AGRO-MORPHOLOGICAL AND MOLECULAR CHARACTERIZATION OF ENSET (*Ensete ventricosum* (Welw.) Cheesman) LANDRACES FROM ETHIOPIA

A THESIS SUBMITTED

TO

THE SCHOOL OF GRADUATE STUDIES

COLLEGE OF NATURAL SCIENCE

ADDIS ABABA UNIVERSITY

BY

ZERIHUN YEMATAW GEBRE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN BIOLOGY

(APPLIED GENETICS)

ADDIS ABABA JUNE, 2018

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SUPERVISOR: DR. KASSAHUN TESFAYE

DEDICATION

This thesis is dedicated to enset producing farmers in Ethiopia. I also dedicate this thesis to the immortal senior colleague Endale Taboge, who spent much of his life for enset research project establishment at Areka.

DECLARATION

I declare that the thesis hereby submitted by me for the Degree Doctor of Philosophy (PhD) in Biology (Applied Genetics) to the School of Graduate Studies of Addis Ababa University is my own independent work and has not previously been submitted by me or anybody else at another university. The materials obtained from other sources have been duly acknowledged in the thesis.

Signed on 25th of June 2018, The School of Graduate Studies, Addis Ababa University, Addis Ababa.

PhD Candidate ____Zerihun Yemataw

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Nothing shall be impossible for God!

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II. Yemataw Z., Tesfaye K.., Zeberga A., and Blomme G. (2016). Exploiting indigenous knowledge of subsistence farmers' for the management and conservation of Enset (*Ensete ventricosum* (Welw.) Cheesman) (Musaceae family) diversity on-farm, (**Published in Journal of Ethnobiology and Ethnomedicine 12:34.DOI 10.1186/s13002-016-0109-8)**.

III. Yemataw Z., Mekonen A., Chala A., Tesfaye K., Mekonen K., David S. Kalpana S. (2017) Farmers' knowledge and perception of enset *Xanthomonas* wilt in the southern Ethiopia (**Published in Agricultural and Food Security Journal *6:62:* DOI 10.1186/s40066-017-0146-0).**

IV. Yemataw Z. Chala A., Ambachew D., Studholme D. Grant M , Tesfaye K. (2017) Morphological variation and inter-relationships of quantitative traits in enset (*Ensete ventricosum* (Welw.) Cheesman) germplasm from south and south-western Ethiopia (**Published in Plants Journal, *6*: 56. Doi:10.3390/plants6040056)**

V. Yemataw Z., Tesfaye K., Grant M., Studholme D.J, Chala A. (2017) Multivariate analysis of morphological variations in enset (*Ensete ventricosum* (Welw.) Cheesman) shows regional and clinal variation in germplasm from South and South western Ethiopia. (**Accepted in Australian Journal of Crop Science**).

VI. Yemataw Z., Blomme G., Tesfaye K. (2017) Assessing qualitative and pHenologic traits diversity in Ethiopian enset (*Ensete ventricosum* (Welw.) Cheesman) landraces. (**Accepted in Fruit Journal**)

VII. Zerihun Yemataw, Sadik Muzemil, Daniel Ambachew, Leena Tripathi, Kassahun Tesfaye, Alemayheu Chala, Audrey Farbos, Paul O'Neill, Karen Moore, Murray Grant, David J. Studholme: Genome sequence data from 17 landraces of *Ensete ventricosum*, the staple food crop for millions in Ethiopia. **Published in Data in Brief 18(2018)285–293.**

ACRONYMS AND ABBREVIATIONS

AAU	Addis Ababa University
Africa RISING	Africa Research in Sustainable Intensification for the Next Generation
AARC	Areka Agricultural Research Center
AFLP	Amplified fragment length polymorpHism
BXW	Banana *Xanthomonas* wilt
CA	Cluster analysis
CAPS	Co-dominant amplified polymorpHism
CCRP	Collaborative Crop Research Program
CSA	Central Statistics Authority
CTAB	Cetyltriethylammonium bromide
CV	Coefficient of variation
D^2	Genetic distance
EBI	Ethiopian Biodiversity Institute
EIAR	Ethiopian Institute of Agriculture
EXW	Enset *Xanthomonas* wilt
H'	Shannon Weaver diversity Index
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
ISSR	Inter specific Single sequence repeates
KA	Kebele Administration
LSD	Least significance difference
MOA	Ministry of Agriculture
MSE	Mean square of error
PCA	Principal component analysis
PCR-RFLP	Polymerase chain reaction restriction fragment digest polymorpHism
RAPD	Random amplified Polymorphic DNA
SARI	Southern Agricultural Research Institute
SAS	Statistical Analysis System
SNNPRS	Southern Nation Nationalities Peoples Regional State
SNPs	Single Nucleotide polymorpHism
SPSS	Statistacal Package for Social Science
SRA	Sequence Read Archive
SSR	Simple sequence repeates

ABSTRACT

The study was conducted with the objective of assessing and documenting indigenous knowledge and perception associated with the distribution, diversity, Enset Xanthomonas Wil, its etiology and mode of transmission, and management of enset in the country, and the genetic diversity of enset landraces that were obtained from different geograpHical locations in Ethiopia, using Phenotypic traits and to develop a genome sequence data, identify and develop single nucleotide polymorpHism (SNPs) and genotyping of landraces that serve as molecular markers for future marker assisted breeding.

Enset genetic resource utilization and management study was conducted in eight ethnic groups in the Southern Nations, Nationalities and Peoples' Regional State. The data was collected mainly through individual interviews and direct on-farm participatory monitoring and observation, key informant interviews. Relevant secondary data, literature and inter-personal data were collected from unpublished progress report from National Enset Research Project, elderly people and senior experts. Enset-based farming system is one of major agricultural systems in Ethiopia that serves as a backbone for at least one-forth of country's population. Farmers used three morphological characters, two growth attributes, disease resistance and five use values traits in folk classification and characterization of enset. A total of 312 folk landraces have been identified. The number of landraces cultivated on individual farms ranged from one to twenty eight (mean of 8.08 ± 0.93). All ethnic groups in the study area use five use categories in order of importance: kocho yield and quality, bulla quality, amicho use, fiber quality and medicinal/ritual value. Of the 312 landraces 245 landraces having more than two use types. Management and maintenance of on-farm enset diversity is influenced by systematic propagation of the landraces, exchange of planting material and selective pressure. Farmers' knowledge and perception of enset Xanthomonas wilt showed that a significant number of farmers are aware of EXW, its symptoms, etiology and transmission and spread, but they are not able to readily relate modes of spread to control methods. Since 2002, EXW became prominent in Hadiya, with the highest EXW incidence and severity, followed by Wolaita, and Kembata-Tembaro. Farmers identified EXW as the major cause for declining production and productivity of enset in the region. EXW has spread widely and rapidly in southern Ethiopia, with significant socioeconomic impacts in smallholders' livelihoods. There is a need for developing knowledge-based strategies and awareness-raising campaign for EXW management. In general, the existing farmers' knowledge on naming, classification and diversity should be complemented with maintenance of the creative dynamics of traditional knowledge and transmission of the knowledge are crucial for constructing sustainable management.

Assessment of genetic diversity in enset using Phenotypic markers were subjected to ANOVA and the variations among the landraces and regions were significant ($p \leq 0.01$) for all the 15 traits studied. Mean for plant height, central shoot weight before grating, and fermented squeezed kocho yield per hectare per year showed regional variation along an altitude gradient and *across cultural differences related to the origin of the collection. Furthermore, there were significant correlations among most of the characters. This included the correlation among agronomic characteristics of primary interest in enset breeding such as plant height, pseudostem height, and fermented squeezed kocho yield per hectare per year. Altitude of the collection sites also significantly impacted the various characteristics studied. Cluster analysis grouped the landraces into five distinct groups, with two outlying landraces. Landraces originating from regions with similar agro-climatic conditions grouped together. Principal component analysis showed that the first four principal components accounted for ~74% of the total variance of the 387 enset landraces for the 15 quantitative traits studied. The linear discriminant analyses depicted about 40.8% (160 of the 387) and 45.2% (175 of 387) correct origin-based classification of the germplasm in terms of altitude zones and regions, respectively. Six qualitative morphological traits were also analyzed using the Shannon Weaver diversity index (H').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 H' revealed highly significant (p<0.01) differences among regions for all traits. Cluster analysis grouped the landraces into four clusters. A high proportion of landraces sourced from similar altitude classes and similar regions were grouped together. This indicated that there was wide variability among landraces studied. The Phenotypic differences in these 15 traits suggest significant degrees of genetic variation and that these traits can be exploited to identify potential donors for future enset improvement efforts. The implication of the current results for plant breeding, germplasm collection, and in situ and ex situ genetic resource conservation are discussed.*

Seventeen (for genome sequence analysis) and four hundred eighty (for SNP catalogue development) different enset landraces used were obtained from Areka Agricultural Research Center field germplasm. We present raw sequence reads and genome assemblies resulting from the sequencing of 17 landraces of the crop plant enset. Landraces having the same names but different origin showed different reads. For SNP detection, we considered only sites either homozygous or heterozygous for all 17 data sets. We were able to identify 33,200 single-nucleotide variant sites. We generated a series of phylogenetic trees and there was no sequence variation at this locus among the 17 genomes presented here. By examining the pattern of bands in agarose electrophoresis of the product after restriction digestion, it is possible to assess the genotype at that SNP location. We applied the 22 PCR-RFLP assays to single accession of E.ventricosum. Further, we then went on to apply 5 of these assays to several hundred E. ventricosum landraces. This findings will facilitate high-resolution studies to determine the genetic architecture of traits of economic and ecological importance, to study the structure of enset populations and to apply genomic selection in breeding programs. In general, farmers cognitive, morphological, sequence and SNP output clearly distinguished between all landraces, even though they were genetically similar.

Keywords: *Enset, Ethiopia, Farmer's knowledge, In situ and ex situ conservation, Landraces, On-farm diversity and management , Phenotypic variation, Southern Ethiopia, SNP, Xanthomonas wilt*

CHAPTER 1

General Introduction

Ethiopia is identified as one of the eight gene centres of crops (Vavilov 1951). Many crops such as *Tef* (*Eragrostis tef*), *Noug* (*Guizotia abyssinica*), *Gesho* (*Rhamus prinoides*), *Enset* (*Ensete ventricosum*), Coffee (*Coffea arabica*) and *Khat* (*Chata edulis*) are supposed to have originated in Ethiopia (Harlan 1969). Enset (*Ensete ventricosum* (Welw.) Cheesman) is an orphan or little researched food crop cultivated only in Ethiopia. Tsegaye (2002) reported that the enset farming system of southern and south western Ethiopia is practiced on the most densely populated areas of the country supporting the lives of more than 20 millions of the population.

Enset is cultivated at altitudinal range of 1200-3100 meters above sea level (masl), but scattered plants can also be found at lower altitudes (Haile et al. 1996). However, it grows luxuriously in elevation between 2000 and 2750 masl (Diro and Taboge 1994). For optimum growth, the plant requires an average rainfall of 1100-1500 mm per year and mean temperature of 16 –20 °C. Enset is not tolerant to freezing. Frost damage on upper leaves is commonly observed at 2800 masl and serious stunting is seen above 3000 masl (Taboge 1997). Enset grows well in most soil types provided they are sufficiently fertile and well drained. The ideal soils are moderately acidic to alkaline (pH= 5.6 – 7.3) with 2-3% organic matter (Uloro et al. 1996).

Enset is a multipurpose crop and every part of the plant has some sort of uses. Most significant are the corm and the pseudostem that contain large quantities of starch reserves readily available to humans (Tesfaye 2002). The edible parts of the plant are the underground stem (corm) and pseudo stem, which are pulverized and fermented into a starch-rich product called *kocho*. *Kocho* is mainly consumed after making pancake-like bread. The corm can be harvested at almost any stage of the crop, and cooked and consumed in the same way with other root and tuber crops, relieving hunger during periods of critical food shortages. *Kocho* can be stored for a long time (for 10 years and even more) without being spoiled (Brandt et al. 1997).

Preliminary reports indicate that there exists a great wealth of enset landraces in Ethiopia (Negash 2001). Different enset landraces are recognized in different growing areas, and are being grown in mixture. Each enset landrace as identified by the farmer has its own name that is uniformly spread across the region that speaks the same language (Taboge et al. 1996). A previous Phenotypic evaluation indicated that there are similar landraces known by different vernaculars and there are also different landraces known by similar vernaculars and with similar Phenotypic appearance (Taboge et al. 1996; Taboge 1997). Farmers' method of enset characterization is expected to be ambiguous because it is based in part on subjective description (Tsegaye 2002).

Farmers have managed the diversity of enset landraces for centuries with limited influences from outside. This genetic variation needs to be assessed using morphological, agronomic and molecular traits, in order to conserve and utilize the existing genetic diversity. Farmers select enset landraces based on the quality and quantity of food products, maturation period, disease and drought tolerance, forage and bread quality, medicinal value, ease of scraping, quality of corm and productivity. Since one landrace never fulfills all criteria, farmers tend to maintain a diverse range of enset types on their farms (Tsegaye 2002). Each region has its own language and thus a unique set of names for different landraces. It is likely that farmers have developed their own way of characterization and selection criteria.

Studies indicate that numerous enset landraces were identified in each region and the observed genetic diversity in cultivated enset in a particular area appears to be related to the extent of enset cultivation and the culture and distribution pattern of the different ethnic groups (Shigeta 1990; Alemu and Sandford 1996; Negash 2001; Tesfaye 2002; Birmeta 2004; Yemataw et al. 2014; Olango et al. 2014). Understanding farmer's indigenous knowledge for folk naming, classification, distribution and abundance of enset landraces and the corresponding knowledge related to utilization, management and conservation might help to recognize how farmers value, use and conserve genetic diversity.

Enset production and productivity are constrained by several biotic and abiotic factors. Bacterial wilt, caused by *Xanthomonas* bacteria, is an economically important disease of enset, putting the sustainability of enset farming systems in jeopardy (Yirgou and Bradbury 1968; Ashagari 1985; Tripathi et al. 2009). Up to 80% of enset farms in Ethiopia are currently infected with enset *Xanthomonas* wilt (EXW) (McKnight 2013). The disease causes total loss of yield as the infected plant and fruit cannot be consumed by humans and or livestock. The disease has forced farmers to abandon enset production resulting in critical food shortage in the densely populated areas of southern Ethiopia (Spring et al. 1996; Tadesse et al. 2003). This disease directly affects the livelihood of more than 20 million enset growing farmers in the country.

Farmers can provide substantial information about local diseases and practices to manage the disease as traditional farmer's knowledge is often impressively broad and comprehensive (Thurston 1992). Farmers' knowledge of diseases is well documented on many crops such as cotton (Ochou et al. 1998), rice (Price 2001), beans (Trutmann et al. 1996), and vegetables (Obopile et al. 2008). Similar documentation for enset is scant and not up-to-date, however; there is no systematic information that explicitly describes indigenous knowledge about EXW in Ethiopia and the impact of farmer's practices on the spread of EXW in Ethiopia. It is therefore important to understand farmer's knowledge about EXW and their perceptions about crop loss. This information could help to guide EXW management practices in a sustainable manner.

Enset germplasm collection and *ex situ* conservation have been conducted by the Areka Agricultural Research Center. About 600 enset vernaculars collected from south and south western parts of the country are now maintained in field gene banks by the center. For *ex situ* conservation, back-up samples *in vitro* would, however, be very useful in order to avoid loss of landraces due to biotic and abiotic factors (Yeshitla and Yemataw 2012). Many of these landraces have not been evaluated in the country using morphological and DNA molecular markers.

Phenotypic estimates are used to present the degree of genetic relationship and difference between lines; it is presumed that similarity in phenotype characteristics reflects genetic similarity of genotypes (Cox et al. 1985). The application of agro-morphological traits has been used as a powerful tool in the classification and grouping of lines, to study taxonomic status, identification, determination of genetic variation and correlation of characters with agronomic potential (Millan and Cubero 1995; Van Beuningen and Busch 1997).

Given the wide geographical range of its cultivation and regional cultural influences, enset domestication has most likely led to extensive genetic variation in "landraces" or landraces. Taboge (1997) found large variability in most of the characters assessed on 79 enset landraces collected from various parts of the country. Bekele et al. (2013) distinguished and described 120 distinct enset landraces that fall in to eleven broad clusters differing in maturity time, plant height, pseudostem height, pseudostem circumference, leaf number, leaf sheath number, grated corm, *bulla* and fibre yield. Similarly, other studies (Yemataw et al. 2012; Yemataw et al. 2014b;

Yeshitla 2014) showed substantial Phenotypic variation in enset germplasm for phenologic, morphologic and agronomic traits. To date, six improved enset varieties have been released from direct selection from farmers' varieties (Yeshitla and Yemataw 2012).

However, this approach has its limitations. Complex quantitatively inherited traits are difficult to trace based solely on morphology. For this reason, DNA-based methods such as RAPD, AFLP, SSR, and ISSR have been employed in studies of enset genetic diversity and in genetic improvement of the crop (Negash 2001; Tsegaye 2002; Birmeta 2004; Tobiaw and Bekele 2011; Olango et al. 2015). DNA markers have provided breeders with new tools to understand and more efficiently select for complex traits in breeding programmes (Akinbo et al. 2007; 2008). However, no efforts have been carried out on development, diversity and breeding work using single nucleotide polymorpHisms (SNPs) marker. While, the availability of this genetic and genomic resource will facilitate in depth genetic study and in turn will aid in the development of enset landraces with improved resistance to biotic and abiotic stresses and desirable agronomic traits. The data from SNP is known to be consistent with each other and independent of the techniques used to produce them and is reproducible between laboratories and SNPs produce more reliable data than microsatellites. Due to their abundance and distribution through-out the genome, they are preferred for mapping, marker-assisted breeding and map-based cloning.

However, the previous investigations conducted by agronomists and geneticists have assessed the level of morphological and molecular genetic diversity, cultural practices and use value of enset landraces found in some parts of the country. In addition, there was no comprehensive characterization that includes as many landraces as possible and conducted across many zones of different ethnic groups. Hence, knowledge on the level of diversity, cultural practices and use value of enset in different ethnic groups is important. There are several collections that need to be characterized before they can be utilized effectively and efficiently in enset breeding programmes.

The overall objective of this study were to identify infra-specific diversity of enset and study farmers' traditional knowledge, innovations and practices related to conservation and management of enset in communities and on household farms and to analyze and describe the magnitude of genetic diversity in Ethiopian enset landraces for the benefit of future breeding programmes. The specific objectives of this study were:

1. To identify and document indigenous knowledge for folk naming, classification, distribution and abundance of enset landraces and understanding the corresponding knowledge related to utilization, management and conservation of enset landraces.

2. To identify the extent of genetic variation among the enset landraces using morpho-agronomic traits and promising landraces for different traits that will be utilized in breeding programs.

3. To develop a genome sequence data, identify and develop single nucleotide polymorphism (SNPs) and genotyping of landraces that serve as molecular markers for future marker-assisted breeding.

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CHAPTER 2

Literature Review

Abstract

Enset is called in Ethiopia “The tree against hunger” as it once acted as the key crop against hunger by supplying the main food energy for people of southern and south western Ethiopia. Enset is one of the indigenous crops in Ethiopia with a huge potential for year-round food production. The corm and the pseudostem of the enset plant are the most important sources of food. Enset was initially farmed in a system of shifting cultivation and fully domesticated in Ethiopia between 10,000 and 5,000 years ago. This long history with enset has contributed to the high within-species diversity seen for this crop. Studies have identified numerous landraces per region, with genetic diversity in a particular area related to the extent of enset cultivation and the culture and distribution pattern of the different ethnic groups and environmental regimes present in traditional farming systems**.** The objective of this paper is to provide an overview of past and ongoing research activities and knowledge linked to enset diversity and its use, and to provide insight into remaining enset germplasm-related research gaps. Farmers’ rich knowledge of enset, accumulated over many years, plays a significant role in the characterization and maintenance of the existing genetic diversity of this crop. Farmers identify one landrace from the other Phenotypically by looking at the colour of petiole, mid-rib, leaf sheath, angle of leaf orientation, size and colour of leaves and circumference & length of pseudostem**.** Characterization of enset germplasm using morphological traits shows much variability in quantitative and qualitative morphological, growth and yield traits among enset landraces, including maturation rate, plant height, colour and susceptibility to disease. Farmers are the main curators of enset diversity and hundreds of varieties have been reported by various authors**.** Enset diversity provides resilience and food security despite challenging environmental conditions. Management of enset diversity is a dynamic process, with much exchange between regions due to changing food preferences, climate, pests and diseases, cultivation systems, and infrastructure. However, farmers have also lost landraces to diseases, abiotic selection pressures, or changes in land use systems. Several research gaps need to be addressed in order to improve the long-term conservation of this diversity

Key words: diversity, enset, enset bacterial wilt, genetic resources, germplasm

2.1 Introduction

Enset (*Ensete ventricosum* (Welw) Cheesman) is an important multipurpose indigenous crop for Ethiopian farming households, ensuring food security in a country that is food deficient (Brandt et al. 1997). With only household derived inputs, enset provides year-round food production (both human & animal), traditional medicine and fiber (Bezuneh 1984). The enset cultivation system is economically viable and well adapted to Ethiopian agricultural systems (Bezuneh and Feleke 1966). Farmers often say that enset is their food, their cloth, their house, their bed, their cattle feed and their plate (Brandt et al. 1997).

The corm and the pseudostem of the enset plant are the most important sources of food, commonly harvested as: *kocho* (fermented starch obtained from the decorticated (scraped) leaf sheaths and grated corm); *bulla* (a white powder produced by dehydrating squeezed sap from scraped leaf sheaths and grated corms); and *amicho* (boiled corm pieces of young enset plants, prepared and consumed in a similar manner to other root and tuber crops (Alemu and Sandford 1991; Brandt et al. 1997). Enset plays a crucial economic role, providing a higher and more dependable yield than other crops in Ethiopia. The crop also plays an important environmental role, protecting the soil from erosion, providing shade, and a continuous accumulation of litter, which improves soil fertility and understory growth (Lee and Zawdie 1997; Woldetensaye 1997).

Brandt et al. (1997) posited that enset was initially farmed in a system of shifting cultivation and fully domesticated in Ethiopia between 10,000 and 5,000 years ago. By the mid-Holocene (4,000-5,000 years ago), domestication of livestock and the use of manure to maintain soil fertility enabled a more intensified farming system without the need for shifting cultivation (Brandt et al. 1997). This long history with enset has contributed to the high within-species diversity seen for this crop. Studies have identified numerous landraces per region, with genetic diversity in a particular area related to the extent of enset cultivation and the culture and distribution pattern of the different ethnic groups and environmental regimes present in traditional farming systems (Wood and Lenne 1999; Tsegaye 2002; Birmeta 2004). The high genetic diversity of enset warrants conservation, as it provides resilience to the enset farming system and thus food security for farming communities.

The objective of this paper is to provide an overview of past and ongoing research activities and knowledge linked to enset diversity and its use, and to provide insight into remaining enset germplasm-related research gaps.

2.2 Enset taxonomy

Enset (also ensete, false banana, Ethiopian banana or Abyssinian banana) is a monocotyl of the order Scitamineae, the family Musaceae, and the genus *Ensete.* Banana also belongs to the Musaceae, but in the genus *Musa.* Enset was first described by Bruce (1790) and later classified under the genus *Musa* by Gmelin in the 13th edition of Systema Naturae in 1791. Horaninow renamed the species *Ensete edule* in 1862 (Cheesman 1947).

Studying specimens in the Botanical Garden of Kew, Cheesman (1947) reclassified 25 *Musa* spp. as *Ensete* with the reservation that some may prove to be synonymous following field study. In 2015, Olango *et al.* writes that the genus *Ensete* consists of 5 or 6 species depending on the author (Baker and Simmonds 1953; Simmonds 1962). Two wild enset species are found in Asia and four wild species in sub-Saharan Africa and Madagascar (Baker and Simmonds 1953; Simmonds 1958). Of these, *Ensete ventricosum* (Welw.) Cheesman is the only known wild species in Ethiopia, which is believed to be its center of origin (Vavilov 1926). Enset is of particular significance for Ethiopian farming systems in the South and Southwestern regions, although it is also found in the central and northern highlands around Lake Tana, the Simien

Mountains, and as far north as Adigrat and into southern Eritrea (Simoons 1960 and 1965; Brandt et al. 1997). *Ensete ventricosum* is the only species of the genus that has been domesticated. It is locally known by its vernacular names *enset* (by the ethnic group Amhara), *asat* (Gurage), *weise* (Kambata), and *wassa* (Sidama). From here on, reference to "enset" refers to *E. ventricosum* unless otherwise specified.

Most wild and a few cultivated plants are produced from seed, and have more than one parent (Alemu and Sandford 1991). Most domesticated enset plants, however, are propagated from suckers, and are landraces of their one parent. Therefore, in the literature, enset landraces are often referred to as landraces. In this review we will use the term landrace to designate between crop populations that have not been bred as varieties by scientists but which farmers have adapted to local conditions through years of natural and artificial selection, as defined by Melaku (1991).

2.3 Enset diversity: vernacular names, phenotypic plasticity and genotypic differentiation

Farmers' rich knowledge of enset, accumulated over many years, plays a significant role in the characterization and maintenance of the existing genetic diversity of this crop. Farmers differentiate one landrace from the other Phenotypically by looking at the colour of petiole, mid-rib, leaf sheath, angle of leaf orientation, size and colour of leaves and circumference & length of pseudostem (Shambulo et al. 2012; Yemataw et al. 2014a). Vernacular names are often descriptive and reflect variations of landraces in places of origin, morpHology, as well as agronomic and cooking characteristics (Olango et al. 2014). Elderly members of households are generally the best informed about enset diversity and this knowledge is transferred through oral tradition (Negash 2001).

Characterization of enset germplasm using morphological traits shows much variability in quantitative and qualitative morphological, growth and yield traits among enset landraces, including maturation rate, plant height, colour and susceptibility to disease (Tabogie 1997; Yeshitla and Diro 2009; Yemataw et al. 2012). The number of landraces grown is closely associated with the importance of enset for a certain ethnic group (Zippel 2005). At farmers' level, the same landraces may have different vernacular names depending on the ethnic or linguistic groups and agro-ecological zones. Such nomenclatural duplication of names is mostly due to different uses of the same landrace, as exchange of planting materials is common and vernacular names may be altered after long-term adaptation of the exchanged plant, corresponding to the farmer's own preferences and language. For example, landraces with similar vernacular names are often in fact identical, i.e. *Katino* and *Ketano*, *Chele bocho* and *Ganji bocho*, and so forth. In other instances, genotypes may be exchanged across largely varying agro-ecological systems and geograpHical distances, resulting in very different vernacular names for the same landrace. Several authors have reported on the difficulty of evaluating enset diversity due to such duplication of names for the same landrace (Tabogie 1997, Negash 2001, Tsegaye 2002, Yemataw et al. 2014a). Women (vs men) and elderly (vs younger) farmers are generally more knowledgeable about the different attributes of enset landraces and able to recall more landraces than men during group discussions (Negash 2001).

Farmers' own taxonomy categorizes enset landraces as either male or female based on particular morphological or phenological properties (Yemataw et al. 2014a; Tsehay and Kebebew 2006; Negash 2001). For example, male farmers generally prefer male enset landraces, which are late maturing and disease resistant, but with a lower quality *amicho* and *kocho*. By contrast, female farmers prefer female enset landraces, which mature earlier and have a tastier *kocho* and *amicho*, but are less vigorous and susceptible to disease (Table 2.1).

Table 2.1 Characteristics of 'male' and 'female' enset landraces in Wolaita, Gamo Goffa and Dawro Zones of Southern Ethiopia.

	Category	
Characteristics	Male enset	Female enset
Plant vigor	Vigorous	Less vigorous
Disease reaction	Tolerant	Susceptible
Kocho quality	Less quality	More quality
Maturity	Late maturing	Early maturing
Amicho palatability	Not preferred	Edible and tasty
Fiber quality	High strength	Low strength
Productivity (plant^{-1}/yr)	Highly productive	Less productive

Source: (Yemataw et al. 2014a)

Field experiments have demonstrated that landraces differ in their site requirements (Zippel 2005). Yemataw et al. (2016b) showed strong crossover genotype x environment interaction with a significant change of rank for mean yield performance from one environment to the other. The large variation in agro-ecologies suitable for enset farming systems combined with low regional differentiation of enset genotypes, suggests Phenotypic plasticity (Negash 2001). Phenotypic plasticity is the capacity of a single genotype to exhibit a range of phenotypes in response to variation in the environment (Fordyce 2006), thus enabling the adaptation of enset genotypes to different agro-ecological conditions with elevations ranging from 1400 to 3100 meters above sea level (Taboge et al. 1996). This also complicates enset landrace identification based on morphological and physiological characteristics.

The analysis of molecular markers is a useful tool to analyze genetic diversity and evolutionary relationships among enset landraces. Found in the whole genome, molecular markers are independent of plant tissue, influence of environmental and management practices and thus particularly suited to crops such as enset (Manifesto et al. 2001; Altintas et al. 2008). Molecular genetic marker techniques such as Amplified Fragment Length Polymorphism (AFLP), Random

Amplified Polymorphic DNA (RAPD), Inter Simple Sequence Repeats (ISSR) and Simple Sequence Repeat (SSR) have been used to evaluate the germplasm of cultivated enset from several enset-growing regions of Ethiopia (Negash 2001; Tsegaye 2002; Birmeta 2004; Tobiaw and Bekele 2011; Olango et al. 2015). However, even with molecular analysis, apparently identical landraces may still in fact be different. Negash (2001) suggested that an increase in resolution of molecular differentiation techniques might improve differentiation between closely related landraces of enset. For example, the landraces *Choro* and *Ketano* showed no molecular differentiation despite easy distinction by farmers based on morphological characteristics (Negash 2001).

2.4 Diversity management of enset landraces *in situ* and *ex situ*

On-farm maintenance of agro-biodiversity minimizes risk, stabilizes production and yields, promotes dietary diversity and maximizes returns using low levels of technology and limited resources (Altieri 2004). Farmers are the main curators of enset diversity and hundreds of varieties have been reported by various authors (Shigeta 1990; Alemu and Sandford 1991; Negash 2001; Tsegaye 2002; Birmeta 2004; Tsehay and Kebebew 2006; Yemetaw 2014b; Olango 2014; Yemetaw 2016a; Table 2.2). The diversity of landraces is not spread evenly, with a small number of highly abundant landraces grown over larger areas and a larger number of moderately common or rare landraces (Yemataw et al. 2014a).

An extensive comparison of previous reports on enset diversity, showed considerable changes over a 50-year period, with increasing number of enset landraces in Sidama, but decreasing diversity of landraces in other regions (Zippel 2005). Some enset landraces disappeared over time in certain regions, while new ones also emerged (Zippel 2005). This would appear to contradict the statement by Gebremarium (1997) that many valuable landraces have been lost due to various human and environmental factors.

Table 2.2. Number of farmer varieties recorded by different authors in major enset producing areas of Ethiopia.

Number of farmers' varieties	Study sites	Information source
76	South Omo (Ari)	Shigeta, (1990)
158	Dawro, Gamo Goffa & Wolaita	Alemu and Sandford (1991)
146	Keffa-Sheka, Sidama, Hadiya & Wolaita	Negash (2001)
166	Hadiya, Sidama & Wolaita	Tsegaye (2002)
79	Sidama	Tesfaye (2002)
111	9 different geograpHical sites (Wolkite, Setunae, Seltae, Bonga, Shonae, Worka, Answae, Wondo, Chencha)	Birmeta (2004)
42	Kaffa	Tsehay and Kebebew, (2006)
218	7 different zones (Dawro, Gamo Goffa, Gurage, Hadiya, Kembata Tembaro, Sidama and Wolaita)	Yemataw (2014b)
67	Wolaita	Olango (2014)
312	8 different zones (Dawro, Gedeo, Gurage, Hadiya, Kembata Tembaro, Sidama, Silte and Wolaita)	Yemataw (2016a)

For enset, conservation of genetic resources *ex situ* as seed in cold storage is difficult due to the rarity of enset seeds and their difficult germination. However, the existence of stored seed material is important, particularly in the context of crop improvement programs. Guzzon and Müller (2016) surveyed plant genetic resource databases, gene and seed banks, research centers and interviewed individual researchers, but found a seed accession of only one of the enset species (*E. ventricosum*), in the Millenium Seed Bank of the Royal Botanic Garden, Kew. In 2004 Birmeta demonstrated that wild enset populations show a higher genetic variability with potentially useful traits for domesticated enset, making them prime candidates for plant breeding programs. There are currently no enset breeding programs.

Ex situ conservation of enset is done either *in vitro* or in field genebanks (Negash 2001). Building on previous endeavors by Bezuneh (1984) and Negash et al. (2000), Birmeta and Welander (2004) developed a three-step protocol for *in vitro* propagation of enset, including initiation, bud proliferation and shoot elongation and rooting stages. Diro and van Staden (2005) noted that the apical meristem should preferably be split or wounded in order to release lateral buds from apical dominance of the tip during micropropagation.

Enset germplasm collections are important for their contribution to conservation, potential enset breeding programs and as a place where farmers can access better-performing landraces, diversify their enset stock or retrieve previously lost landraces. To date, enset germplasm at the Areka Agricultural Research Center (AARC) has not been systematically evaluated. A non-exhaustive collection of 623 landraces from 12 enset growing areas of Ethiopia is conserved in field gene banks at the AARC. Olango et al. (2014) noted that the AARC collection represented only 40% of the landraces known to the Wolaita farming communities, suggesting that true diversity is not yet represented. The AARC started its enset research programme in 1986, focussing on agronomy, conservation and socio-economy of enset farming systems (Yeshitila and Yemataw 2012).

2.5 Evaluation of enset varieties for different uses

Different agronomic, culinary and morpHologic properties of enset landraces have been evaluated either *ad hoc* during on-farm surveys or in randomized controlled field trials.

The average yield of *kocho* ranges from 7 to 12 tons ha^{-1} year^{-1}, although yields as high as 43 tons ha^{-1} year^{-1} have been reported (Bekele and Taboge 2008). *Kocho* yields are variable across agro-ecologies (Shambulo et al. 2012) and between landraces. For example, *Halla* shows general superiority, but it is more preferable in highland than mid altitude areas, where *Tuzuma* is equally accepted. Other landraces such as *Falakia*, *Gena* and *Maziya* are preferred in highland whereas *Nakaka* and *Kekeruwa* are more common in mid altitude areas (Shambulo et al. 2012). Yeshitla and Yemataw (2012) report on the dissemination of selected farmer landraces for better *kocho* yield and quality: *Yanbule*, *Gewada* and *Endale* (early maturing - 3 to 4 years) and *Kelisa*, *Zerita* and *Mesena* (late maturing - 4 to 5 years). The average *kocho* yield of these landraces was 10 to 31 tons ha^{-1} $year^{-1}$ (Yeshitla and Yemataw 2012).

Similarly, landraces differ in the quantity and quality of *amicho* produced, whereby a landrace that is good for *kocho* is not necessarily also preferred for *amicho*. Yemataw et al. (2016b) found a superior corm yield for the landraces *Chohot, Ashakit*, *Bose* and *Gazner* when tested across different locations by the AARC. However, it is important to note that desirable sensory and utilization characteristics equally contribute in farmer decision-making (Yemataw et al. 2016b).

Enset is also processed for non-edible products, such as the fiber, which remains after *kocho* and *bulla* have been extracted. *Bulla*, which is edible, may also have other applications, such as starch for textile, paper, adhesive components and many other industrial products. Moreover it can be used as alternative starch in pHarmaceutical industries (Wondimu and Gebremarium 2014). The high quality enset fiber, comparable to Abaca fiber, is used for different social and cultural purposes (Bezuneh 2012), including the fabrication of ropes and sacks. Bezuneh and Feleke (1966) suggest variations in fiber quality, depending on the landrace. The importance of fiber was demonstrated during a recent farming system study of eight ethnic groups where more than forty landraces were identified for fiber use (Yemataw et al. 2016a). Farmers also ranked the production of high quality fiber as a very important characteristic (Olango et al. 2014).

2.6 Evaluation of enset landraces to pests and diseases

Enset is plagued by a number of disease threats, including several bacteria, nematodes, fungi, and viruses. The most serious of these constraints is bacterial wilt disease, caused by *Xanthomonas campestris* pv. *musacearum* (Yirgou and Bradbury 1968; Ashagari 1985; Quimio 1991; Quimio and Tessera 1996; Welde-Michael 2000). To date, none of the landraces screened has shown complete resistance to Xanthomonas wilt (Ashagari 1985). However, disease symptoms have been shown to develop with variable intensity on a large number of landraces tested by Welde-Michael et al. (2008). Some landraces, such as *Maziya*, showed a relative tolerance to the disease (Handoro and Welde-Michael 2007; Welde-Michael et al. 2008). Yemataw et al. (2014b) reported that farmers preferred *Maziya* and *Gena* because of their perceived resistance to *Xanthomonas* wilt. Variable levels response to the *Xanthomonas* wilt disease depending on the landrace have been observed under farmers' field conditions and using artificial inoculation in on-station trials (Spring et al. 1996; Welde-Michael 2000; Welde-Michael et al. 2008; McKnight CCRP 2013; Haile et al. 2014; Hunduma et al. 2015; Table 2.3).

Table 2.3. Enset landraces found to be tolerant to *Xanthomonas* wilt.

Name of landrace	Collection zone	Mean disease incidence (%)	Reference
Nobo	Sheka	6.7	Haile et al. 2014
Nechuwe	Gurage	11	Welde-Michael et al. 2008
Dere	Gurage	11	Welde-Michael et al. 2008
Bezeriyet	Gurage	11	Welde-Michael et al. 2008
Maziya	Dawro	19.31	Hunduma et al. 2015
Lemat	Gurage	22	Welde-Michael et al. 2008
Anikefiye	Gurage	33	Welde-Michael et al. 2008
Hiniba	Kembata-Tembaro	33	Welde-Michael et al. 2008
Sorpie	Kembata-Tembaro	33	Welde-Michael et al. 2008
Halla	Wolaita	33	Welde-Michael et al. 2008
Badadiat	West & SW Shewa	34.26	Hunduma et al. 2015
Hiniba	West & SW Shewa	30.18	Hunduma et al. 2015
Dirbo	Kembata-Tembaro	35	McKnight CCRP 2013 Annual report
Onjamo	Kembata-Tembaro	18.75	McKnight CCRP 2013 Annual report
Hala-a	Dawro	22.50	McKnight CCRP 2013 Annual report

Few other studies have examined variable response of enset landraces to pests and diseases. Bogale et al. (2004) observed large differences in the densities of *P. goodeyi* extracted from roots of different landraces sampled in farmers' fields, suggesting that there may be inherent differences in susceptibility among them.

2.7 Research gaps and future directions

Enset is characterized by a high genetic diversity, which has been curated by farmers for thousands of years. Enset diversity provides resilience and food security despite challenging environmental conditions. Management of enset diversity is a dynamic process, with much exchange between regions due to changing food preferences, climate, pests and diseases, cultivation systems, and infrastructure. However, farmers have also lost landraces to diseases, abiotic selection pressures, or changes in land use systems.

Several research gaps need to be addressed in order to improve the long-term conservation of this diversity: 1) development of a taxonomic key and descriptor list to characterize enset diversity; 2) collection, research and *ex situ* conservation of enset seeds from domesticated and wild relatives; 3) expansion of the existing field gene bank at AARC, in combination with appropriate biotechnological approaches such as the use of improved tissue culture methods, rapid propagation and distribution of planting material; 4) varietal screening programs to identify possible sources of resistance or tolerance to the most common (a)biotic constraints; 5) improved exploitation of the industrial potential of enset.

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CHAPTER 3

Enset genetic resource utilization and management in south and south western parts of Ethiopia

3.1 Indigenous Knowledge of Farmers' for the Management and Conservation of Enset (*Ensete ventricosum* (Welw.) Cheesman) (Musaceae family) Diversity On-farm

Abstract

Enset (*Ensete ventricosum (*Welw.) Cheesman) belongs to the order *Sctaminae*, the family *Musaceae.* The *Musaceae* family is subdivided into the genera *Musa* and *Ensete.* Enset is an important staple crop for about 20 million people in the country. Recent publications on enset ethnobotany are insignificant when compared to the diverse ethnolingustic communities in the country. Hence, this paper tries to identify and document indigenous knowledge associated with the distribution, diversity, and management of enset in the country. The study was conducted in eight ethnic groups in the Southern Nations, Nationalities and Peoples' Regional State. In order to identify and document indigenous knowledge, the data was collected mainly through individual interviews and direct on-farm participatory monitoring and observation with 320 farm households, key informant interviews. Relevant secondary data, literature and inter-personal data were collected from unpublished progress report from National Enset Research Project, elderly people and senior experts. Enset-based farming system is one of a major agricultural system in Ethiopia that serves as a backbone for at least a quarter of country's population. Farmers use three morphological characters, two growth attributes, disease resistance and five use values traits in folk classification and characterization of enset. A total of 312 folk landraces have been identified. The number of landraces cultivated on individual farms ranged from one to twenty eight (mean of 8.08 ± 0.93). All ethnic groups in the study area use five use categories in order of importance: *kocho* yield and quality, *bulla* quality, *amicho* use, fiber quality and medicinal/ritual value. Of the 312 landraces 245 landraces, have more than two use types. Management and maintenance of on-farm enset diversity is influenced by systematic propagation of the landraces, exchange of planting material and selective pressure. It can be concluded that the existing farmers' knowledge on naming, classification and diversity should be complemented with maintenance of the creative dynamics of traditional knowledge and transmission of the knowledge are crucial for constructing sustainable management.

Key words: Enset, Ethiopia, Indigenous knowledge, Landraces, On-farm diversity, On-farm management

3.1.1 Introduction

The Ethiopian highlands are center of genetic diversity for enset, tef, sorghum, barley and finger millet (Engles and Hawkes 1991). Enset (*Ensete ventricosum (*Welw.) Cheesman) belongs to the order *Sctaminae*, the family *Musaceae*. The *Musaceae* family is subdivided into the genera *Musa* and *Ensete* (Simmonds 1966). Enset is an important staple crop for about a quarter of the population of the people living in the densely populated regions of South and Southwestern Ethiopia. The crop is grown in mixed subsistence farming systems, often in association with coffee, multi-purpose trees, and annual food and fodder crops (Zippel 2002). Enset is also used for livestock feed, fuel wood, construction materials, containers, and as a provider of shade to intercropped annual or perennial crops (Shigeta 1990). It is cultivated between 1500 and 3100 meters above sea level (masl), where daily average minimum and maximum temperatures are 8 and 27°C, respectively (Bacha and Taboge 2003)

The major food types obtained from enset are *kocho*, *bulla* and *amicho*. *Kocho* is fermented starch obtained from decorticated (scraped) leaf sheaths and grated corms. *Bulla* is obtained by squeezing out the liquid containing starch from scraped leaf sheathes and grated corm and allowing the resultant starch to concentrate into white powder. *Amicho* is boiled enset corm pieces, mainly obtained from young enset plants that are prepared and consumed in a similar manner to other root and tuber crops (Brandt et al. 1997).

Studies indicate that numerous enset landraces were identified in each region and the observed genetic diversity in cultivated enset in a particular area appears to be related to the extent of enset cultivation and the culture and distribution pattern of the different ethnic groups (Birmeta 2004).

A clear understanding of the diversity and distribution of enset is important for crop improvement programs and for managing genetic resources. To measure the status of crop diversity in the field the most common method is counting named varieties. There are two main landrace diversity indices, namely: landraces richness, which represents the number of landraces in a community, and landraces evenness, representing the relative abundance of the individuals among the various landraces present in the community (Frankel et al. 1995; Powers et al. 2000). For farmers, genetic diversity means varietal diversity, which farmers can clearly distinguish on the basis of agro-morphological traits, phenological attributes, post-harvest characteristics, and differential adaptive performance under abiotic and biotic stresses (Sthapit et al. 1996).

Indigenous technical knowledge is the tool by which local people interact with the environment in order to meet needs and goals ranging from survival goals to that of achievement and esteem (Atte 1993). It is knowledge, which is unique to a local area, culture, or society, passed down from one generation to the next, usually through oral tradition. Indigenous knowledge has to do with theories, beliefs, practices, and technologies that local people have elaborated without any assistance from the modern, formal and scientific communities and/or institutions McCorkle 1989). Indigenous people have a long tradition in maintaining biodiversity as a sustainable resource. Farmers have played and still continue to play a tremendous role in developing and nurturing crop genetic diversity. Many studies have shown that farmers in developing countries have intimate knowledge of environmental processes and make rational resource management decisions based on that knowledge (Olango et al. 2014).

The southern and southwestern part of Ethiopia has an extraordinary biological and cultural diversity. Recent publication on enset ethnobotany including those by Olango et al. (2014); Tesfaye (2008) attempt to document farmers' indigenous knowledge on enset in some cultural groups at specific location. However, those documentations are insignificant when compared to the diverse ethnolingustic communities in the country. This paper seeks to contribute towards filling this knowledge gap, based on an empirical study of enset farmers in Ethiopia. The paper address the following main question: what are farmers' knowledge associated with the distribution, diversity, and management of enset in the country? The underlying assumption behind this question is that all farmers are equally likely to be knowledgeable about the crop.

Hence, the objectives of this study was to identify and document indigenous knowledge for folk naming, classification, distribution and abundance of enset landraces and understanding the corresponding knowledge related to utilization, management and conservation of enset landraces.

3.1.2 Materials and methods

3.1.2.1 The study area

The SNNPR is one of the regions in Ethiopia. It is located in south and southwestern part of Ethiopia, 4.43° - 8. 58° N latitude and 34.88° - 3914° E bordering Kenya to the south and South Sudan to the west and southwest, the Ethiopian region of Gambela to the northwest, and the Ethiopian region of Oromia to the north and east (Figure 3.1.1).The region has a total area of 110,931.9 square kilometers lying within elevations of 378 to 4207 meters above sea level (Abebe 2005). The annual temperature is less than 10°C in the extreme highlands to over 27°C in the lowlands of the south. The regions are sub divided into zones, which are organized in to weredas/districts. The zones are named based on the name of the dominant ethnic group for that specific location. Within weredas, kebeles are the smallest administrative units.

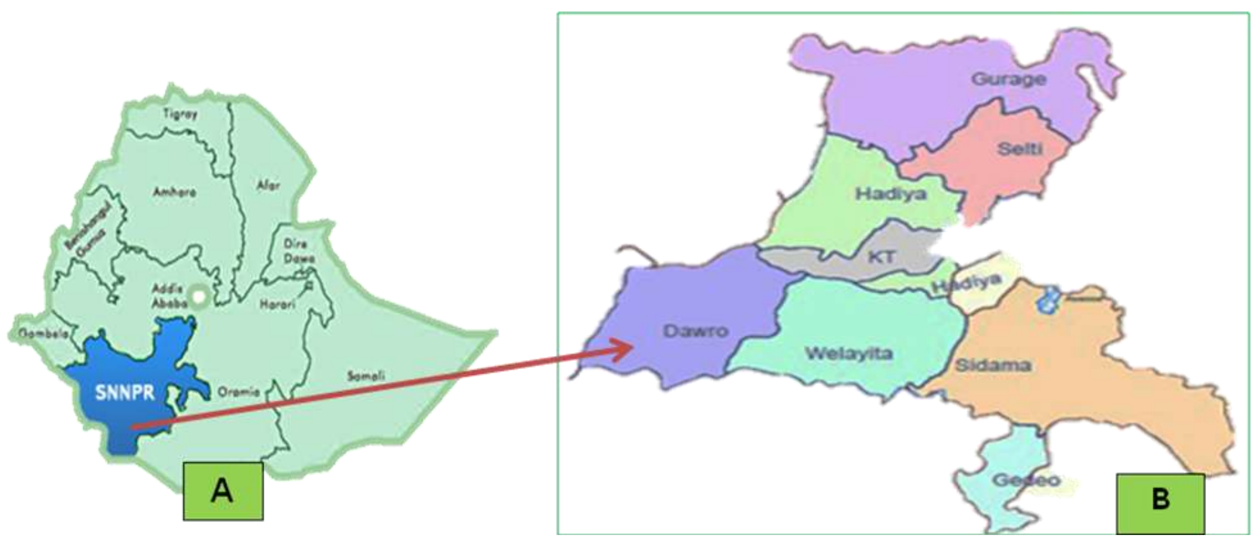

Figure 3.1.1 (A) Map and position of the study region in Ethiopia. (B) Detail Zones map of the study region.

3.1.2.2 Study site selections

The study was conducted in eight ethnic groups/zones (Dawro, Gedeo, Gurage, Hadiya, Kembata-Tembaro, Sidama, Silte, and Wolaita) in the Southern Nations, Nationalities and Peoples' Regional State (SNNPRS). The eight ethnic groups were selected for the following reasons:

1. The crop has coexisted with the people for centuries and enset production is pre-dominantly based on farmers' varieties. Hence, farmers' are expected to have an established folk naming, classification system of appraisal of enset.
2. The ethnic groups had rich on-farm genetic resources of enset that made it suitable to study ethnobotanical descriptions of enset (Olango et al. 2014; Tesfaye 2008).
3. In the region, enset cultivation is the center of the cropping system in which the entire farming system is based and the crop is the major food security and livelihood source (Olango et al. 2014; Tesfaye 2008).

Two weredas were selected from each ethnic groups based on enset diversity (Table 3.1.1). Then, two kebeles which are major enset growing areas were purposively selected from each wereda/district based on the importance of enset cultivation and information about enset distribution obtained from the Departments of Agriculture and Natural Resource of the respective zones.

3.1.2.3 Sampling

Multistage sampling technique was employed for selection of samples, zones, weredas and kebeles. All stages were selected purposefully from high (> 2500 m.a.sl) and mid altitude (1500 -2500 m.a.sl) (CSA 2011) areas in consultation with stakeholders engaged in the subsector. Eight Zones, two weredas from each zone (16 wereda) and two Kebele Administration (KA) (Kebeles are the lowest administrative unit) from each wereda (32 KAs), were selected purposefully based on agro-ecology variant. A total of 320 households (40 household heads from each ethnic) over the selected ethnic groups in the two crop ecologies were directly monitored on farms. The survey focused on the investigation of farmers' folk knowledge for naming, classification, diversity and management of enset landraces in the region (Appendix 1).

3.1.2.4 Data collection

Diverse data collection methods were employed in order to understand the many features for the acquirement of local knowledge of enset naming, classification, diversity and management in the center of diversity. The data collection was conducted mainly through: i) individual interviews and direct on-farm participatory monitoring and observation, ii) key informant and focus group discussions, and iii) secondary data and literature survey.

Table 3.1.1. Description of surveyed woredas and their agro-ecological characterization

No.	Zone	Woreda	Elevation(m. a.sl)	Minimum and Maximum T^o	Annual RF (mm)
1	Gedeo	Bulle	2428	15 - 22.5	1200-1800
		Gedebe	2171	12 - 21	800-1150
2	Wolayta	Boloso Sore	1871	14 - 25	1100-1500
		Sodo Zuria	2200	14 - 25	1100-1800
3	Guragie	Cheha	2638	11- 21	1100-1850
		Geta	2731	10 -22	1000-1800
4	Kembata-Tembaro	Angacha	2465	15- 24	900- 1750
		Doyogena	2748	10-22	1000-1800
5	Silte	Mirab Azerenet	3191	11 - 18	950 - 1900
		Alicho Werero	2707	12 - 22	700 - 2000
6	Hadiya	Dunna	2619	11-21	1100-1850
		Misha	2367	12-21	800-1150
7	Daworo	Mareka	2482	12-21	1200-1800
		Tocha	2754	12-21	1200-1800
8	Sidama	Dalle	1855	12-26	1000-1800
		Hulla	2759	10 - 17	900 -1850

Individual interviews and direct on-farm participatory monitoring and observation

Before interviews were performed, informal conversation was conducted with 20 inhabitants of the enset community with the objective of determining which type of information needed to be collected. Based on these conversations, semi-structured interviews were designed and data collected with the head of the household or the person responsible for maintenance of the enset plantation. Three hundred twenty farmers were interviewed and directly monitored on farms, over the selected weredas in order to assess the farmers' ethnobotany knowledge on enset.

The questionnaire covered different topics such as information about the study area, landholdings, crops commonly grown and specific information on the use and management of enset. The detailed information was focused on enset diversity, cultural practices, source of planting materials, and traditional use values of enset. The respondents were also asked about their perception on enset production constraints and their indigenous knowledge about the disease.

Key informant interviews

In order to assess the general indigenous knowledge of farmers' in each ethnic group: key informants up to five per KA, community leaders, local administrations, and MOA (Ministry of Agriculture), and other members in each ethnic site were interviewed.

Secondary data and literature survey

National Enset Research Project progress report was visited for secondary data and personal communication and discussion with elderly people and senior experts in line with ethnobotany tradition of enset. Literatures on enset culture were reviewed from published and unpublished sources and reports.

3.1.2.5 Data analysis

Informal discussion with elderly farmers, and key informants were carried out to validate the information gathered from individual interviews. Lists of all landraces described throughout the study area were summarized after grouping known synonyms or names that refer to the same landraces in each wereda with the help of elderly farmers.

Collected survey data were subjected to descriptive statistics (frequencies, percentages, and average) using SPSS Ver. 16. Landrace richness, diversity and dominance per farm were calculated using Microsoft excel 2010. Richness was calculated as the total number of landraces per farm and averaged this figure per ethnic group. Abundance was calculated as the total number of individual plants of each landraces per farm/household. Frequency was estimated as the number of individuals of a landraces with respect to the total number of landraces composing the enset farm. With these parameters we calculated the ecological importance index of each landraces per farm.

The Shannon and Weaver (Shannon 1949) and Simpson (Simpson 1949) diversity indices are two of the most widely used measures of heterogeneity (Magurran 1988). Both of them were calculated for all the surveyed zones. 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. It was calculated using the formula, $H' = - \Sigma\, pi \ln pi$, (Magurran 1988). Where pi, the proportional abundance of the i^{th} landrace. Then we calculated the dominance as a measure representativeness of each landrace through the Simpson index. Simpson's Index of Diversity (1 – D) was computed for all the zones and all the landraces using the function: Simpson's Index of Diversity (1-D) = $1-\sum (n/N)^2$.

$D = \sum_{i-1}^{n} \frac{(n_i\,(n_i - 1)}{(N(N-1)}$ where, n_i= the frequency of the i^{th} landrace, frequency being the number of farms in which the landrace is found in the district, and N = the total number of farms surveyed in the zone.

Equity, the proportion of the observed diversity with respect to the maximum diversity expected was calculated through the Pielon index: J= H'/H'max, in which J is equity; H' = diversity; H'max= maximum diversity, H'max was calculated as the ln(S) S being the number of landraces in a sample. Pearson's correlation coefficient was used to compare diversity and distribution values at different ethnic groups.

We used a multiple use curve (Balick 2004) concept to describe the rate at which ethnobotanical data is collected, check whether the essential part of the available information on the landraces had been collected. This curve plotted the cumulative number of uses recorded against the number of informants. To analyze the use values of the landraces, we regrouped the uses into broad categories, where each category contained uses of a similar nature. In this way, three main categories were created, namely; food (*kocho* yield and quality, *bulla* quality, *amicho* use), fiber (fiber quality) and medicinal/ritual categories. Food and medicinal categories refer to use by both humans and animals.

3.1.3 Result and Discussion

3.1.3.1 Strategic importance of enset

Enset-based farming system is one of a major agricultural systems in Ethiopia that serves as a backbone for at least one-fourth of country's population. Enset has been selected as a typical multipurpose crop of which every part is thoroughly used for food, feed, medicinal, construction and ornamental purposes. Throughout the growth stage, the corm, pseudostem and leaves are used for various purposes. Enset is intimately associated with the daily lives of the farmers. Owing to these facts, farmers indicated that, 'enset is everything for us'. 'It is our food' (Figure 3.1.2A), 'it is our plate' (Figure 3.1.2B), 'it is our house' (Figure 3.1.2C), 'it is our bed' (Figure 3.1.2D), 'it is our bag' (Figure 3.1.2E) 'it is our cattle feed' (Figure 3.1.2F) and 'it is our medicine' (Figure 3.1.2G). It is the most important crop in the farmers' livelihoods and security.

