DIVERSITY OF CULTIVATED AND WILD YAMS (*Dioscorea* spp) IN SOUTHWEST ETHIOPIA BASED ON FARMERS MANAGEMENT PRACTICES, AGRO-MORPHOLOGICAL TRAITS AND NUTRITIONAL COMPOSITION

PhD DISSERTATION

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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DIVERSITY OF CULTIVATED AND WILD YAMS (*Dioscorea* spp) IN SOUTHWEST ETHIOPIA BASED ON FARMERS MANAGEMENT PRACTICES, AGRO-MORPHOLOGICAL TRAITS AND NUTRITIONAL COMPOSITION

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THESIS SUBMITTED TO
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(Submission Sheet-1)

This is to certify that the thesis entitled "**Diversity of Cultivated and Wild Yams (***Dioscorea* spp**) in Southwest Ethiopia Based On Farmers Management Practices, Agro-Morphological Traits and Nutritional Composition"** submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) with specialization in Horticulture**,** the Graduate Program of the School of Plant and Horticultural Sciences, College of Agriculture, and is a record of original research carried out by **Tsegaye Babege Worojie**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend it be accepted as fulfilling the thesis requirements.

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We, the undersigned, members of the Board of Examiners of the final open defense by **Tsegaye Babege Worojie** have read and evaluated his thesis entitled "**Diversity of Cultivated and Wild Yams (***Dioscorea* spp.**) in Southwest Ethiopia Based on Farmers Management Practices, Agro-Morphological Traits and Nutritional Composition"**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the Doctor of Philosophy degree (PhD).

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DECLARATION

I hereby declare that this PhD dissertation is my original work and has not been presented for a degree in any other university, and all sources of material used for this dissertation have been duly acknowledged.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CSA	Central Statistical Agency
DTE	Days to Emergence
DTF	Days to Flowering
DTM	Days to Maturity
FAOSTAT	Food and Agriculture Organization Statistics
IITA	International Institute of Tropical Agriculture
IPGRI	International Plant Genetic Resources Institute
PCA	Principal Component Analysis
RCBD	Randomized Complete Block Design
UPGMA	Unweighted Pair Group Method Average

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THESIS ABSTRACT

DIVERSITY OF CULTIVATED AND WILD YAMS (*Dioscorea* spp) IN SOUTHWEST ETHIOPIA BASED ON FARMERS MANAGEMENT PRACTICES, AGRO-MORPHOLOGICAL TRAITS AND NUTRITIONAL COMPOSITION

Yam (Dioscorea spp) is a traditional crop that has long been cultivated in Ethiopia as a co-staple crop. Several yam species might have their origin in Ethiopia and are among those crops with wild relatives in the country. Though the genus Dioscorea *is reported to show a wide range of variation, it has not been studied across its range of distribution. This study was investigated the diversity of wild and cultivated yams in Bench-Sheko and Sheka Zones, Southwest Ethiopia. Toward this effort, 5 studies were carried out. The first 2 studies were designed to investigate folk biosystematics, diversity and distribution and the local management practices of yams in Southwest Ethiopia. In the third study, accessions from South and Southwest Ethiopia were considered to investigate the diversity of yams based on agro-morphological traits. In the fifth study, we link two data sets to assess the knowledge of wild yam and the process of domestication. Lastly, we analyze the nutritional compositions based on selected yam landraces. We also have another study which is underway and was part of our initial project initiated with the objective of studying the true genetic diversity of yams using SSR marker.*

An ethnobotanical survey was conducted on 15 Kebeles in 5 districts of Bench-Sheko and Sheka Zones from Dec., 2016 to Nov., 2017. Data were collected using a semi-structured questionnaire from 272 households. Seventy-five yam accessions corresponding to 30 differently named landraces were used for morphological study. Sixty of the 75 accessions were collected in Kaffa, Bench-Sheko and Sheka Zones of Southwest Ethiopia. The rest represented previously collected accessions from Basketo, Gamo-Gofa and Wolaita areas of Southern Ethiopia. They were grown in RCBD with 2 replicates in 2018 at Hawassa University research field. The process of wild yam manipulation in Southwest Ethiopia was studied by linking two data sets derived from (1) ethnobotanical survey using 231 interviews and (2) morphological study using 47 selected accessions. Twelve landraces composed of different species and contexts were analyzed for nutritional composition in Addis Ababa at the Ethiopian Health and Nutrition Research Institute.

Results obtained from ethnobotanical study suggest that there exists a systematic and well-developed folk naming and taxonomic system in Sheko and its environs. Sheko and Bench botany of yam recognizes 58 named individuals. These individuals are grouped into 3 well recognized ranks, namely sub-variety, variety and supra variety. Taxa assigned to each ranks have distinct features that mark them as members of a separate group. Farmers manage a wide range of morphological characters and some other attributes other than morphological ones for grouping of the taxa assigned to distinct groups. An account of each of these aspects and its link with the taxa recognized in the domain of formal science are presented. A folk biological classification of yam consisting of 4 taxonomic ranks is proposed. Our result showed much information of biological and functional aspects which can aid the taxonomic and genetic study of yams in Ethiopia.

Our assessment also showed that there exists a wide range of yam diversity in Southwest Ethiopia. Altogether, 40 actually grown yam landraces, including those found in farms of unsampled households were recorded; making Bench-Sheko and Sheka Zones an area of notably high landrace diversity. The greatest number of these individuals had a narrow

distribution and low abundances, with a few being cosmopolitan. This was evident in a positive and significant correlation between distribution and local abundance, such that a few cosmopolitan landraces were locally more abundant. Maintenance and distribution range of landraces is related with the local management practices. A description of farmers' decisions to the on-farm landrace maintenance is presented and implication for the collection and conservation of yam germplasm are suggested.

Morphological diversity study based on 37 qualitative and 13 quantitative traits has shown a considerable variability among accessions of yam species studied. Our multivariate analysis showed that all the traits used were useful for capturing the variability among accessions, but 21 traits (17 of which are qualitative traits) were useful for capturing the variability among accessions of distinct species. The remaining traits were useful for capturing the variability among accessions within and between species, which could be exploited, if improvement need arises. The overall structure of morphological diversity is consistent with the locally perceived biota. Yet, no clear morphological variations were obtained among some differently/similarly named landraces, suggesting the need for DNA-based studies to show the full extent of the existing diversity.

The observed manipulations of wild growing yams in Southwest Ethiopia suggest that yam domestication is still an active process. Knowledge of domestication was shared by 44% of the farmers, even by those that had never practice it. Farmers who have recent transplants in their garden varied from 4% in Bench to 10% in Sheko. The duration of domestication can take up to 6 years, but with most of the individuals it only takes 3 to 5 years. By linking two types of evidences, two divergent adaptation processes are distinguished: (1) parents of recent domesticate expressing a domestication syndrome belongs to wild D. abyssinica *or* D. praehensilis*, and (2) populations of incipient domesticate that might be derived from feral or diverse types of hybrids. A description and analysis of each of these processes and their role on the adaptation process of yams is presented. Based on this account, the term adoptive transplantation is proposed to replace domestication.*

Although only a few landraces were used, a considerable variability existed in nutritional compositions among the studied samples. The results of nutritional study showed that landraces from D. alata *contained high amounts of crude fat and ash contents that make them a good source of energy and minerals. Landraces from the* D. cayenensis *complex contained low moisture content that makes them suitable for prolonged storage and processing. The variability observed both among different species and among landraces in a single species highlights their potential in future breeding.*

More generally, this PhD study documented a great wealth of knowledge on distribution, the level of diversity within the yam, the taxonomic status, folk biosystematics and the local management practices. This constitutes an essential step towards setting development priorities and for enhancing the traditional yam farming in the studied areas. This study thus form an important part of an ongoing study aimed at designing an effective collection and conservation strategies for efficient utilization in future yam improvement.

Key words: Accession, Agro-Morphological traits, Distribution, Diversity, Domestication, Ethnobotany, Farmers management, Folk taxonomy, Nutritional composition, Yams

CHAPTER 1

1. GENERAL INTRODUCTION

1.1. Taxonomy and other important features of yams

The word yam is applied only to members of the genus *Dioscorea* L. that belong to family Dioscoreaceae classified under the monocotyledons (Alexander and Coursey, 1969). The world checklist in Kew Royal Botanic Gardens includes 644 species in Dioscoreaceae in 5 genera: *Dioscorea, Rajania, Tacca, Stenomeris* and *Trichopus* (Govaerts et al., 2007). *Dioscorea* is among the largest genus in this family containing over 600 species (Burkill, 1960) and was first described by Linnaeus in 1753, when he considered three species (Degras, 1993). In 1924, Knuth established the prevailing systematic based on gross morphological criteria. Following this system, the genus *Dioscorea* is divided into distinct botanical sections. According to present knowledge, yams are distributed in 59 botanical sections 6 of which contain economically important yam species (Hamon et al., 1995). These include *Enantiophyllum, Asterotricha, Opsophyton, Lasiophyton, Cambilium* and *Macrogynodium*. Within these sections, species are classified according to the botanical concept which states that the similarity of component individuals in a group is greater than the similarity between different groups (Hamon et al., 1995).

The section *Enantiophyllum* is the largest in terms of number of species and includes all the species with a rightward stem twining direction and all develop entire leaves (Degras, 1993). The most important yam species: *D. alata* L., *D. rotundata* Poir., and *D. cayenensis* Lam., belong to this section. At least 15 species of this section are edible and among them only the greater yam develops wing on the stem. Thus, it was named *D. alata* from the Latin word *ala*, which means wing in Latin and is the first winged yam to be included in the Linnaean taxonomic system. The section *Asterotricha* also contains all the species with

anticlockwise stem twining direction (Hamon et al., 1995), while others such as *Cambilium*, *Opsophyton*, *Macrogynodium* and *Lasiophyton* includes all the species with a leftward stem twining direction (Burkill, 1960). Table 1.1 summarizes the main botanical sections and the corresponding species under the genus *Dioscorea*.

All species of economic importance usually develop thickened underground tubers, which serve as a storage organ. The *Enantiophyllum* species usually produce one to three large tubers while others such as *D. esculenta* (Lour.) Burk., and *D. trifida* L. f. produce a larger number of small sized tubers (Okonkwo, 1985). Stems are climbing vines, twining either to the right or the left according to species and in many species vines have spines. Yam possesses fibrous root systems that are generally smooth but some species possess spiny roots. The wild relatives have more spiny roots than the domestic yams (Okonkwo, 1985).

Most *Dioscorea* species develop entire leaves, with cordate/sagittate shapes and usually arranged alternately/oppositely. But some such as *D. trifida* has winged stem and palmate leaves (3 to 5 lobes) and *D. dumetorum* (Kunth.) Pax and *D. pentaphylla* L. has compound leaves (5 leaflets) (Onwueme, 1978). The leaves vary in shape, size, and color from one to another species or even within the same species of individual plants (Hildebrand, 2003). The flowers of most *Dioscorea* are dioecious, with male (staminate) and female (pistilate) flowers borne on separate plants. Female plants produce spike inflorescences with round trilocular capsules that contain two seeds per locule, and male plants produce spike inflorescences with small sessile flowers (Okonkwo, 1985). In *D. rotundata*, the time of flower initiation varied with sex (Ayensu and Coursey, 1972), with staminate plants flowering earlier than pistilate flowers. But, flowering is erratic and seeds are seldom produced. Thus, reproduction is ensured by vegetative propagation (Malapa et al., 2006).

The genus *Dioscorea* is among the most difficult genus for cytogenetic studies because of small size of the chromosomes in some species (Degras, 1993). The basic chromosome number of yam species is controversial, but it has been recognized as being 10, and most of the results found in the literature indicate the existence of 2n = 4x, 6x, and 8x chromosomes (Coursey, 1967; Essad, 1984; Malapa et al., 2006). All Asiatic species have a haploid chromosome set of x = 10, but is present in only 52% of the African species (Bousalem et al. 2006). Yet, convincing findings are challenging the validity of these generality. Segarra-Moragues et al. (2004) obtained a new basic chromosome number of six, and classified *D. rotundata* as tetraploid. Evidences obtained from progeny of monoecious plant grouped *D. rotundata* as diploid, with x = 20 and 2n = 2x = 40 (Scarcelli et al., 2005). *D. abyssinica* Pax and *D. praehensilis* Benth., are considered as wild relatives of *D. rotundata* (Terauchi et al., 1992). These two species have been assumed to be tetraploid, with x = 10 and 2n = 4x = 40 (Miege, 1952), but Scarcelli et al. (2005) regarded them to be diploids, with x = 20 and 2n = 2x = 40. The situation even got more confusing when Scarcelli et al. (2005) obtained the same number of alleles per DNA locus for cultivated *D. rotundata* and its wild relatives.

Table 1.1. The main sections and the corresponding species under the genus *Dioscorea*

Main botanical sections	**Scientific name of the corresponding species**	**Common names of the corresponding species**	**Twining direction**
Asterotricha	*D. schimperana* Kunth	……..	To the right, or anticlockwise
Enantiophyllum	*D. alata*	Water/greater/winged yam	
	D. rotundata	White Guinea yam	
	D. cayenensis	Yellow Guinea yam	
	D. abyssinica	……..	
	D. praehensilis	……..	
	D. sagittifolia Hochst. Ex Kunth	……..	
	D. opposita Thunb.	Cinnamon yam	
	D. japonica Thunb.	Chinese yam	
Opsophyton	*D. bulbifera* L.	Aerial/potato yam	To the left, or clockwise
Lasiophyton	*D. dumetorum*	Bitter/trifoliate/cluster yam	
	D. quartiniana A. Rich	……..	
	D. hispida Dennst.	Asiatic bitter yam	
Cambilium	*D. esculenta*	Lesser/Asiatic yam	
Macrogynodium	*D. trifida*	Cush-Cush yam	

1.2. Origin and Distribution of yams

The genus *Dioscorea* is among the most primitive angiosperms and differentiated as old and new world species (Coursey, 1967). Two dominant speculations have been made with regard to its dispersal. The first theory is that it dispersed worldwide at the end of the Cretaceous era when South America split from Gondwanaland; it evolved in different directions all over the new and old world, and resulted in distinct species (Coursey, 1967; Lebot, 2009). Yet, Coursey (1967) believed that the separation of Asiatic and African yam was much more recent because two sections (*Enantiophyllum* and *Opsophyton*) are represented by very similar species on the two continents and one species (*D. bulbifera*) is common to both. The two groups are separated by the deserts of the Middle East that probably were formed in late Miocene era. The major yam species appear to have originated from tropical areas of three separate continents: Southeast Asia (*D. alata* and *D. esculenta*), Africa (*D. cayenensis* and *D. rotundata*, also known as Guinea yams) and South America (*D. trifida*) (Coursey, 1967; Degras, 1993; Lebot, 2009).

The African species, also known as Guinea yams, is believed to have originated in West Africa (Degras, 1993). It is believed that there has been an east-to-west movement of African species, as is also the case in Asian species. The African species moved westward to the America during the 16th century. It has since been dispersed in West Indies and East Africa, but there is little or no cultivation of the African species in Asia (Onwueme and Charles, 1994). The Asiatic yam might have originated in tropical Burma and Thailand (Ayensu and Coursey, 1972). The Asian species moved westward to Africa. Of all, *D. alata* moved to India and Pacific regions more than 2000 years ago (Coursey and Martin, 1970), reaching to Africa at about 1500 BC and then introduced to America from Africa during the 16th century (Onwueme and Charles, 1994). The Cush-Cush yam, *D. trifida*, is native to South America and it has since been widely dispersed in Southeast Asia and

Pacific regions, but remains a minor crop in all areas in which it is grown and currently its cultivation is restricted to West Indies (Onwueme and Charles, 1994). The aerial yam, *D. bulbifera,* is native to both Africa and Asia, and the cultivars of *D. bulbifera* were independently domesticated from the local wild relatives (Terauchi et al., 1991).

1.3. Overview of yam species in Ethiopia

Several species of yams are growing in Ethiopia. According to Miege and Sebsebe (1997) the genus *Dioscorea* has 11 species in Ethiopia: *D. cayenensis + rotundata, D. abyssinica, D. praehensilis, D. sagittifolia, D. alata, D. bulbifera, D. schimperana, D. gillettii* Milne-Redh, *D. dumetorum, D. quartiniana* and *D. cochleariapiculata* De Wild. Many authors pooled the first four species into one species complex, known as the *D. cayenensis* complex (Wilkin et al., 2000; Hildebrand, 2003). It is a provisional name for a set of sub-Saharan yam species whose taxonomic relations are currently being examined. The member species are native to Ethiopia and occur all over the South and Southwest regions. Of these, *D. cayenensis + rotundata* occur in cultivated form while *D. sagittifolia* occur both in cultivated and wild form (Table 1.2). This complex also includes *D. praehensilis* and *D. abyssinica*, both of which occur only as wild (Miege and Sebsebe, 1997). With regard to the within species diversity, about 21 native yam types belonging to this species complex have been reported in Sheko district, Southwest Ethiopia (Hildebrand, 2003). Of these, 14 are cultivated and 7 grow wild. Similarly, 24 indigenous yam types belonging to this species complex have been reported by the upland Bench (Sisay, 2008). In Southern Ethiopia, other social groups identified about 35 landraces which appears to have similarity to this complex (Tamiru et al., 2008a).

D. alata is not native to Ethiopia and in Ethiopia and is only grows in cultivated form (Miege and Sebsebe, 1997). Some cultivars of *D. alata* produce both underground and

aerial tubers (Edwards, 1991). With regard to the within species diversity, 4 landraces belonging to *D. alata* have been reported in Southwest Ethiopia (Hildebrand, 2003; Sisay, 2008). Despite the scientific knowledge that ascribes their origins to Southeast Asia, the Southwest Ethiopians regarded all cultivars of *D. alata* as native to their area. This species has not been reported in Southern Ethiopia, suggesting that it must have first entered to Southwest Ethiopia as a cultivar well before the time periods known in local oral historic memory. The aerial yam, *D. bulbifera*, is native to Ethiopia, tropical Africa, Southeast Asia and the pacific regions (Miege and Sebsebe, 1997). In Ethiopia, it has both cultivated and wild forms; the latter is said to be violently poisonous (Edwards, 1991). Farmers in South and Southwestern Ethiopia have identified two groups of cultivated *bulbifera* (Hildebrand, 2003; Sisay, 2008; Tamiru et al., 2008a).

Of the 11 Ethiopian yam species, seven are growing wild. Of these, *D. abyssinica* grows wild in hilly areas of wooded grasslands between 1000 and 1800 m across the west and Southwestern region (Table 1.2). The *D. praehensilis* is mentioned as famine food; grow wild in secondary forests westward to Ilubabor (Miege and Sebsebe, 1997). The other wild yam species with both tuber types is the *D. schimperana*. It is not mentioned as edible in the flora of Ethiopia and Eritrea (Miege and Sebsebe, 1997), but in Sheko both tuber types are consumed in times of food shortage (Hildebrand, 2003). It grows wild in *Acacia* woodlands and forest edges between 1600 and 2100 m. It is also recorded as thriving on terraces at much lower elevations (up to 800 m) where annual rainfall is between 900 and 1400 mm (Edwards, 1991; Miege and Sebsebe, 1997). The Ethiopian species also includes *D. quartiniana, D. dumetorum, D. cochleariapiculata* and *D. gillettii*, all of which occur only as wild (Table 1.2). They are recorded in *Acacia-Commiphora* woodlands and deciduous wooded grasslands between 850 and 2650 m (Miege and Sebsebe, 1997).

Table 1.2. *Dioscorea* species of Ethiopia, their edibility and distributions, summarized from Meige and Sebsebe (1997).

List of species		Edibility of tubers	Contexts	Distribution
1	*D. quartiniana*	Reported as famine food, but needs detoxification	Wild	All except Afar and Kaffa
2	*D. cochleariapiculata*	Not mentioned	Wild	Tigray
3	*D. dumetorum*	Poisonous and needs detoxification	Wild	Tigray, Gondar, Wollega
4	*D. gillettii*	Not mentioned	Wild	Sidama, Bale
5	*D. bulbifera*	Edible, but the wild types need detoxification	Cultivated and wild	Tigray, Gondar, Gojjam, Kaffa, Illubabor
6	*D. schimperana*	Not mentioned, but eaten by Sheko (Hildebrand, 2003)	Wild	All except Afar, Harrar, Bale
7	*D. alata*	Edible	Cultivated	Illubabor, Kaffa
8	*D. cayenensis/D. rotundata* complex	Edible	Cultivated	Shewa, Sidama, Kaffa
9	*D. abyssinica*	Not mentioned	Wild	All western provinces
10	*D. sagittifolia*	Edible	Cultivated and wild	Shewa, Kaffa
11	*D. praehensilis*	Edible; famine food	Wild	Westward to Illubabor

1.4. Importance of yams

Yams are principally grown for food and have organoleptic qualities that make them the preferred carbohydrate food where they are grown. In countries where yams are generally cultivated, wild yams are used as food in times of shortage or famine (Coursey, 1967). Yam constitutes the predominant starchy staple especially in West Africa yam belt. Yam is a source of income to access food, lead to reduction in imported food and thus add to local food self-sufficiency and food security. Yam is considered to be the most nutritious of the tropical root crops (Wanasundera and Ravindran, 1994). It contains approximately four times as much protein as cassava (Onwume, 1978). Yam is also a good source of vitamins A and C, and of fiber and minerals. Apart from food, *Dioscorea* species are also used in medicine (Bhandari et al., 2003). It regulates the female reproductive system, such as menstrual distress and menopause, and is also used in treating infertility.

Considering its importance, yam is seen as a major root crop in many countries. Globally, the mean annual production of yams for the period from 2009-2018, was estimated at about 62.62 million metric tons on 7.12 million hectares of land. Of this, about 60.74 (97%) of the world annual production comes from Africa with West Africa accounting on average about 57.4 million metric tons (91.6%) of this supply. Annual production of yams in Africa has increased by 55% for the period between 2009 and 2018. But yield per hectare has decreased for the same period. The decline in yield per hectare of yam in Africa for the period between 2009 and 2018 was estimated at over 21%. In 2018 cropping season, the annual production of yams in Ethiopia was estimated at over 1.35 million metric tons on 45,254 hectares of land, accounting over 90% of eastern Africa production (FAOSTAT, 2018). Though, high fresh tuber supply comes from Ethiopia, the production status is still remaining far below the level realized in some West African countries.

1.5. Assessing genetic diversity study of yams

Diversity in crops can be described as the degree of differentiation between or within species of plants. Ramanatha Rao and Hodgkin (2002) defined biological diversity in crops as the variation present in all species of plants, their genetic material and the ecosystems in which they occur. Swingland (2001) defined genetic diversity as the amount of genetic variability among individuals of a variety, population or species and can be expressed differences in heritable characters. The variation in heritable characters may express itself in the form of altered morphological, biochemical and physiological features or DNA sequences. Reliable information on the genetic diversity is a prerequisite to device a sound conservation and crop improvement strategy.

1.5.1. Local management practices

Great intraspecific diversity of crop plants is among the features of agricultural evolution, but this diversity presents several scientific issues. In order to understand these issues, the local management practices must be examined in relation to the genetic diversity of that crop. The local management of diversity includes processes such as the folk taxonomy, the selection and seed exchange systems, the practices of domestication and others (Brush et al., 1981; Boster, 1985; Quiros et al., 1990).

It is widely recognized that traditional farmers in the center of crop origin and evolution maintain considerable diversity of plants. Investigating how and why farmers in centers of crop evolution maintain diversity can usually begin with folk taxonomy. As Quiros et al. (1990) has noted, for whatever reason that diversity is maintained, farmers must have a specific means to accomplish this, and a folk nomenclature and taxonomy can be helpful toward this end. It has been firmly established for clonal crops that folk taxonomy is the keys to understand the behavioral patterns that affect crop evolution (Boster, 1985; Brush et al., 1981; Haan et al., 2007). Folk taxonomy of yams has been studied in different countries including Ethiopia (Hildebrand, 2003; Tamiru et al., 2011; Malapa et al., 2006; Nascimento et al., 2015). Each of these studies has indicated that the folk classification system is based on morphological traits or attributes that are less clear to morphological ones. Studies have compared the folk taxa with the variation obtained using standard markers on yam (Malapa et al., 2006; Tamiru et al., 2011) and other clonal crops (Elias et al., 2001a; Almaz and Niehof, 2004). Much of these studies showed that folk taxa reflect the variation that exists at morphological and molecular levels. Individual households can thus serve as operational taxonomic units for assessing intraspecific diversity in traditional agriculture (Bizuayehu and Ludders, 2003).

The knowledge and management of local farmers is a key for the maintenance of local agro-biodiversity. Earlier works have examined this on yams from the perspective of enriching diversity in cultivated forms (Hildebrand, 2003; Dumont and Vernier, 2000; Mignouna and Dansi, 2003; Scarcelli et al., 2006a). According to these authors, such enrichment is due to the continual incorporation of new landraces through exchange of seed tubers. It is also probably due to the domestication of wild types by the local farmers. Farmers' adoption of wild materials can lead to integration of wild genotypes into the cultivated gene pool, and hence, enhance genetic diversity of domestic yams. Among other studies providing information in this respect are those by Hildebrand (2003) and Scarcelli et al. (2006a, b) with the yam cultivated by farmers in Ethiopia and Benin. However, factors such as the rapid growth and increase of monoculture and the replacement of local varieties by commercial varieties have induced genetic erosion of many crops, including the yam species (Dansi et al., 1999; Zannou et al., 2004). Therefore, the local knowledge should need to be preserved to guide efficient conservation strategies.

1.5.2. Marker assisted studies

Most *Dioscorea* species have showed high degree of genetic variability both among and within species. As a result, morphological, isozyme and molecular markers have been widely used in the study of yam, specifically to determine the relationships between the various species and landraces, as well as to develop identification keys (Hamon and Toure, 1990a, b; Dansi et al., 1999, 2000b; Mignouna et al., 2002b; Tamiru et al., 2011). These studies contribute towards broadening of our understanding on the patterns of genetic variations. About 152 morphological descriptors list have been reported by IPGRI/IITA (1997) for yam species. Attempts have been made to use these descriptors in genetic diversity study of yams (Bressan et al., 2011; Norman et al., 2011; Tamiru et al., 2008a;

Nascimento et al., 2015). Most of the descriptors used in each of these studies were discriminatory. But, morphological markers did not give conclusive results due to their high degree of variability. As a result, different molecular markers have been applied for diversity study of yams (Terauchi et al., 1992; Dansi et al., 2000a; Tamiru et al., 2007; Wendawek et al., 2013a, b). Molecular markers enable detection of differences among yam cultivars that were considered to be similar based on morphological marker.

Marker assisted studies have contributed towards explaining the taxonomic link between the *D. cayenensis* and *D. rotundata*. Some morphological studies regarded them as a single species (Ayensu and Coursey, 1972; Martin and Rhodes, 1978; Hamon, 1987). Studies by Terauchi et al. (1992) and Hamon et al. (1997) obtained molecular evidences in support of this opinion. While, in other morphological studies, *D. cayenensis* and *D. rotundata* are regarded as distinct species (Burkill, 1960; Akoroda and Chheda, 1983). Studies by Dansi et al. (2000a) and Mignouna et al. (2004) obtained molecular evidences in support of the idea that they are distinct.

The genetic diversity and variability of yam species with respect to tuber quality traits have been examined in different countries including Ethiopia (Egbe and Treche, 1983; Gebre-Mariam and Schmidt, 1998; Tamiru et al., 2008b; Abara, 2011; Polycarp et al., 2012; Wu et al., 2016). Much of these studies reported a high variability for mineral and protein contents both among and within yam species. Substantial diversity was also observed in macromolecular characteristics of isolated starch. However, such variation might be related to their genetic origin, geographical sources and the level of maturity at harvest. Thus, it is crucial to assess the nutritional compositions of some selected yam landraces to facilitate the conservation and improvement of yam germplasm.

1.6. Justification of the study

Ethiopia represents one of the main centers of crop diversity and domestication (Vavilov, 1926; Meyer et al., 2012). The better known root crops such as Oromo dinch (*Plectranthus edulis* (Vatke.) Agnew), anchote (*Coccinia abyssinica* (Lam.) Cogn.), enset (*Ensete ventricosum* (Welw.) Cheesman), and bagana (*Amorphophallus abyssinicus* (Rich.)) were domesticated in Ethiopia (Dadi and Engels, 1982). Besides, several yam species might have their origin in Ethiopia and are among those crops with wild relatives in the country (Harlan, 1969; Edwards, 1991; Engels and Hawkes, 1991; Miege and Sebsebe, 1997). These and other reports contributed towards exploring the yam species, their edibility and distribution in Ethiopia. Though such reports are available in the more general references (Westphal, 1975; Engels et al. 1991), much of these reports provide only lists of a few of the yam species found in Ethiopia and more notably, only a few works has yet tackled the issue of the within species yam diversity in Ethiopia.

With regard to the intraspecific diversity in Ethiopia, about 134 non-synonymous landraces have been reported by preliminary studies (Hildebrand, 2003; Tamiru et al., 2008a; Sisay, 2008; Tewodros, 2016; Tsegaye et al., 2021a). Over 97% of these belong to the section *Enantiophyllum* and within this section high degree of polymorphism have been identified in the *D. cayenensis* complex. This species complex shows a very wide range of variation in Ethiopia, but it has not been studied throughout its range. The most in-depth genetic diversity studies using this species complex have been done either without considering wild types (Tamiru et al., 2007, 2008a, 2011) or ethnobotanical aspects (Wendawek, 2008). Such studies should thus be needed in areas with the oldest yam culture in Ethiopia. Within Ethiopia its Southwest region has proven to be one of the richest areas, wherein this species complex exists with broad genetic basis. This work may shed a new light towards revising the taxonomic boundaries of the member species in the *D. cayenensis* complex.

The far Southwest Ethiopians maintain high number of yam landraces (Hildebrand, 2003; Sisay, 2008). Each locality has its own unique set of names for different landraces, but the same landraces may be known by different vernacular names or distinct landraces sometimes referred to by the same name. Linguistic polymorphism constitutes a difficulty to the reliable identification of landraces and their eventual use for breeding program. No study has yet tackled the issue of whether these named landraces represent the true diversity. We assume that there exists a great wealth of yam landrace diversity, but it is not put to in effective use as the available landraces is poorly known. To this end, the on farm landrace diversity, their distribution and the associated management practices of farmers are needed to be assessed. The insight that this provides is valuable for conservation of yams in Southwest Ethiopia and in Ethiopia at large. Besides, the available landraces have to be characterized based on morphological and nutritional traits. The study therefore was conducted with the following objectives.

1.7. Objectives of the study

1.7.1. General objective

The general objective was to contribute towards the improvement of traditional yam farming and the conservation and utilization of yam diversity through knowledge of folk biosystematics and local management practices as well as through agro-morphological and nutritional study of existing yam landraces.

1.7.2. Specific objectives

- ✓ To document and describe the commonly recognized folk wisdom of identifying, naming, and classifying yam landraces by the Sheko and Bench farmers.
- ✓ To investigate the diversity and distribution of yam landraces and the management practices of local farmers in Bench-Sheko and Sheka Zones, Southwest Ethiopia.

- ✓ To investigate diversity of cultivated and wild yams from South and Southwestern Ethiopia based on agro-morphological traits.
- ✓ To investigate the knowledge of wild yam and wild yam manipulation in Southwest Ethiopia based on ethnobotanical and morphological evidences
- ✓ To investigate the nutritional composition of the most widely grown yam landraces in Southwest Ethiopia.

We also have another study which is underway. This study forms part of our initial project initiated with the main objective of assessing the diversity in Ethiopian yams, and aims to reveal the full extent of the existing genetic diversity using SSR marker.

1.8. Outline of the thesis

The specific objectives indicated above were addressed in different chapters that comprise this thesis. The chapters are written as an independent paper, each of which is interrelated in terms of conceptual and logical framework. The chapters are organized as follows:

Table 1.3. Chapters and the corresponding titles that comprise this thesis

Chapters	Title
1	General Introduction
2	Indigenous Biosystematics of Yams (*Dioscorea* spp) in Southwest Ethiopia: Folk Taxonomy, Ethnolinguistic Analysis and Folk Descriptors
3	Diversity, Distribution and Farmers Management of Yam Landraces (*Dioscorea* spp) in Bench-Sheko and Sheka Zones, Southwest Ethiopia
4	Diversity of Cultivated and Wild Yams (*Dioscorea* spp) from South and Southwestern Ethiopia Based on Agro-Morphological traits
5	Cultivation and Possible Domestication of Feral and Possibly Wild Yams (*Dioscorea* spp) in Southwest Ethiopia: Ethnobotanical and Morphological Evidence
6	Analysis of Nutritional Composition in Selected Yam Landraces Corresponding to three different Species.
7	General Summary, Conclusion and Recommendations

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CHAPTER 2

2. Indigenous Biosystematics of Yams (*Dioscorea* spp) in Southwest Ethiopia: Folk Taxonomy, Ethnolinguistic Analysis and Folk Descriptors

ABSTRACT

In Southwest Ethiopia, indigenous crops are coexisting in wild and cultivated forms. This provides an ideal setting for studying folk biosystematics of neglected species. One of such species is the Dioscorea species, in which we studied to investigate the commonly applied and recognized folk wisdom of identifying, naming, and classifying yams by Sheko and Bench farmers. This study was conducted in Bench-Sheko and Sheka Zones using 272 farmers. Data on the lists of local names and system of folk taxonomy; the inherent logic, etymons and consistency of names; and the folk descriptors involved in classification were collected. Data were collected by establishing participatory research appraisal tools, i.e., informant interviews and researcher direct observation. The result suggests that there exists a systematic and well-developed folk taxonomic system in Sheko and Bench. This is evident in the recognition of four distinct folk ranks: *sub-variety, variety, supra-variety and folk generic. Taxa assigned to each of the ranks have distinct features that mark them as members of separate categories. Farmers differentiate 58 named individuals. Of these, 37 represented varietal taxa while the rest are sub-varieties. Over 78% of the varieties are labeled with unitary names, but all the sub-varieties are labelled with binary names. Farmers used a total of 26 characters and 74 character states for identifying the different taxa. More than 84% of these refer to aspects of plant characteristics. Tuber characters played a key role in the local identification of varietal and sub-varietal taxa whereas contexts and gender played a key role in the recognition of supra-variety categories. This study documented a great wealth of knowledge on folk biosystematics of yams; constitutes an essential step towards setting development priorities aimed at in situ conservation. The study clearly demonstrated the value of folk biosystematics for assessing the actual extent and spatial dynamics of yam diversity in the traditional farming.*

Key words: *Dioscorea* species, Farmers, Folk biosystematics, Yam varieties

2.1. INTRODUCTION

Root and tuber crops such as potato, sweet potato, enset, cassava, and yam play an enormous role in feeding the world. They are among the most adaptable staple food crops to addressing food security for millions of peoples globally and are nutritionally rich staples that contribute towards the dietary demands of the society (Emshwiller, 2006). Thus, they serve as an important safety net against starvation. Many of these crops are grown primarily for subsistence, under traditional farming systems, which still represent much of world agriculture. The local agro-ecosystems retain a great diversity potential for future use, yet studies on the evolution and conservation needs of these crops are few. Evolution under domestication is affected by the management of folk cultivars, mainly when humans act as agents of selection and is thus said to be linked with the knowledge of indigenous biosystematics of crop plants (Motley et al., 2006; Parra et al., 2010).

This paper presents the indigenous biosystematics of yams. Indigenous biosystematics can be defined as the commonly applied and recognized folk wisdom of identifying, classifying, naming, and relating living organisms as practiced by a particular culture or ethnic group (Haan et al., 2007). Scientific studies of indigenous biosystematics seek to unravel the classification of folk ranks and taxa, the morphological character states applied in classification and the inherent logic as consistently applied to vernacular names. In earlier works the term folk taxonomy had been more widely used (Brush, 1992, 2004; Zimmerer, 1996). Though it is a more widely used term, its use in literature may relate to very different component of classification ranging from a mere list of local names to a hierarchical system of classification. Its common use does not necessarily address how particular cultures classify living organisms. Besides, basic ethnolinguistic analysis, *i.e.*, questions concerning the inherent logic, meaning, etymology and consistency of names are

not always considered as part of folk taxonomy. Here, folk taxonomy is considered as one component of folk biosystematics, which involves a broader set of subsystems.

Studying indigenous biosystematics is thus essential for a number of reasons. First and more notably, it provides a better understanding to the nature and extent of diversity and how this diversity is perceived and valued by farmers. Second, by detailing the inherent subsystems of folk biosystematics, an insight to its relation with the taxa recognized in the domain of formal science can be obtained. Finally, better understanding of indigenous biosystematics is of utmost importance because it is not only the unit of on farm diversity, but also the unit how individual households actually manage and conserve it.

The Southwest Ethiopian farmers maintain high numbers of intraspecific yam diversity (Hildebrand, 2003; Sisay, 2008). Each of these is perceived as distinct and given a separate name. But, studies on how farmers identify, name and classify yam landraces are poorly studied. Accounts on the consistency of folk names and their importance as part of indigenous biosystematics of yams is scarce. Formal descriptors for yam had already been developed early in the nineteenth and twentieth century (Poiret, 1813; Chevalier, 1936) and have been improved at several instances (Ayensu and Coursey, 1972; Martin and Rhodes, 1978; IPGRI/IITA, 1997). Equally important but poorly studied aspect is accounts on the use of folk descriptors. The descriptors recognized by farmers have been little studied. The few attempts made in South and Southwest Ethiopia (Hildebrand, 2003; Tamiru et al., 2011) have focused only on folk taxonomy and have not covered the multiple dimensions of folk biosystematics.

This study aimed to test the following hypotheses. Classification of yam by the Southwest Ethiopians is over-differentiated at the intraspecific level (Hildebrand, 2003). Knowing that such over-differentiation is rare, and is often related with crops of great importance

(Berlin et al., 1973); we hypothesized that this knowledge is widely shared within the community and across locations. Assuming that farmers manage various morphological characters and attributes other than morphological ones for classification (Hildebrand, 2003; Sisay, 2008; Tamiru et al., 2011), we hypothesized that classification is based on a consistent sets of descriptors and can influence practical decisions of maintaining yam diversity. Considering that some locally recognized taxa are consistent to a considerable extent with the variability obtained with marker assisted studies (Tamiru et al., 2011; Wendawek et al., 2013a, b), we assumed that folk taxonomy has a clear biological and functional implications. The present study was thus conducted with the objectives (i) to document and describe the commonly recognized folk wisdom of identifying, naming, and classifying yam landraces by the Sheko and Bench farmers, (ii) to assess the inherent logic as consistency applied to vernacular names, and (iii) to identify a set of orders of folk ranks recognized by farmers and compare it with the formal taxonomy.

2.2. MATERIALS AND METHODS

2.2.1. Location and Demographics

The study was conducted in Bench-Sheko and Sheka Zones, Southwest Ethiopia. They are part of the Southern Nations, Nationalities and Peoples Region (SNNPR) of Ethiopia. The Regions are sub-divided into 13 Zones, which are organized into Woredas (CSA, 2017). Kebeles are the smallest administrative units within Woredas (districts). Fig. 2.1 presents map of the study area, indicating the surveyed points in Bench-Sheko and Sheka Zones. Bench-Sheko Zone is sub-divided into six districts. Based on the population projection values of 2017, this Zone has a total population of 596,814 of whom 464,398 or 77.81% are rural inhabitants (CSA, 2013). Bench-Sheko is the western and northwestern part of former Bench-Maji Zone. Based on the 2007 Census conducted by the CSA, the former

Zone is well known by its multi-ethnic diversity and contains seven main ethnic groups. The seven largest ethnic groups reported in the former Zone were the Bench (45.11%), the Me'enit (21.36%), the Amhara (8.23%), the Kefficho (6.55%), Dizzi (5.17%), Sheko (4.21%), and the Suri (3.88%). The remaining 5.49% of the population comprises a diverse mix of other ethnic groups.

