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# ENSET LANDRACE DIVERSITY IN MAJOR ENSET GROWING REGIONS OF SOUTHERN ETHIOPIA

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## ABSTRACT

Enset [*Ensete ventricosum* (Welw.) Cheesman] is an important food security crop of the Southern Ethiopian highlands. The cultivation of enset is characterised by a wide variety of landraces, suitable to varying agro-ecological conditions and with multiple uses by households. The objective of this paper is to present enset landrace diversity, characteristics and uses in Ethiopia. The study was done through interviews with 375 households covering 20 communities (kebeles) and eight ethnic groups, along an altitudinal range of 1,500 to 3,000 masl across the main enset-producing belt in Southern Ethiopia. A total of 296 locally named enset landraces were recorded. Landrace presence was mostly constrained at the kebele and zone levels, with limited overlap in landrace names across these boundaries. Moderate to high enset landrace diversity was observed on farms across the entire study region. Cultivating a variety of landraces not only allowed for diversified uses, but increases the likelihood of retained yield and food security under variable environmental circumstances. Farmer experience and indigenous knowledge allow for the selection of specific landraces suited to prevalent agro-ecological conditions. We identified a perception bias in the attribution of landrace agro-ecological characteristics, with farmer insight often dependent on the environmental conditions that the local community was exposed to. We underscore the importance of research-based characterisation of enset landraces, to ensure optimal cultivation of this food security crop in changing climatic conditions.

*Key Words*: *Ensete ventricosum*, kebeles, Xanthomonas wilt

## RÉSUMÉ

Le bananier d'Abyssinie [*Ensete ventricosum* (Welw.) Cheesman] est une culture importante pour la sécurité alimentaire des hauts plateaux du sud de l'Éthiopie. La culture de l'Ensete se caractérise par un grand nombre de variétés, adaptées à des conditions agro-écologiques variables et à des utilisations multiples par les ménages. L'objectif de cet article est de présenter la diversité, les caractéristiques et les utilisations des variétés d'Ensete en Éthiopie. L'étude a été réalisée par le biais d'entretiens avec 375 ménages couvrant 20 communautés (kebeles) et huit groupes ethniques, le long d'une gamme altitudinale de 1 500 à 3 000 mètres dans la principale zone de production d'Ensete du sud de l'Éthiopie. Au total, 296 variétés d'Ensete nommées localement ont été enregistrées. La présence de variétés était principalement limitée aux niveaux du kebele et de la zone, avec un chevauchement limité des noms de variétés au-delà de ces limites. Une diversité modérée à élevée de variétés d'Ensete a été observée dans les exploitations agricoles de l'ensemble de la région étudiée. La culture d'une gamme de variétés locales permet non seulement de diversifier les utilisations, mais aussi d'augmenter la probabilité de maintenir le rendement et la sécurité alimentaire dans des conditions environnementales variables. L'expérience des agriculteurs et les connaissances indigènes permettent de sélectionner des variétés spécifiques adaptées aux conditions agro-écologiques dominantes. Nous avons identifié un biais de perception dans l'attribution des caractéristiques agro-écologiques des variétés, les connaissances des agriculteurs dépendant souvent des conditions environnementales auxquelles la communauté locale a été exposée. Nous soulignons l'importance d'une caractérisation des variétés d'Ensete basée sur la recherche, afin de garantir une culture optimale de cette culture de sécurité alimentaire dans des conditions climatiques changeantes.


*Mots Clés*: *Ensete ventricosum,* kebeles, flétrissement de Xanthomonas

## INTRODUCTION

Enset [*Ensete ventricosum* (Welw.) Cheesman] is a food security crop, cultivated in the highlands of south and southwestern Ethiopia. It is a large perennial monocarpic herbaceous plant of the Musaceae family, morphologically similar to the genus *Musa* spp. Unlike the bananas, mature enset plants do not produce edible fruit. Instead, enset is cultivated for its underground corm and pseudostem, which are processed into starchy food products (Borrell *et al.,* 2019). While enset takes multiple years to mature (typically 4–7 years), requiring a long-term investment from the farmer, it has several food security traits that make its investment worthwhile (Borrell *et al.,* 2019).

The crop can grow over a wide range of agro-ecological conditions and shows ability to withstand environmental stress, including periods of drought, heavy flooding, and frost damage (Quinlan *et al*., 2015; Zerfu *et al*., 2018). A large number of enset landraces are cultivated; comprising a high genetic diversity and diverse traits, providing resilience to the enset farming system (Olango *et al*., 2014; Yemataw *et al*., 2014, 2016, 2018). The crop is also not restrictive in harvesting periods, providing continuous availability of food.

Enset can be harvested and used throughout the year and at any growth stage, over several years (up to and including the early flowering stage), although mature enset is generally preferred. Its derived fermented food products (e.g. *kocho* and *bulla*) can be stored for long periods (Garedew *et al*., 2017; Sahle *et al*., 2018). Thus, the combined characteristics of environmental resilience and unrestricted availability provide an important base for food security and has been named 'tree against hunger' (Brandt *et al*., 1997).

In the Ethiopian highlands, enset provides a staple food source for approximately 20 million people (Brandt *et al*., 1997). Additionally, enset is a multipurpose crop, providing feed security (especially during the dry season months), fiber, construction material, packaging and traditional medicine, and has substantial cultural applications (Bezuneh, 1984; Brandt *et al.,* 1997; Blomme *et al*., 2018).

The domestication of enset is unique to the Ethiopian highlands, and small-holder farmers continue with traditional enset farming through a wealth of indigenous knowledge, transferred from one generation to the next. Generally, enset is grown in mixed subsistence farming systems, in association with other crops such as annual food crops, coffee and multipurpose trees (Yemataw *et al.,* 2016).

The high diversity of enset landraces further contributes to observed differences in enset farming systems (Yemataw *et al*., 2014, 2016, 2018). Different landraces are used for various purposes (Negash, 2001), and present a range of agronomic characteristics and environmental tolerances. Enset farmers have account of landrace characteristics and uses, gained *via* indigenous knowledge transferred throughout generations of enset farming communities, and augmented through personal experience.

Documenting and verifying enset landrace diversity and landrace characteristics is important for crop improvement programmes and for managing genetic resources. Ongoing pressures of climate change, indigenous and emerging pests and diseases, as well as rapid population growth, have been shown to negatively influence enset production (Tenaye and Geta, 2009). Identifying landraces adaptive to varying environmental conditions can aid to ensure the sustainability and maintained food security of enset farming systems across the Ethiopian highlands.

Enset landraces are known to be unevenly distributed across the enset-growing region of the Ethiopian highlands, and variations are attributed to a combination of socio-cultural and agro-ecological factors (Tsegaye, 2002). The ethnobotanical framework of enset farming communities is indeed exceptionally diverse. The Southern Nations, Nationalities and Peoples Region (SNNPR), the major enset growing region in Ethiopia, contains over 56 ethnic groups (UNICEF, 2019; The Sidama Region and the South West Ethiopia Peoples' Region were split off from the SNNPR in 2020 and 2021, respectively each with their own language, culture and history, carrying on traditions and customs of farming practices). Indigenous knowledge preserved within these groups, including traditional food processing, botanical knowledge, environmental and agro-ecological knowledge, remains critical for the enset agricultural systems (Tsegaye, 2002; Olango *et al.,* 2014; Yemataw *et al.,* 2016).

The objective of this study was to characterise enset landrace diversity and identify landrace specific characteristics, in relation to tolerance to biotic and abiotic constraints in the main enset growing belt of southern Ethiopia.

## METHODOLOGY

**Study area.** A field survey was conducted across the main enset growing belt in the highlands of the South West Ethiopia Peoples' Region, the Southern Nations, Nationalities, and Peoples' Region (SNNPR) and the Sidama Region (Fig. 1). Eight zones where enset cultivation is omnipresent, and representing major ethnic groups belonging to the Omotic, Cushitic and Semitic language families were selected across the three regions. Five zones were selected in the SNNPR (Gurage, Hadiya, Kembata Tembaro, Gamo and Gedeo), two zone in the South West Region (Kaffa and Dawro), and one zone called Sidama representing the entire Sidama region (Fig. 1).