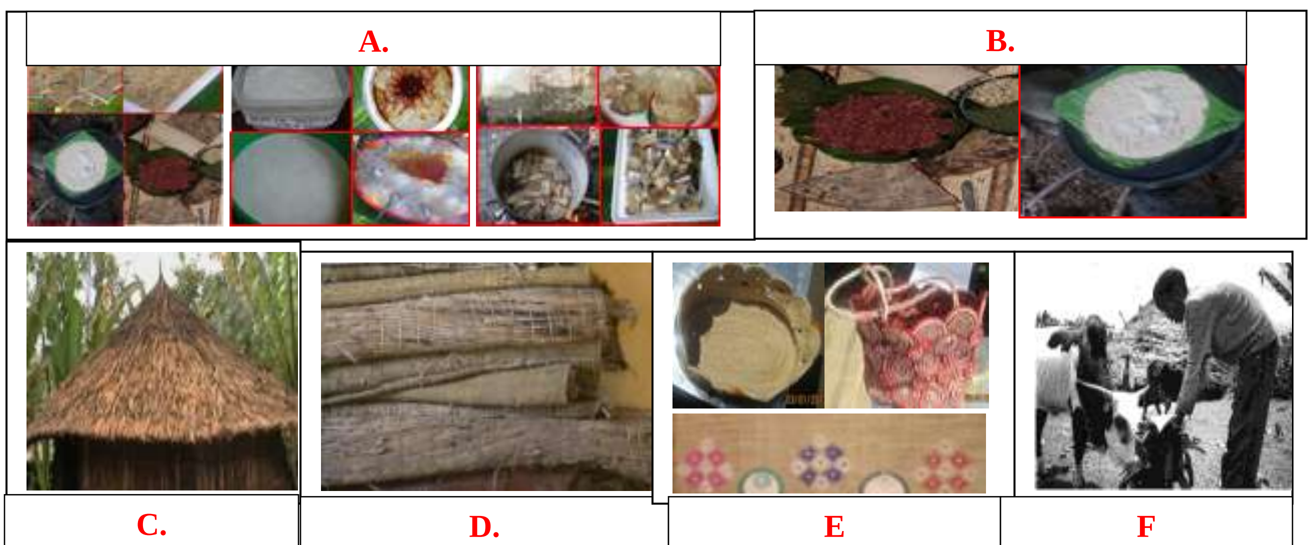

Figure. 3.1.2. Different uses of enset. (A) food products (*Kocho, Bulla and Amicho*) (B) Used as plate. (C) Enset leaf sheath thatching of huts. (D) used as a bed (E) used as bag and decoration. (F) A young boy feeding a cow with enset leaf. (G) Enset landraces used for medicinal use value.

Enset is well-established, sustainable, and environmentally resilient farming system that contributes to food security of farmers and, in particular it serves as food security crop in densely populated areas. Enset needs to be present in farmers' pits throughout the year. Enset is the most important crop in the region. According to CSA (2011) report 3,020,143 km^2 of land is covered by enset crop and about 0.69 million tons of enset yields were produced in 2010/11 production season.

All farmers are using the landraces developed by the community (Yemataw et al. 2014b). These landraces have been grown on-farm for thousands of years. These enset-growing traditions still continue in the current generation. Enset represents an important cultural plant in the region. This appreciation is consistent with previous studies on the crop (Shigeta 1990; Brandt et al. 1997; Olango et al. 2014; Tesfaye 2008; Tsegaye 2002; Bezuneh 1984). Such cultural importance is reflected in the multiple uses of enset in the traditional ecological knowledge about the crop, its biological attributes, morphological and quality variation, including size, yield and other use value quality recognized by local people among the different ethnic groups.

3.1.3.2 Indigenous knowledge in naming and classification

Ensete is the genus name, while different ethnic group use different vernacular terms as a local name for *Ensete*. In the study area, *Ensete ventricosum* is identified through various local names (Table 3.1.2). Farmers in the study area use a combination of similar criteria to name and classify enset landraces (Table 3.1.3). They classify their landraces and give different names based on several attributes that distinguish these landraces from one another. Three morphological characters (midrib colour, petiole colour, and leaf colour), growth attributes (vigor, maturity), disease resistance and use value food (*kocho* yield and quality, *bulla* quality, *amicho* use), fiber quality and medicinal value were the major criteria used by farmers.

Table 3.1.2. Local names of *Ensete ventricosum*

Ethnic group	Local name
Dawro	U'tt'a
Gedeo	Workicha
Gurage	Aset
Hadiya	Weisa
Kembata-Tembaro	Wessa
Sidama	Wessie
Silte	Weisa
Wolaita	Utta

The interviewees referred first to the morphological characters (48%) (Figure 3.1.3) of any enset landrace when asked for key classifying characteristics. The food usage, food quality, and other use value characters were usually mentioned as those of second importance for classification. It is witnessed that the names given by all enset growing farmers to the different landraces and the classification criteria are generally consistent.

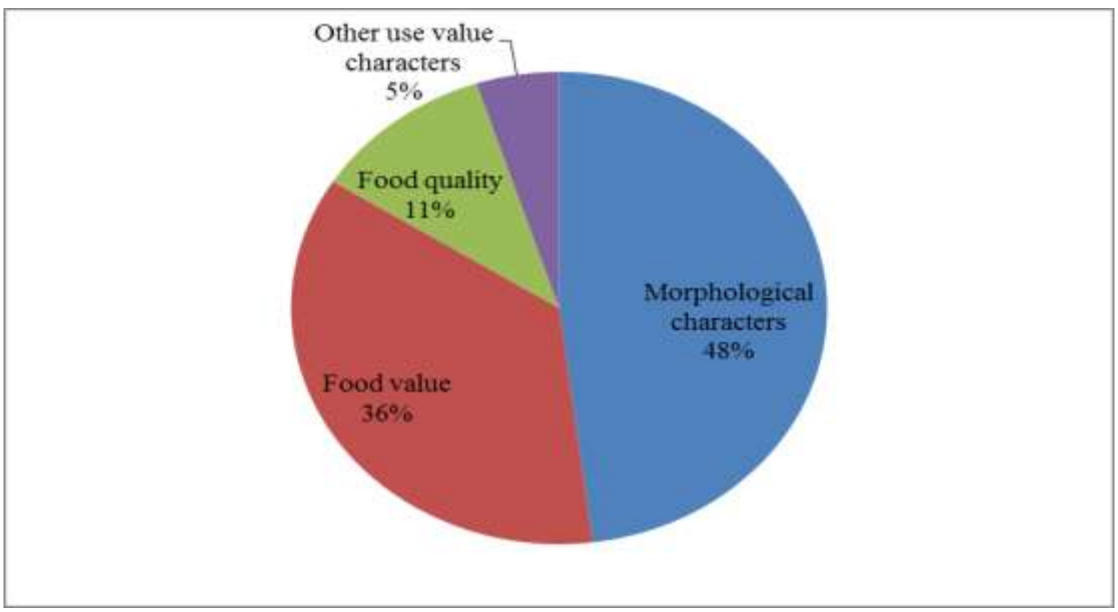

Figure 3.1.3 Proportional importance of different selection criteria's in all the communities studied in the SNNPRS, Ethiopia

Table 3.1.3. Farmers' criteria for classification of enset landraces in, the eight Ethnic groups and frequency distribution of the 320 respondents.

Trait	Descriptor state	Respondents
Plant vigor	Poor (<4m)	22
	Medium (4-6m)	40
	High (>6m)	38
Maturity (cycle duration)	Early (<4 years)	33
	Intermediate (4 -5 years)	43
	Late (> 6 years)	24
Kocho yield	Low (<9.9 t ha^{-1} yr^{-1})	9
	Medium (9.9 to 20 t ha^{-1} yr^{-1})	53
	High (> 20 t ha^{-1} yr^{-1})	38
Bulla quality	Not good	12
	Good	88
Corm use	Not used	58
	Used	42
Fiber quality	Low	23
	Medium	51
	High	26
Medicinal value	Not used	88
	Used	12
Disease response	Susceptible	80
	Intermediate	8
	Tolerant	12

Trait	Descriptor state	Respondents
Petiole colour	Green	45
	Green yellow	1
	Pink purple	4
	Red	29
	Red purple	11
	Purple	5
	Brown	4
	Black	1
Midrib colour	Green	36
	Green yellow	1
	Red	17
	Red purple	16
	Pink	14
	Pink purple	10
	Purple brown	4
	Black	1
	Ivory	1
Leaf colour (upper surface)	Light green	61
	Medium green	24
	Green	15

Farmers' rich knowledge that is accumulated on the crop over many years has played a significant role in naming, characterization and maintenance of the existing genetic diversity. Enset producing farmers have their own folk naming and classification system to distinguish one landrace from the other. Sometimes it is difficult to understand and reclassify, even while watching them to characterize. The classification of enset landraces has been accommodated by Phenotypic differences, unique traits and specific uses of landraces. As pointed out by Shigeta (1990); Olango et al. (2014); Tesfaye (2008), these are common characteristics of folk classification systems in enset. Folk nomenclature is an integral part of the variety management in enset farming systems (Tesfaye 2002; Yemataw et al. 2014a). In view of this, the multitude of names in various folk taxonomic levels indicated the occurrence of on farm genetic diversity at infra-specific level. As indicated by Olango et al. (2014), landrace names given by farmers' have been used as farmers' diversity unit for estimating unit for the extent and distribution of enset diversity as well as *ex situ* collection. This is also in agreement where folk taxonomy is used to highlight the amount of genetic diversity (Simpson 1949; Yemataw et al. 2012; Yeshitla et al. 2011). In this study, over 300 landrace names (Appendix 2) have been identified which indicated the level of on farm genetic diversity. The meaning of the names of most landraces is not known. It is difficult to know unless the people who named it or the place of origin are traced back. It has been repeatedly reported that unexplained meanings of folk names were common in other ethnic groups (Olango et al. 2014). A similar pattern was observed in other crops like sorghum and rice (Mekbib 2007; Appa Rao et al. 2002) .

Enset landraces were commonly exchanged and distributed according to the folk names. The finding of this study (Table 3.1.5) and other similar studies (Tesfaye 2002 & 2008; Abebe 2005) depict identically named landraces were also reported in more than one ethno-linguistic communities. Folk classification can help in identifying the comparative value of landraces (for example Table 3.1.6, 3.1.7 & 3.1.8) for proper characterization and pre-breeding activities. A similar study on sorghum in Ethiopia (Mekbib 2007) and rice in Nepal (Appa Rao et al. 2002) has shown that name of the varieties indirectly related showed the functional value for the variety.

Commonly, knowing folk names and classification may distinguish varieties that are actually genetically very close. Farmer in one household generally knows which households certainly have named varieties and their particular agronomic and use value related characteristics. Knowing folk taxonomy also helps in developing planting material distribution, flow channels, and regional landrace map. Thus, even if landrace names and classification are a necessary basis, they are not sufficient to describe genetic diversity. Integrative indicators have been designed e.g. complementing the naming and folk classification with parameters of genetic diversity. Our data thus needs to be complemented by Phenotypic and genotypic information which helps to avoid redundancies and optimizing the efficient conservation and sustainable use of the crop.

3.1.3.3 Level of on-farm richness, diversity and pattern of use

We recorded a total of 440 folk varieties (landraces) across the eight ethnic groups. From the total 128 (29%) landraces shared the same name in at least two ethnics and the total number of landraces reduced to 312 (Appendix 2). As farmers over years have selected their landraces for multipurpose values, they do group them according to the use values landraces renders. Each landrace is clearly distinguished by its vernacular name and peculiar characteristics. Of the 312 landraces, 288 were reported to be known by all of the interviewees, whereas the 24 landraces were found in less than 5% of the respondents' farm.

Based on the total number of different landraces recorded (richness of the ethnic group) and the number of enset landraces per farm, Dawro farmers' had the highest number of landraces (75) accounting for 24% of the total number of recorded landraces across the study area. In contrast, the lowest richness was found in Gedeo farmers' with 26 landraces accounting for 8.33% of the total number of recorded landraces (Table 3.1.4). The number of landraces cultivated on individual farms ranged from one to twenty eight (mean of 8.08 ± 0.93) (Table 3.1.4). Average number of landraces per farm ranged between 10.43 for Silte to 3.55 for Wolaita. Dawro and Sidama with 10.2 and Gurage with 9.45 landraces per farm had high farm level richness (Table 3.1.4).

Diversity indices for the eight ethnic groups studied were computed from the numbers of landraces present on the 40 farms within the ethnic groups (Table 3.1.4). Although ethnics differed in richness, they were similar in diversity. The Simpson's 1-D ranged between 0.97 (Dawro) to 0.9 (Gedeo), H′ ranged between 3.71 for Dawro to 2.6 for Gedeo, while evenness also had a very narrow range: 0.89 for Gurage to 0.8 for Gedeo (Table 4). Both the H' and 1-D indices were highly correlated with landrace number at each ethnic (r = 0.90 and 0.70). All these values indicate the high enset diversity in these eight ethnic groups.

All ethnic groups in the study area use a combination of different criteria to group enset landraces. We recorded three use categories, as defined by Yemataw et al. (2014a), in order of importance: Food (*kocho* yield and quality, *bulla* quality, *amicho* use), fiber (fiber quality) and medicinal/ritual value as described in Table 3.1.3. Of the 312 landraces: only eleven landraces having one use type, 56 landraces having two use types and a total of 245 landraces having more than two use types (Figure 3.1.4). In addition, Figure 3.1.5 shows the comparative result of the use categories according to the ethnic groups. Fair analysis between ethnic groups revealed that the highest value for food (*kocho* yield and quality) were (≥35 house hold/ethnic) observed in all ethnic groups.

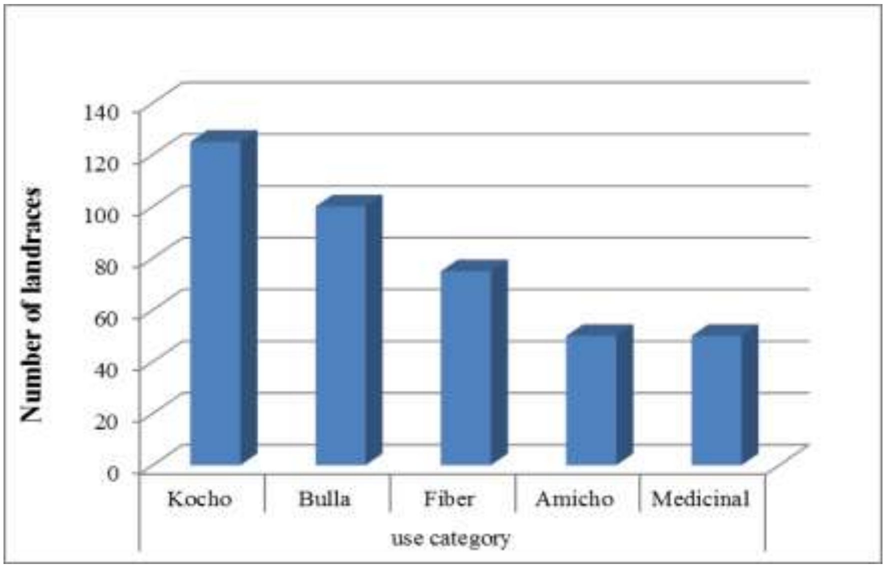

Figure 3.1.4 Uses of the landraces recorded in the home gardens of all the communities studied in the SNNPRS Ethiopia

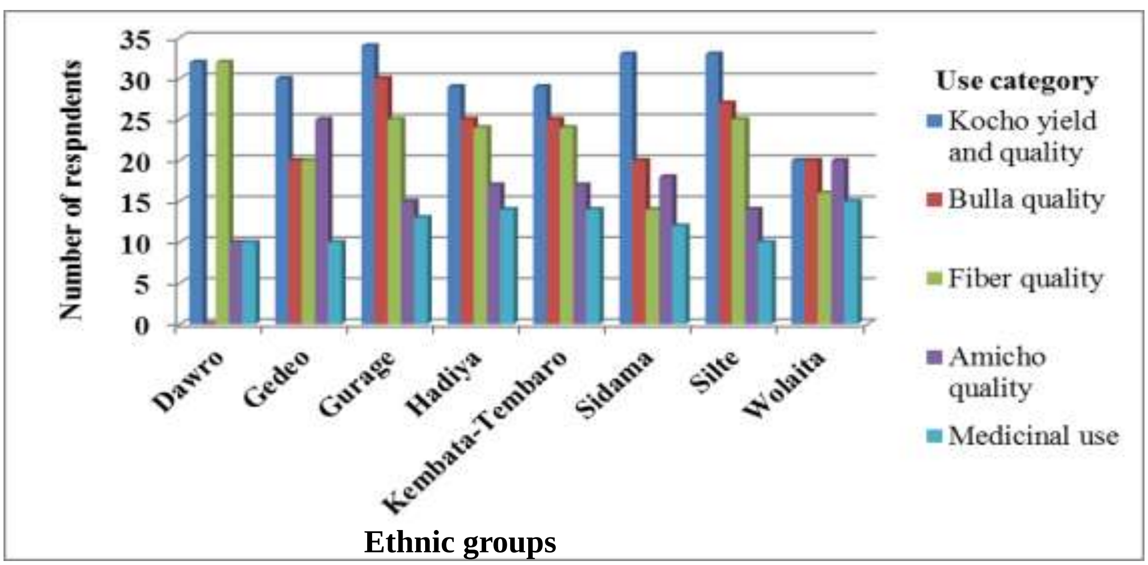

Figure 3.1.5. Comparative analysis of use category in each ethnic group studied in the SNNPRS, Ethiopia

Table 3.1.4. Enset landrace diversity in the eight ethnic groups, Southern Ethiopia, Expressed as richness, Simpson(1-D) and Shannon (H') diversity indices, and Evenness

Districts	**Richness (%)**	**Mean richness / farm**	**Minimum richness**	**Maximum richness**	**No. of unique landraces**	**1-D**	**H'**	**Evenness**
Dawro	75 (17.04)	10.2	1	28	21	0.97	3.71	0.86
Gedeo	26 (5.91)	4.75	1	8	20	**0.9**	**2.6**	**0.8**
Gurage	63 (14.32)	9.45	3	21	15	0.96	3.69	0.89
Hadiya	51 (11.59)	8.19	4	15	20	0.95	3.4	0.86
Kembata-Tembaro	66 (15)	7.83	3	15	15	0.96	3.62	0.86
Sidama	62 (14.1)	10.27	3	28	45	0.96	3.5	0.85
Silte	69 (15.68)	10.43	3	24	20	0.96	3.67	0.87
Wolaita	28 (6.36)	3.55	2	7	15	0.93	2.86	0.86

Almost all of the landraces used for good *kocho* and *bulla* yield and quality have got a wider distribution and diversity (Table 3.1.5). The fiber uses showed higher values for all ethnic groups. Farmers also reported enset landraces having longer and/or stronger fibers, and higher fiber yield and quality (Table 3.1.6). Forty two landraces were identified by farmers for *amicho* use value (Table 3.1.7). In addition, some enset landraces are known by farmers to have medicinal value for both humans and animals. These landraces are poorly producing and to be maintained for special traditional or religious uses (Table 3.1.8). Almost all landraces in this category have got sweet *amicho* test. Therefore, both categories share more than 50% of the landraces. In addition to the above use value; farmers in each ethnic group use biotic and abiotic tolerance as a trait for diversity maintenance. Fifty and thirty three landraces were identified by farmers as tolerant to enset bacterial wilt and drought (Table 3.1.9 & 3.1.10).

Table 3.1.5. Number of farmers who are growing the most abundant and widely distributed enset landraces per ethnic group.

No.	Landrace name	**Number of respondents (N= 40)**									
		Da[1]	Ge	Gu	Ha	Ke	Si	Sil	Wo	Total	ethnic group
1	*Ado*						34			34	1
2	*Agade*			38				38		76	2
3	*Ahero*							19		19	1
4	*Amiya*	15								15	1
5	*Argama*	17								17	1
6	*Arkeya*	21								21	1
7	*Astara*		31	21						52	2
8	*Badedet*	24		26				23		73	3
9	*Bazereye*			21						21	1
10	*Beneze*							21		21	1
11	*Bira*						16			16	1
12	*Birbo*						15			15	1
13	*Boser*			17						17	1
14	*Boza*	20								20	1
15	*Chacho*						15			15	1
16	*Dere*			19						19	1
17	*Dirbo*					16				16	1
18	*Desho*				28					28	1
19	*Enquafye*			18						18	1
20	*Etene*					18				18	1
21	*Ferezye*			23						23	1
22	*Genbo*				34	15		22		71	3
23	*Genna*						21			21	1
24	*Genticha*		37				39			76	2
25	*Guarye*							17		17	1
26	*Gulumo*						16			16	1
27	*Hiniba*							20		20	1
28	*Kinbat*							30		30	1
29	*Kiticho*						24			24	1
30	*Mazia*	28								28	1
31	*Merza*					16				16	1
32	*Midasho*						25			25	1
33	*Nefo*		23							23	1
34	*Qibnar*			17						17	1
35	*Seskela*				25	34				59	2
36	*Sheleqe/Shelequmia*					15			25	40	2
37	*Shirteye*			22				20		42	2
38	*Shododinia*	37								37	1
39	*Torore/Toracho*		20		19					39	2
40	*Tuzuma*								22	22	1
41	*Uwisho*						21			21	1
42	*Yaka*	22								22	1

[1]Da= Dawro, Ge= Gedeo, Gu=Gurage, Ha= Hadiya, Kem=Kembata-Tembaro, Sid= Sidama, Sil= Silte, Wol= Wolayita

Table 3.1.6. List and distribution of enset landraces reported by farmers for better fiber yield and quality

No.	Landrace name	Location	Frequency of respondents (N=40)	No.	Landrace name	Location	Frequency of respondents (N=40)
1	*Abatemerza*	Kembata-Tembaro	31	23	*Lemat*	Gurage	17
2	*Ayase*	Kembata-Tembaro	24	24	*Ankefuye*	Gurage	20
3	*Digmerza*	Kembata-Tembaro	28	25	*Enba*	Gurage	15
4	*Ferchase*	Kembata-Tembaro	23	26	*Yeshirakinke*	Gurage	32
5	*Zobira*	Kembata-Tembaro	19	27	*Gimbo*	Gurage	30
6	*Unjame*	Kembata-Tembaro	32	28	*Tikur Badadiet*	Gurage	24
7	*Sapara*	Kembata-Tembaro	30	29	*Teriye*	Gurage	25
8	*Gishira*	Kembata-Tembaro	32	30	*Bedade*	Gurage	30
9	*Disho*	Kembata-Tembaro	21	31	*Sabora*	Gurage	19
10	*Gishira*	Kembata-Tembaro	28	32	*Toracho*	Sidama	17
11	*Siskella*	Kembata-Tembaro	32	33	*Kiticho*	Sidama	14
12	*Gimbo*	Kembata-Tembaro	20	34	*Ado*	Sidama	26
13	*Shetadena*	Kembata-Tembaro	14	35	*Midasho*	Sidama	24
14	*Agade*	Kembata-Tembaro	18	36	*Gena*	Sidama	29
15	*Mazia*	Wolayita	24	37	*Wundiraro*	Sidama	16
16	*Bedade*	Wolayita	20	38	*Tsella*	Dawro	20
17	*Gefeteno*	Wolayita	26	39	*Kertia*	Dawro	18
18	*Halla*	Wolayita	32	40	*Yeka*	Dawro	22
19	*Godoria*	Wolayita	20	41	*Yesha Mazea*	Dawro	26
20	*Amaratye*	Gurage	22	42	*Bota Mazea*	Dawro	24
21	*Agade*	Gurage	24	43	*Mecha Boza*	Dawro	21
22	*Nechiwe*	Gurage	20				

Table 3.1.7. List and distribution of Enset landraces reported by farmers for better *amicho* use quality

No.	Landrace name	Ethnic group	Frequency of respondents (N=40)	No.	Landrace name	Ethnic group	Frequency of respondents (N=40)
1	*Sebera*	Kembata-Tembaro	37	22	*Tessa*	Kembata-Tembaro	33
2	*Switea*	Wolaita	36	23	*Fenqo*	Gurage	30
3	*Sirareia*	Wolaita	33	24	*Agade*	Gurage	23
4	*Bose*	Kembata-Tembaro	29	25	*Musula*	Dawro	30
5	*Leqaqa*	Kembata-Tembaro	31	26	*Bukuniya*	Dawro	25
6	*Neqaqa*	Wolaita	29	27	*Qibnar*	Gurage	32
7	*Bino*	Kembata-Tembaro	26	28	*Qoyina*	Kembata-Tembaro	31
8	*Shelequmia*	Wolaita	33	29	*Neqaqa*	Dawro	33
9	*Matiya*	Dawro	30	30	*Guariye*	Kembata-Tembaro	34
10	*Chohot*	Gurage	35	31	*Argema*	Dawro	29
11	*Diqa*	Dawro	26	32	*Arkiya*	Dawro	32
12	*Keteniya*	GamoGoffa	30	33	*Niffo*	Gededo	33
13	*Ashakit*	Gurage	29	34	*Addo*	Sidama	29
14	*Gena*	Wolaita	32	35	*Gedeme*	Sidama	33
15	*Switeia*	Dawro	33	36	*Qinware*	Silte	32
16	*Tuffa*	Dawro	27	37	*Agincho*	Kembata-Tembaro	29
17	*Zinka*	Dawro	23	38	*Tessa*	Hadiya	26
18	*Astara*	Gurage	27	39	*Darasicho*	Sidama	29
19	*Silqantia*	Wolaiyta	29	40	*Kiticho*	Sidama	30
20	*Sheleqe*	Kembat-Tembaro	30	41	*Disho*	Kembata-Tembaro	28
21	*Gazner*	Gurage	33	42	*Guarye*	Silte	32

Table 3.1.8. List and distribution of enset landraces reported by farmers for their medicinal and ritual purposes.

No.	**Landrace name**	**Frequency of respondents**	**No.**	**Landrace name**	**Frequency of respondents**
1	*Addo*	12	16	*Garercho*	15
2	*Agade*	15	17	*Gesher*	25
3	*Agunited*	13	18	*Gulemo*	17
4	*Altecho*	11	19	*Qeqele*	35
5	*Arikiya*	12	20	*Keter*	28
6	*Askale*	10	21	*Lochinge*	33
7	*Astera*	18	22	*Merze*	16
8	*Badedet*	20	23	*Munderaro*	19
9	*Botate*	19	24	*Nerim*	21
10	*Chacho*	20	25	*Nifo*	27
11	*Cherkuwa*	17	26	*Qibnar*	26
12	*Chovet*	22	27	*Signore*	28
13	*Dem woured*	31	28	*Swetiya*	30
14	*Dere*	29	29	*Tenako*	19
15	*Guarye*	28	30	*Tesa*	29

Table 3.1.9. *Xanthomonas wilt* tolerant landraces reported/used by farmers in the eight surveyed ethnic group

No	Landrace name	Frequency of respondents **(N= 40)**	**No**	Landrace name	Frequency of respondents **(N= 40)**
1	*Addo*	24	26	*Gatecho*	26
2	*Agade*	20	27	*Gena*	32
3	*Ager amer*	13	28	*Ginbura*	21
4	*Agunta*	15	29	*Gishera*	24
5	*Ahiro*	19	30	*Gosala*	14
6	*Altecho*	12	31	*Kombat*	19
7	*Amiya*	17	32	*Kotecha*	20
8	*Argama*	20	33	*Kuruma*	26
9	*Ashekit*	21	34	*Kuruwa*	29
10	*Astara*	24	35	*Maziya*	32
11	*Badedit*	30	36	*Midasho*	28
12	*Banko*	19	37	*Nechwe*	25
13	*Baze*	20	38	*Nifo*	14
14	*Beker*	12	39	*Sesekela*	27
15	*Benezhe*	18	40	*Shodedine*	25
16	*Bera*	13	41	*Shasha*	18
17	*Berbo*	15	42	*Sheleqe*	20
18	*Degomerza*	18	43	*Shirteye*	13

Table 3.1.9. continued

No	Landrace name	Frequency of respondents **(N= 40)**	No	Landrace name	Frequency of respondents **(N= 40)**
19	*Dere*	22	44	*Tegeded*	15
20	*Dewarama*	18	45	*Tsela*	17
21	*Enba*	20	46	*Tuzmia*	19
22	*Enkufaye*	21	47	*Unjame*	22
23	*Etne*	24	48	*Wanadia*	20
24	*Gadami*	18	49	*Yesha maziya*	28
25	*Garado*	23	50	*Zegez*	21

Enset is a multipurpose crop which has different use values. Based on their use value and folk classification large differences were evident between landrace abundance and distribution in the region. Some landraces, particularly those having merits of better *kocho* yield and quality have got a wider distribution within and between ethnic groups/zones. For example, the enset landraces '*Shododenia*' and '*Addo'* were encountered on respectively 37 and 34 (92.5 and 85%) farms visited in Dawro and Sidama, but were not found in any other surveyed zones. Some landraces had a very high local abundance at one or two locations and were absent from the rest. For example *Shodedenia* was encountered on 100% of the farms visited in Dawro. It was encountered on all the 40 (100%) farms visited in Dawro. Likewise, Tesfaye (2002) reported a small number of landraces (for instant *Genticha*) playing a dominant role in Sidama zone. Our study revealed that the highest use values of the landraces were found in the region which also corresponds to where the landraces had the highest abundance in the farming system. This suggests a positive relationship between plant abundance and use. These findings corroborate the "apparency hypothesis" which describes dominant, large and more abundant plant species as having the highest use values.

Table 3.1.10 List and distribution of enset landraces reported by farmers as drought tolerant

No.	Landrace name	**Location**	Frequency of respondents (N=40)	**No.**	Landrace name	**Location**	Frequency of respondents (N=40)
1	*Toracho*	Sidama	24	18	*Kertia*	Dawro	19
2	*Genticho*	Sidama	28	19	*Shododina*	Dawro	23
3	*Nifo*	Sidama	19	20	*Yesha mazea*	Dawro	25
4	*Quarase*	Sidama	25	21	*Bota mazea*	Dawro	26
5	*Kiticho*	Sidama	27	22	*Attuma boza*	Dawro	22
6	*Ado*	Sidama	24	23	*Bonga arkia*	Dawro	17
7	*Midasho*	Sidama	29	24	*Ankefuye*	Gurage	24
8	*Gena*	Sidama	30	25	*Enba*	Gurage	20
9	*Gena*	Sidama	30	26	*Gimbo*	Gurage	29
10	*Wundiraro*	Sidama	27	27	*Tikur badadiet*	Gurage	27
11	*Ayase*	Kembata-Tembaro	23	28	*Teriye*	Gurage	23
12	*Sapara*	Kembata-Tembaro	26	29	*Bedade*	Gurage	30
13	*Gishira*	Kembata-Tembaro	22	30	*Sabara*	Gurage	25
14	*Unjame*	Kembata-Tembaro	24	31	*Beneze*	Gurage	20
15	*Disho*	Kembata-Tembaro	25	32	*Mazia*	Wolita	26
16	*Gimbo*	Kembata-Tembaro	28	33	*Halla*	Wolita	29
17	*Tsella*	Dawro	20				

Enset bacterial wilt, caused by *Xanthomonas campestris* pv. *musacearum*, is the most important biotic constraint to enset cultivation (Brandt et al. 1997). In order to alleviate this biotic stress, farmers integrate EXW tolerant landraces in their farms. The *kocho* yield of these disease tolerant landraces is however below average (Yemataw et al. 2012; Yeshitla et al. 2011). Moreover, some enset landraces are known by farmers to have medicinal value for both humans and animals. These landraces are most often poor yielding and are only maintained for special traditional or religious purposes/uses. Those landraces are reported to heal bone fractures, are used for treating diarrhea and during child delivery i.e. assisting the discharge of the placenta. Most reports of medicinal and ritual uses of enset indicate that farmers' intentionally maintain the landraces together with other landraces. For example, Yemataw et al. (2014b) described fourteen enset landraces based on their medicinal and ritual use value. Likewise, Yemataw et al. (2012) reported a number of different enset landraces to have medicinal and religious (ritual) significance for preventive treatment, healing and other therapeutic purposes and as protection against evil spirits. Farmers also categorize enset landraces as male or female based on different characteristics (Yemataw et al. 2014b; Tsehaye and Kebebew 2006; Negash 2001). However, the designation of landraces as 'male' or 'female' is not linked to their reproductive biology. According to farmers, the male enset landraces are drought tolerant. This designation is very important for maintaining landraces for *amicho* use value. Female landraces are described by farmers as less vigorous, susceptible to disease, having a higher *kocho* quality and producing edible and tasty *amicho* (Negash 2001). In addition, they are early maturing and have poor fiber strength. Surprisingly, few landraces have more than one use value. For example, the landraces '*Astara*' and '*Addo*' are known for their *kocho* yield and fiber quality. Similarly, in the Kembata area the landrace '*Siskela*' is maintained by farmers for its high fiber yield and quality in addition to its high *kocho* yield. Studies by Yemataw et al. (2014a); Tesfaye (2008) revealed that in most ethnical groups farmers maintain a single landrace for multiple uses. In some cases, poorly producing landraces continue to be maintained for special traditional (e.g. medicinal value) or religious uses. Farmers often maintain low yielding landraces that have medicinal values (Yemataw et al. 2014a). Similar observations have been made in banana-based communities in Uganda (Gold et al. 2001) or in rice systems in Asia (Witcombe 1996).

Knowledge of the local usage of enset resources is essential for the elaboration of conservation strategies. This is the first time that the use values according to various ethnic groups in the study area have been evaluated in detail for enset. Overall, we found less diverse ethnic variation in knowledge and use values of enset, as has been found for difference within the same ethnic group (Olango et al. 2014; Tesfaye 2008). In general, this study and the previous studies have shown that different ethnic groups in the enset farming system demonstrated the existence of considerable amount of indigenous ethnobotany knowledge. High landrace diversity in a region may indicate extended periods of enset cultivation and a more subsistence form of production.

3.1.3.4 Indigenous knowledge on the management of enset diversity

People in the study area maintain their enset farm with considerable structured planting, diversity and flexibility that support production of this livelihood crop. They have managed to select landraces that adapt the local environment and that give multiple benefits. According to the information we obtained during individual interview, key informant and focus group discussion, management and maintenance of on-farm enset diversity is influenced by: (i) systematic propagation of the landraces, (ii) exchange of planting material (iii) selective pressure.

(i) Systematic propagation of the landraces

Systemic propagation of the landraces is practices used by all farmers in the study area to adjust and to maintain the landrace diversity. Almost all farmers in the study area use corms of 3 to 4 years old enset plants with some portion of the pseudostem to produce enset seedlings (Figure 3.1.6 & Table 3.1.11).

Table 3.1.11. Type of planting materials used by Enset producing farmers

No.	Type of planting material	Frequency(N=320)	Percent
1	Corm	238	73.7
2	Suckers	63	19.5
3	Corm & Suckers	10	3.1
4	Botanical seed	0	0

Almost all respondents indicated that there are three to four growth stages or frequency of transplanting before harvesting (Table 3.1.12). The informants indicated that the propagation starts from the third stages of transplanting (Figure 3.1.6E). Farmers traditionally practiced removal of the central shoot and removal of the apical dominance corms ready for burring (Figure 3.1.6A). Hypothetical question posed in the interviews was what happen if you plant the corm without removal of the central part? The respondents indicated that the removal of the central area helps the propagated corm to produce more number of suckers (≥ 50 suckers /corm) for next season multiplication (Figure 3.1.6B). The first sucker production stage stays one year after emergence from the buried corm (Figure 3.1.6C). In the second stage, the produced multiple suckers from the buried mother corm detached and planted in rows with two to three suckers in a group, or in rows of single plants (Figure 3.1.6D). A consecutive transplanting produces the third stage (Figure 3.1.6E). Farmers' indicated that the third stage is used as both the source of mother corm for sucker multiplication and harvested for consumption when there is less amount of food in the stock. At the end of the third stage, the suckers are transplanted a fourth time to the permanent field (Figure 3.1.6F). The total time required from first planting to harvesting can be around 7–8 years. The propagation usually carried out in the dry season (November to early February). Farmers propagate a diverse landraces available in the farm. Some multipurpose landraces are propagated by the majority of households interviewed.

Table 3.1.12. Local names of the different enset transplanting stages.

Location	1st stage	2nd stage	3rd stage	4th stage
Dawro	Halua	Bashashua	Gardwa	Wossa
Gedeo	Simma	Kassa	Satta	Daggicho
Gurage	Fonfo	Simma	Teket	Hiba
Hadiya	Dubo	Simma	Ero	Weasa
Kembata-Tembaro	Dubo	Simma	Ero	Ballessa
Sidama	Funta	Awulo	Qatalo	Daqicho
Silte	Bosho	Dafaro	Kiniba	Waise
Wolaita	Halua	Bashashiya	Gardwa	Wasa

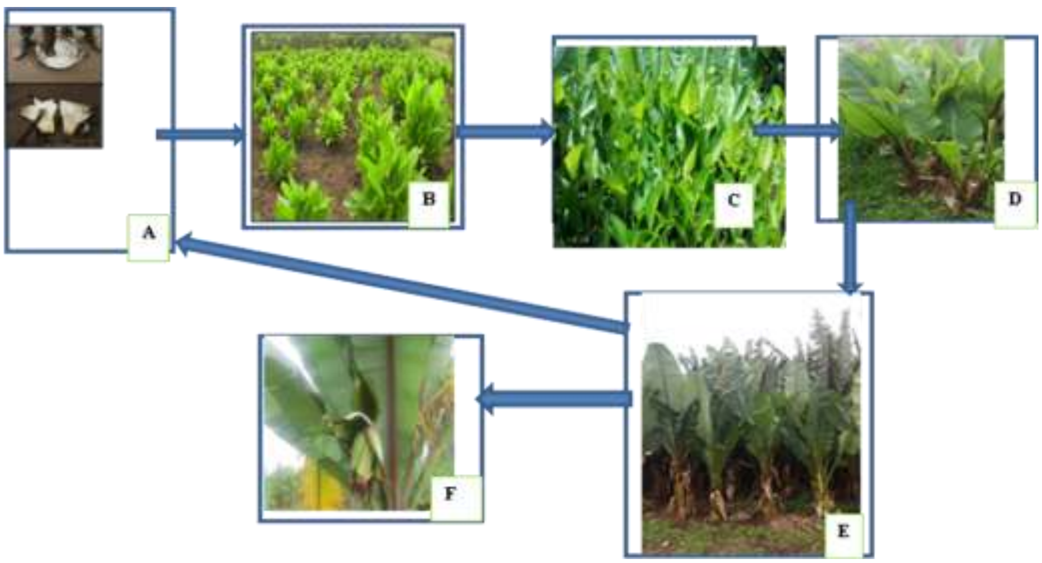

Figure 3.1.6. Systemic propagation of enset. A) mother corm ready for burring; B) suckers emerged from the mother corm; C) 1st stage transplanting; D) 2nd stage transplanting; E) 3rd stage transplanting; F) Matured enset ready for harvesting

(ii) Exchange of planting material

Traditional planting material exchange system is an important source of diversity for majority of farmers. Out of the 320 farmers interviewed 249 farmers use corms from their own farms (Figure 3.1.7). One fourth of the 320 farmers' interviewees mentioned that they often hand out or sell corms/planting material to neighbors or fellow villagers. Neighbors, relatives, and market were the sources of planting material and exchange, gift, purchase and free distribution were the main bases of enset planting material flow. Planting material flow took place inside and outside the village.

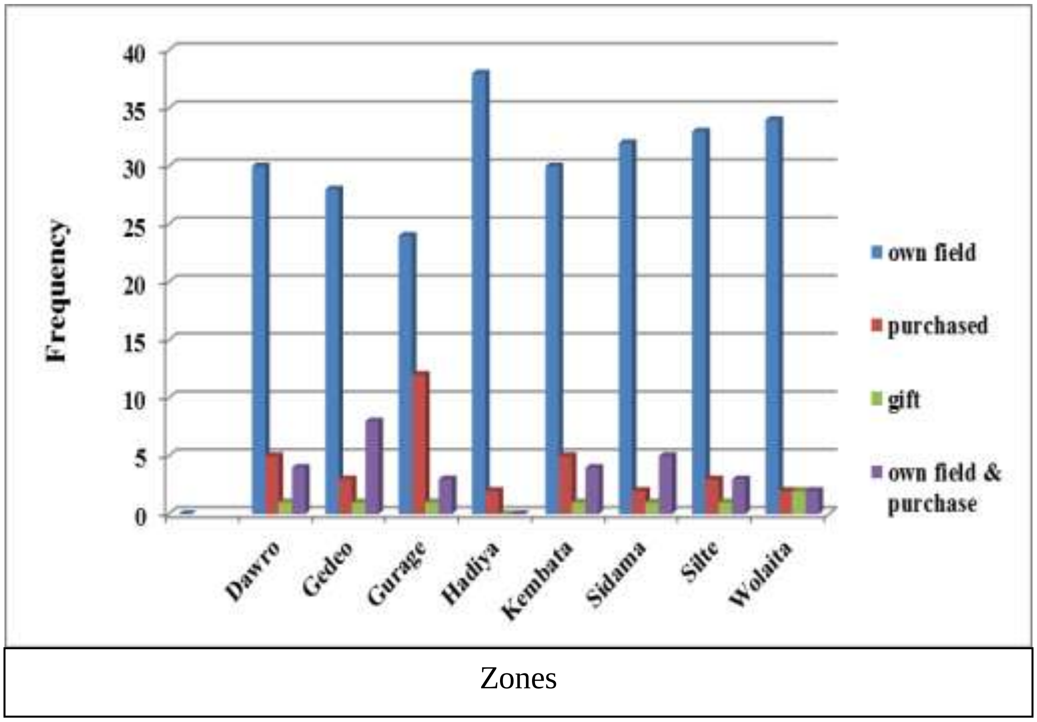

Figure 3.1.7. Source of planting material in the surveyed zones

(iii) Selective pressure

Farmers continue to face many risks because of enset's vulnerability to biotic and abiotic problems, and global climate change. Landraces which perform better under different biotic stress, and diverse agro-ecological conditions, and having multiple uses should be recommended to these subsistence farm households in order to sustain their livelihoods. Almost all informants stated that the population of enset has declined in recent times both in abundance and in distribution. The factors purportedly responsible for this decline were both agriculture and natural (disease and pest and drought) (Table 3.1.13).

Almost all farmers' reported that Enset *Xanthomonas* wilt (EXW) had the greatest impact on enset production. Nearly 36% of farmers reported the existence of EXW in their fields (Table 3.1.13). Each respondent was able to name a significant number of vernacular names though not all landraces are planted and maintained in his or her backyard. Prior to the arrival of EXW, farmers in the region would have selected enset landraces for a number of traits. However; this disease causes complete death of the plant within weeks after the first symptoms and it has completely wiped out enset in some areas. The disease has forced farmers to abandon enset production resulting in critical food shortage in the densely populated areas of southern Ethiopia. It is now recognized as a national problem, having increased in severity.

Table 3.1.13. Most frequently reported enset production constraints in the study area.

Major constraints in enset production	Reported by % of farmers
Enset *Xanthomonas* Wilt	35.9
Enset root mealy bug	34.6
Leaf hopper	19.5
Mole rat	24.7
Porcupine	52.2
Swine	12.4
Corm rot	52.8
Drought	8.9

In the region, farmers' manage local enset landraces within traditional production and processing systems oriented towards meeting household subsistence needs. Both women and men as producers, selectors, processors and marketers of enset are traditionally the custodians of *in situ* conservation. Farmers generally choose planting material from their existing mats. Farmers plant their enset landraces mixed on their fields, usually two or ten, but sometimes up to twenty landraces in one plot. It is traditional to use a corm and sucker as planting material and use of different transplanting stages in enset producing farmers. It was found that many households could propagate enset landraces in at least two ways and this flexibility of propagation might also reflect a relative preference for growing in a large area. A similar observation was also reported in other enset growing areas (Olango et al. 2014; Tsehaye and Kebebew 2006; Negash 2001). However it is yet to be identified whether such variations in propagation have some implications on maintenance of diversity *in situ*. Farmers observe and select the landraces based on their planting intentions for the coming year than the proportion to the quantity they have. This scenario has been maintained by the systematic propagation of 3-4 years old enset landraces. Other study (Olango et al. 2014) revealed that regular propagation and harvesting restrain; organized assemblage and arrangement of landraces in the home gardens and landrace composition regulation in the home gardens have been the major factor for indigenous management and maintenance of enset landraces on-farm. The rich selection experience on indigenous crop such as enset is also applied to other crops like sorghum (Tesfaye 2002).

The number of landraces grown at a given locality, their genetic similarity and the areas they occupy over time and space are influenced by planting material source, exchange and supply. Most planting material exchange is local, though a small proportion extends beyond the local group of villages reflecting relationships among neighbors and kin in most cases. All landraces used in the region are local farmer-named varieties. Among the surveyed farms, most farmers produce their own planting material. In addition farmers in the region have fixed systems to ensure the sustainance of planting material supply for each season. Farmers in cereal based farming system have well-established systems to ensure self-sustaining seed supply system and they often operate the exchange of planting material in the local market (Abebe and Tadesse 1998). In general, on-farm conservation enhances continued source and supply of genetic material and continued diversity-based agriculture as compared to monoculture by ensuring intra-specific and inter-specific diversity of crops. Farmers themselves perceived an advantage in continuing to grow diverse traditional crops and their participation in conservation of a traditional seed system proved to be self-sustaining.

Similarly farmers in the region quite frequently practices grow their landraces in mixture to stabilize their crop production, especially under adverse growing condition. Farmers may retain their preferred landraces over many years, often claiming they received no external inputs of seed/planting material. Plant diseases can also reduce the level of biodiversity or limit the variety of plants grown in an area. It has been observed that, the genetic base has been vulnerable to a range of very damaging biotic and abiotic stresses such as Enset *Xanthomonas* wilt (EXW), enset root mealy bug, leaf hopper, mole rat, Porcupine, wild pigs, corm rot, and drought. It is the EXW which has had the greatest impact on enset production. In Hadiya zone Lemu wereda 30% of enset crop are affected by EXW (Yemataw et al. 2015). Therefore, farmers are forced to develop their copping strategies. Almost all surveyed farmers in the region practice cropping and dietary patterns change and grow more number of disease resistant plants as a strategy for the management of the disease. For instance, Rao and Hodgkin (2002) indicated genetic diversity can be seen as a defense against problems caused by genetic vulnerability. To reduce the likelihood of spread, establishment and growth of EXW in enset crops, a systematic operational approach to the management of EXW should be adopted. This should include giving training to farmers on appropriate production practices, using healthy suckers and planting in clean soils. Future efforts surely need to focus on developing core collections representative of the widest possible genetic diversity for enset improvement and using this to strengthen *in situ* or on farm conservation.

3.1.4 Conclusion

The information collected in the region and presented here shows that a certain wealth and diversity of knowledge regarding traditional naming, uses of plants and diversity management as a part of the cultural heritage of the community. The farmers' knowledge and enset have been coevolving together. This has resulted in the prevalence of rich indigenous knowledge of the farmers. Any attempt to improve the crop needs to take in to account the farmers knowledge and experience. Folk naming and classification are not consistent across all ethnic groups. The inconsistency is highly related with the ethnolinguistic variation in the region. Integrated folk-formal classification and characterization will be imperative for management and utilization of on farm genetic resources. A principal conclusion from the present study is that the biggest uses of landraces, in terms of the number of citations in the literatures, are for *kocho, bulla, amicho*, fiber and medicine. Certain traditional practices (for example spiritual or rituals) also lead farmers to maintain small quantities of uncommon landraces that may not produce well. This scenario points to the importance of use value based and other criteria similarity and differences for landrace diversity maintenance and management. Hence, formal enset improvement program needs to positioned in to multipurpose enset variety development scheme and include farmers and their knowledge in the research-extension continuum. Landrace diversity in the region is affected by a number of factors. EXW is the main factor limiting enset richness and diversity. Any attempt to improve enset has to give empHasis on enhancement of farmers' varieties and a systematic operational approach to the management of EXW. It can be concluded that the existing farmers' knowledge on naming, classification and diversity should be complemented with maintenance of the creative dynamics of traditional knowledge and transmission of the knowledge are crucial for constructing sustainable management.

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3.2 Farmers' knowledge and perception of enset *Xanthomonas* wilt in southern Ethiopia

Abstract

Enset Xanthomonas wilt (EXW) was first reported in 1939 and continues to threaten the sustainability of farming systems in south and southwestern parts of Ethiopia. The present study was conducted in the central zones of southern Ethiopia to assess farmers' knowledge and perception about EXW, its etiology and mode of transmission, and its implications for the management of EXW. A survey was conducted in 240 households across Hadiya, Kembata-Tembaro and Wolaita zones of southern Ethiopia using focus group discussions and a structured questionnaire to assess farmers' perceptions of causes and modes of EXW transmission, and their knowledge on symptom identification. In addition, EXW prevalence, incidence and severity were determined for each zone. Data were analyzed through descriptive statistics. The results showed that a significant number of farmers are aware of EXW, its symptoms, etiology and transmission and spread, but they are not able to readily relate modes of spread to control methods. Since 2002, EXW became prominent in Hadiya, with the highest EXW incidence and severity, followed by Wolaita, and Kembata-Tembaro. Farmers identified EXW as the major cause for declining production and productivity of enset in the region. EXW has spread widely and rapidly in southern Ethiopia, with significant socioeconomic impacts in smallholders' livelihoods. Noticeably, all enset growing farmers must be trained and empowered to decide on a refined practical EXW management recommendations, in particular disinfecting farming and processing tools, keeping fields and surrounding areas free of weeds and volunteer plants (alternative hosts), controlling wild and domestic animals from browsing, use of clean planting materials and strict control of the movement of planting material from one area to other (developing local quarantine). There is a need for developing knowledge-based strategies and awareness-raising campaign for EXW management.

Key words: Enset, Farmer's knowledge , Southern Ethiopia, *Xanthomonas* wilt,

3.2.1 Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a perennial, herbaceous and monocarpic crop belonging to the family Musaceae. Its appearance resembles that of banana, but enset is taller and thicker, with no edible fruits, and is thus named 'false banana'. It is propagated vegetatively from suckers emerging from an underground rhizome (also called the corm). Over time, a sucker develops into a new fruit-bearing plant. It has traditionally ranked as the first in importance as cultivated staple food crop in the highlands of central, south and southwestern Ethiopia, and is also considered as a food security and cash crop. About 302, 143 ha of land is covered by enset crop (CSA 2011), and more than 20% of Ethiopia's population depends upon enset for human food, animal forage, fiber, construction materials and medicines (Azerefegn et al. 2009).

The main food product, known locally as 'kocho', is obtained by fermenting a mixture of the scraped pulp from the pseudostem, pulverized corm and the stalk of the inflorescence. The corm can be harvested at almost any stage of the crop; it can be cooked and consumed in the same way as other root and tuber crops, relieving hunger during periods of critical food shortages. *Kocho* can be stored for a long time without being spoiled. The crop is grown in mixed farming systems, often in association with coffee, multi-purpose trees, and annual food and fodder crops (Brandt et al. 1997).

Despite enset's importance, production and productivity are constrained by several biotic and abiotic factors. Bacterial wilt, caused by *Xanthomnas campestris* pv. *musacearum* is an economically important disease of enset, putting the sustainability of enset farming systems in jeopardy (Yirgu and Bradburry 1968; Ashagari 1985; Tripathi et al. 2009). Up to 80% of enset farms in Ethiopia are infected with enset *Xanthomonas* wilt (EXW) (Mcknight 2013). The disease has forced farmers to abandon enset production resulting in critical food shortage in the densely populated areas of southern Ethiopia (Spring 1996; Tadesse et al. 2003). This disease directly affects the livelihood of more than 20% of farmers in the country.

In Ethiopia, EXW was first described in 1939 (Castellani 1939). Subsequently, the causal agent was described as *Xanthomonas campestris* pv. *musacearum* (Xcm) (Yirgou and Bradbury 1968). EXW is now recognized as a national problem, as it spread quickly to neighboring regions of SNNPR and Oromia and on bananas since its initial discovery on enset. Forty years after its initial discovery in Ethiopia, banana *Xcm* was reported in central Uganda in 2001 (Tushemereirwe et al. 2004), and thereafter the disease rapidly spread and developed into a full-blown epidemic on banana, spreading to neighboring countries, including Tanzania (Mgenzi et al. 2006), the Democratic Republic of Congo (Ndungo et al. 2006), Rwanda (Reeder et al. 2007), Burundi (Carter et al. 2010) and Kenya (Ochola et al. 2014), where it reportedly caused 80 to 100% crop loss, especially in beer bananas (ABB genome). Such losses drastically affected poor and vulnerable farmers who depended on the consumption of the crop and where there are already high or medium levels of food insecurity (Vurro et al. 2010).

EXW invades the vascular system of enset, causing permanent wilting and eventual death of the plant. Primarily, EXW is transmitted via insects, contaminated tools and infected planting materials (Welde-michael et al. 2008). Symptomless enset and / or banana bunches and leaves used to wrap bunches for transport to markets are another important source of *Xcm* inoculum that may be responsible for its long distance spread (Nakato et al 2013). The main symptoms of EXW are wilting and necrosis of leaves and vascular discolouration. Internally, yellowing and/or brown discolouration of vascular bundles can be seen throughout the plant when the plant is sectioned, but this discolouration is often much more apparent in the central tissues of the pseudostem than in the outer leaf sheaths. A cream or yellow-coloured ooze exudes within a few minutes of cutting tissue

(Fig. 3.2.1). Initial symptoms on affected plants vary depending on the point of infection. When Xcm transmission occurs via contaminated garden tools, infected plants display a progressive yellowing of leaves from the leaf tip towards the petioles. Most infected suckers die prematurely (Tripathi et al. 2009; Welde-michael et al. 2008).

Figure 3.2.1. (A) Enset plantation in Hadiya zone, (B) Healthy enset plants with strong pseudostem, (C) Xanthomonas wilt infected enset plant, and (D) Yellow ooze from cut pseudostem.

Control of EXW is challenging, as there are no resistant landracess or effective chemical or biological measures. Sanitation and reducing Xcm transmission are the main measures to manage this disease. Management practices recommended for EXW and BXW include uprooting and discarding infected plants, planting healthy, disease-free plants from less susceptible varieties, disinfecting farm tools after every use, crop rotation, avoiding overflow of water from infected to uninfected fields, removing alternate hosts around plants, and controlling leafhoppers, apHids and mole rats that may transmit *Xcm* (Tadesse et al. 2003; Blomme et al. 2013). However, the most labor-intensive practices may not always be adopted by farmers, and recommendations like burying or burning of infected enset stems has been abandoned by farmers in some enset and banana producing areas ([Hunduma et al. 2015; Kubiriba et al. 2014).

Effective disease management intervention requires a good understanding of disease epidemiology and the pathogen's transmission dynamics in time and space (Bouwmeester et al. 2016; Shaw et al. 2011; Shimwela et al. 2016). Knowledge of the specifics that surround disease development is crucial for identifying risk factors, designing efficient surveillance methods and identifying control strategies (Shimwela et al. 2016). Local farmers can provide substantial information about local diseases and practices to manage the disease as farmers' traditional knowledge is often impressively broad and comprehensive (Thurston 1992). Farmers' knowledge of diseases is well documented on many crops such as cotton (Ochou et al. 1998), rice (Price 2001), beans (Trutmann et al. 1996), and vegetables (Obopile et al. 2008). Similar documentation for enset is scant and not up-to-date. A few studies have documented farmers' perceptions and ethnobotanical knowledge of the enset crop; however, there is no systematic information that explicitly describes indigenous knowledge about EXW in Ethiopia and the impact of farmers' practices on the spread of EXW in Ethiopia. It is therefore important to understand farmer's knowledge about EXW and their perceptions about crop loss. This information could help to guide EXW management practices in a sustainable manner.

