	1	2	2	3
79	Banga	Dawro	3	3.00	1	1	1	2	2	1
80	Berjiye	Dawro	3	2.00	9	10	7	11	2	3
81	Bota-meziya	Dawro	3	2.00	1	10	1	2	2	3
82	Buba	Dawro	3	3.00	1	10	1	10	2	3
83	Bukuniye	Dawro	3	2.00	9	10	7	10	2	3
84	Bumbe	Dawro	3	2.00	9	10	1	10	1	3
85	Dika	Dawro	3	2.00	10	10	5	10	2	3
86	Donkolola	Dawro	2	2.00	1	1	1	2	2	1
87	Dorta	Dawro	2	3.00	5	11	7	10	1	1
88	Elore	Dawro	2	3.00	5	10	1	10	1	3
89	Fenchariya-yepa	Dawro	3	2.00	9	10	7	10	1	3
90	Goshindiya	Dawro	3	2.00	1	10	1	10	2	3
91	Hala-a	Dawro	2	2.00	1	1	1	2	1	3
92	Hasa-bedadiye	Dawro	2	3.00	1	10	1	10	2	1
93	Hoendiye	Dawro	2	2.00	1	10	1	10	1	1
94	Kazia	Dawro	3	2.00	9	10	1	10	1	1
95	Kekere	Dawro	3	2.00	5	10	7	10	1	1
96	Keteniya	Dawro	3	2.00	9	10	7	10	2	3
97	Sanka	Dawro	3	3.00	1	2	1	2	1	1
98	Tena	Dawro	2	1.00	1	10	1	10	1	3
99	Yesha	Dawro	3	3.00	5	10	1	10	1	3
100	Erpha12	Dawro	3	1.00	5	10	1	10	1	3
101	Erpha13	Dawro	3	1.00	1	10	1	1	2	3
102	Erpha18	Dawro	3	1.00	1	1	1	2	2	3
103	Erpha14	Dawro	3	2.00	9	10	7	10	1	3
104	Erpha8	Dawro	3	2.00	5	10	7	7	1	3
105	Erpha2	Dawro	3	1.00	1	10	1	10	2	3
106	Erpha3	Dawro	3	1.00	1	1	1	2	1	1
107	Erpha7	Dawro	3	2.00	9	10	1	10	1	3
108	Zergesa	Dawro	2	2.00	9	5	1	7	1	3
109	Mecha-boza	Dawro	2	3.00	5	10	1	10	1	3
110	Meziya	Dawro	2	2.00	5	10	1	10	1	3
111	Shelekuma	Dawro	2	2.00	1	10	1	1	2	3
112	Shemera	Dawro	3	2.00	1	1	1	2	2	3
113	Gulumo	Dawro	3	2.00	9	10	7	10	1	3
114	Erpha19	Dawro	3	1.00	5	10	7	7	1	3
115	Bosena	Dawro	3	2.00	1	10	1	10	2	3
116	Yesha-Mezia	Dawro	3	2.00	1	10	1	2	2	3
117	Anko-Meziya	Dawro	3	3.00	1	1	1	2	2	1

Supplementary Table 1. (Continued).