The number of zones per region was determined according to the size of the enset production area. In each zone, two kebeles (wards) with a long history in enset farming and importance of enset in production systems were selected. In the Gedeo and the Sidama zones, where enset cultivation is widespread (Zerihun Yemataw, personal communication, 2022), two additional kebeles were selected, in order to cover all potential diversity within these zones.

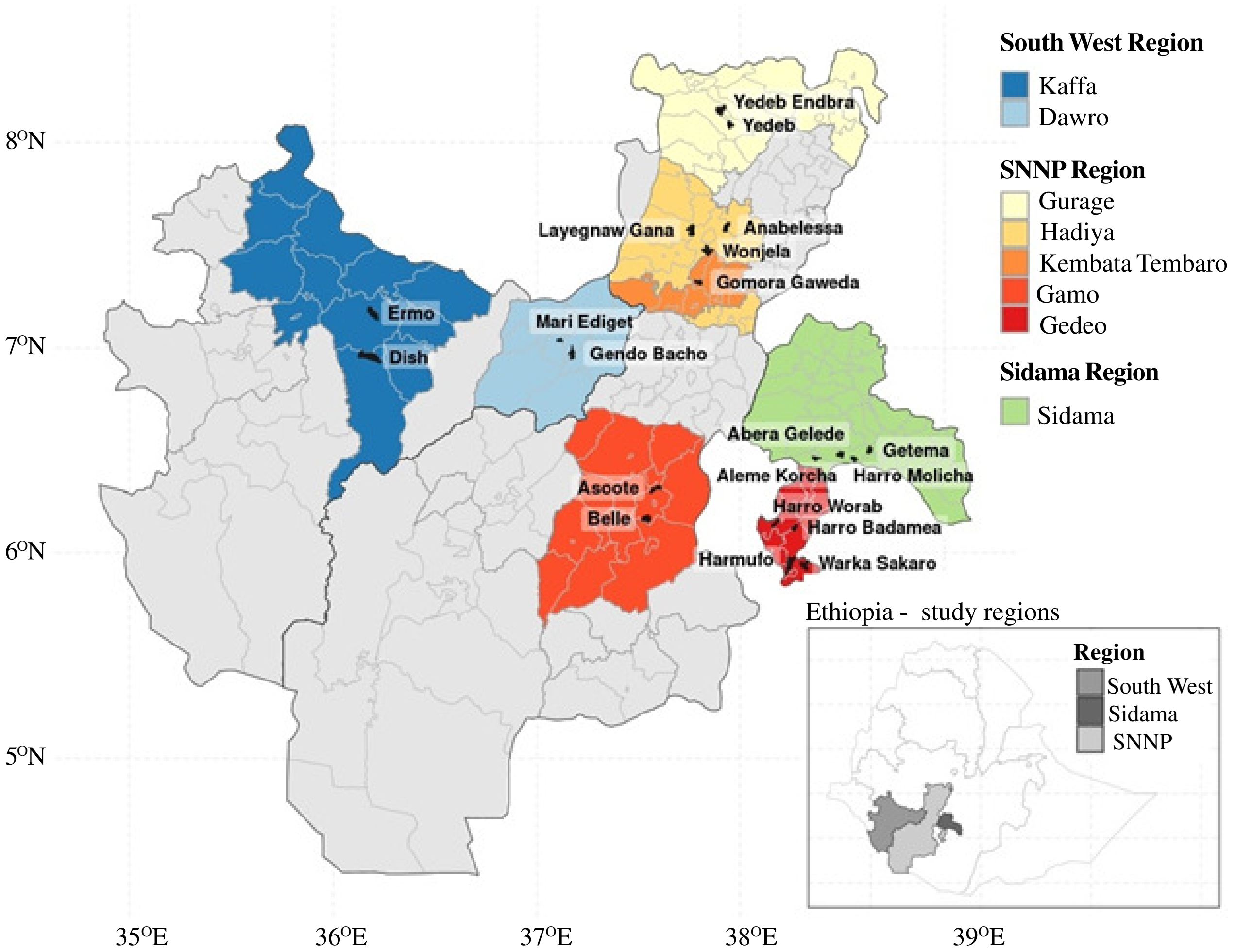


Figure 1. Map of Ethiopia showing the zones involved in this study. Each zone is indicated in a different colour. The kebeles (wards) participating in the survey are filled in black, with the kebele name indicated in bold.

A kebele is the smallest administrative units in Ethiopia, comprising on average 500 households, equivalent to 3,500 - 4,000 persons; although this can vary substantially (Treiber, 2010; Anonymous, 2022).

**Survey procedure.** Nine to 21 enset-growing households were randomly selected per kebele, and an overall total of 375 households participated in the study (Table 1). The selected kebeles covered an altitudinal range of 1,500 to 3,000 masl (Table 1), to assess a possible altitudinal effect on enset landrace presence and diversity.

For each household considered in the survey, interviews were carried out with the household head, except where a different person was responsible for farm management; in this case, this person accompanied the head of the household during the interview. Accordingly, one to two people in each household participated to the survey.

A semi-structured questionnaire was used; whereby structured multiple choice and yes/no questions on general farm management practices, were combined with open follow-up questions, allowing the farmer to provide more detailed responses. In this study, we focused solely on enset landrace diversity, and characterisation of landrace traits and uses by the households. The presence and estimated abundance of each landrace on a farm was established for each household.

All enset vernacular landrace names were captured as reported by the interviewees and documented accordingly. Minor variations in the spelling of vernacular names, and phonetically similar vernacular names, were recorded as a single landrace name.

**Important computations.** The diversity of enset landraces grown in a household was determined *via* a combination of commonly used diversity indices, including landrace richness, Simpson's diversity index, the Shannon–Weaver index and Pielou's evenness index. The similarity of landraces cultivated between households was evaluated using Jaccard's similarity index (Legendre and Legendre, 2012).

Landrace richness was calculated as the total number of different landraces cultivated on a farm. Simpson's diversity index was based on the sum of squared species proportions (Simpson, 1949). For a vector of species counts x, the dominance index was defined as:

$$D = \Sigma_i p_i^2$$

Where:

$p_i$ is the species proportion, $p_i = x_i / N$, and $N$ is the total number of counts.

This is equal to the probability of selecting two individuals from the same species, with replacement. Simpson's index is defined here as $1 - D$, or the probability of selecting two individuals from different species, with replacement. The Shannon–Weaver diversity index accounts for both abundance and evenness of the landraces present and can be increased either by greater evenness or more unique landraces (Shannon and Weaver, 1949). The Shannon-Weaver index is defined as:

$$H' = - \Sigma_i p_i \ln p_i$$

Where:

$p_i$ is the proportional abundance of species i.

Equity, the proportion of the observed diversity with respect the maximum diversity expected was calculated through the Pielou's evenness index (Pielou, 1966) as:

$$J = H'/H'max$$

Where:

H' is the Shannon-Weaver diversity and H'max is the maximum diversity calculated as ln(S), with S being the number of landraces in a sample.