The purpose of this study was to investigate farmers' knowledge and perceptions of the cause and spread of EXW, and their indigenous practices in managing EXW. The specific objectives were to (i) identify enset production constraints based on farmers' perception of their importance, (ii) assess farmers' awareness of EXW incidence and severity, and (iii) document farmers' knowledge about EXW, their damage, and indigenous management practices.

3.2.2 Materials and Methods

3.2.2.1 The study area

The SNNPR is located in the south and southwestern part of Ethiopia, 4.43° - 8. 58° N latitude and 34.88° - 39.14° E, bordering Kenya to the south and South Sudan to the west and southwest, and the Oromia region of Ethiopia to the north and east (Fig. 3.2.2). It has a total area of ~ 111,000 square kilometers, lying within elevations of 378 to 4207 meters above sea level. The annual mean temperature is less than 10°C in the extreme highlands and over 27°C in the lowlands. The region is sub-divided into zones, which are organized into woredas/districts. Within woredas, kebeles are the smallest administrative units. This study was conducted in the three zones of SNNPR, namely Hadiya, Kembata-Tembaro and Wolaita, a hot spot for EXW disease (McKnight 2013). Two woredas per zone were selected (Table 3.2.1). In each woreda, two kebeles were selected. Selection of the woredas and kebeles were done in consultation with the zone, woreda and kebele agricultural officers and extension experts based on the enset production records. Twenty households per kebele were selected, which brought the total number of households to 240. The areas selected for the study were those with the highest enset production. Farmers were selected based on their involvement in enset cultivation for at least one cycle (4-6 years) and their willingness to participate in this study.

Table 3.2.1. Description of surveyed woredas and their agro-ecological characterization

Zone	Wereda	Altitude range (masl)	Temp. (^{o}C) range	Annual rainfall range (mm/year)
Hadya	Lemu	1780-2780	15-21	1000-1200
	Misha	1400-2980	21-27	800-1150
Kembata Tembaro	Angacha	1700-3028	15- 24	900-1750
	Doyogena	1900-2800	15-20	1000-1800
Wolaita	Boloso Sore	1800-2900	14 – 25	1100-1500
	Sodo Zuria	1500-2300	14 – 25	1100-1800

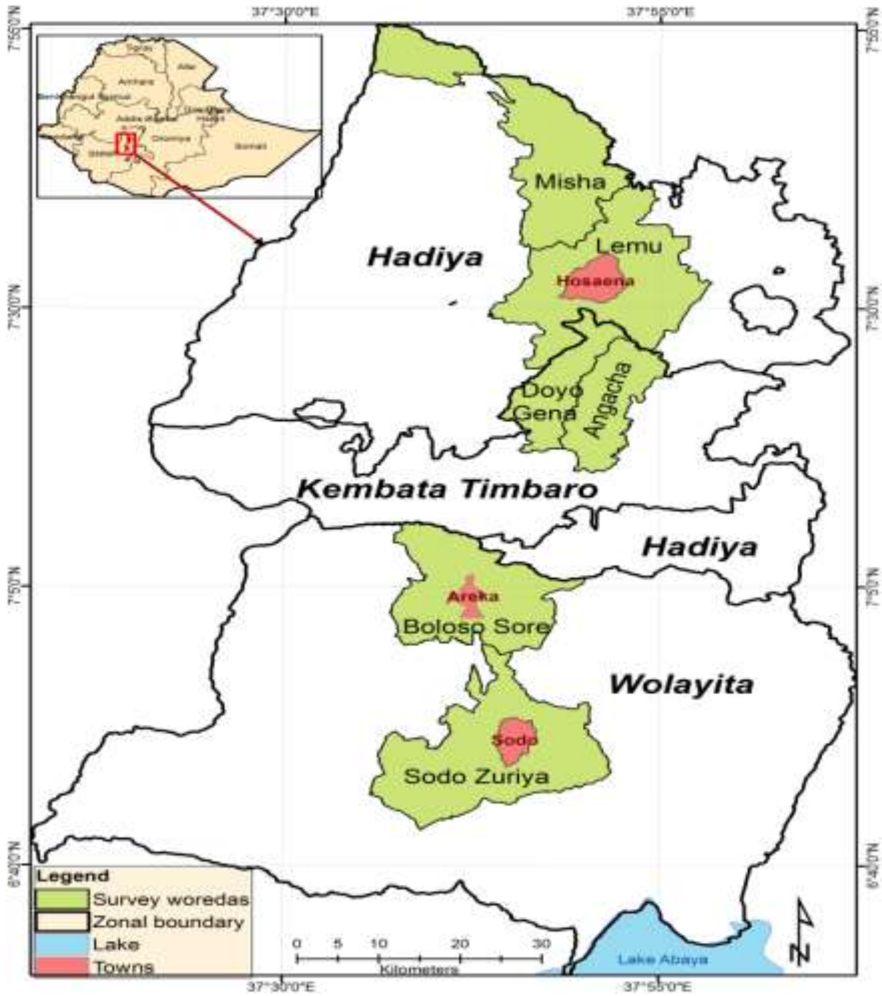

Figure 3.2.2. GeograpHical location of SNNP region of Ethiopia where enset Xanthomonas wilt surveys were conducted in 2015.

3.2.2.2 Baseline survey

A detailed baseline survey was carried out in 240 households in 2015. The questionnaire was pre-tested among the farming community living near to Areka Agricultural Research Center at Wolaita in December 2014, and found to capture the intended data. Surveys were conducted by experienced Areka Agricultural Research teams and well trained agricultural extension officers from woredas in collaboration with international institutes such as the International Livestock Research Institute, and International Potato Center. The data collection was conducted mainly through: (i) individual interviews and direct on-farm participatory monitoring and observation; (ii) key informant and focus group discussion; and (iii) secondary data and literature reviews.

Individual interviews, direct on-farm participatory monitoring and observation

Semi-structured interviews were designed and data were collected with the head of the household or the person responsible for maintenance of the enset plantation. Two hundred and forty farmers were interviewed and data were collected on a farmer's indigenous knowledge about EXW, their perceptions of causes and modes of EXW transmission, means of disease management, and each farmer's knowledge about symptom identification. In addition, information about the study area, landholdings, crops commonly grown and specific information on challenges of enset production were also collected.

Key informant interviews and focus-group discussion

To assess the farmers' indigenous knowledge in each zone, key informants were interviewed, including up to five individuals per kebele, community leaders, local administrations, and Ministry of Agriculture (MoA) officials, and other members in each zone. One focus group discussion was conducted in each of the studied kebele. Each of these 12 focus group discussions consisted of 15-20 people, including enset farmers, model enset farmers, kebele leaders, and development agents.

Secondary data and literature survey

Data sources included the National Enset Research Program and McKnight project progress report (McKnight 2013) as secondary data and personal communication and discussion with elderly people and senior experts in line with knowledge of farmers on EXW. Literature on EXW management was reviewed from published and unpublished sources and reports.

3.2.2.3 Data analysis

Data were analyzed through descriptive statistics (frequencies, percentages, cross-tabulation and means) to generate summaries and tables at zone level using SPSS Ver. 20 software. Chi-squared tests were conducted to test for significant differences between zones for variables: (i) frequencies of households who observed EXW for the first time in their farm, (ii) perceptions on causes and modes of EXW transmission, and (iii) knowledge on symptom identification was calculated. We calculated EXW incidence (number of households with at least one EXW infected plant) and EXW severity (proportion of EXW infected plants per household with EXW infected fields) in 2015 for each zone. Throughout this paper, the term 'household' will be used to refer to a group of persons who normally live and eat their meals together in the same dwelling.

3.2.3 Results and discussion

3.2.3.1 Characteristics of interviewed households

Most (80%) of the interviewed heads of households were men, while the rest (20%) were female household heads who are widows or divorced (Table 3.2.2). Household resource leaders are mostly males as is the case in other enset growing regions (McKnight 2013; Negash 2001; Yemataw et al. 2016) and other African countries (Jogo et al. 2011; Muthoni et al. 2013; Gebru et al. 2017). In all zones, the ages of interviewed heads of households ranged from 24 to 92 years, about 62% of respondent households were within the range of working age (24–65 years old), whereas 38% of them were older than 65 years.

On average, the level of education of the households was found to be high; 56% had completed one form of formal education or the other, while the remaining 44% had no formal education at all. This indicates that more than half of the farmers had at least a primary-level education to understand basic farming practices that can positively affect the adoption of agricultural technologies. Furthermore, farmers’ education could be extended through reading materials such as pampHlets, leaflets, and other aids (Jogo et al. 2011; Kateta et al. 2015). Another study on adoption of modern beehive technologies by smallholder farmers confirmed that there was a positive correlation between education level and adoption of technologies (Yehuala et al. 2013).

Mean family size of households in Wolaita and Kembata-Tembaro zones were similar (7), while that of Hadiya was 8 family member (Table 3.2.2). As pointed out by previous studies (McKnight CCRP 2013; Negash 2001; Yemataw et al. 2016), higher family size of household is a common characteristic in enset growing regions. As family labor increases, it is expected that agricultural activities can also be accomplished on time. On the other hand, large household size may not guarantee increased labor efficiency as school age children are always in school during working periods (Simonyan and Obiakor 2012). Area under enset cultivation was mostly very small, although plantation ages, and years of enset farming experience varied widely among the interviewed households of Hadiya, Wolaita and Kembata-Tembaro zones. Enset farming experience of households ranged from 12 to 70 years, and total land size occupied by a household ranged from 0.15 to 4 ha (Table 3.2.2) , of which enset farm size occupied by enset ranged from 0.01 to 0.4 ha (Table 3.2.2). This suggests that smallholder farmers have allocated their land for different crops to maintain or improve their household food security.

Table 3.2.2. Household characteristics of interviewed farmers from four zones of SNNP region, Ethiopia in January-February of 2015.

Household Characteristics		Zones		
		Hadiya	**Wolaita**	**Kembata Tembaro**
Head of household	Male	68[1]	66	60
	Female	12	14	20
Age (years)		28-70	24-70	32-92
Education (grade)	0	0	3	0
	1-4	52	59	74
	5-8	28	14	6
	9-10	0	4	0
Household size (persons)		4-7	5-8	5-8
Plantation age (years)		2-19	3-21	2-26
Enset farming experience (years)		4-61	6-33	3-34
Total farm size (ha)		0.25-3.50	0.30-4	0.15-3.50
Area under enset (ha)		0.01-0.38	0.01-0.25	0.02-0.63

[1]Household surveyed per zone is 80, see materials and method section for detailed information

3.2.3.2 Enset production trends, constraint and source of planting material

Enset production trends in the last 15 years varied among three zones according to the information collected from sample respondent (Table 3.2.3). About 86%, 81% and 27.5% of respondents from Hadiya, Kembata-Tembaro and Wolaita zones, respectively, reported decreasing enset production. At the same time in Wolaita zone, 40% of respondents reported increasing enset production, whereas 31% mentioned no change in production ($\chi 2 = 75.42$, $P<0.00016$). Farmers also identified various enset production constraints in their locality. The majority of the respondents from Hadiya (88%) and Wolaita (50%) zones believe pests and diseases, especially EXW, to be a major cause for declining production and productivity of enset in the region, while 61.1% of farmers in Kembata–Tembaro zones believe that climate change is the major constraint ($\chi 2 = 80.79$, $P < 0.00034$). Among others, minimal use of good agricultural practices was also cited the most times as an important constraint in Kembata-Tembaro zone, followed by shortage of clean suckers and poor enset value chain. For many years enset was the dominant crop in the SNNPR, while teff, cassava, sweet potatoes, and maize were considered as minor crops (CSA 2016). In the past, people who consumed maize, cassava, sweet potato, potato and taro were considered poor. With the recent outbreak of EXW in the SNNPR, farmers have expanded maize, potato and cassava production, and about 67% of the farmers in the region reduced their consumption of enset due to EXW (McKnight 2013). Moreover, the area under maize, potato, sweet potato, and taro in the SNNPR has increased significantly in recent years (CSA 2016). The same trend was observed in Uganda (Karamura et al. 2006; Karamura et al. 2010) and Tanzania (Shimwela et al.2016).

Table 3.2.3. Farmers perception on the enset production trend, reasons for decreasing production and sources of planting materials among Hadiya, Wolaita and Kembata Tembaro zones of SNNP region of Ethiopia.

Variables	Zones[1]			Chi square test	Chi square *P*- value
	Hadiya (%)	Wolaita (%)	Kembata Tembaro (%)		
Enset production trend since the last 15 years					
Increasing	10	40	8.8		
Decreasing	86.2	27.5	81.2	75.42	1.62E-15
No change	3.8	32.5	10		
Reasons for the decreasing production					
Pest and diseases (EXW%)	88.4 (75)	50(16.5)	12.3(27.5)		
Climate change	11.6	42.3	61.5		
Minimal use of good agricultural practices	0	7.7	21.5	80.79	3.38E-14
Shortage of clean suckers	0	0	3.1		
Poor value chain	0	0	1.5		
Sources of enset planting material					
Research center	0	0	29		
Relatives	12.5	100	0	2.89	1.56E-59
Neighbor	87.5	0	42		
Local market	0	0	29		

[1]% of respondents, total number of surveyed households were 80 per zone

3.2.3.3 EXW prevalence, incidence and severity

The interviewed farmers observed EXW for the first time in different years on their farms (Fig. 3.2.3A), but interventions in terms of EXW control have not been implemented. There are some years where the number of households observing EXW for the first time in their farms was high and vice versa. EXW was observed in four of the interviewed farmers' fields for the first time in 1952 at Hadiya, in one in 1980 at Kembata–Tembaro and in 1981 at Wolaita zone (Fig. 3.2.3B), indicating that the farmers from these zones observed EXW much later than the initial discovery of EXW Castellani (1939) published in 1939. The number of farmers with EXW was very low (2) until 1980, increasing to eight in 1981, ten in 1982, twelve in 1985, and thirteen in 1987 and 1990. During 1991 to 2001, the number of farmers reporting EXW ranged from one to six: only once at Kembata Tembaro, three at Hadiya and seven at Wolaita. All farmers considered 2009 to be the year with the highest EXW prevalence in their area. Since 2002, EXW has become prominent in Hadiya with highest EXW incidence and severity (incidence = 69, severity = 11.4%), followed by Wolaita (incidence = 18, severity = 8.6%), and Kembata–Tembaro (incidence = 6, severity = 4.5%) in 2015 (incidence $\chi 2 = 117.86$, df = 3, $P < 0.00025$, and severity $\chi 2 = 128.6$, df = 3, $P < 0.00013$) (Fig. 3.2.4). The results from this study corroborated previous findings that EXW was most prevalent in Hadiya zone (Wolde et al. 2016; Africa RISING 2014). A previous study (Hunduma et al. 2015) also confirmed that, EXW was the most important constraint in West Shewa zone. A more comprehensive study (McKnight CCRP 2013) in the southern region revealed that on average 28.7% of enset stands were lost due to EXW disease. These levels are high and suggest large potential economic losses if EXW is not controlled. Further studies are required to determine the economic losses due to EXW in Ethiopia.

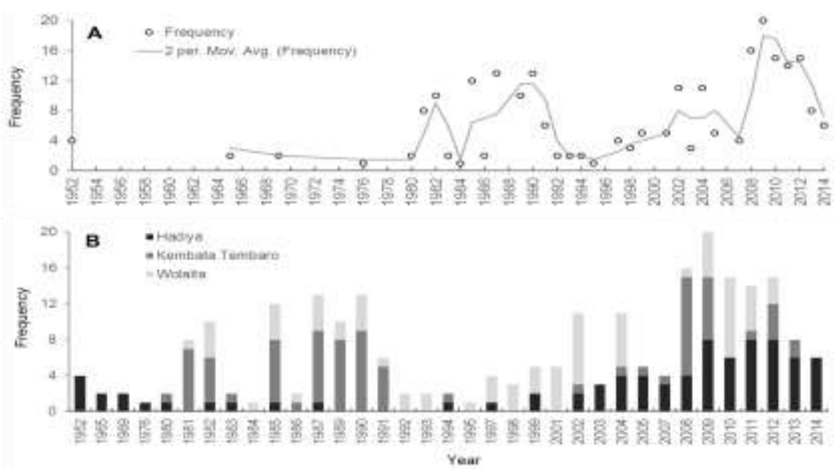

Figure 3.2.3. Number of farmers who observed EXW for the first time in their farm, (A) prevalence of EXW in moving average pattern during 1952 to 2014, and (B) frequency distribution of interviewed farmers during 1952 to 2014 when they observed the prevalence of EXW in Hadiya, Kembata Tembaro and Wolaita zones of SNNPR, Ethiopia.

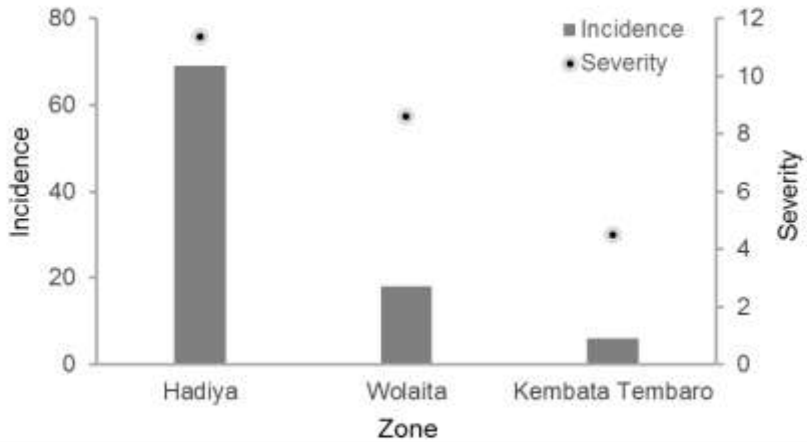

Figure 3.2.4. EXW incidence (number of household with at least one EXW infected plant) and EXW severity (proportion of EXW infected plants /household with EXW infected fields) among surveyed households from Hadiya, Wolaita and Kembata Tembaro zones in 2014-2015.

3.2.3.4 Etiology and means of EXW spread

Most of the interviewed farmers (71%) could identify EXW wilt symptoms. Despite no significant difference in diagnostic capacity, about 59% of households knew leaves yellowing, 40% households knew leaves wilting, and 2% knew the appearance of a pale to yellow ooze from cut pseudostem as a symptom of EXW (data not shown). Most of the respondents (77%) said that contaminated tools, diseased plant debris, animals, animal dung and wind are the etiology of EXW, while nearly 23% said they did not know (Table 3.2.4).

Farmers in the study areas have their own ways of understanding for the means of EXW transmission and spread (Table 3.2.4). Most respondents (70-80%) identified contaminated tools, diseased plant debris, insects and animals as principal means while a minority of the respondents mentioned that animal dung and wind are the major source of EXW transmission and mentioned spread from an external source to the farmers’ fields, and from infected to healthy enset plants. Many farmers know that contaminated farm tools contribute to the rapid spread of Xcm, but recommendations such as the use of disinfectants, use of sterile tools, removal of infected suckers, mat and corms are not practiced in SNNPR, although they are used in Uganda for banana (Kubiriba et al. 2014). Moreover, enset and banana traders who move among farms and harvest with nonsterile tools also contribute significantly to EXW spread. Thus, traders must also be trained to use safe harvesting practices.

Table 3.2.4. Awareness of farmers of EXW etiology, transmission and spread.

Variables	Hadiya (%)	Kembata-Tembaro (%)	Wolaita (%)	Chi square test	Chi square P- value
EXW etiology					
Contaminated farm tools	47.8	33.3	20		
Animal and Insect	11	6.4	10		
Infected leaf left in enset farm	1.2	12.8	27.5		
Wind	0	24.4	13.7	70.8	2.26867E-10
Environmental shock	2.5	3.8	11.2		
Animal dung	0	2.6	3.8		
No idea	37.5	16.7	13.8		
Means of EXW transmission from external source					
Contaminated materials	41	36.25	42.5		
Animal and Insect	20	17.5	28.75		
Animal dung	20	11.25	6.25		
Air	5	5	3.75	30.51	0.002
Farm tools	5	10	5		
Run off	8.75	10	7.5		
No idea	0	10	6.25		
Means of EXW transmission from internal source					
Contaminated materials	70	47.5	53.75		
Animal and Insect	8.75	8.75	5		
Contact between infected and healthy plants	5	15	12.5	17.3	0.068
Air	9	20	18		
Farm tools	3.75	2.5	8.75		
No idea	3.75	6.25	2.5		

The different actions taken by farmers in response to infected plants have their own impacts on EXW dissemination. Most farmers uproot the infected enset plant, and either throw it away or feed it to their livestock. The difference in type of action taken by farmers for infected plant is statistically significant ($\chi^2 = 28.01$, $P < 0.014$) (Table 3.2.5). The destruction of infected plants is labor intensive, and lack of labor was cited by farmers as a major reason for not carrying out

Xanthomonas wilt control practices in Ethiopia and other African countries (Mwangi et al. 2006). In addition, they also believe that droppings from animals that consumed infected plants are the source of inoculum to the healthy ones. It seems farmers are not able to readily relate modes of spread, for example via infected plant, to methods of control. These observations demonstrate the need to develop knowledge-based strategies and an awareness creation campaign for EXW management.

Table 3.2.5. Farmers perceptions on the mode of EXW transmission and their actions on the infected plant

Perception		**Hadiya (%)**	**Kembata-Tembaro (%)**	**Wolaita (%)**	**Total (%)**	**Chi square test**	**Chi square P-value**
Infected enset plant can be cured	Yes	16.2	5	17.5	12.9	6.74	0.34
	No	85.8	95	82.5	87.1		
Use diseased enset for livestock feed	Yes	55.8	14.3	50	36.2	27.57	1.03E-06
	No	44.2	85.7	50	63.8		
Infected enset plant can infect others	Yes	65	9	7	28	48.31	3.2304E-11
	No	35	91	93	72		

Interviewed farmers' perceptions also varied significantly in identifying the progress of EXW symptoms in their farm (χ^2=26.89, P<0.00021) (Table 3.2.6). Most of the farmers believe that Xcm severely attacks enset at all stages of the plant growth. Even though there is little difference in response, nevertheless the majority of farmers believe that the first symptom of EXW is shown in the leaf and it spreads to other parts of the plant, while some farmers from Kembata-Tembaro and Wolaita zones believe the first symptom of EXW appears on shoot tip and moves downwards. This is in line with the previous findings that Xcm can infect enset at any stage of plant growth and EXW symptoms vary also with a plant's phenology and depends on the point of infection (Tripathi et al. 2009; Karamura et al. 2008).

Farmers in the study areas have different beliefs on the seasonality of EXW (Table 3.2.6). The majority of farmers (65%) from Wolaita zone believe EXW is seasonal, and about 50% of farmers from Hadiya and Kembata-Tembaro zones do not believe in the seasonality of EXW ($\chi 2=8.65$, $P<0.013$) (Table 3.2.6). Most of the respondents think dry season is favorable for occurrence and development of EXW. The results from this study corroborated farmer observations in Uganda and Tanzania that BXW symptoms increased and were more noticeable in dry seasons soon after the wet seasons (Tripathi et al. 2009; Karamura et al. 2008; Shimwela et al. 2016). 7, 26]. The incubation period between Xcm infection and EXW symptom development ranges from 2 weeks up to 3 months (Tripathi et al. 2009; Blomme et al. 2007). Some studies have shown that moisture on leaves is an important factor in Xcm survival, establishment and spread on plant (Mwangi et al. 2006). Thus, infection likely took place in the rainy season where the nutirent, hydration and environmental conditions are ideal for growth and development and symptoms appeared in dry season.

Table 3.2.6. Farmers perceptions on the susceptibility of enset plant, EXW progression on plants and seasonality of EXW

Variables	Hadiya (%)	Kembata-Tembaro (%)	Wolaita (%)	Total (%)	Chi square test	Chi square P-value
Age of enset						
< 6 months	20.1	22.5	16.2	19.6		
7-12 months	0	7.5	10	5.8		
1-2 years old	1.2	2.5	8.8	4.2		
2-4 years old	52.5	32.5	37.5	40.8	24.58	**0.017**
Mature	1.2	3.8	2.5	2.5		
Al l stage	7.5	5	1.2	4.6		
No idea	17.5	26.2	23.8	22.5		
First symptom of EXW						
Shoot tip	31.2	58.8	55	48.3		
Leaf	68.8	33.8	43.8	48.8	26.89	**2.10E-05**
Leaf and corm	0	7.5	1.2	2.9		
Seasonality of EXW						
Yes	48.8	42.5	65	52.1	8.65	**0.013**
No	51.2	57.5	35	47.9		
Favorable season for EXW						
Wet season	11.2	6.2	14.3	9.2	2.058	**0.725**
Dry season	37.5	35	35.7	36.2		
Both	51.2	58.8	50	54.6		

3.2.4 Conclusion

In conclusion, EXW has spread widely and rapidly in southern Ethiopia, causing significant socioeconomic impacts in smallholders' livelihoods. Its impacts may include complete crop loss in the field, disease management cost as well as the cost of switching to other crops. Management of EXW should be concentrated towards developing and disseminating control strategies including symptom identification, epidemiology and etiology of EXW, right at the field level. Continued public awareness creation program about the disease is essential. Intensive, harmonized and extended efforts are needed to provide a continuous public awareness towards EXW and developing knowledge-based strategies for its management. Practices, such as leaf removal throughout the year, should be accompanied by tool sterilization. EXW recommendations need to consider what farmers can do, given their resources. Noticeably, all enset growing farmers must be trained and empowered to decide on a refined practical EXW management recommendations, in particular disinfecting farming and processing tools, keeping fields and surrounding areas free of weeds and volunteer plants (alternative hosts), controlling wild and domestic animals from browsing, use of clean planting materials and strict control of the movement of planting material from one area to other (developing local quarantine). Investment in developing and disseminating control strategies would be profitable.

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CHAPTER 4

Assessment of genetic diversity in enset using phenotypic markers

4.1 Morphological variation and inter-relationships of quantitative traits in enset (*Ensete ventricosum* (Welw.) Cheesman) germplasm from south and south-western Ethiopia

Abstract

Enset (*Ensete ventricosum* (Welw.) Cheesman) is Ethiopia's most important root crop. A total of 387 landraces, collected from nine different regions of Ethiopia, were evaluated for 15 quantitative traits at Areka Agricultural Research Centre to determine the extent and pattern of distribution of morphological variations. The variations among the landraces and regions were significant ($P \leq 0.01$) for all the 15 traits studied. Mean for plant height, central shoot weight before grating and fermented squeezed *kocho* yield per hectare per year showed regional variation along an altitude gradient and across cultural differences related to the origin of the collection. Furthermore, there were significant correlations among most of the characters. This included the correlation among agronomic characters of primary interest in enset breeding such as plant height, pseudo stem height and fermented squeezed *kocho* yield per hectare per year. Altitude of the collection sites also significantly impacted the various characters studied. These results reveal the existence of significant Phenotypic variations among the 387 landraces as a whole. Regional differentiations were also evident among the landraces. With regard to utilization of our diverse germplasm of enset, the study as a whole confirmed the presence of considerable quantitative trait diversity which can be exploited in the genetic improvement of the crop. The enormous variation identified will provide breeders with new opportunities for breeding and selection of improved enset genotypes. The implications of the current results important for plant breeding, germplasm collection and *in situ* and *ex situ* genetic resources conservation.

Key words: landraces, Phenotypic variation, *in situ* and *ex situ* genetic resource conservation germplasm, landrace, Phenotypic variation

4.1.1 Introduction

In Ethiopia, the enset-based farming system is a major agricultural system that serves at least one-fourth of country's population. The total area covered with enset crop has more than quadrupled over the past 50 years from ~65,000 ha in the 1960's (Stanley 1966) to ~300,000 ha in 2010 (CSA 2011). The Southern and Oromia regions produce 80% of the crop. The productivity of the crop is very high compared to other root and tuber crops and has the advantage of year round food production, but varies depending on edapHic factors, altitude, cultural practices and varietal differences (Birmeta 2004). Sustained extensive cultivation of enset in Ethiopia reflects the values attributed to every part of the plant, be it for food, fodder, construction or ornamental purposes (Tsegaye et al 2002; Tesfaye 2008; Yemataw et al. 2016).

Enset **(***Ensete ventricosum* (Welw.) Cheesman) is the only species of the genus *Ensete* that is cultivated and consumed as a crop (Brandt et al. 1997). It belongs to the family Musaceae and is a giant herbaceous monocotyledonous plant consisting of adventitious root system and underground stem structure known as corm, a pseudostem which is formed from leaf sheaths that extend from the base of the plant, leaves and inflorescence (Smeds 1955). Ethiopia is both the centre of origin and centre of diversity for enset (Smeds 1955). Enset cultivation has been largely confined to Ethiopia and genetic improvement of this crop is entirely dependent upon characterisation and exploitation of Ethiopian germplasm resources. The main food product, known locally as *kocho* is obtained by fermenting a mixture of the scraped pulp from the pseudostem, pulverized corm and a stalk of inflorescence. The corm can be harvested at almost any stage of the crop, and cooked and consumed in the same way as other root and tuber crops, relieving hunger during periods of critical food shortages. *Kocho* can be stored for a long time without being spoiled (Brandt et al. 1997).

Given the wide geographical range of its cultivation and regional cultural influences, enset domestication has most likely led to extensive genetic variation in “landraces” or landraces. Taboge (1997) found large variability in most of the characters assessed on 79 enset landraces collected from various parts of the country and Bekele et al. (2013) distinguished and described 120 distinct enset landracess that fall into 11 broad clusters differing in maturity time, plant height, pseudostem height, pseudostem circumference, leaf number, leaf sheath number, grated corm and *bulla* and fiber yield. Similarly, other studies (Yemataw et al. 2012 and 2014; Yeshitla 2014) showed substantial Phenotypic variation in enset germplasm for pHenologic, morpHologic and agronomic traits. To date, six improved enset varieties have been released from direct selection from farmers' varieties (Yeshitla and Yemataw 2012).

The genetic diversity, which has been collected from different parts of the country, has been conserved *ex situ* in the gene bank of Areka Agricultural Research Centre (Yeshitla and Yemataw 2012). However, the value of conserved germplasm in the bank depends on the information generated through characterization and evaluation for different traits (Fig 1) (Blair et al. 2010). Several authors have empHasized that it is important that gene banks have detailed descriptors of morphological characterization and extent of genetic diversity to provide an essential foundation to explore the genetic variability in breeding programs (Bhullar et al. 2009; Freitas et al. 2010). Frankel and Brown (1984) also stated that genetic resource activities have got three pHases *viz*. first empHasizing biogeography, taxonomy, and evolution; second conservation; and the third, utilization of germplasm. However, none of these phases has been accomplished satisfactorily in enset.

To estimate and preserve the genetic variability of enset in Ethiopia, a gene bank was established in 1986 at Areka Agricultural Research Centre, Ethiopia. Attempts have been made to collect and preserve all the possible enset germplasm in Ethiopia and currently comprises 623 enset landraces from 12 major enset growing areas of Ethiopia. As key objective of the National Enset Research Project, is to better understand and effectively utilize enset germplasm. The present study has undertaken detailed morphological characterization of part of the collection (based on the availability of planting material), with the objective of accessing the extent and pattern of distribution of morphological variation for quantitative characters among a large number of enset landraces.

4.1.2 Materials and methods

4.1.2.1 Description of the study site

Enset landraces were evaluated at the Areka Agricultural Research Centre, 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 Centre is located at 7^0 09' N latitude and 37^0 47' E longitude at an elevation range of 1750 to 1800 m above sea level (ma.s.l). The soil is silt loam 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 1539 mm, and minimum and maximum mean temperatures were 14.5^{o}C and 25.8$^{°C}$, respectively. Thus, the weather conditions were within the normal range for the growth and development of enset crop in the study area.

4.1.2.2 Plant materials and study design

The plant materials used for this study consisted of 387 landraces obtained from a single mother corm, of which 381 were enset landraces derived from nine different regions (Table 4.1.1) and six standard controls (released varieties) (Yanbule, Gewada, Endale, Zereta, Kellisa and Messena) (Yeshitla and Yemataw 2012) conserved *ex situ* by the Southern Agricultural Research Institute of Agricultural Research at Areka.

Based on the altitude at the collection site, the 387 landraces were divided into four sets. These were: (i) 44 lowland landraces (<2000 ma.s.l), (ii) 138 intermediate landraces (2001–2400 ma.s.l) (iii) 178 highland landraces (2401–2800 ma.s.l) (iv) 27 extreme highland landraces (>2800 ma.s.l). Mean data of the landraces including the regions and altitudes of collection, and the vernacular names are summarized in Appendix 3.

The experiment was carried out in an augmented block design (Federer 1956) consisting of three blocks in which the 381 landraces were planted in un-replicated plots and the six standard checks were replicated three times (once in each block) to estimate error variance. Eight suckers of each of the 387 landraces were planted in two rows with intra and inter-row spacing of 3m and 1.5m, respectively. All pre- and post- stand establishment management practices were performed as per Diro and Tsegaye (2012).

Table 4.1.1. Regions of origin, altitude and numbers of landraces used for this study.

Collection region or altitude zone	Total no. populations
Region	
Kembata & Hadiya	78
Dawro	55
Gamogoffa	45
Wolaita	36
Sidama	41
Gurage	37
Yem special woreda	40
West & SW Shewa	32
Kaffa	23
Altitude zones	
≤2000 ma.s.l	44
2001-2400 ma.s.l	138
2401-2800 ma.s.l	178
>2800 ma.s.l	27

4.1.2.3 Quantitative traits and data recording

Data were collected for a total of 15 important quantitative (metric or count) pHeno-morphological and agronomic traits (Table 4.1.2). All the traits were measured based on published procedures (Taboge 1997; Yemataw et al. 2012), from the middle four plants of each landraces.

4.1.2.4 Statistical analysis

We evaluated the germplasm using Augmented Incomplete Block design with six standard check varieties viz. Yanbule, Gewada, Zereta, Kellisa, Endale and Messena in three blocks. For all the traits assessed on individual plants, the means of the 4 sample plants from each plot were used for analyses. All statistical analyses were done using SAS software (SAS 2004). Data were analyzed using the restricted maximum likelihood (REML) model to fit a mixed model with standard controls as a fixed effects and non-replicated landraces as random effects (Comadran et al. 2008). The standard controls were used for estimating error variance in mixed models. The REML model produced best linear unbiased predictors (BLUPs), which can handle unbalanced data while accounting for differences in the amount of data available for each landraces (Etten et al. 2008). A mixed model procedure was employed to fit analysis of variance of the form: $Y_{ij} = \mu + L_i + ß_j + e_{ij}$

where: Y_{ijk} is response variable, μ is general mean, L^i is the fixed effect of i^{th} standard checks and random effect of landraces, $ß_j$ is the random effect of the i^{th} block, e_{ij} is the random errors.

Analysis of variance for the region was made for 15 quantitative characters as described by Pecetti and Damania (1996). The mean squares of the nine regions were tested against pooled mean squares of landraces within regions. The pooled means squares for landraces within regions of origin and the mean squares of landraces within each region were tested against the pooled within region error mean squares. Means, ranges of means and percent coefficient of variation (computed as a ratio of standard deviation of each character to the corresponding entire data mean and expressed as percentage) for all the characters were computed for each region of origin and for the entire data. The regional means were compared using Duncan's multiple range testing (Ayana and Bekele 2000).

Pearson correlation coefficients between the characters were computed at three levels following published procedures (Bekele 1984; Thorpe 1976; Ayana and Bekele 2000). First correlations of all the characters were assessed based on the mean of the 387 enset landraces, then the correlation between regions was computed using the means of characters for each region. Lastly, a series of intra-region correlation coefficients were obtained for each region using the accession means from that region for the characters.

Table 4.1.2. List of quantitative characters recorded in the study.

Quantitative trait	Code	Description
Maturity time	MT	Number of years from transplanting up to harvesting.
Plant height (m)	PLHT	Measurement from ground level to the tip of the longest leaf at flowering.
Pseudostem height (m)	PSHT	Measurement from ground level to the start of the petioles.
Pseudostem circumference (m)	PSCIR	Measurement at the middle height of the enset pseudostem.
Leaf number	LFNO	The number of 50% green and 50% unrolled leaves.
Leaf length (m)	LFL	Measurement of all functional leaves from the end of the petiole to the tip of the leaf and their mean was taken for analysis.
Leaf width (m)	LFWTH	Measurement of the widest part of all functional leaf blades just below flag leaf and their mean was taken for analysis.
Leaf sheath number	LFSTH NO	Count of all decorticable leaf sheathes obtained from each plant at harvest.
Leaf sheath weight before decortication (kg)	LFSTH BD	The weight of all leaf sheathes for each plant before decortication and measured before decortication
Leaf sheath weight after decortication (kg)	LFSTH AD	Weight of pulp for each plant after decortication and measured after decortication.
Central shoot weight before grating (kg)	CSBG	The weight of central shoot after the inflorescence removed measured before grating.
Corm weight before grating (kg)	CORM BG	The weight of corm measured after fibrous root removal and prior to grating.
Unfermented *kocho* yield per hectare per year	UFK	*Kocho* yield comprising the mixture of decorticated leaf sheath, grated central inflorescence bearing shoot and corm immediately after processing.
Fermented unsqueezed *kocho* yield per hectare per year	UNSQK OCH	The unfermented *kocho* yield is left in the pit for some time usually 30 days for fermentation.
Fermented squeezed *kocho* yield per hectare per year	SQKOC HO	The fermented *kocho* yield was squeezed by applying human force to reduce its water as much as possible.

4.1.3 Results and Discussion

4.1.3.1 Univariate statistics

The analysis of variances indicated significant difference ($P \leq 0.01$) among landraces, controls (Standard checks), and landraces *versus* controls for 13 of the 15 quantitative characters assessed; maturity time, plant height, pseudostem circumference, corm weight before grating, and leaf sheath number in landraces (tests) *versus* controls, and pseudostem circumference in controls were not significant (Table 4.1.3). These data indicate a high level of morphological variation in Ethiopian enset landraces within each region that could be exploited through breeding programmes (Fig. 4.1.1).

For example, the variation for maturity time offers greater flexibility for developing improved varieties suitable for various agro-ecologies of the regions that differ in growing period length. Similarly, there is potential to develop early maturing variety by improving traits that correlate to days to maturity. This study detected high levels of variation among landraces in regions of origin based on quantitative characters. The detected morphological variation in enset landraces is strongly influenced by environmental factors. Although morphological diversity in enset has been previously reported (Taboge 1997; Yemataw et al. 2012; Yeshitla 2014), by assessing 15 traits *via* a statistically robust experimental design, this study is the most comprehensive and detailed to date.

Analysis of variance revealed that there were significant differences ($P \leq 0.01$) among the nine regions of origin of the 387 enset landraces for all characters studied (Table 4.1.4). The results suggested the occurrence of significant regional differentiation and existence of significant Phenotypic variation among the landraces as a whole. Region-wise separation of the variance indicated additional significant within-region differences ($P \leq 0.01$) among the populations within Kembata & Hadiya, Gamo Gofa, Wolaita, Sidama, Kaffa, Gurage, Yem special woreda and West & South-West Shewa for all the 15 characters, and for 14 characters within Dawro (Table 4.1.4).

Characters which are important for farmers, and used as a selection criterion showed relatively high Phenotypic variance. For instance, the within region variation in leaf sheath number, central shoot weight before grating, leaf sheath weight before decortication, fermented unsqueezed *kocho* yield per hectare per year, fermented squeezed *kocho* yield per hectare per year was greater than plant height, pseudostem height, pseudostem circumference for all the regions.

Assuming a significant portion of the underlying Phenotypic variation has a genetic basis, it would be possible from a breeding perspective to select for any of the first group of characters within a particular region. It was understandable that between regions variance was greater than between landraces pooled over regions and the latter was greater than that between landraces in some regions. Since significant variation was found between regions and between landraces within regions, it would be necessary to collect material from as many regions as possible and to adequately sample the potential local population variation within regions.

Table 4.1.3. Analysis of variance of 15 quantitative traits

Source	DF	MT[a]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO	LFSTHBD
Block	2	2.84***	1.32***	0.05 *NS*	0.09 *NS*	8.01***	16.73***	0.29***	32.7***	11484***
Landraces	386	4.33***	3.92***	0.51***	0.92 ***	14.08 ***	1.42 ***	0.04***	57.8***	3789***
Test (Landraces)	380	4.29***	3.92***	0.51***	0.93 ***	14.02 ***	1.42 ***	0.04***	58.3***	3809***
Control (Standard checks)	5	7.95***	4.43***	0.59***	0.23 *NS*	19.87***	1.81***	0.02***	36.6***	2478***
Tests vs Controls	1	0.05*NS*	0.15*NS*	0.18***	0.002 *NS*	13.02 ***	6.59 ***	0.21***	0.68 *NS*	7515***
Error	10	0.06	0.36	0.19	0.83	1.09	0.29	0.08	1.88	12.74
CV		5.67	6.75	11,18	70.1	10.55	8.48	12.2	9.68	19.83

[a] See the materials and methods section for the abbreviations of the characters; *NS*: not significant; *: significant at *P*≤ 0.5 (5%); ***: and significant at *P*≤ 0.01(0.1%)

Table 4.1.3. Continued

Source	DF	LFSTHAD[a]	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
Block	2	2832.7***	74.87***	88.09***	119.6*	185.00***	70.4***
Landraces	386	882.68***	160.9***	682.3***	1206***	186.30***	90.9***
Test (Landraces)	380	888.01***	162.4***	672***	1213***	187.60***	91.2***
Control (Standard checks)	5	545.37***	57.97***	1597***	904.9***	118.60***	86.6***
Tests vs Controls	1	1334.5***	161.2***	28.62*NS*	342.6***	168.60***	86.0***
Error	10	5.94	2.95	4.52	5.19	2.37	1.85
CV		19.02	17.98	16.12	14.18	15.64	17.6

[a] See the materials and methods section for the abbreviations of the characters. *NS*: not significant; *: significant at *P*≤ 0.5 (5%); **:, ***: and significant at *P*≤ 0.01(0.1%)

Table 4.1.4. Analysis of variance for 9 regions based on 15 quantitative characters in enset germplasm

Source	DF	MT[a]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO
Region	8	16.38***	12.95***	0.34***	0.13***	8.79***	1.07***	0.02***	49.4***
Pooled landraces within region	378	0.84***	0.75***	0.12***	0.05***	3.45***	0.3***	0.01***	14.01***
Landraces within									
Kembata & Hadiya	77	4.09***	2.96***	0.49***	0.11***	15.49***	1.19***	0.03***	31.73***
Dawro	54	4.88***	4.29***	0.62***	0.24***	13.61***	1.81***	0.05***	118.86***
Gamogoffa	44	3.73***	3.51***	0.67***	0.32***	9.87***	1.15***	0.03***	29.04***
Wolaita	35	4.28***	3.50***	0.27***	0.17***	17.54***	1.35***	0.03***	42.30***
Sidama	40	3.44***	2.14***	0.22***	0.19***	13.86***	0.86***	0.04***	31.36***
Gurage	36	2.53***	2.50***	0.26***	0.13***	8.75***	0.90***	0.02***	137.33***
Yem special woreda	39	1.61***	3.44***	0.45***	0.15***	8.93***	0.94***	0.01***	45.69***
West & SW Shewa	31	1.44***	1.03***	0.79***	0.14***	18.40***	1.31***	0.02***	41.24***
Kaffa	22	1.86***	2.48***	0.30***	0.38***	20.47***	0.98***	0.05***	17.50***

[a] See the materials and methods section for the abbreviations of the characters; significant at $P \leq 0.01(0.1\%)$

Table 4.1.4. Continued

Source	DF	LFSTHBD[a]	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
Region	8	2832.22***	732.93***	170.84***	255.97***	2831.53***	233.82***	125.33***
Pooled landraces within region	378	741.37***	176.87***	37.68***	162.74***	223.7***	38.61***	19.38***
Landraces within								
Kembata & Hadiya	77	3457.22***	827.10***	103.72***	675.21***	1289.52***	195.17***	83.93***
Dawro	54	3262.67***	1030.80***	158.48***	657.74***	1016.38***	133.44[NS]	96.93***
Gamogoffa	44	2549.44***	552.37***	290.40***	839.27***	732.30***	126.14***	63.82***
Wolaita	35	2307.94***	451.31***	102.54***	377.69***	971.23***	190.72***	79.39***
Sidama	40	3020.00***	636.33***	111.05***	811.09***	1271.21***	295.42***	150.18***
Gurage	36	2400.18***	794.97***	89.20***	607.69***	1207.37***	200.91***	100.59***
Yem special woreda	39	3239.8***	698.68***	146.53***	355.21***	360.11***	34.45***	27.87***
West & SW Shewa	31	2211.52***	372.71***	107.49***	413.04***	105.55***	55.71***	36.89***
Kaffa	22	3794.08***	692.86***	335.26***	895.62***	256.46***	79.36***	45.43***

[a] See the materials and methods section for the abbreviations of the characters; *NS*: not significant; significant at $P \leq 0.01(0.1\%)$

Figure 4.1.1. Agro-morphological characterization activity at Areka Agricultural Research Center. A, B & C: Typical arrangement of landraces for pHenotyping; D-H Example of morphological variation in pseudostem colour; I-M: Example of morphological variation in petiole colour.

The Duncan's multiple range testing for regional means over all the characters is shown in Table 4.1.5. Notably, much more regional differentiation was observed for plant height, central shoot weight before grating, unfermented *kocho* yield per hectare and fermented squeezed *kocho* yield per hectare per year. More diverse zones favoured the development of different quantitative traits. Landraces from Kembata and Hadiya and Sidama zones showed superior plant height and flowered significantly earlier than those from other regions. The means for number of days to flowering for the landraces from the West and South West Shewa were significantly higher than those from the other regions ($P \leq 0.05$). The highest mean number of leaves per plant was also observed for the West and South-West Shewa landraces. This can be explained by the longer the duration of induction of floral primordia, and more enset leaf formation (Taboge 1997).

Landraces from Dawro, Gamogofa and Wolaita are inferior in *kocho* yield. Landraces from Sidama are characterized by vigorous plants; being superior in plant height, pseudostem height, pseudostem circumference, leaf length and leaf width. It is a common scenario to observe Sidama farmers feeding their animals with enset leaves. The mean leaf sheath number, leaf sheath weight before decortication (a trait directly related to yield) was high for landraces from Gurage, West and South-West Shewa and Yem special woreda, though this was not statistically significant compared with most of the rest of the regions.

The landraces from Kembata and Hadiya and Sidama zones were not significantly different from each other for all the characters studied. Thus, the landraces from Kembata and Hadiya and Sidama could be a good source of early flowering and plant height genes for which there is an urgent need in Ethiopia. Early flowering traits are particularly important for enset production in lowland areas where there is a limited amount of rainfall and a short growing season.

In general, landraces from Yem special woreda and West and South-West Shewa were characterised by tall pseudostem height and late maturity time. On the other hand, landraces from the other regions were characterised by short pseudostem height and early maturity time, suggesting the possibility of obtaining genes for early flowering and short stature from these landraces. It has been previously speculated that cultural differences have impacted enset selection (WestpHal 1975; Brandt 1997; Tsegaye 2002) and we suggest that this is reflected in these regional Phenotypic differences.

Table 4.1.5. Regional means for 15 characters in enset

Region	**MT**[*]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO
Kembata & Hadiya	3.98d	5.71ab	1.76b	1.16b	10.36b	3.49ab	0.65ab	19.43abc
Dawro	4.54c	5.32bc	1.68b	1.19ab	9.98b	3.24bc	0.67ab	20.16ab
Gamogoffa	4.57c	5.31bc	1.72b	1.18ab	10.07b	3.27bc	0.65ab	17.73c
Wolaita	4.11c	5.13c	1.61b	1.13b	10.34b	3.24c	0.65ab	17.99c
Sidama	3.82d	5.79a	1.78ab	1.11b	10.08b	3.51ab	0.69a	18.35bc
Gurage	3.82d	5.45abc	1.64b	1.18ab	10.22b	3.34bc	0.62b	20.24a
Yem special woreda	5.33ab	5.39abc	1.72b	1.27a	10.51b	3.43ab	0.66ab	20.4a
West & SW Shewa	5.56a	4.41d	1.94a	1.28a	11.62a	3.68a	0.68a	20.68a
Kaffa	5.02b	3.77e	1.62b	1.18ab	10.72b	3.12c	0.66ab	18.96abc

[*] See the materials and methods section for the abbreviations of the characters.

Means of each character followed by the same letter were not significantly different at $P \leq 0.05$ (5%) according to Duncan's multiple range test.

Table 4.1.5. Continued

Region	LFSTHBD[*]	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
Kembata & Hadiya	69.74a	30.06ab	15.41cd	28.91ab	43.18a	16.24a	10.51cde
Dawro	63.36ab	30.97ab	16.23bcd	26.71ab	35.49bc	12.17b	8.94de
Gamogoffa	50.17b	23.78c	14.91cd	27.48ab	33.86c	12.2b	8.32e
Wolaita	51.38b	24.27c	13.7d	24.27b	35.31bc	13.38b	8.79de
Sidama	60.01ab	28.67bc	15.17cd	25.9b	41.28ab	16.57a	10.96bcd
Gurage	62.17ab	29.42abc	15.93bcd	25.02b	45.85a	16.7a	11.68bc
Yem special woreda	71.1a	35.76a	18.83ab	29.63ab	23.07d	12.39b	9.38de
West & SW Shewa	71.85a	34.91ab	20.77a	33.02a	25.47d	17.37a	13.03ab
Kaffa	54.13b	29.71abc	17.27bc	27.91ab	23.81d	18.11a	13.79a

[*] See the materials and methods section for the abbreviations of the characters.

Means of each character followed by the same letter were not significantly different at $P \leq 0.05$ (5%) according to Duncan's multiple range test.

4.1.3.2 Range and coefficient of variance

The minimum and maximum values of the accession means demonstrated a wide variation between the regions and the landraces within the regions for the characters studied (Table 4.1.6). Of note were the large differences between the genotypes in years to flowering. Among the landraces studied, *Azenora* was found to be the earliest (2.1 years) while *Hasa-badadea* was the late maturing (6.3 years) (Appendix 3). Traits varied from 3 to more than 20-fold. For example, plant height varied more than 3-fold, from 2.14 to 7.71 m; as did number of leaves per plant which ranged from 5 to 17; leaf sheath number ranged from 11 to 48; leaf sheath weight before decortication from 10 to 200 t ha^{-1} yr^{-1}; leaf sheath weight after decortication from 3.0 to 85.0 t ha^{-1} yr^{-1}; fermented unsqueezed *kocho* yield per plant from 1.88 to 42.3 t ha^{-1} yr^{-1}; fermented squeezed *kocho* yield per plant from 1.26 to 25.14 t ha^{-1} yr^{-1}. Differences between maximum and minimum values for other characters were also large. The wide range in each of the traits studied offers broad opportunities for selecting parents of interest in breeding programs to develop varieties suitable for different agro-ecologies of the country and for different purposes. The broad range noted in pHenology as illustrated by maturity time (2.1 to 6.37 year) for example, offers great flexibility for developing varieties suitable for different agro-ecological zones of the country that greatly differ in the length of the growing period and/or for use in various cropping systems. Likewise, the variation in plant height, pseudostem circumference and number of leaf sheaths per plant (Table 4.1.6) indicates promising prospects for increasing *kocho* yield in enset. These results support previous studies (Taboge 1997; Yemataw et al. 2012) that Ethiopia, with its unique geograpHic and climatic features, possesses a tremendously high degree of morphological variation for enset.

In the present study, high coefficients of variation were observed between regions and within each region for central shoot weight before grating, leaf sheath weight after decortication and corm weight before grating (Table 4.1.7).

Notably, landraces from Gurage, Gamo Gofa, Sidama and Yem special Woreda were relatively more variable, demonstrating the tremendous trait variability of within regional enset landraces. Interestingly, the landraces from Kembata and Hadiya, Kaffa and Dawro had relatively low coefficients of variation for many characters, indicating relatively high within region uniformity. The different levels of regional variability of a particular character could be due to differences in natural adaptive selection, a specific selective force, or reflect the impact of human selection. Similar results were reported in tetraploid and hexaploid wheats (Bekele 1984) and in tetraploid wheat (Pecetti and Damania 1996).

Analysis of the diversity pattern among the enset landraces revealed considerable morphological variations between and within regions. Our results also provided scientific evidence for the occurrence of significant geograpHical variation and corroborated the idea that regions have high variation for enset in Ethiopia. The overall patterns of similarity or difference between regions seemed to depend on environmental factors such as rainfall, temperature, length of growing season and altitude. Similar results have been reported in barley (Negassa 1985; Demissie and Bjørnstad 1996) and tef (Ketema 1997; Assefa et al. 2001).

Table 4.1.6. Range of landraces means for 15 quantitative characters in enset germplasm by region of origin

Region	**MT**[a]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO
Kembata & Hadiya	2.07 - 6.00	3.92 - 7.61	1.08 - 2.86	0.75 - 1.55	5.00 - 14.50	2.04 - 4.67	0.42 - 0.93	13.50 - 26.50
Dawro	2.5 - 6.02	2.29 - 7.35	0.96 - 3.61	0.54 - 1.66	4.96 - 14.50	1.05 - 4.62	0.33 - 0.91	11.00 - 37.00
Gamogoffa	2.3 - 5.95	2.89 - 7.15	0.97 - 2.84	0.78 - 2.00	6.00 - 13.20	2.23 - 4.40	0.43 - 0.86	12.00 - 23.00
Wolaita	2.4 - 5.88	3.32 - 7.09	1.09 - 2.11	0.83 - 1.56	6.50 - 17.00	1.72 - 4.32	0.43 - 0.87	13.00 - 25.50
Sidama	2.32 - 5.78	3.68 - 7.26	1.29 - 2.16	0.80 - 1.59	6.25 - 14.50	2.41 - 4.51	0.48 - 0.94	13.00 - 25.50
Gurage	2.71 - 5.73	3.01 - 6.77	1.00 - 2.09	0.86 - 1.58	8.00 - 12.75	2.43 - 4.24	0.42 - 0.78	12.50 - 48.50
Yem special woreda	3.62 - 6.37	4.15 - 7.71	1.11 - 2.46	0.89 - 186	7.00 - 13.25	2.43 - 4.68	0.56 - 0.82	12.00 - 27.75
West & SW Shewa	3.06 - 5.99	3.51 - 5.30	0.89 - 3.17	0.84 - 1.57	8.25 - 16.25	2.01 - 4.69	0.52 - 0.80	12.50 - 25.50
Kaffa	3.71 - 5.98	2.14 - 5.01	1.14 - 2.33	0.58 - 1.81	7.50 - 17.00	2.17 - 4.20	0.33 - 0.84	15.70 - 22.25

[a] See the materials and methods section for the abbreviations of the characters.

Table 4.1.6. Continued

Region	LFSTHBD[a]	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
Kembata & Hadiya	20.46 - 200.63	11.96 - 84.88	6.46 - 29.12	4.96 - 69.46	11.98 - 95.47	5.08 - 40.25	3.20 - 23.17
Dawro	9.96 - 137.30	2.96 - 84.24	1.96 - 32.38	6.46 - 62.96	7.06 - 69.57	1.88 - 26.98	1.26 - 20.12
Gamogoffa	13.71 - 127.21	7.46 - 66.96	5.96 - 60.46	8.21 - 72.46	10.49 - 83.52	3.28 - 30.65	1.72 - 21.27
Wolaita	11.96 - 110.46	5.46 - 48.96	3.96 - 26.96	10.46 - 46.46	8.40 - 72.17	2.56 - 34.08	1.52 - 21.20
Sidama	25.21 - 143.96	12.71 - 63.96	7.96 - 29.96	7.46 - 87.96	20.27 - 82.84	5.82 - 42.30	2.82 - 25.14
Gurage	32.96 - 133.71	10.71 - 60.96	7.46 - 28.46	9.46 - 74.46	17.23 - 96.96	6.97 - 33.94	4.25 - 24.55
Yem special woreda	27.71 - 151.88	16.21 - 71.55	8.76 - 39.71	12.85 - 65.21	11.65 - 54.46	7.04 - 20.35	4.78 - 16.34
West & SW Shewa	22.51 - 116.11	13.71 - 50.06	8.71 - 32.21	16.14 - 67.96	16.71 - 40.92	10.65 - 27.19	7.90 - 19.78
Kaffa	20.49 - 131.96	12.34 64.80	7.55 - 44.46	13.47 - 67.29	11.21 - 47.13	12.42 - 27.15	9.21 - 20.15

* See the materials and methods section for the abbreviations of the characters.