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
118	Shado-Diniya	Dawro	2	3.00	9	10	7	11	2	3
119	Tuzuma	Dawro	2	3.00	1	10	1	2	2	3
120	Gena	Dawro	2	2.00	1	10	1	10	2	3
121	Feleke	Dawro	3	3.00	9	10	7	10	2	3
122	Nekaka	Dawro	3	3.00	9	10	1	10	1	3
123	Chemerotiya	Dawro	3	3.00	10	10	5	10	2	3
124	Hala-Meziya	Dawro	3	3.00	1	1	1	2	2	1
125	Anko-Gena	Dawro	3	3.00	5	11	7	10	1	1
126	Azuma-Boza	Dawro	3	2.00	5	10	1	10	1	3
127	Shuta-ziya	Dawro	4	3.00	9	5	1	7	1	3
128	Akisha	Gamo Gofa	3	3.00	5	1	1	2	1	3
129	Ame	Gamo Gofa	1	2.00	6	10	5	2	2	3
130	Argozo	Gamo Gofa	2	3.00	5	10	7	7	1	3
131	Ayissade	Gamo Gofa	2	3.00	1	1	1	2	1	1
132	Babiso	Gamo Gofa	2	2.00	9	10	7	7	1	3
133	Banga	Gamo Gofa	3	3.00	1	1	1	2	1	1
134	Bergude	Gamo Gofa	2	3.00	1	1	1	2	1	1
135	Berzie	Gamo Gofa	2	2.00	9	10	7	7	1	3
136	Beshera	Gamo Gofa	2	3.00	1	10	1	2	1	1
137	Boda	Gamo Gofa	2	1.00	5	1	1	2	1	3
138	Bossa-gena	Gamo Gofa	1	2.00	1	10	1	2	2	1
139	Bundo	Gamo Gofa	1	1.00	1	1	1	2	1	1
140	Butta	Gamo Gofa	2	2.00	5	1	1	2	1	3
141	Checho-I	Gamo Gofa	3	2.00	6	10	5	2	2	3
142	Checho-II	Gamo Gofa	2	2.00	6	11	5	2	1	3
143	Dellea	Gamo Gofa	3	3.00	1	10	1	7	2	1
144	Dellulle	Gamo Gofa	2	3.00	1	10	1	2	1	3
145	Dimo	Gamo Gofa	1	3.00	9	9	7	6	2	3
146	Dolla	Gamo Gofa	4	2.00	1	1	1	2	1	1
147	Fekekie	Gamo Gofa	4	2.00	1	1	1	2	2	1
148	Fello	Gamo Gofa	3	2.00	9	10	7	7	1	1
149	Gena-II	Gamo Gofa	3	2.00	1	10	1	2	2	3
150	Golia	Gamo Gofa	3	2.00	1	10	1	2	2	3
151	Haleko	Gamo Gofa	3	2.00	1	1	1	2	2	1
152	Harambo	Gamo Gofa	2	2.00	9	10	9	8	1	3
153	Kekera	Gamo Gofa	2	3.00	9	10	7	8	1	3
154	Kerta	Gamo Gofa	3	2.00	9	9	7	6	2	3
155	Keteme	Gamo Gofa	1	2.00	9	9	7	6	2	3
156	Ketene	Gamo Gofa	2	2.00	1	1	1	2	1	1
157	Ketisse	Gamo Gofa	3	2.00	1	1	1	2	1	1
158	Mesho-gemo	Gamo Gofa	2	3.00	1	10	1	2	1	3
159	Mezie	Gamo Gofa	2	3.00	5	10	7	7	1	3
160	Pello	Gamo Gofa	3	3.00	5	10	7	7	1	3
161	Pello-2	Gamo Gofa	3	3.00	2	10	5	2	1	1
162	Pemia	Gamo Gofa	4	2.00	5	10	1	2	1	3
163	Shalda	Gamo Gofa	4	3.00	1	1	1	2	1	1

Supplementary Table 1. (Continued).