TABLE 1. Enset landrace diversity

| Zone | Kebele | Altitude | n | Richness | 1 – D | H' | J | Jaccard similarity |
|---|---|---|---|---|---|---|---|---|
| Kaffa | Ermo | 1956 ± 12 | 16 | 5.5 ± 1.4 cdef | 0.76 ± 0.05 abcd | 1.54 ± 0.22 bcd | 0.92 ± 0.05 ab | 0.31 ± 0.08 efg |
| | Dish | 2270 ± 34 | 20 | 5.9 ± 2.2 cde | 0.72 ± 0.08 abcde | 1.47 ± 0.31 cd | 0.86 ± 0.08 abc | 0.35 ± 0.06 def |
| Dawro | Mari Ediget | 2448 ± 24 | 20 | 8 ± 2.9 bc | 0.78 ± 0.07 abc | 1.74 ± 0.34 bc | 0.87 ± 0.06 abc | 0.43 ± 0.06 cd |
| | Gendo Bacho | 1704 ± 76 | 18 | 4.2 ± 1 ef | 0.7 ± 0.07 abcde | 1.3 ± 0.21 d | 0.93 ± 0.08 ab | 0.4 ± 0.11 cde |
| Gurage | Yedeb Endbra | 1992 ± 17 | 20 | 5.9 ± 1.9 cde | 0.77 ± 0.08 abc | 1.6 ± 0.31 bcd | 0.92 ± 0.07 ab | 0.42 ± 0.09 cd |
| | Yedeb | 2005 ± 295 | 17 | 11.6 ± 3.7 a | 0.86 ± 0.04 a | 2.19 ± 0.22 a | 0.88 ± 0.06 abc | 0.46 ± 0.11 bc |
| Hadiya | Layegnaw Gana | 2219 ± 36 | 21 | 7.4 ± 2.5 bcd | 0.75 ± 0.07 abcd | 1.61 ± 0.28 bcd | 0.83 ± 0.12 abcde | 0.28 ± 0.06 fg |
| | Anabelessa | 2321 ± 87 | 21 | 6.2 ± 1.3 cde | 0.79 ± 0.05 abc | 1.65 ± 0.22 bcd | 0.92 ± 0.09 ab | 0.3 ± 0.07 fg |
| Kembata | Wonjela | 2194 ± 22 | 16 | 6.6 ± 1.3 cde | 0.72 ± 0.16 abcde | 1.54 ± 0.37 bcd | 0.81 ± 0.18 abcde | 0.44 ± 0.1 cd |
| Tembaro | Gomora Gaweda | 2704 ± 67 | 19 | 7.3 ± 3.3 bcd | 0.69 ± 0.12 bcde | 1.48 ± 0.41 cd | 0.8 ± 0.11 bcde | 0.24 ± 0.06 g |
| Gamo | Asoote | 2981 ± 18 | 20 | 5.4 ± 1.1 def | 0.3 ± 0.24 f | 0.68 ± 0.5 f | 0.39 ± 0.26 g | 0.55 ± 0.13 ab |
| | Belle | 2261 ± 16 | 18 | 2.9 ± 0.8 f | 0.52 ± 0.2 e | 0.87 ± 0.35 ef | 0.85 ± 0.2 abcde | 0.37 ± 0.09 def |
| Gedeo | Harro Worab | 1877 ± 63 | 20 | 7.1 ± 1 cd | 0.84 ± 0.03 ab | 1.9 ± 0.15 ab | 0.97 ± 0.03 a | 0.59 ± 0.06 a |
| | Harro Badamea | 2473 ± 10 | 20 | 7.4 ± 3.3 bcd | 0.61 ± 0.15 de | 1.29 ± 0.38 d | 0.69 ± 0.15 de | 0.47 ± 0.06 bc |
| | Harmufo | 2326 ± 39 | 19 | 6.1 ± 1.1 cde | 0.59 ± 0.22 de | 1.22 ± 0.44 de | 0.68 ± 0.24 ef | 0.43 ± 0.08 cd |
| | Warka Sakaro | 2060 ± 52 | 20 | 9.7 ± 3 ab | 0.67 ± 0.16 cde | 1.53 ± 0.41 bcd | 0.69 ± 0.16 ef | 0.47 ± 0.08 bc |
| Sidama | Abera Gelede | 2744 ± 52 | 20 | 6.2 ± 2.8 cde | 0.64 ± 0.19 cde | 1.3 ± 0.41 d | 0.74 ± 0.21 cde | 0.45 ± 0.05 cd |
| | Aleme Korcha | 1857 ± 9 | 10 | 3.6 ± 1.8 ef | 0.27 ± 0.22 f | 0.5 ± 0.38 f | 0.47 ± 0.34 fg | 0.46 ± 0.08 bcd |
| | Getema | 2162 ± 36 | 20 | 6.3 ± 2.5 cde | 0.72 ± 0.11 abcde | 1.5 ± 0.38 cd | 0.86 ± 0.07 abcd | 0.37 ± 0.07 def |
| | Harro Molicha | 2780 ± 0 | 20 | 11.9 ± 1.2 a | 0.73 ± 0.07 abcde | 1.69 ± 0.2 bcd | 0.67 ± 0.13 efg | 0.55 ± 0.07 ab |

Number of households that participated in the survey (n), altitude of the households (masl). Average household enset landrace diversity represented by the landrace richness (number of landraces on a farm), Simpson's diversity index (1 - D), Shannon-Weaver diversity index (H') and Pielou's evenness (J). Similarity of landrace composition between households within a kebeles is presented by the Jaccard similarity index. Standard deviations are provided. Means in a column followed by the same letter are not significantly different ($P < 0.05$)

The similarity of landraces grown between the households of the same kebele, between kebeles and between zones was assessed using the Jaccard similarity index based on presence/ absence of landraces. The distance matrix was computed using the 'vegdist' function of the R package 'vegan', and all diversity indices were computed using the 'diversity' function of the same R package (Oksanen *et al.*, 2022).

The variation in household landrace diversity and traits was assessed depending on the kebele, the altitude and the economic status of the household. The kebele is an indicator for cultural background and ethnic group the household belongs to. The altitude at which the farm is located (Table 1) is an indicator for the agro-ecological zone and the associated environmental conditions.

The economic status of the household is a perceived status as reported by the head of the household as rich, medium or poor. Some households did not know how to assess their economic status, and were categorised *a posteriori* by the size of their family, the area of cultivated land and the number of livestock they owned.

**Data analysis.** Descriptive statistics were used to present responses to categorical binary questions (yes/no responses) in terms of uses and agro-ecological characteristics, as the percentage for which households provided the same response.

Pearson correlations were used to assess the relation between various numerical responses (e.g. if diversity changed with altitude), and an analysis of variance followed by a Tukey test at 5% probability level for mean separation was used to assess if numerical responses varied with categorical groups (e.g. diversity and economic status, or differences between kebeles). All analyses were performed using R version 3.6.3 (R core team, 2020).

## RESULTS

**Landrace diversity and composition.** Across the entire study belt, a total of 296 locally named enset landraces was recorded. The number of landraces cultivated on individual farms (richness) ranged from 1 to 19, and varied significantly across kebeles (Table 1). The landrace richness varied from 2.9 (± 0.8) at Belle in the Gamo zone, and 11.9 (± 1.2) at Harro Molicha in the Sidama zone.

Most kebeles showed relatively high values of the diversity indices [Simpsons diversity, Shannon-Weaver index and Pielou's evenness] (Table 1), indicating a generally high level of household landrace richness and evenness. As such, the highest diversity was observed in the kebele Yedeb of the Gurage zone. The diversity indices, however, identified two kebeles, Aleme Korcha in Sidama and Asoote in the Gamo zone that had a low household-level diversity in enset landraces. The low Simpson's 1-D of 0.27 (± 0.22) and 0.30 (± 0.24), low Shannon-Weaver of 0.50 (± 0.38) and 0.68 (± 0.50), and low Pielou's evenness of 0.47 (± 0.34) and 0.39 (± 0.26), show a tendency to cultivate high abundance of few landraces, potentially combined with a few rare landraces in low numbers.

The specific landraces grown varied substantially across households, kebeles and zones. A range of 23 to 55 different landraces were reported at the zone level, and 7 to 42 landraces at the kebele level. Some popular landraces were identified in specific zones. For example, in Sidama and Gedeo, the landrace 'Genticho' was reported in 100% and 96% of the households. Additionally, 'Astara' (91%), 'Niffo' (91%) and 'Toracho' (76%) were common in Gedeo, and 'Midasho' in Sidama (88%). 'Siskela' and 'Merza' were common in Kembata Tembaro (83% and 77%), 'Amerat' in Gurage (89%), 'Nobbo' and 'Bajo' in Kaffa (97% and 75%), 'Gimbo' in Hadiya (93%) and 'Maziya' in Dawro (87%). Nevertheless, most of the other landraces were only rarely reported by the interviewees.