Table 4.1.7. Percent of coefficients of variation for 15 quantitative characters in enset germplasm by region of origin

Region	**MT**[a]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO
Kembata & Hadiya	25.34	15.00	19.67	14.13	18.89	15.51	14.63	14.23
Dawro	24.61	19.64	23.62	20.80	18.64	20.97	17.34	27.24
Gamogoffa	21.18	17.65	22.80	24.04	15.60	16.72	12.53	15.19
Wolaita	25.17	18.23	16.12	18.49	20.24	18.54	14.14	18.06
Sidama	24.31	12.65	13.07	19.77	18.45	13.22	14.57	15.26
Gurage	20.84	14.55	15.44	15.16	14.46	14.35	10.77	28.94
Yem special woreda	11.92	17.20	19.47	15.96	14.22	13.78	8.68	16.57
West & SW Shewa	10.81	11.51	22.98	14.43	18.45	15.50	9.43	15.53
Kaffa	13.62	20.84	16.78	26.22	21.10	15.93	17.48	11.03

[a] See the materials and methods section for the abbreviations of the characters.

Table 4.1.7. Continued

Region	LFSTHBD[a]	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
Kembata & Hadiya	42.29	43.48	32.86	44.63	41.53	42.80	43.36
Dawro	45.22	51.87	39.08	48.46	45.14	47.90	55.25
Gamogoffa	50.32	49.41	57.16	52.71	39.96	46.03	48.01
Wolaita	46.75	43.76	36.97	40.03	44.13	51.62	50.67
Sidama	45.79	44.01	34.74	54.97	43.18	51.87	52.03
Gurage	39.40	47.91	29.65	49.27	37.89	42.42	42.93
Yem special woreda	40.02	36.96	32.15	39.76	41.13	23.67	28.16
West & SW Shewa	32.72	27.65	24.95	30.77	20.17	21.50	23.31
Kaffa	6.42	44.29	53.01	53.62	33.62	24.59	24.35

[a] See the materials and methods section for the abbreviations of the characters.

4.1.3.3 Bivariate statistics

Breeders aims to select superior genotypes on the basis of Phenotypic expression. However, for the quantitative characters, genotypes are influenced by environment, thereby affecting the Phenotypic expression. Information regarding the nature and extent of association of morphological characters to landraces would be helpful in selecting desirable traits and improving yield, a complex character for which direct selection is not effective.

Phenotypic correlation coefficients for the 15 quantitative characters were computed for all data (Table 4.1.8), for between regions (Table 4.1.9) and for within regions (data not shown). The matrix developed for correlation coefficients for the entire data showed significant positive correlation of fermented squeezed *kocho* yield per hectare per year with twelve other characters and negative correlation with maturity time. Days to maturity had a positive Phenotypic correlation with pseudostem height (0.15), pseudostem circumference (0.18), corm weight before grating (0.39), unfermented squeezed *kocho* yield per hectare per year (0.32) and fermented squeezed *kocho* yield per hectare per year (0.19) (Table 4.1.8). This is in agreement with a previous report that *kocho* yield was positively and significantly correlated with plant height, pseudostem circumference, leaf sheath number, and leaf sheath weight (Taboge 1997). Characterstics that are positively correlated Phenotypically are useful in conventional breeding techniques because selection or breeding for one character will likely improve or influence the others.

Eleven of the 15 characters also showed positive correlations with altitude of the collection sites (Table 4.1.8). Altitude had a positive and significant correlation with maturity time, pseudostem height, pseudostem circumference and leaf height (Table 4.1.8). As previously discussed (Harlan et al. 1973), ecological characteristics have influenced the genotypic constitution of landraces during domestication and hence a relationship exists between the agro-ecology at the collection site and the morphological characteristics of the landraces. Thus, positive correlation between collection site variables and plant characteristics would suggest that the variation between landraces is related to agro-ecological variations among the collection sites (Elings 1991). The correlation coefficients between leaf number, unfermented *kocho* yield per hectare per year, fermented squeezed *kocho* yield per hectare per year and altitude were negative but nonsignificant, indicating that other environmental factors (other than altitude) and/or non-environmental factors might account for the variation for these particular characters. The trend of between region and within region associations of characters was similar to that of the entire data. For instance, maturity time was significantly and positively correlated with central shoot weight before grating, corm weight before grating (Table 4.1.9).

Knowledge of the magnitudes and the direction of the correlation coefficients between quantitative characters would assist the interpretation of the patterns of variation. Within the limits of experimental error and environmental effects, high correlation coefficients among characters may reflect a common underlying element of genetic control, or else the impact of unlinked genetic characters responding similarly to geograpHic variation in selection pressures (Bekele 1984; Thorpe 1976). The between-region (also called inter-region) correlation coefficient among the characters measures the concordance of their patterns of regional variation, while the within region (also called intra-region) correlation coefficient measures the association arising from genetic factors not affected by regional variation (Thorpe 1976).

Since this study showed significant positive correlations intra-regionally for some character combinations, it would imply correlations between the various characters had a genetic basis. However, it appeared that similar response to regional variation was playing a greater role than common genetic control as shown by the much more significant and moderate to high correlation coefficients inter-regionally than intra-regionally.

Correlations among characters can help plant breeders identify easily measured characters that could be used as indicators of more important (but more complex to score) traits. They are also useful in pointing out the possibility and limitation of simultaneous selection of desirable characters (Amurrio 1993).

Table 4.1.8. Simple correlation coefficients between 15 quantitative characters and with altitude of the collection site based on the mean for 387 enset landraces

	MT[a]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO	ALT
MT	1															
PLHT	-0.28**	1														
PSHT	0.15**	0.41**	1													
PSCIR	0.18**	0.38**	0.32**	1												
LFNO	-0.15**	0.16**	0.20**	0.36**	1											
LFHT	0.04	0.30**	0.37**	0.33**	0.24**	1										
LFWTH	-0.03	0.40**	0.41**	0.50**	0.28**	0.39**	1									
LFSTHNO	-0.06	0.20**	0.16**	0.42**	0.46**	0.18**	0.25**	1								
LFSTHBD	0.04	0.47**	0.44**	0.69**	0.38**	0.37**	0.52**	0.54**	1							
LFSTHAD	0.07	0.44**	0.41**	0.65**	0.35**	0.35**	0.52**	0.45**	0.88**	1						
CSBG	0.07	0.26**	0.37**	0.60**	0.38**	0.28**	0.47**	0.35**	0.66**	0.68**	1					
CORMBG	0.39**	0.36**	0.42**	0.58**	0.08	0.22**	0.33**	0.14**	0.54**	0.57**	0.48**	1				
UFK	-0.52**	0.56**	0.24**	0.40**	0.30**	0.26**	0.41**	0.34**	0.57**	0.57**	0.43**	0.29**	1			
UNSQKOCH	-0.33**	0.31**	0.33**	0.41**	0.42**	0.26**	0.41**	0.37**	0.59**	0.64**	0.53**	0.35**	0.70**	1		
SQKOCHO	-0.20**	0.27**	0.34**	0.46**	0.42**	0.26**	0.40**	0.39**	0.61**	0.66**	0.55**	0.40**	0.61**	0.93**	1	
ALT	0.10*	0.043	0.10*	0.12*	-0.01	0.14**	0.05	0.07	0.06	0.06	0.04	0.02	-0.07	-0.09	-0.07	1

ALT = Altitude; *: significant at $P \leq 0.05$ (5%), **: significant at $P \leq 0.01$ (1 %), [a] See the materials and methods section for the abbreviations of the characters.

Table 4.1.9. Inter-region simple correlation coefficients among 15 quantitative characters (based on the mean of the 9 regions of origin)

	MT[a]	PLHT	PSHT	PSCIR	LFNO	LFL	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
MT	1														
PLHT	-0.65	1													
PSHT	0.37	0.04	1												
PSCIR	-0.14	0.26	0.27	1											
LFNO	0.71*	-0.65	0.61	0.09	1										
LFHT	0.16	0.27	0.91**	0.35	0.52	1									
LFWTH	0.39	-0.25	0.52	-0.17	0.31	0.31	1								
LFSTHNO	0.44	-0.11	0.34	0.19	0.46	0.42	-0.03	1							
LFSTHBD	0.33	0.17	0.62	0.50	0.45	0.74*	0.15	0.85**	1						
LFSTHAD	0.51	-0.08	0.52	0.43	0.53	0.58	0.25	0.86**	0.95**	1					
CSBG	0.85**	-0.49	0.59	0.01	0.81**	0.51	0.36	0.76*	0.69*	0.79*	1				
CORMBG	0.79*	-0.37	0.78*	0.35	0.79*	0.62	0.40	0.54	0.66	0.72*	0.87**	1			
UFK	-0.93	0.71*	-0.15	0.26	-0.59	0.05	-0.44	-0.20	-0.09	-0.33	-0.67	-0.59	1		
UNSQKOCH	-0.05	-0.42	0.27	0.18	0.51	0.29	0.15	0.17	0.17	0.25	0.27	0.22	0.08	1	
SQKOCHO	0.27	-0.65	0.26	0.03	0.65	0.21	0.22	0.35	0.24	0.39	0.54	0.39	-0.22	0.93**	1

*: significant at $P \leq 0.05$ (5%), **: significant at $P \leq 0.01$(1 %), [a] See the materials and methods section for the abbreviations of the characters.

The large Phenotypic variation observed in this study and previous studies (Yemataw et al. 2012) in enset germplasm could be ascribed to many factors. One important factor is the fact that enset is grown in many different environmental conditions, being influenced by rainfall, temperature, altitude, growing period, and edapHic factors. Other factors such as linguistic, cultural, historical and economic system differences among the people who are cultivating enset (Negash 2001; Tsegaye 2002; Yemataw et al. 2014 and 2016), likely contribute to its variation. The various pHysical, biological and human factors as well as complex interactions among such factors all seem to have contributed to the wide range of variation of the current enset landraces in the country.

4.1.4 Conclusion

Overall, this detailed Phenotypic study provided confirmation of widespread statistically significant Phenotypic variation in traits at both regional and within-region levels. We predict that the diverse agro-ecology of Ethiopia, coupled with the long years of cultivation of the crop under a variety of socio-economic and cultural situations plays a major factor in the evolution of the highly diverse phenotypes observed. These findings generally indicate that future enset germplasm collection and conservation strategies cannot easily discriminate among the different regions and altitude zones. With regard to utilization of our diverse germplasm of enset, the study as a whole confirmed the presence of considerable quantitative trait diversity which can be exploited in the genetic improvement of the crop. The enormous variation identified will provide breeders with new opportunities for breeding and selection of improved enset genotypes.

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4.2 Multivariate analysis of morphological variations in enset (*Ensete ventricosum* (Welw.) Cheesman) shows regional and clinal variation in germplasm from South and South western Ethiopia

Abstract

Enset (*Ensete ventricosum* (Welw.) Cheesman) is cultivated by millions of people across Ethiopia in diverse agro-ecological and cultural settings, selecting for various agronomic traits. However, as for other underutilized crops, our understanding of the diversity and utilization of enset remains limited. This work sought to redress this limitation by estimating morphological diversity among enset landraces collected from major enset growing regions, including across altitudinal gradients. In total, landraces comprising 387 landraces originating from nine regions of Ethiopia were characterized using multivariate analysis of 15 quantitative traits. Cluster analysis grouped landraces in to five distinct classes with maximum number of landraces 338 in cluster (I) and minimum 1 in cluster (V). The clustering of landraces did not show grouping on the basis of region of origin. The first four principal components accounted for ~74% of the total variance. Linear discriminant analysis indicated that around 40.8% (160 landraces) and 45.2% (175 accession) of the studied landraces were correctly classified to their respective regions of origin altitude groups, respectively. The breadth of Phenotypic differences in these 15 traits suggests significant degrees of genetic variation. These traits will be exploited to identify potential donors for future enset improvement efforts.

Key words: Agro-morphological variation, *Ensete ventricosum*, Ethiopia, landrace, multivariate analysis

4.2.1 Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) belongs to the order Zingiberales, family Musaceae and the genus *Ensete*. It is a giant herbaceous monocotyledonous plant consisting of an adventitious root system, an underground stem structure known as corm and a pseudostem, which is formed from leaf sheaths, leaves and inflorescence (Smeds 1955). Enset is a multipurpose crop used for human food and animal feed and traditional medicine as well as for ornamental purposes. Farmers say that enset is their food, their cloth, their house, their bed, their cattle feed and their plate (Brandt et al. 1997). Enset is eaten either as *kocho* (a bread-like food made from fermented corm and pseudostem), *bulla* (dehydrated starch rich juice collected during decortication of the pseudostem and grating of the corm, subsequently rehydrated from concentrate and prepared as pancake or porridge), or *amicho* (boiled corm pieces, eaten like potato) (Brandt et al. 1997).

Enset is an indigenous crop grown in the highlands of Ethiopia, usually between 1200 and 3100 meters above sea level (masl) but scattered plants can be found at lower altitudes (Haile et al. 1996). Ideal growth conditions appear to be between 2000 and 2750 masl (Diro and Taboge 1994) and for optimum growth enset requires an average rainfall of 1100 - 1500 mm per year and a mean temperature of 16–20 °C. Enset is not tolerant to freezing; frost damage on upper leaves is commonly observed at 2800 masl and serious stunting is seen above 3000 masl (Taboge 1997). The productivity of the crop is very high compared to other root and tuber crops but varies depending on edapHic factors, altitude, cultural practices and varietal differences (Birmeta 2004).

Ethiopian farmers usually grow enset as a mixture of different morpHotypes (Tsegaye 2002; Tesfaye 2008; Yemataw et al. 2014). Enset landraces have been studied using morphological (Taboge 1997; Yemataw et al. 2012; Bekele et al. 2013; Yeshitla 2014) and molecular (Negash 2001; Birmeta 2004; Tobiaw and Bekele 2011; Getachew et al. 2014; Olango et al. 2015) markers. The different studies have contributed to identifying useful germplasm for plant breeding purposes and for developing appropriate collection and conservation strategies. However, most studies concentrated on samples collected from only a subset of the growing regions. On the basis of observed diversity, Areka Agricultural Research Centre has collected and maintained about 600 enset landrace landraces (Yeshitla and Yemataw 2012). Detailed knowledge about the collections, evaluation and cataloguing will help to elucidate the patterns of variation and the paths of evolutionary history, which are required for efficient utilization of the genetic potential held in germplasm collections (Brown 1978).

Multivariate methods like principal component analysis (PCA), cluster analysis (CA) and, discriminant analysis have proved useful for characterization and classification of plant genetic resources. These are powerful tools to estimate extent of genetic diversity for choosing potential parents in breeding programs, and to elucidate the patterns of variation in germplasm collection (Cowen and Frey 1987).

Selection of enset landraces displaying useful agronomic characteristics is dependent on knowledge of the extent of genetic diversity. Different investigators have described the usefulness of multivariate methods in many crops like barley (Abebe et al. 2010), tef (Assefa et al. 2003), sorghum (Ayana and Bekele 1999), wheat (Damania et al. 1996), rice (Kanwal et al. 1983) and also enset (Bekele et al. 2013; Yeshitla 2014). However, these studies, especially those on enset, were focused on the level and structure of diversity on enset within a given region, while regional variations was seldom considered. In addition, most of the enset landraces collected and preserved at the Institute of Agricultural Research have not yet been studied for their genetic diversity.

This study was initiated to survey morphological diversity among enset landraces collected over 20 years from nine major enset growing regions and sampled across an altitudinal gradient. Farmers' selection practices were a driver to identify areas with high variation, which is important for selection and establishment of *in situ* conservation sites. The objectives of the present study were to: i) determine the extent and pattern of distribution of morphological variations for 15 quantitative characters in 387 enset landraces and, ii) to identify groups of landraces quantitatively similar in respect of those characters, using a range of multivariate statistical methods.

4.2.2 Materials and methods

4.2.2.1 Description of the study site

Enset landraces were planted during April 2011 to April 2017 at the Areka Agricultural Research Centre, South 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 (Refere chapter 4.1 section 4.1.2.1).

4.2.2.2 Plant materials and study design

A total of 387 enset landraces, representing 381 landraces and six released varieties (controls), were used in this study. The 381 enset landraces were collected from nine different regions across varying altitudes (Refere chapter 4.1 section 4.1.2.1). Data were collected for a total of 15 important quantitative (metric or count) pHeno-morpHological and agronomic traits (Refere chapter 4.1 section 4.1.2.1). The detailed passport data of the landraces including the regions and altitudes of collection and the vernacular names is summarized in Appendix 3.

4.2.2.4 Statistical analysis

The data were standardized to a mean of zero and a variance of unity to avoid differences in scales used for recording data on the different characters before undertaking a series of multivariate analysis. Multivariate statistical analysis including cluster analysis (CA), principal component analysis (PCA) and discriminant analysis, as well as non-hierarchical, and hierarchical clustering of landraces based on the Average Linkage Method were performed using SAS V9.1.3 (SAS 2004). Statistics, pseudo F statistics, pseudo t^2 statistic generated by SAS were examined to decide the number of optimum clusters. Genetic distance between clusters, as standardized Mahalanobis's D^2 statistics were calculated following the recommendation by Singh and Chaudary (1985) as follows:

$$D^2ij= (Xi - Xj) S^{-1} (Xi -Xj)$$

Where D^2ij is the distance between cases i and j; Xi and Xj are the vectors of the values of the variables for cases i and j; and S^{-1} is the pooled within groups variance-covariance matrix.

The D^2 values obtained for pairs of clusters were considered as the calculated values of chi square (X^2) and were tested for significance at 1 and 5% probability levels against the tabulated value of X^2 for 'P' degree of freedom, where P is the number of parameters considered.

Principal component analysis was performed using the correlation matrix to define the patterns of variation both between landraces, and between their regions of origin and altitudinal classes. In this study, only PCs with Eigen value greater than unity were considered important in explaining the variability. As suggested by Johnson and Wichen (1988) trait coefficient or eigenvector greater than half divided by the standard deviation (square root) of the Eigen value of the respective PC was employed as general guideline for weighing the relative significance of traits constituting the PCs.

Linear discriminant analyses were also employed to examine the validity of the origin-based grouping of the landraces with respect to their regions and altitude groups of collection, and also to check the grouping of the landraces obtained through cluster analysis. The PROC DISCRIM procedure of SAS V9.1.3 (SAS 2004) was used for discriminant analysis.

4.2.3 Results and Discussion

4.2.3.1 Cluster analysis

Cluster analysis demarcates genotypes into clusters, which exhibit high homogeneity within a cluster and high heterogeneity between clusters (Jaynes et al. 2003). The 387 landraces distinguished five clusters of varying size (Table 4.2.1 and Appendix 4). Furthermore, the diversity was reflected by the substantial variation among the cluster means for the 15 different characters (Table 4.2.2). Cluster I contained the highest number of landraces (338), accounting for 87.3% of the landraces tested in this study. Enset plants that fall into this cluster have intermediate maturity time, plant height, pseudostem height, pseudostem circumference, leaf sheath number and fermented squeezed *kocho* yield per hectare per year. These landraces were scattered across all regions but the majority were grouped in altitude group II (2001-2400 masl) and III (2401-2800 masl) (Table 4.2.3).

Cluster II was the second largest cluster comprising 45 landraces, representing 11.6% of the tested enset landraces. Landraces with the highest agronomic and yield-related traits were included in this cluster. This cluster included landraces from all regions, with the highest representation (15) being from the Kembata & Hadiya region.

Cluster III consisted of only two landraces with inferior morphological and agronomical characteristics. Enset landraces in this cluster have the shortest plant height, lowest pseudostem height, the narrowest pseudostem circumference and leaf width, the lowest leaf sheath before decortication, leaf sheath after decortication and the lowest fermented squeezed *kocho* yield per hectare per year.

Clusters IV and V each contained single landraces derived from lowland (≤2000 masl) and intermediate (2001-2400 masl) elevations in Gurage and Gamogoffa (Table 4.2.3). Landraces in cluster IV demonstrated intermediate values for yield-related traits, while cluster V constituted the best yielding accession with the highest values for morphological traits.

Overall, this study demonstrates that enset Phenotypic traits could classify landraces according to their Phenotypic similarity/differences using multivariate analysis. Hence, selection and crossing of enset germplasm landraces included in different clusters would provide greater heterosis in enset breeding programme in Ethiopia.

Our results indicate that landraces from different regions might have similar genetic backgrounds. This could be due to several possible reasons, most likely because farmers will select for a given character based on the adaptive role of characters for the environment, as well as sourcing and exchanging planting material between regions. Even though the geograpHical location of Sidama is distant from Gurage and from Kembata and Hadiya, landraces from these locations showed some similarity (Fig 4.2.1). Indeed, this example reflected a general pattern whereby the distribution of landraces in different clusters did not follow a definite pattern with regard to geographical origin. On the other hand, landraces from different regions based on the 15 pheno-morphic and agonomic traits were closely related regardless of their geograpHic origin. The collection of enset landraces at the Areka Agricultural Research Centre were recorded by the name identified by the farmer. While this nomenclature may be uniform across a specific region that speaks the same language, some landraces (even possibly identical landraces) may have different names in different ethnic groups or different languages (Taboge 1997; Yemataw et al. 2014) and the variation in utilization of the same landraces by local farmers

(Negash 2001). This is illustrated by the clustering of genotypes with greatest morphological similarity, and the composition of these clusters did not include all genotypes derived from the same geograpHic origin. The result agrees with pevious reports in wheat (Ali et al., 2008) and field pea (Singh and Tripathi 1985), which noted the absence of clear interrelationship between geograpHic origin and genetic diversity despite the presence of high intra-and interregional diversity among those crop landraces. Zubair et al. (2007) and Ahmad et al. (2008) also reported lack of association between morpHo-agronomic traits and place of origin in mung bean and barley genotypes, respectively.

Table 4.2.1. Clustering of 387 enset genotypes five clusters using mean of 15 quantitative characters

Cluster	Enset landraces[a]	No. of landraces	Percentage out of landraces
I	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 14, 16, `17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 38, 39, 40, 42, 44, 45, 46, 47, 49, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 76, 79, 80, 81, 82, 83, 85, 86, 87, 88, 90, 91, 92, 93, 96, 97, 98, 99, 100, 101, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, `155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 196, 197, 198, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 216, 217, 218, 219, 220, 221, 222, 223, 225, 227, 229, 230, 231, 232, 235, 236, 237, 238, 239, 240, 241, 242, 244, 245, 246, 247, 248, 249, 250, 251, 253, 254, 255, 256, 258, 259, 261, 262, 263, 265, 266, 267, 268, 269, 270, 271, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 285, 286, 287, 288, 289, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 302, 303, 304, 305, 306, 307, 309, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330. 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 362, 363, 364, 365, 366, 369, 370, 372, 373, 374, 475, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387	338	87.3
II	4, 12, 13, 15, 18, 37, 41, 43, 48, 50, 62, 74, 75, 77, 78, 84, 89, 95, 124, 125, 126, 171, 195, 199, 215, 224, 226, 228, 233, 234, 243, 252, 257, 260, 264, 283, 284, 290, 301, 308, 310, 361, 367, 368, 371	45	11.6
III	94, 102	2	0.5
IV	272	1	0.3
V	139	1	0.3

[a] numbers refer to code of landraces; See the supplementary table for the detail accession number and their name.

Table 4.2.2. Mean values of the 15 quantitative traits in the five clusters

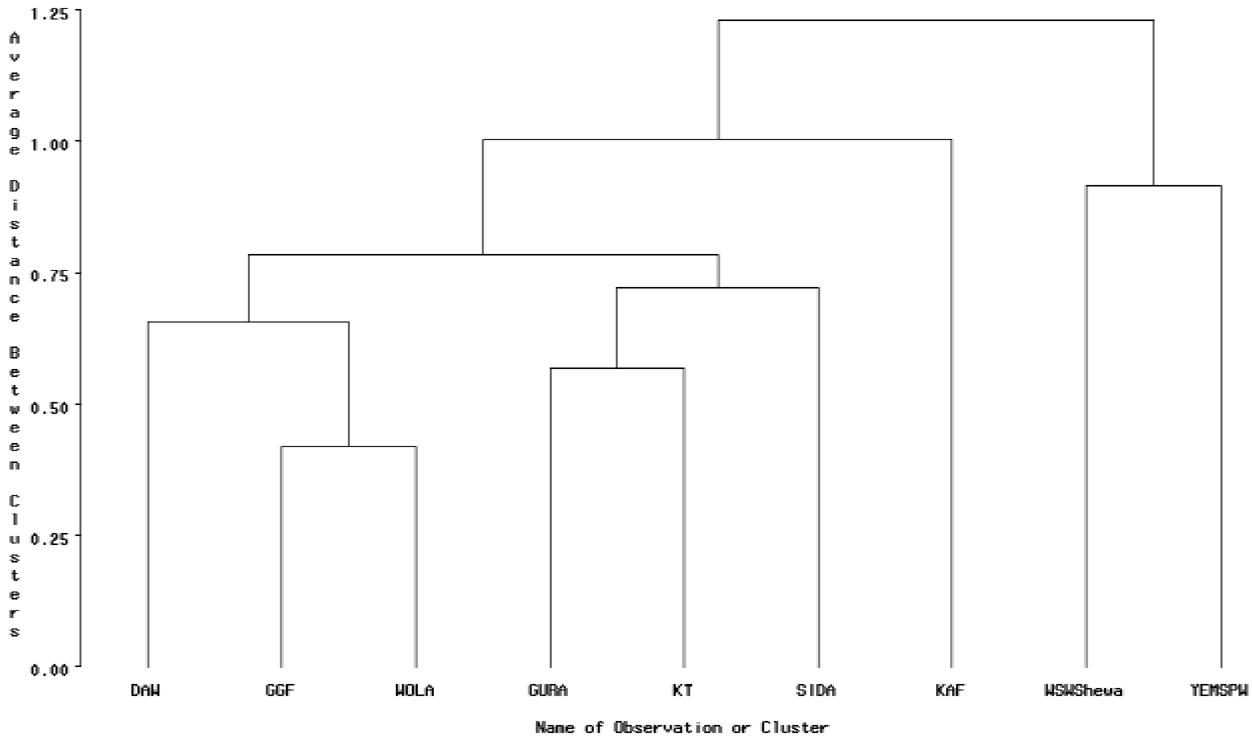
Cluster	MT[a]	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO
I	4.48	5.13	1.69	1.15	10.25	3.34	0.65	18.95
II	4.13	6.47	2.01	1.44	11.46	3.79	0.75	21.78
III	5.01	2.62	0.96	0.61	5.73	1.49	0.35	14.25
IV	3.58	6.24	2.06	1.11	11.5	3.06	0.64	48.5
V	5.13	7.13	2.36	1.91	10.0	3.53	0.86	21.5

Cluster	LFSTHBD	LFSTHAD	CSBG	CORMBG	UFK	UNSQKOCH	SQKOCHO
I	56.479	27.15	15.17	25.34	31.98	13.41	9.37
II	107.94	54.16	23.84	44.78	63.07	25.43	17.55
III	10.46	3.71	2.21	11.71	7.06	2.17	1.34
IV	67.46	34.46	18.46	31.46	50.34	24.21	15.5
V	120.96	66.96	60.46	72.46	83.52	30.65	21.27

[a] See the materials and methods section for the abbreviations of the characters.

Table 4.2.3. Distribution of 387 enset landraces over five clusters by region of origin and altitudinal class.

Region or altitude class	Clusters					
	I	**II**	**III**	**IV**	**V**	**Total**
Region						
Kembata & Hadiya	63	15				78
Dawro	47	6	2			55
Gamogoffa	43	1			1	45
Wolaita	34	2				36
Sidama	33	8				41
Gurage	30	6		1		37
Yem special Woreda	37	3				40
West & SW Shewa	31	1				32
Kaffa	20	3				23
Altitude zones						
≤2000 masl	39	4		1		44
2001-2400 masl	114	22	1		1	138
2401-2800 masl	160	17	1			178
>2800 masl	25	2				27
Total	**338**	**45**	**2**	**1**	**1**	**387**



DAW= Dawro, GGF= Gamogoffa, WOLA= Wolaita, GURA= Gurage, KT= Kembata and Hadiya, SIDA= Sidama, KAF= Kaffa, WSWShewa= West and South-west Shewa, YEMSPW= Yem special woreda

Fig 4.2.1. Dendrogram showing the clustering patterns of the nine regions of origin of enset landraces based on 15 Phenotypic characteristics.

All the 10 pairs of clusters were significantly ($P<0.01$) different (Table 4.2.4). The maximum inter-cluster distance was observed between clusters IV and V (D^2= 221.17) (Table 4.2.4). Each of these "clusters" constituted a single accession from the Gurage and Gamogoffa regions. The second most divergent clusters were clusters III and V (D^2= 190.18); the landraces grouped in these clusters were collected from Dawro and Gamogoffa. On the other hand, the lowest (12.6) inter-cluster distance between clusters I and II indicates that the genotypes of these clusters were probably more genetically similar.

Table 4.2.4. Pair wise generalized squared distances (D^2) among 387 enset landraces in five clusters.

Cluster	**I**	**II**	**III**	**IV**	**V**
I	0	12.6**	28.23**	139.47**	115.75**
II		0	61.17**	145.18**	83.14**
III			0	176.31***	190.18**
IV				0	221.17**
V					0

*** Indicates highly significant differences (p<0.001) and ** significant at p<0.01 level.

Maximum segregation and recombination in the subsequent generation is expected from crosses that involve parents from the greatest inter-cluster distance clusters. Thus these data when combined with other desirable agronomic attributes, provide an evidence-based selection method for future breeding programmes. Such genotypes can also be used in breeding programmes for developing bi-parental crosses between the most diverse and closest groups to break the undesirable linkages between yield and its associated traits (Haddad et al. 2004). However, Singh (1990) suggested that the selection of parents should also consider the specific traits of each cluster and each accession within a cluster depending on the specific objectives of hybridization. Yan and Donaldh (1998) also recommended that in addition to genetic diversity, parents should express the optimum level of the desired component traits for enhanced yield, while being maximally resistant to biotic and abiotic stresses, and that they should fulfill quality parameters required in the breeders' target area.

Generally, the results of clustering and the D^2 analyses have shown that genotypes from the same collection sites were in different clusters and likewise landraces from different collection sites may cluster together, probably reflecting that the environment and farmers' selection criteria for a given character that enhances performance/yield of enset drives the similarity of most of the landraces from different origin.

Genetic distances from quantitative data allow inferences about the adaptation of populations (Camussi et al. 1985). Thus, classification using multiple agronomic characters identifies adaptation of a genotype and would improve the evaluation of genotype for potential adaptation (Souza and Sorrells 1991). Moreover, Zhong and Qualset (1995) have suggested that the evolution of co-adaptive association of quantitative characters might contribute to the observed grouping together of landraces from geograpHically similar areas. The number of enset landraces grown at a given locality, their genetic similarity and the areas they occupy over time and space are influenced by introduction (planting material source), exchange and supply. The landraces might have originally been introduced from the same source, followed by frequent exchange of planting materials among farmers across regions of the country and subsequent selection criteria for the same trait of interest (de Boef et al. 1996). Even if the original sources might vary, the crop might have also been forced to evolve in the same direction by this kind of local breeding for the same targets which may come from similar economic, social, cultural and ecological drivers in the area.

4.2.3.2 Principal Component Analysis

Principal component analysis (PCA) showed that the first four principal components accounted for about 72.5% of the total variance of the 387 enset landraces for the 15 quantitative traits (Table 4.2.5). Of these, the first three PCs explained about 65% of the gross population variance. The first PC contributed nearly 44%, and the second PC ~12% of the total variation. We used a criterion that characters with larger absolute values closer to unity within the first principal component influence the clustering more than those with lower absolute values closer to zero (Chahal and Gosal 2002). Furthermore Hair et al. (1998) suggested that eigenvalues greater than one are considered significant and component loadings greater than ±0.3 were considered to be meaningful. As shown in Figure 4.2.2, fourteen parameters occupied the right side of the biplot whereas only one trait was observed in the upper left side.

The relative magnitudes of eigenvectors for the first PC indicated that traits like leaf sheath before decortication, leaf sheath after decortication, unfermented squeezed *kocho* yield per hectare per year, and pseudostem circumference contributed most to the total diversity and they were the ones that most differentiated enset populations. In the second PC, maturity time, corm weight before grating, and unfermented *kocho* yield per hectare per year had significant contributions. The analysis also revealed that plant height, leaf sheath number, leaf number and pseudostem height constituted a larger part of the total variance explained by the third PC. Leaf height, leaf number and fermented squeezed *kocho* yield per hectare per year were the major contributory parameters in the fourth principal component.

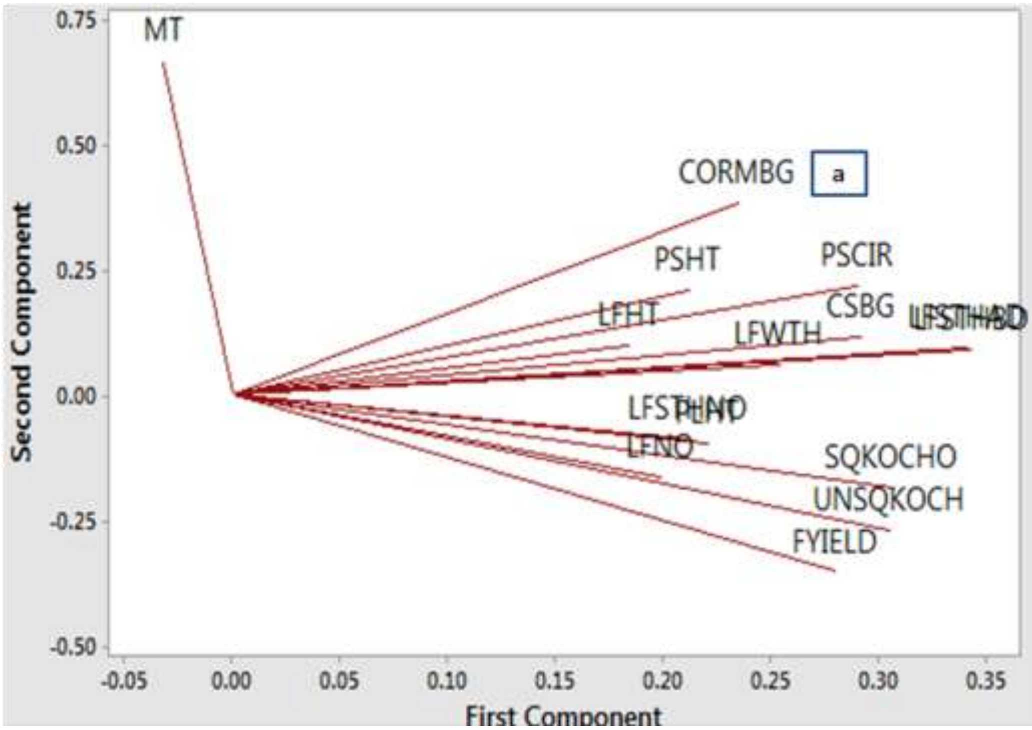
Table 4.2.5. Eigenvectors, eigenvalues, and percent variance explained by the first four principal components (PCs) for 15 different traits of 387 enset landraces

Variable	Eigenvectors			
	Prin1	Prin2	Prin3	Prin4
MT[a]	-0.03	0.67	0.20	-0.03
PLHT	0.22	-0.09	-0.53	0.09
PSHT	0.21	0.21	-0.33	0.17
PSCIR	0.29	0.22	0.10	0.03
LFNO	0.20	-0.16	0.39	0.44
LFHT	0.18	0.10	-0.25	0.54
LFWTH	0.25	0.07	-0.19	0.23
LFSTHNO	0.21	-0.09	0.43	0.31
LFSTHBD	0.34	0.09	0.07	-0.02
LFSTHAD	0.34	0.10	0.07	-0.14
CSBG	0.29	0.12	0.17	-0.10
CORMBG	0.23	0.38	-0.12	-0.36
UFK	0.28	-0.35	-0.19	-0.15
UNSQKOCH	0.30	-0.27	0.09	-0.27
SQKOCHO	0.31	-0.18	0.16	-0.28
Eigen Value	6.65	1.91	1.23	1.01
Per cent of variance explained	0.4437	0.1272	0.0824	0.0671
Cumulative per cent of variance explained	0.4437	0.5709	0.6532	0.7203

[a] See the materials and methods section for the abbreviations of the characters.

PCA was also conducted using the respective means of regional and altitude zones for the 15 quantitative traits to assess the regional and altitudinal pattern of variation. Considering an eigenvalue of more than one, the first three and two PCs explained 82.8 and 88.66% of the total variance among regions and altitude zones, respectively, (Table 4.2.6). The first three PCs contributed ~83% of the total regional variation. Central shoot weight before grating, corm weight before grating, pseudostem circumference, leaf number and leaf sheath weight after decortication had high loadings for the first PC, which accounted for >51% of variation. Similarly, ~18% of the overall variability among regions was accounted by the second PC, largely due to plant height, leaf height and unfermented *kocho* yield per hectare per year. Unfermented squeezed *kocho* yield per hectare per year and fermented squeezed *kocho* yield per hectare per year contributed 51 and 64% for the third PC which explained about 14% of the total regional variance.

Altitude classes resulted in two PCs with eigenvalue greater than one, and the two PCs together explained 88.6% of the total variation. Maturity time, unfermented squeezed *kocho* yield per hectare per year and fermented squeezed *kocho* yield per hectare per year were the most loading contributors in the first principal component. Similarly, leaf number, leaf length and corm weight before grating showed greatest loading in the second principal component.



[a] See the materials and methods section for the abbreviations of the characters.

Fig 4.2.2. Loading plot of PC1 and PC2 for 387 enset landraces.

This PCA analysis confirmed that all morphological characters measured made contributions to the variance existing across the landraces. This in turn indicated the contribution of a number of traits towards the overall observed diversity. These results align with the findings of Assefa et al. (2003) where four PCs contributed 93.9% of total variation in tef populations. Ayalew et al. (2011) extracted four PCs that contributed 81% of the total variation in tef landraces. Similarly, in highland maize landraces of Ethiopia, 71.8% of total variation was accounted by the first four PCs (Beyene et al. 2005).

The combined PCA data indicated that agro-ecologies played a major role in discriminating landraces based on morphological traits, compared to the regions from which the landraces were collected. It was thus possible to observe how altitude and important ecological factors are related and influenced the diversity of enset in the country as previously suggested by Yeshitla and Yemataw (2012).

Table 4.2.6. Eigen vectors, Eigen values, total of the first three and two principal components of the nine regions and altitude classes of origin of 387 enset landraces

	Regions				Altitude		
	PC1	PC2	PC3	PC4	PC1	PC2	PC3
MT[a]	0.29	-0.26	-0.28	0.06	0.32	0.11	0.13
PH	-0.16	0.52	-0.13	0.07	0.27	0.28	0.01
PSH	0.25	0.25	0.09	0.40	0.19	-0.25	0.49
PSC	0.31	-0.01	-0.29	-0.17	0.26	-0.27	0.21
LN	0.31	-0.15	0.15	0.04	0.08	0.47	0.09
LH	0.22	0.40	0.15	0.25	0.15	-0.44	0.04
LW	0.12	-0.05	0.04	0.64	0.30	0.09	-0.29
LSN	0.26	0.20	-0.05	-0.43	0.10	0.28	0.59
LSBD	0.27	0.37	-0.03	-0.15	0.29	0.16	-0.23
LSAD	0.30	0.21	-0.04	-0.20	0.30	0.13	-0.26
CSBG	0.35	-0.05	-0.06	-0.07	0.29	-0.20	-0.19
COBG	0.33	0.02	-0.07	0.15	0.23	0.34	0.13
UFK	-0.22	0.38	0.27	-0.11	-0.29	0.16	-0.21
USQKB	0.13	-0.07	0.64	-0.08	-0.31	0.18	0.004
SQKB	0.20	-0.19	0.51	-0.15	-0.31	0.09	0.22
Eigen Value	7.71	2.66	2.04	1.55	9.23	4.07	1.70
Per cent of variance explained	51.45	17.73	13.62	10.33	61.50	27.13	11.34
Cumulative per cent of variance explained	51.45	69.18	82.80	93.13	61.53	88.66	1.00

[a] See the materials and methods section for the abbreviations of the characters.

4.2.3.3 Discriminant analysis

Discriminant analysis of landraces using the region of origin as a grouping variable showed that 40.8% (160) of the landraces were correctly classified to their respective regions of origin (Table 4.2.7). The percentage of landraces correctly classified varies with regions. The proportion of enset landraces correctly classified with their region was the highest (72%) for West and South West Shewa. This was followed by Yem special district, Kembata & Hadiya, and Kaffa with 70, 59 and 48 % of the landraces respectively correctly classified within their collection region. On the other hand, Wolaita has the smallest percentage of landraces (11%) classified within their region of origin. Nearly 39% of landraces from Wolaita and over 40% of landraces from Gurage were grouped under the Kembata and Hadiya region. Landraces originated from Dawro were grouped under all regions except West and South West Shewa.

The discriminant analysis of the four altitudinal classes of enset landraces showed that 45.2% (175) of the landraces were correctly placed in their respective altitudinal class. The percentage of landraces correctly classified was higher for the second and fourth altitude classes compared to the others. Notably, around 59 and 55 % of studied landraces were misclassified according to the respective regions of origin and altitude groups. Evaluation of the predicted membership for the misclassified landraces of each region revealed that most of these landraces were flow among regions through planting material exchange and flow.

This variability is in line with those of Pecetti and Damania (1996), who reported that the higher the diversity of the group, the higher the probability of misclassification and separation. Similarly Ayana and Bekele (1999) stated that the role of environmental factors has greater importance than regions of origin in discriminating sorghum landraces. When clustering of landraces did not follow their geograpHic origin, more empHasis should be given to agro-ecological parameters than to geograpHic origins as a source of diversity (Alemayehu and Becker 2002).

Table 4.2.7. Discriminant analysis of 387 enset landraces for region of origin and altitude based on fifteen quantitative characters

Regions	Original Accession No.	Kembata-Tembaro /Hadiya	Dawro	Gamo Goffa	Wolaita	Sidama	Gurage	Yem	West &SW Shewa	Kaffa	Landraces classified under their regions of origin(%)
Kembata & Hadiya	78	46	8	10	4	4	5	1	0	0	58.97
Dawro	55	6	13	8	4	3	9	11	0	1	23.64
Gamogoffa	45	5	7	15	5	7	2	4	0	0	33.33
Wolaita	36	14	6	9	4	1	1	1	0	0	11.11
Sidama	41	15	4	5	2	13	2	0	0	0	31.71
Gurage	37	15	8	4	1	2	7	0	0	0	18.92
Yem special Woreda	40	0	2	1	0	1	1	28	7	0	70
West & SW Shewa	32	1	1	2	0	0	0	2	23	3	71.88
Kaffa	23	0	3	0	1	0	0	2	6	11	47.83

Altitude zones	**Original Accession No.**	**≤2000 m.a.s.l**	**2001-2400 masl**	**2401-2800 masl**	**>2800 masl**	**Landraces classified under their regions of origin(%)**
≤2000 masl	44	6	23	14	1	45.45
2001-2400 masl	138	2	71	65	0	47.3
2401-2800 masl	178	2	40	134	2	46.07
>2800 masl	27	1	11	11	4	48.15

4.2.4 Conclusion

Findings of the current work revealed that there is likely to be high genetic diversity present within the Ethiopian enset landraces, though this is not uniformly distributed across the regions and altitudinal gradients. It was observed that landraces from the southern part of the country sharing similar ethno linguistic bases were closely related regardless of their geograpHic origin, though landraces from the same regions of origin might have different genetic backgrounds. There was no definite association between geograpHic origin and genetic diversity. All of the genetic distances between clusters are significant, suggesting the ability to incorporate desirable agronomic traits in subsequent generations from crosses that involve parents from the clusters characterized by significant distances. Future sampling of enset germplasm as a source of diversity should take place in areas with relatively large variation is evident, with due consideration to the cause of genetic erosion and depletion of resource. It must be reempHasized however, that morphological variation alone does not reflect the total variation, but this work opens the way to select landraces for a more comprehensive investigation of genetic diversity using molecular marker and quantitative characters. Such studies are underway and will probably provide a fuller picture about the genetic variation in Ethiopian enset landrace.

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4.3 Assessing qualitative and phenologic traits diversity in Ethiopian enset (*Ensete ventricosum* (Welw.) Cheesman) landraces

Abstract

Enset (*Ensete ventricosum* (Welw.) Cheesman) is one of the major indigenous crops in Ethiopia providing food for over 20% of the population. A total of 286 enset landraces sourced from six different regions of Ethiopia were evaluated for 7 qualitative and Phenotypic traits at the Areka Agricultural Research Centre in south-western Ethiopia, to determine the extent and pattern of morphological/Phenotypic variation. 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 H' revealed highly significant ($p<0.01$) differences between regions for all traits. Cluster analysis grouped the landraces into four clusters. A high proportion of landraces sourced from similar altitude classes and similar regions were grouped together. 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, while these same traits also contributed relatively more to regional differentiation. 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. Generally, considerable variations important for enset improvement work have been observed and regions with highest diversity for some traits have been pinpointed for possible future *in situ* or *ex situ* germplasm conservation work.

Key words: enset germplasm, morphological diversity, Phenotypic traits

4.3.1 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 6 or 7 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). *E. ventricosum* is the only species in the genus *Ensete* that is cultivated and this occurs solely in smallholder farming systems in southern and south-western 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 south-western 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 has not been qualitatively assessed using the Shannon Weaver diversity index.

Enset producing farmers use three morphological characters (midrib, petiole and leaf colour) and plant growth attributes (vigor and maturity time) to distinguish enset landracess (Negash 2001; Yemataw et al. 2014; Yemataw et al. 2016). In this study, aiming to provide useful knowledge for breeders and agronomists, qualitative and Phenotypic traits were used to estimate the level of variation that exists across enset landraces grown in southern Ethiopia. The main objectives of the study were to: (1) estimate the extent of morphological/Phenotypic diversity among enset landraces and (2) assess regional patterns based on qualitative and phenologic trait data.

4.3.2 Materials and methods

4.3.2.1 Description of the study site

Enset landraces, originaly sourced from 6 enset growning regions, 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 Center is located at 7°09′ N latitude and 37° 47′ E longitude at an elevation range of 1750 to 1800 m above sea level (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 1539 mm, and minimum and maximum mean temperatures were 14.5 °C and 25.8 °C, respectively. Thus, the weather conditions were within the normal range for the growth and development of the enset crop in the study area.

4.3.2.2 Plant materials

Two hundred and eighty six enset landraces (i.e. farmers' varieties) sourced from six different enset growing regions (Figure 4.3.1) in Ethiopia, and established at the Areka Agricultural Research Center, were used in this study. Germplasm collection site and altitude information is provided in Table 4.3.1. 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 Appendix 4.

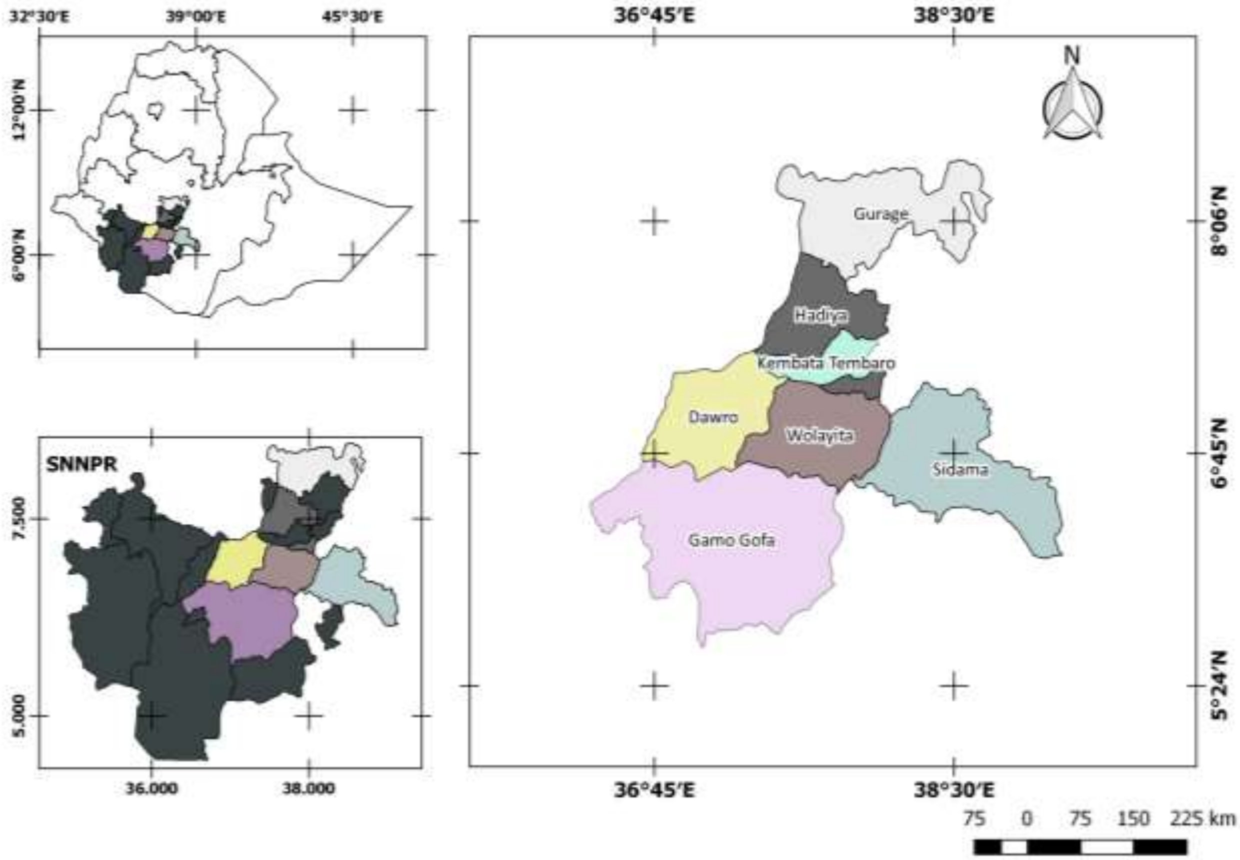

Figure 4.3.1. Map of Ethiopia and SNNP regional state showing the test enset landraces collection regions (Dawro, Gamogoffa, Gurage, Kembata and Hadiya, Sidama, Wolaita)

Table 4.3.1. Number of enset landraces according to the region where the germplasm was collected and the altitude of the collection site.

Collection région / altitude class	Total number of landracess
Region	
Kembata-Tembaro	73
Dawro	54
Gamogoffa	45
Wolaita	36
Sidama	41
Gurage	37
Altitude class	
I (≤2000 masl)	34
II (2001-2400 masl)	115
III (2401-2800 masl)	118
IV (>2800 masl)	19

4.3.2.3 Agro-morphological traits

Three year old enset plants were assessed at the Areka Agricultural Research Center. Two plants obtained from a single mother plant (through macro-propagation) were assessed per landrace. Data were collected for 7 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 4.3.2). The Munsell colour chart was used for characterization (Munsell Colour 1977; Anonymous 1996; Anonymous 2007). The number of Phenotypic classes used for the Shannon-Weaver diversity index differed for each trait (Table 4.3.2).

4.3.2.4 Data analysis

4.3.2.4.1 Diversity index estimation

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

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

Where n is the number of Phenotypic 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, region of origin, and altitude class. Each value of H was standardized by conversion to a relative Phenotypic diversity index (H') by division by $H_{max} = \ln(n)$ in order to express the values of H' in the range of 0-1.

$H' = H/H_{max}$

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

4.3.2.4.2 Statistical analysis

Hierarchical cluster analyses, using the Minitab statistical program (Minitab 2000), were used to examine the aggregation patterns/dendrogram of the 286 enset landraces. The grouping of all the enset landraces into clusters was done on basis of their morphological traits. Trait data were pre-standardized to mean zero and unity variance in order 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 4.3.2. Descriptors used for estimating phenological and qualitative trait diversity in enset landrace landraces, linked classes for each trait, and the proportion (%) of occurrence of a class per trait.

Phenotypic/qualitative trait	Observed classes	Number of classes per trait	Proportion (%)
Maturity time (MT)	1. Early maturing (<4 year)	3	14.7
	2. Intermediate (4-5 year)		61.9
	3. Late maturing(> 6 year)		23.4
Upper-side midrib colour (UPMID)	1. Light to medium green with black patches, and black stripes	10	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
Under-side midrib colour (UNDMID	1. Light to medium green with black patches and black streaks	12	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
Upper-side petiole colour (UPPET)	1. Light to medium green with black patches and black streaks	9	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

Table 4.3.2. Continued

Phenotypic/qualitative trait	Observed classes	Number of classes per trait	Proportion (%)
Under-side petiole colour (UNDPET)	1. Light to medium green with black patches and black streaks	13	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
Upper side leaf lamina colour (LFCL)	1. Light green	2	69.6
	2. Medium green		30.4
Leaf tip edge colour (LTECL)	1. Light green to green	3	17.8
	2. Black		1.7
	3. Brown		80.5

4.3.3 Results and Discussion

4.3.3.1 Frequency distribution

Results of the current study demonstrate wide variations between the 286 enset landraces for the studied traits (Table 4.3.2). Frequency distribution for maturity time shows that 62% of landraces fall in the intermediate group of maturity period (4-5 years) (Table 4.3.2). 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 4.3.2 and Fig. 4.3.2). 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%) (Table 4.3.2).

The frequency distribution for the seven traits according to site of enset landrace collection is shown in Table 4.3.3. The highest frequency was consistently observed for intermediate maturity time (1) (4-5 year) across all 6 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 Wolaita and Sidama (Table 4.3.3). 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 2 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, Gamogoffa 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, 25.9, 28.9 and 45.9%) (Table 4.3.3). Enset landraces from Kembata and Hadiya, Wolaita 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, Wolaita and Sidama (Table 4.3.3). 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; Yemataw et al. 2014).

Frequency distribution across the 4 altitude groups also revealed that the intermediate maturity group (2) consistently scored highest (Table 4.3.4). The most abundant upper-side midrib colour across all altitude groups was “Light to medium green with black patches, and black stripes” (1) (Table 4.3.4). 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 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 4 altitude ranges (Table 4.3.4). These results are in agreement with Taboge (1997) who studied morphological traits of enset landraces in 2 regions (Wolaita 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 4 altitude ranges (Table 4.3.4). Across the 6 geograpHical regions and 4 altitude ranges, there were two classes observed for upper side leaf lamina colour and the most frequent was “Light green” (1) (Tables 4.3.3 and 4.3.4). The predominant occurrence of light green leaf laminas in enset was also reported by Taboge (1997) and Yeshitla (2014). The most frequent leaf tip edge colour was “Brown” (3) across regions and altitude ranges (Tables 4.3.3 and 4.3.4). These results also agree with Yeshitla (2014) who reported that the most predominant leaf tip edge colour in enset was brown-purple.