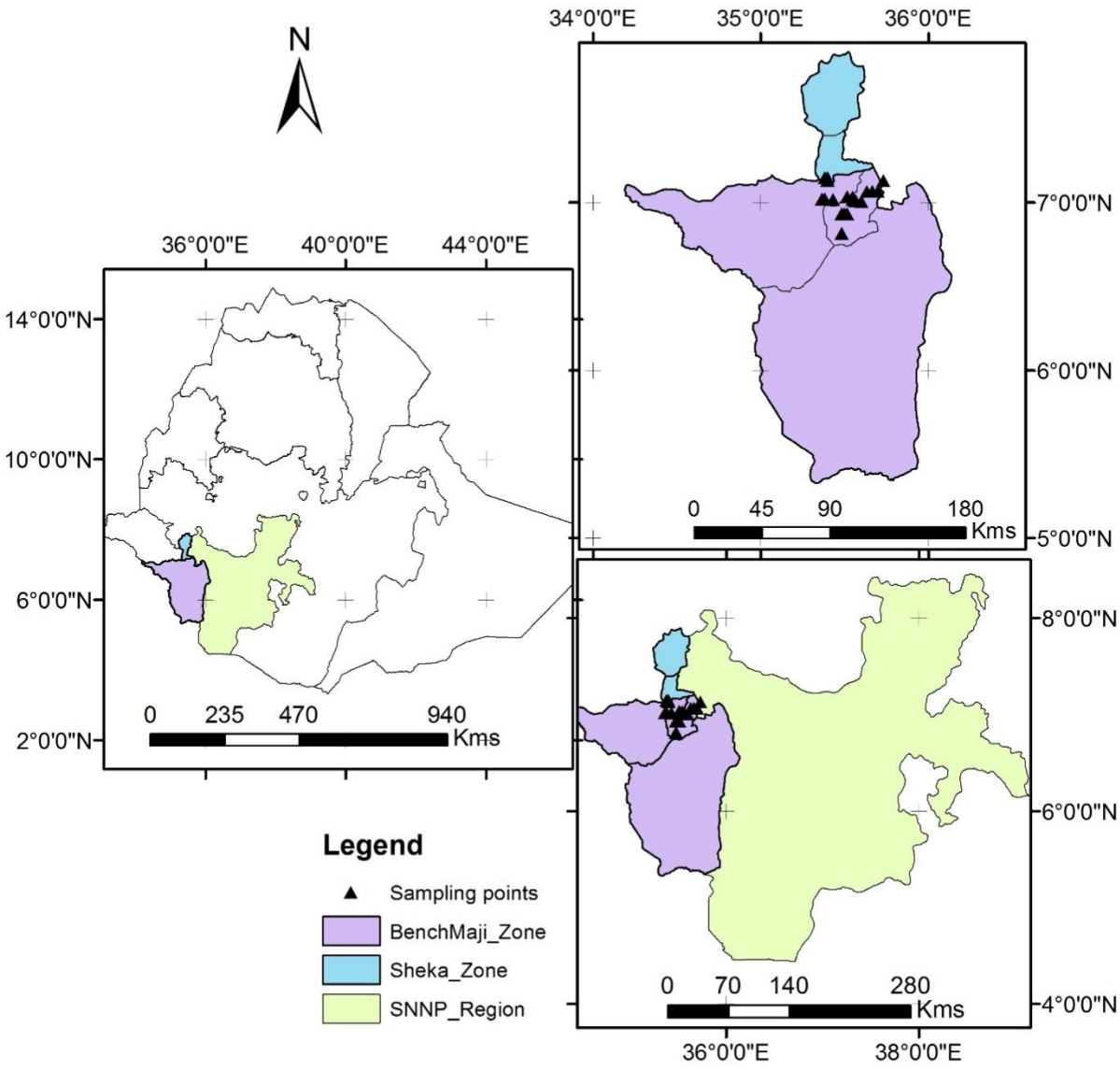

Fig. 2.1. Map of the studied areas, indicating the surveyed points in Bench-Sheko and Sheka Zones, Southwestern Ethiopia.

NB**:** Bench-Sheko is the Northern part of the former Bench-Maji Zone

Sheka Zone is sub-divided into 3 districts. Sheka is bordered on the south by Bench-Sheko Zone, on the west by the Gambella region, on the north by the Oromia region, and on the east by Keffa. The administrative center of Sheka is Masha. Based on the population projection values of 2017, this Zone has a total population of 269,243 of whom 196,524 or 72.99% are rural inhabitants (CSA, 2013). Based on the 2007 Census conducted by the CSA, Sheka Zone is well known by its multi-ethnic diversity and has seven largest ethnic groups. The seven largest ethnic groups reported in this Zone were the Shakacho (32.41%), the Amhara (22.17%), the Kafficho (20.16%), the Oromo (7.39%), the Bench (5.23%), the Sheko (4.24%), and the Majang (1.73%). The remaining 6.67% of the population comprises a diverse mix of other ethnic groups.

2.2.2. Climatic condition and cropping profile

Both Bench-Sheko and Sheka Zones are characterized by a tropical humid climate with short dry seasons (October-January) and long rainy seasons (February-September). The main rainy season in the area starts in mid February its intensity peaking in August and terminates in middle of October. The annual rainfall varies from 1200 to 2000 mm. The mean annual temperature varies from 15^{O}C to 30^{O}C during dry season. The area has two cropping seasons; Belg (February-June) is the main cropping season and Meher (June-August) (Hildebrand, 2003).

The main food crops in these Zones include maize, taro, and enset, while sorghum, teff, wheat, barley are cultivated to a significant extent. Cash crops such as coffee, fruits (banana, papaya, mango and avocado and spices (coriander, ginger, pepper, turmeric, and hell) are also widely cultivated. Based on inspection records from the Ethiopian Coffee and Tea Authority, the bulk of national cash crop production comes from these areas. Others such as low land rice, hell, black pepper, cassava, tea and rubber tree grow successfully in

these Zones. Bench-Sheko and its neighboring Zones are endowed with abundant natural resource and favorable ago ecological conditions and they are on the level that can host the growth of wild plants sufficiently. Wild plants such as yam, enset, anchote and kororim are growing. These features make these areas an ideal environment for research interests through different disciplines.

2.2.3. Yam farming profiles

The environment of the study area has proven to be well suited to the growth of yams. Within Ethiopia, the two zones in Southwest Ethiopia receive ample rainfall due to a short dry season. The far southwest Ethiopians have exceptionally good access to wild yams due to the retention of some forest patches and extended fallow areas. Wild yams occur throughout the district, but most frequently in the natural environment of open wooded grasslands and in the anthropogenic environments of disturbed areas where they had no known history of human manipulation. Some Sheko and Bench farmers still manipulate wild growing yams, bringing them from uncultivated areas to transplant into their gardens. Cultivated yams thrive in farms within mid-altitude and some upland areas that have moist, forested surroundings. Our GPS record also showed that the prime altitudinal zones of domestic yam growing farms ranges from 1091 to 2080 m and cultivated yam thrives well on average elevation of 1376 m.

Comparison of cultivation trends in Southwest Ethiopians suggests that within the region, the degree of yam farming differ widely. In the entire region, where cultivation of yam is environmentally feasible, the complexity of Sheko yam farming and their historical focus on it is unique. The Bench, upland Omotic-speakers east of the Sheko, claims a greater emphasis on taro and enset farming. Despite the comparable yam farming they had, the Bench credit the Sheko with having initiated yam cultivation and thought it to them. The

Shakacho, upland Omotic-speaking peoples to the North favor enset farming over yams. The Majang to the North and Northwest, the Agnuak to the West, and the Me'enit to the South are all Nilo-Saharan speaking peoples who favor grains over root crop farming.

2.2.4. Data collection procedure

This study was conducted in Bench-Sheko and Sheka Zones, Southwest Ethiopia. Yam growing farmers were purposively considered for this survey. Secondary data regarding the accessibility and culture of yam farming were assessed in Bench-Sheko and Sheka Zones. The secondary data obtained from each Zone were used to select yam growing districts. A total of five yam growing Woreda (districts) were considered in this study. Within these districts informal survey was conducted to identify yam farming Kebeles. In addition, secondary information regarding the accessibility of yams was assessed in each district. Based on the result of informal survey and secondary data, three Kebeles were chosen in each Woreda, bringing the total number of sampled households to 272. This study was conducted from December, 2016 to November 2017 and aimed at documenting the process of local management of yam diversity. Traditional households' management of diversity includes processes such as selection and local classification systems (Bizuayehu, 2008; Tamiru et al., 2011). Data collected during the collection mission was complemented with additional data generated from a farm-level survey conducted during the 2018/2019 cropping season.

The local yam classification system was studied using 272 semi-structured interviews (Annex, 1). Informants interview were adapted from ethnobotanical field inquires as suggested by Martin (2004). Here, indigenous biosystematics and its inherent subsystems were researched. The data collection procedures employed for recording each of the subsystems is described below.

Folk taxonomy: Folk taxonomy was researched with the use of informant interviews, researcher observations and comparison of farmers recognized taxa with formal taxonomy. Sheko and Bench folk ranks and taxa were recorded according to the universal scheme proposed by Berlin et al. (1973) and Berlin (1976). There are at least five, perhaps six, taxonomic ethnobiological categories which appear to be highly general if not universal in folk biological science. Yet, applying these basic principles, it can be reduced into a set of four general nomenclatural categories as follows:

1) Farmers were asked to free list the names to all kinds of yams they knew at and above species level. Taxa satisfying this condition are generic; their labels are generic names.
2) A category called intermediate taxa is included the fact that farmers recognized supra-variety categories that are labelled by names. Taxa satisfying this condition are sub-generic (specific); their labels are supra variety names.
3) Farmers were asked to free list the names of varieties that they perceive it as a distinct unit. Taxa satisfying this condition are varietal; their labels are variety names.
4) Some taxa are marked only by binary names, containing further divisions of a variety. Taxa satisfying this condition are sub-varietal; their labels are sub-variety names.

Ethnolinguistic analysis: A basic ethnolinguistic analysis, i.e., questions concerning the inherent logic and consistency of folk names was researched with the use of farmers' interview and researcher observations. Individual farmers were asked to free list the local names of yam varieties and sub-varieties they grew or knew. All the folk names were registered and translation considering meaning, origin and structures of folk names was made with the use of elderly farmers. The consistency of folk names was assessed with the use of fixed landrace samples. Of all farms surveyed, landraces that were encountered in

more than ten farms were selected as a fixed sample. Accordingly, 15 landraces were identified as fixed samples.

Folk descriptors: Folk descriptor was researched based on the farmer free listing of individual taxa along with their descriptors; according to informants own order of priority without major researcher intervention. Informants were asked to free list the names of (both known and actually grown) individual taxa. For each of the names, farmers were asked how they were able to identify it. All the folk descriptors were registered and supplemented with field observation by the researcher to verify the information gathered.

2.3. RESULT AND DISCUSSION

2.3.1. Folk taxonomy

2.3.1.1. Names and naming of yams at and above species level

Assessment of folk taxonomy in Southwest Ethiopia suggests that within the region where yam cultivation is feasible, Sheko and Bench folk taxonomy is unique. It is polytypic in Sheko, as is also the case in Bench. This is evident in the recognition of four taxonomic ranks in both cases. Despite their separate taxa in scientific terms, at and above species level, all the cultivars of underground yam types have been merged into Sheko concepts of *Kachi*. The Bench, upland Omotic speaking peoples to the east of Sheko, knew yam by the generic name *Boyye*. But, Bench credits the Sheko with having initiated yam culture; some of them knew it by Sheko name *Kachi*. Unlike the underground yam types, the cultivated *bulbifera* plant has distinct generic names in Sheko and Bench. In Sheko, it is usually called *Ama* while it is called *Oake* in Bench (Table 2.1).

Farmers also gave the generic folk names to wild growing yams. Wild yams are usually named by adding prefixes to the generic names of domestic yams. Growing location was used as the main differentiating criterion in naming of yams at generic level. The prefixes

"*Karka"* and "*Shah"* added to the names of wild yam refer to the location in the wild places. Thus, *Kachi* is a generic term that is usually used to refer the cultivated underground yam types at the genus level, but not exclusively applied to yam species. When farmers were asked to list all kinds of yams they grew or knew, they linked plants of other species as yams though they are not yam. For instance, cassava (*Manihot esculenta* Cranz) is to some extent linked to yams and is commonly known as *Enchet-Kachi* (Table 2.1). Our result is in accord with other reports for yam in Ethiopia (Hildebrand, 2003) and in Oceania (Hayes, 1976; Malapa et al., 2006), enset in Ethiopia (Olango et al., 2014), species of Mesoamerican columnar cacti (Casas et al., 1997; Parra et al., 2010) and potato in the Andes (Brush, 1992, 2004; Zimmerer, 1996), where the local farmers there recognize the generic level folk taxa in a similar way.

Table 2.1. Sheko and Bench folk classification of yams at and above the species level

Scientific name	**Context**	**Folk generic names**	
		Sheko	**Bench**
D. alata	Cultivated	*Kachi*	*Boyye/Kachi*
D. bulbifera	Wild	*Karka-Ama*	*Balakay-Oake*
	Cultivated	*Ama*	*Oake*
D. cayenensis complex	Wild	*Karka-Kachi*	*Shah-boy (Karckabat)*
	Cultivated	*Kachi*	*Boyye/Kachi*
M. esculenta	Cultivated	*Enchet-kachi*	*Enchet-kachi*

2.3.1.2. Names and naming of varieties and sub-varieties

At least two well recognized species (*D. bulbifera* and *D. alata*) and one species complex (the *D. cayenensis* complex) grow in the studied area. The far Southwest Ethiopians classify these species into at least 37 varietal taxa. Some varieties are further composed a number of subordinate units. In our case, ten varieties are composed of 21 sub-varieties, bringing the total numbers of the recorded folk names to 58 (Table 2.2). Of these, 34 represented actually grown landraces of yam. Besides these, six additional landraces were

found in farms of unsampled households while the rest reported verbally. This suggests that Sheko and Bench taxonomy of yams is over-differentiated at intraspecific level. Such over-differentiation is rare, and is often related with crop of great importance (Berlin et al., 1973, Martin, 2004). A similar distinction has been made to yam in South and Southwest Ethiopia (Hildebrand, 2003; Sisay, 2008; Tamiru et al., 2008). The same trend of using folk biosystematics was reported for enset in Sidama and Wolaita (Bizuayehu, 2008; Olango et al., 2014) and for sorghum in Eastern Ethiopia (Firew, 2007). In Southern Ethiopia, Sidama botany of enset recognizes 103 enset varieties (Bizuayehu, 2008). The study reported that many of the names and their implied characteristics are known to most members of the community and across locations, reflecting the relative importance of enset clones to the subsistence farmers in Sidama.

2.3.1.3. Names and naming of supra variety categories

Yams in the lowest taxonomic levels are grouped into named categories. These categories are labeled and usually group several varieties and sub-varieties together by a single criterion; they are thus make up supra variety categories. Table 2.3 presents a description of nine supra-variety categories that are common in Sheko and its environs. Applying Berlin (1976) scheme, the taxa assigned to supra variety groups constitutes intermediate ranking rather than separate taxa, *i.e*., are groupings higher than the folk variety. The recognition of labelled mid-level taxa is highly relevant in order to obtain insights into the basic principles of indigenous taxonomy and should not be ignored by placing too much stress solely on the named groups at smaller ranks. It is rare in most formal system and only a few works has yet reported such taxa. Such ranks have been reported in folk taxonomy of potatoes by the Quechua communities in the Andes (Brush, 1992, 2004).

Table 2.2. Lists of local names and the underlying basis of the classification

List of local names **I. *D. cayenensis* complex**		Contexts	Structures	Meaning of names or the basis of classification/identification: compiled quotes from informant interviews
1	*Karka-kachi*	W	PU	"*Karka*" means forest in Sheko dialect and its name is said to be derived from the wild location. Whole tuber of *Karka-Kachi* is dark purple and bitter in taste. If tuber has bright orange color at stem junction, it is red (*submseb*), if it has dark grayish purple pigment at proximal end, it is black (*tsaa'nseb*) and if it is un-pigmented, it is white (*ga'nse*b).
	Karka-kachi submseb *Karka-kachi tsaa'nseb* *Karka-kachi ga'nseb*		PB	
2	*Shah-boy, Karckabat*	W	PU	"*Shah*" means forest in Bench dialect, its name thus refers to the area name in a wild place. Its tuber has pale purple color with few pale orange colors at proximal end.
3	*Upfa**	W	SU	Name translation is not given. Yet, its tuber has patches of purple pigment at proximal end, and white elsewhere
4	*Karka-Kachi*	WT	PU	Tuber of this variety is generally pale purple. If it has dark purple pigment at stem junction, it is black (*tsaa'nseb*); if it is un-pigmented, it is white (*ga'nse*b); if it has patches of orange color at proximal end, and white elsewhere; it is spotted (*guignseb*).
	Karka-kachi tsaa'nseb *Karka-Kachi ga'nseb* *Karka-Kachi guignseb*		PB	
5	*Yasind*	WT	SU	Tubers of *Yasind* are very similar in size and shape. But, if its tuber has purple pigment at proximal end, it is black (*Tsid*); if it has patches of purple orange color at proximal end and white elsewhere, it is white (*Dal*)
	Tsid yasind *Dal yasind*.		SB	
6	*Kaibab/Baidai-kachi*	RT	PU	*Kaibab* is the area name in northeast Sheko. *Baidai* is said to come from a *Kaibab* area. Whole tuber is purple with white, but if it has patches of grayish purple pigment at proximal end, it is black (*tsaa'nseb*), if it is un-pigmented, it is white (*ga'nseb*).
	Kaibab-kachi tsaa'nseb *Kaibab-kachi ga'nseb*		PB	
7	*Chabsha*	RT	SU	Tubers of *Chabsha* varieties are similar in size and shape, but *Tsid Chabsha* has pale purple proximal end and pale grey stems, while *Dal Chabsha* does not.
	Tsid Chabsha *Dal Chabsha*		SB	
8	*Tolubab*	RT	SU	Name means "tubers with a bitter taste". Tuber has patches of pale purple color at proximal end and white elsewhere
9	*Torbay*	RT	SU	Name means "tubers with a bad taste". Tuber has patches of pale orange color at proximal end and white elsewhere
10	*Beri*	LT	SU	Name means "desert" wherein it is said to be come from lowland desert areas. Tuber and basal stem edges of this variety have pale purple color.

Table 2.2 (*Cont*…….)

List of local names **I. *D. cayenensis* complex**		Contexts	Structures	Meaning of names or the basis of classification/identification: compiled quotes from informant interviews
11	*Don*	LT	SU	*Don* means "wide and short" it is named so because its tuber doesn't elongate like other kinds. Tubers of *Don* varieties are similar in size and shape, but *Don babu* (fat man) has more strongly pigmented tubers and stems while *Don bayye* (fat woman) show a tendency to branching
	Don bayye *Don babu*		SB	
12	*Dizzu-Kachi*	LT	PU	*Dizzu* is the Sheko term for their Bench neighbors to the east and is said to come from Bench areas. If the tuber and basal stems of this variety has dark purple color, it is black (*tsaa'nseb*), whereas (*ga'nseb*) does not.
	Dizzu-Kachi tsaa'nseb *Dizzu-Kachi ga'nseb*		PB	
13	*Kachi-kundi**	LT	SB	*Kundi* means "feather or filament at rear end of a chicken" Tubers has a sizeable numbers of spiny roots on its crown
14	*Lekut*	LT	SU	Tuber is white with purple at distal end and white elsewhere
15	*Logit*	LT	SU	Tuber is purple with white at middle, and white elsewhere
16	*Shure*	LT	SU	Name means "worm". It is so named because, tubers is worm like shape.
17	*Konkay*	LT	SU	Name means "crispy while easting". The tuber and basal stems of this variety has a pronounced dark purple color.
18	*Kachi-Kuch'ai**	LT	SB	Tubers of easy cooking and tasty
19	*Banda boy*	LT	SB	Name means "of multicolored". White purple tuber and cylindrical shape. If it is white at distal end and white purple elsewhere, it is (*Tsam*), if it is pale purple at proximal end and white elsewhere, it is (*Tsenah*)
	Tsam banda boy *Tsenah banda boy*		PB	
20	*Shapinsin*	LT	SU	Tuber is flat, white at distal end and purple white elsewhere
21	*Kuchuu'bai*	LT	SU	White tuber and irregular shape.
22	*Zansul*	LT	SU	Whole tuber is white and flattened at distal end
23	*Tsid boy*	LT	SB	Whole tuber is dark purple
24	*Dal boy*	LT	SB	Whole tuber is white
25	*Don boy**	LT	SB	Whole tuber is pale purple
26	*Shamut*	LT	SU	Irregular tuber shape.
27	*Kappar*	LT	SU	White purple tuber, very firm flesh, oval tuber shape.
28	*Kalu**	LT	SU	White purple tuber and cylindrical shape
29	*Bud boy**	LT	SB	Whole tuber is white with purple and oval shape.
30	*Tush boy**	LT	SB	White purple tuber, very firm flesh, oval shape
31	*Bunkri**	LT	SU	Tuber shape is in between cylindrical and oval

Table 2.2 (*Cont*…….)

List of local names		Contexts	Structures	Meaning of names or the basis of classification/identification: compiled quotes from informant interviews
II.	***Dioscorea alata***			
1	*Ongubay, Baday*	LT	SU	*Ongubay* means "foolish" while *Bada* means distinct. It is so named because its foliage differs from that of other kinds. Whole tuber is white but, if its tuber and stem edges has dark orange color, it is red (*submseb*)
	Submseb Ongubay		SB	
2	*Earkubai*	LT	SU	Name means "of sharp taste". Tuber and stem edges of this variety have purple pigment and irregular in shape.
3	*Zenkuru*	LT	SU	Name means "seeker". It is so named from a lazy man who doesn't work but seeks to eat food prepared by other person
4	*Dak'oi**	LT	SU	Whole tuber is white and irregular tuber shape.
III	***Dioscorea bulbifera***			
1	*Karka-ama/Balakay-oake*	W	PU	Grouping of a *bulbifera* plant as wild vs. cultivated relied on the area of growth. *Ama/oake* grows in garden while *Karka ama/Balakay oake* grow in wild area. If the bulbils of cultivated *bulbifera* has traces of dark color near edges, it is black (*tsaa'nseb/Tiab*); if not it is white (*ga'nseb/don*)
2	*Ama or Oake*	LT	SU	
	Ama tsaa'nseb/Tiab oake *Ama ga'nseb/Don oake*		SB	

*Indicates the list of names of varieties, where their characteristics are given based upon only folk provided descriptors the fact that they were not encountered during the survey.
Contexts: W – Wild; WT – Wild Transplant; RT – Varieties of cultivated yams that are known to be recently transplanted to open field; LT – Varieties of cultivated yams that are regarded as longtime cultivars
Structures: SU – Simple Unitary; SB – Simple Binary; PU – Productive Unitary PB – Productive Binary

2.3.2. Ethnolinguistic analysis

2.3.2.1. Meaning and origin of names

Names of varieties are derived from wide range of sources. The sources from which names are originated include locations where it grows or comes from, attributes of a person or social groups, and specific plant characters. The meaning and etymology of variety names is not static; farmers can give novel names to yams acquired through travel or adoptive transplantation. Translation of names revealed that 49% of the names have meanings while the rest have no meanings or their word origin is lost. The lists of names of the varieties

and their implied meanings are presented in Table 2.2. Naming is based on a consistent set of linguistic categories. A survey with 15 fixed landrace samples showed that over 87% of the landraces are consistently named (Annex 2.1). Naming was considered consistent if more than 80% of the seed lots to which a particular name was attached represented the same variety (Nuijten and Almekinders, 2008). The inherent logic is consistently applied to vernacular names across locations. Identification of the taxa assigned to different groups is also made based on a consistent set of character states. Across the district, farmers often rely on plant morphological traits to name the individual yam taxa.

The meaning of the names is quite descriptive of the plant characteristics or its geographic origin. Besides, knowledge of the names and the characteristics of locally recognized taxa are widely shared within the community across locations. This is evident in the recognition of a consistent set of names as well as in the use of a consistent set of characters and character states for recognizing and naming of the taxa assigned to different groups. This suggests that there appears to be strong relationships between the ethnolinguistic forms of naming and the characters with which it labels. But, for the majority of the recorded names, their implied etymology was not explained by farmers. In Ethiopia, similar unexplained names were reported in these and other areas for yam and enset varieties (Hildebrand, 2003; Sisay, 2008; Bizuayehu, 2008; Olango et al., 2014).

2.3.2.2. Structures of names

Structure of variety names: Naming of varieties takes place in two structures. These are (1) those that are composed of a single word (unitary names), and (2) those that are consisted of two words (binary names) (Table 2.2). Unitary names can be divided into two obvious classes. Some unitary names such as *Chabsha, Yasind, etc*., are unanalyzable form, containing unique words which can be shown to be semantically unitary and

linguistically distinct. These forms are known as simple unitary names. Others such as *Karka-Kachi*, *Baidai*/*Kaibab-kachi, etc*., are analyzable linguistically. They are noticeable in that their expression shows the origin of a subordinate category. For instance, *Karka-Kachi* is kind of wild *Kachi* obtained from wild area, and *Baidai-kachi* is a kind of domestic *Kachi* originated from *Kaibab* area, and so on. These forms are known as productive unitary names. Some varieties such as *Tsid boy*, *Dal boy, etc*., are labelled with binary names. These forms are known as simple binary names. Simple binary forms, like productive unitary forms, are identifiable in that each of the expression carries a modifier that marks a characteristic of the subordinate category. But, it differs from productive unitary forms in that the modifiers they carry are related to specific plant characters. About 78% of the varieties are labeled with unitary names, indicating that the labeling system used for naming a given variety is skewed to uninominal (Table 2.2).

Structure of sub-variety names: Examination of the naming structure used for labeling sub-varieties shows that all consisted of binary lexemes (Table 2.2). Two forms of binary names can be recognized. One group contains a simple unitary name of a given variety in a modified form such as *Tsid Chabsha, Dal yasind,* and so on. They are noticeable in that the modifiers they carry are related with the characteristics of a sub-variety. These forms are known as simple binary names. Another groups such as *Karka-kachi submseb, Kaibab-kachi ga'nseb, etc*., are identifiable in that they carry modifiers of a variety plus modifiers related with the characteristics of a sub-variety. These forms are known as productive binary names. The basic name of a sub-variety is thus a binary structure consisting of a word designating a variety plus a prefix/suffix added to it. The prefix/suffix is meaningless alone because several sub-varieties in different varieties may have the same specific prefix or suffix.

In all ethnobiological lexicons, one may distinguish two types of names for any classes of plants and animals (Berlin et al., 1973; Berlin, 1976), confirming the general structure obtained in our study. Unitary structure was found to be predominant in variety names while all the sub-varieties consisted of binomial names. The existence of two distinct labeling structures at smaller taxonomic levels can be taken as a clear evidence of the existence of two separate folk categories. In Ethiopia, a similar labeling structure was reported for varieties and sub-varieties of yam and enset (Hildebrand, 2003; Bizuayehu, 2008; Tamiru et al., 2008, 2011). In Sidama region, over 94% of enset varieties are labeled with unitary names (Bizuayehu, 2008).

2.3.3. Folk descriptors

2.3.3.1. Identification and distinction of sub-varieties

The lowest level of yam taxonomy is the sub-variety, i.e., composed of further divisions of a given variety. The lists of sub-varieties together with the description of descriptors that the farmers used to distinguish between them are presented in Table 2.2. Altogether, 21 sub-varieties are recognized by farmers as distinct. Some sub-varieties of a given variety were reported to have the indicative features of the main variety; each was also reported to differ from all the others and the main variety at least in one aspect. Distinction of sub-varietal category is principally or sometimes exclusively relying on the color of the tuber (Annex 2.2). The folk descriptor identified in this study is comparable with descriptors reported for yam in Ethiopia (Hildebrand, 2003) and in Oceania (Malapa et al., 2006), where farmers mainly relied on tuber color for sub-varietal distinction. Folk descriptor recognized in our study is also comparable with that reported for potato in the Andes (Zimmerer, 1991; Brush, 1992; 2004; Haan et al., 2007), where the only distinction between potato sub-varieties is color of the tubers.

2.3.3.2. Identification and distinction of varieties

A total of 37 named varieties are recognized by farmers as distinct. The lists of names of varieties together with the descriptors that the farmers used to distinguish between them are presented in Table 2.2. Farmers used a total of 14 characters and 43 character states for distinction and identification of varietal categories (Annex 2.2). More than half of these refer to aspects of a variety's morphology, thus showing that morphological characters played a key role in the local identification of yam varieties. Of these, tuber characteristics such as shape, color, size and texture played a key role in the local identification of yam varieties. In some cases, non-tuber traits such as stem or leaf characters are also used. Non-plant characters such as location where it grows or comes from and attributes of persons, social groups, or animals can also used to distinguish varieties (Table 2.2). The folk descriptors recorded in this study are comparable with descriptors reported for yam varieties in Ethiopia (Hildebrand, 2003; Tamiru et al., 2008; 2011). The descriptors recognized for yam generally shares the descriptors used for recognizing enset varieties in Sidama and Wolaita areas (Bizuayehu, 2008; Olango et al., 2014).

2.3.3.3. Groupings of supra variety categories

Farmers have a number of additional systems for grouping yam varieties. Two major ways of groupings can be identified. One grouping distinguishes yams by contexts, describing them as cultivated, wild or wild transplant. A second grouping distinguishes yams by gender describing them as female or male. Each of these groupings is formed by assembling several varieties and sub-varieties together; they are thus supra-variety categories. Farmers used a total of 19 characters and 54 character states while grouping of yams by contexts and gender (Annex 2.2). The characteristics of the different supra variety categories and the underlying basis of the classification are presented below.

2.3.3.3.1. Groupings on the basis of contexts

On the basis of contexts, yam varieties fall into three main supra-variety groups: a) yams of the *D. cayenensis* complex, or *D. bulbifera* that are growing wild, b) yams of the *D. cayenensis* complex that have been recently transplanted from wild area to garden, and c) yams of the *D. cayenensis* complex, *D. bulbifera,* or *D. alata* that are of under cultivation.

***Wild growing yams*:** Wild growing yams are morphologically related to some domestic yams but unlike domestic yams, they have not been domesticated yet and exist in a wild context. The term '*wild'* refers to those plants that are growing wild in forest and had no known history of human manipulations. It also assembles hybrid or volunteer plants that are growing in un-cultivated areas without farmers help. In the studied area, wild growing yams are found in degraded forests, field margins, river banks and disturbed habitats. Such yam types are known in Sheko as *Karka-Kachi* as a general category, with several one word names for smaller categories. Such types are known in Bench as *Shah-boy* as a general category, with no smaller categories (Table 2.2; Fig. 2.2, Plate 1). The folk basis and the characteristics of this supra-variety category are presented in Table 2.3.

Wild transplant yams: Wild transplant yams are those yams transplanted from wild context and grown in home garden beneath a large tree. Unlike the cultivated yams that are replanted in an annual cycle, this group of yams is left in the same place for several years. Hence, this group of yam qualifies as yams under domestication, and not just as yams under cultivation. We therefore designate this supra-variety group as '*wild transplants*' to differentiate it from wild and cultivated yams. In the studied area, many gardens contain a few yams that seem on the state of transition, yams transplanted from wild contexts where many of them had no known history of cultivation in a garden along row of stakes. In Sheko such yams are usually known as *Karka-kachi* while it is called *Yasind* in Bench as a

general category; with each of them have several one word names for smaller categories (Table 2.2; Fig. 2.2, Plate 2 and 3). The folk labels and the corresponding characteristics are presented in Table 2.3.

Table 2.3. Sheko and Bench intermediate folk categories of yams at the sub-generic level

Folk basis	Categories	Folk labels/names	Scientific category	Characteristics of each category as described by local farmers	Number of taxa
Context	Wild	*Karka-ama/Balakay-Oake*	[1]	None-edible tuber	1 (0)
		Karka-Kachi, Shay-boy, or Karckabat	[2]	Spiny vines, highly prickled roots on the tuber crown and surface, vigorous, late maturing, flowering, set seed and thin elongated and bitter taste tubers.	3 (3)
	Wild transplant	*Karka-Kachi, Yasind*		Is very similar with wild yam, but its tuber tends to change to fat and tasty over the course of years of cultivation	2 (5)
	Cultivated	Recent transplants (I) + Longtime variety (II)			
	I	*Kaibab-Kachi*	[2]	Medium to high spines on vine, prickly roots on the tuber crown and surface, medium sized light green leave, vigorous. Broad and tasty tuber.	4 (4)
	II	*Kachi/Boyye*		Few to medium spines on vine, few to intermediate prickly roots on the tuber crown and surface, medium sized dark leaves, early maturing and flowering	22 (6)
		Baday-kachi	[3]	Non-woody, spineless and large sized green leaves. Early maturing and not flowering	4 (1)
		*Ama/Oake**	[1]	Edible tuber	1 (2)
Gender	Female	*Kachi/Baday-kachi*	[2 , 3]	Early maturing, less vigorous, double harvest, susceptible to stress, tasty tuber	24 (7)
	Male	*Karka/Kaibab-kachi Shay-boy/Yasind*	[2]	Late maturing, single harvest, vigorous, stress tolerant, bitter taste tuber	9 (12)

*refers aerial yam, values in () are No. of sub-varieties (N = 21); values without () are the No. of varieties (N = 37). No. within the scientific category is referring, 1: *D. bulbifera*; 2: *D. cayenensis* complex; 3: *D. alata*

Farmers did not provide consistent morphological grounds for differentiating between wild and wild transplant yams. Yet, some farmers are able to describe the distinction between the two contexts. According to farmers, wild transplant yam retains its wild traits for the first few years after transplantation and thus, they knew it by the name of wild places though it grows in a home garden. It begins to take on the traits of domestic yam, and in

fact farmers credit wild transplant yams as having broader and tasty tubers over the course of three to five years of cultivation. If they are satisfied with the modifications, they may rename it to a variety of domestic yam it resembles most closely. Sheko usually renames *Karka-Kachi* as *Torbay* or *Baidai/Kaibab-Kachi,* whereas the Bench renames *Yasind* as *Chabsha* or *Tolubab*. There is no strict rule in naming and renaming to a variety of other domestic yam is also possible. Other studies have made similar distinctions between wild and wild transplant yams and parallel changes in morphology of tubers over the course of 3 to 5 years of cultivation (Hildebrand, 2003).

Cultivated yams: This supra-variety group of yams is further divided into two main subordinate categories: those known to be recent transplants and those regarded as longtime variety.

***Those known to be recent transplants*:** This group of yam represented a variety of cultivated yams but their morphotype is closely related with wild transplant yams. Some individual plants are known to be recently transplanted to open field. Farmers reported four varieties belong to this supra-variety category, namely *Baidai-kachi, Chabsha*, *Torbay* and *Tolubab* (Table 2.2; Fig. 2.3, Plates 1-4). Some of these names can also be used interchangeably for yams that have been recently transplanted from wild contexts and grow beneath a large tree. The name *Baidai-Kachi* is sometimes used as a gloss for all varieties in this supra-variety category (Table 2.3). The trend of naming reflects the diversity of forms through which humans drive its evolution under domestication. Similar distinction has been made in Sheko for yams (Hildebrand, 2003).

***Those regarded as longtime variety*:** Of all yam varieties recorded, 27 have a longtime history of propagation and cultivation by humans. They are usually grown in small plots of open field along rows of stakes. They can be further divided into three obvious classes.

The first group assembles 22 varieties, most of which seem to have similarity to different members of the *D. cayenensis* complex (Table 2.2; Fig. 2.3, Plates 5-14). Of the *Dioscorea* species used by Sheko and Bench, this species complex is of the most economically important, but also has the greatest numbers of locally threatened varieties. Six varieties, namely *Shure*, *Don*, *Kappar, Dal boy, Zansul and Kuchuu'bai* are undergoing serious genetic erosion. Others such as *Kachi-kundi, Kachi-Kuch'ai, Kalu, Bud boy, Tush boy* and *Bunkri* are already abandoned. Farmers usually labelled this class of yams by the name *Kachi/Boyye* (Table 2.3). Despite the scientific taxa that describes their origins to separate areas in Africa; farmers regarded all of the varieties as native to their area. In Ethiopia, preliminary works have identified several indigenous yam types as having a longtime history of cultivation by humans (Hildebrand, 2003; Sisay, 2008; Tamiru et al., 2008).

A second class comprises four longtime varieties belonging to *D. alata* (Table 2.2; Fig. 2.3, Plate 15 and 16). Of this, *Baday* is the most common, both in terms of its distribution and relative abundances. Farmers usually labelled this class of yam as *Baday-Kachi* (Table 2.3). The names *Baday* and *Ongubay* are used interchangeably for one another, and sometimes used as a gloss for all varieties of *D. alata*. This species is not native to Ethiopia and in Ethiopia it grows only as a cultivar (Miege and Sebsebe, 1997). A variety of *D. alata* is readily distinguished due to its large sized foliages and four winged stems. They had no known history of introduction to these areas, but farmers regarded that all of these varieties as native to their area. *D. alata*, thus, must have first entered these areas as a cultivar well before the time periods known in local oral historic memory (Hildebrand, 2003). The meaning of *Baday* (Table 2.2), suggest that farmers are aware of the distinct nature of this yam in relation to other kinds of yam.

A third class comprises a single cultivar of *bulbifera* that is known by the name *Ama/Oake* (Fig. 2.3, Plate 17). It has two sub-varieties, where the primary contrast is between bulbil colors (Table 2.2). The *bulbifera* plant also occurs in wild form. Farmers didn't provide consistent morphological grounds for discriminating between the two contexts. Identification of a *bulbifera* variety as cultivated vs. wild does not depend on the physical traits of the plant, but of its growing location and edibility of the bulbils (Table 2.3).

2.3.3.3.2. Groupings on the basis of gender

On the basis of sex, yam varieties fall into two supra-variety groups: female (*Mine/Baye*) and male (*Babu/Eyane*) (Table 2.3). The distinction as male or female by the farmers is not related to the biological reproduction of yam varieties, but mainly at the stage of maturity, time of harvest, growth habit, taste of the tubers and tolerance to stress. Some farmers claim that early maturing, less vigorous, double harvest and tasty varieties as female while they are male otherwise. For instance, the late maturing groups such as *Torbay*, *Tolubab* and *Chabsha* are among others that farmers considered as male varieties. All the wild and wild transplant yams are also considered as male varieties. Others such as *Don*, *Dizzu-kachi*, *Tsid boy*, etc., are among others that are recognized as female varieties.

Gender can thus be considered an alternative and distinct way of classifying yam varieties and influence practical decisions of maintaining diversity. Similar trend of gender related categorical system was reported on yams in Southern and Southwestern Ethiopia (Sisay, 2008; Tamiru et al., 2011). This gender-related categorization in the study area is not limited to yams, where Almaz and Nieof (2004) reported gender based category for enset in Southwest Ethiopia. A similar trend exists for enset in Sidama and Wolaita, Southern Ethiopia (Bizuayehu, 2008; Olango et al., 2014), where enset varieties are separated as male and female partly based on shape of pseudo-stem.

Fig. 2.2. Yams of the *D. cayenensis* complex that are growing wild, or that have been recently transplanted from wild location to home garden

Plate 1: *Karka-kachi***

Plate 2: *Yasind**

Plate 3: *Karka-kachi**

*NB: ** = Wild, * = Wild transplant*

Fig. 2.3. Yams of the *D. cayenensis* complex, *D. bulbifera*, or *D. alata* that are of under cultivation

Plate 1: *Kaibab/Baidai Kachi*

Plate 2: *Torbay*

Plate 3: *Tolubab*

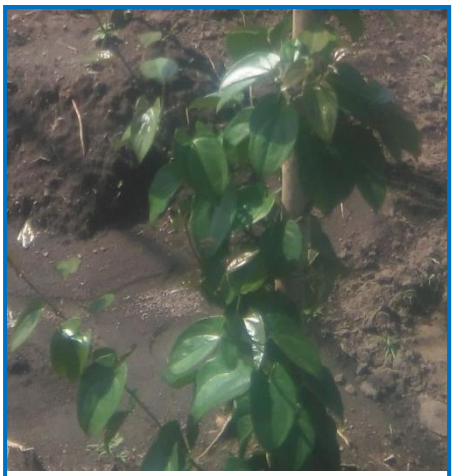

Plate 4: *Chabsha*

Plate 5: *Beri*

Plate 6: *Banda boy*

Plate 7: *Shamut*

Plate 8: *Tsid boy*

Plate 9: *Shapinsin*

Plate 10: *Dal boy*

Plate 11: *Dizzu-Kachi Tsano*

Plate 12: *Dizzu-Kachi tsaa'nseb*

Plate 13: *Dizzu-Kachi ga'nseb*

Plate 14: *Dizzu-Kachi*

Plate 15: *Ongubay/Baday*

Plate 16: *Earkubay*

Plate 17: *Ama/Oake*

2.3.4. Comparison of folk and formal taxonomy

The folk classification system reported in Sheko and Bench shows a pattern of hierarchy starting from the least to the most inclusive groups. Three major groups of folk categories recognized by farmers have been described above. The local classification system thus recognizes four taxonomic groups of yam. Each of these can be considered as belonging to different level and thus arranged hierarchically. In order from the least to the most inclusive group are sub-variety, variety, supra-variety, and folk generic. Table 2.4 provides comparison of formal and folk taxonomic systems. Applying Berlin et al. (1973) scheme, the folk recognized ranks can be assigned to four formal biological divisions such as sub-varietal, varietal, sub-generic and generic. Taxa assigned to the folk generic, and varietal categories correspond to the formal biologically recognized groups at the genus, and varietal levels, respectively. Taxa assigned to supra-variety and sub-varietal categories may also correspond to the biologically recognized divisions at the sub-generic and sub-varietal levels, respectively (Brush, 1992).

One interesting observation between the two system is that formal taxonomy focuses at and above species level, while folk taxonomy concentrates on intraspecific diversity, i.e., at the folk varietal and sub-varietal ranks. We found the highest number of taxa at the folk varietal and sub-varietal ranks. The recognition of rich varietal taxa can be used as a clear evidence of its significance to the local farmers. As shown here, moderate overlap between the two systems exists. Yet, the overlap is far from perfect and the standards in folk taxonomy are not expected to be absolutely consistent across locations and social domains, there are therefore some anomalies. In view of this, the two systems can be combined to obtain insights into the links of classification rationale and systems applied to the management and utilization of on farm genetic resource.