Landraces were often found to be uniquely cultivated at specific kebeles (Fig. 2). Limited overlap in landrace names was found beyond zonal boundaries, with low Jaccard similarity indeces ranging between 0 and 0.13 (0

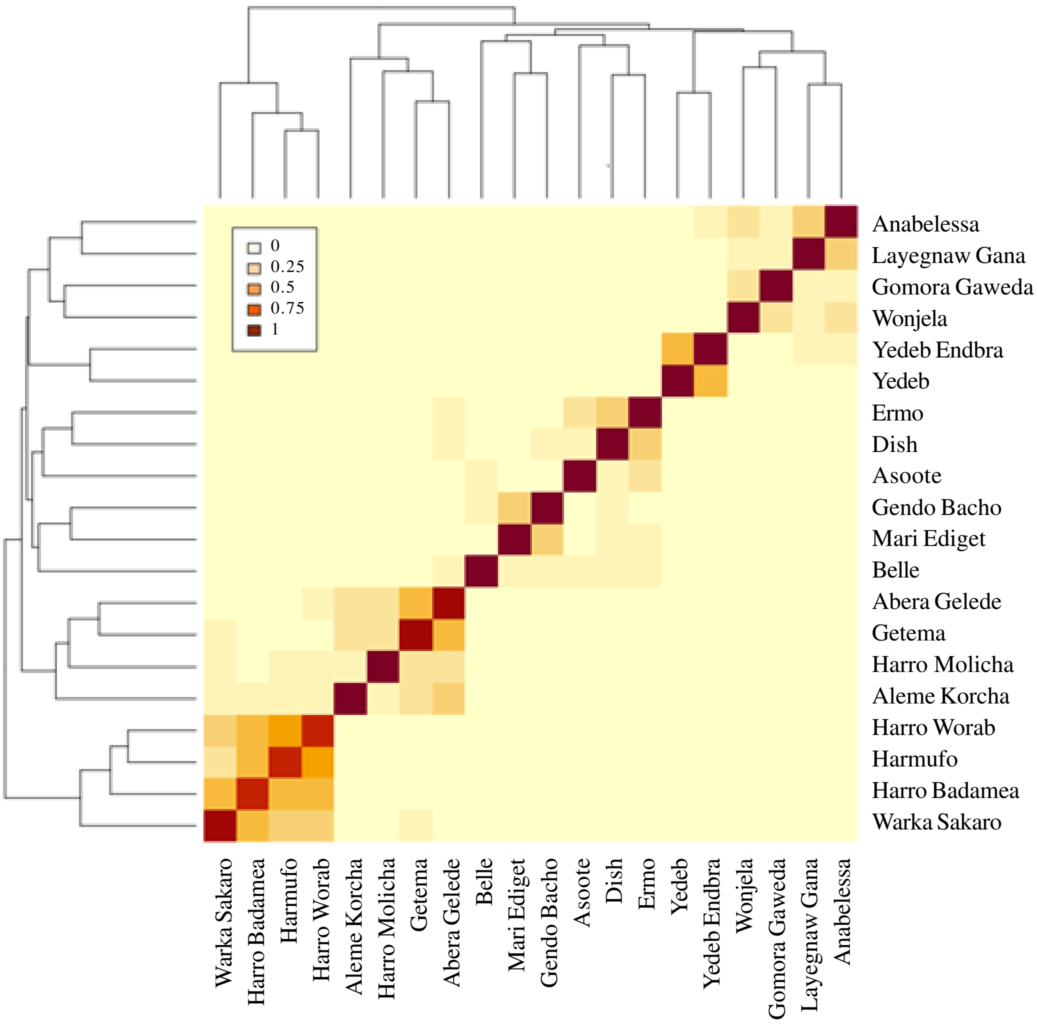


Figure 2. Pairwise Jaccard similarity of enset landraces cultivated between kebeles in Ethiopia. The Jaccard similarity provides a range between 0:1, with 0 depicting no overlap in landraces grown and 1 depicting full overlap in landraces grown. The kebeles with the highest similarity are grouped together.

meaning no overlap in landraces grown and 1 full overlap in landraces grown). For example, some similarity was found between Kaffa and Gamo (Jaccard similarity of 0.13) sharing 7 landraces, between Hadiya and Kembata Tembaro (0.11) sharing 10 landraces, Gurage and Hadiya (0.05) sharing 4 landraces, and Gedeo and Sidama (0.06) sharing 5 landraces. Accordingly, the landrace names were not clustered beyond zones within the larger linguistic boundaries.

Landrace selection also varied between households within kebeles. Landrace selection was most similar between farms of the kebele Harro Worab (pairwise Jaccard similarity of 0.59 ± 0.06), and most diverse at Gomora Gaweda (0.24 ± 0.06) (Table 1).

The composition of landraces on farms was similarly highly variable, particularly in abundance. Among all interviewed households, 23.8% cultivated one landrace (in an abundance > 50%). The low number of households cultivating landraces in a high abundance of more than 50% is in line with the relatively high evenness found through the diversity indices (Shannon-Weaver and

Pielou's evenness). Accordingly, most landraces were grown in lower abundances and landrace composition plots were mostly skewed to a higher number of landraces cultivated at low abundances (Fig. 3). Median abundances ranged between low values of 2.7% at Harro Molicha and of 4.1% at Warka Sakaro, to higher values of 32.8% at Belle.

Most farm-level rare and rarest landraces were also not very common, i.e. they often did not occur on other farms within a kebele. However, several of these rare or rarest landraces were also cultivated in low numbers in other households of the same kebele. For instance at Asoote, the landraces 'Sorge' and 'Falake', were cultivated in 50% of the households, although in a low abundance.

Landrace diversity was found to be partially related to the socio-economic conditions of a household, to their ethno-linguistic background and to agro-ecological conditions of the farm. Firstly, the size of the farm and the land area attributed to enset cultivation positively related to overall farm-level landrace richness ($r = 0.283$, $P < 0.001$), and accordingly, richness increases with the total number of enset plants cultivated on the farm ($r = 0.142$, $P < 0.01$). Poorer household, according to interviewees, on average cultivated significantly fewer landraces ($4.9 \pm 2.3$, $P < 0.01$) compared to medium to rich households ($6.9 \pm 3.1$).

The Shannon-Weaver index was also significantly lower in these poorer households ($1.04 \pm 0.55$, $P < 0.01$, $1.47 \pm 0.47$), indicating that the present landraces are cultivated with a more uneven distribution in terms of abundance. Secondly, richness of cultivated landraces shows a relation to the cultural background of the groups with kebeles belonging to the Omotic linguistic group maintaining a significantly lower ($P < 0.001$) landrace richness of $5.5 \pm 2.4$ compared to those of the Semitic ($8.6 \pm 4$) and the Cushitic groups ($7.4 \pm 2.9$). Finally, the three diversity indices accounting for abundance show a significant relation with altitude, indicating that both diversity and evenness decrease with altitude (1-D: $r = -0.349$, $p < 0.001$; H: $r = -0.285$, $P < 0.001$; J: $r = -0.456$, $P < 0.001$). Landrace richness, however, did not relate to altitude.

**Uses of enset landraces.** Households generally reported multiple uses for their cultivated landraces (Table 2, Blomme *et al.*, 2023). Food consumption in general was one of the main uses reported; 96% of all cultivated landraces reportedly used for kocho, 77% used bulla and 34% used amicho. Kocho is thus the main food product across all kebeles, while the use for bulla and amicho varied considerably.

Other general uses included extracted for fiber (89%) and feed (85%), of the cultivated landraces. Landraces for medicinal use were rarely reported (14%) and cultivated at significantly lower abundances ($P < 0.001$). The kebeles in the Kembata Tembaro zone and Gurage zone specifically reported higher proportions of landraces used for medicinal purposes (34-40% of landraces). The cultivation of landraces for medicinal use was lowest in rich households ($5\% \pm 9$, $P < 0.05$) compared to poor to medium households ($16\% \pm 23$).