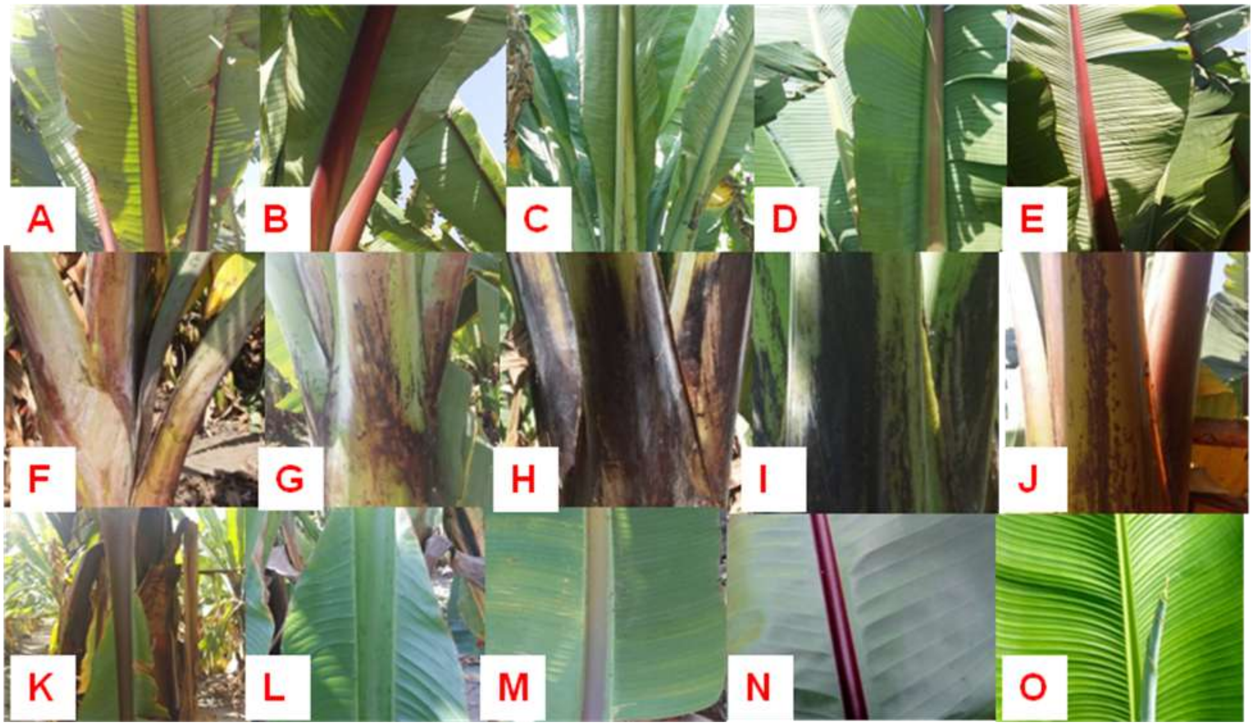

Figure 4.3.2. A-E: examples of morphological variation in under-side midrib colour; F-J: examples of morphological variation in under-side petiole colour and K-O: examples of morphological variation in upper-side midrib colour.

Table 4.3.3. Frequency distribution (%) for different Phenotypic classes of seven traits according to enset landrace collection site.

Site of enset landrace collection	Qualitative/ Phenological 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	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	-	-	-	-	-	-	-	-	-	-
Gamogoffa	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	-	-	-	-	-	-	-	-	-	-

"-" is only for classes that don't 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 4.3.2. for the observed Phenotypic classes per trait.

Table 4.3.3. Continued.

Site of enset landrace collection	Qualitative/ Phenological trait[#]	Observed Phenotypic class[*]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
	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	-	-	-	-	-	-	-	-	-	-	-
Wolaita	LTECL	5.6	0	94.4	-	-	-	-	-	-	-	-	-	-
	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	-	-	-	-	-	-	-	-	-	-	-
Sidama	LTECL	26.8	4.9	68.3	-	-	-	-	-	-	-	-	-	-
	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	-	-	-	-	-	-	-	-	-	-	-
Gurage	LTECL	24.3	0	75.7	-	-	-	-	-	-	-	-	-	-

"-" is only for classes that don't 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 4.3.2. for the observed Phenotypic classes per trait.

Table 4.3.4. Frequency distribution (%) for different Phenotypic classes of seven qualitative characters according to altitude ranges.

Altitude ranges (masl)	Qualitative/ Phenological trait#	Observed Phenotypic class*												
		1	2	3	4	5	6	7	8	9	10	11	12	13
	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	3	11.8	2.9	8.8	8.8	8.8	0	0	14.8	2.9	2.9	0
≤2000	LFCL	70.6	29.4	-	-	-	-	-	-	-	-	-	-	-
masl	LTECL	35.3	2.9	61.8	-	-	-	-	-	-	-	-	-	-
	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	-	-	-	-
2001-	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
2400	LFCL	73	27	-	-	-	-	-	-	-	-	-	-	-
masl	LTECL	12.1	0.9	87	-	-	-	-	-	-	-	-	-	-
	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	-	-	-	-
2401-	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
2800	LFCL	68.6	31.4	-	-	-	-	-	-	-	-	-	-	-
masl	LTECL	16.1	2.5	81.4	-	-	-	-	-	-	-	-	-	-
	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
> 2800	LFCL	52.6	47.4	-	-	-	-	-	-	-	-	-	-	-
masl	LTECL	31.6	0	68.4	-	-	-	-	-	-	-	-	-	-

#, *: see Tables 4.3.2 and 4.3. 3

4.3.3.2 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 4.3.5. The 7 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, upper-side petiole colour had an intermediate diversity.

Table 4.3.5. 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.

Traits	H'	H'_{cl}	H'_{cl}/H'	$(H' - H_{cl})/H'$
MT[a]	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

[a]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

H' = diversity index for each trait calculated from the entire dataset; H_{cl} = average diversity index of each trait for the six localities; H_{cl}/H' = proportion of diversity within localities and $(H' - H_{cl})/H'$ = proportion of diversity between localities in relation to the total variation.

The Phenotypic diversity estimates based on the Shannon-Weaver diversity index (H') for the different collection regions are shown in Table 4.3.6. Enset landraces from the Kembata and Hadiya regions showed the highest H' values (Table 4.3.6) for maturity time, under-side petiole colour, upper-side midrib colour and under-side midrib colour. The highest degree of diversity in the Wolaita-sourced landraces was recorded for days to maturity, under-side petiole colour and under-side midrib colour. Enset landraces from Gamogoffa exhibited the highest diversity index for maturity time and leaf lamina colour. The least mean diversity index values for the seven traits were obtained for the Dawro sourced enset landraces. At 2001-2400 masl, highest H' values were observed for maturity time, upper- and under-side petiole colour and upper-side midrib colour (Table 4.3.7). Leaf colour had the largest H' value at altitudes above 2800 masl. On the other hand, under-side midrib colour and leaf tip edge colour had highest H' values in the altitude zone below ≤2000 masl. The highest overall mean diversity index value was recorded for enset landraces obtained below 2000 masl. Analysis of variance for H' revealed highly significant ($p<0.01$) differences among all regions, altitude classes and this for all traits (Table 4.3.6 & 4.3.7). 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 (Yemataw et al. 2016).

Table 4.3.6. Estimates of the Shannon-Weaver diversity indice (H') for seven traits in 286 enset landrace 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 where enset landraces were sourced	Traits							Mean ±se
	MT[a]	UPMID	UNDMID	UPPET	UNDPET	LFCL	LFTPEDG	
Kembata and Hadiya	0.83	0.66	0.63	0.63	0.73	0.5	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
Gamogoffa	0.75	0.57	0.38	0.44	0.46	0.84	0.59	0.57±0.06
Wolaita	0.84	0.69	0.74	0.69	0.79	0.5	0.2	0.63±0.08
Sidama	0.81	0.73	0.69	0.72	0.76	0.96	0.69	0.76±0.03
Gurage	0.7	0.37	0.32	0.31	0.61	0.99	0.5	0.54±0.09
Mean squares of H' (df=5)	0.20**	0.73**	1.55**	1.48**	1.08**	2.68**	1.87**	

[a]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; df = degrees of freedom; ** significant at $P \leq 0.1$(1%)

Table 4.3.7. Estimates of the Shannon-Weaver diversity indices (H'), in 286 enset landrace 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	**Traits**							**Mean ±se**
	MT[a]	UPMID	UNDMID	UPPET	UNDPET	LFCL	LFTPEDG	
≤2000 masl	0.81	0.72	0.65	0.76	0.72	0.87	0.7	0.74±0.03
2001-2400 masl	0.88	0.77	0.58	0.77	0.76	0.84	0.38	0.71±0.06
2401-2800 masl	0.84	0.76	0.54	0.79	0.69	0.89	0.5	0.71±0.05
> 2800 masl	0.63	0.4	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**	

[a]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; df = degrees of freedom; ** significant at $P \leq 0.1$(1%)

4.3.3.3 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 4.3.8 and Fig 4.3.3). 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 for 40.9% of the total experimental materials. Cluster I clearly showed the close relationship between landraces from the Kembata and Hadiya, Dawro, Gamogoffa and Gurage regions (Table 4.3.9). Cluster II contained 74 landraces which account for 25.87% of the total experimental materials. A relatively large number of landraces in this cluster were from the Kembata and Hadiya (18) and Gamogoffa (14) regions (Table 4.3.9). Similarly, the contribution of altitude classes II (2001-2400 masl) and III (2401-2800 masl) 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 2401-2800 masl altitude range. Cluster IV consisted of 56 landraces accounting for 19.58 % of the total experimental materials. Landraces from the Gamogoffa and Sidama regions and altitude class II (2001-2400 masl) 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. 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 introduction (planting material source), conservation and exchange (Yemataw et al. 2017).

The landraces might have originally been introduced from the same source, followed by frequent exchange of planting materials among farmers across regions of the country, while similar selection criteria (Yemataw et al. 2016) might have been used by farmers of different regions. Traits like yield stability, resistance to biotic and abiotic stresses and low dependence on external inputs are often used by farmers (de Boef et al. 1996). Even if the original sources might have varied, 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.

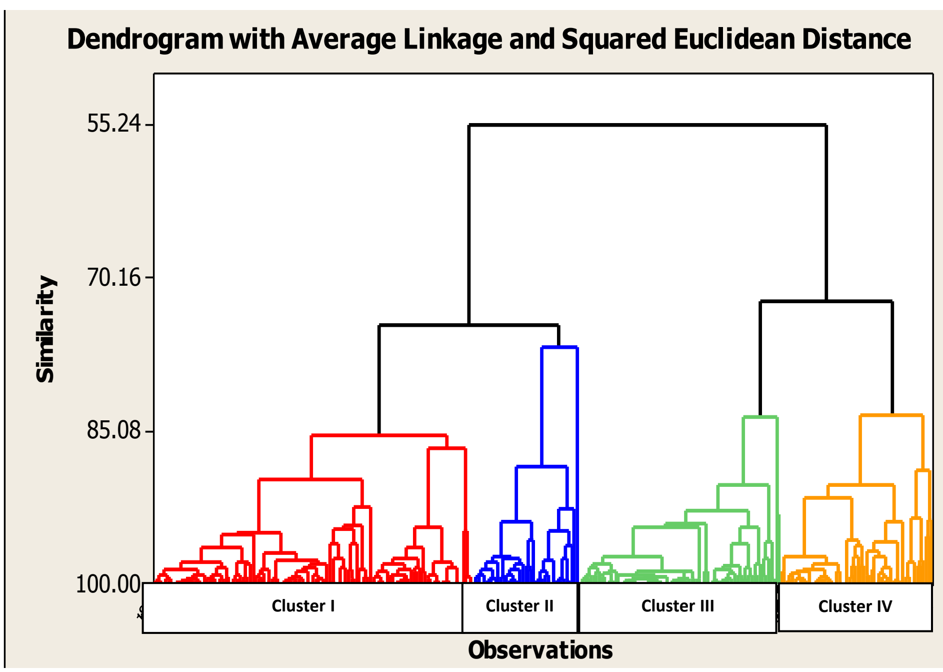

Figure 4.3.3. Dendrogram showing the clustering pattern of 286 enset landraces computed using date collected on 7 qualitative traits.

Table 4.3.8. Clustering of 286 enset landrace landraces into 4 groups using seven qualitative characters.

Cluster	Enset landraces	No. of landraces	Percentage out of total population
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	40.91
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	25.87
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	13.64
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	19.58

[a] numbers refer to code of landraces; See Appendix 4 for the detail accession number and their name.

Table 4.3.9. Distribution of the 286 enset landraces over 4 clusters according to region of origin and altitude class.

Region or altitude class	Clusters				Total
	I	II	III	IV	
Region					
Kembata and Hadya	32	18	15	8	**73**
Dawro	29	10	9	6	**54**
Gamogoffa	17	14	-	14	**45**
Wolaita	8	11	10	7	**36**
Sidama	14	12	2	13	**41**
Gurage	17	9	3	8	**37**
Altitude zones					
≤2000 m.a.s.l	9	13	3	9	**34**
2001-2400 m.a.s.l	48	25	20	22	**115**
2401-2800 m.a.s.l	54	31	14	19	**118**
>2800 m.a.s.l	6	5	2	6	**19**
Total	**117**	**74**	**39**	**56**	**286**

4.3.4 Conclusion

A total of 286 enset landraces, sourced from 6 enset growing regions, were evaluated for 7 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 diverse agro-ecology of Ethiopia, similar selection criteria coupled with the long years of cultivation of the crop under a variety of socio-economic and cultural situations are major contributing factors to the observed Phenotypic diversity. These findings indicate that future enset germplasm collection and conservation strategies cannot easily discriminate among the different regions and altitude zones. The presence of considerable qualitative trait diversity could be exploited for marker assisted selection in the genetic improvement of the crop.

4.3.5 References

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CHAPTER 5

Genome sequence data from 17 landraces of *Ensete ventricosum*, the staple food crop for millions in Ethiopia

Abstract

Whole-genome sequencing was performed for the first time on a set of cultivated varieties of enset (*Ensete ventricosum* (Welw.) Cheesman) alongside two wild varieties from Ethiopia. Analysis of these sequence data identified a large catalogue of single nucleotide polymorpHism (SNPs) that serve as a resource for developing molecular markers for future marker assisted breeding. Seventeen different enset landraces obtained from Areka Agricultural Research Center field germplasm were used for the genome sequencing. Further, 480 landraces were assayed for several SNP loci, using PCR primers designed using genome sequence data. Genomic DNA was sequenced using the Illumina MiSeq and/or Illumina HiSeq 2500. We identified single-nucleotide polymrophisms (SNPs) by alignment against the reference genome sequence according to the usual programme. Primers were designed from a DNA sequence of *Badediet* using Primer3 web version 4.1.0. All designed primers were validated by PCR amplification. For the PCR primer template, we referred the genome sequences from *Badediet* (GenBank: GCA_000818735.2). We present raw sequence reads and genome assemblies resulting from the sequencing of 17 landraces of the crop plant enset (*Ensete ventricosum* (Welw.) Cheesman). We generated a range of sequencing read-depths between 7.0 X (Wolaita Mazia) to 21.75 X (Onjamo). Landraces having the same names but different origin showed extensive genetic differences. For SNP detection, we considered only sites where depth of coverage by aligned reads was at least 5 X for all 17 datasets and where the single-nucleotide site could be unambiguously called as either homozygous or heterozygous for all 17 datasets. By aligning the enset shotgun sequence reads against this *Badediet* genome sequence, we were able to identify 33,200 single-nucleotide variant sites. To ascertain the pHylogenetic position of the seventeen newly sequenced enset landraces, we generated a series of pHylogenetic trees based on a bar-code pHylogenetic indicator and sequence data from previously published studies. There was no sequence variation at this locus among the 17 Ethiopian genomes presented here, indicating close pHylogenetic relationships among them; but they were distinct from the previously sequenced enset genome, whose full provenance is unknown and did not originate from Ethiopia. The SNP-based PCR-RFLP marker is a co-dominant marker and can be used to differentiate homozygous from heterozygous genotypes. We applied the 22 PCR-RFLP assays to single accession of *E. ventricosum*. Further, we then went on to apply 5 of these assays to several hundred *E. ventricosum* landraces. This resources will facilitate high-resolution studies to determine the genetic architecture of traits of economic and ecological importance, to study the structure of enset populations and to apply genomic selection in breeding programs.

Key words: Enset, PCR-RFLP, SNP

5.1. Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a perennial, herbaceous plant belonging to the same botanical family as bananas and plantains, namely the Musaceae (Cheesman, 1947). Although it does not yield edible fruits, it is the most important cultivated staple food crop in the highlands of central, south and southwestern Ethiopia with cultural significance (Tsehaye and Kebebew 2006) as well as a key role in food security (Brandt et al. 1997; Negash and Niehof 2004). The main food value is in the large starch-rich corm, which can be boiled and consumed in a similar manner to tubers such as potato or can be used to generate a fermented product known as *kocho* (Bezuneh and Feleke 1966; Pijls et al. 1995; Brandt et al. 1997; Yirmaga 2013; Yemataw et al. 2016; Bosha et al. 2016). Enset varieties display a great range of genetic and Phenotypic variation (Birmeta et al. 2002, 2004; Tesfaye and Lüdders 2003; Zippel 2005; Tesfaye 2008; Tobiaw and Bekele 2011; Yemataw et al. 2012; Yemataw et al. 2014) (Figure 5.1) and 15 Phenotypic traits have been assayed for a collection of 387 enset landraces (Yemataw et al. 2017). Integration of Phenotypic measurements with genetic markers could be of great value in breeding improved varieties with enhanced resistance to abiotic and biotic stresses.

Despite its importance for food security of millions in Ethiopia, enset has been relatively neglected in molecular research and few genomic resources are available. Previously a first draft genome sequence of *E. ventricosum* was published (Harrison et al. 2014), but the sequenced individual was obtained from the nursery trade (from the UK-based company Jungle Seeds) and its provenance is unknown and therefore its relevance to Ethiopian agriculture is uncertain. Its phylogenetic relationship with Ethiopian varieties is rather distant, clustering much more closely with *E. ventricosum* e4 (GenBank: FJ428156.1) (Li et al. 2010) and whose provenance is also unknown. In contrast, the data presented here originate from enset landraces collected in

Ethiopia. Most of these enset landraces are sourced from the germplasm collection of the Southern Agricultural Research Institute (SARI), with the exception of Bedadeti, which originated from the collection of the International Institute for Tropical Agriculture (IITA). Therefore, the present study was designed to develop a reference genome sequence , to identify single nucleotide polymorpHism (SNPs) that serve as molecular markers for future marker assisted breeding and cataloguing large numbers of SNPs.

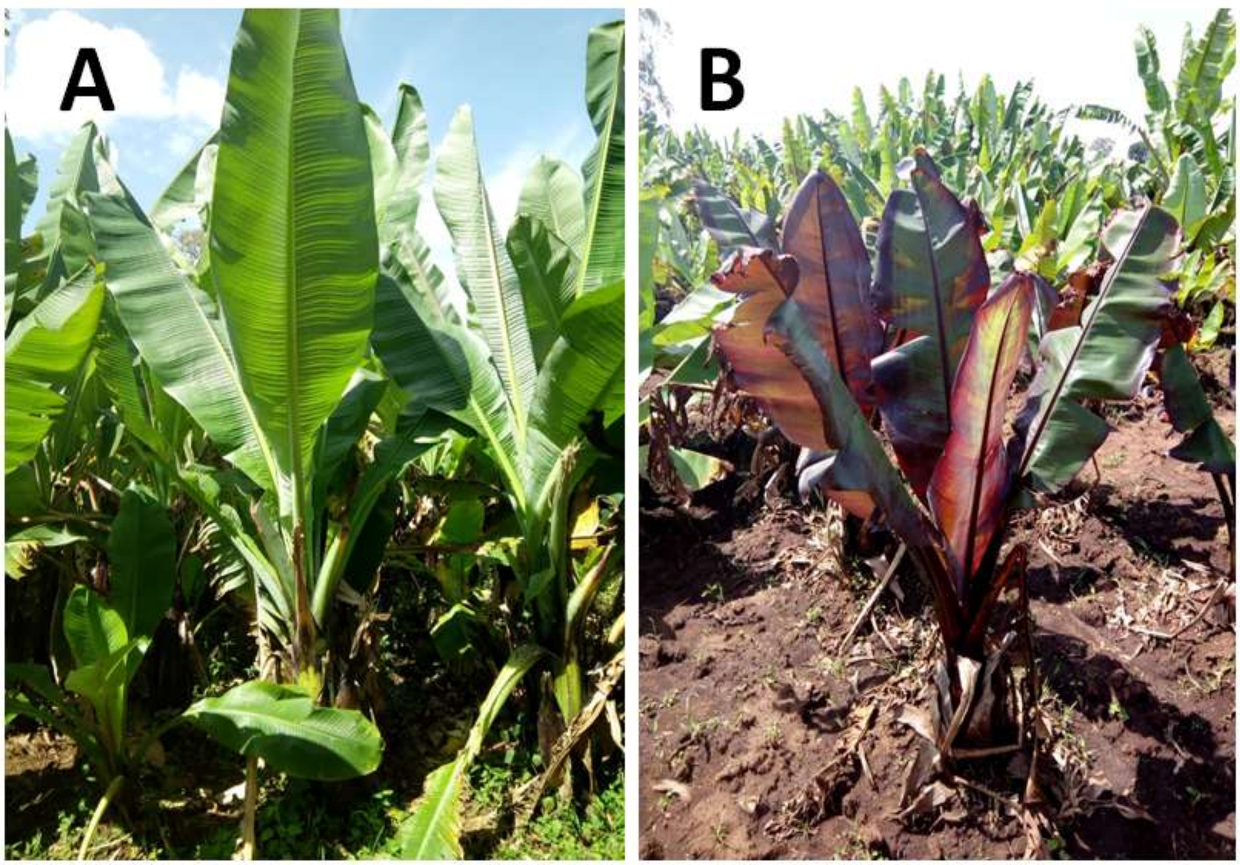

Figure 5.1. Phenotypic variation among sequenced landraces of *Ensete ventricosum*. Panel A shows landraces Mazia and panel B shows Lochingie.

5.2. Materials and Methods

5.2.1. Plant material and DNA extraction

Four hundred fifty eight different enset landraces used were obtained from Areka Agricultural Research Center field germplasm (Appendix 6). Genomic DNA was extracted from the young emerging (cigar) leaves using previously published mini-prep protocol (Doyle and Doyle 1990). Between 0.2 and 0.5g of young and clean leaf was collected per plant and dried in silica gel. From these dried leaves 0.2g was taken from each sample and ground with sterile pestle and mortar. Genomic DNA was isolated from about 0.2 g of pulverized leaf sample using modified triple cetyltrimethylammonium bromide (CTAB) extraction technique (Borsch et al. 2003). The yield and quality of DNA were assessed by agarose gel electropHoresis and by using the NanoDrop spectropHotometer (NanoDrop Technologies, Wilmington, DE).

5.2.2 Genome sequencing and Assembly

Genomic DNA was sequenced using the Illumina MiSeq and/or Illumina HiSeq 2500 (in either Rapid Run mode or normal mode). Read lengths were 2x300 bp for MiSeq, 2x100 bp for HiSeq in normal mode and 2x300 bp for HiSeq Rapid Run mode. Nominal insert size of the libraries was 500 bp. A contig-level assembly of landraces Badediet was generated using SPAdes 3.6.1(Bankevich et al. 2012) and scaffolded using SSPACE v. 3.0 (Boetzer et al. 2011). For the other assemblies, we used SPAdes 3.9.0.

Prior to further analysis, sequence reads were trimmed and filtered using Trim Galore with options "-q 30 –paired". We performed *de novo* sequence assembly for sequence reads from Badediet, Derea and Onjamo. For Badediet, we used SPAdes v. 3.6.1 (Bankevich et al. 2012) to assemble contigs and then scaffolded these using SSPACE v. 3.0 (Boetzer et al. 2011). For Onjamo, we generated contigs and scaffolds using SPAdes v. 3.9.0 and for Derea generated contigs only using SPAdes v. 3.9.0. SPAdes assemblies were performed using the "—careful" option.

5.2.3. SNP discovery

We identified single-nucleotide polymorpHisms (SNPs) by alignment against the reference genome sequence, according to the following procedure. After trimming and filtering with TrimGalore, sequence reads were aligned against the Bedadeti reference genome sequence (GenBank: GCA_000818735.2) using BWA mem (Li and Durbin 2009; Li 2013) version 0.7.15-r1140 with default options and parameter values.

Candidate SNVs were identified using SAMtools/BCFtools package (Li et al. 2009), version 1.6, using the following command-lines: "samtools mpileup -u -f genome.fasta alignment.bam > alignment.bcf" and "bcftools call -m -v --Ov alignment.bcf > alignment.vcf".

The candidate variants were then filtered using the following command line: "bcftools filter --SnpGap 100 --include '(REF="A" | REF="C" | REF="G" |REF="T") & %QUAL>=35 & MIN(IDV)>=2 & MIN(DP)>=5 & INDEL=0' alignment.vcf > alignment.filtered.vcf".

This filtering step eliminates indels with low-confidence single-nucleotide variant calls. It also eliminates candidate SNVs within 10 base pairs of an indel, since alignment artefacts are relatively common in the close vicinity of indels.

Allele frequencies at each SNP site were estimated from frequencies of each base (A, C, G or T) among the aligned reads. Thus, we would expect an allele frequency of close to zero or 1 for homozygous sites and approximately 0.5 for heterozygous sites in a diploid genome. The BAM-formatted BWA-mem alignments were converted to pileup format using the *samtools mpileup* command in SAMtools (Li et al. 2009) version 1.6 with default options and parameter values. From the resulting pileup files, we used a custom Perl script (Yemataw et al. Submitted in Data in Brief) to detect SNPs. For SNP detection, we considered only sites where depth of coverage by aligned reads was at least 5 X for all 17 datasets. For a site to be called as homozygous, less than 1 % or more than 99% of the aligned reads had to support the variant nucleotide; to be called as heterozygous, between 30% and 80% of reads had to support the variant nucleotide at that site. In other words, we excluded from consideration any sites where, for any of the 17 sequence datasets, the aligned-read frequency of a variant fell between 1 and 30% or between 70 and 99% on the grounds that their status was ambiguous. This process yielded approximately one candidate SNP per kilobase of the reference genome sequence.

5.2.4. Primer design and validation

A total of 287 high power SNP assays from sequence reads of *Badediet* (GenBank: CA_000818735.2) were identified for primer design. Primers were designed from a DNA sequence of *Badediet* using Primer3 web version 4.1.0 () by setting the following parameters: amplification product size 100-501bp, and Tm difference = 1^{o}C. All designed primers were validated by PCR amplification. For the PCR primer template, we referred the genome sequences from *Badediet* (GenBank: GCA_000818735.2) (Yemataw et al 2018). Based on the PCR results, primer pairs were considered potentially amplifying if they i) generated a unique amplicon, ii) were potentially working at an annealing temprature between 51-60^{o}C, and iii) showed an absolute differences of ≤3 ^{o}C between the forward and its reverse. To experimentally validat primer pairs, selected sets of primers were evaluated by PCR amplification using a pre-screening panel of two enset samples.

PCR was performed using 20µl of reaction mixture containing 2 µl of 10xPCR buffer, 0.6 µl of 50mMx MgSo4, 2mM of 0.4 µl each of dNTPs, 1 µl conc of Taq polymerase and 2 µl conc of genomic DNA. Forward (1 µl) and reverse (1 µl) primers and 12 µl of water were provided for amplification. The initial denaturation step was performed at 94^{O}C for 3 min, followed by 30 cycles at 94 ^{O}C for one min, annealing steps for 45 min of 60 - 51^{O}C of 1 ^{O}C touchdown for forward an reverse primers, 72 ^{O}C for 30 min and a polishing step of 72 ^{O}C for 5 min with a final extension for 20 min. Products were separated on 2% agarose gel electropHoresis run at 100 volts to check for efficiency of amplification and to ensure that only a single band product of the expected size was present.

5.2.5. SNP genotyping

The identification of relatively high-confidence SNPs, distributed throughout the genome at a density of approximately one SNP per kilo base, provides the possibility to develop markers that could be used for genotyping large numbers of plant landraces without the need for large-scale sequencing. One straightforward approach is polymerase chain reaction restriction fragment digest polymorpHism (PCR-RFLP) technique (Masao and Jerzy 2007). Another is co-dominant amplified polymorpHism (CAPS) (Konieczny and Ausubel 1993). In the PCR-RFLP assay, oligonucleotide primers are designed to amplify a PCR product that flanks a SNP that falls within the recognition site for a restriction enzyme such that one variant is cleavable by the restriction enzyme whilst the other variant is not. Thus, by examining the pattern of bands in agarose electropHoresis of the product after restriction digestion, it is possible to assess the genotype at that SNP location. We applied 5 of these assays to several hundred *E. ventricosum* landraces; agarose gels showing the products of digesting the PCR products can be found in Appendix 7.

5.3. Result and Discussion

5.3.1. Genome sequencing and assembly

We sequenced the enset genomic DNA using a combination of Illumina MiSeq and/or Illumina HiSeq 2500 in either normal or rapid-run mode, as detailed in Table 5.1. The 17 sequenced landraces included 15 distinct named varieties. We sequenced two different landraces for landraces Mazia and two different landraces for landraces Lochingie; one accession was sequenced for each of the other varieties. Raw sequence reads and were submitted to the Sequence Read Archive (SRA) (Leinonen et al. 2011) under the accession numbers listed in Table 5.1. We generated a range of reads between 7.0X (Wolaita Mazia) to 45.81X (Bedadeti). Landraces having the same names but different origin showed different reads. For instance *Mazia* from Wolaita (7.0X) having different reads against *Mazia* from Dawro (8.24X). The same trend was followed by *Lochinge* and *Arkia* landraces collected from Dawro and Wolaita area (Table 5.1). We generated *de novo* sequence assembly for sequence reads from Badediet, Derea and Onjamo (Table 5.2).

5.3.2. SNPs identification and marker development

Single-nucleotide polymorpHisms (SNPs) are defined as variations in single nucleotide position in genome sequences. It can be valuable markers for crop improvement (Mammadov et al. 2012) but yet have not previously been reported for cultivated and wild enset originated from Ethiopia. We followed the example of Harrison et al. (2014) by performing SNP calling against the high-quality reference genome sequence of Badediet.

To do the alignment, we used Burrows-Wheeler Aligner (BWA) (Li and Durbin 2009) and only considered reads that uniquely align to a single genomic location. By aligning the enset shotgun sequence reads against this Badediet genome sequence, we were able to identify 33,200 single-nucleotide variant sites. Each column in the heat-map represents one of 33,200 single-nucleotide variant sites (Figure 5.2). Each row represents one of the sequenced genomes. Colour indicates the relative frequency of aligned sequence reads with the variant nucleotide at that site in that genome, on a yellow-orange-red palette. Thus heterozygous sites would be expected to be orange, while homozygous sites would be yellow (same as Badediet reference genome sequence) or red (variant from the Badediet reference genome sequence). These frequency values were inferred from mpileup-formatted files, generated by aligning genomic sequence reads against the Badediet reference genome sequence.

Table 5.1. Illumina sequencing of *Ensete ventricosum* landraces.

SARI ID	**Name**	**Collected from**	**Depth of coverage of genome**	**SRA accession number**
362	Arkiya	Dawro	7.36 x	SRR4304969, SRR4304970
455	Arkiya	Wolaita	8.04 x	SRR4304981, SRR4304987
112	Astara	Sidama	15.64 x	SRR4304989
n/a	Bedadeti	Unknown	45.81 x	SRR1515268, SRR1515269
406	Buffero	West Arsi	18.25 x	SRR4304990
435	Derea	Gurage	18.43 x	SRR4308285, SRR4308286
451	ErpHa13	Dawro	9.21 x	SRR4304991, SRR4304992
449	ErpHa20	Dawro	9.43 x	SRR4304971, SRR4304993
221	Lochingie	Dawro	8.86 x	SRR4304972, SRR4304973
253	Lochingie	Wolaita	8.66 x	SRR4304974, SRR4304975
208	Mazia	Wolaita	7.00 x	SRR4304976, SRR4304977
429	Mazia	Dawro	8.24 x	SRR4304978, SRR4304979
39	Nechuwe	Gurage	20.69 x	SRR4304982
49	Nobo	Sheka	17.16 x	SRR4304983
170	Onjamo	Kembata-Tembaro	21.75 x	SRR4308284
183	Siyuti	Wolaita	16.54 x	SRR4304984
54	Yako	Kaffa	17.96 x	SRR4304985

Table 5.2. Assembly statistics for *Ensete ventricosum* genomes.

GenBank accession number	Enset accession	Total length (bp)	Contig N_{50} (bp)	Scaffold N_{50} (bp)
GCA_000818735.2	Bedadeti	451,284,018	20,943	21,097
GCA_001884805.1	Derea (435)	429,479,738	10,278	n.d.
GCA_001884845.1	Onjamo (170)	444,841,970	15,546	16,208

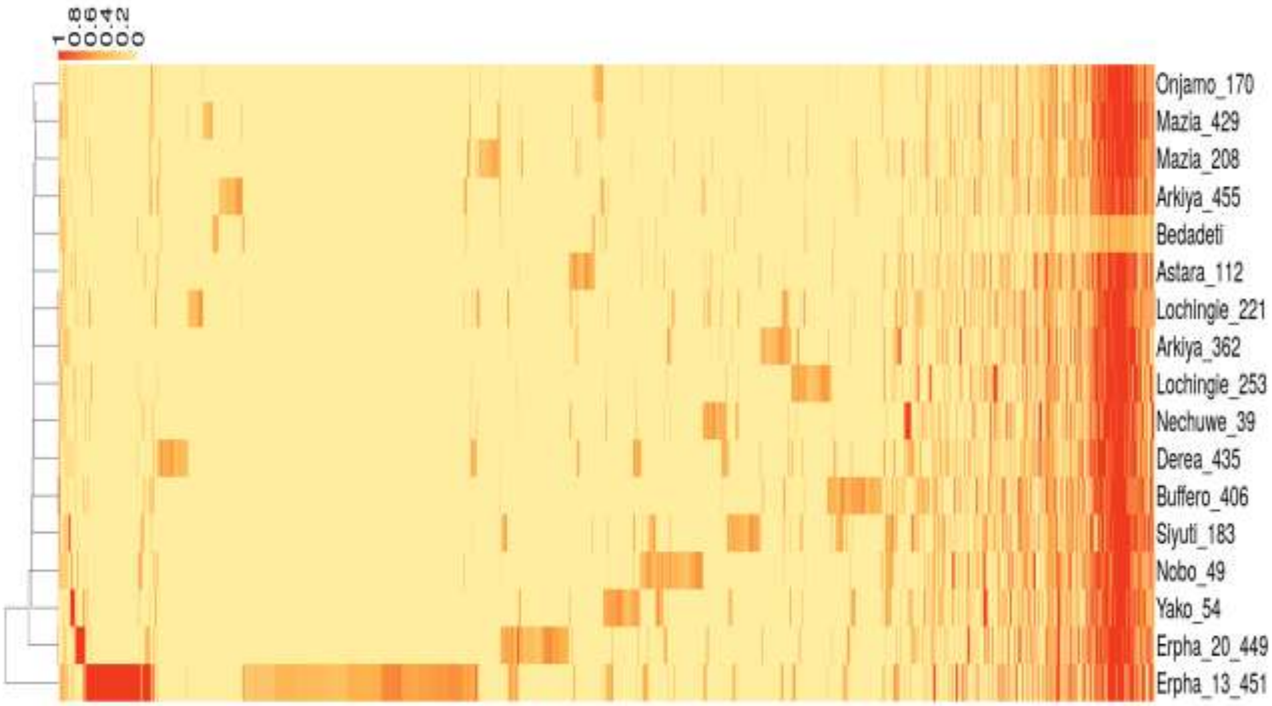

Figure 5.2. Overview of genetic variation in the sequenced *Ensete ventricosum* genomes.

5.3.3. Phylogenetic Relationship

To ascertain the phylogenetic position of the seventeen newly sequenced enset landraces, we generated a series of phylogenetic trees based on a bar code, phylogenetic indicator and sequence data from previously published studies (Bekele and Shigeta 2010; Li et al. 2010; Harrison et al. 2014). There was no sequence variation at this locus among the 17 genomes presented here, as judged by BWA alignments of raw sequence reads against *trnF-trnT* sequence (Figure 5.3). Thus, the branch indicated by the black circle represents the phylogenetic position of all 17 sequenced landraces. A black triangle highlights the position of the "Jungle Seeds" individual whose genome was previously sequenced. The Maximum Likelihood tree presented here is based on a multiple sequence alignment of *trnF-trnT* sequences generated using MUSCLE (Edger 2004). Evolutionary history was inferred by using the Maximum Likelihood method based on the Tamura-Nei model (Tamura and Nei, 1993). The tree with the highest log likelihood (-1249.11) is shown. The percentage of trees in which the associated taxa clustered together is shown next to the branches. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ algorithms to a matrix of pair wise distances estimated using the Maximum Composite Likelihood (MCL) approach, and then selecting the topology with superior log likelihood value. The tree is drawn to scale, with branch lengths measured in the number of substitutions per site. The analysis involved 32 nucleotide sequences. All positions containing gaps and missing data were eliminated. There were a total of 666 positions in the final dataset. Evolutionary analyses were conducted in MEGA7 (Kumar et al. 2016).

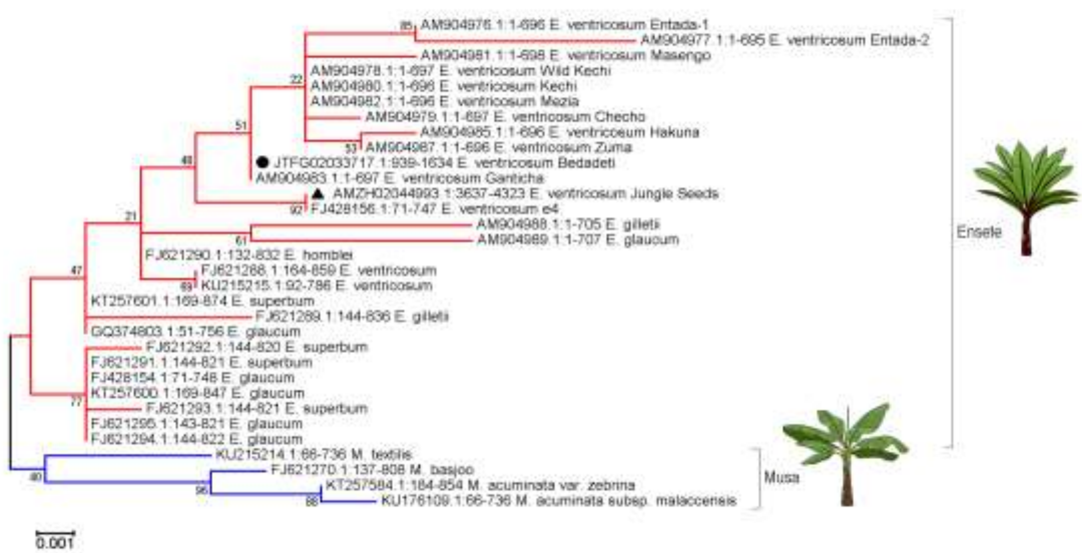

Figure 5.3. Phylogenetic positions of the enset landraces sequenced here compared to that of the previously sequenced enset genome based on sequences of the *trnF – trnT* barcode voucher region of the chloroplast DNA.

5.3.4. Primer design and validation

To validate Twenty two primers produces a potentially amplifiable product on the cultivated enset template sequence on the basis of default parameters (See methods). The selected 22 primers produced a potentially amplifiable product (Figure 5.4) on the cultivated enset template on the basis of default parameters. Details of the validated primer pair sequences with their SNP repeat motifs, annealing temperature, product size, scaffold and contig position on indicated in Table 5.3.

5.3.5. SNP genotyping

The SNP-based PCR-RFLP marker is a co-dominant marker and can be used to differentiate homozygous from heterozygous genotypes. In the PCR-RFLP assay, oligonucleotide primers are designed to amplify a PCR product that flanks a SNP that falls within the recognition site for a restriction enzyme such that one variant is cleavable by the restriction enzyme whilst the other variant is not. Thus, by examining the pattern of bands in agarose electrophoresis of the product after restriction digestion, it is possible to assess the genotype at that SNP location. We applied the 22 PCR-RFLP assays to single accession of *E. ventricosum* (Figure 5.5). Further, we then went on to apply 5 of these assays to several hundred *E. ventricosum* landraces, the results can be seen in the Appendix 7. Detail of the catalogue of the 3 SNPs for 80 landraces produced a clear band were illustrated in Table 5.4. Thus three types of banding profile (uncut-homozygous, cut-homozygous and heterozygous) were observed and scored.

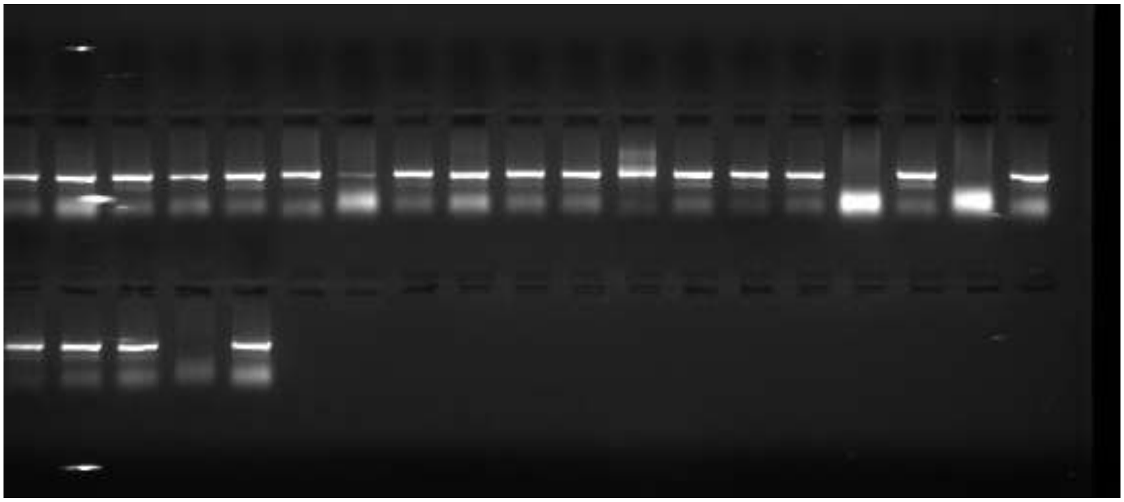

Fig 5.4. PCR amplification of the 22 primer sets

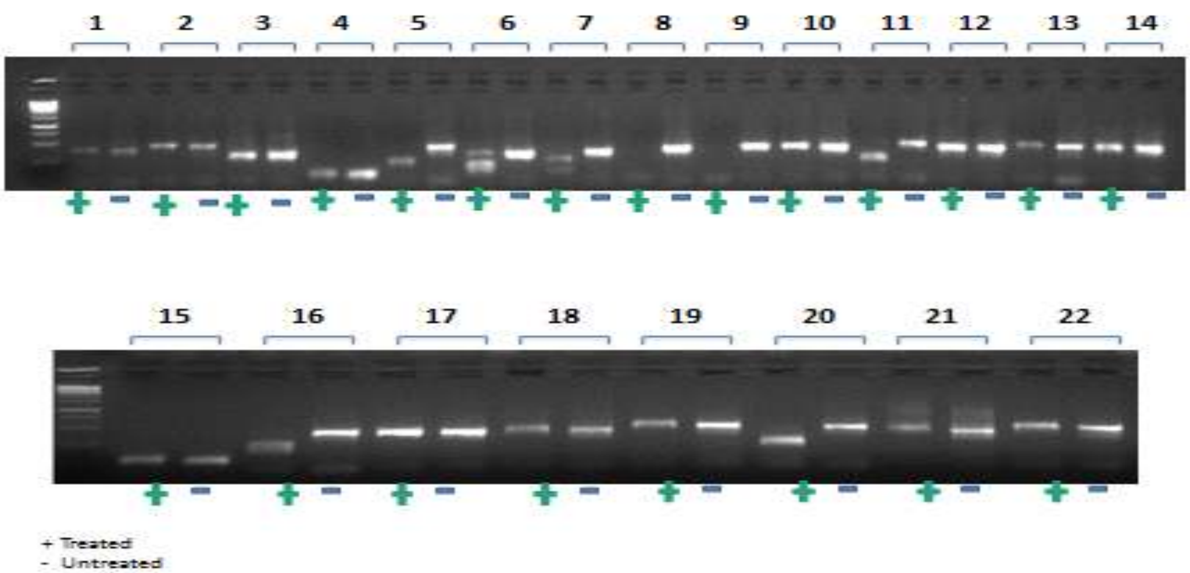

Figure 5.5. PCR-RFLP discriminates among the 22 primers

Table 5.3. Description of the SNPs primers and their restriction enzyme used for enset genetic diversity analysis.

No.	Genomic coordinates of PCR target (GenBank accession number: start-end)	Forward primer (5'→3')	Reverse primer (3'→5')	Restriction Enzyme	Product size	Corresponding location in banana genome
1	JTFG02000023: 86778-87172	tagactgccaagagactgcc	gagtttgttctccacttgctg	Eco RV	395	Chromosome 9
2	JTFG02000451: 2383-2835	caatgaaatgagctctcgaatga	cctccctccctctacacaag	Cla I	453	Chromosome 3
3	JTFG02001079: 44094-44389	agctgcctacttatgtgcca	aggatgggaggatttcactca	Cla I	296	No match
4	JTFG02001701: 16598-16697	gaaagattcaaccacgcaaca	caaagttgcccaaataatagggg	Hind III	100	Chromosome 9
5	JTFG02004430: 21696-22095	acgtaggaaacagaaggcgt	agaatgaaaaccggacagatga	Bg III	400	Chromosome 10
6	JTFG02004708: 2865-3160	gaccaaggttgcaacgatgt	aactccctaaagtggacccg	Hind III	296	No match
7	JTFG02007725: 4758-5078	tgccaattgtagcacgcttt	tcccaatgatcaggatgtcatc	Bg III	321	Chromosome 4
8	JTFG02008123: 5568-5896	agctgatcggtaggctgttt	tgttcacttgctcaacttcaatg	Eco RV	329	Chromosome 4
9	JTFG02010045: 2436-2815	cgaaggaacaagaggacgt	cggcatgaactaaccgctta	Bg III	380	No match
10	JTFG02015245: 4512-4896	agagtagaggtcagcgcatc	aggcgagtgactaaagtgct	Hind III	385	No match
11	JTFG02000797: 35394-35851	gtcatgtagaattcaaaagccca	acccatgaccaagacttttct	Cla I	458	Chromosome 10
12	JTFG02001387: 44650-45026	gcagaatcccgtgaaccatc	tgtaagtttcttctcctccgct	Bg III	377	Chromosome 10
13	JTFG02001793: 29736-30135	tgctttaacctagtgagctacaa	acgtcgcccttttacttttct	Bam HI	400	Chromosome 7
14	JTFG02003127: 17456-17853	gcccatgccattcttaagga	tccaattccatccttcttcatct	Bg III	398	Matches multiple chromosomes
15	JTFG02004277: 15220-15332	actacacaatcctggtccaaaa	cgtagtttccgccctttgag	Eco RV	113	Chromosome 5
16	JTFG02006088: 4069-4489	cctggttgagaatgcggatg	cgaccaattacactaagccca	Bg III	419	Matches several chromosomes
17	JTFG02006206: 13985-14384	tccagcccaacaattgattctt	Ctgaacctcggccaacct	Cla I	400	Matches several chromosomes
18	JTFG02010369: 10275-10674	tgccaaccgaacctctcag	tcagccatctacgacatttaca	Pst I	400	No match
19	JTFG02011833: 6273-6759	tgcttactgactatggagagct	tgcctgtttgagtccatataagt	Bam HI	487	Matches several chromosomes
20	JTFG02024842: 425-876	ctcgttaaggttccccatgc	ccagcgtgggagatcttttg	Eco RV	452	No match
21	JTFG02043259: 629-1019	cgagggcttcatcgaaaagg	Gctgccgacgagttgttc	Bam HI	391	No match
22	JTFG02009519: 11979-12424	cgatcgttacgttgcttcag	ggagccacaaccaaccaatt	Pst I	446	No match

Table 5.4. Detail of the catalogue used for genotyping of the 80 landraces based on 3 primer pairs.

No.	Gel lane number	Primers-1	Primers-5	Primers-13	Haplotype
1	1	Heterozygous	heterozygous	uncut.homozygous	10
2	2	uncut.homozygous	heterozygous	uncut.homozygous	16
3	7	cut.homozygous	heterozygous	uncut.homozygous	3
4	17	cut.homozygous	heterozygous	uncut.homozygous	3
5	27	Heterozygous	uncut.homozygous	uncut.homozygous	12
6	37	Heterozygous	heterozygous	uncut.homozygous	10
7	49	Heterozygous	heterozygous	uncut.homozygous	10
8	52	Heterozygous	heterozygous	uncut.homozygous	10
9	57	cut.homozygous	cut.homozygous	uncut.homozygous	2
10	62	Heterozygous	heterozygous	uncut.homozygous	10
11	74	Heterozygous	heterozygous	uncut.homozygous	10
12	75	Heterozygous	heterozygous	heterozygous	9
13	77	cut.homozygous	cut.homozygous	uncut.homozygous	2
14	80	Heterozygous	heterozygous	heterozygous	9
15	84	Heterozygous	heterozygous	heterozygous	9
16	87	Heterozygous	heterozygous	heterozygous	9
17	88	Heterozygous	cut.homozygous	uncut.homozygous	7
18	89	heterozygous	heterozygous	heterozygous	9
19	91	heterozygous	cut.homozygous	cut.homozygous	5
20	94	heterozygous	heterozygous	uncut.homozygous	10
21	96	heterozygous	cut.homozygous	uncut.homozygous	7
22	98	heterozygous	heterozygous	heterozygous	9
23	102	heterozygous	heterozygous	uncut.homozygous	10
24	106	cut.homozygous	cut.homozygous	uncut.homozygous	2
25	108	heterozygous	cut.homozygous	cut.homozygous	5
26	110	uncut.homozygous	uncut.homozygous	heterozygous	17
27	112	cut.homozygous	cut.homozygous	heterozygous	1
28	122	uncut.homozygous	heterozygous	heterozygous	15
29	125	cut.homozygous	cut.homozygous	uncut.homozygous	2
30	126	heterozygous	cut.homozygous	uncut.homozygous	7
31	127	uncut.homozygous	cut.homozygous	heterozygous	13
32	134	uncut.homozygous	heterozygous	uncut.homozygous	16
33	140	cut.homozygous	cut.homozygous	uncut.homozygous	2
34	141	heterozygous	cut.homozygous	cut.homozygous	5
35	163	cut.homozygous	cut.homozygous	uncut.homozygous	2
36	170	heterozygous	uncut.homozygous	heterozygous	11
37	171	cut.homozygous	heterozygous	uncut.homozygous	3
38	172	heterozygous	cut.homozygous	uncut.homozygous	7
39	183	heterozygous	cut.homozygous	heterozygous	6
40	185	cut.homozygous	cut.homozygous	heterozygous	1

Table 5.5. Continued

No.	Gel lane number	Primers-1	Primers-5	Primers-13	Haplotype
41	188	heterozygous	cut.homozygous	uncut.homozygous	7
42	197	heterozygous	Heterozygous	uncut.homozygous	10
43	200	heterozygous	Heterozygous	heterozygous	9
44	211	heterozygous	cut.homozygous	uncut.homozygous	7
45	217	cut.homozygous	cut.homozygous	uncut.homozygous	2
46	220	heterozygous	cut.homozygous	heterozygous	6
47	225	heterozygous	heterozygous	uncut.homozygous	10
48	246	heterozygous	cut.homozygous	uncut.homozygous	7
49	254	uncut.homozygous	heterozygous	heterozygous	15
50	265	heterozygous	cut.homozygous	heterozygous	6
51	266	heterozygous	cut.homozygous	cut.homozygous	5
52	267	cut.homozygous	heterozygous	uncut.homozygous	3
53	269	heterozygous	cut.homozygous	uncut.homozygous	7
54	270	heterozygous	cut.homozygous	uncut.homozygous	7
55	272	cut.homozygous	uncut.homozygous	uncut.homozygous	4
56	275	heterozygous	uncut.homozygous	uncut.homozygous	12
57	282	heterozygous	heterozygous	cut.homozygous	8
58	289	uncut.homozygous	heterozygous	uncut.homozygous	16
59	290	heterozygous	cut.homozygous	heterozygous	6
60	291	heterozygous	heterozygous	uncut.homozygous	10
61	294	heterozygous	heterozygous	heterozygous	9
62	295	heterozygous	cut.homozygous	uncut.homozygous	7
63	296	heterozygous	uncut.homozygous	uncut.homozygous	12
64	297	uncut.homozygous	heterozygous	uncut.homozygous	16
65	298	uncut.homozygous	cut.homozygous	uncut.homozygous	14
66	299	heterozygous	cut.homozygous	heterozygous	6
67	300	heterozygous	cut.homozygous	uncut.homozygous	7
68	301	cut.homozygous	heterozygous	uncut.homozygous	3
69	303	heterozygous	heterozygous	uncut.homozygous	10
70	304	heterozygous	heterozygous	heterozygous	9
71	305	heterozygous	cut.homozygous	uncut.homozygous	7
72	306	heterozygous	cut.homozygous	uncut.homozygous	7
73	307	heterozygous	cut.homozygous	uncut.homozygous	7
74	308	uncut.homozygous	heterozygous	uncut.homozygous	16
75	309	heterozygous	heterozygous	heterozygous	9
76	312	heterozygous	cut.homozygous	uncut.homozygous	7
77	315	heterozygous	cut.homozygous	uncut.homozygous	7
78	318	cut.homozygous	heterozygous	uncut.homozygous	3
79	320	heterozygous	cut.homozygous	uncut.homozygous	7
80	322	heterozygous	cut.homozygous	heterozygous	6

5.4. Conclusion

The genomic sequence of enset in 17 landraces allowed us to identify functional SNPs and develop robust SNP assays for marker-assisted breeding. This finding describes the creation and analysis of the first high-density SNP array for enset. The SNP discovery technique all proved successful in discovering tens of thousands of high quality Polymorphic SNPs in the enset genome. Linkage mapping and integration with the draft reference genome sequence suggests the SNPs are distributed widely over all chromosomes. Using a panel of 80 enset landraces, we have validated the usefulness of these SNP markers. This SNP array was publicly available in 2018 and will facilitate high-resolution studies to determine the genetic architecture of traits of economic and ecological importance, to study the structure of enset populations and to apply genomic selection in breeding programs.

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CHAPTER 6

General Conclusions and Recommendations

Enset is well-established, sustainable, and environmentally resilient farming system that contributes to food security of farmers and, in particular it serves as food security crop in densely populated areas. Enset needs to be present in farmers' pits throughout the year. All farmers are using the landraces developed by the community. These landraces have been grown on-farm for thousands of years. These enset-growing traditions still continue in the current generation. Enset represents an important cultural plant in the region. Such cultural importance is reflected in the multiple uses of enset in the traditional ecological knowledge about the crop, its biological attributes, morphological and quality variation, including size, yield and other use value quality recognized by local people among the different ethnic groups.

Farmers' rich knowledge that is accumulated on the crop over many years has played a significant role in naming, characterization and maintenance of the existing genetic diversity. Enset producing farmers have their own folk naming and classification system to distinguish one landrace from the other. Sometimes it is difficult to understand and reclassify, even while watching them to characterize. The classification of enset landraces has been accommodated by Phenotypic differences, unique traits and specific uses of landraces. Farmers differentiate one landrace from the other Phenotypically by looking at the colour of petiole, mid-rib, leaf sheath, angle of leaf orientation, size and colour of leaves and circumference & length of pseudostem. Elderly members of households are generally the best informed about enset diversity and this knowledge is transferred through oral tradition (Negash 2001).