Table 2.4. Comparison of Sheko and Bench folk classifications with the formal divisions

Scientific Ranks	Formally recognized folk ranks by earlier studies	Ranks recognized by Sheko and Bench farmers	Number of taxa identified in each categories
Order	Life form	-	-
Family	Covert groups	-	-
Genus	Generic	Folk generic	4 individual labels
species	Sub-generic	Supra-variety	9 labelled groups
	Varietal	Variety	37 individual labels
-	Sub varietal	Sub-variety	21 individual labels

Sheko and Bench taxonomy of yam shares the general classification schemes reported for enset in Ethiopia (Bizuayehu, 2008), potato and cassava in the Andes (Boster, 1985; Quiros et al., 1990; Zimmerer, 1991; Brush, 1992; Haan et al., 2007), columnar cacti in Mexico (Casas et al., 1997) and folk classification of plants in Switzerland (Poncet et al., 2015). A closer look of the two systems showed difference of scales. In the formal taxonomy, varietal taxa occur in contrast sets of few members, the most frequent being a set of two classes (Berlin et al., 1973), while in folk taxonomy; it occurs in contrast sets of many members. Though there is a moderate overlap between them, they are arguably complementary for a number of reasons. First, the folk recognized taxa are consistent to a considerable extent with the variability obtained from a study using morphological marker (Bizuayehu et al., 2021), confirming earlier reports from Ethiopia (Tamiru et al., 2007, 2011; Wendawek et al., 2013a, b) and West Africa (Dansi et al., 1999; 2000a; Tostain et al., 2007). This suggests biological and functional consideration constitutes the basis of folk taxonomy. Second, many of the names and their implied characteristics are known to most members of the community and across locations. This provides additional support to the view that classification and naming of plants is not an activity confined to the domain of formal science only.

2.4. CONCLUSIONS

A number of conclusions can be drawn from the study. First, there exists a systematic and well-developed folk taxonomic system of yams in Southwest Ethiopia. This is evident by the recognition of four botanic ranks: sub-variety, variety, supra-variety and folk generic. Taxa assigned to each of the ranks have distinct features that mark them as members of separate groups. Second, farmers manage a wide range of folk descriptors, each of which contains several character states, and most of these descriptors correspond to the formal descriptors list. As a result, the two systems can be treated as complementary and conservation efforts should take both systems into account.

Third, farmers recognize various individual taxa. Each of these is perceived as distinct and given a separate name. The recognition of rich individual taxa is *prima facie* evidence for great diversity and can be used as the unit of on farm diversity. Individual households are the primary management unit of selection and maintaining diversity. Assessment of diversity kept by different households is essential to have insights into the nature and spatial dynamics of diversity, and this assessment can rely on folk recognized taxa. Research on diversity can draw directly on folk taxonomy as long as the unit of analysis is the household.

More generally, this study documented folk biosystematics of yams in Southwest Ethiopia; constitutes a complex of dynamic indigenous knowledge that is highly relevant for conservation efforts. However, the study is not exhaustive; no objective generalization can thus be drawn regarding the actual extent of yam diversity in Ethiopia. The problem is further complicated by the fact that for the majority of the recorded names, their etymons and implied descriptions are incomplete. Thus, more detailed ethnobotanical studies in these and other areas are of paramount importance to unravel such complexities.

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CHAPTER 3

3. Diversity, Distribution and Farmers Management of Yam Landraces (*Dioscorea* spp.) in Bench-Sheko and Sheka Zones, Southwest Ethiopia

ABSTRACT

An ethnobotanical survey was conducted in southwest Ethiopia with the objective to assess the diversity and distribution pattern of yam landraces and the associated management practices of farmers. A total of 272 households were interviewed from fifteen Kebeles in five districts of Bench-Sheko and Sheka Zones. Altogether, 34 actually grown landraces of yam were recorded throughout the five districts of Bench-Sheko and Sheka Zones. Besides these, six additional landraces were found in farms of unsampled households. Richness of landraces ranged from 1 to 6 (2.63 ± 1.04) per farm, from 5 to 13 (8.73 ± 2.63) per Kebele and from 6 to 16 (12.2 ± 4.15) per district. On average, 79% of landraces found in one Kebele were also found in the other Kebeles within the district whereas 46% of them were common to all Kebeles among districts. Similarity indices between the districts varied from 0.26 to 0.42 (0.35 ± 0.18). The distributions of landraces also varied across the surveyed sites. A small number of highly abundant landraces were grown throughout the surveyed sites whereas the greater numbers of the landraces had a narrow distribution and abundances. The management practices of local farmers were contributed to the continued maintenance of cultivated landrace. Farmers' decisions to the on-farm landrace maintenance were related to the agronomic aspects and recently, many households are concentrated on a few numbers of early maturing landraces. Others are undergoing genetic erosion and in fact some are already abandoned. This entire pattern leads to the necessity for germplasm collection and priority should be given for in situ conservation and the development of strong yam database.

Key words: Ethnobotany; Diversity; Distribution; Landrace; Management; maintenance

3.1. INTRODUCTION

Diversity study in crop plants is vital to obtain reliable information on the extent, distribution and spatial dynamics of diversity. These data provides opportunity for the development of efficient conservation strategies and its utilization in crop improvement program. Diversity within plant species can be studied by morphological, genetic or molecular methods. In situations where documented data are hardly available, folk varietal categories can serve as operational taxonomic units for assessing intraspecific diversity in crop plants. Several studies have demonstrated that traditional folk varietal categories reflect the variation that exists at morphological and molecular levels (Sambatti et al., 2000; Elias et al., 2001a; Tamiru et al., 2011). Farmers recognize distinct intraspecific diversity of plants, known as traditional varieties or landraces. Farmers have names for them and different landraces are understood to differ in adaptation, time of seeding, date of maturity, height, nutritive value, use, and other (Harlan, 1975). However, factors such as the abandonment of the practice of family farming, the rapid growth and increase of monoculture, the replacement of local varieties by commercial varieties, have induced genetic erosion of many crops, including the yam species (Dansi et al., 1999). Therefore, the local knowledge should need to be preserved to guide efficient conservation strategies.

The knowledge and management practice of local farmers is a key for the maintenance of local agro-biodiversity and the genetic diversity of cultivated crops (Elias et al., 2001a, b; Siqueira, 2011; Bressan et al., 2011). Earlier studies have examined the role of farmers management practices of yam from the perspective of enriching diversity in cultivated landraces (Hildebrand, 2003; Dumont and Vernier, 2000; Mignouna and Dansi, 2003; Scarcelli et al., 2006a). According to these authors, such enrichment is probably due to the adoptions of seedlings resulting from natural crossing that become established in cultivated areas, all of which favors gene flow among wild and cultivated populations. It is also

probably due to continual incorporation of new landraces through exchange of seed tubers. Others on the other hand were triggered by concerns over the decline in diversity following the introduction of modern crop varieties into centers of crop domestication (Richards, 1995; Zannou et al., 2004). In Benin, Zannou et al. (2004) reported that the adoption of the variety Alougan from Ivory Coast displacing the local Alougan.

Earlier reports indicated that a wide range of yam species exists in Ethiopia. Edwards (1991) reported that yams are one of those crops with wild relatives in Ethiopia. Harlan (1969) also believed that several yam species might have their origin in Ethiopia. With regard to the within species diversity, about 23 indigenous yam types were reported in Sheko districts, Southwest Ethiopia (Hildebrand, 2003). Thirty actually grown yam landraces were reported in Bench, upland Omotic-speaking peoples residing east of the Sheko (Sisay, 2008). A similar report was evident for cultivated yams under local management in Southern Ethiopia and 37 non-synonymous yam landraces were reported in Wolaita and Gamo-Gofa Zones (Tamiru et al., 2008a). Each of these findings clearly indicated that the genetic diversity of yams in a particular area appears to be related with the management and the distribution pattern of the different ethnic groups.

Diversity and farmers management of yam landraces have been studied in different yam growing areas of Sheka and Bench-Sheko Zones, Southwest Ethiopia. However, some of these studies were limited to a specific growing region within few ethnic groups (Sisay, 2008). Others have focused on genetic divergence without addressing ethnobotanical aspects (Wendawek et al., 2013a, b). It is obvious that the management of folk cultivars in traditional agricultural system is a key to understand how this diversity is perceived and valued by them. The insight this provides is also valuable for the improvement and conservation of yam in Ethiopia. Keeping in view all this point, this study was conducted

with the objective (i) to investigate the diversity and distribution of cultivated yams in traditional farming systems of Bench-Sheko and Sheka Zones and (ii) to assess the associated management practices of farmers in Southwest Ethiopia.

3.2. MATERIAL AND METHODS

3.2.1. Yam diversity recording

Yam diversity record was done by collecting data on the name of local landraces, the number of local landraces grown at household level and the descriptors used by farmers to identify these landraces. During the survey, we gave an immense attention for consistency of landrace names, the fact that it avoids an overestimation of cultivar diversity in a given area due to linguistic polymorphism. Hence, we recorded the name of each landraces together with the descriptors that each farmer used to recognize and distinguish the landrace in question. These sets of descriptors together with our own observations were used to arrive at the basic distinguishable units for each landrace. The process of arriving at distinguishable units included (1) removal of synonymous (a given cultivar known by several names in different Kebeles were removed after we recognize it as the same unit) and (2) separating distinct units (different cultivars known by the same name were separated into distinct units when we recognize it as different units). Elderly farmers were also involved in the process of arriving at distinguishable units.

The survey involved 272 farmers and was aimed at investigating the diversity and distribution of yam landraces in Bench-Sheko and Sheka Zones, Southwest Ethiopia. Table 3.1 presents the number of households and the altitudinal ranges of each Kebeles within the five districts. The detail site description of the study area is presented in the material and method part of chapter two.

Table 3.1: Altitudinal range of study sites in Sheka and Bench-Sheko Zones, Southwestern Ethiopia

Zone	District		Kebele		Number of HHs	Elevation (m)	
	Code	Names	Code	Names		Range	Average
Sheka	I	Yeki	*1a*	Zinki	22	1210 - 1351	1301
			1b	Hibret Fre	21	1120 - 1340	1182
			1c	Addis Alem	14	1149 - 1341	1240
					57	**1120 - 1351**	**1241**
Bench-Sheko	II	Sheko	*2a*	Mehal Sheko	21	1469 - 1724	1644
			2b	Sanka	23	1230 - 1335	1266
			2c	Gaizeka	15	1269 - 1695	1532
					59	**1230 - 1724**	**1481**
	III	Debub Bench	*3a*	Zozo	25	1385 - 1495	1412
			3b	Kite	15	1301 - 1357	1334
			3c	Zemika	10	1278 - 1346	1314
					50	**1278 - 1495**	**1353**
	IV	Semen Bench	*4a*	Gortinamag	20	1407 - 1461	1436
			4b	Wushkin	20	1310 - 1501	1447
			4c	Endakil	25	1712 - 2080	1840
					65	**1310 - 2080**	**1574**
	V	Guraferda	*5a*	Otowa Chole	16	1091 - 1196	1119
			5b	Berji	15	1113 - 1250	1158
			5c	Kuja	10	1368 - 1425	1409
					41	**1091 - 1425**	**1229**
Overall total					**272**	**1091 - 2080**	**1376**

Individual households were interviewed using a semi-structured questionnaire and was carried out from the period from Dec., 2016 to Nov., 2017. Information was collected on trend of yam cultivation, the planting system, the planting season and source of yam for planting. Moreover, data was also recorded on management practices such as spacing, fertilization and pest and disease managements, harvesting and storage. Farmers were also asked to report the vernacular names of landraces that are grown in their vicinity. Finally, field notes of varieties and photographs were taken by the researcher.

3.2.2. Measurement and analysis of diversity

Diversity and distribution are ecological concepts and methods developed in ecology to measure biological diversity at the level of species was used for assessing the diversity and distribution of yam landraces. To this end, diversity is defined as the variation present

among individuals of a variety, population or species and the ecosystems in which they occur. Distribution refers to the number of surveyed locations occupied by a landrace. It is a measure of occurrence on the between-site scale. Diversity of yam landraces was measured in terms of richness and evenness. Richness refers to the number of different kinds of landraces regardless of their frequencies. Evenness, however, measures how similar the frequencies of the different variants are, with low evenness indicating dominance by one or a few types. Yam landrace diversity was measured across sites and the variation in richness and evenness across sites were compared.

Shannon and Simpson diversity indices were used to measure the diversity of yam landraces across Kebeles and districts. Shannon diversity index (*H'*, also termed as the Shannon-Weaver index), combines both richness and evenness of categories considered. The index is defined as:

$$\boldsymbol{H' = -\sum_{i=1}^{S} p_i * ln(p_i)}$$

Where, (*S*) is number of landrace recorded per site, ($P_i = n_i/N$) represents frequency of landrace (*i*), ($\boldsymbol{n_i}$) represents number of farms where landrace (*i*) was found, and *N* represents the sum of the number of farms where individual yam landraces were found. Evenness (*E*) was calculated separately as a measure of the ratio of the observed diversity to the maximum diversity. It is defined by the function, $E = H'/lnS$ where (*H'*) refers the Shannon index and (*S*) refers to the number of landrace recorded per site. The Shannon index is high when the relative abundance of the different landraces in a given area is even and is low when few widespread landrace are ubiquitous across sites. The fact that the Shannon index incorporates both components of diversity means that it is quite difficult to compare sites that differ greatly in richness. Thus, many researchers prefer to combine a

direct measure of landrace richness with some measure of dominance or evenness. The most common measure of dominance is the Simpson's index.

The Simpson's diversity index (*D*) basically measures the probability that two individuals randomly selected from a sample belong to the same category and as *D* increases, diversity (in terms of evenness) decreases. Simpson index is usually reported as its complement (*1-D*), the fact that as (*D*) takes on values between 0 and 1 and when it approaches to 1, it is in the limit of a monoculture. Thus, its complement (*1-D*) provides an insightful estimate of evenness diversity that is much less sensitive to landrace richness (Jarvis et al., 2008). The index (*D*) is defined as:

$$\boldsymbol{Simpson's\ Diversity\ Index\ (D)} = \sum \left(\frac{n_i}{N}\right)^2$$

Where (n_i) represents number of farms where landrace (*i*) was found, and (*N*) sum of the number of farms where individual landraces were found.

We also made comparison of named landraces across sites to summarize the fraction of landraces they share. The variation in landrace composition that occurred between sites was analyzed using Sørenson's similarity index. The index was computed as:

$$\boldsymbol{Sørenson's\ Similarity\ Index} = \frac{2c}{(a+b)}$$

Where, (*a*) represents number of landraces in site *A*; (*b*) represents number of landraces in site *B*; and (*c*) represents number of landraces common to both sites.

3.3. RESULT AND DISCUSSION

3.3.1. Diversity of Yam Landraces in Bench-Sheko and Sheka Zones

Altogether 40 named individuals, including those found in farms of unsampled households was recorded at the 15 locations that were surveyed in five districts of Bench-Sheko and Sheka Zones (Table 3.2). Of these, 34 are actually grown yam landraces, where 2 are unique to Sheka Zone, 24 are unique to Bench-Sheko Zone and 8 are common to both Zones. About 21% of the landraces correspond to two well defined botanical species while the rest represented the unidentified species. Most of the unidentified species of yams share some common morphological features such as un-winged stem, spines at stem base and above the stem base and few to several spiny roots on the tuber crown. This suggests that they seem to have similarity with different members of the *D. cayenensis* complex. In Southwest Ethiopia, other studies have reported similar morphological features for yams of this species complex (Hildebrand, 2003; Wendawek et al., 2013a, b).

The diversity identified here is highly comparable with the diversity detected by earlier works in Ethiopia. In Southern Ethiopia, Tamiru et al. (2008a) reported 37 differently named landraces from Gamo-Gofa and Wolaita Zones. The vernacular names detected in this study entirely differs from those reported in Gamo-Gofa and Wolaita areas. The number of yam landraces recorded in this study is relatively higher than those detected previously in Southwest Ethiopia. 23 indigenous yam types and 30 non-synonymous yam landraces, respectively, were reported from Sheko and Bench districts of Bench-Sheko Zone of Southwest Ethiopia, (Hildebrand, 2003; Sisay, 2008). Comparison of diversity values suggested that majority of previously detected landraces are undergoing genetic erosion. Of the 23 indigenous yam types detected previously in Sheko area, only 26% were encountered in this survey while others were not found in farming community. Moreover,

most of verbally reported landraces were never encountered on farmers' fields during the survey, indicating that the greater numbers of indigenous yam types are abandoned.

The diversity identified here on the other hand is much lower than the level of diversity detected in West African countries. For instances, in Togo, Dansi et al. (2013) reported about 470 farmer-named cultivars of *D. cayenensis* complex and about 134 farmer-named cultivars of *D. alata*. The greater diversity registered in the above report may be the higher sampling effort, where up to 50 villages with diverse ethnic groups were visited. Such record however, has lead to an overestimation of cultivar diversity. As reported on cassava (Elias et al., 2001a, b; Kombo et al., 2012) and also on yam (Tamiru et al., 2008a) different cultivars may be given the same name or one cultivar may be given several names in different villages. This could lead to either an overestimation or an underestimation of cultivar diversity.

Most of the earlier diversity studies in Southwest Ethiopia were based on few farmers provided descriptors which don't show the full extent of within species variability. No sound conclusion can thus be drawn regarding the diversity that exists currently or its spatial dynamics. In this study, the available landraces were characterized using standard morphological descriptors, and a considerable correspondence was obtained between morphological diversity and folk cultivars (Bizuayehu et al., 2021). It may thus shed a new light for capturing the extent and the spatial dynamics of yam landraces there. The result can serve as an indicator of the level of diversity within yam species. The wild yams, known by the name *Karka-kachi* in Sheko, (*Shahboy*) in Bench and *Shebka* in Guraferda were encountered in areas where some forest patches still exist. Farmers' classification of yams as wild growing is mainly depending on the location where they grow.

Table 3.2. Numbers of yam landraces recorded in five districts of Bench-Sheko and Sheka Zones, Southwestern Ethiopia.

No	Name of landraces		Districts					Total No. of Farms	Total No. of Dist.
			I	II	III	IV	V		
1	*Ama-Tsaa'nseb, Tiab-Oake*[a]		17	18	7	9	11	62	5
2	*Ama-Ga'nseb, Don-Oake* [a]		5	4	5	2	-	16	4
3	*Banda boy*		-	-	25	30	-	55	2
4	*Beri*		-	10	-	-	-	10	1
5	*Chabsha* varieties	*Dal-Chabsha*	-	-	1	1	-	2	2
6		*Tsid-Chabsha*	-	-	3	1	-	4	2
7	*Dal boy*		-	-	-	1	-	1	1
8	*Don* varieties	*Don-babu*	-	1	-	-	-	1	1
9		*Don-baye*	-	1	-	-	-	1	1
10	*Earkubay, Wurgit*		19	-	-	1	23	43	3
11	*Kachi-Ga'nseb*		12	-	-	-	-	12	1
12	*Kachi-Tsaa'nseb, Tsano, Dizzu*		45	53	-	-	-	98	2
13	*Kappar*		-	-	1	-	-	1	1
14	*Karka-Ama, Balakay-Oake***[a]		1	2	-	2	-	5	3
15	*Karka-kachi***		2	4	-	-	-	6	2
16	*Karka-kachi**		9	14	-	-	-	23	2
17	*Konkay*		3	-	-	-	-	3	1
18	*Kuchuu'bai*		-	-	2	-	-	2	1
19	*Lekut*		-	-	-	-	8	8	1
20	*Logit*		-	-	-	-	23	23	1
21	*Ongubay, Baday(Badach)*		43	43	11	11	30	138	5
22	*Shamut*		-	-	13	13	-	26	2
23	*Shapinsin*		-	-	6	7	-	13	2
24	*Shebka***		-	-	-	-	2	2	1
25	*Shure*		-	1	-	-	-	1	1
26	*Submseb Ongubay*		-	1	-	-	-	1	1
27	*Tolubab*		-	-	9	19	-	28	2
28	*Torbay*		-	18	-	-	-	18	1
29	*Tsid boy*		-	-	41	54	-	95	2
30	*Yasind* varieties	*Dal-Yasind**	-	-	3	-	-	3	1
31		*Tsid-Yasind**	-	-	1	5	-	6	2
32	*Shahboy/Karckabat* **		-	-	1	1	-	2	2
33	*Zenkuru*		-	1	-	-	-	1	1
34	*Zansul*		-	-	-	1	-	1	1

*District codes are given in Table 3.1; a = aerial yam; * = wild transplant; ** = wild;*

3.3.2. Diversity at District and Kebele Level

Variations in richness and evenness of landraces were observed between the districts. Most districts had maintained a considerable number of landraces. The numbers of landraces per district varied from 6 to 16 (Table 3.3). The highest richness was recorded in Debub and Semen Bench districts of Bench-Sheko Zone, while the lowest diversity (richness) was

observed at Guraferda districts of the same zone. The richest district were also found as the most diverse (*H'* = 2.12 and *H'* = 2.04). Guraferda was found as one of the least diverse district (*H'* = 1.58) (Table 3.3). Similar results are also apparent for Simpson's diversity index. Moreover, the district richness were significantly correlated with the Shannon (r = 0.95**) and Simpson's (r = 0.89*) diversity indices (Annex 3.1); corresponding to greater landrace diversity regardless of their frequency. This was also evident in our F test that showed significant (P< 0.05) variation in richness of landraces among the districts (Annex 3.2). These results are inconformity with Tamiru et al. (2008a) according to which Bolosso-Sore and Damot-Gale districts in Wolayita Zone had the widest diversity.

There were also variations in evenness of landraces among the districts surveyed. Evenness of landraces per district ranged from 0.73 to 0.88 (Table 3.3). Lower evenness of landraces at districts having higher richness, reflecting the dominance of one or few varieties with much of the richness are held in low frequencies. High evenness of landraces was observed at districts having lower richness, suggesting a more even distribution of the few landraces. This was reflected by the significant and negative correlation between evenness and richness (r = -0.91*) of landraces at district (Annex 3.1), reflecting the sensitivity of Shannon index in comparing sites that differ greatly in richness. To this end, the Simpson index (*D*) is more convenient and its complement (*1-D*) is reported as an estimate of evenness diversity the fact that it is less sensitive to landrace richness (Jarvis et al., 2008).

Variations in richness and evenness of landraces were observed between the Kebeles. The numbers of landraces recorded (richness) per Kebele varied from 5 to 13 (8.73 $\pm$ 2.63) (Table 3.3). The highest diversities (up to13) were observed in Zozo Kebele (*3a*) in Debub Bench district of Bench-Sheko zone, while the lowest diversities were observed at Otowa Chole (*5a*) and Berji (*5b*) Kebeles located in Guraferda districts of the same zone. All the

other richness indices were varied in between these Kebeles. Comparable yam diversities were obtained by Sisay (2008) in Debub and Semen Bench districts of Bench-Sheko Zone, where the richness among Kebeles ranged from 8 to 17.

Table 3.3: Landrace diversity in Sheka and Bench-Sheko Zones expressed as uniqueness, richness, evenness, Simpson's (*1-D*) and Shannon (*H'*) diversity indices

Districts	Kebeles	Uniqueness			Richness	Diversity indices		Evenness
		a	*b*	*c*		*1-D*	*H'*	
Yeki	*1a*	1	0		9	0.78	1.75	0.79
	1b	1	1		9	0.76	1.74	0.79
	1c	0	0		7	0.83	1.82	0.94
		2	**1**	2	**10**	**0.80**	**1.85**	**0.80**
Sheko	*2a*	4	3		12	0.83	2.03	0.82
	2b	2	2		9	0.77	1.72	0.78
	2c	0	0		7	0.79	1.71	0.88
		6	**5**	7	**14**	**0.81**	**1.93**	**0.73**
Debub	*3a*	3	1		13	0.82	2.06	0.80
Bench	*3b*	2	1		12	0.84	2.17	0.87
	3c	0	0		7	0.80	1.75	0.90
		5	**2**	3	**15**	**0.83**	**2.12**	**0.78**
Semen	*4a*	6	1		12	0.78	1.88	0.76
Bench	*4b*	1	1		10	0.82	1.95	0.85
	4c	0	0		8	0.78	1.72	0.83
		7	**2**	2	**16**	**0.81**	**2.04**	**0.74**
Guraferda	*5a*	0	0		5	0.77	1.53	0.95
	5b	0	0		5	0.76	1.50	0.93
	5c	1	1		6	0.77	1.60	0.89
		1	**1**	3	**6**	**0.77**	**1.58**	**0.88**

NB: Site codes as given in Table 3.1; *a*: between Kebeles within districts, *b*: between Kebeles among districts, *c*: Between districts.

For both Shannon and Simpson's indices, the lowest diversity indices 1.50 and 0.76, respectively, were obtained at Berji Kebele (*5b*) while the highest (2.17 and 0.84) was recorded at kite Kebele (3b) (Table 3.3). Moreover, richness of landraces among Kebele were significantly correlated with Shannon (r = 0.90***) and Simpson's (r = 0.56*) diversity indices (Annex 3.1), corresponds to greater landrace diversity regardless of their frequency. There were also variations in evenness of landraces among the Kebeles surveyed and ranged from 0.76 to 0.95 (Table 3.3). Evenness of landraces among Kebeles

were negatively and significantly correlated with richness (r = -0.72**, Annex 3.1). This association is attributed to the same contrast that made for the district variation. The higher number of landraces recorded can be attributed to the stratified and multi-location sampling strategies used in the survey. As is evident from the study, each site has unique landrace characteristics associated with it and differs from other locations in landrace richness and evenness. Sampling even at the richest district and the richest Kebele would have captured only 47% and 38% of the total landrace diversity, respectively. Diversity studies in few locations would therefore significantly underestimate the total diversity and failed to discriminate between landrace rich and poor environments.

3.3.3. Diversity at Household Level

There is variation among districts with respect to number of landraces maintained per farm. The numbers of landraces on individual farms ranged from one to six (Table 3.4). Farmers on average grew more than one landraces, because the overall on-farm average diversity is 2.63. Some individual farms in Sheko (II), Debub Bench (III) and Semen Bench (IV) districts contain up to six landraces. This was also evident in our F test that showed a very highly significant ($P < 0.001$) variation in farms growing 1 to 6 landraces per farm (Annex 3.3). Similar results were obtained in Wolaita and Gamo-Gofa zones of southern Ethiopia (Tamiru et al., 2008a), where the number of landraces recorded on individual farms ranged from one to six. But, our result is in contrary to the landrace maintained at farm levels in West Africa, where some Togolese and Beninese farmers had maintained up to 21 (Dansi et al., 2013) and 13 (Zannou et al., 2004) yam cultivars at a time. The number of landraces maintained per individual farm is also far lower than those reported for other clonal crops (Yemataw et al., 2014; Kombo et al., 2012). For instance, Yemataw et al. (2014) reported up to 26 enset clones per farm in Hadiya Zones of Southern Ethiopia. The number of enset

clones recorded per house hold varied between 2 and 24 in Sidama Zones of Southern Ethiopia (Bizuayehu and Ludders, 2003).

Table 3.4. Yam landraces maintained at household level across the five districts in Bench-Sheko and Sheka Zones, Southwestern Ethiopia.

Number of landraces	Number of farms per district					Total
	I	II	III	IV	IV	
1	5	4	3	8	6	26 (10)
2	19	16	24	33	17	109 (40)
3	19	29	15	17	15	95 (35)
4	10	5	6	4	3	28 (10)
5	4	1	1	2	0	8 (3)
6	0	4	1	1	0	6 (2)
Total	**57**	**59**	**50**	**65**	**41**	**272**
Mean	**2.81**	**2.91**	**2.62**	**2.41**	**2.35**	**2.63**
Std deviation	**1.06**	**1.15**	**0.99**	**0.99**	**0.83**	**1.04**

NB: Site codes as given in Table 3.1; Numbers in the parenthesis refers percentage of households growing 1 to 6 landraces per farm.

The overall proportions of farms growing different number of landraces per individual farm also varied widely. From a total of 272 individual households; 26 (10%) cultivated only one variety, 109 (40%) grew two varieties and 95 (35%) grew three varieties. Farmers that cultivate more than three cultivars per farm represent 15% of the total (Table 3.4). This is less than even half of the 35% households cultivating three cultivars per farm. Therefore, majority of the households had less than four cultivars per farm and in fact households that grew two to three cultivars were the most frequent (75% of the interviewees). Although there were some slight variations; the same general trends were observed by Tamiru et al. (2008a) in southern Ethiopia.

3.3.4. Compositional Similarity at district and Kebele level

The similarities between districts with regard to composition of named landraces were measured using Sorenson's similarity index. The overall compositional similarities of landraces between two districts varied from 0.19 to 0.77. Semen Bench and Debub bench districts located in Bench-Sheko zone were the most similar districts (77%), followed by Yeki and Sheko (58%) districts of the same zone. Guraferda and Debub-Bench were the most dissimilar districts (19%) followed by Guraferda and Sheko (Table 3.5). Regarding the compositional similarity of districts, both the most similar and dissimilar pairs of districts were among those located relatively in close proximity. This suggested that similarity of districts mainly correspond to the ethnic memberships. Most of the farmers in Semen-Bench and Debub-Bench districts belong to Bench ethnic group, while most farmers in Yeki and Sheko districts are Sheko ethnic groups. This result is in contrast to those reported by Tamiru et al. (2008a), according to which the most dissimilar pairs of districts in Wolaita and Gamo-Gofa zones were among those located relatively farther apart. In our study, on average, 35% (± 0.18) landrace similarity was observed among the districts also suggested that similarity of districts partly due to exchange of planting material. It has been reported that other social groups in Southern Ethiopia carried out similar informal seed exchange on yam and other clonal crops. For instance, Tamiru et al. (2008a) reported that on average 46% of yam clones were shared among the districts in Wolaita and Gomo-Gofa areas.

The similarity indices of landraces at Kebele level ranged from 0.00 to 1.00 (Table 3.5). Otowa Chole (5a) and Berji (5b) Kebeles in Guraferda district were the most similar Kebeles (100%) whereas Gortinamag (4a) Kebele in Semen Bench and Gaizeka (4b) Kebele in Sheko districts were the most dissimilar Kebeles (0%). All the other value of the similarity indices varied in between the two.

The most dissimilar pairs of Kebeles were among those located between districts than those located within districts, suggesting that cultivar exchange is preferably extensive and widespread between Kebeles within the district. This is evident in a very high mean compositional similarity of landraces between Kebeles within districts (0.79 ± 0.04), with individual average ranges from 0.62 to 0.95. The most similar Kebeles such as Otowa Chole (*5a*) and Berji (*5b*) (100%), Kuja (*5c*) with Otowa Chole and Berji (91%) were located in Guraferda district, followed by 89% similarity in Zinki (*1a*) and Hibret Fre (*1b*) Kebeles of Sheko district (Table 3.5). Compositional similarity of landraces in these Kebeles may partly correspond to the ethnic groupings. Most of the farmers in Kebeles (*5a, b and c*) belong to Me'enit ethnic group whereas those in Kebeles (1a and b) belong to Sheko ethnic group.

On the other hand, about 46% of landraces found in one Kebele were also found in the other Kebele among the district, indicates the informal seed diffusion system is not only confined to between Kebeles within districts, but also extends to some distant Kebeles among the district. This finding comparatively agrees with the result of Sisay (2008), who reported that on average 55% of the yam landraces were shared among locations in Bench-Sheko Zone. Bizuayehu and Ludders (2003) also reported that 52% of the enset clones were shared among locations in Sidama area.

Table 3.5: Sorenson similarity estimates of yam landrace diversity between the different districts and between the Kebeles within and among the district in Bench-Sheko and Sheka Zones, Southwestern Ethiopia

Sites	*Yeki*			*Sheko*			*D/Bench*			*S/Bench*			*Guraferda*			b/n Kebeles among dist.	Between districts
	1a	*1b*	*1c*	*2a*	*2b*	*2c*	*3a*	*3b*	*3c*	*4a*	*4b*	*4c*	*5a*	*5b*	*5c*		
Yeki					**0.58**			**0.24**			**0.38**			**0.37**			**0.39 ± 0.14**
1a		**0.89**	**0.87**	0.67	0.67	0.62	0.27	0.29	0.37	0.29	0.32	0.35	0.43	0.43	0.40	0.49 ± 0.21	
1b	**0.89**		**0.87**	0.57	0.67	0.62	0.27	0.29	0.37	0.19	0.32	0.35	0.43	0.43	0.40	0.47 ± 0.22	
1c	**0.87**	**0.87**		0.53	0.62	0.57	0.30	0.32	0.43	0.21	0.32	0.40	0.50	0.50	0.46	0.49 ± 0.20	
Sheko		**0.58**						**0.21**			**0.27**			**0.20**			**0.32 ± 0.18**
2a	0.67	0.57	0.53		**0.67**	**0.74**	0.24	0.25	0.32	0.08	0.18	0.30	0.35	0.35	0.33	0.40 ± 0.20	
2b	0.67	0.67	0.62	**0.67**		**0.75**	0.27	0.29	0.37	0.09	0.21	0.35	0.43	0.43	0.40	0.44 ± 0.20	
2c	0.62	0.62	0.57	**0.74**	**0.75**		0.20	0.21	0.29	0.00	0.23	0.27	0.50	0.50	0.46	0.43 ± 0.23	
D/Bench		**0.24**			**0.21**						**0.77**			**0.19**			**0.36 ± 0.28**
3a	0.27	0.27	0.30	0.24	0.27	0.20		**0.80**	**0.70**	0.72	0.69	0.76	0.33	0.33	0.31	0.44 ± 0.23	
3b	0.29	0.29	0.32	0.25	0.29	0.21	**0.80**		**0.74**	0.58	0.64	0.80	0.35	0.35	0.33	0.45 ± 0.22	
3c	0.37	0.37	0.43	0.32	0.37	0.29	**0.70**	**0.74**		0.53	0.71	0.93	0.50	0.50	0.46	0.52 ± 0.19	
S/Bench		**0.38**			**0.27**			**0.77**						**0.27**			**0.42 ± 0.24**
4a	0.29	0.19	0.21	0.08	0.09	**0.00**	0.72	0.58	0.53		**0.64**	**0.60**	0.23	0.23	0.23	0.33 ± 0.23	
4b	0.32	0.21	0.25	0.18	0.21	0.23	0.69	0.64	0.71	**0.64**		**0.77**	0.40	0.40	0.37	0.43 ± 0.21	
4c	0.35	0.35	0.40	0.30	0.35	0.27	0.76	0.80	0.93	**0.60**	**0.77**		0.46	0.46	0.43	0.52 ± 0.21	
Guraferda		**0.37**			**0.20**			**0.19**			**0.27**						**0.26 ± 0.08**
5a	0.43	0.43	0.50	0.35	0.43	0.50	0.33	0.35	0.50	0.23	0.40	0.46		**1**	**0.91**	0.49 ± 0.21	
5b	0.43	0.43	0.50	0.35	0.43	0.50	0.33	0.35	0.50	0.23	0.40	0.46	**1**		**0.91**	0.49 ± 0.21	
5c	0.40	0.40	0.46	0.33	0.40	0.46	0.31	0.33	0.46	0.23	0.37	0.43	**0.91**	**0.91**		0.46 ± 0.20	
																0.46 ± 0.21	**0.35 ± 0.18**
B/n Kebeles	**0.88**	**0.88**	**0.87**	**0.70**	**0.71**	**0.74**	**0.75**	**0.77**	**0.72**	**0.62**	**0.70**	**0.68**	**0.95**	**0.95**	**0.91**	**0.79 ± 0.04**	
w/n districts		**0.88**			**0.72**			**0.75**			**0.67**			**0.94**			

NB: Site codes as given in Table 3.1.

3.3.5. Distribution and Abundance of landraces

Large differences were evident between cultivated yam landraces in their distribution across the sites surveyed. Of the 34 landraces, 17 (50%) had a narrow distribution and were specific to one districts while 12 (35%) were distributed in two districts. Landraces recorded in more than two districts represent 15% of the total. From this, two (6%) landraces namely, *Ongubay* (*Baday*) and *Ama-Tsanseb* (*Tiab-Oake*) were found in the entire districts surveyed (Fig. 3.1A). A similar general trend was also apparent with regard to the relative abundance of landraces. A small numbers of more abundant landraces are growing across the districts. For instance, *Ongubay* (*Baday, Badach*) and *Ama-tsaa'nseb* (*Tiab oake*) were recorded in 50% and 23% of the farms surveyed, respectively (Fig. 3.1B). Some narrowly distributed landraces had high local abundance at few sites and disappeared virtually from the rest. For instance, *Kachi-Tsaa'nseb* (*Tsano, Dizzu-Kachi*) and *Tsidboy* were ubiquitous at two districts, but had high local abundances. This indicates that the production efforts of many households are concentrated on a few numbers of selected cultivars.

According to the farmers, these landraces assemble almost all the desirable agronomic traits such as high yielding ability, tolerance to drought and pests, earliness to maturity and double harvest characters. The most ubiquitous landraces may be harvested as early as June, providing an opportunity to the farmer to safeguard food shortage at the time food deficit. Additionally, small individual tubers (mini sets) will be produced following first harvest and are ready to second harvest by late September and/or early October. This character of the landraces gives an option to the farmer to use the mini sets as an alternative source of planting material.

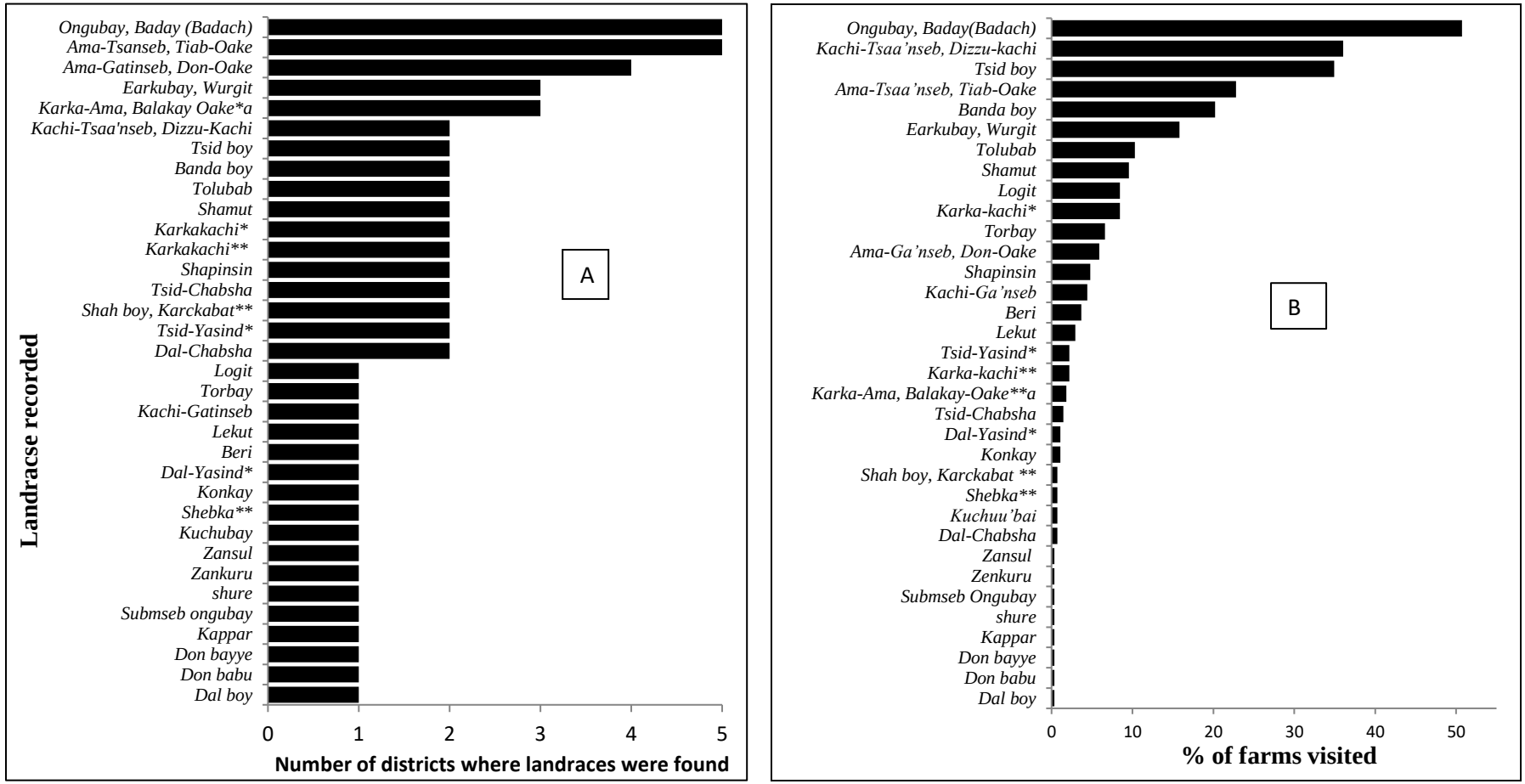

Fig. 3.1. Distribution (A) of landraces across districts and relative abundance (B) of landraces recorded all over the 272 farms of Sheka and Bench-Sheko Zones, Southwestern Ethiopia.

District level distribution was positively and very highly significantly correlated (r = 0.62***) with local abundance (Annex 3.4), such that few wide spread landraces occurred more frequently. Similar results were reported by Tamiru et al. (2008a) in Gamo-Gofa and Wolaita zones of Southern Ethiopia for yam where ubiquitous landrace were found as the most abundant. Similar observations were also made for other clonal crops such as enset (Bizuayehu and Ludders, 2003) and cassava (Kombo et al., 2012). Bizuayehu and Ludders (2003) reported that a small number of highly abundant enset clones are widely distributed throughout Sidama Zone of Southern Ethiopia.