**Growing conditions and expected yields.** Farms select specific landraces in part based on the landrace's suitability to grow in specific agro-ecological conditions. In several kebeles, farmers report selecting a majority of landraces suited for growing in poor soil (e.g., 97% (± 7) in Getema, and 81% (± 18) in Harro Worab), suited for dry conditions (e.g. 100% of landraces in Belle, and 99% (± 3) in Abera Gelede), and/or frost (92% (± 14) in Dish, 89% (±17) in Wonjela) (Table 3). Particularly in Harro Molicha, farmers report all selected landraces (100%) to be suited for all three investigated conditions.

Overall, the number of landraces selected for these conditions relate to the altitude of the farm. Reported landraces suited for poor soil decreased with altitude ($r = -0.199$, $P < 0.001$), and the importance of drought tolerant landraces and frost tolerant landraces increased

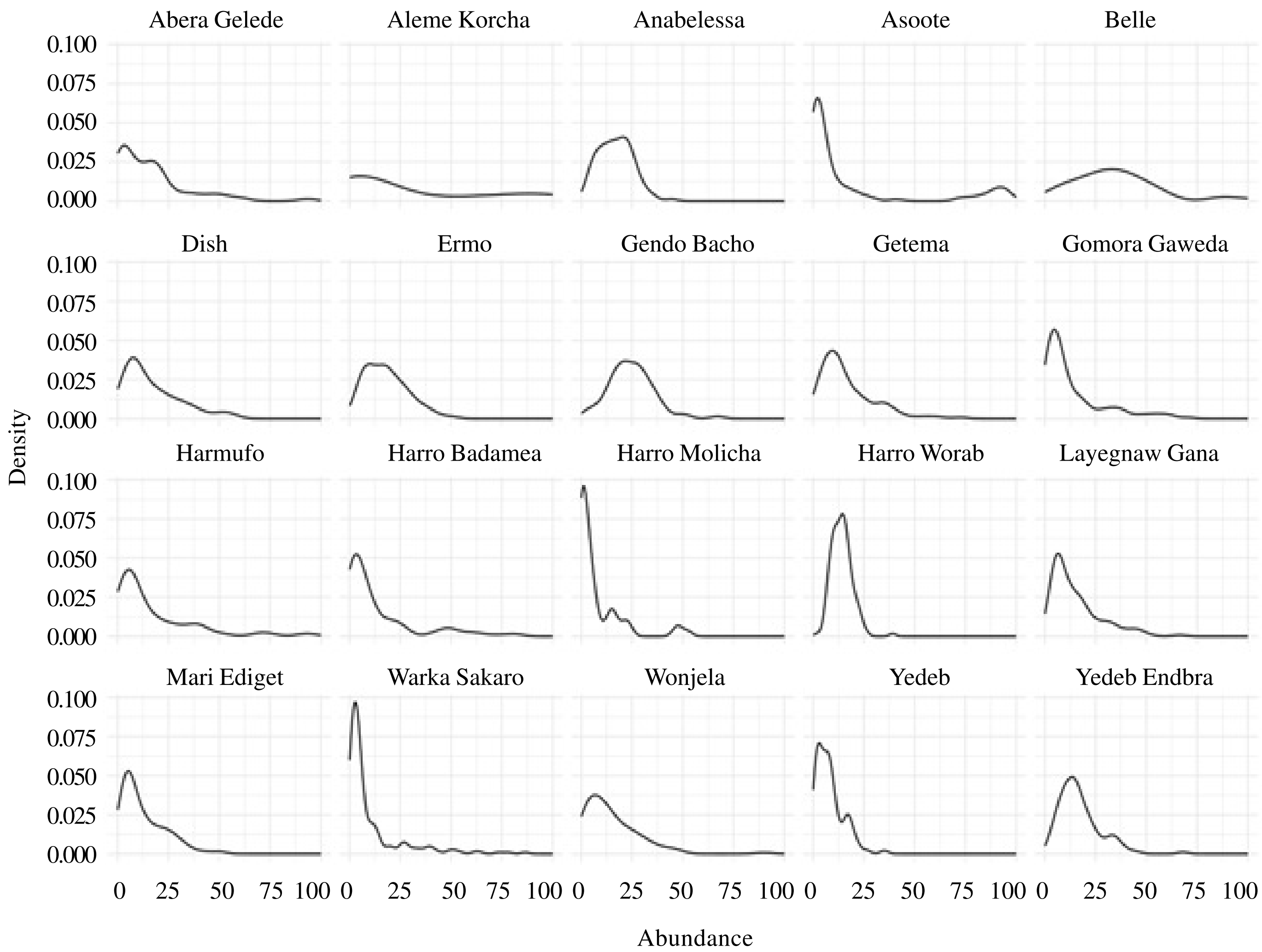


Figure 3. Density distributions of landrace abundances within kebeles in Ethiopia.

TABLE 2. Common uses of landraces

| Zone | Kebele | Food products | | | Fiber | Medicine | Feed |
|---|---|---|---|---|---|---|---|
| | | Kocho | Bulla | Amicho | | | |
| Kaffa | Ermo | 100 ± 0 a | 67 ± 13 cd | 42 ± 19 bc | 88 ± 15 abc | 4 ± 8 c | 98 ± 8 abc |
| | Dish | 100 ± 0 a | 34 ± 18 de | 37 ± 28 c | 99 ± 5 ab | 1 ± 4 c | 97 ± 15 abc |
| Dawro | Mari Ediget | 100 ± 0 a | 0 ± 0 f | 0 ± 2 c | 86 ± 12 bc | 0 ± 0 c | 98 ± 7 ab |
| | Gendo Bacho | 99 ± 5 a | 21 ± 47 ef | 0 ± 0 c | 100 ± 42 a | 9 ± 32 bc | 100 ± 41 a |
| Gurage | Yedeb Endbra | 91 ± 16 a | 96 ± 29 ab | 66 ± 41 ab | 96 ± 27 ab | 35 ± 27 a | 61 ± 51 d |
| | Yedeb | 95 ± 12 a | 92 ± 28 abc | 91 ± 23 a | 88 ± 29 abc | 34 ± 23 a | 84 ± 38 abcd |
| Hadiya | Layegnaw Gana | 100 ± 0 a | 100 ± 0 a | 67 ± 33 ab | 100 ± 0 ab | 1 ± 4 c | 92 ± 16 abc |
| | Anabelessa | 56 ± 27 b | 36 ± 33 de | 24 ± 33 c | 29 ± 27 d | 5 ± 15 c | 12 ± 26 e |
| Kembata | Wonjela | 100 ± 0 a | 88 ± 13 abc | 49 ± 31 bc | 89 ± 17 abc | 40 ± 32 a | 99 ± 5 ab |
| Tembaro | Gomora Gaweda | 99 ± 2 a | 99 ± 2 a | 32 ± 25 c | 98 ± 4 ab | 38 ± 24 a | 98 ± 4 ab |
| Gamo | Asoote | 91 ± 11 a | 89 ± 12 abc | 28 ± 22 c | 85 ± 10 bc | 10 ± 14 bc | 83 ± 19 abcd |
| | Belle | 100 ± 0 a | 96 ± 11 ab | 23 ± 30 c | 100 ± 0 ab | 4 ± 11 c | 90 ± 26 abcd |
| Gedeo | Harro Worab | / | / | / | / | / | / |
| | Harro Badamea | 97 ± 13 a | 97 ± 7 ab | 12 ± 25 c | 99 ± 3 ab | 6 ± 11 bc | 70 ± 39 bcd |
| | Harmufo | 82 ± 2 ab | 83 ± 24 abcd | 60 ± 57 abc | 73 ± 9 bcd | 18 ± 2 abc | 82 ± 2 abcd |
| | Warka Sakaro | 100 ± 2 a | 79 ± 14 abcd | 24 ± 14 c | 81 ± 11 bc | 24 ± 10 ab | 90 ± 5 abcd |
| Sidama | Abera Gelede | 98 ± 6 a | 100 ± 2 a | 67 ± 32 ab | 100 ± 2 ab | 8 ± 16 bc | 99 ± 3 ab |
| | Aleme Korcha | 72 ± 44 b | 69 ± 46 bcd | 54 ± 41 abc | 68 ± 42 cd | 17 ± 28 abc | 61 ± 47 cd |
| | Getema | 100 ± 0 a | 100 ± 0 a | 3 ± 7 c | 99 ± 3 ab | 3 ± 11 c | 90 ± 24 abc |
| | Harro Molicha | 100 ± 2 a | 92 ± 3 ab | 8 ± 3 c | 92 ± 3 abc | 10 ± 5 bc | 92 ± 3 abc |