In view of this, the multitude of names in various folk taxonomic levels indicated the occurrence of on farm genetic diversity at infra-specific level. The landrace names given by farmers' have been used as farmers' diversity unit for estimating unit for the extent and distribution of enset diversity as well as *ex situ* collection. In this study, over 300 landrace names have been identified which indicated the level of on farm genetic diversity. The meaning of the names of most landraces is not known. It is difficult to know unless the people who named it or the place of origin are traced back. Enset landraces were commonly exchanged and distributed according to the folk names. The finding of this study and other similar studies depict identically named landraces were also reported in more than one ethno-linguistic communities. Commonly, knowing folk names and classification may distinguish varieties that are actually genetically very close. Knowing folk taxonomy also helps in developing planting material distribution, flow channels, and regional landrace map. Thus, even if landrace names and classification are necessary basis, they are not sufficient to describe genetic diversity. Integrative indicators have been designed e.g. complementing the naming and folk classification with parameters of genetic diversity.

Based on their use value and folk classification, large differences were evident between landrace abundance and distribution in the region. Some landraces, particularly those having merits of better *kocho* yield and quality have got a wider distribution within and between ethnic groups. For example, the enset landraces '*Shododenia*' and '*Addo'* were encountered on respectively 37 and 34 (92.5 and 85%) farms visited in Dawro and Sidama, but were not found in any other surveyed zones. Some landraces had a very high local abundance at one or two locations and were absent from the rest. For example *Shodedenia* was encountered on 100% of the farms visited in Dawro. Our study revealed that the highest use values of the landraces were found in the region which also corresponds to where the landraces had the highest abundance in the farming system. This suggests a positive relationship between plant abundance and use.

The number of landraces grown at a given locality, their genetic similarity and the areas they occupy over time and space are influenced by planting material source, exchange and supply. Most planting material exchange is local, though a small proportion extends beyond the local group of villages reflecting relationships among neighbors and kin in most cases. All landraces used in the region are local farmer-named varieties. Among the surveyed farms, most farmers produce their own planting material. In addition farmers in the region have fixed systems to ensure the sustenance of planting material supply for each season.

Despite enset's diversity and importance, production and productivity are constrained by several biotic and abiotic factors. Bacterial wilt, caused by *Xanthomnas campestris* pv. *musacearum* is an economically important disease of enset, putting the sustainability of enset farming systems in jeopardy. Up to 80% of enset farms in Ethiopia are currently infected with enset *Xanthomonas* wilt (EXW). The disease has forced farmers to abandon enset production resulting in critical food shortage in the densely populated areas of southern Ethiopia. This disease directly affects the livelihood of more than 20% of farmers in the country. Farmers' knowledge of diseases is well documented on many crops however, similar documentation for enset is scant and not up-to-date. A few studies have documented farmers' perceptions and ethnobotanical knowledge of the enset crop; however, there is no systematic information that explicitly describes indigenous knowledge about EXW in Ethiopia and the impact of farmers' practices on the spread of EXW in Ethiopia. This information could help to guide EXW management practices in a sustainable manner.

Control of EXW is challenging, as there are no resistant landracess or effective chemical or biological measures. Management of EXW should be concentrated towards developing and disseminating control strategies including symptom identification, epidemiology and etiology of EXW, right at the field level. Continued public awareness creation program about the disease is essential. Intensive, harmonized and extended efforts are needed to provide a continuous public awareness towards EXW and developing knowledge-based strategies for its management. Practices, such as leaf removal throughout the year, should be accompanied by tool sterilization. EXW recommendations need to consider what farmers can do, given their resources. Noticeably, all enset growing farmers must be trained and empowered to decide on a refined practical EXW management recommendations, in particular disinfecting farming and processing tools, keeping fields and surrounding areas free of weeds and volunteer plants (alternative hosts), controlling wild and domestic animals from browsing, use of clean planting materials and strict control of the movement of planting material from one area to other (developing local quarantine).

Folk naming and classification are not consistent across all ethnic groups. The inconsistency is highly related with the ethnolinguistic variation in the region. Integrated folk-formal classification and levels and patterns of genetic diversity will be imperative for management and utilization of on farm genetic resources. Information on the levels and patterns of genetic diversity is valuable for effective utilization of materials in breeding program to meet the ever-changing needs of growers and consumers in the face of changing and unpredictable environmental challenges.

A prerequisite for the genetic improvement program of enset is knowledge of the extent of genetic variation present between landraces and genetic distances between them and related species with which hybrids could be produced. This could be achieved through characterization of germplasm using morphological, and molecular markers. Enset landraces were obtained from Areka Agricultural Research Center/SARI for characterization based on Phenotypic and SNP markers, a combination of both markers as well as evaluation of for EXW tolerance.

Fifteen quantitative and six qualitative traits measured proved to be a useful tool in determining the genetic variations as well as the relationships among landraces as differences were observed between the landraces for the traits studied. The variations among the landraces and regions and the correlations among most of the characters were significant. Altitude of the collection sites also significantly impacted the various characteristics studied. Qualitatively inherited morphological characteristics could be used to characterize landraces for collection and maintenance of germplasm and for parental selection through heterotic groups to improve enset. In addition, cluster analysis, PCA and discriminant analyses based on Phenotypic markers separated and grouped different landraces according to their genetic distances/similarity. Since morphological traits do not cover the entire genome, this has to be confirmed on molecular level. Furthermore, conventional breeding supplemented with Marker assisted selection of designed traits hastens progeny selection for increased yield, disease and pest resistance as well as other use value traits.

Fermented squeezed *kocho* yield per hectare per year revealed a positive and significant with plant height, pseudostem height. Since this study showed significant positive correlations intra-regionally for some characteristic combinations, it would imply correlations among the various characteristics had a genetic basis. However, it appeared that similar response to regional variation was playing a greater role than common genetic control as shown by the much more significant and moderate to high correlation coefficients inter-regionally than intra-regionally. Correlations among characteristics can help plant breeders identify easily measured characteristics that could be used as indicators of more important (but more complex-to-score) traits. Negative significant correlations were observed among some traits which could be utilized in breeding for negatively correlated traits.

The Phenotypic differences in these 15 traits suggest significant degrees of genetic variation and that these traits can be exploited to identify potential donors for future enset improvement efforts. Regional differentiations were also evident among the landraces. The implication of the current results for plant breeding, germplasm collection, and *in situ* and *ex situ* genetic resource conservation are discussed.

We present raw sequence reads and genome assemblies resulting from the sequencing of 17 landraces of the crop plant enset (*Ensete ventricosum* (Welw.) Cheesman) using the Illumina HiSeq and MiSeq platforms. Also presented is a catalogue of single-nulceotide polymorphisms inferred from the sequence data at an average density of approximately one per kilobase of genomic DNA. The landraces having similar folk name and obtained from different regions were genetically different, indicating a a diffirent ancestral source of the breeding materials. It is recommended that a combination of folk classification, morphological and DNA characterization can be used for selection of breeding material and for genetic conservation. It is also recommended that the enset breeding program include new genetically unrelated genotypes in their breeding program in order to broaden the genetic bases of the material.

In conclusion, the present study has explained the relevance of employing farmers' indigenious knowledge on folk classification and diversity managment, Phenotypic markers together with molecular markers to determine the extent and pattern of genetic variation and evolutionary relationships for enset landraces diversity to identify genetically valuable potential accession/s for future enset improvement. Distinct enset landraces that have been identified with a combination of Phenotypic and SNP markers need to be included in breeding program. Moreover, the results from the present study could contribute to *in situ* and *ex situ* conservation and effective utilization of enset material.

APPENDICES

Appendix 1. Baseline Survey on socio-economics and bio-pHysical aspects on Enset Based Farming Systems in SNNPRS

1. General information

Classifying information	Response (Answer) name and signature
Name of the enumerator	
Date of interview	
Region	
Zone	
District (Woreda)	
Kebele (PA	
Village	
Name of the supervisor	

2. Respondent and general household information

Name of household head	
Sex of Household head	1= Male 2 = Female
Age of HHH, in years	
Educational level head of HH	1=None (illiterate), 2=read and write, 3=Primary (1-4), 4=Junior (5-8), 5=Secondary (9-10), 6=Tertiary
Name and responsibility of respondent (different from HHD)	l=head 2=wife 3=so 4. Daughter; name____________
2.6. Marital Status of the HHD	1. Single 2. Married 3. Divorced 4. Widowed 5. others

3. Family characteristics

3.1 Family characteristics

No	Name (Each family member)	Age	Sex*(use code)	Education (Years)	Re(use code) relationship**	Occupation

** 1. Male 2. Female ** 1. Husband 2. Wife 3. Son 4. Daughter 5. Relatives 6. Hired 7. Others*

3.2. During the past year, has any member of the household migrated? l=yes 2=no

3.3. If yes to question 8 answer the following

No.	Name	Duration of stay (yrs)	reason for migration*	place of migration	Remittance per year (if any)

** 1. Land shortage 2. Underemployment 3. Education 4. Others (specify)________*

4. Household assets and basic facilities

4.1. What types of assets does the household currently own?

Asset type	Asset	Number owned (0=none)	Estimated total value if sold (In birr)
Communication items	Radio		
	Television		
	DVD Player		
	Tape recorder		
	PHone (fixed or mobile)		
	Satellite dish		
	Others (Specify)__		
Transportation	Motorcycle		
	Bicycle		
	Donkey		
	Horse		
	Donkey cart		
	Horse cart		
	Others (Specify)__		
Farm tools and machineries	Hoe/mattock		
	Spade/shovel		
	Ox plough (set)		
	Sickle		
	'Mensh' (Fork)		
	Decorticator (enset mefakya)		
	Grater (Amicho)		
	Others (Specify)____		
Household items	Furniture (bed, table, chair etc)		
	Water tank		
	Others (Specify)__		
Farmhouses and structures	Main houses		
	Kitchen (kushina)		
	Grain stores		
	Feed s stores		
	livestock houses		
	Water troughs		
	Feed troughs		
	Water harvesting pond		
	Others (Specify)__		
Other assets	Mills		
	Weighing balance		
	Shop		
	Others (Specify)__		

4.2. Main house description

4.2.1. What is the roofing material of the main house? 1 = Grass 2 = Iron sheet 3 = Bricks 4 =bamboo 5= Others (Specify) ________________

4.2.2. What is the wall materials of the main house 1 = Mud bricks 2 = Iron sheets 3 = Bricks/stone 4 = Wood 5 = Others (Specify) _________________

4.2.3. What is the floor material of the main house 1 = Earth 2 = Cement, 3 = Wood 4 = Tiles 5 = Others (Specify) ______

5. Access to basic facilities

Type of facility	Do you have access 1 = Yes 2 = No	If yes, distance in km	Self perception on the facilities 1 = Good 2 = Average, 3 = Poor	If no, why (use codes)
Electricity		------------------		
All weather road				
Schools				
Health services				
Animal health services				
Credit services				
Public telepHone services				
Piped water				
Agricultural extension service				
Markets (nearest)				

Codes: 1 = No access, 2 = Financial constraints, 3 = Not available, 4 = Political instability, 5 = Insecurity, 6 = Cultural beliefs, 7 = Religious beliefs, 8 = No need

6. Cropping pattern (2007 belg and 2007/8 meher season)

No.	Crop	Area cultivated (ha)	Total Yield (qt)	Amount consumed (qt)	Amount sold (qt)	Average sale price/qt (birr)
	Enset					
	Wheat					
	Food barley					
	Tef					
	Maize					
	Sorghum					
	Faba beans					
	Field peas					
	Chick pea					
	Haricot beans					
	Potato					
	Tomato					
	Shallot					
	Fruit					
	Cassava					
	Taro					
	Others_________					

7. Livestock ownership

7.1. Please indicate in details the livestock inventory in the last one year

Type of Livestock	Number currently owned			Purpose of keeping this animal *(codes*)*
	Improved	Local	Total	
Cows				
Breeding bulls				
Oxen				
Heifers				
Calves				
Sheep				
Goats				
Poultry				
Bees				

Type of Livestock	Number currently owned			Purpose of keeping this animal *(codes*)*
	Improved	Local	Total	
Donkey				
Mule				

Purpose of keeping this animal: 1 = Insurance, 2 = Store of wealth, 3 = Finance future expenditure, 4 = Prestige, 5 = Replacing stock, 6 = Manure production, 7 = Milk production, 8 = Animal draft,

7.2. If you keep livestock for others farmers indicate the reasons:____
7.3. If other farmers keep livestock for you, reasons ____
7.4 List the type of crops used for anima____

8. Enset production activities

8.1 Total size of own land_______ (timad), Rented in/shared in _______ (timad) , Rented Out /shared out_____(timad)
8.2. Do you have enset in your farm? 1. Yes 2. No
8.3. If yes, how much land is allocated for enset production (total) _______ (timad)
8.4 Type of enset planting material (1 = Corm, 2 = Botanical seed 3=Suckers)
8.5. Source of Planting material (1 = Own, 2 = purchased 3=Gift 4=Research centers 5= BoA 6=NGOs)
8.6. Gender involved in planting (1 = Male, 2 = Female, 3= Children, 4 = male and Female
8.7. Type of planting labor (1 = Family, 2 = Hired permanent, 3 = Casual labor)
8.8. How many Enset plants do you have on the Enset field (number)? 1. Suckers______2. New transplants_______ 3. Medium (2-3 years)________ 4. Matured (>4 years)__________
8.9. Do you practice transplanting? 1. Yes 2. No
8.10. If yes to, how many times did you transplant enset?_________
8.11. State their name in local language: 1. ________, 2. _______, 3. _________ 3. _______ 4. _______ 5. _______
8.12. What are the possible reasons for transplanting?____
8.13. Mention the name of different stages and method of transplanting (use question number 8.11 for name of diff stages)

Enset transplanting stage	Planting method (1. Row 2. Random)	Stage duration (years)	Gender involved (1 = Male, 2 = Female, 3 = Children, 4 = Male & female 5 = all members)	Spacing (between plant, row)

8.14. Time and method of land preparation for different transplanting stages ((use question number 8.11 for name of diff stages)

Enset stage (name in local language)	Time of land preparation	Frequency of land preparation	Method of land preparation (1=oxen plow, 2= hand hoe, 3=other)	Gender involved (1 = Male, 2 = Female, 3 = Children, 4 = Male & female, 5 = all members)

8.15. Fertilizer application (use question number 8.11 for name of diff stages)

Enset stage	Fertilizer type 1. Manure 2. DAP 3. Urea 4. Compost	Time of application (months)	Frequency of application	Rate of application/plot	Method of application (1. Broad cast 2. Ring 3. Side/heaping, 4. Other, specify

8.16. Enset weeding (use question number 8.11 for name of diff stages)

Enset stage	Time of weeding (Month)	Type of labor involved in weeding (1 = Family, 2 = Hired permanent, 3 = Casual labor)	Gender involved in weeding (1 = Male, 2 = Female, 3= Children, 4 = Male and Females 5 = all members)	Frequency of weeding

8.17. Would you practice Intercropping enset with other crop? 1. Yes 2. No

8.18. If your answer for question 8.16 yes, please mention the name of possible intercrops _______

9. Enset landrace diversity, distribution and farmers selection criteria

9.1. Do you use different criterions to conserve various enset landraces? 1. Yes 2. No

9.2. If yes, rank the matrix below for various landrace selection criterions

Landrace Selection and conservation criterions	A	B	C	D	E	F	G	H	I
high kocho yield (A)	A								
High bulla yield (B)		B							
Fiber yield/quality (length and strength) (C)			C						
Best Kocho taste/quality (colour, fermentation period, ease of decortications) (D)				D					
Bulla taste/quality (E)					E				
Amicho taste/quality (F)						F			
Tolerance to drought (G)							G		
Disease resistance (H)								H	
Early maturity (I)									I

9.3. Do you have enset landraces particularly used for medicinal and/or ritual purpose? 1. Yes 2. No

9.4. If yes, please mention the name of each landrace with their respective purpose?

Name of the landrace	Medicinal purpose

List types of Enset landraces grown on your farm and purpose of growing/their special characteristics

Name of each Landrace		Number (main field)	Maturity after transplanted to the main field*	purpose of the landrace**			Yield of the landrace***				Quality of the landrace****				Disease vulnerability *****
				Primary	Secondary	Tertiary	Kocho	Bulla	Amicho	Fiber	Kocho	Bulla	Amicho	Fiber	
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															

*1.early (<=4years) 2. Medium (4-5 years), 3. Late (>5 years); **A=Kocho, B= Bulla, C= Fiber, C= Amicho, D=Medicine, E= Drought Tolerance F= Feed

***1=high, 2=medium, 3=low; *****1= Tolerant 2=Intermediate 3= susceptible

10. Disease and pest
10.1 List out the major constraints of enset production in your farm in their order of importance (use code)?
1. Enset Bacterial wilt, 2. Enset mealy bug 3. Leaf hopper 4. Mole rate 5. Porcupine 6. Wild pig 7. Corm rout
10.2 When the EBD occur at your enset field (if any)(E.C)?__________
10.3. Is there any plant affected by EBW in 2004/5? 1. Yes 2. No
10.4. If yes, How many enset plants infected by EBW disease at your field?_____________
10.5. Do you clearly identify the disease right after the prevalence? 1. Yes 2. No
10.6. How to identify weather it is EBW disease or not? ____
10.7. In your opinion what are the causal agents of the disease? ____
10.8. Did you get any information about the diseases from locality? 1. Yes 2. No
10.9. If yes, what information did you get about the disease? ____
10.10. What is the trend of enset production in the past 15 years? 1. Increasing 2. Remain the same 3. Decreasing
10.11. Reason for the trend: ____
10.12. Landrace changes

List of Enset landrace (lost in the past years if any)	Reason for the loss	List of Enset landraces newly acquired	Reason for acquisition	Source of new landrace

10.13. At what stage the diseases severely attack enset plant? ______________________
10.14. Which part of the plant shows the first symptoms when attacked by the disease? _______________________
10.15. Can you briefly explain the progress of the disease from the first incident until the death of the plant?
____
10.16. What are mechanisms for EBW disease transmission from external source to you field? _________________
10.17. What are mechanisms for EBW disease transmitted from the infected plant to healthy __________________
10.18. Do you believe that an infected enset plant can be cured? 1. Yes 2. No
10.19. Do you believe that an EBW disease infect other plant? 1. Yes 2. No
10.20. If yes, would you mention the plant that can be potential host to the disease? __________________________
10.21. Do you believe that all enset landraces are equally susceptible for the disease? 1. Yes 2. No
10.22. If no, would you mention name of enset landrace tolerant to EBW ______,______________,_______
_______,
10.23. What do you do when one or more enset plants in your field are infected by EBW disease?____
10.24. Have you or your family members ever attend training about the EBW disease and other enset production technologies by experts? 1. Yes 2. No
10.27. If yes, who provides the training? 1. BoA 2. NGOs 3. Research centers 4. Others (specify) _________
10.28. Do you believe that EBW problem was season dependent? 1. Yes 2. No
10.29. If yes, for question 9.29 which season is more favorable for EBW ______________________________

11. Other insect pest and disease

Name of disease/pest	Causal agent	Stage of Enset attack*	Enset Parts attacked**	Tolerant landraces	Susceptible landraces	Favorable season***	Latest time of occurrence (year)	Control measures

** 1. sucker 2. First transplant 3. Second transplant 4. Third transplant 5. Main field*
*** 1. Corm 2. Pseudo steam 3. Leaf 4. Others specify__________*** 1. Dry season 2. Onset of rain season 3. Wet season*

Thank you for your Collaboration!

Appendix 2. List of named landraces in the eight ethnic groups, Diversity of the landraces and richness of the Zones

No	Name of the landrace	Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
		Frequency									
1	Agade	38	38		5		2			83	4
2	Ageramer	11								11	1
3	Ahero	19	6	1						26	3
4	Anzene	2								2	1
5	Ashekit	3	1							4	2
6	Ashura	2		1						3	2
7	Astera	6	21	2	1			31		61	5
8	Aywepe	8								8	1
9	Badedit	23	26	1	1		24			75	5
10	Bamlia	4		2						6	2
11	Bazereye	1	21							22	2
12	Beneze	21	3	1	6					31	4
13	Boseda	1								1	1
14	Boser	10	17							27	2
15	Chigezh	1								1	1
16	Dem wered	6								6	1
17	Dere	10	19	3						32	3
18	Dereketa	2		2						4	2
19	Dirbo/Dirbwa	2	2	16	4					24	4
20	Enkufaye	7	18							25	2
21	Etnete	1		18	1					20	3
22	Eyase	1		2						3	2
23	Fechecho	1		2						3	2
24	Ferezeye	6	23							29	2
25	Gafet	4								4	1
26	Guareye	17	12	3						32	3
27	Gimbo	22	10	15	34					81	4
28	Geradiye	1								1	1
29	Ginbura	1								1	1
30	Ginjina	1		2	1					4	3
31	Gomboter	2		1						3	2
32	Guder	3								3	1
33	Hinib	20		1						21	2
34	Kaker ginbo	2								2	1
35	Kaset	2		1	6					9	3
36	Keter	1								1	1
37	Kibnar	11		1						12	2
38	Kinbat	30	6							36	2
39	Kogogot	1								1	1
40	Kombeter	1								1	1
41	Lemat	1	8							9	2
42	Meriye	2		6	8					16	3
43	Mintigre	3								3	1
44	Moche	4	1	4	9				1	19	5
45	Nechewo	3	15	2						20	3

[1]Da= Dawro, Ge= Gedeo, Gu=Gurage, Ha= Hadiya, Kem=Kembata-Tembaro, Sid= Sidama, Sil= Silte, Wol= Wolayita

Appendix 2. continued

No	Name of the landrace	Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
		Frequency									
46	Sebera	9		2						11	2
47	Sesekila	4		34	25					63	3
48	Setner	2		3						5	2
49	Shesha shirteye	3								3	1
50	Shirteye	20	22	1			1			44	4
51	Showrat	9			1					10	2
52	Sino	6								6	1
53	Sorat yebadedit	3	1							4	2
54	Tegeded	11	7	2						20	3
55	Tereye	1	4							5	2
56	Torore/Toracho	3	1	6	19	2	1	20	1	53	8
57	Uzkurze	1		3	8					12	3
58	Wahe,a	1		4	1					6	3
59	Woshamada	7		3						10	2
60	Welegele	1								1	1
61	Wunado	3	1		6					10	3
62	Yedebir	3								3	1
63	Yesherafere	8	9							17	2
64	Yezer badedit	3	4	1						8	3
65	Zagez	1								1	1
66	Zebre	1								1	1
67	Zeget	2	1							3	2
68	Zelebedadit	5	2	1						8	3
69	Zigiz	1								1	1
70	Amerat		4							4	1
71	Anash		3							3	1
72	Argama		1	4	1	1	17			24	5
73	Art		1							1	1
74	Aseso ert		1							1	1
75	Azina		2							2	1
76	Baritsya		1							1	1
77	Botena		1							1	1
78	Boza		2				20			22	2
79	Bukuniya		1				7			8	2
80	Chehoyet		4							4	1
81	Emreye		7	1						8	2
82	Enba		2							2	1
83	Gasa		1							1	1
84	Genbene bazereye		1							1	1
85	Genna		1			6	4		21	32	4
86	Gezit		2							2	1
87	Kanchuwe		3		1					4	2
88	Katania		2				3			5	2
89	Kekle		2	5						7	2
90	Kuanchewe		1							1	1

[1]Da= Dawro, Ge= Gedeo, Gu=Gurage, Ha= Hadiya, Kem=Kembata-Tembaro, Sid= Sidama, Sil= Silte, Wol= Wolayita

Appendix 2. continued

No		Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
	Name of the landrace	Frequency									
91	Kushkusheye		2							2	1
92	Natsam		1							1	1
93	Nech bazer		1							1	1
94	Neriye		2							2	1
95	Qey b azer		3	2						5	2
96	Qibnar		17							17	1
97	Serat		5							5	1
98	Sheme agaye		1							1	1
99	Tederader		5							5	1
100	Woret		1							1	1
101	Yeilma		1							1	1
102	Yekela enset		1							1	1
103	Yergeye		1							1	1
104	Zegurt		1							1	1
105	Abet merze			5						5	1
106	Ambo			1						1	1
107	Aniya			1						1	1
108	Banko			2						2	1
109	Cherkuwa			1	1					2	2
110	Dego			8	2					10	2
111	Desho			6	28					34	2
112	Diqaa			1						1	1
113	Farachase			2						2	1
114	Gesher			15	10					25	2
115	Goderete/Godere			1		1				2	2
116	Gonmora			1						1	1
117	Haeala			6		8				14	2
118	Keberbeye			1						1	1
119	Koyena			2	6					8	2
120	Lekaka			15	1					16	2
121	Menduleka			1						1	1
122	Mereze			16	7					23	2
123	Mesmes/Mesmesiya			2	10	1				13	3
124	Sheleqe			15	8					23	2
125	Shesha shirteye			2						2	1
126	Sorpe			12						12	1
127	Tebere			2						2	1
128	Tesa			6	5					11	2
129	Udole			1						1	1
130	Unjamo			16	9					25	2
131	Wacheso			2						2	1
132	Walema			1						1	1
133	Wolanche			5	2					7	2
134	Bekuch				3					3	1
135	Bose				3					3	1

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Appendix 2. continued

No	Name of the landrace	Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
		Frequency									
136	Ezgera				2					2	1
137	Fuga				1					1	1
138	Gozod				2					2	1
139	Haywena				10					10	1
140	Hekecha				1					1	1
141	Henuwa				5					5	1
142	Kekir				1					1	1
143	Korin				2					2	1
144	Lokenda				3					3	1
145	Separa				10					10	1
146	Shate				5					5	1
147	Shodedina				2					2	1
148	Shumbiratie				1					1	1
149	Sinere				6					6	1
150	Sinkute				1					1	1
151	Sowandiya				1					1	1
152	Ti'ona				1					1	1
153	Zobira				4					4	1
154	Ankogena					2	1			3	2
155	Alagena					9				9	1
156	Anekuwa					4				4	1
157	Arekiya					6	21			27	2
158	Atane					1				1	1
159	Botiya					2				2	1
160	Chemeya					3				3	1
161	Checheya					1				1	1
162	Dinka					1				1	1
163	Gefetanuwa					12				12	1
164	Lenbo					5				5	1
165	Lochanegeya					2	7			9	2
166	Mazia					4	28			32	2
167	Naqaqa					11				11	1
168	Qabarecho					4				4	1
169	Qabariya					15				15	1
170	Qucha					1				1	1
171	Shala qomiya					25	1			26	2
172	Sutiya					1	1			2	2
173	Tuzuma					22	5			27	2
174	Wanaqbariya					2				2	1
175	Wanadeya					10				10	1
176	Adinona						2			2	1
177	Adnar						1			1	1
178	Agina						7	4	3	14	3
179	Agunsa areziya						1			1	1
180	Alodnita						1			1	1

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Appendix 2. continued

No	Name of the landrace	Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
		Frequency									
181	Amiya						`15			0	1
182	Amraga						1			1	1
183	Anko maziya						6			6	1
184	Ante argal						1			1	1
185	Areteya						1			1	1
186	Bakiya						1			1	1
187	Bala arkiya						2			2	1
188	Bale geziya						1			1	1
189	Bale maziya						1			1	1
190	Bale shedodeniya						2			2	1
191	Barjia						1			1	1
192	Betaniya						1			1	1
193	Betsena						2			2	1
194	Banga						1			1	1
195	Bosena						12			12	1
196	Bota maziya						5			5	1
197	Botindira						2			2	1
198	Deka						1			1	1
199	Deka arikiya						2			2	1
200	Digaa						1			1	1
201	Ealoria						2			2	1
202	Erantia						2			2	1
203	Gadeye						1			1	1
204	Gamaria						2			2	1
205	Giea						1			1	1
206	Hal maziya						7			7	1
207	Hoindia						4			4	1
208	Kareta mati						1			1	1
209	Kartiya						8			8	1
210	Kekefeya						4			4	1
211	Keruma						9			9	1
212	Koziya						1			1	1
213	Kuruwa						12			12	1
214	Macha shededin						1			1	1
215	Manjo maziya						1			1	1
216	Mataka						7			7	1
217	Mushwa						1			1	1
218	Samra						3			3	1
219	Sanka						6			6	1
220	Shedodeniya						37			37	1
221	Shemoya						3			3	1
222	Shemta						1			1	1
223	Shesha						2			2	1
224	Shuchfin						2			2	1
225	Sirara						4			4	1

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Appendix 2. continued

No	Name of the landrace	Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
		Frequency									
226	Tsela						13			13	1
227	Woaya						2			2	1
228	Yaka						22			22	1
229	Yapa						9			9	1
230	Yerga						1			1	1
231	Yesha						3			3	1
232	Yesha maziya						9			9	1
233	Yiliga						6			6	1
234	Zira maziya						3			3	1
235	Denbola							8		8	1
236	Deneka							2		2	1
237	Dimoye							8		8	1
238	Filil							2		2	1
239	Fokonie							2		2	1
240	Foneqe							2		2	1
241	Galasho							1		1	1
242	Ganetecho							37	39	76	2
243	Gatara							2		2	1
244	Gosalo							4	10	14	2
245	Haramo							7		7	1
246	Haranjo							1		1	1
247	Helila							1		1	1
248	Kake							1		1	1
249	Mundame							3		3	1
250	Nefo							23	4	27	2
251	Qarasie							15		15	1
252	Qelitate							1		1	1
253	Qeralicho							1		1	1
254	Qorqor							2		2	1
255	Shasha							2		2	1
256	Shegna							2		2	1
257	Toramy							6		6	1
258	Adem ado								2	2	1
259	Addo								34	34	1
260	Alom a								1	1	1
261	Altecho								9	9	1
262	Arsho								2	2	1
263	Askale								14	14	1
264	Aydira								1	1	1
265	Batota								3	3	1
266	Berberachu								1	1	1
267	Bericho								1	1	1
268	Bero gantecha								1	1	1
269	Bewot ado								2	2	1
270	Bira								16	16	1

[1]Da= Dawro, Ge= Gedeo, Gu=Gurage, Ha= Hadiya, Kem=Kembata-Tembaro, Sid= Sidama, Sil= Silte, Wol= Wolayita

Appendix 2. continued

No	Name of the landrace	Silte	Gur	Kem	Had	Wol	Daw	Ged	Sid	TOT	Zones
		Frequency									
271	Birbo								15	15	1
272	Birdere								1	1	1
273	Bonjo								6	6	1
274	Borganticha								6	6	1
275	Bufere								4	4	1
276	Bulo								6	6	1
277	Chacho								15	15	1
278	Damala								2	2	1
279	Derese ado								3	3	1
280	Dersem								1	1	1
281	Dersete								11	11	1
282	Dewane								1	1	1
283	Deweramo								6	6	1
284	Enboma								3	3	1
285	Gabewo								3	3	1
286	Gademe								12	12	1
287	Gamachala								2	2	1
288	Garbo								1	1	1
289	Goloma								1	1	1
290	Gulumo								16	16	1
291	Haho								3	3	1
292	Hamsesa								1	1	1
293	Hawe								1	1	1
294	Hekece								1	1	1
295	Kanda								1	1	1
296	Keshe								6	6	1
297	Kiticho								24	24	1
298	Kule								10	10	1
299	Lemecho								4	4	1
300	Mada								4	4	1
301	Mendenar								8	8	1
302	Midasho								25	25	1
303	Monofila								1	1	1
304	Nech enset								1	1	1
305	Resecho								1	1	1
306	Sercho								1	1	1
307	Serero								2	2	1
308	Sidera								1	1	1
309	Uwisho								21	21	1
310	Wankore								2	2	1
311	Washa								1	1	1
312	Worm kalo								1	1	1
Richness of zones		69	63	66	51	28	75	26	62		
Number of rare landraces		21	26	15	20	15	58	20	55		

[1]Da= Dawro, Ge= Gedeo, Gu=Gurage, Ha= Hadiya, Kem=Kembata-Tembaro, Sid= Sidama, Sil= Silte, Wol= Wolayita

Appendix 3 Means of 15 Quantitative traits of the 387 enset landraces tested at Areka.

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
1	Abatmerza	1	3	4.80	6.71	2.19	1.36	9.50	4.36	0.69	16.50	70.46	32.96	13.96	36.46	37.51	12.05	8.25
2	Abato	1	2	2.85	6.35	1.85	1.26	10.00	3.69	0.64	19.00	60.46	29.96	19.21	18.21	49.67	14.01	10.34
3	Airo	1	2	4.08	4.81	1.51	0.91	12.50	3.10	0.54	17.50	38.96	19.96	9.71	19.46	25.67	12.69	8.51
4	Ashura	1	3	4.76	5.71	1.76	1.38	12.00	3.66	0.68	20.50	96.96	46.46	16.96	62.96	58.96	21.64	17.57
5	Astara	1	2	5.93	4.21	1.36	1.16	7.50	2.44	0.51	25.00	26.46	12.46	10.46	30.46	18.20	5.08	3.20
6	Azenora	1	3	2.07	4.36	1.11	0.81	13.50	2.98	0.61	21.00	49.96	25.46	11.46	4.96	41.70	16.36	8.93
7	Becherota	1	3	3.25	5.17	1.49	1.21	10.00	3.26	0.64	14.50	38.96	22.96	12.96	15.46	34.50	10.11	5.44
8	Bedadeda	1	2	5.98	4.17	1.21	1.04	5.00	2.04	0.56	16.00	40.46	16.96	9.46	30.96	18.97	5.17	4.51
9	Bedediet	1	2	3.95	5.47	1.66	1.16	11.50	3.25	0.54	19.00	53.46	30.46	13.46	37.46	43.83	19.11	11.95
10	Beleka	1	3	2.98	5.44	1.46	1.26	14.50	3.64	0.62	21.50	71.46	36.96	17.46	28.96	58.89	15.14	6.73
11	Bikamo	1	2	4.90	5.16	1.69	1.09	8.00	3.18	0.62	16.00	42.46	17.46	10.96	23.96	23.24	8.90	6.06
12	Bikamo	1	2	3.27	6.91	2.11	1.28	12.50	4.21	0.85	21.50	97.46	52.96	26.96	37.71	76.17	34.25	23.17
13	Bishato	1	3	4.86	7.51	2.39	1.27	9.00	4.67	0.69	23.00	106.96	42.96	14.46	46.46	45.97	17.66	14.12
14	Boela	1	2	2.24	4.78	1.34	1.07	9.00	3.16	0.68	22.00	72.46	18.71	13.96	11.96	41.24	13.34	10.11
15	Bossie	1	3	3.31	7.16	2.31	1.55	10.00	4.22	0.80	21.50	108.46	56.46	26.46	42.96	80.95	21.07	11.77
16	Chereka	1	3	3.81	5.99	1.99	1.01	10.25	3.26	0.56	17.50	65.46	23.96	13.71	34.71	40.76	17.29	11.62
17	Dengicho	1	3	4.32	6.11	1.71	1.08	10.00	3.59	0.57	16.50	46.46	24.96	10.96	38.46	36.79	8.24	4.92
18	Denticho	1	2	2.80	7.42	2.06	1.54	11.00	4.42	0.79	18.50	89.00	60.96	22.46	44.46	95.47	40.25	20.50
19	Digomerza	1	3	2.54	5.21	1.46	1.16	10.50	3.29	0.67	16.00	61.46	31.96	19.21	14.96	54.43	22.57	14.76
20	Dirbo	1	3	3.22	5.17	1.39	1.15	10.00	3.21	0.62	17.50	54.46	26.71	12.71	22.46	40.57	15.28	10.29
21	Disho	1	3	5.23	4.79	1.51	1.01	8.50	3.24	0.68	18.50	40.46	23.46	23.46	14.96	25.28	6.95	4.68
22	Etinie	1	3	6.00	4.71	1.51	1.26	6.50	3.06	0.66	16.50	76.96	34.46	10.96	27.46	23.86	9.13	8.31
23	Fechachie	1	2	4.79	6.08	1.76	1.35	11.00	3.84	0.81	22.00	90.46	24.96	21.96	28.46	34.47	14.02	9.19
24	Ferchasa	1	3	5.58	5.80	2.10	1.09	10.50	3.75	0.56	20.00	64.46	25.96	6.46	26.96	22.99	10.56	8.82
25	Ferezia	1	2	3.99	4.79	1.41	1.09	10.00	2.90	0.56	17.50	57.96	21.46	11.96	23.46	30.43	15.30	8.56
26	Fugatesa	1	3	2.93	5.34	1.61	1.01	8.50	3.21	0.61	21.00	52.46	25.46	11.46	18.96	40.19	16.14	11.46
27	Gimbo	1	3	3.21	5.62	1.52	1.47	13.75	3.58	0.81	21.50	81.46	41.96	24.46	30.71	63.99	19.71	9.92
28	Ginjena	1	2	3.15	5.94	1.69	1.21	10.00	3.69	0.67	18.00	85.96	43.96	16.96	17.96	52.39	21.85	14.35
29	Gishera	1	3	4.24	5.36	1.59	1.01	10.00	3.51	0.72	20.00	51.46	37.96	10.46	32.46	41.60	11.53	5.47
30	Goemerrie	1	3	4.80	5.65	2.04	0.96	7.50	3.27	0.71	15.00	60.46	25.46	14.46	28.46	30.77	10.05	6.91
31	Gotedirbo	1	1	2.81	6.59	1.96	1.21	11.50	3.96	0.67	18.50	76.46	35.96	17.96	23.96	58.62	16.12	9.21
32	Gozeza	1	3	5.86	5.38	2.19	1.16	5.00	3.15	0.64	19.00	71.96	29.96	11.96	33.46	23.92	8.77	7.04
33	Guarye	1	2	2.44	5.54	1.21	0.96	14.00	3.72	0.65	21.50	47.46	22.46	8.46	11.46	36.18	16.17	11.03
34	Gulfe	1	3	3.81	5.99	1.99	1.01	10.50	3.26	0.56	13.50	43.46	17.96	14.21	21.21	29.93	14.57	7.69

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
35	Gureza	1	3	3.06	5.69	1.66	1.10	11.00	3.56	0.65	18.50	57.96	30.46	17.96	13.96	44.83	14.87	8.52
36	Hankuchie	1	3	2.83	5.31	1.51	0.94	11.50	3.31	0.62	18.50	45.96	22.96	11.46	10.46	33.34	9.65	4.92
37	Hargamo	1	2	3.74	7.11	2.01	1.06	10.00	4.26	0.72	20.50	95.96	46.46	17.96	44.46	62.32	26.01	16.41
38	Heilla	1	2	3.75	5.67	1.54	1.04	9.00	3.35	0.57	20.50	49.46	27.46	9.46	26.96	36.33	14.16	8.75
39	Henuwa	1	3	4.28	5.45	1.79	1.25	11.50	3.10	0.52	20.00	70.96	40.46	16.46	43.96	49.65	14.85	9.70
40	Hiniba	1	2	5.00	4.66	1.46	0.96	7.50	2.94	0.54	19.50	36.46	20.46	8.96	23.46	23.02	8.39	5.57
41	Jegeda	1	3	2.55	6.08	1.66	1.42	13.50	3.75	0.74	22.50	85.46	38.46	17.96	19.96	62.65	29.07	22.51
42	Keberichie	1	2	3.62	5.01	1.46	0.99	7.50	3.16	0.56	17.00	62.46	26.46	12.96	14.96	31.93	16.68	7.88
43	Kembat	1	3	4.74	6.55	2.01	1.13	10.50	4.16	0.64	24.00	103.46	51.96	13.21	47.96	50.97	19.27	13.73
44	Kerbo	1	2	2.24	4.24	1.39	0.97	12.00	2.74	0.52	24.50	63.46	28.46	15.46	5.46	45.98	23.21	16.26
45	Kerkerie	1	3	4.04	5.31	1.64	1.19	12.00	3.42	0.63	26.50	93.46	41.46	14.46	34.46	48.04	17.86	12.23
46	Keshkeshiya	1	2	4.11	5.35	1.61	1.09	11.50	3.72	0.65	15.50	32.96	16.46	9.46	11.96	19.77	7.99	5.17
47	Kessiet	1	3	4.61	6.06	2.42	1.10	10.00	3.27	0.70	20.50	53.46	26.21	15.46	50.46	43.07	14.94	7.84
48	Kinchie	1	3	2.51	6.40	2.06	1.31	11.50	4.38	0.87	23.00	105.96	63.96	25.96	20.46	93.70	31.85	7.58
49	Korttie	1	3	3.75	6.43	1.96	1.07	14.00	3.59	0.66	19.50	50.21	24.46	20.96	28.96	43.19	21.45	14.87
50	Lekaka	1	2	5.31	7.61	2.56	1.42	10.00	4.66	0.74	22.50	130.46	50.46	19.46	69.46	56.65	20.00	16.50
51	Manduluka	1	2	4.16	5.20	1.66	1.14	12.50	3.36	0.75	16.00	61.46	31.96	18.46	14.96	33.62	14.12	9.23
52	Mariya	1	3	3.06	5.52	2.16	1.04	10.00	3.55	0.62	19.00	75.46	28.46	15.96	20.21	44.28	9.76	4.88
53	Menera	1	3	3.80	6.71	1.91	1.09	10.50	3.26	0.54	18.00	54.46	26.96	10.96	28.96	37.49	16.51	10.75
54	Mesmesa	1	3	5.85	4.86	1.24	1.46	6.00	3.28	0.64	17.00	75.46	33.96	9.46	45.46	28.45	9.32	7.98
55	Nechiwe	1	3	4.01	5.85	1.91	1.27	12.50	3.40	0.74	22.50	64.46	28.96	15.96	37.46	43.71	16.57	11.39
56	Oniya	1	3	3.23	5.28	1.50	1.12	12.00	3.38	0.66	20.00	65.96	24.71	13.46	15.46	35.21	11.62	7.19
57	Onjamo	1	3	4.58	6.19	1.93	1.42	11.96	3.91	0.71	20.00	74.46	38.96	20.96	39.96	46.86	13.31	9.56
58	Ored	1	3	4.27	5.79	1.71	1.30	11.75	3.32	0.71	24.00	88.46	40.21	16.46	38.71	47.97	17.43	13.13
59	Ososa	1	2	3.81	5.97	1.94	1.14	12.00	3.55	0.54	22.00	73.46	32.46	12.46	27.46	40.86	16.43	10.75
60	Senkutie	1	3	5.84	4.33	1.08	1.10	7.00	2.76	0.42	17.00	45.96	15.96	8.96	13.96	11.98	5.82	3.66
61	Sesikila	1	3	5.32	6.20	1.79	1.16	9.00	4.21	0.68	17.50	30.46	12.96	12.46	22.46	19.38	10.48	8.26
62	Sessa	1	1	4.80	7.51	2.86	1.02	12.00	4.34	0.65	21.50	105.96	48.46	12.96	47.96	48.97	19.21	13.61
63	Shelekie	1	3	4.17	6.16	1.94	1.29	11.00	3.94	0.71	18.50	82.46	36.21	15.46	34.46	44.84	13.52	10.11
64	Tebuttie	1	2	4.01	3.92	1.29	0.75	10.50	2.24	0.46	15.00	20.46	11.96	8.46	10.71	16.58	6.07	4.48
65	Tegaded	1	3	5.20	5.94	1.84	1.11	10.00	3.78	0.69	21.50	46.46	19.46	9.96	22.46	21.44	9.89	6.38
66	Tesa	1	3	4.08	5.50	1.66	1.09	9.00	3.11	0.66	20.00	61.46	27.96	11.46	29.46	36.27	16.53	10.98
67	Wechered	1	3	3.90	6.44	1.56	1.20	10.00	3.74	0.74	17.50	74.21	39.36	17.96	32.46	49.26	19.61	11.85
68	Wellachie	1	3	3.16	6.12	1.79	1.27	12.00	3.89	0.62	18.00	67.96	40.46	15.96	20.96	52.02	22.30	13.20

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
69	Wenadie	1	3	4.51	4.51	1.66	1.06	12.00	2.58	0.57	15.50	28.21	14.96	10.46	27.96	25.40	9.60	7.19
70	Weshmeda	1	3	5.41	5.07	1.71	1.08	9.00	3.04	0.62	18.50	38.46	17.96	12.11	33.96	25.61	9.58	7.77
71	Wohie	1	2	3.13	6.06	1.84	1.20	11.00	3.90	0.73	19.50	62.96	28.96	14.96	21.46	43.97	18.40	11.36
72	Zebro	1	2	3.43	5.40	1.54	1.16	11.50	3.34	0.68	17.00	65.46	30.21	18.46	21.71	43.65	17.22	8.37
73	Zeriyie	1	2	4.80	5.18	1.61	1.22	9.50	3.39	0.56	17.50	39.96	15.46	13.46	25.46	24.47	12.65	7.76
74	YANBULE	1	2	2.58	6.98	2.27	1.52	9.83	4.44	0.93	19.17	150.13	72.21	29.12	40.13	94.14	28.59	19.77
75	ENDALE	1	2	4.68	6.65	2.14	1.23	9.25	4.28	0.68	22.50	112.71	53.80	23.21	50.38	51.74	27.83	18.83
76	ZERITA	1	2	3.47	5.82	1.73	1.15	10.83	3.09	0.51	21.00	86.55	49.26	20.38	31.21	46.25	24.63	16.76
77	GEWADA	1	2	3.07	7.08	2.51	1.35	11.50	3.86	0.68	20.17	121.88	62.63	23.38	35.05	72.10	27.40	18.43
78	KELISA	1	2	3.95	6.09	1.97	1.27	9.42	3.35	0.61	26.50	200.63	84.88	24.63	55.30	73.81	26.44	19.72
79	MESENA	1	2	3.60	4.46	1.59	0.87	8.83	2.39	0.45	17.00	70.46	42.15	19.63	26.63	67.47	20.90	13.06
80	Aeluwa	2	2	4.85	6.03	1.94	1.16	8.50	3.81	0.80	16.50	61.96	27.46	10.46	17.96	24.91	8.67	6.23
81	Aguasa(ta)	2	2	5.42	4.00	1.52	0.61	8.50	2.21	0.53	11.00	9.96	5.96	6.46	13.96	10.40	2.56	1.37
82	Akachiya	2	2	4.87	4.76	1.46	0.86	9.00	2.76	0.54	12.50	26.46	12.46	7.96	42.46	27.74	12.75	8.12
83	Argema	2	3	5.73	6.16	1.99	1.37	11.00	3.91	0.73	18.50	82.46	40.46	13.96	62.96	44.29	14.93	12.49
84	Ayina	2	3	4.74	5.61	1.81	1.56	9.00	3.69	0.81	19.50	78.46	43.46	15.46	53.46	50.94	21.71	17.63
85	Banga	2	3	5.90	5.85	1.91	1.43	10.50	3.53	0.84	16.50	89.96	43.96	15.96	58.46	41.45	7.91	6.64
86	Berjiye	2	3	4.73	4.76	1.60	1.10	7.50	2.34	0.66	12.50	37.96	24.96	15.46	43.46	38.04	7.67	5.17
87	Bota-meziya	2	3	3.81	5.36	2.29	1.05	13.00	3.76	0.60	22.00	61.71	25.96	16.71	22.46	36.85	17.31	14.18
88	Buba	2	3	5.77	3.66	1.36	0.84	8.00	2.06	0.46	15.00	22.96	14.46	5.96	18.96	14.74	3.34	2.39
89	Bukuniye	2	3	4.20	6.59	1.86	1.33	11.00	3.70	0.80	19.00	86.96	39.96	25.46	45.96	56.61	26.98	20.12
90	Bumbe	2	3	4.04	6.31	1.79	0.93	7.00	3.19	0.61	14.50	29.96	14.46	9.46	14.46	20.35	5.26	3.14
91	Dika	2	3	3.67	5.09	1.44	1.09	12.00	3.07	0.54	21.00	49.96	24.96	15.96	23.21	37.14	15.87	11.10
92	Donkolola	2	2	3.82	4.76	1.46	0.86	9.50	2.76	0.54	15.00	38.46	15.46	11.46	16.96	24.60	7.70	4.11
93	Dorta	2	2	5.74	4.67	1.59	1.14	9.00	2.83	0.57	17.00	37.96	17.96	14.96	27.96	23.44	10.57	7.84
94	Elore	2	2	5.91	2.96	0.96	0.68	4.96	1.94	0.37	14.00	10.96	2.96	1.96	16.96	7.06	1.88	1.26
95	Fenchariya-yepa	2	3	4.69	7.32	2.41	1.64	11.00	4.33	0.85	20.50	124.96	60.96	18.46	55.46	62.91	24.42	17.63
96	Goshindiya	2	3	4.81	5.79	1.76	1.25	10.50	3.60	0.85	17.50	50.46	24.46	16.46	46.46	39.61	16.60	11.03
97	Hala-a	2	2	4.95	4.55	1.44	0.95	9.50	2.70	0.61	15.00	31.96	13.96	6.96	16.46	16.23	5.60	3.22
98	Hasa-bedadiye	2	2	5.81	3.25	1.21	0.96	6.50	2.47	0.66	15.50	67.96	32.46	21.96	25.46	23.12	7.47	5.02
99	Hoendiye	2	2	3.03	6.23	1.36	1.22	8.00	3.71	0.70	16.00	67.96	32.46	21.96	25.46	55.71	15.30	13.73
100	Kazia	2	3	3.24	5.09	2.19	1.11	10.50	3.07	0.58	14.50	45.96	20.46	17.46	15.46	34.85	12.68	6.81
101	Kekere	2	3	4.60	4.32	1.41	0.96	8.00	2.37	0.59	19.00	27.46	14.46	9.46	22.96	21.96	10.21	6.53
102	Keteniya	2	3	4.11	2.29	0.96	0.54	6.50	1.05	0.33	14.50	9.96	4.46	2.46	6.46	7.06	2.46	1.41

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
103	Sanka	2	3	5.88	4.68	1.64	0.90	8.50	2.73	0.56	14.00	27.46	19.46	9.46	30.46	21.84	5.10	2.90
104	Tena	2	2	2.76	5.60	1.29	1.18	12.50	3.60	0.73	18.50	50.46	25.46	17.46	14.46	43.80	16.72	13.68
105	Yesha	2	3	5.22	4.94	1.64	0.97	8.00	3.10	0.67	16.50	44.96	18.96	11.46	16.96	19.57	7.02	3.59
106	ErpHa12	2	3	2.69	5.91	1.54	1.28	11.25	3.88	0.69	23.50	64.96	12.84	16.46	22.96	47.68	15.13	10.73
107	ErpHa13	2	3	2.64	5.16	1.55	1.47	11.75	3.17	0.71	32.50	94.96	41.88	18.80	18.21	60.07	15.75	11.37
108	ErpHa18	2	3	2.90	5.43	1.64	1.28	11.00	3.29	0.70	24.00	87.13	35.96	15.46	17.46	69.57	22.13	16.68
109	ErpHa14	2	3	4.91	5.54	1.74	1.33	11.25	3.43	0.78	28.50	70.09	32.21	17.71	17.46	41.84	11.51	8.23
110	ErpHa8	2	3	3.17	5.02	1.43	1.25	11.25	3.19	0.65	29.00	73.88	33.71	17.09	15.46	37.77	16.42	12.48
111	ErpHa2	2	3	2.93	4.94	1.41	1.34	11.00	3.42	0.70	29.00	83.88	38.46	16.30	19.63	60.97	18.18	13.37
112	ErpHa3	2	3	2.88	2.96	2.11	1.24	9.75	3.21	0.74	30.00	69.46	29.42	20.84	13.21	24.88	20.04	15.87
113	ErpHa7	2	3	3.16	4.91	1.36	1.10	8.00	3.30	0.66	18.25	47.71	26.46	14.84	29.71	41.92	11.34	6.75
114	Zergesa	2	2	4.78	5.19	1.70	1.20	9.25	4.08	0.62	20.00	67.71	27.71	23.71	17.21	22.14	7.86	5.15
115	Mecha-boza	2	2	5.22	6.83	1.86	1.31	11.00	3.90	0.91	19.75	117.46	47.29	27.29	26.80	22.65	9.61	7.27
116	Meziya	2	2	3.56	5.86	1.53	1.61	12.00	3.70	0.72	18.00	55.21	26.71	20.21	30.71	35.10	10.87	7.82
117	Shelekuma	2	2	4.75	6.01	1.87	1.29	11.50	3.94	0.74	19.75	76.88	23.30	15.96	16.84	11.83	5.25	3.75
118	Shemera	2	3	3.09	5.82	2.05	1.05	10.25	2.88	0.75	20.00	74.71	35.96	20.09	30.46	17.59	18.96	14.38
119	Gulumo	2	3	4.75	6.35	1.69	1.38	12.00	3.29	0.64	27.00	53.46	18.71	15.71	15.71	16.54	9.95	6.62
120	ErpHa19	2	3	2.50	5.38	1.67	1.20	10.25	3.16	0.65	37.00	65.46	21.46	16.59	20.84	58.04	18.99	13.19
121	Bosena	2	3	3.20	5.83	3.61	1.13	11.50	3.31	0.68	16.25	44.13	30.61	19.80	19.63	50.66	8.93	5.60
122	Yesha-Mezia	2	3	4.38	5.50	1.64	1.22	10.75	3.45	0.69	19.00	69.96	42.71	15.05	24.46	41.56	10.02	18.54
123	Anko-Meziya	2	3	5.73	5.30	1.21	1.46	10.00	4.26	0.68	28.25	45.46	24.51	11.71	18.59	26.89	7.07	3.35
124	Shado-Diniya	2	2	6.01	6.53	1.95	1.58	14.50	3.75	0.77	24.00	101.63	60.21	25.13	42.30	54.15	16.58	11.45
125	Tuzuma	2	2	6.02	6.29	1.94	1.52	11.50	4.62	0.76	25.00	109.63	74.31	17.55	37.13	53.16	15.75	9.99
126	Gena	2	2	4.36	7.35	1.36	1.66	12.25	3.28	0.86	27.00	137.30	84.24	32.38	43.71	50.07	16.03	14.01
127	Feleke	2	3	5.87	5.46	1.63	1.14	8.00	3.59	0.67	21.00	53.29	34.31	16.30	20.04	44.83	7.66	4.78
128	Nekaka	2	3	5.80	5.93	1.88	1.31	12.00	4.12	0.68	20.50	99.58	46.81	24.33	27.46	45.09	14.47	9.98
129	Chemerotiya	2	3	5.98	5.17	1.65	1.20	10.00	3.34	0.80	22.50	86.13	48.26	14.63	26.13	48.36	15.57	10.76
130	Hala-Meziya	2	3	5.51	5.63	1.58	1.22	10.00	3.16	0.64	23.00	59.80	37.76	15.55	18.29	46.66	11.67	8.55
131	Anko-Gena	2	3	5.98	4.92	1.58	1.25	8.00	2.80	0.73	20.50	74.71	32.66	9.96	24.96	22.56	4.38	2.38
132	Azuma-Boza	2	3	4.99	7.01	1.89	1.30	11.00	1.81	0.69	22.25	92.84	42.59	29.21	42.59	17.55	13.67	10.22
133	Shuta-ziya	2	4	5.09	4.68	1.59	1.10	10.25	3.53	0.51	17.00	68.46	38.88	26.46	28.54	41.00	14.74	12.29
134	Argozo	3	2	5.09	5.43	1.66	1.06	8.25	4.01	0.64	17.00	48.96	22.96	13.96	38.96	32.58	17.89	13.67
135	Ayissade	3	2	3.87	6.14	1.74	1.24	10.50	2.84	0.69	16.50	45.96	24.46	11.21	11.21	25.81	14.84	11.26
136	Babiso	3	2	5.95	4.89	1.67	1.04	6.50	3.46	0.57	12.50	32.46	21.46	9.96	31.46	21.65	6.60	5.12