The distribution of the cultivars varied across the Kebeles surveyed. Of the 34 landraces, 11 (32%) had a narrow distribution and were specific to one Kebele whereas 23 (68%) were recorded at more than one Kebele. Only a small numbers of widespread landraces are growing in most of the Kebeles surveyed. Of the landraces that were found at more than one Kebele, *Ongubay* (*Baday, Badach*) and *Ama-Tsaa'nseb* (*Tiab-Oake; Wakach*) were recorded in fourteen of the fifteen Kebeles. Other widespread landraces include *Ama-Ga'nseb* (*Don-Oake*) and *Erkubay* (*Wurgit*) and were recorded in ten and seven Kebeles, respectively (Fig. 3.2). Kebele distribution was positively and very highly significantly correlated (r = 0.76***) with local abundance (Annex 3.4), such that more widespread landraces were also typically more abundant. In Southwest Ethiopia, Sisay (2008) reported that a small number of highly abundant landraces are widely distributed throughout Debub and Semen Bench districts of Bench-Sheko Zone.

Using Brown's (1978) scheme, yam landraces have been grouped into two distinct categories on the basis of their distribution and abundance (Table 3.6). As is evident from this study, 7 (21%) of the landraces are occurring with frequency greater than 10% while all others are never occurring with frequency greater than 10%. Localized and widespread

rare landraces make up a substantial fraction of the distribution range at district and Kebele levels, respectively. The unequal distribution and rare abundance of landraces provides strong evidence for the selection effort by farmers. Similar observations have been made with traditional management of enset clone in Sidama Zone, Southern Ethiopia (Bizuayehu and Ludders, 2003).

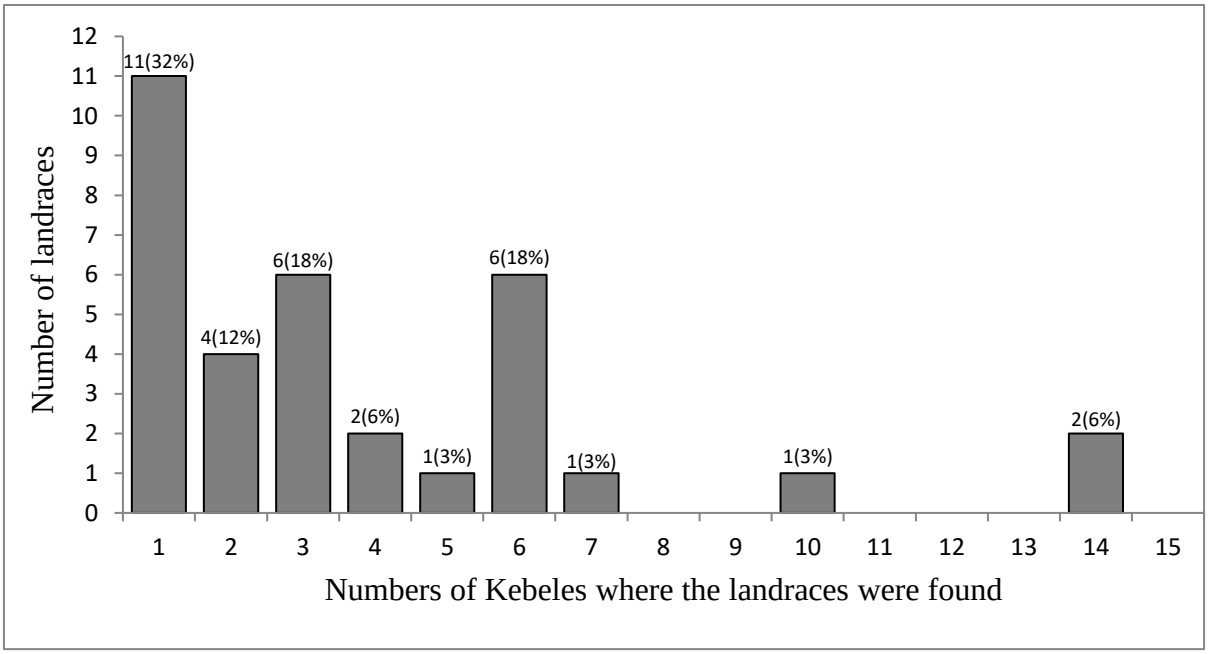

Fig. 3.2. Distribution range of yam landraces across the surveyed Kebeles in Bench-Sheko and Sheka Zones, Southwestern Ethiopia

Table 3.6. Classification of yam landraces based on distribution range and population size.

Category	Category Index	**Number of landraces**	
		Districts	Kebeles
Common	**Occurring with frequency > 10%**		
Widespread	Distributed at > 2 sites	3	7
Sporadic	Distributed at 2 sites	4	0
Rare	**Never occurring with frequency > 10%**		
Widespread	Distributed at > 2 sites	2	12
Sporadic	Distributed at 2 sites	8	4
Localized	Specific to only one site	17	11
Total		34	34

Farmers also verbally reported 32 landrace names that were no longer found in their community. Some of the reported vernacular names were corresponded to those landraces encountered on some farms while 56% of them were never encountered in the farms of sampled households or not listed in farms of unsampled households. This finding agrees markedly with that of Hildebrand (2003), who reported a serious genetic erosion of native yam types in Sheko area. Similar results were also evident in Bench areas of Bench-Sheko zone, Southwestern Ethiopia (Sisay, 2008). Other social groups in Southern Ethiopia reported 46 landrace names that were no longer found in their area and 41% of them were never encountered on farmers' fields during the survey (Tamiru et al., 2008a).

3.3.6. Farmer's management of yam diversity

3.3.6.1. Trends of landrace maintenance

The numbers of cultivars maintained by farmers in the study area are tending to decline. From the total individual interviewees, 79% of the respondents said the trend is decreasing and in fact in most localities the existing landraces are even undergoing serious erosion (Table 3.7). This is also reflected in large numbers of vernacular names of yams reported by farmers that were no longer found in their community currently. According to the farmers, landraces maintained by many households are those that assemble almost all the desirable agronomic characteristics (high yield, earliness to maturity and tolerance to drought, pest and diseases) and food values (tuber quality in terms of palatability). Other factors such as economic value (market demand), availability of planting material and the ability to store are the other important factors determining the landraces to be maintained on individual farms. The trends of landrace maintenance were inconsistent throughout the district and in fact most farmers were relied on few selected landraces, reflecting the relative importance of these landraces and provide strong evidence to farmers' selection

effort. Similar results were reported on yam by Tamiru et al. (2008a) in Gamo-Gofa and Wolaita zones of Southern Ethiopia. Similar observations were also made on cassava by Kombo et al. (2012) in the South of the Republic of Congo.

3.3.6.2. Type and source of seed tubers

The types of planting materials for propagating yams include the true botanical seeds and seed tubers. True botanical seeds were not directly used as a planting material but its use may occur indirectly through volunteer seedlings. Such volunteer seedlings are common in most gardens and in some cases farmers may adopt them as cultivated plants. The most common type of planting materials used in the studied areas was the seed tubers. The seed tubers used for propagation varies with the type of landraces to be grown. In case of late maturing landraces, farmers retained the proximal end of the tuber during harvesting. Then this tuber is used as planting material either as a whole piece or by dividing it into smaller pieces. According to those who use the entire pieces, the practice allows better yield. In double-harvested landraces, each mini sets - small individual tubers produced following first harvest - can serve as an ideal planting material. But there are still some farmers who did not ignore the use of whole tubers as propagation material. These farmers also explained the same contrast that it allows them better yield.

The sources of planting material are diverse and included own saved, exchange with neighbors or relatives and to a lesser extent, purchases from local markets. Majority of the farmers (83%) depend on own saved seed tubers while others (14%) acquire it through exchanges with neighbors or relatives. Only few farmers (3%) obtain seed tubers through purchases from markets (Table 3.7). There is no formal seed system for yam in Bench-Sheko and Sheka Zone or in Ethiopia at large. Other social groups in Gamo-Gofa and Wolaita zones, southern Ethiopia and East Wollega and Ilu Ababora zones of Western

Ethiopia (Tamiru et al., 2008a; Yeshitila and Temesgen, 2016) relied on their own planting-materials saved from the previous cropping season.

Table 3.7. Sources of planting-materials and trends in the number of landraces maintained by farmers in Bench-Sheko and Sheka Zones, Southwestern Ethiopia

Districts	Sources of planting materials			Trends of landrace maintenance		
	Own	Neighbors	Market	Increasing	Decreasing	No change
I	53 (93)	4 (7)	0 (0)	1 (2)	50 (88)	6 (10)
II	50 (85)	7 (12)	2 (3)	4 (7)	51 (86)	4 (7)
III	42 (86)	6 (12)	2 (4)	4 (8)	35 (70)	11 (22)
IV	44 (68)	17 (26)	4 (6)	3 (5)	48 (74)	14 (21)
V	36 (88)	5 (12)	0 (0)	1 (2)	32 (78)	8 (20)
Total	**225 (83)**	**39 (14)**	**8 (3)**	**13 (5)**	**216 (79)**	**43 (16)**

NB: Site codes as given in Table 3.1; Numbers in parenthesis refer to percentage values based on the number of farmers interviewed in each district

Despite the high percentage of farmers who used own saved tubers compared to those who depend on exchange with neighbors and markets, the local seed system is a key for maintaining yam diversity. This is evident from the large number of vernacular names recorded in this study and the relatively high compositional similarity values at district and Kebele levels. In this regard, on average, 79% of landraces found in one Kebele were also found in the other Kebeles within the same district (Table 3.5). This confirms that acquisition of seed tubers from neighbors between the same ethnic groups (Kebeles within the district) happens when their neighbors have new cultivars that they would also like to try. On the other hand, the average similarity of districts was 35% indicating that exchange of cultivars between districts does not necessarily imply all the times new cultivars rather some selected landraces could just be circulating among districts (Table 3.5). Targeting the local seed system should thus be a key aspect of yam improvement program.

3.3.6.3. Time of planting

Time of planting in Bench-Sheko and its neighboring zone begins in late October and continued until early February. Majority of the farmers (44%) carried out planting in November. A significant proportion of the farmers (22%) also carried out planting either in early or late November. However, few farmers (5%) delayed planting until late January or early February (Fig. 3.3). A similar practice of time of planting for yam was reported in Sheko, Semen-Bench, Debub-Bench and Sheko districts in Bench-Sheko Zones of southwest Ethiopia (Hildebrand, 2003; Sisay, 2008). Time of planting we reported here is also comparable with the planting time reported in Gamo-Gofa and Wolaita Zones of southern Ethiopia. Famers there begin planting in October and continued until January (Tamiru et al., 2008a).

Yams are planted either in a shady plot beneath large trees or in an open field on ridges along rows of stakes. The wild transplant yams known by the name *Karka-kachi* in Sheko and *Yasind (Dal-Yasind and Tsid-Yasind)* in Bench are grown beneath a large tree. Unlike the cultivated landraces that were replanted in an annual cycle, this group of yams is left in the same place for many years. The aerial and some cultivated underground yams (*Torbay, Chabsha* varieties and *Tolubab*) are also grown beneath a large tree. Such planting method would allow a gene flow between cultivated and wild yams. Genes from wild plants may enter into the cultivated populations through wild transplantations. This occurs if female wild transplants are fertilized with pollen from the nearby cultivated male parents. For many authors, the wild transplant yams are wild yams, because farmers collect them from non-cultivated areas to transplant them into their garden (Dumont and Vernier, 2000; Hildebrand, 2003; Mignouna and Dansi, 2003; Scarcelli et al., 2006a). The vast majority of cultivated landraces however, are planted in an open field on ridges along a row of stakes

within an annual cycle of transplanting. In most farms, the early and late maturing cultivated landraces are planted separately to make harvesting easier.

Planting arrangement also varies across the sites surveyed. In Sheko district, a typical row of stakes are nearly 20 m long and contain 40-70 individual plants. Each row is usually positioned at about 1 to 2 m apart. According to farmers, this practice has an immense importance for management practices when intercropped with other species. In all the other districts however, plants are arranged in more densely manner. Both inter and intra row spacing varied widely but with most of the individual plants is usually arranged at a spacing of 50-100 cm between rows and 15-30 cm between plants. Hilderbrand (2003) reported similar ways of planting pattern of yams in Sheko districts of Southwest Ethiopia. Most farmers' plant yam intercropped with other crops such as maize, haricot bean, cabbage, sweet potato, cassava and beet root. However, there were also few farmers who plant yams separately as rows of hedges. Other social groups in Gamo-Gofa and Wolaita Zones of southern Ethiopia have adopted similar cropping system (Tamiru et al., 2008a). The crops planted with yams in these areas, included maize, sweet potato, cabbage, beans and to a lesser extent, coffee. Similar reports are also evident in East Wollega and Ilu Ababora Zones of western Ethiopia (Yeshitila and Temesgen, 2016).

Farmers consider weeds as an important problem for about three to four months after planting and hence, most farmers employ frequent weeding. Some farmers in Sheko and Yeki area reported nematodes, beetles and termites as a production constraint of cultivated yams. Pig and porcupine are also mentioned as a pest of both cultivated and wild yam. Significant pest control methods were not employed at both districts. However, some Sheko farmers undertook cultural practices such as smoking of cow dung to control hedgehog and putting ash in the soil to control termites. In earlier works, pests such as

beetles, porcupines, red ants, pigs, termites and small ants has been reported as a major threat of yam production in Bench-Sheko Zone (Sisay, 2008). Yeshitila and Temesgen (2016) also reported wild animals as a pest of yam in East Wollega and Ilu Ababora Zones of western Ethiopia.

3.3.6.4. Harvesting and Storage of yams

Farmers in the study area carried out both single and double harvest practices. The early maturing landraces are harvested twice. Timing of first harvest in double harvest landrace mainly depends on the time of planting together with phenological signals including senescence of inflorescence and wilting of vine tips. The late-maturing landraces however, are harvested only once at full senescence of vines. Wild growing yams and adoptive transplants were among the single harvest landraces which are harvested from September to February. Some late maturing cultivated landraces such as *Torbay, Chabsha* varieties and *Tolubab* also follow this pattern.

Others are early maturing and double harvest landraces are harvested twice a year. Some early maturing landraces including *Don* Varieties, *Kachi-Tsano* and *Tsid boy* may be harvested as early as June and ready to second harvest by late September and/or early October. These landraces also remain available until late November. All the other early maturing landraces are ready to first harvest by late June or early July and remain available until late November (Fig. 3.3). But, in some districts farmers bypass first harvest in double harvest landraces to maximize yield and improve palatability. In this regard, Tamiru et al. (2008a) reported a similar result in Southern Ethiopia, where early maturing landraces planted in October; first harvest begins in May or June. Yeshitila and Temesgen (2016) also reported that first harvest in East Wollega and Ilu Ababora Zones of western Ethiopia takes place in July followed by second harvest in December.

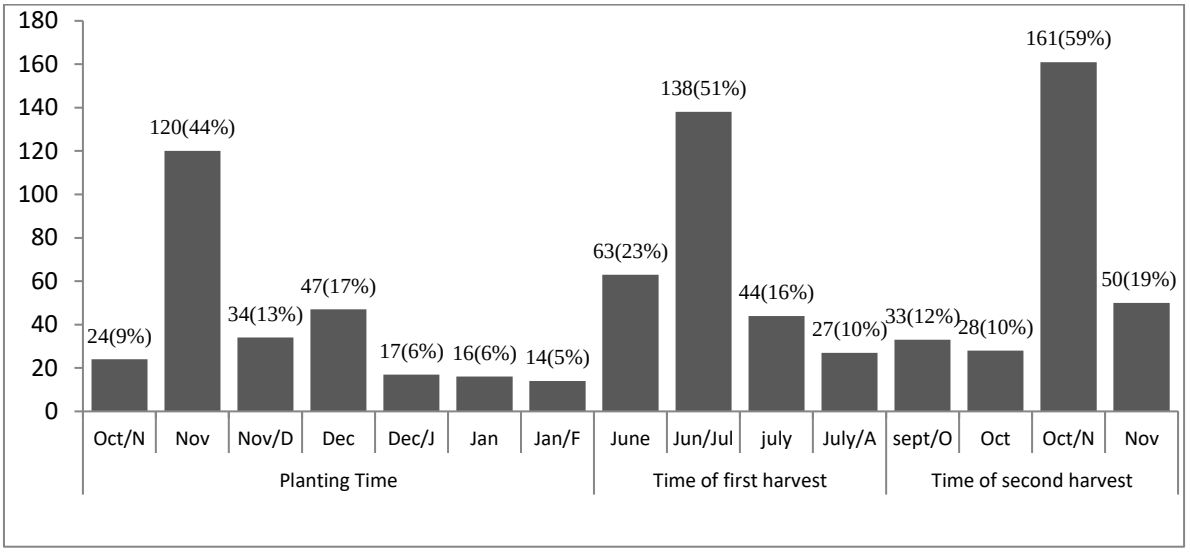

Fig. 3.3: Variations in time of planting and harvesting in Bench-Sheko and Sheka Zones.

Most farmers responded that yams can be stored for 2-4 months either using shade outside their home, or stored in home. However, there were also some farmers who stored yams up to 5 month. Farmers usually stored yams on a bed prepared from cereal stalks at a cool place as a separate small outdoor storage. This is a common method for storing yams to be used for consumption purpose. Farmers also stored yams under shade covered with enset leaves or cereal straws. This is a common method for storing yam tubers to be used as a propagation material. The storage site may be changed from this place to pit storage when it is required to initiate sprout on the tuber.

During pit storage, the seed tubers are lightly covered with soil in shady plot through the late dry season. The seed tubers then start to initiate sprouts on the tuber or may produce shoots that may attain a length of 1 meter. Then the sprouted tubers were transplanted to the open field during the onset of small rains. The ability of yam tubers to be stored for longer period without deterioration is considered by farmers as a good attribute since it allows them to manage the harsh ecological conditions and also permits propagules to survive a prolonged dry season. Sisay (2008) reported the use of similar storage patterns on yam in Bench-Sheko Zone, SW Ethiopia.

3.4. CONCLUSION

Wide ranges of yam landraces were recorded in Bench-Sheko and Sheko Zones of Southwestern Ethiopia. This suggested that yams have long been key components of local subsistence. However, the richness and distribution of landraces were varied widely across the surveyed sites. A small number of highly abundant landraces are growing throughout the surveyed sites whereas the greater numbers of landraces had a narrow and unequal distribution and rare abundances. For this reason, the greatest numbers of indigenous yam types are undergoing serious genetic erosion. This leads to the necessity for their collection and conservation to avoid their total loss. It is also notable that this ethnobotanical survey represents only a small part of the rural population engaged in yam cultivation. However, this work showed that yam cultivation activity is of great importance to the subsistence farmers. Thus, more detailed diversity studies should be needed in these and other areas to develop strong yam database in the nation.

Results of this study also revealed that those of the far southwest Ethiopian farmers have maintained high levels of yam genetic diversity. In the majority of the localities surveyed, it has been observed that some farmers were very conscious with regard to the maintenance of diversity through continual growing of landraces. Farmers' decisions of maintenance were related to the agronomic, economic and food values of these landraces. Earliness to maturity, tuber quality, resistance to drought and pest and the possibility to store are among the important reasons determining the on-farm maintenance by farmers. Thus, the agronomic, economic and environmental factors that influence the associated management practices are needed to be studied to enhance sustainable maintenance of yam genetic diversity in Bench-Sheko and Sheka Zone of Southwest Ethiopia and in Ethiopia at large.

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CHAPTER 4

4. Diversity of Cultivated and Wild Yams (*Dioscorea* spp.) from South and Southwestern Ethiopia based on Agro-Morphological traits

ABSTRACT

This study was done with the objective to investigate the diversity of wild and cultivated yams based on agro-morphological traits. The variability obtained in morphological study was also compared with the local classification system. A total of 75 accessions were assessed in this study and were grown in a randomized complete block design with two replications by the year 2018 at Hawassa University research field. We have assessed 50 agro-morphological traits (37 qualitative and 13 quantitative) which were subjected to multivariate analysis. The PCA showed that all the traits used were useful for capturing the variability among accessions, but 21 traits (17 qualitative and 4 quantitative) were useful for capturing the variability among species. All the other traits were useful for capturing the variability among accessions of the same and different species. The cluster study separated the 75 accessions into four major clusters based on qualitative traits and into five major clusters based quantitative traits. The discriminatory traits detected in PCA were also useful to separate accessions into distinct clusters. The study indicates that the local classification corresponds well with the morphological variability. Yet, some landraces which farmers regarded as different have been classified together and no clear morphological variations were observed among them. Few landraces known by the same vernacular names were also morphologically distinct. This study showed the existence of a wide range of morphological variability among the accessions studied, which could be exploited if improvement need arises. But, concerning the taxonomic status of the member species within the D. cayenensis *complex, many questions remain confusing, and should need to be solved with DNA based studies.*

Key words: Accession, Agro-morphological traits, *Dioscorea* species, Diversity, Yam

4.1. INTRODUCTION

Morphological diversity study in crop plants is essential to define the morphological descriptors for the characterization and management of genetic resources (Beyerlein and Pereira, 2018). About 152 plant descriptors list (IPGRI/IITA, 1997) have been reported for characterizing yam species. Attempts have been made to use these descriptors in assessing the genetic diversity among *Dioscorea* species (Mwirigi et al., 2009; Bressan et al., 2011; Norman et al., 2011; Nascimento et al., 2015). Bressan et al. (2011) used 24 descriptors to study the variation in 35 *D. alata* cultivars and concluding that 67% of the morphological characters used were discriminatory. Norman et al. (2011) used 28 characters to assess diversity of yam among 52 genotypes from Sierra Leone and reported that all the 28 traits contributed towards phenotypic variability, indicating high degree of morphological polymorphism within the accessions of *Dioscorea* species studied. Tamiru et al. (2011) assessed morphological diversity of yams among 84 accessions in Southern Ethiopia and identified considerable discriminatory morphological markers. Wendawek (2008) also studied the genetic diversity of wild and cultivated yams in southwest Ethiopia using 27 morphological traits and reported that the first 23 traits account for 100% of the observed variation between the accessions.

Surveys carried out in different parts of Ethiopia (Hildebrand, 2003; Tamiru et al., 2008a; Sisay, 2008; Tewodros, 2016; Tsegaye et al., 2021a) have showed the existence of a considerable number of vernacular names. In these surveys, altogether about 134 non-synonymous yam landraces have been reported from at least eight ethnic groups. Each linguistic group has its own set of unique names for different landraces. Such linguistic polymorphism may lead to biased estimate landrace diversity that is present a given area. Thus, it is necessary to define the specific or common characteristics of landraces. The morphological description is important for the differentiation of landraces with similar

characteristics and also vital for subsequent genetic and evolutionary studies. Attempts have been made to study local classification systems in relation to marker assisted studies. Studies in Woliata and Gamo-Gofa areas of southern Ethiopia have found that folk taxonomy corresponds well with the morphological diversity study (Tamiru et al., 2011). In Brazil, Bressan et al. (2011) demonstrated that 70% of the morphological variability was also found within household cultivars. Studies in Andean oca found that folk taxonomy corresponds well with molecular data, but provide a net underestimate of genotypic diversity (Emshwiller, 2006). Other studies in cassava demonstrated that most of the variability that was observed with marker assisted studies was also found within household landraces (Sambatti et al., 2000; Elias et al., 2001a, b).

Accurate passport and characterization data are highly required to develop core collections and for further utilization in crop improvement programs. The characterization data consist of information on agromorphological characters recorded following internationally standardized morphological descriptors. In Benin, Dansi et al. (1999) was also able to use agromorphological variation to identify the patterns of variations among the yam landraces. In Ethiopia, the Ethiopian Biodiversity Institute has been established about 114 accessions at Choche field gene bank. However, the institute didn't characterize the collection and the passport data for most of the accessions are incomplete and duplicates are yet to be eliminated. An effort is underway by this study to use molecular marker to identify duplicates in the collection. This effort forms part of our initial project initiated with the main objective of characterizing diversity of yams in Ethiopia.

So far no sound agromorphological characterization of yams has been done in Southwest Ethiopia to examine whether the locally named landraces represent the actual diversity. Most of the earlier studies were limited to either few phenotypic markers provided by

farmers (Sisay, 2008) or researchers (Wendawek, 2008). Such scenario would substantially underestimate the genetic diversity present in these areas and in fact a great variability is evident in many of morphometric traits. Morphological diversity analysis of yams with numerous morphometric traits is expected to contribute towards diversity study, by facilitating preface characterization. Thus, this research was conducted to address the following objectives: (i) to investigate the diversity of cultivated and wild yams in South and Southwest Ethiopia based on morphological traits, (ii) to determine the most discriminatory traits that are used to capture the variability among the studied accessions and (iii) to establish links between morphological diversity and locally perceived biota.

4.2. MATERIALS AND METHODS

4.2.1. Agro-morphological characterization

4.2.1.1. Composition of accessions and Sampling location

A total of 75 individuals, consisting of 5 wild, 5 wild transplant and 65 cultivated yam accessions were considered for this study. Sixty of the 75 accessions were collected from different districts in Kaffa, Bench-Sheko and Sheka Zones of Southwest Ethiopia while the remaining constitute previously collected yam accessions from Basketo, Gamo-Gofa and Wolaita districts of Southern Ethiopia. The distinct contexts are described as follows.

Wild yams are morphologically related to some domestic yams but unlike domestic yams, they have not been domesticated yet and exist in wild contexts. Wild growing yams are found in relatively undisturbed forest, secondary forest, fallow lands, and ravines or stream banks with disturbed vegetation. They have no known history of human husbandry, although it is possible that they are feral or have genetic material derived from nearby populations of cultivated yams. Many gardens contain a few yams that seem on the state of transition, yams transplanted from wild contexts where many of them had no known

history of cultivation. They are usually grown in gardens beneath tree. Unlike the domestic yams that are replanted in an annual cycle, they left in the same place for many years. Hence, they qualify as yams under domestication, and not just as yams under cultivation. We therefore designate them as '*wild transplants*' to differentiate it from wild and domestic yams.

Cultivated yams, in contrast, have a long history of cultivation and propagation in gardens by humans. They are usually grown in small plots of open field along rows of stakes and are usually replanted in an annual cycle. Some cultivated yams are known to be recently transplanted to small plots of open field (Tsegaye et al., 2021a). Some of these names can also be used interchangeably for group of yams that have been recently transplanted from wild contexts. Farmers relate certain wild, wild transplant and cultivated varieties to one another. They are also capable of reporting both specific and general patterns of adoptive transplantation. If the wild transplant proves to resemble a cultivated variety, farmers may give it the cultivated variety name a few years after transplantation. Accessions from Southwest Ethiopia were collected during the period from 23 to 25 Nov., 2017 while the accessions from Southern Ethiopia were obtained from the maintained samples at Hawassa University research field. During sampling, the tubers were either directly harvested from farmers' field, or chosen when they were stored, with four to five tubers from a single plant were sampled per accessions. The local name, the species identity, altitude and geographic coordinates of the accessions considered in this study are presented in Table 4.1.

Table 4.1. List of local names and geographic origin of yam accessions considered for agro-morphological study

Scientific name	Accessions assessed			Origin	Alt (masl)	Geographic coordinates	
	Accession codes		Local names			Latitude (N)	Longitude (E)
D. cayenensis complex	1	BMJ 001	*Karka-Kachi**	Sheko	1473	7º2'21.16''	35º31'10.35''
	2	BMJ 002	*Karka-Kachi**		1696	7º2'34.05''	35º31'10.65''
	3	BMJ 003	*Karka-Kachi***		1300	7º2.435'	35º33.452'
	4	BMJ 004	*Karka-Kachi**		1677	7º2.435'	35º31.180'
	5	BMJ 005	*Karka-Kachi**		1680	7º2.358'	35º31.147'
	6	BMJ 006	*Karka-Kachi***		1266	7º1.179'	35º33.498'
	7	BMJ 007	*Yasind**	S/Bench	2083	7º4'40.25''	35º42'34.79''
	8	BMJ 008	*Beri*	Sheko	1645	7º2'18.30''	35º31'10.29''
	9	BMJ 009	*Torbay*		1645	7º2'18.30''	35º31'10.29''
D. alata	10	BMJ010a	*Ongubay*		1696	7º2'18.30''	35º31'10.29''
	11	BMJ 010b	*Ongubay*		1696	7º2'18.30''	35º31'10.29''
	12	BMJ 011	*Ongubay*		1296	7º2'34.05''	35º31'10.65''
D. cayenensis complex	13	BMJ 012	*Kachi-Tsano*		1680	7º2.358'	35º31.147'
	14	BMJ 013	*Dizzu Kachi*		1296	7º2'34.05''	35º31'10.65''
	15	BMJ 014a	*Kachi-Tsano*		1673	7º2'21.16''	35º31'10.35''
	16	BMJ 014b	*Kachi-Tsano*		1673	7º2'21.16''	35º31'10.35''
	17	BMJ 015	*Kachi-Tsano*		1696	7º2'34.05''	35º31'10.65''
D. alata	18	BMJ 016	*Ongubay*		1696	7º2'34.05''	35º31'10.65''
D. bulbifera	19	BMJ 017	*Ama*		1296	7º2'34.05''	35º31'10.65''
D. cayenensis complex	20	BMJ 018	*Beri*		1645	7º2'18.30''	35º31'10.29''
	21	BMJ 019	*Dal boy*	D/Bench	1399	6º49'51.71''	35º29'10.23''
	22	BMJ 020	*Shapinsin*		1380	6º49'47.39''	35º29'17.20''
	23	BMJ 021	*Tsid boy*		1380	6º49'47.39''	35º29'17.00''
	24	BMJ 022a	*Tsid boy*	S/Bench	1855	7º3'58.84''	35º40'2.59''
	25	BMJ 022b	*Tsid boy*		1855	7º3'58.84''	35º40'2.59''
	26	BMJ 023	*Tsid boy*		1810	7º4.104'	35º39.825'
	27	BMJ 024	*Chabsha*		1857	7º4'00.36''	35º40'4.26''
	28	BMJ 025a	*Banda boy*	D/Bench	1383	6º49'46.30''	35º29'07.96''
	29	BMJ 025b	*Banda boy*		1383	6º49'46.30''	35º29'07.96''
	30	BMJ 026	*Banda boy*		1400	6º49'56.16''	35º29'15.19''
	31	BMJ 027	*Tolubab*		1400	6º49'56.16''	35º29'15.19''
	32	BMJ 028a	*Shamut*		1395	6º49'46.32''	35º29'07.96''
	33	BMJ 028b	*Shamut*		1395	6º49'46.32''	35º29'07.96''
	34	BMJ 029	*Tsid boy*		1407	6º49'57.76''	35º29'13.01''
	35	BMJ 030	*Tsid boy*	S/Bench	1706	7º3'58.93''	35º38'38.15''
D. cayenensis complex	36	BMJ 031	*Tsid boy*	D/Bench	1390	6º49'51.07''	35º29'09.26''
	37	BMJ 032	*Banda boy*		1390	6º49'51.07''	35º29'09.26''
	38	BMJ 033a	*Shamut*		1402	6º49'54.95''	35º29'12.34''
	39	BMJ 033b	*Shamut*		1402	6º49'54.95''	35º29'12.34''
	40	BMJ 034a	*Karka-Kachi***	Sheko	1241	7º01.173'	35º33.498'
	41	BMJ 034b	*Karka-Kachi***		1241	7º01.173'	35º33.498'
	42	BMJ 034c	*Karka-Kachi***		1241	7º01.173'	35º33.498'
	43	SHK 001a	*Kachi-Tsaa'nseb*	Yeki	1293	7º12'42.02''	35º22'24.06''
	44	SHK 001b	*Kachi-Tsaa'nseb*		1293	7º12'42.02''	35º22'24.06''
	45	SHK 002	*Kachi-Tsaa'nseb*		1312	7º12'44.45''	35º22'25.06''
	46	SHK 003	*Kachi-Ga'nseb*		1305	7º12'46.05''	35º22'27.51''
	47	SHK 004	*Kachi-Ga'nseb*		1293	7º12'42.02''	35º22'24.06''
D. alata	48	SHK 005	*Baday*		1293	7º12'42.02''	35º22'24.06''
	49	SHK 006	*Baday*		1285	7º12'45.67''	35º22'23.95''

Table 4.1. Continued …….

D. cayenensis complex	50	SHK 007	*Konkay*	Yeki	1152	7o8'39.20''	35o24'12.89''
	51	SHK 008	*Konkay*		1202	7o8'40.20''	35o24'12.89''
	52	SHK 009a	*Kachi-Tsaa'nseb*		1162	7º8'44.88''	35º24'17.00''
	53	SHK 009b	*Kachi-Tsaa'nseb*		1162	7º8'44.88''	35º24'17.00''
	54	SHK 010	*Baidai-kachi*		1278	7º12'45.23''	35º22'26.56''
D. alata	55	SHK 011	*Earkubay*		1278	7º12'42.05''	35º22'24.06''
	56	SHK 012	*Earkubay*		1309	7º12'45.42''	35º22'27.71''
	57	SHK 013	*Baday*		1149	7º8'39.13''	35º24'14.20''
	58	SHK 014	*Baday*		1144	7º8'37.23''	35º24'12.20''
D. cayenensis complex	59	KAF 001	*Ochino*	Gimbo	1961	7º18'31.01''	36º5'10.29''
	60	KAF 002	*Ochino*		1961	7º18'31.01''	36º5'10.29''
	61	BAS 001	*Durndufa*	Basketo	1847	6º19'31.7''	36º38'43.1''
	62	BAS 002	*Afra*		1847	6º19'31.7''	36º38'43.1''
	63	BAS 003	*Durndufa*		1911	6º20'65.3''	36º36'34.8''
	64	BAS 004	*Wolgidae*		1840	6º18'79.7''	37º35'84.2''
	65	BAS 005	*Katayna*		1911	6º20'65.3''	36º36'34.8''
	66	DAR 001	*Oha*	Daramalo	1924	6º17'04.2''	37º19'22.1''
	67	DIT 001	*Ayno*	Dita	2099	6º17'10.5''	37º19'16.5''
	68	BAS 006	*Wolgidae*	Basketo	1840	6º18'79.7''	37º35'84.2''
	69	BAS 007	*Ayna*		1905	6º20'62.7''	36º36'56.3''
	70	DAR 002	*Oha*	Daramalo	2024	6º18'36.0''	37º22'22.1''
	71	DAR 003	*Wodella*		2024	6º18'36.0''	37º22'22.1''
	72	BAS 008	*Wolgidae*	Basketo	1840	6º18'79.7''	37º35'84.2''
	73	BAS 009	*Wat'sayna*		1905	6º20'62.7''	36º36'56.3''
	74	DAR 004	*Oha*	Daramalo	1924	6º17'04.2''	37º19'22.1''
	75	WOL 001	*Wollabo*	B/Sore	1901	7º00'31.5''	37º40'37.6''

* = Wild transplant yams, ** = Wild growing yams, D/Bench = Debub Bench, S/Bench = Semen Bench, B/Sore = Boloso Sore

4.2.1.2. Research design and field planting

All the collected tubers were brought to Hawassa University from 26 to 27 Nov., 2017. The seed tubers were subjected to field storage until field layout preparation. The seed tubers were planted at experimental fields by 05 Jan., 2018 in randomized blocks with two replications. Based on the availability of planting materials, two to three seed tubers were planted in a single row of plots at a spacing of 1.5 m between rows and 1 m between plants. Plots were regularly irrigated to ensure the plant establishment and then, the plots were kept free of weeds throughout the experimental period. Weeding was done with hand hoe and by hand-pulling whenever required. Plants were also protected from pests such as porcupine with guards. Plants were supported by staking material and nearly a 3m long

eucalyptus stakes were used. Aerial vegetative parts were monitored for six months for the period between Feb., to July, 2018. Harvesting was started from 10 Aug., 2018 and continued for three successive months and terminated on 20 Nov., 2018.

4.2.1.3. Data collection procedure

Morphological characterizations were carried out on individual plants in each replication and performed according to the standard procedures previously employed to characterize yams. The most pertinent yam descriptors list were recommended by Martin and Rhodes (1978) and International Plant Genetic Resources Institute (IPGRI) or International Institute of Tropical Agriculture (IITA). In this study, we have used the one suggested by IPGRI/IITA (1997). Data collection procedures were performed in three different stages including establishment, growth and harvest stage. Data on establishment stage was started shortly after emergence which was then regularly monitored throughout the growing period. Data on young stems and leaves were assessed after about 20-30 days from emergence. Data on mature stems and leaves were assessed before senescence while, data on tubers were assessed by harvesting tubers at full senescence. A total of 37 qualitative and 13 quantitative traits were assessed in this study. The measurements made on qualitative traits were transformed into different classes, attributing codes to each class (Table 4.2). To avoid scale differences in the final output all the measurements are standardized by subtracting the mean and by dividing to its respective standard deviation.

Table 4.2. List of agro-morphological characters and the respective codes of each character states

Descriptors and descriptors code (Young plant)		
I	**Qualitative traits**	
1	Stem color, young stem	1= Green, 2 = Brownish green, 3 = Purplish green, 4 = Purple
2	Young stem wing color	1= Green, 2 = Green with purple edge, 3 = Purple, 4 = Green with red edge
3	Spines on young stems	0 = none, 1 = few, 2 = many
4	Colored spot at spine base	0 = Absent, 1= Present
5	Color of young leaves	1= Light green, 2 = Green, 3 = Pale green, 4 = Brownish green, 5 = Purplish green, 6 = Purplish brown, 7 = Purple
6	Petiole color, young leaves	1= Light green, 2 = Pale Green, 3 = Green, 4 = Green with brown base, 5 = Green with purple base, 6 = Green with purple leaf junction, 7 = brownish green, 8 = brownish green with purple base, 9 = Purplish green, 10 = Purplish green with purple base, 11 = Purplish green with purple leaf junction, 12 = Purplish brown, 13 = Purple with purple base, 14 = Purple
7	Petiole wing color, young leaves	0 = None, 1= Light green, 2 = Pale Green, 3 = Green, 4 = Green with purple edge, 5 = Brownish green, 6 = Purplish green, 7 = Purplish brown, 8 = Purple
	Descriptors and descriptors code (mature plant)	
8	Twining direction	1= Clockwise, 2 = Anticlockwise
9	Stem color	1 = Green, 2 = Brownish green, 3 = Purplish green, 4 = Purple
10	Spines at stem base	0 = None, 1 = Very Few, 2 = Very few to few, 3 = Few 4 =
11	Spines at stem above base	Few to intermediate, 5 = Intermediate, 6 = Intermediate to high, 7 = High, 8 = High to very high, 9 = Very High
12	Spine shape	0 = None, 1 = Straight, 2 = Curved
13	Wings on the stem	0 = Absent, 1 = Present
14	Stem wing color	0 = None, 1 = Green, 2 = Green with purple edge, 3 = Purple
15	Leaf position	1 = Alternate, 2 = Opposite, 3 = Alternate at base/ Opposite above
16	Leaf margin color	1 = light green, 2=green
17	Leaf lobation	1= Shallow, 2 = Deep
18	Vein color, US	1 = Yellowish, 2 = Light green, 3 = Pale green, 4 = Green
19	Vein color. LS	1 = Light green, 2 = Green
20	Leaf color	1 = Light green, 2 = Pale green, 3 = Green, 4 = Dark green 5 = Purplish green
21	Leaf Shape	1= Ovate; 2 = Cordate; 3 = Cordate long; 4 = Cordate broad; 5 = Sagittate long; 6 = Sagittate broad; 7 = hastate
22	Distance between lobes	1 = No distance; 5 = Medium; 9 = Very distant
23	Downward arching along MV	0 = Absent, 1 = Present
24	Upward unfolding of leave	0 = None, 1 = Weak, 2 = Strong
25	Leaf tip color	1 = Light green, 2 = Green
26	Petiole color	1= Green, 2 = Green with brown base,3= Green with brown at both ends, 4= Green with purple base, 5= Green with purple leaf junction, 6 = Green with purple at both ends, 7 = Purple green with purple at both ends
27	Petiole wing color	0 = Not applicable, 1 = Green, 2 = Purple
28	Flowering	0 = Absent, 1= Present

Table 4.2. Continued……..