The average percentage of landraces with reported uses within a household are shown. Standard deviations are provided. Means in a column followed by the same letter are not significantly different ($P < 0.05$)

TABLE 3. Reported landrace tolerances for cultivation on poor soil, adaptive to drought and frost event

| Kebele | Altitude (masl) | Percentage of landraces suited for: | | |
|---|---|---|---|---|
| | | Poor soil | Drought | Frost |
| Asoote | 2981 ± 18 | 13 ± 14 efg | 72 ± 18 a | 34 ± 28 def |
| Harro Molicha | 2780 ± 0 | 100 ± 0 a | 100 ± 0 a | 100 ± 0 a |
| Abera Gelede | 2744 ± 52 | 1 ± 3 g | 99 ± 3 a | 62 ± 48 bcde |
| Gomora Gaweda | 2704 ± 67 | 7 ± 20 fg | 78 ± 22 a | 73 ± 25 abc |
| Harro Badamea | 2473 ± 10 | 33 ± 36 de | 91 ± 19 a | 19 ± 33 f |
| Mari Ediget | 2448 ± 24 | / | / | / |
| Harmufo | 2326 ± 39 | 22 ± 38 defg | 66 ± 44 ab | 29 ± 34 def |
| Anabelessa | 2321 ± 87 | 7 ± 15 fg | 43 ± 22 bc | 3 ± 13 f |
| Dish | 2270 ± 34 | 19 ± 20 efg | 45 ± 19 bc | 92 ± 14 ab |
| Belle | 2261 ± 16 | 0 ± 0 g | 100 ± 0 a | 0 ± 0 f |
| Layegnaw Gana | 2219 ± 36 | 86 ± 27 ab | 86 ± 29 a | 65 ± 48 bcd |
| Wonjela | 2194 ± 22 | 29 ± 17 def | 88 ± 12 a | 89 ± 17 abc |
| Getema | 2162 ± 36 | 97 ± 7 a | 81 ± 32 a | 29 ± 41 ef |
| Warka Sakaro | 2060 ± 52 | 50 ± 13 cd | 85 ± 13 a | 7 ± 10 f |
| Yedeb | 2005 ± 295 | 50 ± 24 cd | 29 ± 31 bc | 29 ± 36 ef |
| Yedeb Endbra | 1992 ± 17 | 66 ± 23 bc | 34 ± 21 bc | 3 ± 8 f |
| Ermo | 1956 ± 12 | 5 ± 9 g | 42 ± 16 bc | 33 ± 24 def |
| Harro Worab | 1877 ± 63 | 81 ± 18 ab | 93 ± 11 a | 57 ± 18 cde |
| Aleme Korcha | 1857 ± 9 | 9 ± 17 efg | 17 ± 22 c | 33 ± 50 def |
| Gendo Bacho | 1704 ± 76 | / | / | / |

The average percentage of landraces with reported characteristics within a household are shown. Standard deviations are provided. Means in a column followed by the same letter are not significantly different ($P < 0.05$)

with altitude ($r = 0.360$, $p < 0.001$; $r = 0.264$, $P < 0.001$, respectively).

Accordingly, the expected growth rates (Table 4) also related to environmental conditions, with landraces with expected fast growth rates decreasing with altitude ($r = -0.154$, $P < 0.01$), and reversely those with expected slow growth rates increasing with altitude ($r = 0.170$, $P < 0.01$). As such, perceived landrace-specific growth rates reported by farmers are potentially not inherent to the landrace but to the growing conditions. Expected yields (Table 4) however showed no relation to altitude. Reports of expected yields did relate to the farm size attributed to enset cultivation, with households with smaller enset fields cultivating a higher percentage of high-yield landraces (area vs high yields: $r = -0.182$, $P < 0.001$), and inversely a higher percentage of low enset yields in households with more land area for enset ($r = 0.337$, $P < 0.001$).

**Tolerance to Xanthomonas wilt.** Most households reported cultivating several landraces tolerant or intermediately tolerant to Xanthomonas wilt (XW) (Table 5). Nevertheless, in some kebeles, most landraces cultivated were reportedly susceptible to XW. For example, 93% (± 24) of landraces in the Gendo Bacho kebele and 85% of landraces in the Mari Ediget kebele were reported to be susceptible. Across the entire study area, households that had XW on their farms prior or during the survey, in contrast to farms

TABLE 4. Expected yields for kocho and expected growth rates

| Zone | Kebele | Percentage of landraces with kocho yields: | | | Percentage of landraces with growth rates: | | |
|---|---|---|---|---|---|---|---|
| | | High | Mid | Low | Fast | Medium | Slow |
| Kaffa | Ermo | 56 ± 15 def | 41 ± 14 abc | 3 ± 7 ef | 56 ± 17 bc | 34 ± 15 cde | 10 ± 10 bc |
| | Dish | 56 ± 17 def | 38 ± 17 bc | 5 ± 9 ef | 47 ± 16 bc | 45 ± 17 cd | 8 ± 10 bc |
| Dawro | Mari Ediget | 77 ± 15 bcd | 23 ± 15 cde | 0 ± 0 f | 9 ± 11 d | 90 ± 12 a | 0 ± 0 c |
| | Gendo Bacho | 98 ± 8 ab | 0 ± 0 e | 2 ± 8 f | 100 ± 0 a | 0 ± 0 f | 0 ± 0 c |
| Gurage | Yedeb Endbra | 57 ± 21 def | 39 ± 23 bc | 5 ± 9 ef | 49 ± 20 bc | 38 ± 24 cd | 14 ± 12 bc |
| | Yedeb | 65 ± 19 cde | 30 ± 17 cde | 5 ± 6 ef | 60 ± 14 bc | 23 ± 16 def | 18 ± 17 bc |
| Hadiya | Layegnaw Gana | 72 ± 30 cde | 28 ± 30 cde | 0 ± 0 f | 44 ± 27 bc | 49 ± 27 bc | 3 ± 6 c |
| | Anabelessa | 55 ± 23 ef | 42 ± 25 abc | 4 ± 9 ef | 56 ± 20 bc | 42 ± 19 cd | 2 ± 7 c |
| Kembata | Wonjela | 53 ± 18 ef | 29 ± 16 cde | 18 ± 14 cd | 44 ± 19 bc | 42 ± 21 cd | 14 ± 11 bc |
| Tembaro | Gomora Gaweda | 74 ± 22 cde | 25 ± 21 cde | 1 ± 4 f | 69 ± 24 b | 23 ± 26 def | 8 ± 11 bc |
| Gamo | Asoote | 76 ± 13 cde | 2 ± 6 e | 22 ± 13 bc | 56 ± 20 bc | 40 ± 20 cd | 8 ± 11 bc |
| | Belle | 56 ± 34 def | 30 ± 31 cde | 16 ± 23 cde | 43 ± 36 bc | 34 ± 29 cde | 25 ± 29 b |
| Gedeo | Harro Worab | 28 ± 15 g | 58 ± 18 ab | 14 ± 13 cde | 13 ± 16 d | 69 ± 19 ab | 17 ± 8 bc |
| | Harro Badamea | 35 ± 17 fg | 60 ± 18 a | 5 ± 9 ef | 42 ± 31 c | 40 ± 30 cd | 25 ± 20 b |
| | Harmufo | 24 ± 13 g | 33 ± 44 bcde | 42 ± 37 ab | 32 ± 42 cd | 28 ± 35 cdef | 24 ± 13 bc |
| | Warka Sakaro | 31 ± 9 fg | 12 ± 5 de | 56 ± 11 a | 53 ± 23 bc | 39 ± 21 cd | 8 ± 12 bc |
| Sidama | Abera Gelede | 69 ± 21 cde | 26 ± 18 cde | 6 ± 10 def | 39 ± 15 c | 43 ± 19 cd | 17 ± 18 bc |
| | Aleme Korcha | 57 ± 37 def | 36 ± 34 bcd | 7 ± 15 def | 72 ± 24 ab | 0 ± 0 f | 25 ± 26 b |
| | Getema | 100 ± 0 a | 0 ± 0 e | 0 ± 0 f | 70 ± 21 b | 15 ± 16 ef | 15 ± 16 bc |
| | Harro Molicha | 85 ± 5 abc | 7 ± 3 e | 8 ± 3 def | 45 ± 6 bc | 9 ± 5 f | 46 ± 8 a |