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
137	Banga	3	3	5.18	5.66	1.84	0.98	10.00	3.50	0.75	20.00	52.46	18.96	9.46	22.96	21.41	8.18	5.61
138	Bergude	3	2	4.25	6.57	1.84	1.10	11.50	4.40	0.73	16.50	50.46	22.71	19.71	18.71	30.75	14.36	10.32
139	Beshera	3	2	5.13	7.13	2.36	1.91	10.00	3.53	0.86	21.50	120.96	66.96	60.46	72.46	83.52	30.65	21.27
140	Bossa-gena	3	1	5.58	5.59	1.79	1.35	10.50	2.76	0.70	20.50	69.96	33.96	15.46	50.96	38.74	17.02	13.88
141	Bundo	3	1	5.00	4.81	1.81	1.04	10.00	3.46	0.64	15.00	26.46	14.46	11.96	42.46	29.65	14.15	9.21
142	Butta	3	2	5.91	5.20	1.59	1.12	7.00	3.29	0.61	16.00	37.46	19.96	13.96	48.96	27.04	8.96	6.91
143	Checho-I	3	3	2.87	5.21	1.46	1.03	10.00	3.21	0.70	19.00	56.96	31.21	12.21	15.21	43.58	19.21	12.21
144	Checho-II	3	2	3.84	4.90	1.60	0.95	11.00	2.85	0.66	14.00	34.46	15.46	10.21	16.96	23.70	7.44	5.78
145	Dellea	3	3	2.30	4.51	1.56	0.80	9.50	2.70	0.58	17.00	41.96	24.21	12.46	10.71	42.78	13.03	8.08
146	Dellulle	3	2	4.78	4.39	1.42	1.06	11.00	3.31	0.67	17.50	40.46	18.96	11.96	24.46	25.76	10.94	7.58
147	Dimo	3	1	3.30	5.29	1.71	1.09	10.00	2.96	0.69	19.50	67.96	32.96	14.46	20.46	43.40	10.31	6.25
148	Dolla	3	4	3.25	4.81	1.46	1.46	6.00	4.33	0.61	12.00	35.96	18.96	16.46	33.46	44.78	19.43	12.30
149	Fekekie	3	4	5.83	6.50	2.84	2.00	9.50	3.29	0.68	21.00	95.96	35.96	14.46	50.96	34.64	10.86	7.61
150	Fello	3	3	5.29	5.27	1.66	1.56	10.50	3.78	0.71	18.00	49.96	17.46	15.46	38.46	29.11	10.55	7.09
151	Gena-II	3	3	5.03	5.81	1.80	1.30	8.50	2.54	0.60	17.50	60.46	34.46	15.46	47.46	41.68	16.38	12.33
152	Golia	3	3	4.09	4.31	1.41	0.99	11.00	3.75	0.66	17.00	42.96	16.21	9.96	19.96	23.34	8.72	6.10
153	Haleko	3	3	5.00	5.92	1.88	1.24	11.00	3.35	0.77	17.50	57.96	33.96	17.46	15.96	29.73	12.63	9.24
154	Kekera	3	2	3.47	5.61	1.81	1.16	11.50	3.27	0.70	22.00	71.96	37.46	14.46	22.96	46.44	20.70	15.28
155	Keteme	3	1	4.18	5.46	1.66	1.11	11.00	3.20	0.57	15.00	34.46	18.46	10.46	25.96	28.30	10.46	7.33
156	Ketene	3	2	3.11	6.19	2.66	0.96	11.50	4.13	0.65	15.00	47.46	23.96	15.96	18.46	39.60	17.22	10.78
157	Ketisse	3	3	3.33	6.36	2.09	1.01	12.50	3.44	0.76	20.50	64.96	26.96	14.71	20.46	39.49	20.29	9.81
158	Mesho-gemo	3	2	4.00	6.26	1.91	1.31	10.50	3.34	0.80	19.50	90.46	43.96	16.46	40.21	54.04	17.95	12.41
159	Pello	3	3	5.76	5.36	1.74	1.15	10.50	3.65	0.68	20.50	46.96	22.46	10.46	30.46	23.82	10.29	6.72
160	Pello-2	3	3	4.99	6.06	1.51	1.16	11.50	2.74	0.71	21.00	45.46	22.46	15.46	30.46	29.84	10.62	7.39
161	Pemia	3	4	4.71	4.58	1.54	1.19	9.50	2.71	0.58	13.50	24.46	14.96	6.46	22.46	20.86	8.07	4.40
162	Shalda	3	4	3.73	4.74	1.44	0.91	8.50	4.24	0.52	15.50	30.96	16.46	10.21	18.46	25.39	15.14	8.39
163	Sorte	3	3	4.87	7.01	2.49	1.12	7.50	2.42	0.75	16.50	82.96	32.96	15.96	45.96	41.86	14.29	9.88
164	Tsisse	3	3	5.86	4.50	1.75	1.33	9.00	3.25	0.51	16.00	24.46	11.96	5.96	25.96	15.14	3.28	1.72
165	Werzia-macho	3	3	5.62	5.78	1.81	1.05	9.50	2.78	0.65	15.00	36.46	22.46	15.46	28.96	25.72	9.08	6.59
166	Zinke-bukema	3	3	5.67	4.62	1.49	0.91	9.00	2.39	0.64	15.00	31.46	13.96	8.46	22.46	17.10	7.77	5.68
167	Zoa-zinke	3	3	5.32	4.44	1.69	0.78	8.00	4.03	0.57	14.00	13.71	7.46	8.46	9.96	10.49	4.62	2.90
168	Shibr	3	1	4.45	7.15	2.18	1.55	11.00	3.38	0.67	18.00	36.96	16.34	16.34	30.84	37.27	11.81	8.42
169	Ame	3	1	5.02	4.44	1.21	1.06	9.00	2.71	0.61	17.25	26.96	13.96	9.71	14.71	43.88	6.07	4.61
170	Kerta	3	3	5.82	4.95	1.10	1.98	12.50	2.65	0.56	23.00	99.71	35.96	23.46	39.96	33.53	13.24	6.60

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
171	Mezie	3	2	3.15	6.83	2.29	1.54	10.25	3.45	0.60	17.75	127.21	53.96	25.34	34.96	44.80	23.17	17.44
172	Tuffa	3	3	3.70	4.30	0.97	0.98	10.00	3.70	0.58	20.25	37.34	11.84	17.96	8.21	49.08	4.73	3.31
173	Akisha	3	3	4.29	4.72	1.45	1.36	9.00	3.92	0.74	19.00	31.11	11.59	12.21	13.59	50.38	7.50	5.81
174	Shelekumia	3	2	5.01	2.89	1.14	1.16	12.25	3.34	0.69	22.25	25.46	10.71	11.46	9.71	61.92	5.15	2.69
175	Boda	3	2	5.24	4.05	1.35	0.84	11.00	2.81	0.72	19.00	44.96	14.96	9.46	19.59	24.63	7.81	4.33
176	Yilla	3	2	4.80	3.69	1.17	0.88	11.50	2.23	0.43	17.25	26.96	15.96	33.84	9.34	22.84	5.89	4.18
177	Berzie	3	2	5.07	5.09	1.38	1.36	13.25	3.41	0.58	20.75	50.21	27.96	13.21	49.84	23.14	9.65	7.30
178	Harambo	3	2	3.07	5.37	2.54	1.05	11.00	2.57	0.68	19.00	34.46	15.34	12.21	10.46	20.30	12.04	8.61
179	Adinona	4	2	4.78	4.39	1.50	0.85	8.00	2.49	0.52	13.00	23.96	9.96	10.96	21.46	19.49	4.18	2.66
180	Agina	4	2	4.52	3.67	1.36	0.89	10.00	3.34	0.56	14.50	28.96	14.71	12.46	20.96	22.86	7.60	4.71
181	Akacha	4	1	3.00	4.93	1.29	1.07	13.00	3.43	0.65	16.50	44.96	22.46	17.96	24.46	46.06	14.13	11.30
182	Ankiegena	4	1	4.71	5.56	1.76	1.47	11.50	3.34	0.76	14.50	64.96	36.46	16.96	44.96	44.85	11.81	8.85
183	Ankuwa	4	1	2.40	5.28	1.46	1.48	13.50	2.36	0.72	25.00	110.46	33.46	19.96	15.96	60.53	21.13	14.69
184	Banga	4	2	4.01	4.14	1.54	0.88	9.63	2.87	0.59	13.50	23.46	14.46	9.71	20.46	23.73	8.46	5.01
185	Bedadia	4	1	4.72	4.71	1.59	0.97	9.50	2.47	0.53	17.50	39.46	17.96	22.46	21.46	28.91	13.81	8.62
186	Botya	4	2	5.81	3.91	1.28	0.84	8.00	3.03	0.54	13.50	15.96	8.46	8.46	19.46	12.78	3.13	2.07
187	Bulua	4	2	4.95	4.25	1.51	1.11	11.00	2.98	0.58	20.00	44.96	21.96	9.96	21.46	23.20	9.74	6.59
188	Chamia	4	1	4.93	5.01	1.74	1.28	9.00	4.05	0.69	20.50	72.96	26.46	12.96	44.46	37.42	18.59	11.01
189	Dirbuwa	4	2	4.46	6.59	2.01	1.20	10.50	2.55	0.87	15.00	73.71	40.96	20.46	31.46	44.59	13.63	9.32
190	Dokozuwa	4	1	5.88	4.00	1.66	0.83	6.50	1.72	0.48	16.00	22.46	8.46	5.46	10.46	8.40	2.56	1.52
191	Erasha	4	2	5.04	3.42	1.09	0.84	8.00	3.55	0.43	14.00	11.96	5.46	3.96	12.96	9.61	4.49	2.97
192	Eslamia	4	2	3.17	5.65	1.73	1.06	8.50	2.78	0.72	20.00	67.96	35.46	12.46	19.46	45.16	22.41	12.34
193	Fenku	4	2	3.21	3.95	1.31	0.89	9.50	2.96	0.59	15.00	28.46	12.96	9.71	11.96	23.02	7.98	4.73
194	Gefetenewa	4	2	4.44	4.87	1.56	1.09	11.00	4.11	0.66	15.50	28.96	16.46	8.46	19.21	21.16	9.56	6.28
195	Gena	4	2	3.34	6.09	1.61	1.36	11.50	3.63	0.70	20.50	91.96	48.96	18.46	46.46	72.17	34.08	21.20
196	Genesa	4	2	3.71	5.71	1.44	1.53	12.50	3.79	0.75	23.00	70.46	30.46	16.96	13.96	34.81	14.70	9.31
197	Gezetiya	4	2	3.68	6.34	1.91	1.14	11.00	3.26	0.66	16.50	71.46	29.96	11.71	27.96	40.29	18.16	11.08
198	Ginawa	4	2	3.13	5.05	1.61	1.21	9.00	4.03	0.68	19.00	62.46	27.96	14.46	16.71	40.25	17.98	9.82
199	Goderia	4	2	3.24	6.56	2.08	1.23	17.00	3.22	0.68	18.50	79.46	37.96	26.96	28.71	61.84	25.04	17.80
200	Kembata	4	1	2.66	5.27	1.61	1.30	12.50	3.36	0.70	25.50	93.46	38.46	19.46	15.96	60.32	18.53	11.87
201	Kikiro	4	2	4.92	5.99	2.06	1.56	9.00	3.31	0.68	16.00	42.96	20.46	11.46	43.46	32.95	15.48	11.11
202	Kualia	4	2	2.71	5.61	1.56	1.09	9.00	2.92	0.65	19.00	46.46	30.21	12.46	19.96	48.67	21.30	13.05
203	Kucharkie	4	2	4.57	4.69	1.49	1.01	9.50	3.80	0.62	16.00	31.71	15.96	9.46	27.21	24.70	7.48	5.12
204	Locha	4	1	3.51	5.43	1.66	1.02	10.75	3.61	0.64	17.00	46.69	23.46	12.20	21.22	34.79	14.34	9.93

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
205	Mattie	4	1	3.00	6.29	1.74	1.07	9.50	3.10	0.70	16.00	44.96	21.96	15.46	17.96	38.91	17.16	10.14
206	Messa	4	2	5.79	4.71	1.59	1.36	7.50	1.95	0.60	20.50	54.96	27.96	9.96	28.96	24.96	10.35	8.86
207	Mochie	4	2	5.50	3.32	1.21	0.85	8.50	4.16	0.47	18.50	15.46	7.71	5.46	19.96	12.99	4.28	2.71
208	Osogurzo	4	3	4.89	7.09	2.11	1.33	10.00	3.26	0.70	23.00	68.46	30.96	11.96	25.96	30.27	10.94	9.18
209	Pokuwa	4	2	5.14	4.91	1.56	1.20	11.00	3.06	0.74	15.50	42.96	22.46	12.46	33.96	29.54	8.01	4.64
210	Posha	4	2	4.30	5.22	1.71	0.99	12.00	3.07	0.75	17.00	40.46	19.46	14.96	26.46	30.75	12.20	6.52
211	Shedodiniya	4	2	2.79	4.99	1.21	1.25	12.50	3.59	0.67	21.00	74.96	37.46	15.96	13.96	51.03	14.72	12.51
212	Shemeroy	4	3	5.13	5.94	2.03	1.02	8.00	3.73	0.65	20.00	42.96	22.96	12.46	33.96	29.21	6.74	4.60
213	Tuzuma	4	3	3.47	6.01	1.91	1.14	13.00	3.31	0.68	20.50	55.96	32.46	19.46	35.46	53.89	21.38	13.23
214	Woisha	4	3	2.41	5.17	1.45	1.24	11.50	4.32	0.70	20.50	67.96	20.46	18.96	14.96	46.97	15.45	11.17
215	Adame-ado	5	3	3.75	6.83	1.81	1.47	11.50	4.02	0.91	20.50	123.46	56.46	18.21	43.21	66.69	29.38	23.37
216	Ado	5	2	5.02	6.39	2.14	1.14	11.00	4.06	0.78	17.50	55.96	29.96	12.96	25.46	29.44	9.44	6.65
217	Alenticho	5	2	3.73	6.91	2.01	1.52	10.50	3.74	0.62	18.00	72.96	35.46	14.96	21.46	40.94	15.08	10.54
218	Astara-SI	5	1	3.68	6.26	2.06	1.31	12.50	3.54	0.66	18.50	61.46	28.46	18.71	33.46	46.81	22.49	16.23
219	Astara-SII	5	2	3.95	5.96	1.86	0.99	10.00	3.35	0.59	19.00	33.96	23.46	11.96	30.96	34.78	7.84	4.28
220	Awusho	5	3	3.14	5.86	1.81	1.06	9.50	3.51	0.79	18.00	56.46	31.46	13.71	17.46	46.03	19.64	11.35
221	Barbo-dancho	5	1	3.55	5.00	1.81	0.83	7.50	3.18	0.64	17.50	43.46	21.46	12.71	24.71	35.27	18.85	14.31
222	Bezeze	5	3	5.12	5.36	1.74	1.11	8.00	2.70	0.57	19.00	49.96	22.96	13.46	31.96	28.90	14.30	11.39
223	Buaecho(Guragies)	5	1	5.28	4.54	1.38	0.98	6.25	4.10	0.56	15.25	33.43	15.18	9.93	27.93	20.27	10.42	7.38
224	Bulle	5	3	3.09	6.86	2.11	1.20	9.50	3.29	0.75	17.00	74.96	47.96	23.96	32.46	72.82	28.55	18.09
225	Buzzare	5	2	4.34	5.33	1.79	0.96	10.50	4.10	0.71	19.00	47.46	19.96	14.96	21.96	28.26	12.75	9.64
226	Chelako	5	3	2.86	6.15	1.69	1.55	14.50	3.40	0.71	21.50	73.46	37.46	17.46	21.46	57.91	25.53	18.14
227	Demela	5	3	4.85	5.41	1.86	1.03	8.00	4.06	0.61	17.50	44.96	26.46	11.96	23.46	27.35	11.74	5.84
228	Derassa-dimela	5	3	3.72	7.26	2.11	1.21	11.75	2.99	0.73	22.00	143.96	63.96	20.46	44.46	74.63	38.45	25.14
229	Dinke	5	2	4.27	3.68	1.65	0.94	8.00	3.09	0.64	14.00	34.46	17.46	13.71	30.96	31.24	6.76	2.82
230	Dubano	5	2	3.78	5.45	1.59	0.93	8.00	3.71	0.70	17.00	37.46	17.96	13.21	13.71	26.93	5.82	4.01
231	Ewisho	5	1	4.00	5.63	1.79	1.29	11.00	3.60	0.73	15.50	45.96	22.96	19.46	28.96	38.41	16.08	12.37
232	Gemechalla	5	1	3.79	5.97	1.96	0.92	10.00	4.44	0.53	19.00	51.96	17.96	11.46	23.46	30.34	16.00	9.04
233	Gena	5	3	3.31	6.41	1.61	1.33	10.00	3.79	0.76	16.50	87.46	44.46	20.96	33.96	65.02	26.63	19.14
234	Gerbo	5	1	2.51	5.81	1.41	1.34	14.00	3.50	0.75	26.00	102.96	43.96	27.46	22.46	78.16	31.60	20.34
235	Gerdicho	5	1	2.86	5.58	1.61	1.13	9.50	2.41	0.63	17.00	49.46	18.96	12.46	17.96	37.46	18.52	12.84
236	Gulama	5	3	5.16	4.24	1.44	0.98	9.50	3.11	0.60	17.00	31.96	15.96	7.96	24.96	20.45	7.22	4.94
237	Gussello	5	2	2.85	5.27	1.61	0.80	8.00	3.86	0.69	17.50	32.96	21.46	8.96	12.46	31.74	12.14	6.96
238	Hawe	5	2	3.78	6.66	2.11	1.11	11.50	3.55	0.64	21.50	76.96	30.96	11.96	27.96	41.10	18.79	13.57

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
239	Hekacha	5	2	2.34	5.36	1.29	0.90	11.50	3.51	0.80	22.50	60.96	21.46	20.46	7.46	46.12	11.85	6.96
240	Hekecha-I	5	2	2.68	6.06	1.76	1.05	9.00	3.43	0.84	17.50	61.46	27.96	17.96	14.96	49.63	17.87	13.39
241	Kerase	5	3	4.60	6.09	2.16	1.17	11.50	3.24	0.77	16.00	60.96	31.71	14.96	30.46	36.28	14.56	8.69
242	Kulo	5	3	2.32	5.28	1.41	0.97	11.50	4.51	0.76	18.00	47.96	23.96	15.96	9.71	47.07	13.69	8.95
243	Ontosha	5	2	2.71	6.74	1.96	1.41	11.50	3.60	0.94	22.00	124.96	54.21	25.96	26.96	82.84	25.53	14.67
244	Seddisse	5	2	2.45	5.63	1.49	0.95	12.50	3.29	0.74	21.00	54.96	16.46	12.96	7.96	33.17	11.03	6.16
245	Sediso	5	2	5.00	5.49	1.90	0.87	6.50	2.94	0.67	13.00	33.46	15.46	9.96	21.96	20.48	9.07	6.90
246	Serane	5	2	3.43	5.44	1.91	0.84	9.00	2.94	0.57	18.00	39.96	17.46	7.96	11.96	23.60	10.84	6.02
247	Serena	5	3	3.72	5.24	1.59	0.89	8.50	3.10	0.51	16.00	30.46	15.71	10.46	16.71	24.52	11.39	7.40
248	Sidiramo	5	2	5.12	5.55	1.71	0.95	9.50	3.97	0.67	13.50	42.46	19.46	11.96	24.46	26.54	9.74	7.45
249	Sirriro	5	1	4.93	6.67	2.11	1.41	12.00	3.47	0.73	25.00	96.96	41.46	19.96	41.46	44.88	16.77	12.19
250	Tunaka	5	3	2.86	6.25	2.01	1.01	9.50	3.22	0.67	16.50	55.46	28.96	12.96	12.46	41.28	19.29	12.85
251	Walanticha-I	5	1	3.41	5.25	1.61	0.80	9.00	4.01	0.48	17.00	25.21	12.71	9.46	10.71	20.92	10.12	6.44
252	Walantiche-II	5	2	4.21	6.16	1.81	1.59	12.50	3.33	0.74	20.00	79.96	43.21	29.96	87.96	81.76	42.30	22.55
253	Wanigaro	5	3	4.78	5.32	1.94	1.03	9.00	3.84	0.60	16.50	47.96	24.46	9.96	20.96	24.89	6.91	3.66
254	Waniwassa	5	2	5.78	6.07	1.63	1.33	9.50	3.55	0.64	17.50	81.96	42.46	15.46	53.46	42.05	9.01	7.14
255	Welanticho	5	2	3.78	5.86	1.96	1.04	10.50	2.76	0.74	21.00	47.96	25.46	12.46	25.21	35.63	15.38	9.72
256	Ameratiye	6	1	3.62	4.60	1.61	1.01	10.50	2.69	0.53	19.00	40.96	23.46	11.96	20.46	32.87	15.38	7.10
257	Anikefiye	6	2	3.04	5.71	1.63	1.50	10.50	2.84	0.69	22.50	96.46	59.46	16.96	24.46	70.06	33.94	24.55
258	Astara	6	4	3.14	4.96	1.56	0.93	8.00	3.41	0.62	17.00	33.21	22.96	14.96	18.46	37.95	14.00	8.34
259	Ayiwegne	6	2	5.02	5.26	1.36	1.01	8.50	3.96	0.59	15.50	64.46	32.96	12.96	18.46	28.08	17.94	10.30
260	Bishkanchiwe	6	4	3.13	6.54	2.01	1.32	12.50	2.56	0.78	25.50	84.46	48.46	20.96	29.21	66.68	30.95	21.80
261	Cherkimad	6	4	4.84	4.69	1.33	1.01	8.50	3.16	0.61	12.50	34.96	17.96	10.96	26.96	24.76	9.48	6.16
262	Egendiye	6	1	3.79	4.58	1.29	1.26	9.50	3.79	0.64	19.00	49.46	49.46	28.46	9.46	61.58	19.77	15.48
263	Eminiye	6	2	5.12	5.81	1.89	1.21	10.00	3.59	0.42	18.50	87.96	41.46	13.46	25.21	33.61	12.18	9.87
264	Engidawork	6	1	5.25	6.19	1.49	1.54	10.50	3.19	0.71	19.50	103.96	60.96	19.96	74.46	64.34	20.67	15.81
265	Esmaele	6	2	3.42	5.56	1.46	1.09	8.00	3.99	0.60	16.50	45.96	25.96	11.96	17.96	35.32	13.54	9.06
266	Geziwet	6	2	4.24	6.39	1.94	1.19	9.50	3.48	0.65	17.50	87.46	40.96	24.96	45.96	57.20	18.22	12.74
267	Guariye	6	1	3.67	5.76	1.76	1.19	10.50	2.64	0.60	18.50	49.46	25.96	15.96	26.96	40.28	19.31	12.34
268	Gumbar	6	4	2.86	4.35	1.24	1.01	9.00	3.49	0.57	18.00	35.46	21.96	10.96	10.21	31.75	9.26	7.69
269	Gurebeshelga	6	4	3.08	5.24	1.46	1.08	10.50	3.30	0.60	16.50	44.96	29.71	14.46	16.21	42.34	18.00	12.05
270	Jobiro	6	1	5.73	5.48	1.84	1.28	9.50	3.23	0.63	17.00	44.46	17.46	13.96	45.96	25.98	7.28	5.39
271	Kanchiwe	6	1	4.84	5.15	1.64	1.13	9.00	3.74	0.65	15.00	46.46	25.46	14.96	37.46	34.59	15.94	13.05

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
272	Kinke	6	1	3.58	6.24	2.06	1.11	11.50	3.06	0.64	48.5	67.46	34.46	18.46	31.46	50.34	24.21	15.50
273	Mayimote	6	2	4.37	4.87	1.64	1.16	9.50	2.78	0.61	17.00	58.71	28.96	11.96	29.46	34.50	13.47	8.77
274	Nechuwe	6	4	4.76	4.50	1.49	0.86	8.00	3.53	0.62	18.50	34.46	16.46	7.46	13.96	17.23	6.97	4.25
275	Nechuwe-II	6	4	3.18	5.66	1.69	1.05	9.00	3.64	0.69	15.00	40.46	27.96	14.46	17.96	41.07	17.63	11.51
276	Sebara	6	4	2.76	5.75	1.61	1.14	11.50	3.34	0.61	24.00	70.46	39.96	14.96	21.46	58.40	23.10	15.52
277	Sherite	6	4	3.17	5.41	1.64	1.08	11.50	2.43	0.65	21.50	52.96	29.46	20.96	11.96	41.82	19.31	12.96
278	Shertiye	6	4	3.14	4.04	1.16	0.94	8.00	3.73	0.53	19.50	39.96	25.46	12.71	11.96	34.90	15.26	10.91
279	Temoyise	6	2	4.11	6.04	1.61	1.26	12.50	3.14	0.68	21.50	81.96	43.46	16.46	23.46	43.68	21.03	16.94
280	Weka	6	2	3.38	5.01	1.44	0.96	11.50	2.65	0.54	18.50	32.96	17.46	11.46	15.96	28.11	15.31	8.73
281	Wered	6	2	4.39	3.01	1.00	1.18	9.50	3.43	0.48	21.00	81.46	32.46	20.21	25.96	38.38	14.33	11.03
282	Weretea	6	2	4.51	5.66	1.80	1.04	9.00	3.73	0.70	15.50	41.96	18.96	11.46	32.96	30.15	9.71	7.45
283	Yegendiye	6	2	3.44	6.04	1.56	1.44	12.00	4.24	0.60	23.00	85.46	52.96	27.46	36.96	73.17	28.59	19.38
284	Yekimech	6	2	3.47	5.89	1.81	1.35	12.50	2.89	0.64	23.00	86.46	55.71	23.21	34.96	70.05	32.20	20.23
285	Yibiye	6	2	4.53	4.65	1.66	1.09	10.00	3.39	0.65	18.50	43.46	21.46	15.46	26.46	30.70	9.40	6.49
286	Dere	6	4	3.28	5.83	1.76	1.09	9.75	4.01	0.56	21.00	45.46	14.34	14.84	14.59	45.71	9.86	7.90
287	Tobiro	6	4	3.80	6.52	2.09	1.39	12.75	3.97	0.69	22.50	79.21	14.96	14.34	23.71	63.71	12.13	10.51
288	Teriye	6	4	3.23	6.48	1.88	1.31	12.00	3.64	0.67	25.00	75.21	15.21	15.84	25.84	44.96	10.37	8.99
289	Yesherafire	6	4	3.33	5.88	1.89	1.22	9.00	4.01	0.59	15.25	44.59	12.21	13.71	16.21	58.46	13.00	11.73
290	Shifire	6	1	2.71	6.77	1.94	1.58	12.75	3.37	0.62	27.50	94.96	17.34	19.30	24.71	96.96	26.46	20.08
291	Gimbuwe	6	2	4.43	5.63	1.71	1.44	11.25	3.02	0.67	24.00	133.71	14.09	15.21	22.71	68.21	10.67	5.94
292	Keweretiye	6	3	3.09	5.46	1.86	1.32	10.25	2.64	0.61	20.75	58.71	10.71	11.46	15.09	38.59	9.07	5.64
293	Sukeru	7	3	4.23	4.79	1.34	1.19	8.25	3.93	0.56	16.00	46.55	22.96	10.48	12.85	11.65	8.47	5.38
294	Koker	7	3	6.00	5.07	1.83	1.41	11.25	3.83	0.65	21.50	105.95	47.04	16.95	26.09	28.46	17.63	12.27
295	Diya feya	7	3	5.91	4.26	2.00	1.12	8.25	3.91	0.65	18.75	73.14	30.86	17.76	19.96	17.63	12.50	8.73
296	Gelaro	7	3	5.84	4.23	2.35	1.05	10.00	3.44	0.69	15.75	52.36	26.71	19.99	18.11	18.74	14.06	9.82
297	Agado	7	3	5.14	4.85	1.52	1.23	13.25	2.88	0.66	22.75	56.91	33.46	15.35	21.13	23.09	14.21	10.42
298	Shotu	7	3	4.65	5.95	1.36	1.29	12.00	2.75	0.64	21.00	58.39	25.34	11.34	17.96	18.40	9.77	6.85
299	Diya	7	3	4.51	5.16	1.32	1.21	10.00	3.62	0.61	20.25	71.45	31.96	13.91	22.81	22.55	12.90	9.06
300	Kamo	7	3	5.65	6.13	1.11	1.09	10.25	3.60	0.66	21.00	74.65	44.15	20.78	19.71	26.96	13.02	9.73
301	Zegera	7	3	6.37	7.02	1.85	1.86	12.00	3.77	0.57	25.75	151.88	71.55	36.13	57.55	43.30	14.15	12.80
302	Acherka	7	3	5.75	6.64	1.70	1.31	13.00	3.55	0.66	24.00	100.71	47.75	26.75	30.10	23.46	10.69	7.95
303	Lobo	7	3	5.78	5.05	1.92	1.26	12.00	3.08	0.69	18.75	52.81	31.99	26.89	24.14	21.84	12.39	9.38
304	Koncha	7	3	4.90	5.11	1.51	1.41	9.25	3.12	0.70	18.25	66.34	35.59	13.76	25.94	17.46	10.23	7.61
305	Anechero	7	3	4.97	4.96	1.52	1.18	13.00	2.86	0.65	21.00	57.79	30.63	12.79	21.66	15.69	10.39	6.84
306	Gimbu	7	3	4.73	7.22	1.45	1.20	11.00	3.94	0.63	23.25	56.96	30.21	18.46	28.71	29.21	11.22	8.91

Appendix 3. Continued

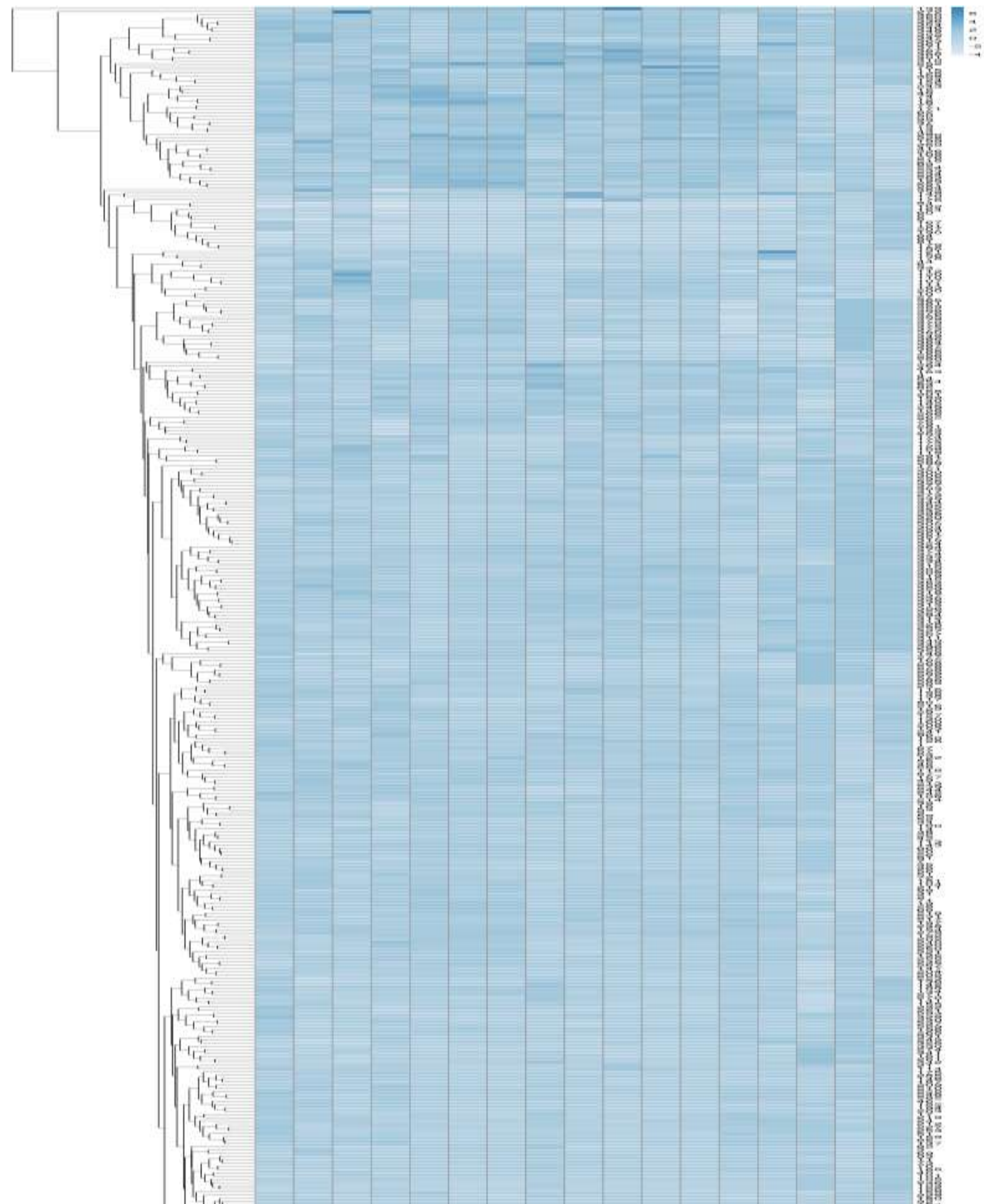
ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
307	Tomoko	7	3	5.91	5.08	1.73	1.35	9.75	4.34	0.60	19.75	58.46	33.21	18.36	21.38	19.13	10.97	8.11
308	Noru	7	3	5.93	7.71	2.12	1.69	13.00	3.63	0.82	26.00	121.96	63.71	18.21	50.71	54.46	17.97	15.59
309	Suwande	7	3	5.73	6.36	1.62	1.43	12.75	3.90	0.70	24.25	88.21	43.80	19.51	35.09	29.68	13.01	10.30
310	Shenea	7	3	6.00	7.16	2.24	1.67	10.00	3.42	0.79	20.50	122.46	66.71	39.71	65.21	52.96	20.35	16.34
311	Astara	7	3	5.37	4.90	1.80	1.30	11.50	3.82	0.71	24.25	61.59	34.09	14.76	24.00	20.00	12.69	8.86
312	Daksi koker	7	3	5.77	5.05	1.73	1.36	10.50	3.45	0.70	21.50	80.56	40.81	15.34	38.09	24.74	13.65	10.78
313	Kerod	7	3	5.50	5.10	1.89	1.36	10.50	3.23	0.68	19.00	79.53	44.84	25.19	43.34	32.21	17.22	13.99
314	Megru	7	3	5.39	4.35	2.46	1.18	10.25	3.14	0.66	16.25	37.59	20.73	22.50	36.75	12.80	9.73	6.41
315	Bulbul	7	3	5.10	4.66	1.52	1.23	10.75	3.52	0.63	19.25	60.74	26.09	17.71	28.84	22.84	14.19	10.70
316	Wagu	7	3	5.67	5.29	1.70	1.49	11.25	3.23	0.74	23.00	121.78	49.84	21.71	50.21	21.34	12.65	8.95
317	Gyeba	7	3	5.26	5.53	1.86	0.96	12.25	3.79	0.72	20.00	54.21	26.34	18.48	26.78	16.46	9.19	6.68
318	Karameregu	7	3	6.00	4.67	1.94	1.43	11.75	3.79	0.75	27.75	69.75	52.46	19.96	39.13	21.83	13.68	11.20
319	Qodena	7	3	6.01	4.55	2.07	1.41	10.50	3.33	0.62	25.00	89.55	34.13	26.10	32.29	20.76	12.91	9.81
320	Aregemu	7	3	4.91	5.13	1.38	1.28	11.25	2.92	0.64	20.25	66.50	33.60	18.11	22.55	17.21	9.94	7.47
321	Kmeiretu	7	3	4.83	6.74	1.24	1.51	10.00	3.26	0.59	25.00	79.21	32.46	19.71	35.71	16.21	7.09	5.50
322	Sumura	7	3	4.47	5.70	1.45	1.18	9.25	2.95	0.57	20.00	48.61	23.46	17.26	29.21	16.21	8.71	6.54
323	Emenasha	7	3	5.85	5.23	2.25	1.41	10.25	3.81	0.64	21.25	100.81	53.80	19.63	42.00	29.63	16.64	12.61
324	Gesero	7	3	5.02	4.52	1.62	1.10	10.25	3.15	0.65	19.00	59.20	28.79	16.23	27.09	19.89	12.89	9.83
325	Mechu	7	3	4.30	6.53	1.44	1.27	9.50	2.57	0.57	19.00	31.96	19.21	15.06	18.96	30.96	13.04	10.80
326	Aylelo	7	3	5.66	4.56	2.10	0.94	7.00	3.04	0.64	12.00	27.71	16.21	17.11	14.86	18.46	12.95	9.47
327	Byera	7	3	5.97	4.20	1.92	1.32	9.00	3.77	0.63	21.00	93.53	39.23	17.79	27.80	17.13	12.31	9.29
328	Dape	7	3	5.99	4.15	2.19	1.07	8.50	3.58	0.66	19.00	99.30	40.76	19.63	31.93	20.46	13.70	11.81
329	Oroda	7	3	4.60	4.91	1.46	1.22	9.50	4.68	0.64	17.00	42.56	23.50	13.20	19.39	13.59	8.71	6.17
330	Finafina	7	3	3.62	5.38	1.16	1.00	8.50	2.43	0.61	14.75	31.71	19.96	8.76	15.34	11.71	7.04	4.78
331	Dano	7	3	5.15	5.95	1.73	0.89	9.25	3.15	0.71	16.00	29.10	19.30	14.63	24.96	19.63	9.64	7.35
332	Chepu	7	3	4.68	5.80	1.58	1.11	10.00	2.97	0.64	17.25	61.63	33.13	17.05	36.96	23.96	13.26	9.97
333	Lemat	8	2	5.88	4.43	1.76	1.48	10.50	3.58	0.69	19.25	92.94	40.64	23.26	27.15	23.80	17.00	11.59
334	Achechet	8	2	5.30	4.49	1.56	1.28	9.75	3.30	0.70	18.00	67.04	32.49	21.71	30.96	25.76	17.70	12.85
335	Tegenen	8	2	4.85	5.02	1.55	1.08	8.50	3.09	0.71	19.00	54.68	30.00	14.38	29.23	22.71	14.10	10.06
336	Workie-kora	8	2	5.88	3.98	2.42	1.30	14.25	4.62	0.73	22.00	89.36	42.96	27.46	32.14	28.66	21.91	16.29
337	Aba-Sheger	8	3	5.92	5.30	2.08	1.57	11.00	3.76	0.77	25.50	83.00	48.34	18.75	39.90	32.34	18.20	13.40
338	Toreret	8	4	5.49	3.96	1.60	1.53	11.00	3.35	0.70	23.25	80.60	38.58	23.09	38.31	19.94	15.21	11.25
339	Beshute	8	4	5.85	4.57	1.73	1.51	11.25	3.96	0.72	19.75	81.61	40.92	23.17	33.37	22.56	15.26	11.05
340	Fegnekor	8	4	5.60	4.09	1.79	1.20	11.00	3.68	0.69	17.25	54.49	27.49	18.64	32.54	24.69	18.05	13.73

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
341	Kibute	8	4	4.58	5.27	1.44	0.84	8.25	2.97	0.57	19.25	37.21	21.46	8.71	27.71	21.09	12.34	8.77
342	Semay-leged	8	4	4.82	4.71	1.64	1.09	8.50	3.00	0.59	12.50	33.21	17.96	13.46	41.71	16.71	10.65	7.90
343	Dubriat	8	4	5.90	4.11	1.98	1.10	10.00	3.93	0.69	18.00	44.73	23.90	17.90	26.60	23.59	16.49	13.16
344	Badadiat	8	3	5.15	4.68	1.42	1.28	10.25	3.20	0.63	17.00	44.57	24.05	19.40	47.41	23.90	15.47	11.09
345	Feresiye	8	3	5.76	4.34	1.85	1.20	12.75	3.68	0.66	22.25	68.56	36.81	19.88	27.81	28.36	18.49	14.33
346	Shertiye	8	3	5.93	3.75	2.34	1.37	13.00	4.69	0.80	25.00	101.54	44.54	23.49	31.09	32.66	27.19	19.57
347	Awegni	8	3	5.99	3.53	1.84	1.02	15.75	3.94	0.71	24.75	81.04	33.74	13.71	22.94	22.11	18.98	13.90
348	Worke-bidu	8	3	5.99	4.07	2.37	1.50	13.00	4.20	0.80	22.00	94.56	39.29	27.66	44.96	30.46	24.39	16.96
349	Garda	8	3	3.06	5.18	0.89	1.14	10.50	2.01	0.52	17.25	22.51	13.71	21.21	22.71	20.96	12.42	8.91
350	Ashakti	8	3	5.83	4.06	2.26	1.36	11.50	3.84	0.71	23.00	106.71	50.06	31.20	40.03	35.26	23.84	19.78
351	Sebara	8	3	5.36	4.38	1.46	1.34	12.50	3.09	0.64	18.75	57.39	28.51	17.44	25.34	21.90	15.09	11.09
352	Kekeri	8	3	5.83	4.07	1.72	1.40	15.50	4.35	0.70	23.75	116.11	49.06	19.69	27.99	17.46	13.59	9.62
353	Gariye	8	3	5.90	4.32	2.18	1.28	12.00	4.08	0.67	24.25	75.49	39.76	19.84	23.54	24.06	16.51	12.39
354	Teteret	8	3	5.85	4.03	2.53	1.29	13.50	4.47	0.69	23.00	95.21	47.21	24.06	39.66	27.64	20.49	15.16
355	Umbatiye	8	3	5.85	3.90	2.51	1.11	12.25	3.75	0.64	18.75	71.39	28.94	17.06	16.14	23.31	17.72	13.41
356	Abajobir	8	3	5.67	5.06	1.97	1.44	11.00	3.61	0.64	19.00	68.75	37.84	22.44	43.99	24.16	15.63	10.58
357	Workie-adi	8	3	5.40	4.42	1.75	1.19	10.25	3.32	0.61	18.50	51.29	25.06	13.99	24.71	20.59	14.05	10.83
358	Achorie	8	3	5.88	4.32	2.04	1.31	15.00	3.60	0.64	23.25	85.75	38.65	23.81	31.84	25.55	17.38	13.33
359	Workie-ija	8	3	5.93	4.24	2.28	1.31	12.50	3.33	0.64	24.50	106.21	41.71	26.76	28.59	26.09	17.65	13.93
360	Nechaset	8	4	5.93	4.21	2.53	1.45	12.00	4.10	0.73	25.00	88.26	41.79	23.61	25.80	28.90	20.32	14.95
361	Workie-dima	8	4	5.90	5.09	3.17	1.53	10.50	4.57	0.77	22.25	85.66	47.54	32.21	67.96	29.09	17.13	13.05
362	Iniba	8	3	4.91	5.09	1.57	1.32	9.00	3.19	0.63	16.00	44.46	26.96	21.96	40.46	21.96	12.00	9.42
363	Baleme	8	3	5.93	3.51	1.95	0.87	16.25	3.85	0.60	22.00	58.74	26.91	17.99	20.99	27.94	19.51	16.79
364	Wania	8	3	5.77	5.13	1.78	1.41	9.00	3.72	0.70	17.75	56.30	30.30	16.68	43.13	40.92	20.99	17.74
365	Bokel-Bocho	9	2	3.96	2.14	1.27	1.16	14.00	2.73	0.70	17.00	34.19	18.00	9.14	13.47	11.21	18.34	11.48
366	Ganji-Bocho	9	2	5.17	4.27	1.74	1.02	9.00	3.54	0.71	17.25	42.84	26.63	17.75	22.63	19.17	12.52	10.04
367	Ageane	9	2	5.95	4.27	2.33	1.70	12.00	4.20	0.83	22.00	131.96	52.58	44.46	67.29	35.63	22.45	18.68
368	Mech-Koto	9	2	5.86	3.83	1.90	1.38	10.00	3.65	0.78	19.25	116.96	46.79	37.13	57.46	47.13	22.94	17.84
369	Omiyo	9	2	5.26	2.29	1.79	1.04	9.00	3.30	0.67	16.25	43.21	27.59	15.89	18.31	14.96	19.59	14.79
370	Adel-Bocho	9	2	5.23	3.35	1.51	1.15	12.25	3.06	0.60	21.00	52.96	30.13	16.39	23.48	23.13	19.36	15.52
371	Utro	9	2	5.98	4.86	1.96	1.81	12.00	3.80	0.84	19.00	114.38	64.80	32.13	57.55	23.13	13.96	10.55
372	Apecho	9	2	5.17	3.43	1.61	1.31	12.00	3.21	0.70	17.00	48.44	30.46	12.84	24.20	26.03	24.94	17.64
373	Aterea	9	2	5.65	5.01	2.01	1.41	10.25	3.29	0.72	19.25	71.38	50.05	16.63	36.55	32.38	17.37	14.39
374	Tayo	9	2	5.95	4.79	1.68	1.57	12.25	3.44	0.71	20.50	74.46	35.96	14.21	41.46	34.46	19.55	15.93

Appendix 3. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	PLHT	PSHT	PSCIR	LFNO	LFHT	LFWTH	LFSTHNO	LFSTHBD	LFSTHAD	CSBG	CORMBG	FYIELD	UNSQKOCH	SQKOCHO
375	Are'ko	9	2	4.33	2.80	1.28	1.27	11.75	2.73	0.67	20.25	34.59	20.84	13.54	20.84	19.05	20.05	14.78
376	Bejo	9	2	5.34	3.89	1.62	1.11	9.00	3.65	0.67	15.75	35.96	23.46	16.96	16.96	24.71	17.63	13.95
377	Gayo	9	2	4.40	3.76	1.44	1.53	9.00	2.66	0.66	17.50	36.46	24.96	14.96	22.96	15.96	12.76	9.24
378	Bongo	9	1	5.25	4.69	1.51	1.25	9.25	3.29	0.66	19.25	72.46	32.96	22.21	40.46	25.96	15.02	12.20
379	Mocho	9	1	5.51	2.95	1.72	1.34	13.00	3.11	0.73	20.75	67.09	38.71	21.50	22.45	26.49	27.15	20.15
380	Yako	9	1	5.15	2.84	1.67	1.11	10.25	3.13	0.62	17.00	50.45	26.34	11.14	19.87	24.15	26.06	18.88
381	Ut'no	9	1	5.26	3.29	1.68	1.06	8.00	3.34	0.78	19.25	47.65	23.71	12.70	20.65	17.83	17.23	12.18
382	Qupo	9	1	4.05	4.00	1.35	1.03	10.75	2.88	0.48	20.75	34.13	22.63	10.13	23.29	29.13	20.37	16.15
383	Kalo	9	1	5.08	3.90	1.46	0.96	17.00	3.20	0.33	20.50	30.46	20.46	10.46	18.96	19.96	15.74	11.23
384	Akbaro	9	1	4.05	3.99	1.33	0.86	9.00	2.46	0.55	16.25	20.49	12.34	7.55	14.16	16.63	12.42	9.21
385	Niko	9	1	4.59	4.21	1.59	0.70	7.50	2.73	0.77	16.13	22.96	16.71	12.46	17.71	21.71	14.56	11.56
386	Koremo	9	1	4.62	4.31	1.70	0.58	11.75	2.25	0.57	22.00	37.84	22.46	17.21	21.59	21.21	14.00	10.98
387	Gomjo	9	1	3.71	3.96	1.14	0.76	7.59	2.17	0.55	22.25	23.63	14.80	9.80	19.55	17.71	12.44	9.90



Appendix 4. Dendrogram showing the clustering pattern of 387 enset landraces computed using date collected on 15 quantitative traits.

Appendix 5. Qualitative traits of 286 enset landraces

ENTRYNO	NAME	CollLoc	CollALT	MT	UPPER MIDRIB	UNDER MIDRIB	UPPER PETIOLE	UNDER PETIOLE	LEAF	TIP & EDGE LEAF
1	Abatmerza	1	3	4.80	9	10	8	11	1	3
2	Abato	1	2	2.85	9	10	9	11	1	3
3	Airo	1	2	4.08	2	3	2	2	1	3
4	Ashura	1	3	4.76	2	1	5	2	1	3
5	Astara	1	2	5.93	10	10	2	11	1	3
6	Azenora	1	3	2.07	2	4	2	6	1	3
7	Becherota	1	3	3.25	2	1	2	2	2	2
8	Bedadeda	1	2	5.98	2	10	2	11	1	3
9	Bedediet	1	2	3.95	2	10	2	11	1	3
10	Beleka	1	3	2.98	2	10	2	13	1	3
11	Bikamo	1	2	4.90	2	2	5	2	1	3
12	Bikamo	1	2	3.27	9	11	5	11	1	3
13	Bishato	1	3	4.86	3	3	2	3	1	3
14	Boela	1	2	2.24	2	10	2	11	1	3
15	Bossie	1	3	3.31	7	10	2	11	2	3
16	Chereka	1	3	3.81	2	4	8	5	1	3
17	Dengicho	1	3	4.32	2	10	5	13	1	3
18	Denticho	1	2	2.80	2	10	2	2	1	3
19	Digomerza	1	3	2.54	2	10	5	11	1	3
20	Dirbo	1	3	3.22	10	11	1	11	1	3
21	Disho	1	3	5.23	10	10	9	10	1	3
22	Etinie	1	3	6.00	10	10	5	11	1	3
23	Fechachie	1	2	4.79	2	2	2	2	1	3
24	Ferchasa	1	3	5.58	10	10	9	9	2	3
25	Ferezia	1	2	3.99	6	10	2	11	1	3
26	Fugatesa	1	3	2.93	10	10	8	11	1	3
27	Gimbo	1	3	3.21	8	10	2	11	1	3
28	Ginjena	1	2	3.15	2	5	2	11	1	3
29	Gishera	1	3	4.24	9	10	9	11	1	3
30	Goemerrie	1	3	4.80	5	10	8	5	1	3
31	Gotedirbo	1	1	2.81	2	7	2	6	1	2
32	Gozeza	1	3	5.86	2	1	2	2	1	3
33	Guarye	1	2	2.44	2	3	2	11	1	3
34	Gulfe	1	3	3.81	6	10	2	11	1	3
35	Gureza	1	3	3.06	2	6	2	11	1	3
36	Hankuchie	1	3	2.83	10	10	9	11	2	3
37	Hargamo	1	2	3.74	9	11	5	11	1	3
38	Heilla	1	2	3.75	10	10	5	8	1	3
39	Henuwa	1	3	4.28	2	10	2	11	1	3
40	Hiniba	1	2	5.00	2	10	2	2	1	3
41	Jegeda	1	3	2.55	2	10	3	8	1	3
42	Keberichie	1	2	3.62	9	11	5	8	1	3
43	Kembat	1	3	4.74	2	1	1	1	1	1
44	Kerbo	1	2	2.24	2	2	2	2	2	3
45	Kerkerie	1	3	4.04	2	1	2	2	1	3
46	Keshkeshiya	1	2	4.11	10	5	5	9	1	3
47	Kessiet	1	3	4.61	2	1	5	2	1	2
48	Kinchie	1	3	2.51	10	10	2	11	1	3
49	Korttie	1	3	3.75	2	5	2	12	1	3

Appendix 5. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	UPPER MIDRIB	UNDER MIDRIB	UPPER PETIOLE	UNDER PETIOLE	LEAF	TIP & EDGE LEAF
50	Lekaka	1	2	5.31	10	10	2	13	1	3
51	Manduluka	1	2	4.16	10	10	2	8	1	3
52	Mariya	1	3	3.06	2	8	2	11	2	3
53	Menera	1	3	3.80	1	5	5	11	1	3
54	Mesmesa	1	3	5.85	2	1	9	2	1	3
55	Nechiwe	1	3	4.01	2	3	5	3	1	3
56	Oniya	1	3	3.23	5	10	5	9	1	3
57	Onjamo	1	3	4.58	2	10	2	6	1	3
58	Ored	1	3	4.27	2	1	5	2	1	3
59	Ososa	1	2	3.81	8	10	2	13	1	3
60	Senkutie	1	3	5.84	2	5	5	11	1	3
61	Sesikila	1	3	5.32	10	10	2	11	1	3
62	Sessa	1	1	4.80	1	5	1	11	1	3
63	Shelekie	1	3	4.17	2	10	8	2	1	3
64	Tebuttie	1	2	4.01	2	3	2	2	1	3
65	Tegaded	1	3	5.20	1	2	2	3	2	3
66	Tesa	1	3	4.08	7	10	2	11	1	3
67	Wechered	1	3	3.90	9	10	5	9	1	3
68	Wellachie	1	3	3.16	9	10	9	13	1	3
69	Wenadie	1	3	4.51	10	5	1	9	1	3
70	Weshmeda	1	3	5.41	2	10	2	1	2	3
71	Wohie	1	2	3.13	9	10	1	9	1	3
72	Zebro	1	2	3.43	9	10	9	9	1	3
73	Zeriyie	1	2	4.80	2	10	8	2	1	3
74	Aeluwa	2	2	4.85	1	5	1	2	2	3
75	Aguasa(ta)	2	2	5.42	9	10	1	12	1	3
76	Akachiya	2	2	4.87	1	10	1	11	1	3
77	Argema	2	3	5.73	5	10	7	11	1	3
78	Ayina	2	3	4.74	1	10	1	2	2	3
79	Banga	2	3	5.90	1	1	1	2	2	1
80	Berjiye	2	3	4.73	9	10	7	12	2	3
81	Bota-meziya	2	3	3.81	1	10	1	2	2	3
82	Buba	2	3	5.77	1	10	1	11	2	3
83	Bukuniye	2	3	4.20	9	10	7	11	2	3
84	Bumbe	2	3	4.04	9	10	1	11	1	3
85	Dika	2	3	3.67	10	10	5	11	2	3
86	Donkolola	2	2	3.82	1	1	1	2	2	1
87	Dorta	2	2	5.74	5	11	7	11	1	1
88	Elore	2	2	5.91	5	10	1	11	1	3
89	Fenchariya-yepa	2	3	4.69	9	10	7	11	1	3
90	Goshindiya	2	3	4.81	1	10	1	11	2	3
91	Hala-a	2	2	4.95	1	1	1	2	1	3
92	Hasa-bedadiye	2	2	5.81	1	10	1	11	2	1
93	Hoendiye	2	2	3.03	1	10	1	11	1	1
94	Kazia	2	3	3.24	9	10	1	11	1	1
95	Kekere	2	3	4.60	5	10	7	11	1	1
96	Keteniya	2	3	4.11	9	10	7	11	2	3
97	Sanka	2	3	5.88	1	2	1	2	1	1
98	Tena	2	2	2.76	1	10	1	11	1	3