29	Sex of plants	1= Female, 2 = Male
30	Type of Inflorescence	1= Spike, 2 = Raceme, 3 = Panicle
31	Type of tuber	1 = Underground, 2 = Aerial
32	Tuber shape	1 = Round, 2 = Oval, 3 = Oval long, 4 = Cylindrical; 5 = Flat; 6 = Irregular
33	Spiny roots on the tuber crown	0 = None, 1 = Very Few, 2 = Very few to few, 3 = Few 4 = Few to intermediate, 5 = Intermediate, 6 = Intermediate to high, 7 = High, 8 = High to very high, 9 = Very High
34	Spineness of tuberous root	0 = None, 1 = Very sparse, 2 = Very sparse to sparse, 3 = Sparse 4 = Sparse to intermediate, 5 = Intermediate, 6 = Intermediate to dense, 7 = Dense, 8 = Dense to very dense, 9 = Very dense
35	Tuber color, proximal end	1 = White, 2 = Purple, 3 = White with purple, 4 = Purple with white
36	Tuber color, middle section	
37	Tuber color, distal end	
II	**Quantitative traits**	
1	Days to emergence	Counting number of days from planting
2, 3	Days to flowering	Number of days from planting and after emergence
4, 5	Days to maturity	Number of days from planting and after emergence
6	Number of inflorescence	Counting the number of inflorescence per flower stalk
7	Length of inflorescence (cm)	Measured on five distinct flower stalks
8	Tuber length (cm)	Recorded at the longest part
9	Tuber width (cm)	Recorded at the widest part
10	Leaf length-1 (cm)	Measured on 20 adult leaves as shown in Fig. 4.1 below
11	Leaf length-2 (cm)	
12	Leaf width-1 (cm)	
13	Leaf width-2 (cm)	

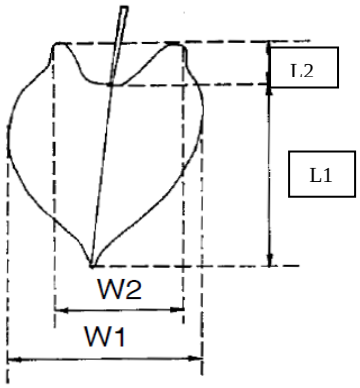

Fig. 4.1. Leaf measurement

4.2.1.4. Data analysis

Data both on qualitative and quantitative traits were subjected to multivariate analysis using cluster analysis (CA) and principal coordinate (PC) analysis in Minitab software. Cluster analysis was used to generate a hierarchical dendrogram through an unweighted

pair group method average (UPGMA) using complete linkage Euclidean similarity index. In principal coordinate analysis, eigenvalues and factor loadings were generated from the data set using varimax rotation technique. The varimax rotation technique is used to simplify factors by maximizing the variance of the loading within the principal coordinates across variables (Tabachnick and Fidell, 2013). The first PCs accounted at least 70-80% of the cumulative variance were retained and used to explain the variability (Stevens, 1986) and traits with loadings greater than 0.45 were considered as relevant scores for the PC (Tabachnick and Fidell, 2013). The first two coordinates were used to present a two dimensional score plots for grouping of accessions. Simple descriptive analysis was also employed for some major descriptors using Microsoft Excel Sheet.

The Shannon diversity index (H') was computed using the phenotypic classes to assess the phenotypic diversity using 31 qualitative traits for the entire accessions and the samples grouped for districts of origin. Districts with sample size less than 10 were included into adjacent districts to reduce bias. The index (H') was estimated as:

$$\boldsymbol{H' = -\sum_{i=1}^{n} p_i * ln(p_i)}$$

Where, p_i is the proportion of accessions in the i^{th} class of an n-class character and n is the number of character states for a given character. Each value of H' was adjusted by dividing it to ln(n), in order to keep the values between 0 and 1. The partitioning of the phenotypic diversity into within and between districts was made using the methods given by Wachira et al. (1995).

4.2.2. Comparison of morphological diversity and folk taxonomy

The variability obtained in morphological study was compared with the locally recognized taxa. The local system of classification, naming and identification of yam landraces by the far Southwest Ethiopians are presented in chapter two in detail.

4.3. RESULT AND DISCUSSION

4.3.1. Agro-morphological characterization

4.3.1.1. Cluster analysis

The cluster study, based on 37 qualitative agro-morphological traits separated the 75 yam accessions into four major clusters (Fig. 4.2). A single accession in major cluster I belongs to *D. bulbifera* while those placed in major cluster II and III belong to *D. alata*. Eight of the ten *D. alata* accessions formed the third major cluster and three of them (11, 49 and 57) form a duplicate. Accessions placed in major cluster IV are belonging to different members of *D. cayenensis* complex (Fig. 4.2). Two sub-clusters are formed within major cluster IV. The first sub-cluster is composed of 22 accessions, where over 86% of them are female landraces. Duplicates were observed between accessions 8 and 20 and between 40, 42 and 43 from Bench-Sheko zone. The second sub-cluster is composed of 42 accessions with over 78% of them are male landraces. Duplicates were observed between the two similarly named accessions (43 and 44) from Sheka Zone and between the three similarly named accessions (64, 68 and 72) from Basketo special Woreda (Fig. 4.2).

The cluster study of 13 quantitative traits separated the 75 accessions into five clusters (Fig. 4.3), with cluster I containing aerial yam and others containing *D. alata* and *D. cayenensis* complex yams. Cluster II is composed of 10 *D. alata* accessions. Cluster III is composed of 34 accessions with over 97% of them are early maturing landraces. Two sub-clusters are formed within the third cluster and landraces with the highest tuber length are formed in the second sub-cluster. A single accession of *D. cayenensis* complex yam (31) formed the fourth major cluster. Cluster V is composed of 29 accessions where 90% of them are late maturing landraces, with the first subcluster contain 10 accessions requiring 10-11 months to mature. The second subcluster is composed of 19 accessions with 85% of them are requiring 9-10 months to mature (Fig. 4.3).

The cluster analysis qualitative traits have indicated a significant morphological variability between the 75 accessions studied and seventeen qualitative traits revealed clear groupings of the variations. Leaf position, twining direction and type of tubers separates the first cluster from others. Wings on the stem, petiole and stem wing color on young and mature plant and petiole color of young leaves separates cluster II and III from others. Flowering traits and prickliness of the stem separates cluster IV from others, with sex of plants separating the two subclusters within this cluster (Fig. 4.2). A similarity range from 0.00 to 0.97 was observed in cluster study of quantitative traits, which present high degree of morphological variation among accessions. Nine traits revealed clear groupings of the variations. Cluster I, II and IV differed from the others mainly due to their highest score for the entire leaf traits (LL_1, LL_2, LW_1 and LW_2), which separates them from others. The entire flowering traits separates cluster III, IV and V from clusters I and II and lateness to maturity separating clusters IV and V from others (Fig. 4.3). Similar studies on different *Dioscorea* species were done by various researchers (Mahalakshmi et al., 2007; Norman et al., 2011; Tamiru et al., 2011; Efisue, 2015; Sheikh and Kumar, 2017). The traits that gave clear groupings of the variations in our study were also apparent in most of these findings.

For the other traits, clustering had failed to show any clear groupings of the variation between accessions but it was clear that all these traits were contributed to distinguish the variability among accessions within the same species. Our cluster analysis had also failed to show any strict grouping on cultivation contexts and geographic grounds and in fact accessions of distinct contexts and origins were clustered together within a group of similar morphotypes and vice versa. Similar morphological distinctions were made for yam by Tamiru et al. (2011) in Southern Ethiopia, is also the case on enset, where Atnafua et al. (2013) reported that the genetic diversity was not apparently related to geographical origins.

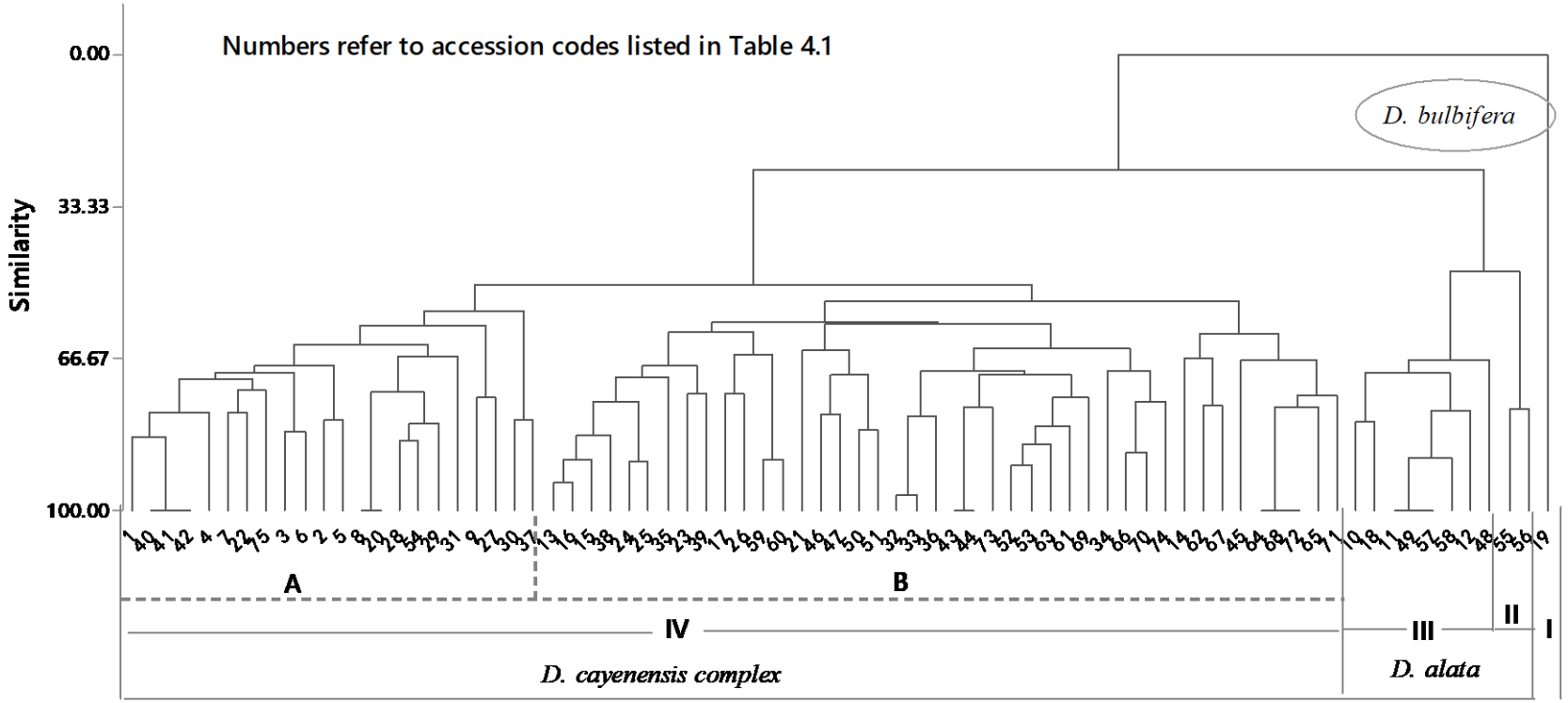

Fig. 4.2. Cluster analysis of the 75 yam accessions based on the 37 qualitative traits using Euclidean similarity index.

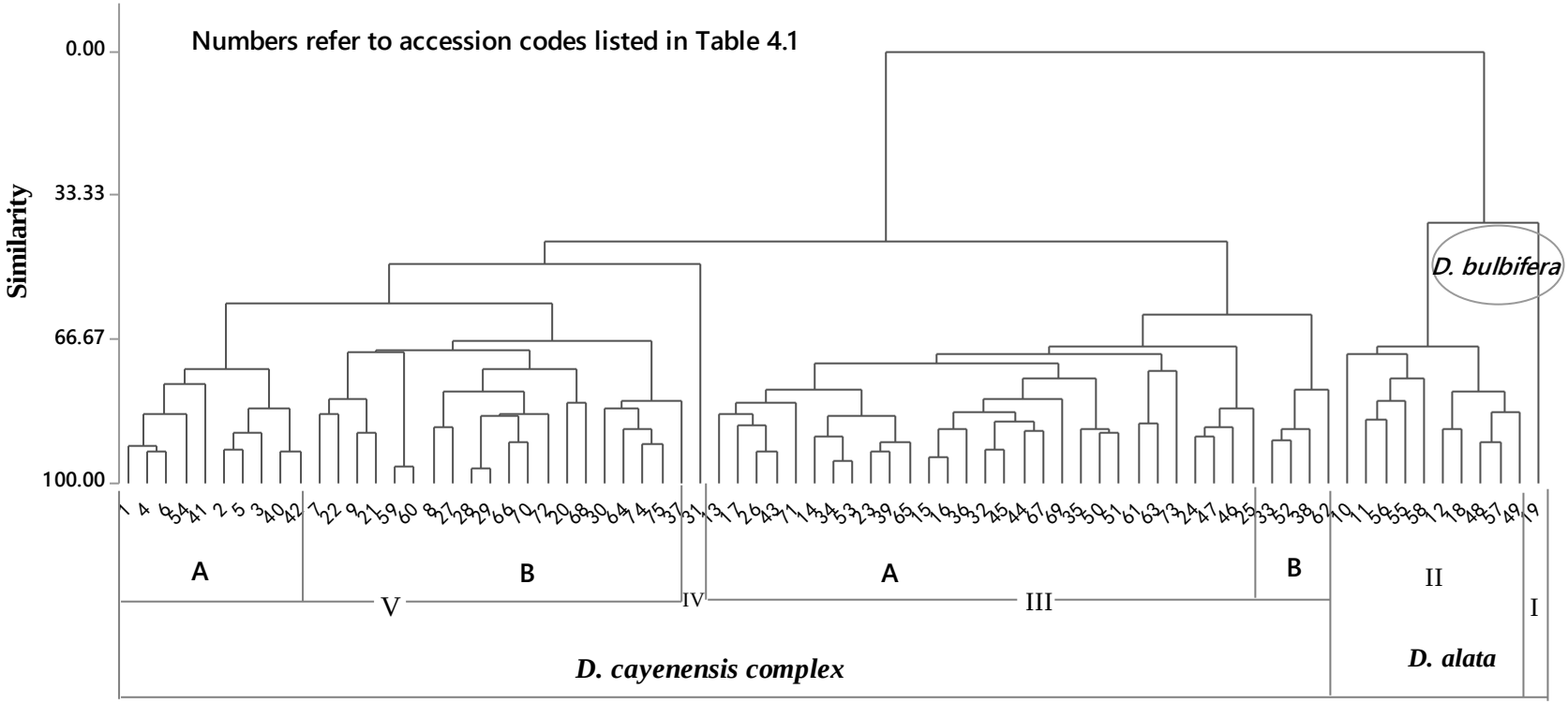

Fig. 4.3. Cluster analysis of the 75 yam accessions based on the 13 quantitative traits using Euclidean similarity index

4.3.1.2. Principal component analysis

The principal component analysis based on the 37 qualitative traits revealed a considerable variability among the 75 accessions studied. The first 8 PCs had eigenvalue greater than 1.5 and together explained 79.5% of the total variation (Table 4.3). Score of PC_1, which accounted for 28.8% of the total variation, was very highly correlated with wings on the stem, petiole and wing color on young and mature stems and petiole color of young leaves. Scores of PC_1 was also highly correlated with other traits such as colored spot at spine base of young stem, flowering and type of inflorescence, spiny roots on tuber surface and density of spines. Scores of PC_2, which explained 13.2% of the total variation, was highly correlated with shoot and leaf traits such as stem and leaf color on young and mature plant and petiole color on mature leaves. Scores of PC_2 was also highly correlated with sex of plants and color of tubers at middle and distal end. Scores of PC_3, which explained 10.3% of the total variation, were highly correlated with leaf and shoot traits such as spines on young stem, spines at stem base and at stem above base, spine shape and leaf margin color.

Score of PC_4, which explained 9.2% of the variation, was highly correlated with leaf position, type of tuber and twining direction. Score of PC_5, which explained 5% of the total variation, was correlated with vein color at lower and upper surface. The scores of PC_6 which explained 4.6% of the total variation was correlated with leaf lobation and tuber shape and tuber color at proximal end. Score of PC_7, which explained 4.3% of the total variation, was correlated with downward arching along vein, distance between lobes and upward unfolding of leaves. The score of PC_8, which explained 4.1% of the total variation, was correlated with leaf traits such as leaf shape and leaf tip color (Table 4.3).

The 37 qualitative traits evaluated in this study were contributed towards morphological variability, and seventeen traits were useful for capturing the variability among accessions

of distinct species. These include prickliness of stems and roots, leaf position, twining direction, type of tuber, wings on the stem, and wing color on young and mature stems, petiole color on young leaves and petiole wing color on young and mature leaves, flowering and type of inflorescence. Most of these traits have high loading coefficients ($r>0.85$) for the relevant score in the PC (Table 4.3). These traits thus, can be used as a marker for identifying and classifying the variability among accessions of the different yam species. The most discriminatory characters obtained in the present study were also the common traits reported by Mwirigi et al. (2009), Bressan et al. (2011), Tamiru et al. (2011), and Norman et al. (2013). Mwirigi et al. (2009) studied the morphological variability between 43 Kenyan yam accessions using 17 morphological characters and concluding all the characters used were useful for the classification of the Kenyan yam accessions. Others such as Bressan et al. (2011) used 24 characters to study the variation in 35 *D. alata* accessions and concluded that 67% of the morphological traits used were discriminatory.

The principal component analysis based on 13 quantitative traits revealed a considerable variability among the 75 yam accessions. The first 4 PCs had eigenvalue greater than 1.21 and together explained 87% of the total variation (Table 4.4). Scores of PC_1, which accounted for 45.5% of the total variation, were very highly correlated with the entire leaf traits and highly correlated with the entire flowering traits. The score of PC_2, which explained 21.7% of the total variation, was highly correlated with number and length of inflorescence and days to maturity from planting and after emergence, respectively. Scores of PC_3 and PC_4, which explained 19.8% of the total variation, were very highly correlated with days to emergence from planting and tuber width (Table 4.4).

Table 4.3. The first 8 principal component (PC) scores of 37 qualitative traits among the 75 yam accessions

	Principal Component (PC) **scores**							
	PC_1	**PC_2**	**PC_3**	**PC_4**	**PC_5**	**PC_6**	**PC_7**	**PC_8**
Eigenvalues	**10.7**	**4.9**	**3.8**	**3.4**	**1.8**	**1.7**	**1.6**	**1.5**
Proportion (%)	**28.8**	**13.2**	**10.3**	**9.2**	**5.0**	**4.6**	**4.3**	**4.1**
Cumulative (%)	**28.8**	**42.0**	**52.3**	**61.5**	**66.5**	**71.1**	**75.4**	**79.5**
Stem color, young	0.334	**-0.72***	-0.360	0.100	0.014	0.012	0.016	0.031
Young stem wing color	**-0.93***	0.259	-0.132	0.104	-0.014	-0.105	0.038	0.092
Spines on young stems	0.408	-0.125	**0.78***	0.068	0.062	-0.062	0.132	-0.163
Colored spot at spine base	**0.71***	-0.138	0.238	0.194	0.028	0.056	-0.166	-0.038
Color of young leaves	**0.48***	**-0.66***	-0.000	0.017	-0.037	0.107	0.130	0.031
Petiole color, young	**-0.94***	0.175	-0.079	0.077	-0.080	0.079	0.009	0.136
Petiole wing color, young	**-0.93***	0.259	-0.132	0.104	-0.014	-0.105	0.038	0.092
Twining direction	0.010	-0.090	0.092	**0.98***	-0.005	0.068	0.011	-0.011
Stem color	0.255	**-0.73***	-0.285	0.092	0.107	-0.002	-0.013	-0.063
Spines at stem base	**0.64***	0.050	**0.67***	0.131	-0.087	0.115	0.039	-0.063
Spines at stem above base	**0.58***	0.119	**0.72***	0.103	-0.070	0.113	0.046	-0.033
Spine shape	**0.45***	-0.027	**0.70***	0.094	-0.041	0.011	0.050	-0.269
Wings on the stem	**-0.93***	0.259	-0.132	0.104	-0.014	-0.105	0.038	0.092
Stem wing color	**-0.94***	0.175	-0.079	0.077	-0.080	0.079	0.009	0.136
Leaf Position	0.010	-0.090	0.092	**0.98***	-0.005	0.068	0.011	-0.011
Leaf margin color	0.139	-0.087	**-0.51***	-0.122	-0.017	0.149	0.409	-0.262
Leaf Lobation	-0.228	0.219	0.169	-0.095	0.045	**-0.72***	-0.040	0.027
Leaf color	0.298	**-0.45***	0.205	0.071	0.209	-0.299	0.275	-0.363
Vein color, US	-0.142	0.108	-0.031	-0.115	**0.78***	-0.059	0.216	0.123
Vein color, LS	0.226	-0.324	-0.092	0.122	**0.73***	-0.059	0.088	-0.173
Leaf Shape	-0.007	0.011	-0.302	-0.097	0.288	-0.134	0.145	**0.71***
Distance between lobes	-0.227	0.234	-0.028	0.124	0.181	0.074	**0.57***	0.240
Downward arching along MV	0.045	0.158	-0.094	0.004	-0.292	-0.027	**-0.64***	0.091
Upward unfolding of leaves	0.146	0.154	0.059	0.049	0.505	0.294	**-0.61***	-0.081
Leaf tip color	0.279	-0.023	-0.067	-0.041	0.273	0.013	0.044	**-0.64***
Petiole color	0.167	**-0.80***	-0.158	0.102	-0.116	0.075	0.134	-0.140
Petiole wing color	**-0.93***	0.259	-0.132	0.104	-0.014	-0.105	0.038	0.092
Flowering	**0.89***	-0.278	0.157	0.219	0.012	0.123	-0.033	-0.092
Sex of plants	**0.62***	**-0.65***	-0.013	0.151	0.150	0.009	-0.064	0.080
Type of Inflorescence	**0.85***	-0.244	0.138	0.200	-0.013	0.138	-0.015	0.027
Type of tuber	-0.010	0.090	-0.092	**-0.98***	0.005	-0.068	-0.011	0.011
Tuber shape	0.026	-0.309	0.187	0.279	-0.012	**0.68***	-0.114	-0.104
Spiny roots on tuber crown	**0.69***	0.133	**0.55***	0.162	-0.096	0.115	-0.089	0.009
Spineness of tuberous roots	**0.60***	0.185	**0.60***	0.137	-0.104	0.128	-0.097	0.046
Tuber color, proximal end	**0.47***	0.036	0.265	-0.146	0.001	**0.48***	0.175	0.005
Tuber color, middle	0.214	**-0.73***	0.245	0.048	0.086	0.158	-0.071	0.163
Tuber color, distal end	-0.013	**-0.80***	0.228	-0.008	-0.002	0.235	-0.025	-0.119

*Factor loadings with relevant scores for the PC contributing significantly to distinguish the variability

The 13 quantitative traits evaluated in this study contributed towards morphological variability, and indicated high degree of morphological polymorphism. Nine of the thirteen traits had high loading coefficients (r>0.85) for the relevant scores in the PC (Table 4.4). Scores with high factor loadings contribute significantly to capture the variability among the accessions. These quantitative traits thus can be used as a marker for identifying the variability between accessions. This result is in consistent with the results reported by Bressan et al. (2011), Norman et al. (2013) and Sheikh and Kumar (2017). Among others, Sheikh and Kumar (2017) reported length and width of mature leaves are contributed towards morphological variability.

Table 4.4. The first 4 principal component scores of 13 quantitative traits among the 75 accessions

	Principal Component (PC) **scores**			
	PC_1	**PC_2**	**PC_3**	**PC_4**
Eigenvalues	**5.92**	**2.82**	**1.36**	**1.21**
Proportion (%)	**45.50**	**21.70**	**10.50**	**9.30**
Cumulative (%)	**45.50**	**67.20**	**77.70**	**87.00**
Leaf length-1	**0.90***	0.001	0.172	-0.198
Leaf length-2	**0.92***	-0.066	0.153	0.032
Leaf width-1	**0.90***	0.151	0.156	0.015
Leaf width-2	**0.96***	0.027	0.053	0.046
Tuber Length	**-0.50***	0.436	0.202	**-0.48***
Tuber-Width	0.201	-0.054	-0.023	**-0.93***
Number of inflorescence	-0.52*	**-0.61***	-0.167	0.052
Length of inflorescence	-0.64*	**0.68***	-0.061	0.169
Days to emergence from planting	0.327	0.076	**0.92***	-0.009
Days to flowering from planting	**-0.87***	0.241	-0.125	0.132
Days to flowering after emergence	**-0.81***	0.242	-0.384	0.139
Days to maturity from planting	0.039	**0.92***	0.260	-0.015
Days to maturity after emergence	-0.181	**0.89***	-0.356	-0.009

*Factor loadings with relevant scores for the PC contributing significantly to distinguish the variability

4.3.1.3. Score plots of the first two coordinates

Score plot of qualitative traits based on the first two coordinates accounting 42% of the total variability showed significant variation among the accessions (Fig. 4.4A). The major groups observed in the cluster study were also formed on the score plot, with the first coordinate separating group I and IV on the right from others on the left. The second coordinate separates group II on the bottom left from group III on top left of the score plot. Similar result is evident on score plot of quantitative traits with the first two coordinates accounting 67.2% of the total variation. The five groups observed in the cluster study were clearly formed on the score plots, with the first coordinate separating group III and V on the left from others on the right (Fig. 4.4B).

The scatter graph obtained from the principal coordinate analysis of qualitative traits (Fig. 4.4A) separates the vast majority of the male groups from the female groups, which showed greater genetic similarity among each other and were grouped on the bottom right, along with the main axis of coordinate two. Analysis of quantitative traits also revealed that the second coordinate separates early maturing groups on the bottom left from late maturing groups on the top left (Fig. 4.4B). This result is similar to those obtained by Mwirigi et al. (2009), Bressan et al. (2011) and Tamiru et al. (2011) on yam, Atnafua et al. (2013) on enset and Boampong et al. (2018) on taro. Most of these studies reported a similar form of grouping patterns with the use of the first two principal coordinates.

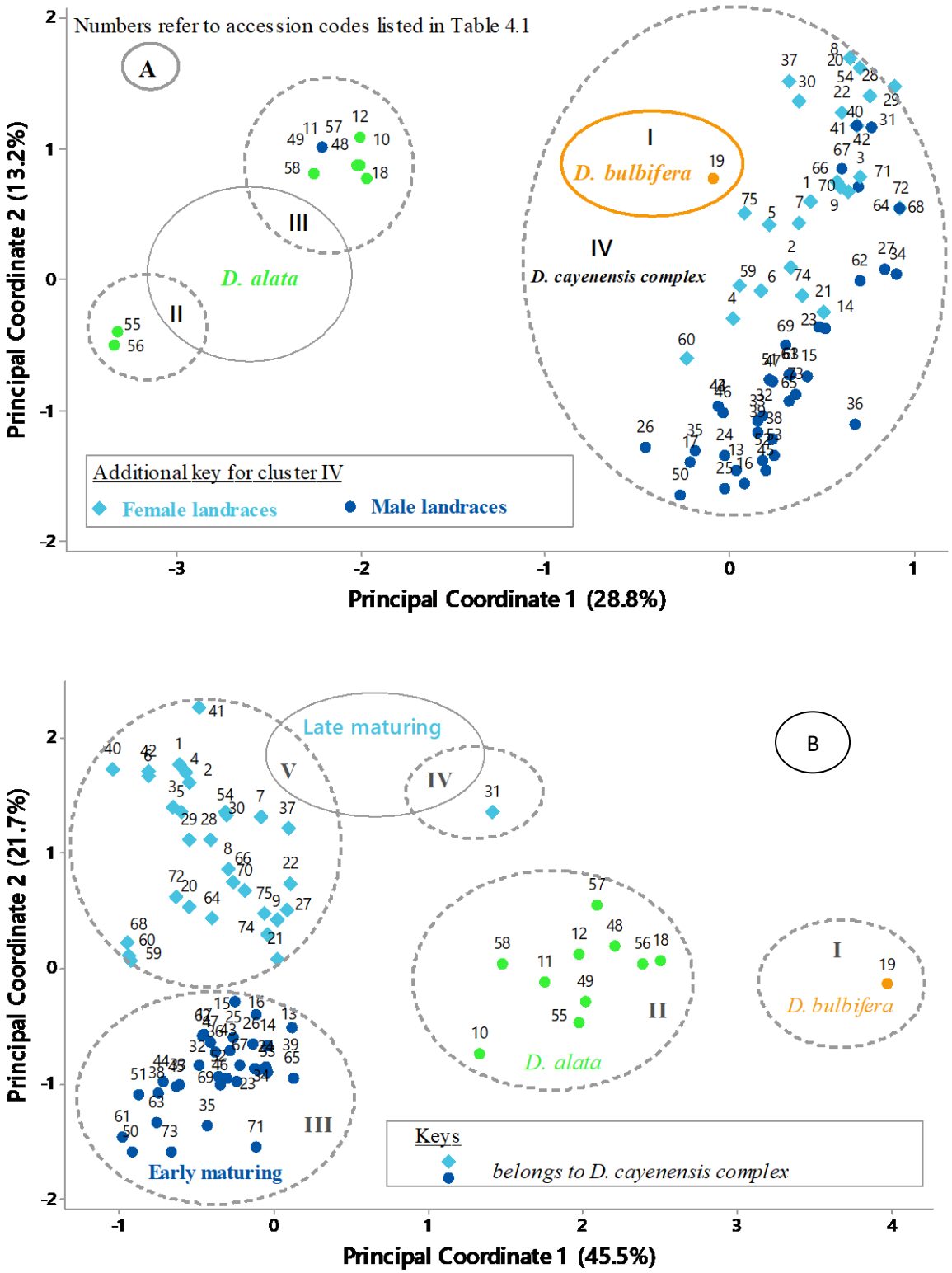

Fig. 4.4: Score plot of the first two principal coordinates based on the 37 qualitative (A) and the 13 quantitative (B) morphological traits.

4.3.1.4. Descriptive statistics of qualitative traits

Of the 37 qualitative traits, three traits were monomorphic to one accession defining the species *D. bulbifera*, showing alternate leaves with a single leaflet, clockwise twining direction and bear aerial tubers (Table 4.5). Flowering capacity was monomorphic to *D. cayenensis* complex, each of which showing well defined sexes and inflorescence types. Twenty-eight (44%) of these produce a spike type of pistilate inflorescence while 36 (56%) are male flowers, with two produce a panicle type of staminate inflorescence. Seven prickle traits were also limited to *D. cayenensis* complex accessions. Seed formation was not observed on accessions that showed flowering but a three winged fruit capsules were observed in the accessions with pistilate inflorescence. Four traits were monomorphic to 10 accessions, defining the *D. alata* and showing wings on the stem, green petiole wings on mature plant and green with purple edge wings on stem and petiole of young plant.

Most accession (77.3%) had sagittate leaf shape with dark green leaves (53.3%), followed by green (41.3%), and pale green (5.3%) leaves. The majority had green petioles (33.3%) with purple at both ends followed by green (29.3%), purple (21.3%) with purple at both ends and green (16%) with brown at both ends. Nearly, 46.7% of the accessions showed green stem color, followed by those with purplish green (36%) and brownish green (14.7%) stem colors (Table 4.5). Most landraces produce tubers with white flesh (73%) at the distal end, purple with white and white with purple (66.6%) at middle and white with purple (37.3%) at proximal end. Also, the shapes of tubers are varying widely. Cylindrical (72%) tubers are more prevalent, followed by irregular (18%) and round (5.3%) shaped tubers, but oval (2.7%) and flattened (1.3%) tubers are uncommon (Table 4.5). Similar levels of variation have been reported for other yam species using similar morphometric markers. For instance, in *D. alata*, Bressan et al. (2011) found 97% sagittate leave shapes, while Norman et al. (2011) found a leaf shape ranging from sagittate long to cordate long.

Table 4.5. Descriptive statistics of the qualitative traits among the 75 yam accessions

Traits	Freq.	%	Traits	Freq.	%
Twining direction			**Petiole color, young**		
Clockwise	1	1	Green	8	10.7
Anticlockwise	74	99	Green with purple leaf junction	2	2.6
Leaf position			Not applicable	65	86.7
Alternate	1	1	**Stem wing color, mature**		
Opposite	74	99	Green	8	10.7
Type of tuber			Green with purple edge	2	2.6
Aerial	1	1	Not applicable	65	86.7
Underground	74	99	**Petiole wing color, Young**		
Flowering			Green with purple edge	10	13
Not applicable	11	15	Not applicable	65	87
Yes	64	85	**Petiole wing color, mature**		
Type of Inflorescence			Green	10	13
Spike	62	97	Not applicable	65	87
Panicle	2	3	**Wings on the stem**		
Sex of plants			Present	10	13
Female	28	44	Absent	65	87
Male	36	56	**Young stem wing color**		
Spines at stem base			Green with purple edge	10	13
Not applicable	11	15	Not applicable	65	87
Very few to few	3	4	**Leaf color**		
Few	10	13	Pale green	4	5.3
Few to intermediate	14	19	Green	31	41.3
Intermediate	3	4	Dark green	40	53.3
High	10	13	**Petiole color**		
High to very high	19	25	Green	22	29
Very high	5	7	Green with brown at both ends	12	16
Spines at stem above base			Green with purple at both ends	25	33
Not applicable	11	15	Purple with purple at both ends	16	21
Very few	5	7	**Stem color**		
Very few to few	4	5	Green	35	46.7
Few	**19**	**25**	Brownish green	11	14.7
Few to intermediate	4	5	Purplish green	27	36
Intermediate	9	12	Purple	2	2.7
High	13	17	**Leaf shape**		
High to very high	9	12	Cordate	5	7
Very high	1	1	Cordate long	1	1
Tuber shape			Cordate broad	11	15
Round	4	5	Sagittate long	48	64
Oval long	2	3	Sagittate broad	10	13
Cylindrical	54	72	**Tuber color, Proximal end**		
Flattened	1	1	White	9	12
Irregular	14	19	Purple	23	31
			White with purple	28	37
			Purple with white	15	20
Tuber color, distal end			**Tuber color, middle section**		
White	36	48	White	22	29
Purple	1	1	Purple	3	4
White with purple	23	31	White with purple	25	33
Purple with white	15	20	Purple with white	25	33

4.3.1.5. Phenotypic diversity of qualitative characters

The estimates of the Shannon diversity index, by origin for the 31 characters are presented in Table 4.6. For all accessions, the value of H' varied from 0.40 for leaf tip color to 0.99 for vein color of leafs in lower surface with an overall mean of 0.76 (Table 4.6). Characters with two to three phenotypic classes generally had lower values than those with more than three classes. This result was in disagreement with that of Amsalu and Endeshaw (1998) who reported that the characters with two to four classes generally had higher H' than those characters with more than four classes. Our result signified the caution that should be made while interpreting the estimates of diversity index of different characters with different classes as measured by the Shannon diversity index. Low H' indicates extremely unbalanced phenotypic classes for individual traits (Perry and Mclntosh, 1991). Thus, it might be misleading to compare the values of H' from characters having different classes.

The phenotypic diversity also varied for the diversity estimates pooled over characters and districts (Table 4.6). The mean value of H' pooled over characters ranged from 0.57 for Basketo to 0.85 for Yeki, with a mean of 0.72. Bench and Basketo districts showed lower values of H' for the entire wing traits and for leaf tip color, petiole color of young leaves and type of inflorescence. The mean value of H' pooled over districts ranged from 0.35 for leaf tip color to 0.97 for color of veins in the lower surface, with a mean of 0.72.

The entire wing traits and others such as downward arching of leafs along the main vein, petiole color on young leaves, upward unfolding of leaves, colored spot at spine base, leaf shape, type of inflorescence and tuber shape showed lower values of H' less than the mean value of 0.72. The remaining traits had higher values of H' greater than the mean value of 0.72 (Table 4.6). This may be attributed to the unequal distributions of accessions of every district over the different classes of traits rather than lack of variation for the character.

Table 4.6. Shannon diversity index for the 75 accessions based on 31 qualitative characters partitioned into within and between districts.

Characters	PC	H'	Districts				H_d	H_d/H'	$\frac{(H'-H_d)}{H'}$
			Sheko	Bench	Yeki	Basketo			
Stem color, young	4	0.91	0.77	0.97	0.92	0.78	0.86	0.95	0.05
young stem wing color	2	0.57	0.68	0.00	0.95	0.00	0.41	0.72	0.28
Spines on young stems	3	0.93	0.96	0.69	0.79	0.73	0.79	0.85	0.15
colored spot at spine base	2	0.73	0.82	0.69	0.79	0.00	0.57	0.78	0.22
Color of young leaves	4	0.95	0.94	0.87	0.92	0.99	0.93	0.98	0.02
Petiole color, young	3	0.42	0.68	0.00	0.82	0.00	0.38	0.90	0.10
petiole wing color, young	2	0.57	0.68	0.00	0.95	0.00	0.41	0.72	0.28
Stem color	4	0.79	0.54	0.83	0.95	0.95	0.82	1.03	-0.03
Spines at stem base	8	0.92	0.90	0.81	0.88	0.87	0.87	0.94	0.06
Spines at stem above base	9	0.91	0.86	0.90	0.88	0.82	0.87	0.95	0.05
Spine shape	3	0.88	0.97	0.65	0.99	0.80	0.85	0.97	0.03
Stem wing color	3	0.42	0.68	0.00	0.82	0.00	0.38	0.90	0.10
Leaf margin color	2	0.97	0.77	0.95	0.89	0.72	0.83	0.86	0.14
Leaf Lobation	2	0.98	0.77	0.68	0.89	0.92	0.82	0.83	0.17
Leaf color	3	0.78	0.99	0.98	0.86	0.90	0.93	1.20	-0.20
Vein color, US	3	0.81	0.90	0.95	0.71	0.99	0.89	1.09	-0.09
Vein color. LS	2	0.99	0.99	0.98	0.95	0.97	0.97	0.98	0.02
Leaf Shape	5	0.67	0.77	0.87	0.34	0.35	0.58	0.87	0.13
Distance between lobes	2	0.84	0.68	0.77	0.99	0.84	0.82	0.98	0.02
Downward arching of leaf	2	0.49	0.00	0.59	0.90	0.00	0.37	0.76	0.24
Upward unfolding of leafs	2	0.60	0.44	0.85	0.70	0.00	0.50	0.82	0.18
Leaf tip color	2	0.40	0.57	0.27	0.54	0.00	0.35	0.86	0.14
Petiole color	4	0.97	0.88	0.90	0.93	0.99	0.93	0.95	0.05
Petiole wing color	2	0.57	0.68	0.00	0.95	0.00	0.41	0.72	0.28
Type of Inflorescence	2	0.49	0.77	0.27	0.95	0.35	0.59	1.20	-0.20
Tuber shape	5	0.53	0.54	0.95	0.75	0.35	0.65	1.21	-0.21
Spiny roots on the tuber	8	0.96	0.93	0.93	0.77	0.88	0.88	0.92	0.08
Spineness of tuberous root	10	0.92	0.91	0.93	0.78	0.92	0.89	0.96	0.04
Tuber color, proximal end	4	0.94	0.96	0.91	0.99	0.87	0.93	0.99	0.01
Tuber color, middle	4	0.88	0.96	0.88	0.98	0.91	0.93	1.06	-0.06
Tuber color, distal end	4	0.79	0.74	0.89	0.96	0.88	0.87	1.10	-0.10
Pooled over character averages		**0.76**	**0.77**	**0.68**	**0.85**	**0.57**	**0.72**	**0.94**	**0.06**

PC = Phenotypic class of each character; H' = Diversity index for each character calculated from the entire accessions; H_d = Average diversity index of each character pooled over districts; H_d/H' = Proportion of diversity within districts in relation to the total variation; $(H'–H_d)/H'$ = Proportion of diversity between districts in relation to the total variation.

The diversity estimates of characters were also compared by partitioning of the phenotypic diversity into within and between the districts (Table 4.6). Ninety-four percent of the total variation was found within districts, while only 6% found between districts, confirming our multivariate analysis using these and other traits which failed to show any strict

groupings on regional grounds. This result was in agreement with that of Amsalu and Endeshaw (1998) and Selamawit et al. (2020), who reported more prominent variations within the regions in sorghum and cowpea accessions.

4.3.1.6. Descriptive statistics of quantitative traits

Accessions of different *Dioscorea* species were compared based on certain quantitative traits of leaf and tuber (Table 4.7). For all the leaf parameters measured, *D. bulbifera* was found highest, followed by the *D. alata* accessions. In *D. alata* leaf length-1 ranges from 11.4 – 15.4 with a mean of 13.77 while in *D. cayenensis* complex ranges from 6.1 – 12.7 with a mean of 8.6 (Table 4.7).

Similar results are also evident for all other leaf quantitative traits. Off the 10 accessions of *D. alata*, the maximum range of leaf length-1 and leaf width-1 was obtained for landraces known by the name *Ongubay*. For the remaining leaf parameters the landrace *Earkubay* was revealed the highest range. Within the *D. cayenensis* complex, the landraces namely, *Durndufa* and *Tolubab* were resulted with the lowest and highest range for all leaf traits. In consistent with our results, in India Soibam et al. (2017) reported similar results of leaf traits for *D. rotundata and D. alata* accessions.

The three species also differs in tuber length and width per plant (Table 4.7). The *D. bulbifera* accession was found lowest for both mean tuber length and width compared to accessions with rest two species. Mean tuber length was highest in *D. cayenensis* complex accessions and exceeds by 8.7 cm with the *D. alata* accessions. With regard to tuber width the *D. alata* accessions exceed by 6.42 cm compared with the *D. cayenensis* complex accessions. This reflects that tuber shape of *D. alata* and *D. cayenensis* complex is round and long cylindrical, respectively. Similar levels of morphological variation have been

reported for other *Dioscorea* species under traditional management studied through morphometric markers. Fauziah and Masudah (2015) reported tuber size variability among species and among varieties within species.

Table 4.7. Comparison of quantitative traits for the 75 yam accessions of 3 different *Dioscorea* species.