The average percentage of landraces with reported yields and growth rates within a household are shown. Standard deviations are provided. Means in a column followed by the same letter are not significantly different ($P < 0.05$)

TABLE 5. Reported landrace Xanthomonas wilt disease tolerances

| Zone | Kebele | Percentage of landraces with EXW disease tolerance: | | |
|---|---|---|---|---|
| | | Tolerant | Intermediate | Susceptible |
| Kaffa | Ermo | 18 ± 6 cdefg | 38 ± 14 abc | 44 ± 11 f |
| | Dish | 17 ± 6 defg | 1 ± 6 e | 82 ± 10 abc |
| Dawro | Mari Ediget | 0 ± 0 g | 15 ± 31 cde | 85 ± 31 ab |
| | Gendo Bacho | 6 ± 24 fg | 2 ± 8 e | 93 ± 24 a |
| Gurage | Yedeb Endbra | 22 ± 12 cdefg | 50 ± 17 ab | 28 ± 19 f |
| | Yedeb | 17 ± 20 defg | 31 ± 25 bcd | 52 ± 25 def |
| Hadiya | Layegnaw Gana | 8 ± 10 efg | 44 ± 33 ab | 48 ± 36 ef |
| | Anabelessa | 2 ± 8 g | 48 ± 21 ab | 51 ± 19 def |
| Kembata | Wonjela | 35 ± 16 bcd | 34 ± 15 bcd | 31 ± 15 f |
| Tembaro | Gomora Gaweda | 72 ± 28 a | 11 ± 16 de | 17 ± 21 f |
| Gamo | Asoote | 11 ± 15 efg | 13 ± 22 de | 76 ± 31 abcd |
| | Belle | 13 ± 29 efg | 30 ± 35 bcd | 56 ± 42 cdef |
| Gedeo | Harro Worab | 24 ± 12 cdefg | 60 ± 15 a | 17 ± 12 f |
| | Harro Badamea | 27 ± 19 cde | 51 ± 23 ab | 29 ± 27 f |
| | Harmufo | 24 ± 13 cdefg | 12 ± 11 de | 63 ± 22 abcdef |
| | Warka Sakaro | 25 ± 11 cdef | 16 ± 14 cde | 59 ± 13 bcdef |
| Sidama | Abera Gelede | 37 ± 13 bc | 28 ± 22 bcd | 36 ± 23 f |
| | Aleme Korcha | 54 ± 38 ab | 38 ± 38 abcd | 10 ± 13 f |
| | Getema | 13 ± 26 efg | 13 ± 18 cde | 74 ± 31 abcde |
| | Harro Molicha | 24 ± 7 cdefg | 16 ± 2 cde | 60 ± 7 bcdef |

The average percentage of landraces with reported disease tolerances within a household are shown. Standard deviations are provided. Means in a column followed by the same letter are not significantly different ($P < 0.05$)

where XW was not observed, had significantly more susceptible landraces (64% vs 48%) and less tolerant landraces (12% vs 35%). Moreover, households that received training on XW disease management cultivated significantly more tolerant landraces (43% vs 8%) and less susceptible landraces (35% vs 73%) than those who did not receive training.

In total, across all households, 107 landraces were reported as disease tolerant, by at least one household (Blomme *et al.*, 2023). As various landraces were only reported by a single household, the XW tolerance of most landraces cannot be verified. Additionally, the reports on landrace XW tolerance were generally not unanimous across households. Landraces with a more reliable reporting of disease tolerance are listed in Table 6.

## DISCUSSION

**Landrace diversity and composition.** A high diversity of farmer-named enset landraces was recorded in this study, with a total of 296 landraces across eight zones. Enset production systems are exceptionally diverse in terms of enset landraces (Yemataw *et al.*, 2018), although landrace diversity remains complicated to determine accurately and is

TABLE 6. Landraces reported as tolerant to Xanthomonas wilt

| Landrace | Nr reported | % reported as EXW tolerant |
|---|---|---|
| Badedat | 14 | 43 |
| Chacho | 31 | 77 |
| Dantira | 11 | 82 |
| Dego | 14 | 43 |
| Etine | 10 | 80 |
| Genticho | 145 | 63 |
| Gimbuwa | 11 | 45 |
| Gishira | 43 | 56 |
| Noboo | 36 | 97 |
| Siskela | 44 | 57 |
| Waniwasa | 10 | 100 |

Nr reported: the total number of households reporting the cultivation of the respective landrace. Only landraces reported by a minimum of 10 households were selected. % reported as disease tolerant: the percentage of households reporting the respective landrace as being disease tolerant. Only landraces reported as tolerant by > 40% of households are selected

prone to error. Previous observations have reported similar high landrace diversity. For example, Tsegaye (2002) recorded 146 different enset landraces in three zones, Yemataw *et al*. (2014) described 218 different enset landraces from seven zones, Zeberga *et al*. (2014) and Yemataw *et al*. (2016) both described 312 different landraces from eight ethnic groups, and Yemataw *et al*. (2019) recorded 387 accessions from nine zones, generally with 30 to 70 landraces recorded within a zone. However, the ethno-linguistic background and use of vernacular names complicate the establishment of the complete picture on enset landrace diversity.

Enset-growing farmers identified and distinguished enset landraces based on morphological traits, knowledge acquired throughout generations within their ethno-linguistic groups (Shumbulo *et al*., 2012; Olango *et al.,* 2014; Yemataw *et al.,* 2018). The vernacular names assigned to landraces are often descriptive and can represent places of origin, morphology, agronomic and post-harvest characteristics and traditional uses (Olango *et al.,* 2014). However, a formal taxonomic classification of enset landraces has not yet been established (Negash *et al*., 2002; Bekele and Shigeta, 2011), and the vernacular names could contain synonyms both within and across ethno-linguistic groups, or different enset landraces could be given the same vernacular name in different localities (Tabogie, 1997; Gerura *et al*., 2019). In the present study, very few farmer-reported landrace names were shared between zones, e.g. only 10 landrace names shared between Hadiya and Kembata Tembaro.

The existing but limited sharing of landrace names between zones which were either geographically close or had a similar linguistic background, corroborates previous findings (Yemataw *et al*., 2014; Zeberga *et al*., 2014; Dilebo *et al*., 2023), indicating that the exchange of planting material historically remained geographically limited within narrowly defined ethnic groups. However, we cannot assume that the vernacular names of landraces have remained the same after exchanges between different ethnic groups (as postulated by Tesfaye, 2002), and more widespread exchanges might have occurred throughout the long history of enset farming in Ethiopia. As such, without extensive linguistic and genetic studies, the actual diversity of enset landraces and the differentiation across the enset-growing region remains allusive.