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
164	Shelekumia	Gamo Gofa	2	3.00	5	10	1	10	1	3
165	Shibr	Gamo Gofa	1	2.00	5	10	1	10	1	3
166	Sorte	Gamo Gofa	3	2.00	9	10	1	10	1	3
167	Tsisse	Gamo Gofa	3	2.00	9	10	7	7	1	3
168	Tuffa	Gamo Gofa	3	3.00	1	1	1	2	1	1
169	Werzia-macho	Gamo Gofa	3	3.00	1	10	1	2	1	3
170	Yilla	Gamo Gofa	2	2.00	9	10	1	2	1	3
171	Zinke-bukema	Gamo Gofa	3	3.00	9	10	7	6	1	3
172	Zoa-zinke	Gamo Gofa	3	2.00	9	10	7	10	2	3
173	Adinona	Wolayita	2	2.00	1	2	5	5	1	3
174	Agina	Wolayita	2	2.00	5	3	2	10	1	3
175	Akacha	Wolayita	1	1.00	4	10	2	7	1	3
176	Ankiegena	Wolayita	1	2.00	2	10	1	3	2	3
177	Ankuwa	Wolayita	1	1.00	1	5	5	10	1	3
178	Banga	Wolayita	2	2.00	2	10	2	2	1	3
179	Bedadia	Wolayita	1	2.00	2	10	5	5	1	3
180	Botya	Wolayita	2	3.00	2	5	2	5	1	3
181	Bulua	Wolayita	2	2.00	2	1	5	5	2	3
182	Chamia	Wolayita	1	2.00	10	10	6	10	1	3
183	Dirbuwa	Wolayita	2	2.00	1	10	5	10	1	3
184	Dokozuwa	Wolayita	1	3.00	2	6	5	10	1	3
185	Erasha	Wolayita	2	3.00	2	2	5	2	1	3
186	Eslamia	Wolayita	2	2.00	10	11	9	10	1	3
187	Fenku	Wolayita	2	2.00	1	1	5	2	2	3
188	Gefetenewa	Wolayita	2	2.00	2	10	5	1	1	3
189	Gena	Wolayita	2	2.00	7	10	5	12	1	3
190	Genesa	Wolayita	2	2.00	1	6	5	10	1	3
191	Gezetiya	Wolayita	2	2.00	9	11	9	10	1	3
192	Ginawa	Wolayita	2	2.00	1	5	5	10	1	3
193	Goderia	Wolayita	2	2.00	2	4	5	3	1	3
194	Kembata	Wolayita	1	1.00	2	2	2	4	1	3
195	Kikiro	Wolayita	2	2.00	4	10	5	7	1	3
196	Kualia	Wolayita	2	1.00	2	10	2	5	1	3
197	Kucharkie	Wolayita	2	2.00	1	5	5	2	2	3
198	Locha	Wolayita	1	2.00	1	1	2	2	1	1
199	Mattie	Wolayita	1	1.00	9	9	7	6	1	3
200	Messa	Wolayita	2	3.00	3	10	3	10	1	3
201	Mochie	Wolayita	2	3.00	1	2	5	4	1	1
202	Osogurzo	Wolayita	3	2.00	9	11	7	8	1	3
203	Pokuwa	Wolayita	2	3.00	2	10	2	10	1	3
204	Posha	Wolayita	2	2.00	2	10	5	4	1	3
205	Shedodiniya	Wolayita	2	1.00	1	5	5	7	1	3
206	Shemeroy	Wolayita	3	3.00	9	9	8	8	1	3
207	Tuzuma	Wolayita	3	2.00	1	10	3	12	1	3
208	Woisha	Wolayita	3	1.00	1	5	1	5	1	3
209	Adame-ado	Sidama	3	2.00	2	10	2	5	2	3

Supplementary Table 1. (Continued).

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
210	Ado	Sidama	2	3.00	1	1	1	2	2	2
211	Alenticho	Sidama	2	2.00	1	2	1	3	2	1
212	Astara-SI	Sidama	1	2.00	10	10	8	12	1	3
213	Astara-SII	Sidama	2	2.00	2	2	5	2	1	1
214	Awusho	Sidama	3	2.00	1	5	5	2	1	3
215	Barbo-dancho	Sidama	1	2.00	10	10	5	3	1	1
216	Bezeze	Sidama	3	3.00	10	11	5	12	2	3
217	Buaecho(Guragies)	Sidama	1	3.00	2	2	5	3	2	1
218	Bulle	Sidama	3	2.00	2	11	3	3	2	3
219	Buzzare	Sidama	2	2.00	2	10	5	5	1	3
220	Chelako	Sidama	3	1.00	4	10	5	10	1	3
221	Demela	Sidama	3	2.00	2	1	5	2	1	1
222	Derassa-dimela	Sidama	3	2.00	5	10	5	10	1	3
223	Dinke	Sidama	2	2.00	2	2	5	2	1	1
224	Dubano	Sidama	2	2.00	1	1	5	13	2	1
225	Ewisho	Sidama	1	2.00	1	10	5	2	1	1
226	Gemechalla	Sidama	1	2.00	2	2	2	2	2	3
227	Gena	Sidama	3	2.00	9	10	6	10	1	3
228	Gerbo	Sidama	1	1.00	7	10	4	7	1	3
229	Gerdicho	Sidama	1	1.00	9	10	6	11	1	3
230	Gulama	Sidama	3	3.00	2	10	2	5	1	3
231	Gussello	Sidama	2	1.00	10	10	8	10	1	3
232	Hawe	Sidama	2	2.00	3	10	2	5	2	3
233	Hekacha	Sidama	2	1.00	2	12	6	7	1	3
234	Hekecha-I	Sidama	2	1.00	9	10	8	7	2	3
235	Kerase	Sidama	3	2.00	1	1	5	2	1	1
236	Kulo	Sidama	3	1.00	1	12	5	2	1	3
237	Ontosha	Sidama	2	1.00	2	10	5	3	1	3
238	Seddisse	Sidama	2	1.00	1	12	5	13	2	3
239	Sediso	Sidama	2	2.00	4	10	2	5	2	3
240	Serane	Sidama	2	2.00	10	11	2	12	1	3
241	Serena	Sidama	3	2.00	2	8	2	5	1	3
242	Sidiramo	Sidama	2	3.00	7	10	2	5	1	3
243	Sirriro	Sidama	1	2.00	2	5	2	5	2	3
244	Tunaka	Sidama	3	1.00	2	1	5	2	1	2
245	Walanticha-I	Sidama	1	2.00	2	2	2	3	2	1
246	Walantiche-II	Sidama	2	2.00	2	8	5	3	2	1
247	Wanigaro	Sidama	3	2.00	10	11	2	10	2	3
248	Waniwassa	Sidama	2	3.00	10	9	9	8	1	3
249	Welanticho	Sidama	2	2.00	9	10	4	10	1	3
250	Ameratiye	Gurage	1	2.00	1	1	1	2	1	1
251	Anikefiye	Gurage	2	2.00	1	10	1	10	2	3
252	Astara	Gurage	4	2.00	9	10	7	10	1	3
253	Ayiwegne	Gurage	2	3.00	9	10	7	7	2	3
254	Bishkanchiwe	Gurage	4	2.00	1	5	1	10	2	3
255	Cherkimad	Gurage	4	2.00	9	10	7	8	2	3