Characters evaluated (cm)	***D. bulbifera***	***D. alata***		***D. cayenensis* complex**		Overall mean
	Mean	Mean	Range	Mean	Range	
Leaf length-1	17.5	13.8	11.4 – 15.4	8.6	6.1 – 12.7	**11.2**
Leaf length-2	4.7	3.1	2 – 3.8	1.3	0.5 – 3.2	**2.1**
Leaf width-1	17.5	9.4	7.8 – 10.7	5.6	4.1 – 10.2	**7.5**
Leaf width-2	12.9	7.6	6.1 – 9	4.1	2.6 – 7.5	**5.8**
Tuber length	8	28.2	19 - 53	36.9	10 – 80	**32.6**
Tuber width	8	22.3	13 - 33	15.8	6 – 35	**19**

4.3.1.6.1. Days to emergence

Variations in days to emergence were observed among wild, wild transplants and cultivated yams. Wild yams have shown a prolonged dormant period (33-69), and days to emergence delayed on average by 54 days. Days to emergence from planting in wild transplant yams delayed on average by 39 days (Table 4.8). A considerable variability with regard to tuber dormancy was also observed among species. Days to emergence was delayed in *D. alata* and *D. bulbifera* accessions, whereas dormant period was intermediate in *D. cayenensis* complex. Days to emergence from planting in the *D. cayenensis* complex accessions, ranged from 9 to 66 days, with the greater number of accessions emerge between 27 and 66 days from planting. In *D. alata* accessions, the duration from planting to emergence ranged from 31 and 95 days. Days to emergence in *D. bulbifera* accession have delayed by 75 from planting. Such differences have a considerable effect on days to maturity from planting and after emergence.

Species and cultivation contexts, therefore, have a considerable effect on days to emergence from planting (Table 4.8). For instance, days to emergence from planting in

wild yam delayed on average by 22 days compared with cultivated yams. The shorter dormant period in cultivated yams could be the result of strong human selection influence. Days to emergence from planting were also varied among species within the cultivated accessions and it was delayed by 29 days in *D. alata* species compared with *D. cayenensis* complex. This results support the view that tuber dormancy is under strong endogenous control and is not affected by either growth or storage environment (Passam et al., 1982b). In *D. rotundata* accessions, days to emergence from harvest were ranged from 60 to 110 days, with the greatest numbers were sprouted between 70 and 80 days after harvest (Craufurd et al., 2001).

Table 4.8: Comparison of phenological parameters among the 75 yam accessions of *Dioscorea* species

Cultivation context	**DTE**		**DTF**				**DTM**			
	From planting		From planting		After emergence		From planting		After emergence	
	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.
Wild	33-69	54	153-197	181	115-146	127	294-319	313	250-296	262
Wild transplant	19-64	39	164-191	179	117-160	139	279-315	295	242-269	255
Cultivated	9-95	32	120-186	147	82-155	120	206-288	245	165-277	213
Species (within the cultivated groups)										
D. cayenensis	9-66	27	120-186	147	82-155	120	206-288	243	168-277	216
D. alata	31-95	56	-	-	-	-	241-284	260	165-237	204
D. bulbifera	75	-	-	-	-	-	241	-	166	-

DTE: Days to emergence, DTF: Days to flowering, DTM: Days to maturity, Av.: Average

4.3.1.6.2. Days to flowering and maturity

Variations in days to flowering were observed within the *D. cayenensis* complex collected at different contexts (Table 4.8). Yams collected in wild and adoptive transplant contexts have showed a prolonged blooming period when compared with cultivated yams. Mean days to flowering after emergence was delayed in wild transplant yams than their wild relatives. However, both flowered at similar time relative to time of planting. In cultivated yam accessions, the duration from planting to flowering ranged from 120 to 186 days and

days to flowering ranged from 82 and 155 days after emergence. Days to maturity was varied among yam species collected at different cultivation contexts. Wild yams have shown a prolonged maturity period compared with yams collected at wild transplant and cultivated contexts (Table 4.8). Days to maturity in wild yams delayed on average by 313 from planting and by 262 days after emergence. In cultivated yams, days to maturity from planting delayed on average by 245 days and by 213 days after emergence.

A considerable variability with regard to maturity period was also observed among species (Table 4.8). Days to maturity from plating was delayed in *D. alata* and *D. bulbifera* accessions, while maturity time was prolonged in *D. cayenensis* complex after emergence. In *D. cayenensis* complex accessions, days to maturity was delayed on average by 243 days from planting, and by 216 days after emergence. In *D. alata* accessions, days to maturity was delayed on average by 260 days from planting and 204 days after emergence. In conformity with this result, in Caribbean island, maturity period delayed by 252 days from planting in *D. rotundata* (Okoli, 1980). It was shorter (up to 180 days) with *D. alata* within the same island (Passam et al., 1982b), which is in contrast to our result.

4.3.2. Correspondence between morphological diversity and folk names

Analysis of morphological variation among the 75 yam accessions using 50 morphological traits has shown a considerable correspondence with the folk detected taxa. In our earlier ethnobotanical study farmers recognized nine supra-variety categories on the basis of a single criterion such as contexts or gender (Tsegaye et al., 2021a). On the basis of contexts, farmers recognize three main supra-variety groups describing them as wild, wild transplant and cultivated yams. Most of the farmers did not provide consistent morphological grounds for differentiating between wild and wild transplant yams. However, some of the farmers are able to describe the distinction between the two contexts. According to these farmers,

wild transplant yam retains its wild traits for the first few years after transplantation and thus, they knew it by the name of wild places though it grows in a garden. It begins to take on the traits of domestic yam, and in fact most of the farmers credit wild transplant yams as having broader and tasty tubers over the course of three to five years of cultivation. All such type of accessions (1, 2, 3, 4, 5, 6, 7, 40, 41 and 42) are clustered together (Figs. 4.2, 4.3); indicating strong correspondence between our morphological study and the folk supra-variety groups that identified in our earlier study (Tsegaye et al., 2021a).

Other varieties such as *Torbay* (9), *Chabsha* (27) and *Tolubab* (31) were recognized by farmers as yams known to be recently transplanted to open field, and their morphotype is closely related to wild transplants. These accessions are clustered together with wild transplant yam accessions in the subcluster A of cluster IV (Fig. 4.2) and in cluster V (Fig. 4.3); a result fitting with our earlier study based folk provided markers (Tsegaye et al., 2021a). Many of the accessions in the subcluster B of cluster IV (Fig. 4.2) and in cluster III (Fig. 4.3) were recognized by farmers as yams that have a longtime history of cultivation and propagation by humans. In our earlier study, two major supra-variety groups of yams have been identified by farmers within the cultivars of underground yam types. These are the *Kachi/Boyye* and *Baday-Kachi* groups. In our multivariate analysis, the *Kachi/Boyye* groups are clustered together in the subcluster B of cluster IV (Fig. 4.2) while the *Baday-Kachi* groups are clustered together in cluster II (Fig. 4.3), both of which are fitting with our earlier study (Tsegaye et al., 2021a). Farmers also distinguish two supra variety groups by gender. Farmers credit that early maturing, less vigorous, and double harvest varieties as female while they are male otherwise. In our cluster analysis of qualitative traits, the female and male groups are clustered together in subcluster A and B of major cluster IV, respectively (Fig. 4.2). Similarly, analysis of quantitative traits showed that the female and

male groups are clustered together in the major cluster V and III, respectively (Fig. 4.3), both of which are fitting with our earlier study (Tsegaye et al., 2021a).

Our findings demonstrated that morphological groups obtained by multivariate analysis are consistent to a considerable extent with the groups recognized by local farmers. The two systems are arguably complementary, for a number of reasons. First, farmers manage a wide range of specific plant characters, most of which correspond to the formal descriptors list, confirming earlier reports from Ethiopia (Wendawek, 2008; Tamiru et al., 2011), West Africa (Dansi et al., 1999, 2000a) and Brazil (Bressan et al., 2011). The situation we described in yam seems to be quite similar to situations reported for cassava from South America (Sambatti et al., 2000; Elias et al., 2004), with a considerable correspondence among households diversity and molecular marker. This suggests biological and functional consideration constitutes the basis of folk taxonomy. Second, many of the names and their implied characteristics are known to most members of the community (Tsegaye et al., 2021a), confirming the findings of morphological study. This was evident from the lack of association between differently named landraces and their origins, where our cluster study had failed to show any strict groupings on geographic grounds. This reflects that the local exchange of yam germplasm may be made according to locally known names; the existing classification system thus has a bearing on the distribution of the various landraces.

In some cases, our cluster analysis failed to show any consistent relationship between morphological diversity and some locally known names. Some of the differently named landraces were found morphologically related and therefore clustered together with a group of similar morphotypes. This demonstrates that there are some identical cultivars that may be known by several names in different areas and such linguistic polymorphism may provide a net overestimate of cultivar diversity. On the other hand, all the similarly

named landraces did not form duplicates and showed a sort of morphological variability. This means that different cultivars may be given the same name in different villages which may provide a net underestimate of landraces diversity. This result corresponds well with the results obtained by Elias et al. (2001a) and Kombo et al. (2012) with cassava, who reported different cultivars may be given the same name or one cultivar may be known by several names in different villages.

Lack of association between morphological diversity and some locally known names can be explained by the fact that there could be some other differences that are less clear to morphological analyses. Farmers used some attributes other than morphological ones and are mainly concerned with the tuber quality traits such as taste and texture of cooked tubers. Non-plant traits such as location where it grows or comes from, attributes of a person, or social groups can also be used to distinguish the different taxa. Studies from Ethiopian and Benin have been reported that groupings of a landrace can be made based on various attributes other than morphological ones (Dansi et al., 1999; Tamiru et al., 2011). This provides additional support to the view that crops are biological as well as cultural entities, which makes the study of both evolution and society possible through diversity.

4.4. CONCLUSION

Morphological analysis based on 50 morphological traits has shown high variability among accessions of *Dioscorea* species studied. The multivariate analysis revealed that all the characters used were useful for capturing the variability between accessions. But, 21 traits (17 qualitative and 4 quantitative) were used to separate accessions belonging to distinct species. Of these, leaf position, twining direction and type of tubers were monomorphic to *D. bulbifera* or *D. alata* and *D. cayenensis* complex accessions. Four wings traits separate the *D. alata* accessions from *D. bulbifera* and *D. cayenensis* complex accessions. Sex of

plants, six flowering and seven prickliness traits separate the *D. cayenensis* complex accessions from *D. bulbifera* and *D. alata* accessions. The remaining 29 traits were useful to capture both the within and between species variability. Our results highlight that all the traits considered in this study can be used as a marker for studying the diversity of yam accessions belonging to distinct species. If a need arise for species specific suggestions, nearly 43, 33 and 29 of the traits can be also used as a marker for studying the diversity of yams belonging to *D. cayenensis* complex, *D. alata* and *D. bulbifera*, respectively.

The overall structure of morphological diversity is consistent with the local classification systems. But, some landraces which farmers regarded as different have been classified together and no clear morphological variations were observed among them. Few landraces known by the same vernacular names were also morphologically distinct. This indicates how important it will be to have recourse to more powerful markers to reveal the full extent of the existing diversity. With regard to the existing taxonomic confusion of African species, the larger question of whether the *D. cayenensis* complex has valid taxonomic units remains far from clear. The results of this study highlight the need for more detailed phylogenetic studies to determine the species identity of the accessions studied. Yet, these preliminary results are interesting and form an important part of an ongoing study aimed at revising classification of species boundaries particularly within the *D. cayenensis* complex.

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CHAPTER 5

5. Cultivation and Possible Domestication of Feral and Possibly Wild Yams (*Dioscorea* spp.) in Southwest Ethiopia: Ethnobotanical and Morphological Evidences

ABSTRACT

The far Southwest Ethiopians transplant wild plant species to their gardens. One of such plant is the Dioscorea *that we studied to assess the knowledge of wild yam and the process of domestication. The study also links two types of evidence to obtain insights into the process of yam domestication. We link two data sets derived from (1) ethnobotanical survey using 231 semi-structured interviews; and (2) morphological study in 47 selected accessions. Our study showed that domestication is still active in some villages in Sheko and its environs. Knowledge of yam domestication was shared by 44% of the farmers' even by those that have never practiced its domestication. Farmers who can describe the trend of domestication and the morphotypes of domesticate accounted 21 and 28%, respectively. Farmers who have recent transplants in their garden varied from 4% in Bench to 10% in Sheko. The domestication process described by the two ethnic groups is quite similar. The duration of domestication can take up to six years, but with most of the individuals it only takes three to five years. By linking the two types of evidence, two adaptation processes are distinguished: (1) populations of recent domesticate expressing a domestication syndrome belongs to* D. abyssinica *or* D. praehensilis, *and (2) plants of incipient domesticate that might be derived from volunteers or diverse types of hybrids. Each of these processes can lead to integration of wild genotypes into the cultivated gene pool, and hence, enhance genetic diversity of cultivated yams. The domestication practices of farmers should thus be taken into account if yam conservation and improvement plans need to be established.*

Key words: Domestication, *Dioscorea* species, Ethnobotanical, Morphological, Yam

5.1. INTRODUCTION

The loss of diversity cultivated crops has been the subject of considerable concern in the past three decades (Brush, 1992). Genetic erosion in the form of local crop varieties has been described as a loss of plants with potential agricultural value, and has implications for food security. Food security is not just about ensuring food availability, but also ensuring sufficient diet diversification. The traditional farmer has maintained a large number of crop diversities through domestication (Elias et al., 2001b; Abbo et al., 2010b; Siqueira, 2011; Bressan et al., 2011). Domestication is a continuous evolutionary process guided by humans, mainly through artificial selection (Darwin, 1859). Domestication is the outcome of a selection process that leads to an increased adaptation of plants to cultivation and utilization by humans (Gepts, 2004). It involves a variety of selection episodes, but of all cultivated crop species globally, such episodes have been cataloged for relatively few species. Numerous ongoing processes of domestication have yet to be studied. They could be a valuable source of information to understand the diversity of forms through which humans drive plant evolution and to reconstruct and understand the earlier phases of domestication (Parra et al., 2010).

Domestication usually involves drastic genetic changes in the material, but in the case of yam, it involves the adaptation of wild plants into cultivated forms without genetic changes (Dumont and Vernier, 2000). To avoid confusion, Scarcelli et al. (2006a, b) proposed the term spontaneous for plants growing without farmers help, and is a general term referring to hybrids, volunteers and even wild plants. In accord, many authors regarded such plants as wild plants (Dumont and Vernier, 2000; Mignouna and Dansi, 2003). The occurrence of distinct yam species in Africa predates human history, and domestication of these species appears to have been done by local populations. Studies carried out in different parts of Africa showed that several wild yams have been brought under cultivation by African

farmers through domestication (Vernier et al., 2003; Hildebrand, 2003; Baco et al., 2007; Tostain et al., 2007; Scarcelli et al., 2006a, 2019). *D. cayenensis* and *D. rotundata* are one of the earliest domesticated yams in Africa, and *D. abyssinica* and *D. praehensilis* have been proposed as probable wild progenitors (Dumont and Vernier, 2000; Mignouna and Dansi, 2003). Studies by Chair et al. (2005) and Scarcelli et al. (2006a, b) obtained molecular evidence in support of this opinion.

The adaptation process in yam thus involves intense vegetative multiplication and selection procedures of those plants to obtain modifications mainly in form, size and taste of its tuber. It can take a variable period of time, but with most of the individuals, it takes only three to five years (Mignouna and Dansi, 2003). During this period, farmers submit the tuber of spontaneous plants to stress in order to induce some modifications. If farmers are satisfied with the modifications, the tubers are mixed with tubers of a similar variety, or they may rename it to a variety of domestic yams that resembles most closely (Scarcelli et al., 2006a). This trend differs from one ethnic group to another in a given area. It is thus useful to document the process among the distinct ethnic groups in a given locations.

This paper presents the practices of wild yam domestication in Southwest Ethiopia. The definition of domestication in the case of yam was adopted from earlier studies (Dumont and Vernier, 2000; Mignouna and Dansi, 2003; Scarcelli et al., 2006a). Accordingly, ‘domestication’ is defined as the adaptation of spontaneous plants to cultivation contexts without genetic changes. According to this definition, ‘spontaneous’ is a general term referring to feral, diverse types of hybrids and possibly wild types growing without farmers help. Here, we use the name ‘wild’ in reference to plants growing spontaneously; ‘wild transplant’ in reference to plants that farmers intend to adopt and ‘domestic/cultivated’ in reference to plants that are of under cultivation.

Compared with other areas in Ethiopia, those of the far Southwest Ethiopians have a strong tradition of yam farming and excellent knowledge of domestication. But, this great wealth of native knowledge has not been well documented. In an attempt, Hildebrand (2003) has documented the motives and opportunities of domestication by the Sheko farmers. Nothing has been documented regarding the domestication trends by the Bench, upland Omotic speaking peoples to the east of Sheko. Recently, this knowledge is beginning to deteriorate as farming reorients toward cash crops and in fact convinced evidences confirmed that yam farming is in danger of being replacement by coffee farming. Authors own observation also suggest that yam is one of the most understudied root crops, with high conservation and improvement concern in Southwest Ethiopia. Thus, the practice of wild yam manipulation by the local farmers emerges as an essential research direction to focus on. The results of this study will be compared with our ongoing molecular study to link this knowledge with the scientific parameters. Here, we describe ethnobotanical and morphological evidences of domestication. The objectives of the present study were (1) to investigate the knowledge of wild yam and wild yam manipulation; (2) to assess the process of yam domestication; and (3) to link ethnobotanical and morphological evidences in order to obtain insights into its adaptation under domestication.

5.2. MATERIALS AND METHODS

5.2.1. Ethnobotanical evidence of domestication

This study was conducted in Bench-Sheko and Sheka Zones of Southwestern Ethiopia. From a total of 272 informants considered for ethnobotanical study, the knowledge of wild yam and wild yam manipulation was assessed using 231 farmers. Ethnobotanical evidence of domestication was thus assessed based on two groups of data derived from (1) 231 semi-structured interviews aimed at documenting the knowledge of wild yam and wild

yam domestication; and (2) 32 semi-structured interviews aimed at assessing the detail process of yam domestication. The knowledge of wild yam and domestication were assessed based on questions like (i) knowledge of wild yam (ability to identify the different types of wild yams, and knowledge on the existence of wild yam in their environment, abundance and distribution of wild yams, time of wild yam availability and use wild yams as food), (ii) knowledge of domestication (to know that wild yams can become cultivated yams by domestication, to know a simple knowledge of domestication or ability to describe the technique of domestication), (iii) ability to describe the morphotypes or product of domestication (ability to describe the distinct morphotypes between wild and domesticable yams or ability to describe cultivars currently known as the result of domestication) and (iv) actual practice of it.

Semi-structured interviews were conducted with households who are currently practicing domestication. The detail domestication process were assessed by collecting data on the type and source of wild material used for domestication, how these materials were gathered, the areas where these wild yams were collected and the procedure of the domestication itself. Questions asked to farmers were include; years of cultivation needed to obtain the intended modifications, the morphological variations that were observed during the process and the techniques used to transform the wild yam into cultivated types.

5.2.2. Morphological evidence of domestication

Morphological evidence of domestication was derived from the data of morphological study using 47 selected yam accessions belonging to the *D. cayenensis* complex. The local name and geographic location of the selected yam accessions considered in our study are presented in Table 5.1.

Table 5.1. List of local names and geographic origin of *Dioscorea* accessions that were selected for domestication study

Accession code		Local name	Area of collection	Accession code		Local name	Area of collection
1	BMJ 001	*Karka-Kachi**	Sheko	25	BMJ 026	*Banda boy*	Debub Bench
2	BMJ 002	*Karka-Kachi**		26	BMJ 027	*Tolubab*	
3	BMJ 003	*Karka-Kachi***		27	BMJ 028a	*Shamut*	
4	BMJ 004	*Karka-Kachi**		28	BMJ 028b	*Shamut*	
5	BMJ 005	*Karka-Kachi**		29	BMJ 029	*Tsid boy*	
6	BMJ 006	*Karka-Kachi***		30	BMJ 030	*Tsid boy*	Semen-Bench
7	BMJ 007	*Yasind**	Semen-Bench	31	BMJ 031	*Tsid boy*	Debub-Bench
8	BMJ 008	*Beri*	Sheko	32	BMJ 032	*Banda boy*	
9	BMJ 009	*Torbay*		33	BMJ 033a	*Shamut*	
10	BMJ 012	*Kachi-Tsano*		34	BMJ 033b	*Shamut*	
11	BMJ 013	*Dizzu Kachi*		35	BMJ 034a	*Karka-Kachi***	Sheko
12	BMJ 014a	*Kachi-Tsano*		36	BMJ 034b	*Karka-Kachi***	
13	BMJ 014b	*Kachi-Tsano*		37	BMJ 034c	*Karka-Kachi***	
14	BMJ 015	*Kachi-Tsano*		38	SHK 001a	*Kachi-Tsaa'nseb*	Yeki
15	BMJ 018	*Beri*		39	SHK 001b	*Kachi-Tsaa'nseb*	
16	BMJ 019	*Dal-boy*	Debub-Bench	40	SHK 002	*Kachi-Tsaa'nseb*	
17	BMJ 020	*Shapinsin*		41	SHK 003	*Kachi-Gatinseb*	
18	BMJ 021	*Tsid boy*		42	SHK 004	*Kachi-Gatinseb*	
19	BMJ 022a	*Tsid boy*	Semen-Bench	43	SHK 007	*Konkay*	
20	BMJ 022b	*Tsid boy*		44	SHK 008	*Konkay*	
21	BMJ 023	*Tsid boy*		45	SHK 009a	*Kachi-Tsaa'nseb*	
22	BMJ 024	*Chabsha*		46	SHK 009b	*Kachi-Tsaa'nseb*	
23	BMJ 025a	*Banda boy*	Debub-Bench	47	SHK 010	*Kaibab-kachi*	
24	BMJ 025b	*Banda boy*					

* = Wild transplant yams, ** = Wild growing yams

Characters which are frequently used by farmers for identification were deliberately considered in this study. Accordingly, we have selected 24 characters; six are related to leaf traits, seven are related to stem traits and eight are related to the tuber traits. For each accession, flowering ability, sex and phenological related traits were also recorded (Table 5.2). Quantitative traits were not considered in the cluster analysis, yet to give an idea of the leaf and tuber dimension, some average values are indicated for each landrace. Data collection procedures were described in detail in chapter two.

Table 5.2. Morphological descriptors

Tuber traits	**Stem traits**	**Leaf traits**
Tuber shape	Color of the young stem	Color of the young leaf
Spiny roots on the tuber crown	Spines on the young stem	Color of the adult leaf
Spineness of tuberous roots	colored spot at spine base	Leaf Shape
Tuber color, proximal end	Color of adult stem	Leaf petiole color
Tuber color, middle section	Spines at adult stem base	Leaf length (cm)
Tuber color, distal end	Spines at stem above base	Leaf width (cm)
Tuber length (cm)	Spine shape	
Tuber width (cm)	**Others**	Flowering ability
	Maturity time (days)	Sex of plants

5.2.3. Data analysis

Data on qualitative traits were subjected to cluster analysis in Minitab software using complete linkage Euclidean similarity index.

5.3. RESULT AND DISCUSSION

5.3.1. Ethnobotanical evidence of domestication

At least three species, i.e., *D. alata*, *D. bulbifera* and *D. cayenensis* complex grow in the study areas. The later is a provisional name for a set of species whose botanic relations are currently being examined: *D. cayenensis, D. rotundata, D. abyssinica*, *D. praehensilis*, and *D. sagittifolia* (Wilkin et al., 2000). Member species are native to Ethiopia and occur all over Sub-Saharan Africa (Miege and Sebsebe, 1997). The *D. cayenensis* complex is the only species known to be a subject to domestication. Farmers recognize 49 landraces that belong to this complex (Tsegaye et al., 2021a). Of these, 27 represented actually grown landraces while the rest reported verbally. Ethnobotanical evidence allows for the recognition of three groups of yam population: (a) yams that are growing wild; (b) yams that have been recently transplanted from wild area; and (c) yams that are of under cultivation.

Some farmers in Southwest Ethiopia manipulate wild growing yams, bringing them from uncultivated areas to transplant into their gardens. Wild-growing yams are found in relatively undisturbed forest, secondary forest, fallow lands, and ravines or stream banks with disturbed vegetation. They have no known history of human husbandry, although it is possible that they have genetic material derived from nearby populations of cultivated yams. Many gardens contain a few yams that seem on the state of transition, yams transplanted from wild contexts where many of them had no known history of cultivation. They are usually grown in gardens beneath tree. Unlike the domestic yams that are replanted in an annual cycle, they left in the same place for many years. Hence, they qualify as yams under domestication, and not just as yams under cultivation. We therefore designate them as '*wild transplants*' to differentiate it from wild and domestic yams.

Domestic yams, in contrast, have a long history of cultivation and propagation in gardens by humans. They are usually grown in small plots of open field along rows of stakes and are usually replanted in an annual cycle. Some domestic yams such as *Baidai-kachi*, *Chabsha*, *Torbay* and *Tolubab* are known to be recently transplanted to small plots of open field. Some of these names can also be used interchangeably for group of yams that have been recently transplanted from wild locations to home garden. Farmers relate certain wild, wild transplant and domestic varieties to one another. They are also capable of reporting both specific and general patterns of adoptive transplantation. If the wild transplant proves to resemble a domestic variety, farmers may give it the domestic variety name a few years after transplantation.

5.3.1.1. The knowledge of wild yam

Sheko and Bench farmers have excellent knowledge of transforming wild growing yams into cultivated contexts. Knowledge about wild yam is important for its utilization and also

to conserve the diversity. It has been realized in this survey that 167 (72%) farmers in Southwest Ethiopia have a simple knowledge of wild yam existence in their environment. Significant proportions of the individuals also know the time of wild yam availability (48%) and abundance and distribution (56%) of wild yams in their environment. According to the farmers, wild yams are widely distributed in the open wooded grasslands and in the disturbed forest areas, and the best time for gathering wild yams varies between Septembers to February. The use of wild yam as food is common, and about 30% of the farmers consumed it during their short hunting journeys in the forest (Table 5.3). The data obtained in this survey is a proof of local knowledge in using and selecting wild yams for domestication. In Benin, researches have reported similar information that supports our view (Mignouna and Dansi, 2003; Scarcelli et al., 2006a, b).

The knowledge of wild yam domestication is still alive even among farmers who have never recently practicing domestication. About 44% of the farmers know that wild yams can become cultivated yams by domestication. Moreover, about 21% of the individuals can describe the techniques of domestication in spite of stopping this practice a long time ago (Table 5.3). They have described the techniques as follows. First, they select the tubers of spontaneous plants from uncultivated areas for its likeliness to domestic varieties and plant it in their garden. Farmers explained that successive harvests of the tubers during the cultivation cycle induce phenotypic modifications, particularly in the tuber form, shape and taste. Among other studies providing information in this respect are those by Vernier et al. (2003) who reported the simple knowledge of domestication is shared on average by 82.5% of the farmers in Benin and 62.5% of the farmers in Nigeria. The same source also reported that the proportions of farmers capable of describing the techniques range from 22% to 47% in Benin and from only 10% to 77% in Nigeria.

This survey also indicated that 28% of the respondents are capable of describing the distinct morphological differences between domesticated and non-domesticated yams (Table 5.3). The characteristics that distinguish domesticated yams from their progenitors in general includes decrease in prickliness of stem and root, loss of dormancy, changes in size and shape of the tuber, loss of bitter properties and changes in the propagation system. This data would have an immense importance in studying how conscious or unconscious selection process has affected yam adaptation in domestication. It becomes apparent that conscious selection may have been responsible for most of the changes. Yet, changes in dormancy and propagation system of domesticates may occur, despite the domesticators consciousness. In view of this, Abbo et al. (2011b) reported that domestication is unlikely to have been resulted by the way of unconscious selection rather it is due to a well-focused and highly conscious selection episode.

Table 5.3 Knowledge of wild yams and wild yam domestication in Sheko and its environs, Southwest Ethiopia

Of a total of 231 interviewees, respondents in which those:	**Answers in:**	
	Frequency	%age
Know the existence of wild yam in their environment	167	72
Know abundance and distribution of wild yams	130	56
Know time of wild yam availability	112	48
Use wild yams as food	69	30
Have a simple knowledge of domestication	101	44
Can describe the technique of domestication	49	21
Can describe the distinct morphotypes of wild and domesticated yams	65	28
Practice techniques of domestication	32	14

Based on the domestication syndrome described above, we have identified two distinct morphotypes for domesticated across locations. According to some Bench farmers, non-domesticated yam is known by its thicker stem bearing several prickles that are long and generally curved. Its tuber has patches of purple to grey pigmentation near the stem

junction. The morphotype of domesticable yam in Bench area is recognized by its intermediate stem diameter bearing prickles with variable length. The tuber has dark grayish flesh and its top is protected by a considerable number of prickly roots. Similar morphological distinctions have also been made by most Sheko farmers. However, some Sheko farmers in the lowland area described additional morphological differences between domesticable and wild yams.

These farmers recognized the non-domesticable yam by its medium sized stem bearing short prickles. Farmers said it did not exhibit very prickly roots in the tuber crown. The morphotypes of domesticated yams in the lowland areas of Sheko was recognized by its small stem diameter bearing few and short prickles. The tuber color varies from purple to white, is less fibrous, and the top of the tuber crown is protected by very few prickly roots. Cognizant of the observed morphotypes, we suspect that the wild ancestor of domesticated yam belongs either to *D. abyssinica* or *D. praehensilis*. In agreement with our results, Chair et al. (2005) reported that farmers in northern Benin identify four different morphotypes of domesticable yams and one morphotypes of non-domesticable yams.

The current study also indicates that only few farmers are currently practicing the actual techniques of domestication. This represents only 14% of the 231 farmers interviewed in Sheko and Bench (Table 5.3). The domestication trend however varies with respect to the two ethnic groups. It seems to be more widespread in Sheko compared with Bench. Of the 32 domesticators, only 9 (4%) were Bench. This is less than half of the yam domesticators identified in Sheko. The few attempts made in Southwest Ethiopia confirmed that this trend is declining (Hildebrand, 2003). A similar result was obtained by Mignouna and Dansi (2003) in Benin, where only 5% of Nago and Fon ethnic groups practice yam

domestication. Similarly, Dumont and Vernier (2000) estimated the proportion of domestication is about 3.7% by Bariba group in northern Benin.

5.3.1.2. The process of domestication

The farms of 32 household contain a few yams that seem on the state of transition, yams transplanted from wild contexts and were used to assess the process of domestication. All informants said that tuber is the sole type of original material used during domestication. Most farmers obtained it from forest areas but, nearly 33% of the individuals meet their demand by collecting tubers growing spontaneously in fallow lands (Table 5.4). During gathering wild materials, farmers left pieces of tubers *in situ* for ensuring the survival of wild yam populations. First, farmers select a spontaneous tuber for its likeness to cultivated varieties and plant it in their fields. Farmers submit it to stress, e.g. two harvests of the tuber during the cultivation cycle, to obtain phenotypic modifications in the plant. The duration of domestication in general can take up to six years but with most of the individuals it only takes three to five years (Table 5.4). Farmers were often splaying their fingers toward the ground to mimic the small, branching tubers of wild yams, while they credit wild transplant yams as having broader tubers. Farmers report that wild transplant yam retains its wild traits for the first few years after transplantation. It begins to take on the traits of domestic yams after four or five years of cultivation (Table 5.4). Domestic yams are characterized as broader and tastier. Other studies have described similar distinctions between wild and domestic yams, and parallel changes in the morphology of tubers taken from the wild over the course of five years of cultivation (Hildebrand, 2003; Zannou et al., 2004; Mignouna and Dansi, 2003; Scarcelli et al., 2006a, b).

Understanding the evolutionary history of wild transplantation may be valuable for inferring how yam diversity was shaped under domestication. In this regard, 47% of the farmers had a known history of adoptive transplantation. Of these, nearly 2(13%) and 4(27%) of them said they had transplanted it about 4 and 5 years ago, respectively. While, 53% of the respondents were not precise in their response, some said it happened 10 years earlier, while others said it was 15 years earlier (Table 5.4). Some of the yams are known to be recently transplanted to an open field and grow along rows of stakes; suggesting that at least some of the known domestic yams in Southwest Ethiopia are of local origin. Knowledge on crop evolution under domestication and the diversity patterns of their progenitors are highly relevant for crop improvement through efficient utilization of wild germplasms (Scarcelli et al., 2006a).

Table 5.4 The process of yam domestication in Sheko and its environs, Southwest Ethiopia

Questions		Responses	Frequency	Percentage
Which type of planting material do you use for domestication?		Tuber	32	100
		Seed	0	0
Where do you get the original planting material?		In the Forest	21	67
		Near the village	11	33
How long does it take to transform it into cultivated context?		2 years	0	0
		3 years	6	19
		4 years	11	34
		5 years	13	41
		6 years	2	6
Do you know history of transplantation?		Yes	15	47
		No	17	53
If yes	When did you bring it to the home garden?	3 years ago	1	7
		4 years ago	2	13
		5 years ago	4	27
		>10 years ago	5	33
		>15 years ago	3	20
Do you use any obstacle to limit tuber growth?		Yes	0	0
		No	32	100
Why do you domesticate Yam?	For dietary reasons		17	53
	To enrich the existing diversity		9	28
	For curiosity/to sustain native knowledge		6	19

When interviewees were asked to describe the techniques of domestication; all responded that no particular technique is used to limit the length of the tubers during domestication. Farmers simply undertook an intensive vegetative multiplication of the wild transplants (Table 5.4). For the first few years after transplantation, tubers were repeatedly harvested, but pieces of tubers were left in the soil for subsequent re-growth. This process induces changes in the morphology of tubers. No genetic changes are expected during the process since only vegetative propagation is used. The wild transplant yams are left in the same place for several years. A similar result was obtained by Mignouna and Dansi (2003) with yams domesticated by Nago and Fon groups in Benin. However, in Benin, Vernier et al. (2003), and Zannou et al. (2004) reported that the local farmers in Benin place some obstacles in the soil mounds in order to restrict the tuber length.

When respondents were asked the reason for domestication, they said that they do it for simple curiosity, for dietary reasons, and in order to enrich the existing crop's diversity. Among these, those who said that they did it for dietary reasons and for enriching the existing diversity represent 53 and 28%, respectively. But, 19% of the farmers were not precise in their response; some said they do it to maintain what they heard from their parents, whereas others said they do it for simple curiosity (Table 5.4). Among other studies providing information in this respect are those by Scarcelli et al. (2006a, b) with the yam in Benin. Farmers there enrich their cultivated stock of variation with wild materials. In Mexico, Parra et al. (2010) reported that local management of columnar cacti has promoted morphological divergence between wild and managed populations.

5.3.1.3. Contribution and current trends of domestication

A full description on the role of domestication about the evolutionary changes of yam is beyond the scope of this study. However, our survey clearly indicates that the

domestication practice of traditional farmers allows gene flow between wild and cultivated populations, thereby allowing integration of wild genotypes into the cultivated gene pool. This enhances the genetic diversity of domestic yams. Genes from the wild populations enter into domestic parents through wild transplantation. This occurs if female wild transplants are fertilized with the pollen from the nearby cultivated male parents. Many gardens in Sheko and its environs contain a few adoptive transplants, most of which are morphologically close to some domestic yams. This can be taken as a clear evidence for occurrence of such processes. Other studies have documented similar results (Dumont and Vernier, 2000; Mignouna and Dansi, 2003; Scarcelli et al., 2006a).

Yam domestication is a constantly repeating process in Southwest Ethiopia. Traditional farmers there maintain high levels of genetic diversity through domestication. However, the majority of the cultivated landraces are undergoing sever genetic erosion and some have almost disappeared; suggesting that the knowledge of domestication is beginning to deteriorate. Several factors are responsible for this. The decline in domestication appears to be high in some areas of Sheko where non-native yams are common. The declining trend of domestication became more conspicuous in most areas of the Bench where pressure on the limited available land is high, and only few forest reserves remained. Earlier studies by Scarcelli et al. (2006a, b) and Vernier et al. (2003) also described similar reasons for the declining trend of domestication in Benin. The latter authors further added that in northern Benin, wild yam domestication is considered as a shameful act. In some lowland areas, we observed that it is in danger of being replacement by cassava varieties. Most farmers considered cassava as a non-staked yam and usually known as *Enchet-Kachi*. In accord to our result, Zannou et al. (2004) reported locally threatened yam varieties in Benin by the introduction of other varieties with different characters that are used for the same purpose.

5.3.2. Morphological evidence of domestication

5.3.2.1. Relationship between wild and cultivated yams

Evidence derived from the morphological study on 47 selected yam accessions belonging to *D. cayenensis* complex suggests that the process of domestication is still active in some villages; confirming earlier reports (Hildebrand, 2003; Wendawek et al., 2013a, b). These studies have indicated that *D. abyssinica* and *D. praehensilis* are the likely wild candidates that show clear morphological similarity to some domestic yams. These species have been assigned to have different putative roles in the domestication process.

Morphologically diverse individuals of the wild *D. praehensilis* were encountered in the surveyed area, yet certain traits remain constant for most of the individuals: medium to large sized light green or green leaves, very prickly stem, with or without a spot at the base, very highly prickled roots on the tuber crown and on the tuber surface (Fig. 2.2 and 5.1, Plate 1). These traits can be also observed in yam populations that have been recently transplanted from wild locations to gardens (*Karka-Kachi* and *Yasind*) (Fig. 2.2 and 5.1, Plate 2 & 3) or within the cultivated forms (*Kaibab-Kachi, Tolubab, Torbay*, *Dal-boy* and *Shapinsin*) (Fig. 2.3, Plate 1-3 and 9 & 10; Fig. 5.1, Plate 4-7; Annex 5.1). Some of the domestic yams used by the Sheko and Bench farmers may thus be the possible domestication products of *D. praehensilis*.

The wild *D. abyssinica* is also the most diverse species in surveyed areas. Individuals of *D. abyssinica* with various foliar shapes, ranging from the cordate to sagittate type, have been encountered. The prickliness of the stem and root varies widely from slightly armed to very prickly. The morphology of the tuber is also highly diverse. Yet, certain traits remain constant for most of the observed individuals: small to medium sized green or dark green leaves, unarmed or slightly armed stems, unarmed or slightly spiny roots on the tuber

crown and on the tuber surface. These characters can also be recognized in some domestic yams. Four varieties namely *Dizzu-kachi, Kachi-Tsano/Tsaa'nseb, Konkay* and *Kachi ga'nseb* were morphologically very similar to *D. abyssinica* (Fig. 2.3, Plate 11-14; Fig. 5.1, Plate 13-15; Annex 5.1), and might have been domesticated from this species.

Others might be derived from interspecific hybridization between the two wild species. Five domestic yam types, namely *Banda boy, Shamut, Beri, Tsid-boy,* and *Chabsha* seems to combine the characteristics of both *D. praehensilis* and *D. abyssinica* and might be interspecific hybrids (Annex 5.1). Leaf characters are much more likely to be of the '*D. abyssinica*' type (Fig. 2.3, Plate 4-8)while the stem and tuber characters are typically of the '*D. praehensilis*' type (Fig. 5.1, Plate 8-12). The observed relationship suggests that at least some of the domestic yams in Southwest Ethiopia are of local origin and are the possible products of incipient or recent domestication. A similar relationship between domestic and wild species has been reported for yam in Ethiopia (Hildebrand, 2003) and West Africa (Zoundjihekpon et al., 1994; Dansi et al., 1999; Mignouna and Dansi, 2003; Chair et al., 2005; Scarcelli et al., 2006a, b).

5.3.2.2.Relationship between the three yam populations

The cluster analysis of qualitative traits separated the 47 accessions into six major clusters (Fig. 5.2, Table 5.5). Many of them, although recorded under different names and contexts were morphologically related and thus classified together. The wild and wild transplant yam accessions are clustered together in the first cluster. Some domestic yams that are known to be recent transplants (accessions 9, 22, 26 and 47) and that are of longtime varieties (accessions 8, 15, 16, 17, 23 and 24) have been clustered together with the wild and wild transplant yams in major cluster I and II (Fig. 5.2, Table 5.5).

Fig. 5.1: Variation in tuber characteristics among yam landraces corresponding to accessions of the *D. cayenensis* complex.