At farm level and within communities (kebeles), vernacular inconsistencies are most likely less common, and the reported landrace richness highlights the extensive enset diversity maintained across all enset farming systems. We recorded an average of 7 ± 3 different landraces per household, although significantly varied between kebeles, ranging between 1 and 19 landraces. These farm-level richness levels are in line with previous observations, e.g. with a mean of 8.9 landraces observed on farms by Yemataw *et al.* (2014), 8.1 landraces by Yemataw *et al.* (2016) and 8.2-10.2 by Dilebo *et al.* (2023), although higher maximum richness values of 28 and 32 were also observed (Yemataw *et al.*, 2016; Dilebo *et al.*, 2023).

The variability of landrace richness among kebeles was found to be related to the overall importance of enset cultivation on the farm, the economic status of the households, and the ethno-linguistic background of the community. Landrace diversity on a farm has indeed been shown to depend on the importance of enset in a particular area and to be strongly influenced by ethnic group preferences (Zippel, 2005; Yemataw *et al.*, 2018). Communities with a rich indigenous background and tradition in enset cultivation envision a variety of traits needed and constraints to account for, and diversify their crop accordingly (Yemataw *et al.*, 2014). Cultivating a variety of enset landraces can also be a sign of status within the community (Tsegaye and Struik, 2002).

**Uses of enset landraces.** Most households in this study reported using landraces for multiple uses. As such, a majority of landraces were used for kocho, bulla, fiber and feed. Fewer landraces were reported for the use of amicho, indicating either a specific suitability of landraces for producing palatable amicho, or the reduced preference of preparing and eating amicho in some households and communities. Most enset farmers maintain a high landrace richness to diversify their uses, and specific landraces were often preferred by farmers for various purposes (Shumbulo *et al.*, 2012; Jacobsen *et al.*, 2018).

A lower number and abundance of landraces is cultivated for medicinal purposes. The majority of landraces are grown for food and income, while only a few landraces are perceived as having medicinal properties of which few plants are needed. The customs of the local ethnic groups might drive farmers to select a variety of landraces with tailored medicinal uses. Medicinal uses include the treatments of bone fractures, birth problems, and diarrhoea in people (Negash, 2001; Nuraga *et al.*, 2019). In the zones Kembata Tembaro and Gurage, a larger number of landraces were reportedly used for medicinal purposes. Here, landraces perceived to have medicinal properties are also grown for other uses, including food products. These multi-use landraces are as such grown in larger abundances.

Across the entire study area, however, richer households report cultivating a reduced number of landraces for medicinal use. Their increased financial means might allow them to purchase medicine from other sources.

**Growing conditions and expected yields.** The high diversity of enset landraces maintained on farms and across the entire enset-growing belt provides important benefits and value in terms of food security and overall risk mitigation, as different landraces present differential adaptive performance under abiotic and biotic stresses. Cultivating a range of landraces that can withstand varying levels of rainfall, temperature, soil quality or disease susceptibility ensures an increased likelihood of retained yield and food security under variable environmental circumstances. The environmental stress tolerances of the various landraces reported by the households are based on extensive indigenous and generational knowledge and experience. While highly valuable, shifting environmental conditions expected with ongoing climate change (decreases in stream flows and groundwater levels, increases in the frequency of both floods and droughts (Climate Risk Profile: Ethiopia, 2021) can impact enset cultivation, and extreme conditions can prove to be beyond the current experience-based knowledge of farmers. Indeed, a perception bias in landrace environmental tolerances is observed. Namely the importance of drought tolerant landraces reportedly increased with altitude, whilst there is a tendency for more rain at higher elevations (Shara *et al.*, 2021). At lower altitudes, farmers have more experience with drought, and as such have a better idea of which landraces are tolerant or susceptible to drought. Accordingly, at these lower altitudes, the entire range of drought suitability is reported. At higher altitudes however, farmers have less experience with severe drought, and landraces susceptible to drought are potentially not noticed by farmers. Here, farmers report most landraces as being adaptive for drought, whilst this might not be the case when the severity of the drought increases. Similarly, expected growth rates of specific landraces are reported to decrease with altitude. Slower growth rates are normal at higher elevations with lower temperatures, and not necessarily an inherent trait of a landrace. Expected yields of landraces accordingly do not reduce with altitude, although it takes more time for the plants to become large and mature. More extensive research into the susceptibility to environmental stresses and the optimal growth ranges of enset landraces could ensure the sustainability of enset farming systems. Inter-regional knowledge exchange, combining indigenous knowledge based on a range of environmental conditions from across the entire altitudinal range of the enset-growing region, would be highly valuable.

**Tolerance to Xanthomonas wilt.** A substantial number of landraces are reported to be tolerant to Xanthomonas wilt in the present study, and are more commonly integrated into farms that are impacted by the disease. Enset Xanthomonas wilt (EXW), caused by *Xanthomonas vasicola* pv. *musacearum*, is the most important biotic constraint to enset cultivation (Brandt *et al.*, 1997), and the integration of disease tolerant landraces within the landrace composition on the farm is an important aspect of disease management and risk mitigation. In the present survey, however, farmers mainly reported tolerance based on their own experience. This often translates into inconsistencies in reporting of tolerances, with landraces perceived as tolerant by some farmers while as susceptible by others. This is the case for the landrace 'Badedat', which has been shown to have tolerant characteristics (although spelled as 'Bedadet' or 'Bededet'; Muzemil *et al.*, 2021), although only 43% of households cultivating 'Badedat' report the landrace as being tolerant. On the other hand, consistent reports of tolerance are reported for 'Noboo', by 97% of the households cultivating the landrace (phonetically similar to 'Nobo', shown to be tolerant (Handoro and Said, 2016). Reporting by farmers based on indigenous knowledge and experience remains critical and can drive ongoing research in EXW disease resistance. Several EXW tolerant enset landraces (e.g., 'Mezya', 'Bedadet', 'Hiniba', 'Mazia', 'Nobo') have been identified through experimental research and shown to recover after (mild) XW infections (Welde-Michael *et al.*, 2008; Hunduma *et al.*, 2015; Handoro and Said, 2016; Wolde *et al.*, 2016; Said *et al.* 2020; Muzemil *et al.*, 2021). Extensive screening of enset landrace responses against EXW infections has been carried out over past decades (e.g. Welde-Michael *et al.*, 2008; Hunduma *et al.*, 2015; Muzemil *et al.*, 2021).

Importantly, households that had received training into disease management reported cultivating more disease-tolerant landraces, thereby mitigating the risk and impact of EXW. Extension services hold a key role in advising farmers facing both biotic and abiotic stresses, and can helping to maintain the sustainability of enset farming systems. Integrated approaches to extension services tackling broader issues that farmers face, e.g. combining disease management needs with other environmental issues (Ocimati *et al*., 2018; Blomme *et al*., 2020) or integrating the issue of XW into overarching food security projects (Mbure *et al*., 2018) prove to be an important way forward.

## CONCLUSION

In-depth morphological trait assessments and genome analysis of the vast number of enset landraces needs to be carried out, to pinpoint synonyms and obtain insight into the real enset landrace diversity in Ethiopia. Simultaneously, assessments of landraces growing under differing/contrasting agro-ecological conditions will inform on the ranges and optimal growth conditions of these landraces. Indigenous knowledge linked to enset landrace traits and use, acquired over many centuries across ethnic groups and geographical regions, should form the backbone of knowledge transfer. Farmer insight is however shown to be often dependent on the environmental conditions that the local enset landrace pool is exposed to, and this knowledge might not transfer easily to other agro-ecological regions. Nevertheless, changing environmental conditions and the occurrence of extreme weather events, expected with climate change, compels the need for knowledge transfer across agro-ecological regions, combined with potential landrace exchange, this as a contingency measure to maintain the sustainability of the enset growing systems. Training by extension services is expected to be an important component in knowledge collection and transfer, as was demonstrated with the improved EXW tolerant landrace selection in affected production landscapes.

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