Appendix 5. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	UPPER MIDRIB	UNDER MIDRIB	UPPER PETIOLE	UNDER PETIOLE	LEAF	TIP & EDGE LEAF
99	Yesha	2	3	5.22	5	10	1	11	1	3
100	ErpHa12	2	3	2.69	5	10	1	11	1	3
101	ErpHa13	2	3	2.64	1	10	1	1	2	3
102	ErpHa18	2	3	2.90	1	1	1	2	2	3
103	ErpHa14	2	3	4.91	9	10	7	11	1	3
104	ErpHa8	2	3	3.17	5	10	7	8	1	3
105	ErpHa2	2	3	2.93	1	10	1	11	2	3
106	ErpHa3	2	3	2.88	1	1	1	2	1	1
107	ErpHa7	2	3	3.16	9	10	1	11	1	3
108	Zergesa	2	2	4.78	9	5	1	8	1	3
109	Mecha-boza	2	2	5.22	5	10	1	11	1	3
110	Meziya	2	2	3.56	5	10	1	11	1	3
111	Shelekuma	2	2	4.75	1	10	1	1	2	3
112	Shemera	2	3	3.09	1	1	1	2	2	3
113	Gulumo	2	3	4.75	9	10	7	11	1	3
114	ErpHa19	2	3	2.50	5	10	7	8	1	3
115	Bosena	2	3	3.20	1	10	1	11	2	3
116	Yesha-Mezia	2	3	4.38	1	10	1	2	2	3
117	Anko-Meziya	2	3	5.73	1	1	1	2	2	1
118	Shado-Diniya	2	2	6.01	9	10	7	12	2	3
119	Tuzuma	2	2	6.02	1	10	1	2	2	3
120	Gena	2	2	4.36	1	10	1	11	2	3
121	Feleke	2	3	5.87	9	10	7	11	2	3
122	Nekaka	2	3	5.80	9	10	1	11	1	3
123	Chemerotiya	2	3	5.98	10	10	5	11	2	3
124	Hala-Meziya	2	3	5.51	1	1	1	2	2	1
125	Anko-Gena	2	3	5.98	5	11	7	11	1	1
126	Azuma-Boza	2	3	4.99	5	10	1	11	1	3
127	Shuta-ziya	2	4	5.09	9	5	1	8	1	3
128	Akisha	3	3	5.09	5	1	1	2	1	3
129	Ame	3	1	3.87	6	10	5	2	2	3
130	Argozo	3	2	5.95	5	10	7	8	1	3
131	Ayissade	3	2	5.18	1	1	1	2	1	1
132	Babiso	3	2	4.25	9	10	7	8	1	3
133	Banga	3	3	5.13	1	1	1	2	1	1
134	Bergude	3	2	5.58	1	1	1	2	1	1
135	Berzie	3	2	5.00	9	10	7	8	1	3
136	Beshera	3	2	5.91	1	10	1	2	1	1
137	Boda	3	2	2.87	5	1	1	2	1	3
138	Bossa-gena	3	1	3.84	1	10	1	2	2	1
139	Bundo	3	1	2.30	1	1	1	2	1	1
140	Butta	3	2	4.78	5	1	1	2	1	3
141	Checho-I	3	3	3.30	6	10	5	2	2	3
142	Checho-II	3	2	3.25	6	11	5	2	1	3
143	Dellea	3	3	5.83	1	10	1	8	2	1
144	Dellulle	3	2	5.29	1	10	1	2	1	3
145	Dimo	3	1	5.03	9	9	7	7	2	3
146	Dolla	3	4	4.09	1	1	1	2	1	1
147	Fekekie	3	4	5.00	1	1	1	2	2	1

Appendix 5. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	UPPER MIDRIB	UNDER MIDRIB	UPPER PETIOLE	UNDER PETIOLE	LEAF	TIP & EDGE LEAF
148	Fello	3	3	3.47	9	10	7	8	1	1
149	Gena-II	3	3	4.18	1	10	1	2	2	3
150	Golia	3	3	3.11	1	10	1	2	2	3
151	Haleko	3	3	3.33	1	1	1	2	2	1
152	Harambo	3	2	4.00	9	10	9	9	1	3
153	Kekera	3	2	5.76	9	10	7	9	1	3
154	Kerta	3	3	4.99	9	9	7	7	2	3
155	Keteme	3	1	4.71	9	9	7	7	2	3
156	Ketene	3	2	3.73	1	1	1	2	1	1
157	Ketisse	3	3	4.87	1	1	1	2	1	1
158	Mesho-gemo	3	2	5.86	1	10	1	2	1	3
159	Mezie	3	2	5.62	5	10	7	8	1	3
160	Pello	3	3	5.67	5	10	7	8	1	3
161	Pello-2	3	3	5.32	2	10	5	2	1	1
162	Pemia	3	4	4.45	5	10	1	2	1	3
163	Shalda	3	4	5.02	1	1	1	2	1	1
164	Shelekumia	3	2	5.82	5	10	1	11	1	3
165	Shibr	3	1	3.15	5	10	1	11	1	3
166	Sorte	3	3	3.70	9	10	1	11	1	3
167	Tsisse	3	3	4.29	9	10	7	8	1	3
168	Tuffa	3	3	5.01	1	1	1	2	1	1
169	Werzia-macho	3	3	5.24	1	10	1	2	1	3
170	Yilla	3	2	4.80	9	10	1	2	1	3
171	Zinke-bukema	3	3	5.07	9	10	7	7	1	3
172	Zoa-zinke	3	3	3.07	9	10	7	11	2	3
173	Adinona	4	2	4.78	1	2	5	6	1	3
174	Agina	4	2	4.52	5	3	2	11	1	3
175	Akacha	4	1	3.00	4	10	2	8	1	3
176	Ankiegena	4	1	4.71	2	10	1	3	2	3
177	Ankuwa	4	1	2.40	1	5	5	11	1	3
178	Banga	4	2	4.01	2	10	2	2	1	3
179	Bedadia	4	1	4.72	2	10	5	6	1	3
180	Botya	4	2	5.81	2	5	2	6	1	3
181	Bulua	4	2	4.95	2	1	5	6	2	3
182	Chamia	4	1	4.93	10	10	6	11	1	3
183	Dirbuwa	4	2	4.46	1	10	5	11	1	3
184	Dokozuwa	4	1	5.88	2	6	5	11	1	3
185	Erasha	4	2	5.04	2	2	5	2	1	3
186	Eslamia	4	2	3.17	10	11	9	11	1	3
187	Fenku	4	2	3.21	1	1	5	2	2	3
188	Gefetenewa	4	2	4.44	2	10	5	1	1	3
189	Gena	4	2	3.34	7	10	5	13	1	3
190	Genesa	4	2	3.71	1	6	5	11	1	3
191	Gezetiya	4	2	3.68	9	11	9	11	1	3
192	Ginawa	4	2	3.13	1	5	5	11	1	3
193	Goderia	4	2	3.24	2	4	5	3	1	3
194	Kembata	4	1	2.66	2	2	2	5	1	3
195	Kikiro	4	2	4.92	4	10	5	8	1	3
196	Kualia	4	2	2.71	2	10	2	6	1	3

Appendix 5. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	UPPER MIDRIB	UNDER MIDRIB	UPPER PETIOLE	UNDER PETIOLE	LEAF	TIP & EDGE LEAF
197	Kucharkie	4	2	4.57	1	5	5	2	2	3
198	Locha	4	1	3.51	1	1	2	2	1	1
199	Mattie	4	1	3.00	9	9	7	7	1	3
200	Messa	4	2	5.79	3	10	3	11	1	3
201	Mochie	4	2	5.50	1	2	5	5	1	1
202	Osogurzo	4	3	4.89	9	11	7	9	1	3
203	Pokuwa	4	2	5.14	2	10	2	11	1	3
204	Posha	4	2	4.30	2	10	5	5	1	3
205	Shedodiniya	4	2	2.79	1	5	5	8	1	3
206	Shemeroy	4	3	5.13	9	9	8	9	1	3
207	Tuzuma	4	3	3.47	1	10	3	13	1	3
208	Woisha	4	3	2.41	1	5	1	6	1	3
209	Adame-ado	5	3	3.75	2	10	2	6	2	3
210	Ado	5	2	5.02	1	1	1	2	2	2
211	Alenticho	5	2	3.73	1	2	1	3	2	1
212	Astara-SI	5	1	3.68	10	10	8	13	1	3
213	Astara-SII	5	2	3.95	2	2	5	2	1	1
214	Awusho	5	3	3.14	1	5	5	2	1	3
215	Barbo-dancho	5	1	3.55	10	10	5	3	1	1
216	Bezeze	5	3	5.12	10	11	5	13	2	3
217	Buaecho(Guragies)	5	1	5.28	2	2	5	3	2	1
218	Bulle	5	3	3.09	2	11	3	3	2	3
219	Buzzare	5	2	4.34	2	10	5	6	1	3
220	Chelako	5	3	2.86	4	10	5	11	1	3
221	Demela	5	3	4.85	2	1	5	2	1	1
222	Derassa-dimela	5	3	3.72	5	10	5	11	1	3
223	Dinke	5	2	4.27	2	2	5	2	1	1
224	Dubano	5	2	3.78	1	1	5	14	2	1
225	Ewisho	5	1	4.00	1	10	5	2	1	1
226	Gemechalla	5	1	3.79	2	2	2	2	2	3
227	Gena	5	3	3.31	9	10	6	11	1	3
228	Gerbo	5	1	2.51	7	10	4	8	1	3
229	Gerdicho	5	1	2.86	9	10	6	12	1	3
230	Gulama	5	3	5.16	2	10	2	6	1	3
231	Gussello	5	2	2.85	10	10	8	11	1	3
232	Hawe	5	2	3.78	3	10	2	6	2	3
233	Hekacha	5	2	2.34	2	12	6	8	1	3
234	Hekecha-I	5	2	2.68	9	10	8	8	2	3
235	Kerase	5	3	4.60	1	1	5	2	1	1
236	Kulo	5	3	2.32	1	12	5	2	1	3
237	Ontosha	5	2	2.71	2	10	5	3	1	3
238	Seddisse	5	2	2.45	1	12	5	14	2	3
239	Sediso	5	2	5.00	4	10	2	6	2	3
240	Serane	5	2	3.43	10	11	2	13	1	3
241	Serena	5	3	3.72	2	8	2	6	1	3
242	Sidiramo	5	2	5.12	7	10	2	6	1	3
243	Sirriro	5	1	4.93	2	5	2	6	2	3
244	Tunaka	5	3	2.86	2	1	5	2	1	2
245	Walanticha-I	5	1	3.41	2	2	2	3	2	1

Appendix 5. Continued

ENTRYNO	NAME	CollLoc	CollALT	MT	UPPER MIDRIB	UNDER MIDRIB	UPPER PETIOLE	UNDER PETIOLE	LEAF	TIP & EDGE LEAF
246	Walantiche-II	5	2	4.21	2	8	5	3	2	1
247	Wanigaro	5	3	4.78	10	11	2	11	2	3
248	Waniwassa	5	2	5.78	10	9	9	9	1	3
249	Welanticho	5	2	3.78	9	10	4	11	1	3
250	Ameratiye	6	1	3.62	1	1	1	2	1	1
251	Anikefiye	6	2	3.04	1	10	1	11	2	3
252	Astara	6	4	3.14	9	10	7	11	1	3
253	Ayiwegne	6	2	5.02	9	10	7	8	2	3
254	Bishkanchiwe	6	4	3.13	1	5	1	11	2	3
255	Cherkimad	6	4	4.84	9	10	7	9	2	3
256	Dere	6	4	3.79	1	5	1	11	2	3
257	Egendiye	6	1	5.12	9	10	7	8	1	3
258	Eminiye	6	2	5.25	9	10	1	11	1	3
259	Engidawork	6	1	3.42	1	1	1	2	1	3
260	Esmaele	6	2	4.24	5	10	7	1	2	3
261	Geziwet	6	2	3.67	9	10	7	3	2	3
262	Gimbuwe	6	2	2.86	9	10	7	11	2	3
263	Guariye	6	1	3.08	9	10	7	2	1	1
264	Gumbar	6	4	5.73	1	10	1	1	1	3
265	Gurebeshelga	6	4	4.84	1	1	1	2	1	1
266	Jobiro	6	1	3.58	1	5	1	2	2	3
267	Kanchiwe	6	1	4.37	1	1	1	2	1	1
268	Keweretiye	6	3	4.76	1	1	1	2	1	1
269	Kinke	6	1	3.18	1	1	1	2	1	1
270	Mayimote	6	2	2.76	9	10	7	7	2	3
271	Nechuwe	6	4	3.17	1	10	1	2	1	3
272	Nechuwe-II	6	4	3.14	9	10	1	11	1	3
273	Sebara	6	4	4.11	9	10	1	11	2	3
274	Sherite	6	4	3.38	1	10	1	2	1	3
275	Shertiye	6	4	4.39	1	1	1	2	2	1
276	Shifire	6	1	4.51	1	1	1	2	1	1
277	Temoyise	6	2	3.44	9	10	7	11	2	3
278	Teriye	6	4	3.47	9	10	7	11	2	3
279	Tobiro	6	4	4.53	5	10	7	1	2	3
280	Weka	6	2	3.28	9	10	7	11	2	3
281	Wered	6	2	3.80	9	10	7	8	2	3
282	Weretea	6	2	3.23	9	10	7	8	2	3
283	Yegendiye	6	2	3.33	9	10	7	11	1	3
284	Yekimech	6	2	2.71	9	10	1	11	2	3
285	Yesherafire	6	4	4.43	1	10	1	2	2	1
286	Yibiye	6	2	3.09	9	10	7	10	2	3

Appendix 6. Table 1. List of enset landraces, collection zone, DNA concentration, purity of DNA, RNA and Nuclic acid

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
1	Argozo	Gamogoffa	873.10	2.08	2.14
2	Gemechalla	Sidama	454.00	2.06	2.10
3	Dellea	Gamogoffa	735.70	2.14	2.35
4	Mesho-gemo	Gamogoffa	1131.70	2.08	2.18
5	Dimo	Gamogoffa	484.10	2.08	2.18
6	Welanticho	Sidama	1367.50	2.24	2.96
7	Ketene	Gamogoffa	1484.80	2.25	2.86
8	Gedime	Sidama	561.20	2.09	1.88
9	Geziwet	Gurage	425.20	2.12	1.71
10	Wanadia	Wolaita	933.80	2.22	3.18
11	Beshera	Gamogoffa	808.30	2.13	2.13
12	Omiyo	Kaffa	1427.10	2.21	2.78
13	Chongo	Kaffa	689.70	2.09	1.64
14	Gini	Sheka	321.30	2.18	1.54
15	Gemo	Sheka	551.60	2.17	2.01
16	Diya feya	Yem Special Woreda	429.40	2.17	1.50
17	Bedo	Sheka	345.70	2.10	2.45
18	Kueitare	Yem Special Woreda	325.80	2.13	1.87
19	Wango	Sheka	638.60	2.16	1.60
20	Genticha Xtra long	West Arsi	875.50	2.18	1.60
21	Akeru	Yem Special Woreda	879.30	2.36	1.66
22	Lemat	West & SW Shewa	1048.00	2.36	1.72
23	Karona	Yem Special Woreda	574.00	2.13	1.60
24	Sebara	West & SW Shewa	434.80	2.17	1.44
25	Kaga	Yem Special Woreda	534.30	2.24	1.27
26	Dape	Yem Special Woreda	1218.50	2.37	1.55
27	Wassa-ayife	Gamogoffa	880.50	2.32	1.78
28	Oko	Sheka	851.40	2.43	1.54
29	Ogiyo	Sheka	1018.30	2.36	1.47
30	Asetna	Yem Special Woreda	783.00	2.27	1.47
31	Bukuma	Gamogoffa	874.30	2.48	1.67
32	Bino	Gamogoffa	693.80	2.24	1.06
33	Mone	Gamogoffa	547.50	2.19	1.32
34	Dubano	Sidama	536.70	2.15	1.33
35	Adame-ado	Sidama	752.00	2.48	1.48
36	Kmeiretu	Yem Special Woreda	315.40	2.14	1.29
37	Yobo	Sheka	836.00	2.47	1.67
38	Zonga	Gamogoffa	392.70	2.29	1.05
39	Nechuwe	Gurage	684.60	2.11	1.79
40	Adinona	Dawro	249.40	2.21	1.51
41	Bosoberadi	Sheka	1478.00	2.31	1.81
42	Akisha	Gamogoffa	1066.40	2.14	1.43
43	Chocho	Gamogoffa	1532.10	2.00	1.52
44	Digo-Merza	Kembata-Tembaro	821.10	2.19	1.51
45	Tena	Dawro	1402.70	2.30	1.67
46	Henuwa	Kembata-Tembaro	925.20	2.44	2.16
47	Dellulle	Gamogoffa	770.20	2.26	1.33
48	Mezie	Gamogoffa	1663.40	2.28	1.50
49	Nobo	Sheka	1037.30	2.18	1.51
50	Dubriat	West & SW Shewa	1890.80	2.25	1.67

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
51	Zonga-2	Gamogoffa	754.80	2.50	1.95
52	Bulbul	Yem Special Woreda	1302.00	2.20	1.50
53	Nechaset	West & SW Shewa	1181.70	2.08	1.69
54	Yako	Kaffa	1248.50	2.36	1.57
55	Mosso	Gamogoffa	1790.80	2.33	1.60
56	Butta	Gamogoffa	788.80	2.44	1.94
57	Unknown	Gamogoffa	1599.50	2.34	1.60
58	Dokaze	Gamogoffa	755.30	2.18	1.49
59	Beshelga	West & SW Shewa	1477.10	2.37	1.69
60	Apecho	Kaffa	2348.80	2.11	1.68
61	Sidiramo	Sidama	1955.70	2.32	1.50
62	Ankie-gena	Wolaita	1476.80	2.20	1.46
63	Unknown	Gamogoffa	1640.00	2.25	1.84
64	Gareye tekure	Yem Special Woreda	359.50	2.13	2.08
65	Ayo	Gamogoffa	1671.20	2.18	1.36
66	Qodena	Yem Special Woreda	1320.20	2.18	1.51
67	Aba-Sheger	West & SW Shewa	1866.20	2.18	1.49
68	Gimbu	Yem Special Woreda	1114.40	2.18	1.56
69	Argema	Dawro	678.30	2.20	1.59
70	Noru	Yem Special Woreda	1498.20	2.14	1.68
71	Megru	Yem Special Woreda	787.60	2.19	7.67
72	Manduluka	Kembata-Tembaro	474.60	2.16	1.72
73	Kessiet	Kembata-Tembaro	686.30	2.21	1.69
73	Mundrarie	West Arsi	926.80	2.12	2.13
75	Aregemu	Yem Special Woreda	1146.20	2.18	1.72
76	Yesha-mezia	Dawro	1161.00	2.18	1.48
77	Boso	Sheka	717.40	2.20	1.44
78	Areko	Sheka	1063.60	2.19	1.62
79	Mech-Koto	Kaffa	1289.30	2.17	1.47
80	Feluwa	Wolaita	1274.80	2.18	1.53
81	Gussello	Sidama	822.10	2.19	1.40
82	Sessa	Kembata-Tembaro	1102.80	2.21	1.48
83	Meso	Sheka	1134.10	2.18	1.58
84	Gena-2	Gamogoffa	1183.60	2.18	1.42
85	Berasho	Sheka	1229.70	2.15	1.57
86	Yegendiye	Gurage	1263.20	2.18	1.64
87	Yiregiye	Gurage	1673.10	2.13	1.43
88	Kekille	Kembata-Tembaro	1376.70	2.16	1.47
89	Semay-leged	West & SW Shewa	1134.60	2.21	1.52
90	Ashakti	West & SW Shewa	944.10	2.20	1.47
91	Sewandiya	Kembata-Tembaro	1339.50	2.14	1.35
92	Maro	Sheka	1681.90	2.17	1.41
93	Gyeba	Yem Special Woreda	1437.90	2.21	1.39
94	Apecho	Kaffa	1558.30	2.17	1.46
95	Emenasha	Yem Special Woreda	1407.70	2.14	1.61
96	Nekaka	Dawro	1011.70	2.18	1.48
97	Tuzuma	Dawro	1294.70	2.22	1.53
98	Koina	Kembata-Tembaro	671.60	2.30	1.28
99	Gefetenewa	Wolaita	917.10	2.29	1.24
100	Fugicho	Kembata-Tembaro	875.60	2.39	1.19

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
101	Gena	Sidama	784.80	2.08	0.96
102	Kekeri	West & SW Shewa	640.50	2.40	1.48
103	Ketenia	Wolaita	659.60	2.32	1.24
104	Tita	Kembata-Tembaro	1238.10	2.24	1.31
105	Feleke	Dawro	692.10	2.24	1.24
106	Chichiye	Dawro	358.30	2.21	1.14
107	Gesa	Dawro	1163.70	2.17	0.98
108	Tela	Wolaita	685.40	2.24	1.28
109	Elore	Dawro	845.30	2.27	1.23
110	Gena	Sidama	646.00	2.23	1.05
111	Mariya	Kembata-Tembaro	908.20	2.07	1.23
112	Astara	Sidama	631.40	2.25	1.44
113	Buba	Dawro	691.60	2.32	1.24
114	Walema	Kembata-Tembaro	949.20	2.12	1.28
115	Zerfisha	Kembata-Tembaro	494.40	2.02	1.03
116	Banga-arkiya	Dawro	483.20	2.14	1.10
117	Mengi	Sheka	647.40	2.29	1.23
118	Okashiya	Dawro	942.60	2.15	1.05
119	Kekera	Gamogoffa	1142.40	2.27	1.22
120	Gemorcha	Wolaita	1060.90	2.18	1.36
121	Ageane	Kaffa	1082.20	2.08	1.24
122	Agadie	Kembata-Tembaro	781.60	2.27	1.16
123	Beradi	Sheka	2103.50	2.13	1.67
124	Deluliya	Dawro	1829.10	2.20	1.63
125	Bedadeda	Kembata-Tembaro	774.40	2.17	1.72
126	Akacha	Wolaita	251.90	1.87	1.08
127	Bokel-Bocho	Kaffa	555.50	2.15	1.50
128	Kaziya	Dawro	1585.90	2.17	1.58
129	Hiniba	Kembata-Tembaro	133.50	1.92	1.61
130	Serane	Sidama	1485.90	2.17	1.37
131	Tikur Genticha	West Arsi	1025.10	2.17	1.50
132	Sanka	Wolaita	2098.20	2.17	1.57
133	Yeshira-fire	West & SW Shewa	1154.00	2.25	1.39
134	Qupo	Kaffa	850.80	2.15	1.40
135	Chicho	Gamogoffa	1088.20	2.24	1.34
136	Gishera	Kembata-Tembaro	1295.10	2.19	1.41
137	Cherkimad	Gurage	812.70	2.27	1.33
138	Akachiya	Dawro	1283.50	2.19	1.61
139	Demeshasha	West Arsi	856.80	2.21	1.98
140	Aylelo	Yem Special Woreda	341.80	2.31	1.60
141	Bejo	Kaffa	728.60	2.14	1.36
142	Zebro	Kembata-Tembaro	905.30	2.25	1.38
143	Dolla	Gamogoffa	1247.40	2.06	1.37
144	Mishiko	Kaffa	1327.40	2.19	1.42
145	Bedadia	Wolaita	1793.60	2.22	1.55
146	Ajero	Sheka	1856.50	2.23	1.29
147	Bundo	Gamogoffa	1844.20	2.23	1.29
148	Demela	Sidama	1271.60	2.34	1.27
149	Tsisse	Gamogoffa	573.10	2.14	1.53
150	Siniwet	Gurage	1235.20	2.35	1.50

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
151	Fosho	Gamogoffa	924.20	2.40	1.35
152	Jegreda	Kembata-Tembaro	911.00	2.41	1.24
153	Shingiya	Dawro	1415.00	2.35	1.47
154	Mech-shododiniya	Dawro	1083.10	2.41	1.26
155	Locha	Wolaita	1580.00	2.23	1.40
156	Sultiya	Dawro	1243.90	2.27	1.36
157	Shelekuma	Dawro	963.20	2.25	1.50
158	Wenadia	Gamogoffa	895.80	2.35	1.27
159	Sanka	Dawro	710.00	2.40	1.45
160	Ayissade	Gamogoffa	1113.50	2.28	1.38
161	Nechiwe	Kembata-Tembaro	529.20	2.10	2.05
162	Shibr	Gamogoffa	1287.70	2.28	1.39
163	Keteniya	Dawro	900.80	2.26	1.49
164	Ferezia	Kembata-Tembaro	1485.40	2.22	1.49
165	Koncha	Yem Special Woreda	879.70	2.24	1.35
166	Fenchariya-yepa	Dawro	1459.50	2.31	1.28
167	Yilga	Dawro	900.20	2.32	1.47
168	Anikefiye	Gurage	1419.00	2.26	1.37
169	Tuzuma	Wolaita	977.80	2.37	1.40
170	Onjamo	Kembata-Tembaro	731.90	2.40	1.42
171	Chamia	Wolaita	994.80	2.33	1.42
172	Keberia	Wolaita	826.80	2.35	1.27
173	Kerase	Sidama	788.30	2.23	2.06
174	Koker	Yem Special Woreda	743.10	2.42	1.25
175	Achora	Gurage	779.70	2.37	1.25
176	Mocho	Kaffa	1207.40	2.37	1.37
177	Zira-metiya	Dawro	1577.90	2.30	1.33
178	Bukuniye	Dawro	1094.60	2.37	1.27
179	Dengicho	Kembata-Tembaro	1020.30	2.21	2.23
180	Goemerrie	Kembata-Tembaro	1436.80	2.31	1.38
181	Zergesa	Dawro	1306.90	2.36	1.27
182	bukinia	Wolaita	1110.40	2.37	1.30
183	Siyuti	Wolaita	877.90	2.31	1.59
184	Lekaka	Kembata-Tembaro	1076.30	2.31	1.50
185	Sokidie	Kembata-Tembaro	955.60	2.32	1.42
186	Lemat	Gurage	1899.60	2.30	1.27
187	Sirriro	Sidama	1582.20	2.29	1.31
188	Boza-bukuniya	Dawro	1372.40	2.31	1.65
189	Wechered	Kembata-Tembaro	929.50	2.42	1.41
190	Weysadie	Dawro	971.20	2.35	1.30
191	Bedediet	Kembata-Tembaro	751.90	2.24	2.23
192	Tsela	Dawro	1323.50	2.33	1.42
193	Donkolola	Dawro	1223.80	2.23	1.39
194	Gelaro	Yem Special Woreda	1289.90	2.21	1.22
195	Bezeriyet	Gurage	1043.00	2.26	1.23
196	Erentiya	Dawro	1003.20	2.28	1.26

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
197	Tufa	Wolaita	1007.10	3.29	1.31
198	Bedadiy	Dawro	1059.50	2.26	1.23
199	Dirbuwa	Wolaita	867.80	2.12	1.52
200	Unknown	Gamogoffa	810.50	2.17	1.15
201	Dirbo	Kembata-Tembaro	733.20	2.26	1.22
202	Halaa	Wolaita	1023.00	2.25	1.24
203	Chemerotiye	Dawro	1354.10	2.24	1.39
204	Banga	Gamogoffa	1453.70	2.22	1.41
205	Garda	West & SW Shewa	1117.10	2.24	1.25
206	Wa-ano	Gamogoffa	635.40	2.29	1.51
207	Sediso	Sidama	783.90	2.24	1.21
208	Mazia	Wolaita	918.40	2.22	1.17
209	Berjiye	Dawro	949.40	2.22	1.33
210	Keltentia	Wolaita	1099.00	2.24	1.14
211	Shower	Kembata-Tembaro	897.10	2.26	1.26
212	Cherelo	Sheka	934.00	2.18	1.20
213	Bisha-amerad	Gurage	875.10	2.23	1.38
214	Doko	Wolaita	871.80	2.25	1.27
215	Wania	West & SW Shewa	412.00	2.19	1.20
216	Guariye	Gurage	650.60	2.19	1.29
217	Kertiya	Dawro	1035.50	2.29	1.09
218	Boda	Gamogoffa	1278.80	2.15	1.28
219	Zoa-zinke	Gamogoffa	755.10	2.10	1.97
220	Demorjat	Gurage	830.80	2.23	1.20
221	Lochingie	Dawro	1013.90	2.21	1.23
222	Genjo	Sheka	1078.70	2.23	1.14
223	Chachero	Sheka	933.00	2.17	1.46
224	Garanetsa	Gamogoffa	1253.70	2.22	1.17
225	Hallako	Gamogoffa	590.20	2.07	1.91
226	Keweretiye	Gurage	498.10	2.05	2.15
227	Workie-ija	West & SW Shewa	1030.10	2.20	1.39
228	Chawille	Gamogoffa	1069.80	2.18	1.34
229	Kembat	Kembata-Tembaro	1105.50	2.60	2.02
230	Defawo	Sheka	1336.20	2.30	1.35
231	Teteret	West & SW Shewa	1183.20	2.20	1.36
232	Abato	Kembata-Tembaro	214.00	2.12	1.46
233	Agina	Wolaita	328.50	2.10	2.03
234	Argama	Wolaita	929.10	2.18	1.42
235	Tena	Kembata-Tembaro	666.10	2.15	1.67
236	Kerod	Yem Special Woreda	211.40	2.15	1.21
237	Acho	Sheka	1108.30	2.20	1.39
238	Dinke	Sidama	827.10	2.15	2.05
239	Pello-2	Gamogoffa	626.80	2.13	1.32
240	Yibiye	Gurage	648.60	2.02	2.04
241	Sebara	Gurage	1420.40	2.19	1.24
242	Fegnekor	West & SW Shewa	1474.00	2.20	1.48

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
243	Engida-werk	Gurage	1530.40	2.16	1.63
244	Bejo	Kaffa	1619.90	2.19	1.40
245	Aguasa(ta)	Dawro	1376.20	2.16	1.30
246	Ored	Kembata-Tembaro	1293.30	2.20	1.25
247	Weshmeda	Kembata-Tembaro	1542.80	2.22	1.51
248	Achechet	West & SW Shewa	1524.60	2.18	1.44
249	Anko-mezia	Dawro	1036.60	2.16	1.64
250	Yrio	Sheka	1397.00	2.20	1.47
251	Kuena	Kembata-Tembaro	1338.30	2.19	1.43
252	Wellanchie	Kembata-Tembaro	681.80	2.18	1.44
253	Lochingie	Wolaita	2088.60	2.22	1.34
254	Astara	Sidama	1941.10	2.25	1.39
255	Lokanda	Kembata-Tembaro	793.50	2.25	1.35
256	Tegaded	Kembata-Tembaro	1051.40	2.18	1.31
257	Gotedirbo	Kembata-Tembaro	2148.20	2.20	1.44
258	Unknown	Gurage	1341.70	2.21	1.64
259	Wered	Gurage	1244.70	2.17	1.64
260	Fegneker	West & SW Shewa	1390.20	2.22	1.53
261	Nekaka	Wolaita	14343.10	2.27	1.26
262	Sukeru	Yem Special Woreda	1575.40	2.19	1.55
263	Missed	Sidama	1182.60	2.20	1.67
264	Shelekumia	Wolaita	274.40	2.08	2.03
265	Ut'no	Kaffa	1600.60	2.21	1.37
266	Bergude	Gamogoffa	1222.10	2.17	1.37
267	Eskuris	Kembata-Tembaro	844.80	2.15	1.31
268	Akbaro	Kaffa	1222.10	2.22	1.31
269	Haleko	Gamogoffa	869.20	2.21	1.36
270	Wankebere	Kembata-Tembaro	1285.40	2.20	1.40
271	Banga	Dawro	1491.20	2.21	1.37
272	Halso	Sidama	1795.50	2.22	1.30
273	Chichia	Wolaita	1634.10	2.21	1.21
274	Kekille	Kembata-Tembaro	1228.30	2.17	1.31
275	Beshute	West & SW Shewa	2240.20	2.11	1.48
276	Adinona	Wolaita	1366.70	2.25	1.30
277	Sheliako	Sheka	886.70	2.20	1.70
278	Mochie	Wolaita	1593.20	2.21	1.37
279	Bosena	Dawro	1001.60	2.32	1.54
280	Feresiye	West & SW Shewa	1115.00	2.22	1.43
281	Boshesha	Kembata-Tembaro	810.90	2.26	1.48
282	Kombotic	Kembata-Tembaro	1330.50	2.20	1.62
283	Ayina	Dawro	1262.10	2.24	1.23
284	Kerta	Gamogoffa	687.30	2.33	1.22
285	Oroda	Yem Special Woreda	1299.40	2.19	1.47
286	Shishiri	Sheka	1357.30	2.24	1.38
287	Temoyise	Gurage	1421.20	2.24	1.37
288	Genticha long	West Arsi	814.30	2.10	2.13
289	Pokuwa	Wolaita	922.70	2.27	1.22

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
290	Hawe	Sidama	1615.60	2.21	1.41
291	Badadiat	West & SW Shewa	1445.10	2.24	1.29
292	Shenea	Yem Special Woreda	1464.10	2.20	1.30
293	Bossie	Kembata-Tembaro	1567.10	2.11	2.07
294	Derassa-dimela	Sidama	2993.30	2.06	1.71
295	Zobra	Kembata-Tembaro	1058.60	2.33	1.19
296	Gena	Wolaita	504.30	2.07	2.01
297	Agadie	Kembata-Tembaro	1228.70	2.28	1.28
298	Tasurgo	Dawro	1343.70	2.23	1.56
299	Tororie	Kembata-Tembaro	1579.30	2.23	1.35
300	Anko-gena	Dawro	1610.90	2.25	1.41
301	Astara	Gurage	1499.50	2.22	1.40
302	Fiaa	Yem Special Woreda	1143.20	2.21	1.42
303	Ososa	Kembata-Tembaro	1487.10	2.26	1.31
304	Shisho	Sheka	1627.60	2.19	1.54
305	Shuta-ziya	Dawro	1105.60	2.21	1.31
306	Pello	Gamogoffa	1336.40	2.23	1.37
307	Sesikila	Kembata-Tembaro	355.70	2.06	1.94
308	Ame (Amaye)	Gamogoffa	281.80	2.06	1.62
309	Aeluwa	Dawro	168.70	2.04	1.86
310	Fello	Gamogoffa	408.30	2.07	2.01
311	Morketa	Gamogoffa	557.60	2.11	1.83
312	Aleticho	West Arsi	361.80	2.02	1.73
313	Toreret	West & SW Shewa	679.10	2.07	1.99
314	Utro	Kaffa	199.30	2.05	1.70
315	Pecho	Sheka	6.40	1.04	0.42
315	Pecho	Sheka	31.50	2.14	1.42
316	Weriza-macho	Gamogoffa	516.30	2.10	1.87
317	Shertie	Kembata-Tembaro	859.80	2.16	1.94
318	Felekie	Gamogoffa	364.80	2.01	1.62
319	Omi	Sheka	307.80	2.10	1.94
320	Teriye	Gurage	218.30	2.13	1.97
321	Tebuttie	Kembata-Tembaro	26.50	2.25	1.30
322	Etinie	Kembata-Tembaro	107.40	2.06	1.62
323	Fello	Gamogoffa	283.70	2.07	1.93
324	Bossa-gena	Gamogoffa	664.80	2.60	1.87
325	Guarye	Kembata-Tembaro	186.40	2.06	1.89
326	Teberie	Kembata-Tembaro	855.70	2.20	1.41
327	Sesa	Wolaita	412.70	2.08	2.01
328	Agadie	Gurage	408.70	2.06	2.00
329	Goderitto	Kembata-Tembaro	434.60	2.09	1.97
330	Shuri	Sheka	411.40	2.18	1.23
331	Shelekie	Kembata-Tembaro	638.90	2.18	1.75
332	Mesmesa	Kembata-Tembaro	1079.10	2.17	1.28
333	Uzula	Dawro	544.80	2.19	1.22
334	ErpHa18	Dawro	586.10	2.07	1.64
335	Yoto	Sheka	710.60	2.21	1.35

Appendix 6. Continued

Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
336	Awusho	Sidama	449.70	2.11	1.64
337	Benje	Sidama	335.50	2.05	1.94
338	Mattie	Wolaita	636.50	2.20	1.97
339	Kamo	Yem Special Woreda	216.10	2.03	1.91
340	Liembo	Wolaita	351.70	2.08	1.89
341	Hasa-bedadiye	Dawro	282.50	2.07	1.94
342	Bulle	Sidama	292.20	2.11	1.99
343	Achorie	West & SW Shewa	1241.80	2.16	1.27
344	Mindiraro-1	Sidama	666.60	2.24	1.27
345	Timbri	Sheka	790.70	2.23	1.34
346	Boela	Kembata-Tembaro	156.60	1.97	1.56
347	Gena	Dawro	3.00	0.85	0.50
347	Gena	Dawro	3.90	1.08	1.32
348	Noru	Jimma	358.00	1.85	1.27
349	Zinkia	Wolaita	318.60	1.92	1.28
350	Shefire	Gurage	484.40	2.13	1.44
351	Ameratiye	Gurage	18.10	1.03	0.79
352	Hiniba	West & SW Shewa	519.50	2.18	1.22
353	Zeriyie	Kembata-Tembaro	243.40	2.06	1.80
354	ZERETA	Released	115.30	2.16	1.57
355	Wagu	Yem Special Woreda	287.10	2.23	1.46
356	Genticha wide	West Arsi	540.00	2.14	1.36
357	Shertiye	Gurage	320.60	2.03	1.71
358	Shodo-diniya	Dawro	314.20	2.21	1.24
359	Ketenie	Jimma	560.40	2.13	1.25
360	Beneguea	Kembata-Tembaro	722.70	2.21	1.82
361	Abajobir	West & SW Shewa	104.50	1.83	1.39
362	ARKIA	Dawro (Suceptible)	105.60	2.16	1.85
363	Budunswa	Dawro	212.10	1.50	1.00
364	Gumbar	Gurage	309.50	2.17	1.26
365	Yigebeyie	Jimma	235.30	2.09	1.32
366	Noboburacha	Jimma	550.10	2.06	1.54
367	Gatano	Jimma	61.70	1.94	1.47
368	Wagu	Jimma	366.10	2.19	1.67
369	Hala-a	Dawro	520.50	2.12	1.75
370	Weretea	Gurage	21.80	1.96	1.88
370	Weretea	Gurage	20.90	1.68	1.33
371	Yeshira-Friye	Kembata-Tembaro	779.00	2.27	1.44
372	Genticha	West Arsi	2.30	1.36	0.55
372	Genticha	West Arsi	17.40	1.66	1.22
373	Topacho	Sheka	670.00	2.23	1.84
374	Ado	West Arsi	258.30	2.08	1.86
375	Bosoyafi	Sheka	6.60	1.81	1.56
375	Bosoyafi	Sheka	13.60	1.74	0.92
376	Metako	Sheka	1027.60	2.28	1.44
377	Shoto	Kaffa	688.30	2.36	1.97
378	Daksi koker	Yem Special Woreda	700.20	2.44	1.34

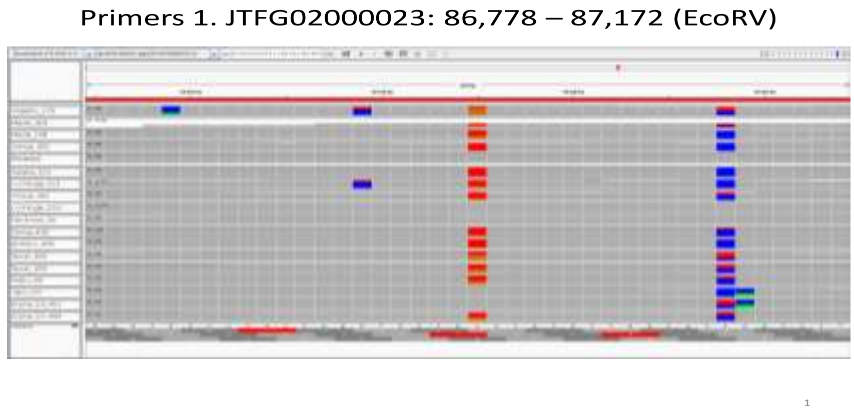
Appendix 6. Continued

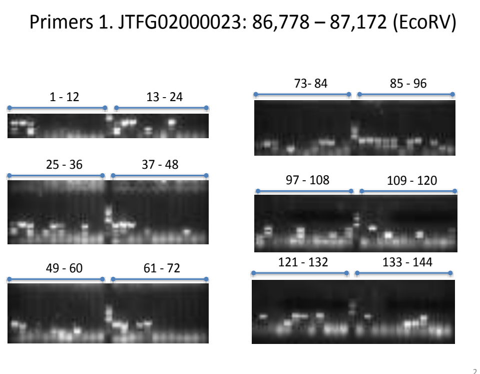
Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
379	WILD-4	Wild from A.A	144.40	1.79	1.88
380	SEED-5	Seed from Epo	5.90	1.83	0.49
380	SEED-5	Seed from Epo	12.30	2.60	1.27
381	Sigezo-Saruma	Kembata-Tembaro	79.90	2.20	1.64
382	ENDALE	Released	172.00	2.15	2.09
383	Botetie	West Arsi	218.80	2.19	1.60
384	Kalo	Kaffa	171.50	2.13	1.63
385	Kokerie	Jimma	6.30	1.98	0.51
385	Kokerie	Jimma	3.60	2.77	1.01
386	Anchro3	Jimma	1032.30	2.21	1.42
387	Sagie	Jimma	252.30	2.24	2.08
388	Shotu	Jimma	309.00	2.07	1.77
389	Airo	Kembata-Tembaro	550.70	2.16	1.61
390	Sorpie	Kembata-Tembaro	72.70	1.88	1.09
391	Anchronech	Jimma	1166.70	2.33	1.80
392	Tomoko	Yem Special Woreda	593.80	2.43	1.67
393	Beteto	Sheka	575.00	2.39	1.68
394	Worke-bidu	West & SW Shewa	103.30	2.08	1.54
395	Serena	Sidama	301.00	2.06	1.14
396	Yeshera-fire	Gurage	239.20	1.93	1.25
397	Acherka	Yem Special Woreda	47.60	2.03	1.31
398	Werabo	Jimma	258.90	2.00	1.57
399	Koremo	Kaffa	533.50	2.57	1.25
400	Checho	West Arsi	126.20	1.82	1.36
401	Esmaele	Gurage	368.40	2.15	1.47
402	Unknown2	Jimma	243.80	1.66	1.08
403	Fechachie	Kembata-Tembaro	53.00	2.03	1.38
404	Bongo	Kaffa	538.10	2.14	1.49
405	Shdi	Sheka	260.70	1.83	1.30
406	Buffero	West Arsi	554.60	2.16	1.28
407	Molgie	Jimma	28.90	2.00	1.27
408	Keroni	Jimma	358.30	2.15	1.24
409	Wohie	Kembata-Tembaro	264.70	2.07	1.31
410	Kekaro	Sheka	664.40	2.29	2.06
411	SEED-01	Seed from Epo	571.60	2.12	1.25
412	WOLAITA ARKIA	Wolaita	359.90	2.10	1.46
413	Bulbuli	Jimma	181.60	2.21	1.46
414	SEED-02	Seed from Epo	155.80	2.08	1.62
415	HALLA	Wolaita	421.40	2.12	1.32
416	Gito	Sheka	436.80	2.22	1.26
417	Giracha	Jimma	762.90	2.32	2.21
418	KELLISA	Released	696.50	2.28	2.55
419	GEWADA	Released	224.40	2.40	1.48
420	Ado	Sheka	2062.00	2.24	1.85
421	Gagewi	Jimma	743.30	2.36	1.56
422	Barbo-dancho	Sidama	1048.50	2.28	1.61
423	Kibute	West & SW Shewa	1787.00	2.26	1.78

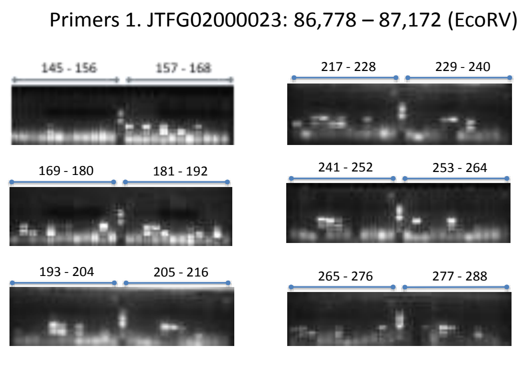
Appendix 6. Continued

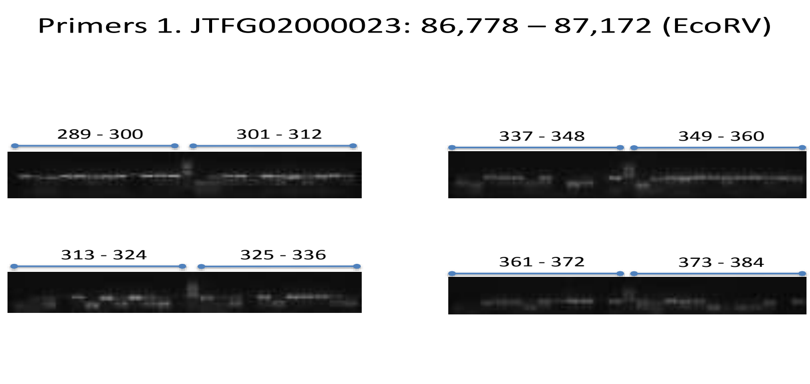
Sample #	Landraces name	Collection zone/ Ethnic group	**Amount of DNA/µl (ngm/µl)**	**Purity of DNA & RNA (260/280)**	**Nuclic Acid Purity (260/230)**
424	Teo	Sheka	1960.10	2.21	1.90
425	YANBULE	Released	601.40	2.20	1.19
426	Karona	Jimma	867.20	2.20	2.97
427	SEED-04	Seed from Epo	1013.00	2.20	1.51
428	Sorte	Gamogoffa	445.40	2.12	1.36
429	MAZIA	Disease Tolerant	496.90	2.18	1.38
430	Adel-Bocho	Kaffa	1928.30	2.18	1.64
431	Goteno	Sheka	621.30	1.99	2.59
432	Kezo	Jimma	322.90	2.09	1.52
433	Burity	Jimma	760.70	2.15	1.50
434	SEED-03	Seed from Epo	661.30	2.07	2.65
435	Dere	Gurage	1743.50	2.11	1.97
436	Bosogeji	Sheka	1378.40	2.15	1.69
437	Anechero	Yem Special Woreda	1240.40	2.14	1.78
438	Diya	Yem Special Woreda	856.20	2.12	1.91
439	Oniya	Kembata-Tembaro	401.00	2.19	1.41
440	Tessa	Kembata-Tembaro	244.70	2.14	1.87
441	Ontosha	Sidama	232.70	2.09	1.82
442	Bezeriyie	Kembata-Tembaro	539.00	2.12	1.65
443	BOTA ARKIA	Wolaita	762.40	2.07	2.17
444	MESSENA	Released	579.50	2.20	1.37
445	Ado	Sidama	924.80	2.12	1.85
446	Nobo	Jimma	200.70	2.19	1.57
447	Atewi	Jimma	401.60	2.18	1.49
448	Finafina	Yem Special Woreda	725.80	2.05	2.10
449	ErpHa20	Dawro	686.70	2.03	2.20
450	Choro	Kaffa	1805.70	2.13	1.84
451	ErpHa13	Dawro	818.90	2.06	1.86
452	Gonosa	Jimma	64.80	2.05	1.56
453	Silikentie	Wolaita	681.80	1.99	2.94
454	Niko	Kaffa	601.30	2.19	1.32
455	Arkia	Wolaita	301.00	2.08	1.99
456	Keshkeshiya	Kembata-Tembaro	1075.90	2.13	1.64
457	Shotu	Yem Special Woreda	925.60	2.10	1.83
458	Bisha-kanchiwe	Gurage	15.60	1.95	0.70
458	Bisha-kanchiwe	Gurage	5.60	1.59	0.68

Appendix 7. PCR-RFLP assay amplifing a PCR product that flanks a SNP that falls within the recognition site for a restriction enzyme







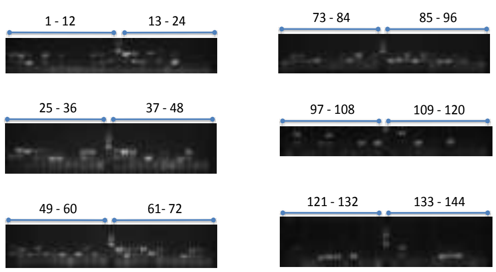


Appendix 7. Continued

Primers 5. JTFG02004430: 21,696 - 22,095 (BglII)

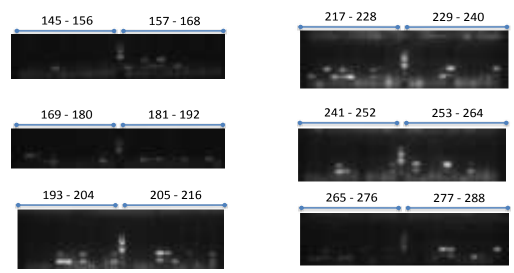
5

Primers 5. JTFG02004430: 21,696 - 22,095 (BglII)



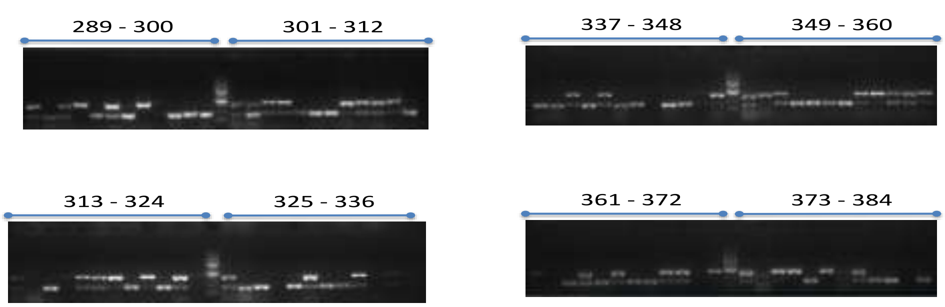
6

Primers 5. JTFG02004430: 21,696 - 22,095 (BglII)



7

Primers 5. JTFG02004430: 21,696 - 22,095 (BglII)



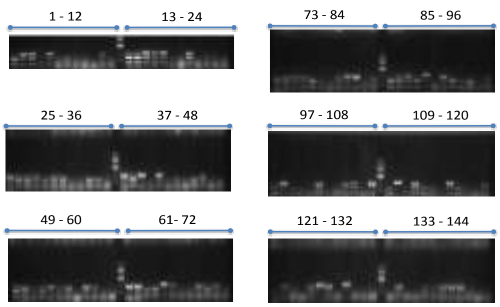
8

Appendix 7. Continued

Primers 7. JTFG02007725: 4758 - 5078 (BglII)

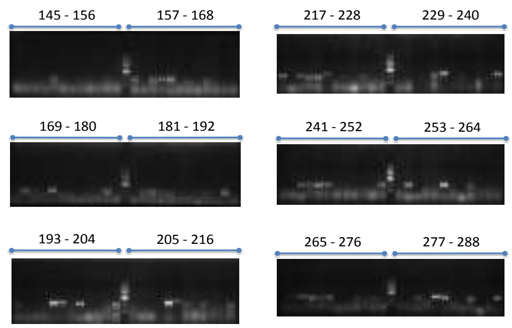
9

Primers 7. JTFG02007725: 4758 - 5078 (BglII)



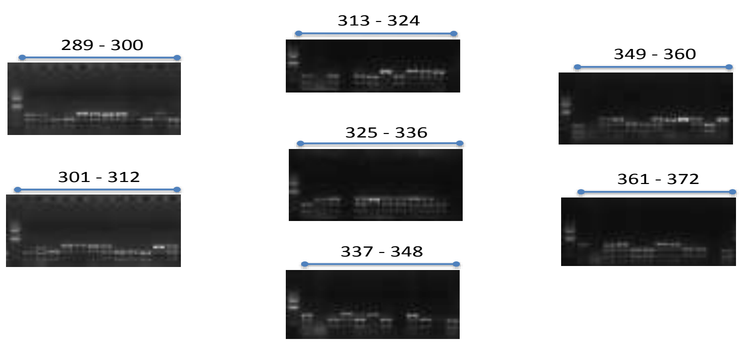
10

Primers 7. JTFG02007725: 4758 - 5078 (BglII)



11

Primers 7. JTFG02007725: 4758 - 5078 (BglII)



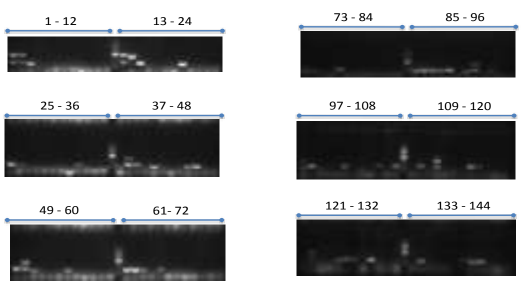
12

Appendix 7. Continued

Primers 11. JTFG02000797: 35,394 - 35,851 (ClaI)

13

Primers 11. JTFG02000797: 35,394 - 35,851 (ClaI)



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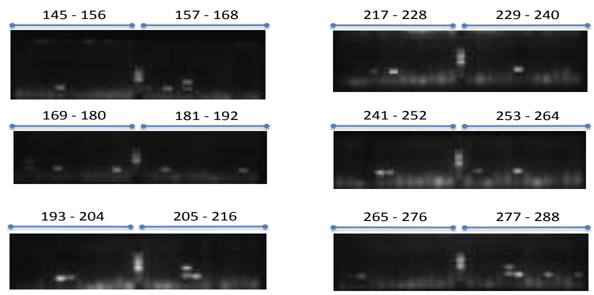
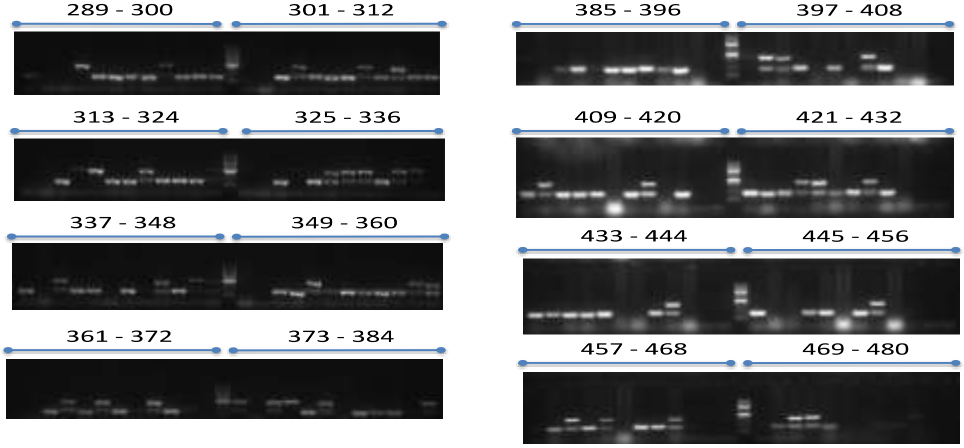
Primers 11. JTFG02000797: 35,394 - 35,851 (ClaI)



15

Primers 11. JTFG02000797: 35,394 - 35,851 (ClaI)



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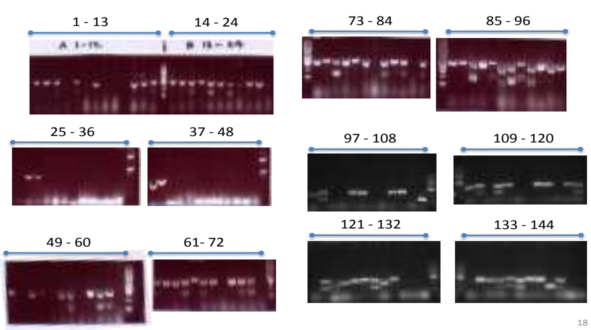
Appendix 7. Continued

Primers 13. JTFG02001793: 29,736 - 30,135 (BamHI)

17

Primers 13. JTFG02001793: 29,736 - 30,135 (BamHI)



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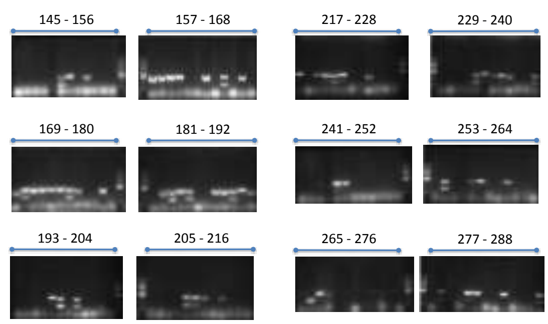
Primers 13. JTFG02001793: 29,736 - 30,135 (BamHI)



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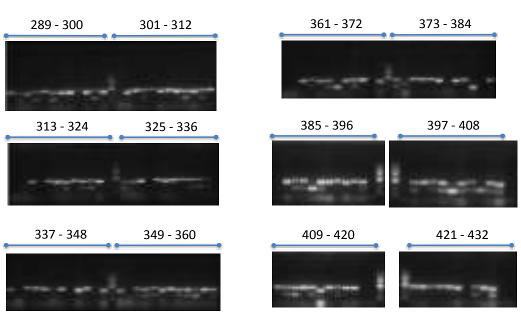
JTFG02001793: 29,736 - 30,135 (BamHI)



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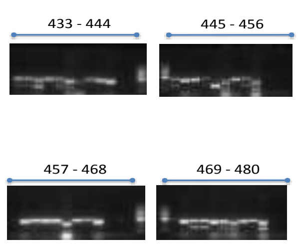
Primers 13. JTFG02001793: 29,736 - 30,135 (BamHI)



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