Pate 1: *Karka-Kachi,* wild (BMJ003, BMJ006, BMJ034a, b, c)

Pate 2: *Karka-Kachi,* wild transplant (BMJ001, BMJ002, BMJ004, BMJ005)

Plate 3: *Yasind* (BMJ007)

Plat 4: *Tolubab* (BMJ027)

Plat 5: *Baidai/Kaibab Kachi* (SHK010)

Plate 6: *Dal boy* (BMJ019)

Plate 7: *Shapinsin* (BMJ020)

Pate 8: *Banda boy* (BMJ025a, b, BMJ026, BMJ032)

Pate 9: *Chabsha* (BMJ024)

Pate 10: *Beri* (BMJ008, BMJ018)

Pate 11: *Tsid boy* (BMJ021, BMJ022a, b, BMJ023, BMJ029, BMJ030, BMJ031)

Pate 12: *Shamut* (BMJ028a, b, BMJ033a, b)

Plate 13: *Kachi-Tsano/Tsaa'nseb* (BMJ012, BMJ014a, b, BMJ015, SHK001a, b, SHK002, SHK009a, b)

Pate 14: *Kachi-ga'nseb* (SHK003, SHK004)

Pate 15: *Dizzu Kachi* (BMJ013)

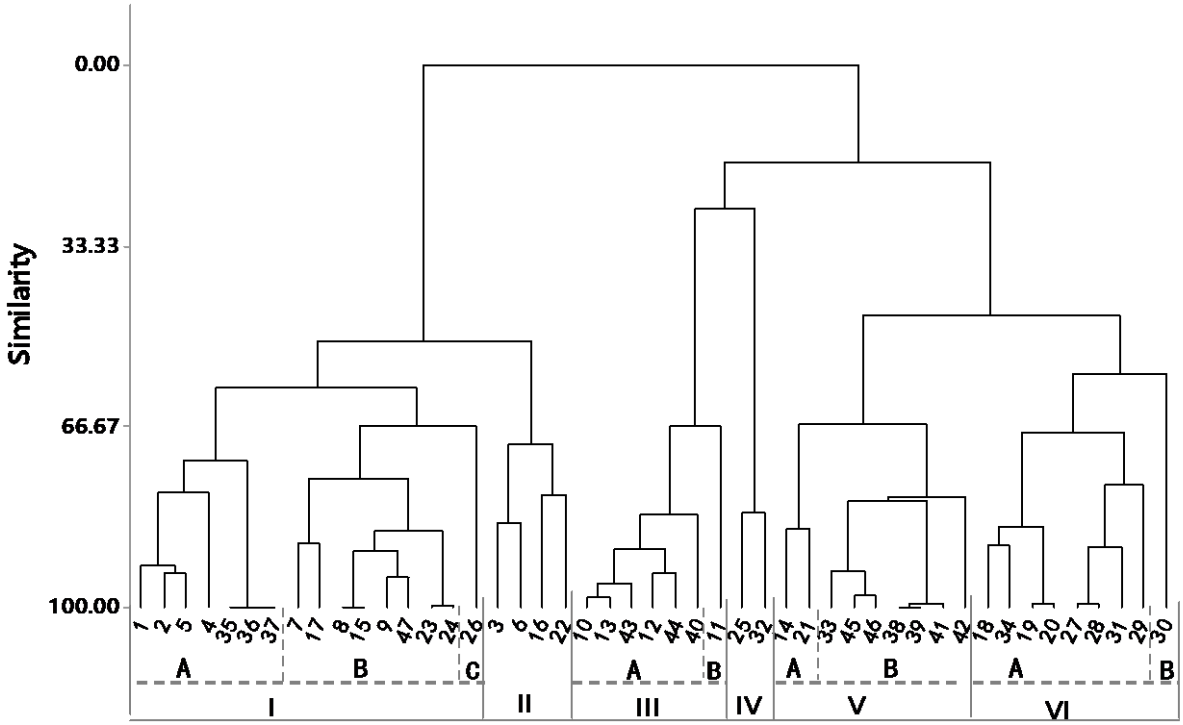

Fig. 5.2: UPGMA dendrogram of yam accessions using Euclidean similarity index.

Table 5.5. Leaf and tuber dimensions and other characteristics of the yam accessions

CL	NA	NL	Accession codes	Local names	Sex	MT	TL cm	TW cm	LL cm	LW cm	FA
I	16	9	35, 36, 37	*Karka-kachi***	F	L	51.3	18.5	8.82	5.7	H
			1, 2, 4, 5	*Karka-kachi**	F	L	49.5	17.3	8.6	6.7	H
			7	*Yasind**	F	L	53	15.5	11	7.4	H
			17	*Shapinsin*	F	L	44.5	15	9.2	7.1	H
			8, 15	*Beri*	F	L	42.5	9	8.3	6.4	M
			47	*Kaibab-kachi*	F	L	41	25	8.4	5.8	H
			9	*Torbay*	M	L	39	21	10.1	6.1	H
			23, 24	*Bandaboy*	F	L	37	8	8.3	5.6	M
			26	*Tolubab*	M	L	30	20.5	12.7	10.1	M
II	4	3	3, 6	*Karka-kachi***	F	L	46.3	18	8.82	5.7	H
			16	*Dal-boy*	F	L	40.5	18	10.5	6.1	M
			22	*Chabsha*	M	L	37	8	7.7	7	M
III	7	3	10, 12,13, 40	*Kachi-Tsaa'nseb*	M	E	32	12.9	9.4	5.2	P
			11	*Dizzu-kachi*	M	E	25.5	17	8.8	5.1	P
			43, 44	*Konkay*	M	E	35.5	12.5	7.5	5.2	P
IV	2	1	25, 32	*Bandaboy*	F	L	24	12	7.8	5.2	P
V	9	4	14,38, 39, 45, 46	*Kachi-Tsaa'nseb*	M	E	31.2	16.5	9	5	P
			41,42	*Kachi-ga'nseb*	M	E	39	20.5	10	5.7	P
			33	*Shamut*	M	E	41	27	9.2	5.1	P
			21	*Tsid-boy*	M	E	27.5	13	9	5.5	P
VI	9	2	18,19,20,29,30,31	*Tsid-boy*	M	E	28.9	17.6	9.5	5.7	P
			27,28,34	*Shamut*	M	E	41	21.2	9.4	5.3	P

CL – Clusters, NA – Number of Accessions; NL – Number of Landraces; F – Female; M – Male; MT – Maturity Time; E – early maturing; L – late maturing; TL – Tuber Length; TW – Tuber Width; LL – Leaf Length; LW– Leaf Width; LA – Leaf Area; FA – Flowering Ability; H – High; M – Medium; P – Poor;

The relationships between the three populations suggest that some cultivated yams may grow in the fallow lands and farmers may collect them when gathering spontaneous plants. Two hypotheses could explain the presence of cultivated populations in the fallow lands. First, these plants could be feral or volunteers derived from some cultivated plants which grow spontaneously in the fallow lands. Some tuber fragments can be left behind in the ground during harvest (Mignouna and Dansi, 2003). Then they could grow the following year and be harvested by farmers, since they frequently collect spontaneous plants from fallow lands. Secondly, these plants could be the result of intervarietal hybridization among the numerous varieties that are simultaneously cultivated in the same field (Scarcelli et al., 2006a). Similar distinctions have been made with yams managed by the local farmers in Ethiopia (Hildebrand, 2003) and in Benin (Dansi et al., 1999). The situation we describe here in yam seems to be quite similar to situations reported for potato in the Andes (Quiros et al., 1992), and species of columnar cacti in Mexico (Parra et al., 2010). The local farmers there collect plants that grow spontaneously in the fallow lands.

Accessions in the later four clusters represented domestic yams with a longtime history of cultivation and propagation by humans (Fig. 5.2, Table 5.5). These yams have shown sort of variations when compared with the wild yam populations. Morphological divergence among the two populations is clear in characters such as tuber size, prickliness, canopy size, and plant cycle. Variation in tuber characters was recognized by most people, and was the principal target of selection favoring abundance of the preferred phenotypes. Plants producing broader and tastier tubers with fewer prickles are more abundant in domestic parents than in wild and wild transplant populations. Our analysis also reveals that plants from domestic populations are earlier maturing than those from wild and wild transplant parents (Table 5.5). A decrease in flowering ability is more prevalent in domestic parents than in wild and wild transplant populations. Domestic yams are propagated vegetatively,

while the wild parents are propagated by seeds. The mechanism underlying the phenotypic modifications is unknown, but three hypotheses could explain these divergences. First, it may be resulted from the differential seed diffusion systems of farmers for attractive phenotypes. Second, domestication involves the feral or possibly wild types produced by sexual reproduction. Through the domestication practice, sexual reproduction contributes to the evolutionary dynamics of yam (Scarcelli et al., 2006a). Third, it could be the result of phenotypic plasticity, epigenetic modifications or somatic mutations (Tostain et al., 2007). A similar pattern of divergence was reported by Hildebrand (2003) with the yams managed by the local farmers in Southwest Ethiopia. A similar trend of variation between the wild and managed parents in the gradient of local selection has also been documented for species of Mesoamerican columnar cacti (Casas et al., 1997; Parra et al., 2010).

As domestication usually implies drastic genetic changes in the material that do not take place with the yams domesticated by farmers in West Africa, Mignouna and Dansi (2003) proposed to replace the term ‘domestication’ with ‘ennoblement’. A similar study in Benin by Scarcelli et al. (2006a) obtained molecular evidences in support of this suggestion. From our study, it emerges that the plants which were used by farmers as starting material in the domestication process were composed of feral, diverse types of hybrids and possibly wild types. The local gathering of wild types by the far Southwest Ethiopians involves the adoption these materials into their garden. According to farmers, this process ends only when some modifications, particularly in the form, size and taste of tubers is obtained. A similar study in Southwest Ethiopia proposed to replace the term ‘domestication’ with ‘adoptive transplantation’ (Hildebrand, 2003). Our results strongly supporting this proposed change in terminology.

5.4. CONCLUSION

The domestication of yam is an active process in Sheko and Bench provinces. The knowledge of feral and wild yams is still alive even among farmers who have never domesticated of yams. These farmers are also capable of describing the morphological differences between wild and domestic yams. Several wild yams have been brought under cultivation by Sheko and Bench farmers, but this trend is tending to decline. Yet, the observed manipulation of wild yams by farmers has shown an interesting implication about the history of its cultivation and utilization by humans in prehistoric times.

Evidences obtained from ethnobotanical and morphological study allows for the recognition of two divergent adaptation processes. First, a population that is positioned medially along the domestication gradient and express elements of domestication syndrome belonging to *D. abyssinica* or *D. praehensilis*. Second, populations that might be derived from cross fertilizations between the wild species or between wild and cultivated species. These populations could also be volunteers derived from some cultivated plants that escaped into wild in the past involuntarily. The two divergent adaptation processes could reflect the selection effort of farmers in the gradient of management intensity. Given the fact that the diversity pattern agrees with the Vavilovian view, we can speculate Ethiopia as an independent center of yam domestication. But, different yam species might have been domesticated independently within Africa or domestication may have occurred simultaneously in each of the areas. No sound generalizations can thus be drawn based on this inquiry. If it will be supported with molecular and archeological evidences, Ethiopia may represent one of the main centers in Africa where yam diversity is noticeably high and some of the member species in the *D. cayenensis* complex could become domesticated.

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CHAPTER 6

6. Analysis of Nutritional Composition in Selected Yam Landraces Corresponding to three different Species

ABSTRACT

The study was conducted to assess the nutritional composition on selected yam landraces. In this study, the most widely cultivated yam landraces correspond to three yam species: D. alata, D. bulbifera and D. cayenensis complex were considered. Samples were analyzed for nutritional composition using standard analytical methods. The mean moisture content of species was 71.84%, with individual values among landraces ranging from 63.29 to 90%. The mean dry matter content of species was 28.16%, with individual values among landraces ranging from 10 to 36.71%. The ranges of crude fiber, crude fat and ash contents among species were 3.16–5.37, 0.16–0.38 and 2.99–4.67%, respectively. The ranges of crude fiber, crude fat and ash contents among landraces were 0.33–5.99, 0.1–0.42 and 2.58–4.71% of dry weight, respectively. Within the underground yam types, landraces from D. alata resulted in higher levels of crude fat and ash contents while landraces from D. cayenensis complex contained higher dry matter contents. Three landraces from the D. cayenensis complex namely Beri, Tsidboy and Tolubab showed high levels dry matter content. Nutritional compositions of wild yams were almost similar to those observed for most of the cultivated yams except for the higher value of moisture content found in wild samples. In light of this, it can be concluded that both the wild and cultivated yams used by Sheko and Bench farmers can be used as reliable source of food and energy.

Key words: *Dioscorea* species, Nutritional composition, Yam landraces

6.1. INTRODUCTION

With ever-increasing population pressure and fast depletion of natural resources, it has become extremely important to diversify the present day agriculture with the cultivation of some nutritionally valuable varieties in order to meet various human nutrient needs. Root and tubers are the most important food crops since time immemorial in the tropics and subtropics (Behera et al., 2009). Root and tubers refers to any growing plant that stores edible material in subterranean root, corm and tuber. The nutritional value of roots and tubers lies in their potential ability to provide one of the cheapest sources of dietary energy in the form of carbohydrates in developing countries (Ugwu, 2009).

In this regard, the different yam species has been suggested to have nutritional superiority when compared with other tropical root and tuber crops (Bradbury, 1988; Wanasundera and Ravindran, 1994). It is greatly superior to those reported for other tropical roots with regard to crude protein and vitamin C content. The protein contents of yam tubers, in general, are higher than those reported for cassava, sweet potato and taro (Onwume, 1978). The higher protein content of yam highlights its nutritional superiority as a staple food. Starch was the predominant fraction of the dry matter of yam tubers. Of the economically important yam species, the tuber dry matter of *D. alata* is reported to have about 76-84% starch (Wanasundera and Ravindran, 1994), *D. rotundata* contain about 85% starch on dry weight basis (Treche and Egbe, 1996), while *D. bulbifera* is reported to have about 43-70% starch (Shanthakumari et al., 2008).

Data on proximate compositions of *Dioscorea* species available in the literature indicate that the proximate principle vary with species, maturity time and cultivars. In this regard, Wanasundera and Ravindran, (1994) reported the average crude protein content of 7.4% for tubers *D. alata* species, with individual values among cultivars ranging from 6.7% to

7.9%. Reports available in the literature show that yams contained generally low levels of crude fiber and fat contents. The crude fiber values of as low as 0.7% to 1.69% (Coursey, 1983; Abara, 2011) have been reported for *D. bulbifera*. Polycarp et al. (2012) reported the mean crude fiber value of 1.67% for *D. alata*, 1.74% for *D. cayenensis* complex and 2.19% for *D. bulbifera*. Wu et al. (2016) reported a mean crude fiber values of 0.99% for *D. alata*.

Diversity analysis of yam landraces has been done in Southwestern Ethiopia (Sisay, 2008; Wendawek et al., 2013a, b). However, the diversity of yam landraces with regard to nutritional value was poorly studied. Farmers select and grow yam landraces based on their own experience. It is obvious that inculcating the traditional knowledge with scientific procedures will improve the output from yam cultivation. Hence, it is very necessary to evaluate most widely grown yam landraces for nutritional values thereby enhance nutrition security in the yam growing areas. Of the economically important *Dioscorea* species; *D. alata, D. bulbifera* and *D. cayenensis complex* are most popular in Ethiopia (Gebre-Mariam and Schmidt, 1998; Hildebrand, 2003; Tamiru et al., 2008b; Wendawek et al., 2013a, b). Despite their popularity, published data on the nutritional composition of locally grown yams is scanty. This study was thus conducted to (i) investigate the nutritional composition of the most common yam landraces used by the local farmers in Southwest Ethiopia, and (ii) to compare the proximate composition of among the yam species and among landraces in a single species.

6.2. MATERIALS AND METHODS

6.2.1. Collection and preparation of samples

A total of 75 accessions representing two well defined species (*D. bulbifera* and *D. alata*) and one species complex (the *D. cayenensis*) from South and Southwestern Ethiopia were considered for morphological study. Of these, 12 yam landraces representing distinct

species and contexts were selected for this study. The botanical names, local names and their respective collection area are presented in Table 6.1. From each landraces, a portion of healthy fresh tuber samples were collected at harvest and stored in the refrigerator prior to the analysis. Proximate compositions were done in Addis Ababa at the Ethiopian Health and Nutrition Research Institute, Food Science and Nutrition Laboratory.

Table 6.1. Local name and collection area of landraces considered for nutritional study.

Species	Local names		Area of collection	Altitude (m asl)	Latitude (N)	Longitude (E)
D. bulbifera	1	*Ama*	Sheko	1296	7º2'34.05''	35º31'10.65''
D. alata	2	*Earkubay*	Yeki	1309	7º12'45.42''	35º22'27.71''
	3	*Baday*		1149	7º8'39.13''	35º24'14.20''
D. cayenensis complex	4	*Torbay*	Sheko	1645	7º2'18.30''	35º31'10.29''
	5	*Shamut*	Debub-Bench	1395	6º49'46.32''	35º29'07.96''
	6	*Shapinsin*		1380	6º49'47.39''	35º29'17.20''
	7	*Tsidboy*		1390	6º49'51.07''	35º29'09.26''
	8	*Tolubab*		1400	6º49'56.16''	35º29'15.19''
	9	*Tsaa'nseb, Tsano*	Sheko	1696	7º2'34.05''	35º31'10.65''
	10	*Beri*		1645	7º2'18.30''	35º31'10.29''
	11	*Karka-Kachi**		1473	7º2'21.16''	35º31'10.35''
	12	*Karka-Kachi***		1241	7º01.173'	35º33.498'

*= Wild transplant, ** = Wild

6.2.2. Proximate analysis

The nutritional compositions were determined with the procedure determined by the Association of Official Analytical Chemists (AOAC, 2016). The moisture and crude fiber contents were analyzed using the AOAC approved method 930.15 and 962.09, respectively. Fat and ash contents were detected in accordance with the AOAC standard methods 2003.06 and 923.03, respectively. The dry matter content was determined by subtracting percent moisture content from 100 and the value was expressed in percentage.

6.2.3. Data analysis

Analysis of variance (ANOVA) was used to test for significant differences between means. LSD was conducted at a level of significance of $p<0.05$ for testing the difference between species means. Orthogonal contrast was also carried out to test for significant differences between means of selected yam landraces within a single species.

6.3. RESULT AND DISCUSSION

6.3.1. Moisture content

The different yam species were varied significantly ($p<0.01$) with regard to the moisture content of fresh tubers (Table 6.3). Of the three species, the *D. alata* presented higher moisture content of fresh tubers. The mean moisture content of species was 71.84%, with individual values among species ranging from 67.53% to 85.39% (Table 6.2). A considerable variability was also observed among landraces within the *D. cayenensis* complex, with three landraces namely *Beri, Tsidboy* and *Tolubab* presenting lower moisture contents (Table 6.3). The result obtained in this study is comparable with the value reported by Polycarp et al. (2012) for *D. bulbifera* and *D. cayenensis* complex and with the result reported by Shanthakumari et al. (2008) and Shajeela et al. (2011) for *D. alata*. In contrary to this study, Polycarp et al. (2012) and Shanthakumari et al. (2008) reported much lower and much higher moisture content of fresh tubers for *D. alata* and *D. bulbifera,* respectively. Landraces with low moisture content would be suitable for prolonged tuber storage and more efficient for industrial processing.

6.3.2. Dry matter content

Dry matter contents of yam landraces showed high significant variability ($p < 0.01$) among species (Table 6.3) and the landraces from *D. alata* had significantly lower dry matter

contents than those from the other two species (Table 6.2). Within the *D. cayenensis* complex, landraces namely, *Beri*, *Tsidboy* and *Tolubab* had the highest dry matter content (>35%), implying that they may be appropriate sources of essential diets. This finding is in conformity with the values reported for *D. bulbifera*, but it is lower than values reported for *D. cayenensis* complex (Ukom et al., 2014). In comparison with previous reports, the mean dry matter content (28.16%) found in this study is higher than the values found by Tewodros et al. (2018), who reported the mean dry matter content of 21.76%. This finding confirmed the frequently reported values for the major cultivated yam species.

Table 6.2. Moisture and dry matter contents of the 12 yam landraces corresponding to three species

Species	Local names		Moisture content (%)	Dry matter content (%)
D. bulbifera	1	*Ama*	**67.53^{b}**	**32.47^{a}**
D. alata	2	*Earkubay*	90.00	10.00
	3	*Baday*	80.78	19.22
	Mean		**85.39 ± 6.52^{a}**	**14.61 ± 6.52^{b}**
D. cayenensis complex	4	*Torbay*	68.73	31.27
	5	*Shamut*	69.24	30.76
	6	*Shapinsin*	72.95	27.05
	7	*Tsidboy*	64.40	35.60
	8	*Tolubab*	63.29	36.71
	9	*Tsaa'nseb*	71.33	28.67
	10	*Beri*	63.53	36.47
	11	*Karka-Kachi**	76.60	23.40
	12	*Karka-Kachi***	73.70	26.30
	Mean		**69.31 ± 4.79^{b}**	**30.69 ± 4.79^{a}**
Overall mean			**71.84**	**28.16**

*= Wild transplant, ** = Wild

6.3.3. Crude fiber content

The mean fiber content was 3.64%, with individual values ranging from 0.33% to 5.99%, and among species ranging from 3.16% to 5.37% (Table 6.4). A significant variability was also revealed among landraces within single species (Table 6.3). Of the seven cultivated landraces from *D. cayenensis* complex, *Shapinsin, Beri*, *Tsaa'nseb, Tsidboy* and *Tolubab* showed significantly higher contents of crude fiber. This finding is in conformity with the values reported for *D. bulbifera* (Shajeela et al., 2011) but it is higher than values reported for *D. alata* varieties (Wu et al., 2014; Polycarp et al., 2012) and *D. cayenensis* complex (Polycarp et al., 2012). Foods with high crude fiber are reported to promote beneficial effects, where it reduces the risk of cardiovascular diseases. Reports have shown that increase in fiber consumption might have contributed to the reduction in the incidence of certain diseases such as diabetes, coronary heart disease, colon cancer and various digestive disorders (Alinnor and Akalezi, 2010). Dietary fiber also promotes digestion and prevents absorption of excess cholesterol (Norman and Joseph, 1995).

Reports available in the literature show that yams contained generally low levels of crude fiber content for different yam species. The crude fiber values of as low as 0.7% (Coursey, 1983) to 1.69% (Abara, 2011) have been reported for *D. bulbifera*. Polycarp et al. (2012) reported the mean crude fiber values of 1.67% for *D. alata*, 1.74% for *D. cayenensis* complex and 2.19% for *D. bulbifera*. Wu et al. (2016) also reported a mean crude fiber values of 0.99% for *D. alata*. The mean crude fiber contents of species in the studied yam tubers was higher than the reported values for other yam species (Afoakwa and Sefa-Dedeh, 2001; Bhandari et al., 2003; Alinnor and Akalezi, 2010). The highest levels of crude fiber content observed in the present study might be related to cultivar identity, geographic origin and levels of maturity of the tubers.

Table 6.3. ANOVA for proximate composition of among the three yam species

Moisture and dry matter content						
Source	DF	Sum Square (SS)	Mean Square (MS)		F value	P > F
Species	2	443.49	221.75		8.82	0.0076
Error	9	226.35	25.15			
contrasts			DF	Contrast SS	Contrast MS	F Value	P >F
1	2 and 3 vs. 4, 5, 6, 7, 8, 9 and 10		1	803.57	803.57	31.95	0.00031
2	4, 5, 6 and 9 vs. 7, 8 and 10		1	129.73	129.73	5.16	0.04924
Crude fiber content						
Source	DF	Sum Square (SS)	Mean Square (MS)		F value	P > F
Species	2	7.14	3.57		0.62	0.5585
Error	9	51.65	5.74			
contrasts			DF	Contrast SS	Contrast MS	F Value	P >F
1	2 and 3 vs. 4, 5, 6, 7, 8, 9 and 10		1	4.79	4.79	0.83	0.3860
2	4 and 5 vs. 6, 7, 8, 9 and 10		1	56.39	56.39	9.82	0.0121
Crude fat content						
Source	DF	Sum Square (SS)	Mean Square (MS)		F value	P > F
Species	2	0.078	0.039		19.49	0.0005
Error	9	0.018	0.0019			
contrasts			DF	Contrast SS	Contrast MS	F Value	P >F
1	2 and 3 vs. 4, 5, 6, 7, 8, 9 and 10		1	0.108	0.108	56.79	0.00004
2	4 and 5 vs. 6, 7, 8, 9 and 10		1	0.0118	0.0118	6.21	0.0343
Crude ash content						
Source	DF	Sum Square (SS)	Mean Square (MS)		F value	P > F
Species	2	3.99	1.99		3.88	0.061
Error	9	4.63	0.51			
contrasts			DF	Contrast SS	Contrast MS	F Value	P >F
1	2 and 3 vs. 4, 5, 6, 7, 8, 9 and 10		1	5.47	5.47	10.72	0.0096
2	4, 5, 6, 9 and 10 vs. 7 and 8		1	6.88	6.88	13.49	0.0051

6.3.4. Crude fat content

Fat contents were significantly ($p<0.001$) varied among the different species and ranged from 0.16 to 0.38% (Table 6.3). Compared with *D. cayenensis* complex and *D. bulbifera*, the landraces from *D. alata* showed highest fat content (Table 6.4). The crude fat content of 0.22% obtained for *D. bulbifera* in this study is similar to the values reported by other studies for the same species (Egbe and Treche, 1984) but lower than the values of 0.54% reported by Polycarp et al. (2012). Reports have shown that yams generally contained low

levels of fat which did not exceed 2% on dry weight basis and 0.3% on wet weight basis (Opute and Osagie, 1978).

Table 6.4. Crude fiber, fat and ash contents of the 12 yam landraces corresponding to three species

Species	Landraces		Crude fiber (%)	Crude fat (%)	Ash content (%)
D. bulbifera	1	*Ama*	**3.16**	**0.22[b]**	**2.99**
D. alata	2	*Earkubay*	4.78	0.34	4.71
	3	*Baday*	5.96	0.42	4.63
		Mean	**5.37 ± 0.83**	**0.38 ± 0.06[a]**	**4.67 ± 0.06**
D. cayenensis complex	4	*Torbay*	0.33	0.21	2.66
	5	*Shamut*	0.66	0.24	2.58
	6	*Shapinsin*	4.64	0.18	2.71
	7	*Tsidboy*	4.67	0.16	4.7
	8	*Tolubab*	5.86	0.12	4.15
	9	*Tsaa'nseb*	5.99	0.15	2.80
	10	*Beri*	5.85	0.16	2.83
	11	*Karka-Kachi**	0.76	0.15	2.69
	12	*Karka-Kachi***	1.12	0.10	3.15
		Mean	**3.32 ± 2.52**	**0.16 ± 0.04[b]**	**3.14 ± 0.76**
Overall mean			**3.65**	**0.204**	**3.38**

*= Wild transplant, ** = Wild

All yam landraces had low fat contents below 1.0% similar to values found by Polycarp et al. (2012) within the Ghanaian yams (0.41 – 0.82). A mean fat content of 0.38% was obtained for landraces from *D. alata*, which is higher than that obtained for *D. cayenensis* complex yams (Table 6.4). This suggests that *D. alata* is a better source of calories over the other yam species. A significant variability was also revealed among landraces within single species (Table 6.3). Of the seven cultivated landraces from *D. cayenensis* complex, *Torbay* and *Shamut* showed significantly higher contents of crude fat. Fat insulates the body, provides greater energy to the body and helps in absorption of fat-soluble vitamins in the gut. It can be broken down in the body to release glycerol and free fatty acids. The glycerol can be converted into glucose by the liver and used as a source of energy (Alinnor and Akalezi, 2010).

6.3.5. Ash content

The mean ash content was 3.38%, with individual values ranging from 2.58% to 4.71% (Table 6.4) and significant differences ($p < 0.005$) were also found among landraces within single species (Table 6.3). The landraces from *D. alata* species presented significantly higher ash content compared with the other two species. Within the *D. cayenensis* complex, two landraces namely *Tsidboy* and *Tolubab* had the highest ash content. The ash content obtained in this study is comparable to the results of other earlier works. Inconformity with our result, the mean ash contents of 2.77% (Abara, 2011) to 2.86% (Shanthakumari et al., 2008) have been reported for *D. bulbifera*. Polycarp et al. (2012) reported the mean ash contents of 3.89% for *D. cayenensis* complex, which is inconformity with our result. The ash content obtained in this study is relatively higher than the mean values reported by Bhandari et al. (2003) and Shajeela et al. (2011) for *D. alata*. But it is lower than the values reported for *D. alata* (Shanthakumari et al., 2008; Polycarp et al., 2012) and for *D. bulbifera* varieties (Polycarp et al., 2012). The mean ash content of 4.67% obtained in this study for *D. alata* varieties, implied good retention of the mineral elements up on drying. Ash is a measure of total mineral content in the samples. The result indicates that the samples could be a good source of mineral having nutritional importance.

6.4. CONCLUSION

Based on the nutritive study on the selected yam landraces, it can be concluded that most of them were found to be a good source of diets. The mean moisture content of species was 71.84%, with individual values among landraces ranging from 63.29 to 90%. The dry matter content among the species and among landraces in a single species is ranging from 14.61 to 32.47% and 10 to 36.71%, respectively. Landraces from the *D. alata* contained significantly higher amounts moisture, crude fat and ash contents. Three landraces from *D.*

cayenensis complex, namely *Beri*, *Tsidboy* and *Tolubab* distinguish themselves because of low moisture content that makes them suitable for flour production. The latter two landraces also contained high amount of ash content. Nutritional compositions of yam landraces considered in this study were similar to those reported for most cultivated yams in several parts of the world except for the higher value of crude fiber found in our samples. This result suggested that the yam landraces considered in this study could potentially be good sources of diets for the poor dwellings in Southwest Ethiopia. Since only few samples are considered in our study, more studies on nutritional aspects of yam will be a valuable to promote the production and utilization of this underutilized root crop.

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CHAPTER 7

7. General Summary, Conclusion and Recommendations

7.1. General Summary and Conclusion

Farmers in Southwest Ethiopia have strong tradition in cultivating various species of yams with a broad genetic basis. It is a multipurpose crop that has a considerable importance to the subsistence farmers. Cognizant of its importance, this study was designed to investigate the diversity of cultivated and wild yams based on farmers' management of diversity, agro-morphological markers and tuber quality trait. Toward this effort, five research activities were conducted and the results are summarized as follows.

Assessment of the local classification systems in Southwest Ethiopia suggests that within the region where cultivation of yam is feasible, Sheko and Bench botany is unique. It is polytypic in Sheko, as is also the case in Bench. This was evident in the detection of four taxonomic ranks. Each of these can be considered as members of a separate group and thus arranged hierarchically. In order from the least to the most inclusive groups, they are sub-variety, variety, supra-variety, and folk generic. Farmers managed a total of 26 characters and 74 character states for the identification and grouping of the taxa assigned to different groups. More than 84% of these refer to aspects of specific plant characteristics, most of which correspond to the formal descriptors list. Farmers recognized 58 individuals. Each of these is perceived as distinct and given a separate name. Many of the names and their implied characteristics are known to most members of the community. This study has high potential towards broadening our understanding of the way how the local communities classify, name, perceive and value their crop diversity.

Wide ranges of yam landraces were recorded in Bench-Sheko and Sheka Zones, suggesting that yams have long been used as a key component of subsistence in Southwest Ethiopia. Altogether, 40 actually grown yam landraces, including those found in non-sampled farms, were recorded across the surveyed areas. Richness of landraces ranged from 1 to 6 (2.63 ± 1.04) per farm, from 5 to 13 (8.73 ± 2.63) per Kebele and from 6 to 16 (12.2 ± 4.15) per district. The highest diversity was recorded in Debub Bench district (*H'* = 2.12) while the lowest diversity was observed at Guraferda district (*H'* = 1.58). Both the most and the least rich districts were also found as the most and the least diverse. A small number of highly abundant landraces are growing across the surveyed areas while the greatest number of landraces had a narrow distribution and low local abundance. Farmers' decisions to the on-farm landrace maintenance were related to the agronomic, economic and food values of these landraces. Recently, many households are focused on a few numbers of early maturing ones while others are undergoing serious genetic erosion, suggesting the need for their collection and priority will be given for *in situ* conservation. The study doesn't cover all households that engaged in yam cultivation. Yet, even within the small geographic locations studied; this preliminary result is interesting and could substantially contribute towards broadening our understanding of on the diversity and distribution range of yams in Southwest Ethiopia.

Seventy-five yam accessions from South and Southwest Ethiopia were considered for morphological study. Agro-morphological analysis based on 37 qualitative morphometric traits has shown high variability among the accessions studied. The PCA revealed that all the characters used were useful for capturing the variability among the studied accessions. The discriminatory traits detected in principal component analysis were also used to separate the distinct groups in cluster analysis. Yet, 17 qualitative traits separate accessions

belong to distinct species. Of these, alternate leaf position, clock-wise twining direction and aerial tuber types were monomorphic to *D. bulbifera* accession while 14 traits were useful to capture the within species variability for accessions belonging to *D. alata* and *D. cayenensis* complex. The entire wing traits were useful for capturing the variability among the *D. alata* accessions. Sex of plants, flowering capacity, type of inflorescence and other seven prickle related traits of stems and roots were useful for capturing the variability among the *D. cayenensis* complex accessions. All the other qualitative traits were useful to capture the variability among accessions corresponding to a separate species.

Morphological analysis based on 13 quantitative morphometric traits has also shown high variability among the accessions studied. The multivariate analysis revealed that all the characters used were useful for capturing the variability among the studied accessions. Yet, four flowering traits were also useful for capturing the variability among yam accessions belonging to the *D. cayenensis* complex. Size of leaves was also useful for capturing the variability among accessions between species, where accessions from *D. alata* and *D. bulbifera* were resulted in higher values of the entire leaf size measurements. All the quantitative other traits were useful to capture the within and between species variability.

The overall structure of morphological diversity is consistent with the folk classification system. But, some landraces which farmers regarded as distinct have been classified together and no clear morphological variations were observed among them and vice versa. Our study in general showed the existence of a systematic and well-defined folk classification system and a wide range of phenotypic variability among the accessions studied, which could be used to guide efficient conservation strategies.

The process of wild yam domestication is still active in Sheko and its environs. Several wild yams have been brought under cultivation by Sheko and Bench farmers, but this trend

is tending to decline. Yet, the observed manipulation of wild yam has shown an interesting implication to the cultivation and utilization of yam by humans in prehistory times. The diversity found within the domestic forms and the methodology used by the farmers suggest that this practice contribute to integration of wild genotypes into cultivated gene pool and hence enhance the genetic diversity of domestic yams. This was evident in results derived from ethnobotanical and morphological evidences. From this study, it emerges that the plants which were used by farmers in the domestication process were composed of feral, diverse types of hybrids and possibly wild types. The local gatherings of wild types involve the adoption of these materials into home garden. No genetic changes are expected in these materials during the process since only vegetative propagation is used. As a result, the term adoptive transplantation is proposed in place of domestication.

Samples representing *D. alata, D. bulbifera* and *D. cayenensis* complex were analyzed for nutritional composition. The moisture and dry matter contents of yam species ranged from 67.53 to 85.39% and 14.61 to 32.47%, respectively. The ranges of crude fiber, crude fat and ash contents among landraces were 0.33–5.99, 0.1–0.42 and 2.58–4.71% of dry weight, respectively. Within the underground yam types, landraces from *D. alata* contained higher levels of crude fat and ash contents while those from *D. cayenensis* complex showed high levels of dry matter content. Nutritional compositions of wild yams were similar to those observed for most cultivated yams except for the higher values of moisture content found in wild samples. This result suggests that both the wild and cultivated yams used by local farmers can be used as reliable source of food and energy.

7.2. General Recommendations

Based on the results obtained from this study the following insights emerge as an essential research direction to focus on.

- ✓ This ethnobotanical study is not exhaustive; no objective generalization can thus be drawn about the actual extent and spatial dynamics of yam diversity in Southwest Ethiopia. Of the *Dioscorea* species used by Sheko and Bench farmers, the *D. cayenensis* complex species is the most economically important, but also has the greatest number of threatened or locally disappearing indigenous yam types and in fact some are already abandoned. The problem is further complicated by the fact that for the majority of the locally perceived biota, their etymology and implied descriptions are incomplete. Besides, the species identity of landraces for member species within the *D. cayenensis* complex is yet to be established. Thus, more detailed ethnobotanical studies in these and other area is of paramount importance to unravel such difficulties and to thoroughly investigate the available yam landrace diversity in Ethiopia.

- ✓ Despite the potential of morphological markers in diversity analysis, it provides limited genetic information. This was apparent from lack of association among the morphological diversity and some of the differently or similarly named individuals by local farmers. This indicates how important it will be to have recourse to more powerful markers. In view of this, DNA based studies will be a valuable addition to the current knowledge on yam.

- ✓ The observed manipulation of wild growing yams in Southwest Ethiopia suggests that the *D. cayenensis* complex is the only yam species known to be subjected to domestication. But, the larger questions of whether the member species within this complex are the valid taxonomic units is remain far from clear. The results of this study thus highlight the need for additional studies. In light of this, molecular and archeological studies will be of a great role to explore the evolutionary dynamics of yams under domestication and to show the full extent of the true genetic diversity of *Dioscorea* species in Ethiopia.

- ✓ Nutritional compositions of the cultivated and wild yams are generally promising. Yet, utilization of wild yams is limited due to its bitterness. This might be related with the presence of anti-nutritional factors such as tannin and phenols in wild yams. We also managed to obtain the nutritional composition of few selected yam landraces. Further nutritional evaluations considering more samples and wild types are necessary to unravel the mentioned gaps and to promote the utilization of this underutilized root crop.

Annexes

Annex 1. Survey questionnaires

I. General information

1. Date of interview _____
2. Name of interviewer _____
3. Name of respondent: _____, Age ----------
4. Ethnic group _____, religion _____
5. Education level _____, Sex _____
6. Location: Region_____ Zone_____ Wereda _____ Kebele ___
7. GPS Co-ordinates: Latitude:_____ Longitude:_____ Altitude:_____

II. Ethnobotanical information

1. **Cultivated yams**

1.1. **The local classification system and diversity of cultivated yams**

1.1.1. How long is it since yam started to be cultivated in the area? ---------- (years)

1.1.2. Land area available for yam cultivation _____ (ha)

1.1.3. Would you please list the local name of currently available landraces on your farm used as food?

No	Local name	Etymology of names	Meaning of the name	Synonyms name
1				
2				

1.1.4. Would you please list the local name of yam landraces you knew?

No	Local name	Etymology of names	Meaning of the name	Synonyms name
1				
2				

1.1.5. How do you differentiate those named and identified landraces each other? ----------
---

1.1.6. Would you please mention the means of identification and naming of the landraces you grew and knew?

No	Local name	Means of identification
1		
2		
3		

1.1.7. Can you mention any additional ways of grouping of the landraces?

1.1.8. In your opinion, do you think that the production of yam is increasing or decreasing in the past five years? _____

1.1.9. What are the reasons for your answer above i.e. for decrease or increase?

1.1.10. Why you cultivate yam?

A. Only for consumption B. Sale of tubers

1.1.11. If you cultivate it only for consumption, tell me the forms of consumption?

A. Staple food B. Additional food

1.1.12. If you cultivate it for sale what is its market value?

No.	Name of the landrace	Market value of the landrace				
		Not marketed	Low	Medium	High	Very high
1						
2						
3						

1.1.13. Distance to most important market_____, Name of the market_____

1.1.14. Can you mention species /landraces used for medicinal purposes?

No.	Name of the Species	Type of disease cured	Part of the plant used	Method of preparation
1				
2				
3				

1.1.14. Other uses of yam ----------

1.2. Management of Cultivated yam

1.2.1. Where do you get the planting materials for yams?

A. Own C. Neighbors

B. Market D. All

1.2.2. How and on what characteristics you select a particular planting material for planting? ----------
---

1.2.3. Have you faced problem of planting materials?

A. yes B. no

1.2.4. If yes, what were the reasons and how do you think such problems would be coped up? ----------

1.2.5. How is yam grown with other crops?

A. Sole B. Mixed

1.2.6. If mixed, with which crop? ----------

1.2.7. Where do you plant yams? _____

1.2.8. When do you plant your yams? _____

1.2.9. How do you plant yams?

A. Flat C. Mound

B. Ridge D. Other, specify-----

1.2.10. Do you have specific spacing arrangement of the crop?

A. Yes B. No

1.2.11. If yes, specify spacing between rows _____ spacing between plants ___

1.2.12. Do you use of fertilizers and weeding for the crop?

A. Yes B. No

1.1.13. If yes, specify the following:

Organic: method _____ rate _____ time _____

Chemical: type _____ method _____ time _____

Weeding: Number _____ time _____

1.1.14. Disease and pest management.

No.	Name of disease	landraces infected	Control measures used
1			
2			
3			
	Name of the pest	landraces infected	Control measures used
1			
2			
3			

1.1.15. Are you staking yams?

A. Yes B. No

1.1.16. If there are landraces that need no staking would you please tell us there name? ----------

1.1.17. Why? ----------

1.1.18. At what frequency you harvest yam?

A. Single harvest B. Double harvest

1.1.19. If single harvest, would you please tell me the time of harvest? _____

1.1.20. If double harvest, is it possible for all landraces you are growing or for certain?

A. Possible for all B. Possible for certain

1.1.20.1. Time of first harvest? _____

1.1.20.2. Time of second harvest? _____

1.1.21. Is there any special advantage of harvesting yam in the month you have indicated above?

1.1.22. Do you store yam?

A. Yes B. No

1.1.23. If yes, please specify the following:

No.		Conditions	Method of storage	Duration of storage
	Name of landraces	Storage for food		
1				
2				
		Storage for propagation		
1				
2				

1.1.24. What is your opinion on the level of storability of the landrace cultivated on your farm?

No.	Name of the landrace	Their storability			
		Poor	good	Very good	Excellent
1					
2					
3					

1.1.25. How do you consume yam?

A. Raw
B. Cooked
C. Blended with other
D. Other, specify -----

1.1.26. If you blend it with other, please specify its blend ----------

1.1.27. Do you further process yam?

A. Yes
B. No

1.1.28. If yes, please describe the procedures used for processing?

A. Processing for consumption ----------
B. Processing for medical purpose ----------
C. Method of processing ----------
D. Cooking qualities ----------

2. **Wild yams**

2.1. The local classification system and diversity of wild yam

2.1.1. Would you please list those wild yams which are consumed as food purpose in your environment?

No	**Local name**	Etymology of names	Meaning of the name	Synonyms name
1				
2				
3				

2.1.2. Would you please list any wild yams which are used as medicinal purpose in your environment?

No	**Local name**	Etymology of names	Meaning of the name	Synonyms name
1				
2				
3				

2.1.3. How do you know, identify and select those edible wild yams and wild yams that used as medicinal purpose during gathering?