Supplementary Table 1. (Continued).

Entry N°	Landrace name	Collection location/ region	Collection altitude#	Maturity time	Upper-side midrib colour	Under-side midrib colour	Upper-side petiole colour	Under-side petiole colour	Leaf lamina colour	Leaf tip edge colour
256	Dere	Gurage	4	2.00	1	5	1	10	2	3
257	Egendiye	Gurage	1	3.00	9	10	7	7	1	3
258	Eminiye	Gurage	2	3.00	9	10	1	10	1	3
259	Engidawork	Gurage	1	2.00	1	1	1	2	1	3
260	Esmaele	Gurage	2	2.00	5	10	7	1	2	3
261	Geziwet	Gurage	2	2.00	9	10	7	3	2	3
262	Gimbuwe	Gurage	2	1.00	9	10	7	10	2	3
263	Guariye	Gurage	1	2.00	9	10	7	2	1	1
264	Gumbar	Gurage	4	3.00	1	10	1	1	1	3
265	Gurebeshelga	Gurage	4	2.00	1	1	1	2	1	1
266	Jobiro	Gurage	1	2.00	1	5	1	2	2	3
267	Kanchiwe	Gurage	1	2.00	1	1	1	2	1	1
268	Keweretiye	Gurage	3	2.00	1	1	1	2	1	1
269	Kinke	Gurage	1	2.00	1	1	1	2	1	1
270	Mayimote	Gurage	2	1.00	9	10	7	6	2	3
271	Nechuwe	Gurage	4	2.00	1	10	1	2	1	3
272	Nechuwe-II	Gurage	4	2.00	9	10	1	10	1	3
273	Sebara	Gurage	4	2.00	9	10	1	10	2	3
274	Sherite	Gurage	4	2.00	1	10	1	2	1	3
275	Shertiye	Gurage	4	2.00	1	1	1	2	2	1
276	Shifire	Gurage	1	2.00	1	1	1	2	1	1
277	Temoyise	Gurage	2	2.00	9	10	7	10	2	3
278	Teriye	Gurage	4	2.00	9	10	7	10	2	3
279	Tobiro	Gurage	4	2.00	5	10	7	1	2	3
280	Weka	Gurage	2	2.00	9	10	7	10	2	3
281	Wered	Gurage	2	2.00	9	10	7	7	2	3
282	Weretea	Gurage	2	2.00	9	10	7	7	2	3
283	Yegendiye	Gurage	2	2.00	9	10	7	10	1	3
284	Yekimech	Gurage	2	1.00	9	10	1	10	2	3
285	Yesherafire	Gurage	4	2.00	1	10	1	2	2	1
286	Yibiye	Gurage	2	2.00	9	10	7	9	2	3

#: 1. <2,000 m a.s.l.; 2. 2,001–2,400 m a.s.l.; 3. 2,401–2,800 m a.s.l.; and 4. >2,800 m a.s.l.