2.1.4. Would you please characterize those wild yams listed above:

No	**Name of wild yam**	Characteristics
1		
2		
3		

2.2. Knowledge of wild yam and wild yam domestication

2.2.1. Do you know the existence of wild yam in their environment, if yes please describe where they exist? ----------

2.2.2. Do you know the distribution of wild yams, if yes describe ----------

2.2.3. Do you know time of wild yam availability, if yes answer when? ----------

2.2.4. Do you use wild yams as food, if yes please describe when do you use it as food ----------

2.2.5. Do you have a simple knowledge of domestication, if yes describe it the way you domesticate ----------

2.2.6. Can you describe the technique of domestication ----------

2.2.7. Can you describe the distinct morphotypes of wild and domesticated yams, if yes please mention the distinct morphotypes between domesticated and wild yam? ----------

2.2.8. Do you practice techniques of domestication; if yes please mention the techniques of domestication? ----------

3. **Wild transplant yams**

3.1. The local classification system and diversity of wild transplant yam

3.1.1. Would you please list those wild transplant yams which are consumed as food?

No	Local name	Etymology of names	Meaning of the name	Synonyms name
1				
2				
3				

3.1.2. Would you please characterize those wild transplant yams listed above:

No	Name of wild yam	Characteristics
1		
2		
3		

3.2. **The process of domestication**

3.2.1. Is there any yam landraces in your farm under domestication?

A. Yes B. No

3.2.2. If yes, would you please answer the following question

a. Which type of planting material you use for domestication? ----------

b. Where do you get the original planting material? ----------

3.2.3. Do you know history of transplantation? _____

If yes when did you bring it to the home garden? _____

3.2.4. What are the basic management's types you employ at this stage?

3.2.5. Do you observe any agro-morphological variations in yams managed in this way compared with wild and domesticated yams?

A. Yes B. No

3.2.6. If yes, would you please give me a general description of these variations by comparing them either to existing named landraces or the wild yams you had known when you were youth

---

3.2.7. How long it take to obtain morphologically alike landraces to those of cultivated types _____ (years of cultivation)

3.2.8. Can you describe the agro-morphological variations you observed during the domestication process?

	Variations observed during the process		
List of yams under domestication	**Year I**	**Year II**	**Year III**
1			
2			
3			

3.2.9. Do you adopt any specific criteria to select these plants for cultivation?

A. Yes B. No

3.2.10. If yes, would you please mention those packages adopted before mass cultivation in the future?

3.2.11. Do you employ any technique to transform wild types into cultivated type?

A. Yes B. No

3.2.12. If yes, would you tell me please the type of techniques you employ?

3.2.13. Do you have any recently developed yam cultivar in this way?

A. Yes B. N

3.2.14. If yes, would you please specify the name? ----------

3.2.15. Why do you domesticate Yam?

a. For dietary reasons
b. To enrich the existing diversity
c. For curiosity/to sustain native knowledge

Annex 2.1. Assessment of naming consistency with samples occurring in ≥10 farms, out of the 272 farms surveyed.

List of landraces based on the most commonly known	Number of farms where landraces were found	No. of HHs that spot it by commonly known name		No. of households that identify it by other names	
		Freq.	Proportion (%)	Freq.	Other names
Ama-tsaa'nseb, Tiab-oake	62	46	74	16	*Ama/Oake, Wakach*
Ama-ga'nseb, Don-oake	16	13	81	3	*Neep Oake*
Bandaboy	55	55	100	-	-
Beri	10	10	100	-	-
Earkubay	43	23	53	20	*Wurgit*
Kachi-Ga'nseb	12	12	100	-	-
Kachi-Tsaa'nseb	99	80	81	19	*Dizzu-Kachi*
Karka-kachi	23	20	87	3	*Baidai- kachi*
Logit	23	23	100	-	-
Ongubay, Baday	136	110	81	26	*Badach*
Shamut	26	26	100	-	-
Shapinsin	13	13	100	-	-
Tolubab	28	28	100	-	-
Torbay	18	15	83	3	*Baidai/Kaibab-Kachi*
Tsidboy	95	95	100	-	-

NB; Naming is considered consistent, if more than 80% of the samples are identified by the same names across locations.

Annex 2.2. Summary of the characters and character states used by farmers for identification and distinction of the taxa assigned to different groups

Character class	Specific plant characters		Class of taxa	Character states				
	Characters			1	2	3	4	5
Morphological	1	Spines on the stem	SPV	None	Few	Medium	High	Very high
	2	Stem height	SPV	short	Intermediate	Long		
	3	Color of basal stems	V	Green	Red	Pale grey	Black	
	4	Color of leaves	SPV	Light green	Green	Dark green		
	5	Leaf size	V, SPV	Small	Intermediate	Large		
	6	Tuber size	V, SPV	Small	Medium	Large		
	7	Tuber color	V, SBV	Black	White	Spotted	Red	
	8	Tuber shape	V, SPV	Irregular	Cylindrical	Oval	Round	
	9	Tuber length	V, SPV	Short	Medium	Long		
	10	Tuber texture	V	Firm	Soft			
	11	Spines on the tuber	V, SPV	None	Few	Medium	High	Very high
	12	Ability to flowering	SPV	Yes	No			
	13	Ability to produce seed	SPV	Yes	No			
	14	Sex of plants	SPV	Female	Male			
Physiological	15	Plant growth rate	SPV	Less vigor	Intermediate	Vigor		
	16	Tolerance to biotic stress	SPV	Tolerant	Susceptible			
	17	Tolerance to biotic stress	SPV	Tolerant	Susceptible			
Tuber quality	18	Taste of tubers	V, SPV	Sweet	Bitter			
	19	Edibility	SPV	Edible	Inedible			
	20	Texture of cooked tubers	V	Crispy	Firm	Soft		
Plant cycle	21	Maturity time	SPV	Short	Intermediate	Long		
	22	Number of harvest	SPV	Double	Single			
		Non-plant characters						
Origin	23	Contexts	V, SPV	Wild	Cultivated	Wild transplant		
	24	Area where comes from	V	Area name	Ethnic groups			
Physical	25	Attributes of a person	V	Size	Nature	Gender		
	26	Attributes of animals	V	Anatomy	Name of animal			

SPV: Supra variety, V: Variety, SBV: Sub variety

Annex 3.1. Pearson Correlation coefficients between districts and Kebeles among the various diversity indices

	Correlation between districts					Correlation between Kebeles			
	R	*1-D*	*H'*	*E*		*R*	*1-D*	*H'*	*E*
R	1				*R*	1			
1-D	0.89*	1			*1-D*	0.56*	1		
H'	0.95**	0.98**	1		*H'*	0.90***	0.84***	1	
E	-0.91*	-0.77^{ns}	-0.81^{ns}	1	*E*	-0.72**	0.08ns	-0.41ns	1

R = Richness, *1-D* = Simpson's index, *H'* = Shannon index, *E* = Evenness, ns = non significant at 5% probability level, * = significant at 5% probability level, ** = significant at 1% probability level, *** = significant at 0.1% probability level.

Annex 3.2. ANOVA for richness of landraces between districts and among Kebeles within the district.

Source	DF	Sum Square	Mean Square	F value	Pr > F
District	4	52.27	13.07	5.64	0.0186
Kebele	2	26.13	13.07	5.64	0.0296
Error	8	18.53	2.32		
Total	14	96.93			
CV (%)	17.43			17.43	

Annex 3.3. ANOVA for individual households in 15 Kebeles growing 1 to 6 landraces per farm.

Source	DF	Sum Square	Mean Square	F value	Pr > F
Kebele	14	41.65	2.98	3.07	0.0002
Error	257	249.31	0.97		
Total	271	290.97			
CV (%)	37.36				

Annex 3.4. Pearson Correlation coefficients between distribution and local abundance of landraces among districts and Kebeles

	District distribution	Kebele distribution	Abundances
District distribution	1	0.93***	0.62***
Kebele distribution		1	0.76***
Abundances			1

*** = significant at 0.1% probability level.

Annex 4.1. List of the 37 qualitative and the 13 quantitative characters considered for morphological study

a. Qualitative characters			
Characters	**Codes**	**Characters**	**Codes**
Stem color, young	1	Vein color, lower surface	20
young stem wing color	2	Leaf Shape	21
Spines on young stems	3	Distance between lobes	22
colored spot at spine base	4	Downward arching along main vein	23
Color of young leaves	5	Upward unfolding of leaves	24
Petiole color, young leaves	6	Leaf tip color	25
petiole wing color, young leaves	7	Petiole color	26
Twining direction	8	Petiole wing color	27
Stem color	9	Flowering	28
Spines at stem base	10	Sex of plants	29
Spines at stem above base	11	Type of Inflorescence	30
Spine shape	12	type of tuber	31
Wings on the stem	13	Tuber shape	32
Stem wing color	14	Spiny roots on the tuber crown	33
Leaf Position	15	Spineness of tuberous roots	34
Leaf margin color	16	Tuber color, proximal end	35
Leaf Lobation	17	Tuber color, middle section	36
Leaf color	18	Tuber color, distal end	37
Vein color, upper surface	19		
b. Quantitative characters			
Characters	**Codes**	**Characters**	**Codes**
Leaf length-1	1	Length of inflorescence	8
Leaf length-2	2	Days to emergence from planting	9
Leaf width-1	3	Days to flowering from planting	10
Leaf width-2	4	Days to flowering from emergence	11
Tuber Length	5	Days to maturity from planting	12
Tuber-Width	6	Days to maturity from emergence	13
Number of inflorescence	7		

NB: Descriptions of scales for the qualitative character states are presented in Table 4.2

Annex 4.2. The respective scales for each of the qualitative character states used for multivariate analysis.

Accession codes		Character codes and the corresponding scales for each of the character states																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	BMJ 001	1	0	2	1	4	0	0	2	1	8	8	2	0	0	2	1	2	4	2
2	BMJ 002	1	0	2	1	4	0	0	2	1	8	8	2	0	0	2	2	1	4	2
3	BMJ 003	2	0	1	1	5	0	0	2	1	9	8	1	0	0	2	1	1	3	2
4	BMJ 004	2	0	2	1	2	0	0	2	1	8	8	1	0	0	2	1	2	4	2
5	BMJ 005	1	0	2	1	2	0	0	2	1	8	9	2	0	0	2	2	1	4	4
6	BMJ 006	2	0	1	1	5	0	0	2	1	9	8	1	0	0	2	1	1	3	2
7	BMJ 007	2	0	1	1	2	0	0	2	2	8	8	2	0	0	2	1	1	3	4
8	BMJ 008	1	0	1	1	2	0	0	2	1	8	7	1	0	0	2	1	2	3	4
9	BMJ 009	1	0	1	1	2	0	0	2	1	8	7	1	0	0	2	1	2	3	2
10	BMJ010a	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	1	2	3	4
11	BMJ 010b	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	1	2	3	4
12	BMJ 011	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	2	2	3	2
13	BMJ 012	3	0	1	1	4	0	0	2	3	3	3	1	0	0	2	1	2	4	2
14	BMJ 013	1	0	1	1	4	0	0	2	2	3	1	0	0	0	2	1	2	4	2
15	BMJ 014a	3	0	1	1	4	0	0	2	3	4	3	1	0	0	2	1	2	4	2
16	BMJ 014b	3	0	1	1	4	0	0	2	4	4	3	1	0	0	2	1	2	4	2
17	BMJ 015	2	0	1	1	5	0	0	2	3	7	5	1	0	0	2	1	1	4	2
18	BMJ 016	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	2	2	3	4
19	BMJ 017	1	0	0	0	2	0	0	1	1	0	0	0	0	0	1	2	2	3	4
20	BMJ 018	1	0	1	1	2	0	0	2	1	8	7	1	0	0	2	1	2	3	4
21	BMJ 019	2	0	1	1	4	0	0	2	3	8	7	1	0	0	2	2	2	4	2
22	BMJ 020	1	0	1	1	1	0	0	2	1	8	5	2	0	0	2	1	1	3	2
23	BMJ 021	3	0	2	1	4	0	0	2	3	8	5	1	0	0	2	1	1	3	2
24	BMJ 022a	3	0	2	0	5	0	0	2	3	7	7	1	0	0	2	1	1	4	4
25	BMJ 022b	3	0	2	1	5	0	0	2	3	7	7	1	0	0	2	1	1	4	4
26	BMJ 023	2	0	2	1	5	0	0	2	3	8	5	1	0	0	2	1	1	4	4
27	BMJ 024	2	0	1	1	4	0	0	2	1	8	7	1	0	0	2	1	1	4	2
28	BMJ 025a	1	0	1	2	2	0	0	2	1	8	7	1	0	0	2	1	1	3	4
29	BMJ 025b	1	0	1	2	2	0	0	2	1	8	7	1	0	0	2	1	1	3	4
30	BMJ 026	1	0	1	1	2	0	0	2	1	7	5	1	0	0	2	1	1	3	2
31	BMJ 027	2	0	2	1	4	0	0	2	1	8	7	1	0	0	2	2	1	3	4
32	BMJ 028a	3	0	1	2	4	0	0	2	3	4	4	1	0	0	2	2	1	4	3
33	BMJ 028b	3	0	1	2	4	0	0	2	3	5	4	1	0	0	2	2	1	4	3
34	BMJ 029	3	0	0	1	5	0	0	2	4	4	3	0	0	0	2	2	1	4	4
35	BMJ 030	1	0	2	2	4	0	0	2	3	7	5	2	0	0	2	1	2	4	3
36	BMJ 031	4	0	1	2	5	0	0	2	3	3	3	1	0	0	2	2	1	4	3
37	BMJ 032	1	0	1	1	1	0	0	2	2	3	3	1	0	0	2	1	1	3	2
38	BMJ 033a	4	0	1	1	4	0	0	2	3	7	4	1	0	0	2	1	2	4	4
39	BMJ 033b	4	0	1	1	4	0	0	2	3	7	4	1	0	0	2	1	2	3	2
40	BMJ 034a	1	0	2	2	2	0	0	2	1	9	8	2	0	0	2	1	2	4	2
41	BMJ 034b	1	0	2	2	2	0	0	2	1	9	8	2	0	0	2	1	2	4	2
42	BMJ 034c	1	0	2	2	2	0	0	2	1	9	8	2	0	0	2	1	2	4	2

NB: Character codes are as given in Annex 4.1

Annex 4.2. Cont……..

Accession codes		Character codes and the corresponding scales for each of the character states																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
43	SHK 001a	3	0	1	1	4	0	0	2	3	4	3	1	0	0	2	1	1	4	4
44	SHK 001b	3	0	1	1	4	0	0	2	3	4	3	1	0	0	2	1	1	4	4
45	SHK 002	3	0	1	2	5	0	0	2	3	4	3	1	0	0	2	1	1	3	3
46	SHK 003	3	0	1	1	4	0	0	2	3	4	3	1	0	0	2	2	1	4	4
47	SHK 004	4	0	2	1	4	0	0	2	2	8	7	1	0	0	2	2	2	4	4
48	SHK 005	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	2	2	4	4
49	SHK 006	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	1	2	3	4
50	SHK 007	2	0	1	1	5	0	0	2	3	3	2	1	0	0	2	1	1	4	4
51	SHK 008	2	0	1	1	5	0	0	2	3	3	2	1	0	0	2	1	1	4	4
52	SHK 009a	4	0	1	1	4	0	0	2	2	7	5	1	0	0	2	2	1	4	2
53	SHK 009b	4	0	1	1	4	0	0	2	2	5	3	0	0	0	2	2	1	4	2
54	SHK 010	1	0	1	1	2	0	0	2	1	8	7	1	0	0	2	1	1	3	4
55	SHK 011	1	2	0	0	1	6	4	2	1	0	0	0	1	2	2	1	1	2	2
56	SHK 012	1	2	0	0	1	6	4	2	1	0	0	0	1	2	2	1	1	2	2
57	SHK 013	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	1	2	3	4
58	SHK 014	1	2	0	0	1	3	4	2	1	0	0	0	1	1	2	1	2	3	4
59	KAF 001	2	0	1	1	4	0	0	2	2	7	5	2	0	0	2	2	1	4	2
60	KAF 002	2	0	1	1	4	0	0	2	2	7	5	2	0	0	2	2	1	4	2
61	BAS 001	3	0	0	1	1	0	0	2	3	3	2	1	0	0	2	2	1	4	2
62	BAS 002	3	0	1	1	5	0	0	2	1	3	3	1	0	0	2	2	2	3	4
63	BAS 003	3	0	0	1	4	0	0	2	1	4	3	1	0	0	2	2	1	4	2
64	BAS 004	3	0	0	1	4	0	0	2	3	4	3	0	0	0	2	2	1	3	2
65	BAS 005	3	0	0	1	4	0	0	2	3	2	1	0	0	0	2	2	1	2	2
66	DAR 001	2	0	1	1	2	0	0	2	2	3	1	1	0	0	2	2	1	4	4
67	DIT 001	1	0	1	1	2	0	0	2	1	4	3	1	0	0	2	2	2	3	4
68	BAS 006	3	0	0	1	4	0	0	2	3	4	3	0	0	0	2	2	1	3	2
69	BAS 007	3	0	0	1	2	0	0	2	3	4	3	1	0	0	2	2	2	3	4
70	DAR 002	2	0	1	1	2	0	0	2	2	5	3	1	0	0	2	2	1	4	4
71	DAR 003	2	0	0	1	4	0	0	2	1	2	1	0	0	0	2	1	1	2	2
72	BAS 008	3	0	0	1	4	0	0	2	3	4	3	0	0	0	2	2	1	3	2
73	BAS 009	3	0	0	1	5	0	0	2	3	2	1	0	0	0	2	2	1	4	4
74	DAR 004	3	0	0	1	4	0	0	2	2	3	2	1	0	0	2	1	2	4	4
75	WOL 001	1	0	2	1	4	0	0	2	1	8	7	2	0	0	2	1	2	3	4

NB: Character codes are as given in Annex 4.1

Annex 4.2. Cont……..

Accession codes		Character codes and the corresponding scales for each of the character states																	
		20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1	BMJ 001	1	4	2	1	1	2	3	0	1	1	1	1	4	9	8	4	3	1
2	BMJ 002	2	5	3	1	1	2	6	0	1	1	1	1	4	7	7	4	4	3
3	BMJ 003	1	4	2	1	1	2	3	0	1	1	1	1	4	9	8	4	3	1
4	BMJ 004	1	4	2	1	1	2	6	0	1	1	1	1	4	8	7	3	3	4
5	BMJ 005	2	4	2	1	1	2	3	0	1	1	1	1	4	8	7	4	4	3
6	BMJ 006	1	4	2	1	1	2	3	0	1	1	1	1	6	9	9	2	4	3
7	BMJ 007	1	5	2	1	1	2	3	0	1	1	1	1	4	9	8	3	3	3
8	BMJ 008	2	5	2	1	2	2	1	0	1	1	1	1	4	7	6	3	1	1
9	BMJ 009	1	5	2	1	1	1	1	0	1	2	1	1	4	8	7	3	3	1
10	BMJ010a	1	5	3	1	1	1	1	1	0	0	0	1	1	0	0	1	1	1
11	BMJ 010b	1	5	3	1	1	2	1	1	0	0	0	1	4	0	0	1	1	1
12	BMJ 011	2	5	3	1	1	2	1	1	0	0	0	1	4	0	0	1	1	1
13	BMJ 012	2	5	2	1	1	2	6	0	1	2	1	1	4	3	2	2	4	3
14	BMJ 013	2	5	2	1	1	2	6	0	1	2	1	1	1	3	1	3	4	1
15	BMJ 014a	2	5	2	1	1	2	6	0	1	2	1	1	4	5	3	2	3	1
16	BMJ 014b	2	5	2	1	1	2	6	0	1	2	1	1	4	4	3	2	4	3
17	BMJ 015	2	2	2	1	1	2	7	0	1	2	1	1	4	4	3	4	4	4
18	BMJ 016	1	6	2	1	1	1	1	1	0	0	0	1	3	0	0	1	1	1
19	BMJ 017	1	6	2	1	1	2	1	0	0	0	0	2	1	0	0	3	1	1
20	BMJ 018	2	5	2	1	2	2	1	0	1	1	1	1	4	7	6	3	1	1
21	BMJ 019	1	6	3	0	1	2	6	0	1	1	1	1	4	9	8	4	4	3
22	BMJ 020	1	6	3	1	1	2	3	0	1	1	1	1	4	8	7	3	1	3
23	BMJ 021	1	5	3	1	1	2	6	0	1	2	1	1	4	8	7	2	2	3
24	BMJ 022a	2	5	2	1	1	2	6	0	1	2	1	1	4	6	5	2	4	3
25	BMJ 022b	2	5	2	1	1	2	7	0	1	2	1	1	4	6	5	2	4	4
26	BMJ 023	2	3	2	0	1	2	3	0	1	2	1	1	6	4	3	4	4	4
27	BMJ 024	1	6	2	1	1	1	3	0	1	2	2	1	6	7	6	4	3	1
28	BMJ 025a	2	6	2	1	2	2	1	0	1	1	1	1	4	7	6	3	3	1
29	BMJ 025b	2	6	3	1	1	2	1	0	1	1	1	1	4	8	7	3	3	1
30	BMJ 026	2	2	2	1	2	2	1	0	1	1	1	1	4	9	8	3	3	1
31	BMJ 027	2	4	2	0	1	2	1	0	1	2	1	1	4	8	7	3	1	1
32	BMJ 028a	2	5	2	1	2	2	6	0	1	2	1	1	6	7	6	2	4	4
33	BMJ 028b	2	5	2	1	2	2	6	0	1	2	1	1	6	6	5	2	4	4
34	BMJ 029	2	6	3	1	1	2	3	0	1	2	1	1	6	8	7	3	3	1
35	BMJ 030	2	4	2	1	1	2	6	0	1	2	1	1	6	8	7	2	4	4
36	BMJ 031	2	6	2	1	1	2	6	0	1	2	1	1	4	8	7	2	4	3
37	BMJ 032	1	2	2	1	2	2	1	0	1	1	1	1	4	5	4	3	1	1
38	BMJ 033a	2	5	2	1	1	2	7	0	1	2	1	1	4	6	5	2	3	3
39	BMJ 033b	1	5	2	1	2	2	6	0	1	2	1	1	4	7	6	2	4	4
40	BMJ 034a	1	4	2	1	1	2	3	0	1	1	1	1	4	9	8	3	1	1
41	BMJ 034b	1	4	2	1	1	2	3	0	1	1	1	1	4	9	8	3	1	1
42	BMJ 034c	1	4	2	1	1	2	3	0	1	1	1	1	4	9	8	3	1	1

NB: Character codes are as given in Annex 4.1

Annex 4.2. Cont……..

Accession codes		Character codes and the corresponding scales for each of the character states																	
		20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
43	SHK 001a	2	5	2	1	2	2	7	0	1	2	1	1	6	3	2	4	3	3
44	SHK 001b	2	5	2	1	2	2	7	0	1	2	1	1	6	3	2	4	3	3
45	SHK 002	1	5	2	1	1	1	6	0	1	2	1	1	4	3	2	2	4	3
46	SHK 003	2	5	3	0	1	2	7	0	1	2	1	1	6	3	2	4	3	4
47	SHK 004	2	5	3	0	1	2	7	0	1	2	1	1	4	3	2	4	3	3
48	SHK 005	2	5	2	0	1	2	1	1	0	0	0	1	1	0	0	1	1	1
49	SHK 006	1	5	3	1	1	2	1	1	0	0	0	1	4	0	0	1	1	1
50	SHK 007	2	5	2	0	1	2	7	0	1	2	1	1	4	3	2	2	4	4
51	SHK 008	2	5	3	0	1	2	7	0	1	2	1	1	3	3	1	2	4	1
52	SHK 009a	2	5	2	1	1	2	7	0	1	2	1	1	4	3	2	2	4	4
53	SHK 009b	2	5	2	1	1	2	7	0	1	2	1	1	4	4	3	2	4	4
54	SHK 010	2	6	3	1	2	2	1	0	1	1	1	1	4	8	7	3	3	1
55	SHK 011	1	5	2	1	1	2	6	1	0	0	0	1	6	0	0	3	3	3
56	SHK 012	1	5	3	1	1	1	6	1	0	0	0	1	6	0	0	3	3	3
57	SHK 013	1	5	3	1	1	2	1	1	0	0	0	1	4	0	0	1	1	1
58	SHK 014	1	5	2	1	1	2	1	1	0	0	0	1	4	0	0	1	1	1
59	KAF 001	1	2	2	1	1	2	6	0	1	1	1	1	6	5	3	2	2	2
60	KAF 002	1	2	2	1	1	2	6	0	1	1	1	1	6	5	3	3	3	4
61	BAS 001	2	5	2	1	1	2	6	0	1	2	1	1	4	4	3	2	4	3
62	BAS 002	2	5	2	1	1	2	1	0	1	2	2	1	4	3	1	4	3	3
63	BAS 003	2	5	2	1	1	2	6	0	1	2	1	1	4	3	2	2	4	3
64	BAS 004	1	5	2	1	1	2	6	0	1	1	1	1	4	4	3	3	1	1
65	BAS 005	1	5	2	1	1	2	7	0	1	2	1	1	4	3	2	2	4	4
66	DAR 001	2	5	3	1	1	2	7	0	1	1	1	1	4	3	1	3	1	1
67	DIT 001	2	5	2	1	1	2	1	0	1	2	1	1	4	5	4	4	4	1
68	BAS 006	1	5	2	1	1	2	6	0	1	1	1	1	4	4	3	3	1	1
69	BAS 007	2	5	2	1	1	2	6	0	1	2	1	1	4	3	2	2	2	4
70	DAR 002	2	5	3	1	1	2	7	0	1	1	1	1	4	4	3	1	1	1
71	DAR 003	1	5	2	1	1	2	1	0	1	2	1	1	4	3	2	3	3	1
72	BAS 008	1	5	2	1	1	2	6	0	1	1	1	1	4	4	3	3	1	1
73	BAS 009	2	5	2	1	1	2	7	0	1	2	1	1	5	3	2	4	3	3
74	DAR 004	2	5	3	1	1	2	7	0	1	1	1	1	4	3	2	3	3	1
75	WOL 001	1	4	3	1	1	2	1	0	1	1	1	1	4	5	4	3	3	3

NB: Character codes are as given in Annex 4.1

Annex 4.3. The respective scales for each of the quantitative character states used for multivariate analysis.

Accession codes		Character codes and the corresponding values												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	BMJ 001	8.67	0.84	6.57	3.69	55	21	1	15	19	179	160	288	269
2	BMJ 002	8.20	1.31	7.26	3.63	44	13.5	1	13	64	181	117	315	251
3	BMJ 003	8.81	0.60	5.67	3.70	37.5	15	1	12	64	179	115	315	251
4	BMJ 004	9.53	1.33	5.83	3.70	55	21	1	14	33	179	146	296	263
5	BMJ 005	8.17	1.02	7.26	4.00	44	13.5	1	13	54	191	137	296	242
6	BMJ 006	8.81	0.60	5.67	3.70	55	21	1	15	33	179	146	294	261
7	BMJ 007	10.97	1.57	7.38	4.25	53	15.5	1	10	27	164	137	279	252
8	BMJ 008	8.43	1.77	6.47	4.45	42.5	9	3	10	31	164	133	284	253
9	BMJ 009	10.07	1.26	6.07	4.53	39	21	2	5	11	154	143	260	249
10	BMJ010a	11.37	2.00	7.77	6.10	20	16	0	0	55	0	0	241	186
11	BMJ 010b	13.77	2.40	8.67	7.83	23	20.5	0	0	75	0	0	272	197
12	BMJ 011	14.30	3.23	9.27	7.90	37	15.5	0	0	52	0	0	260	208
13	BMJ 012	9.93	1.29	5.50	4.42	16.5	9.5	2	5	31	143	112	241	210
14	BMJ 013	8.83	1.45	5.07	4.07	25.5	17	2	5	13	137	124	223	210
15	BMJ 014a	9.37	1.39	5.32	4.23	38.5	11	2	6	31	137	106	241	210
16	BMJ 014b	9.63	1.67	5.34	4.23	33	13	2	5	33	143	110	241	208
17	BMJ 015	7.59	1.31	4.29	3.76	24	14	3	5	21	167	146	241	220
18	BMJ 016	15.40	3.57	10.69	8.83	35.5	18	0	0	31	0	0	241	210
19	BMJ 017	17.45	4.73	17.45	12.86	8	8	0	0	75	0	0	241	166
20	BMJ 018	8.27	1.67	6.33	4.43	42.5	9	1	10	64	186	122	272	208
21	BMJ 019	10.43	1.29	6.07	3.97	40.5	18	1	5	16	137	121	241	225
22	BMJ 020	9.15	1.58	7.09	5.57	44.5	15	2	5	13	167	154	267	254
23	BMJ 021	9.33	1.40	5.13	3.98	27.5	20	4	6	15	137	122	223	208
24	BMJ 022a	10.27	1.93	6.47	5.00	31	21.5	4	5	31	161	130	231	200
25	BMJ 022b	10.13	1.97	6.17	4.43	30	20.5	4	6	59	163	104	259	200
26	BMJ 023	8.95	1.41	5.56	4.03	27.5	13	3	7	11	137	126	223	212
27	BMJ 024	7.69	2.17	6.95	5.10	37	8	2	6	24	155	145	265	241
28	BMJ 025a	8.43	0.84	5.83	3.93	37	8	1	11	38	163	125	288	250
29	BMJ 025b	8.20	0.85	5.37	3.43	37	8	1	12	38	163	125	288	250
30	BMJ 026	7.26	0.84	5.01	3.48	27	16	1	13	11	164	153	288	277
31	BMJ 027	12.70	3.17	10.15	7.53	30	20.5	2	6	17	169	152	288	271
32	BMJ 028a	9.85	1.31	5.35	3.95	43	14	3	6	33	137	104	223	190
33	BMJ 028b	8.90	1.28	4.90	3.70	45.5	31	3	5	31	137	106	221	190
34	BMJ 029	9.82	0.93	5.82	4.21	24.5	19	2	5	31	143	112	223	192
35	BMJ 030	9.31	1.41	5.27	3.87	27.5	13.5	3	5	55	137	82	223	168
36	BMJ 031	8.27	1.77	5.47	3.92	33	11	4	6	33	137	104	241	208
37	BMJ 032	8.40	1.59	6.06	4.77	21	8	1	13	31	166	135	288	257
38	BMJ 033a	9.23	1.24	5.12	3.83	41	27	4	4	52	159	107	239	187
39	BMJ 033b	9.32	1.12	5.60	4.20	24.5	18.5	3	5	17	137	120	223	206
40	BMJ 034a	8.81	0.60	5.67	3.70	55	21	1	14	69	197	128	319	250
41	BMJ 034b	8.11	0.97	5.51	3.17	44	13.5	1	15	33	153	120	329	296
42	BMJ 034c	9.53	1.33	5.83	3.70	55	21	1	13	69	197	128	319	250

NB: Character codes are as given in Annex 4.1

Annex 4.3. Cont……..

Accession codes		Character codes and the corresponding values												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
43	SHK 001a	9.37	1.39	5.32	4.23	34	10.5	3	6	19	146	127	223	204
44	SHK 001b	7.90	1.15	4.20	3.23	32	14	2	5	38	161	123	223	185
45	SHK 002	8.70	1.33	4.57	3.39	40	18	3	5	33	137	104	223	190
46	SHK 003	9.83	1.62	5.91	4.89	36	20	6	5	31	145	114	241	210
47	SHK 004	10.23	1.41	5.57	4.50	42	21	4	4	31	161	130	241	210
48	SHK 005	14.23	3.03	9.33	7.40	28	29	0	0	31	0	0	260	229
49	SHK 006	13.77	2.40	8.67	7.83	25	26.5	0	0	31	0	0	241	210
50	SHK 007	7.47	1.23	5.08	3.23	35	15	4	3	52	159	107	221	169
51	SHK 008	7.43	1.23	5.27	3.21	36	10	3	4	66	154	88	241	175
52	SHK 009a	9.93	1.29	5.50	4.42	41	25	3	5	33	137	104	223	190
53	SHK 009b	10.10	1.29	5.41	4.49	27.5	19	2	4	31	137	106	223	192
54	SHK 010	8.43	0.84	5.83	3.93	41	25	1	10	17	169	152	288	271
55	SHK 011	14.13	3.83	10.4	7.83	26	23	0	0	95	0	0	260	165
56	SHK 012	14.37	3.67	10.3	9.03	20.5	17.5	0	0	75	0	0	272	197
57	SHK 013	13.70	3.07	9.87	7.47	38.5	27.5	0	0	35	0	0	272	237
58	SHK 014	12.63	2.60	8.93	6.07	28	29	0	0	79	0	0	284	205
59	KAF 001	6.74	0.58	4.62	2.96	42	16	1	13	9	164	155	223	214
60	KAF 002	6.74	0.58	4.62	2.96	40	16.5	1	15	11	164	153	223	212
61	BAS 001	6.11	0.49	4.08	2.58	36.5	16.5	3	4	21	126	105	206	185
62	BAS 002	7.10	0.85	6.40	3.80	46.5	31	2	4	16	133	117	224	208
63	BAS 003	6.11	0.49	4.08	2.58	24.5	19	4	3	14	126	112	224	210
64	BAS 004	6.71	0.97	4.18	3.47	27.5	13.5	2	10	14	133	119	267	253
65	BAS 005	10.20	1.61	6.13	4.72	27.5	16	4	4	14	126	112	224	210
66	DAR 001	6.50	1.20	5.20	5.03	36.5	10.5	1	11	14	152	138	259	245
67	DIT 001	7.83	1.77	6.47	3.57	30.5	16.5	2	6	37	133	96	224	187
68	BAS 006	6.71	0.97	4.18	3.47	47.5	12.5	2	11	49	133	84	267	218
69	BAS 007	7.77	1.08	5.10	5.07	42.5	11.5	2	4	16	120	104	206	190
70	DAR 002	7.80	1.00	4.87	4.50	26.5	9.5	1	12	14	152	138	259	245
71	DAR 003	6.97	1.47	6.03	4.27	17	10	4	4	16	126	110	206	190
72	BAS 008	6.71	0.97	4.18	3.47	43	8.5	2	10	14	133	119	267	253
73	BAS 009	8.67	1.25	5.70	3.60	38	7	6	5	14	133	119	206	192
74	DAR 004	6.50	1.20	5.20	5.03	17	16	2	10	14	152	138	259	245
75	WOL 001	8.07	1.20	6.17	4.40	25	15	2	11	14	152	138	259	245

NB: Character codes are as given in Annex 4.1

Annex 5.1. Variation in major morphological traits among yam landraces corresponding to accessions of the *D. cayenensis* complex

Folk names	Summary of major characteristics of qualitative traits as summarized from agro-morphological study
*Karka-kachi****	Young stem: green with many spines at the base and colored spot. Mature stem: green with very high curved spines at and above the base. Leaf: medium sized, dark green and cordate broad. Petioles: green with brown at both ends. Female flowers. Tubers: cylindrical long, exhibit very high spiny roots on the tuber crown, dense to very dense spines on the tuberous roots.
*Karka-kachi***	Young stem: green with many spines at the base without colored spot. Mature stem: green with high to very high curved spines at and above the base. Leaf: medium sized, dark green and cordate broad. Petioles: green with brown at both ends. Female flowers. Tubers: cylindrical long, exhibit high to very high spiny roots on the tuber crown, dense spines on the tuberous roots.
*Yasind***	Young stem: Brownish green, few spines without colored spot. Mature stem: Brownish green, many spines at and above the base. Leaves: large sized, green, sagittate long and broad. Petioles: green with brown at both ends. Female flowers. Tuber cylindrical long, very high spiny roots on the tuber crown, dense to very dense spines on the tuberous roots.
*Torbay**	Green stems and leaves, few spines at young stem base without colored spot, high to very spines at and above adult stem base, straight spine shape, sagittate long leaves, green petioles, male flowers, cylindrical broad tubers, high to very high spiny roots on tuber crown, dense spines on tuberous roots.
*Kaibab-kachi**	Green stems and leaves, few spines at young stem base without colored spot, high to very high spines at adult stem base, high spines at adult stem above the base, straight spines, sagittate leaves, green petioles, female flower, cylindrical broad tubers, high to very high spiny roots on tuber crown, dense spines on tuberous roots.

Annex 5.1. Cont……

*Chabsha**	Brownish green young stems, few spines at stem base without colored spot, brownish green young leaves, green mature stems, high to very high spines at stem base, high spines at stem above the base, straight spines, dark green and , sagittate broad mature leaves, green petioles with brown at both ends, male flower, irregular tuber, high spiny roots on tuber crown, medium to dense spines on the tuberous roots.
*Tolubab**	Brownish green young stems, many spines at stem base without colored spot; brownish green young leaves; green adult stems and leaves; high to very high spines at stem base; high spines at stem above the base; straight spines; large sized, cordate broad leaves; green petioles, male flower, cylindrical broad tuber, high to very high spiny roots on tuber crown, dense spines on the tuberous roots.
Beri	Green stems and leaves, few spines on young stem without colored spot, high to very high spines at and above adult stem base, straight spine shapes, sagittate long leaves, green petioles, female flowers, cylindrical tubers, high spiny roots on tuber crown, intermediate to dense spines on tuberous roots.
Shapinsin	Green stems, few spines at young stem base without colored spot, light green young leaves, high to very high spines at adult stem base, intermediate spines at adult stem above the base, curved spines, large sized, green and sagittate broad adult leaves, green petioles with brown at both ends, female flower, cylindrical tuber, high to very high spiny roots on tuber crown, dense spines on the tuberous roots.
Banda-boy	Green mature stems, few spines at young stem base with colored spot, high to very high spines at adult stem base, high spines at adult stem above the base, straight spines, green and sagittate broad adult leaves, green petioles, female flower, cylindrical broad tuber, intermediate to very high spiny roots on tuber crown, intermediate to dense spines on the tuberous roots.

Annex 5.1. Cont……

Dal-boy	Brownish green young leaves and stems, few spines at young stem base without colored spot, purplish green mature stems, high to very high spines at adult stem base, high spines at adult stem above the base, straight spines, large sized dark green and sagittate broad leaves, green petioles with purple at both ends, female flower, cylindrical broad tuber, high to very high spiny roots on tuber crown, dense to very dense spines on the tuberous roots.
Konkay	Brownish green young stems, few spines at the base without colored spot, purplish green young leaves and mature stems, few spines at adult stem base, very few to few spines at adult stem above the base, straight spines, dark green and sagittate long leaves, purple petioles with purple at both ends, male flower, oval long tuber, few spiny roots on tuber crown, sparse to very sparse spines on the tuberous roots.
Kachi-Tsaa'nseb, Tsano	Purplish green young stems, few spines at stem base without colored spot, brownish green young leaves, purplish green mature stems, dark green leaves, few to intermediate spines at adult stem base, few spines at adult stem above the base, straight spines, sagittate long leaves, purple petioles with purple at both ends, male flower, cylindrical tubers, very few to few spiny roots on tuber crown, sparse to very sparse spines on tuberous roots.
Tsid-boy	Purplish green young and mature stems and young leaves, many spines at stem base without colored spot, dark green leaves, intermediate to high spines at stem base, intermediate spines at stem above the base, straight spines, sagittate long leaves, green petioles with purple at both ends, male flower, cylindrical tuber, intermediate to very high spiny roots on tuber crown, intermediate to dense spines on the tuberous roots.
Shamut	Purplish green young stems, few spines at stem base with colored spot, brownish green young leaves, purplish green mature stem, dark green leaves, intermediate to high spines at stem base, few to intermediate spines at stem above the base, straight spines, sagittate long leaves, green petioles with purple at both ends, male flower, cylindrical broad tuber, medium to high spiny roots on tuber crown, intermediate to dense spines on tuberous roots.

Annex 5.1. Cont……

Kachi ga'nseb	Purplish green young stems, many spines at stem base without colored spot, brownish green color of young leaves and mature stems, dark green leaves, few to intermediate spines at stem base, few spines at stem above the base, straight spines, sagittate long leaves, purple petioles with purple at both ends, male flower, cylindrical broad tuber, very few to few spiny roots on tuber crown, sparse to very sparse spines on the tuberous roots.
Dizzu-kachi	Green young stems, few spines at stem base without colored spot, brownish green young leaves and mature stem, small sized dark green adult leaves, few spines at stem base, very few spines at stem above the base, sagittate long leaves, green petioles with purple at both ends, male flower, round tuber, very few to few spiny roots on tuber crown, very spare spines on the tuberous roots.

NB: ***= Wild yams; ** = wild transplant yams; * = cultivated yams that are known to be recently transplanted to open field

BIOGRAPHICAL SKETCH

An advisee of mine, Tsegaye Babege Worojie, was born in Abeshge, Gurage Zone in Sept., 15, 1986. He attended his primary school at Holle Elementary School in Abeshge Woreda and attended his high school at Kokebe-Tsibah and Bole Secondary Schools in Addis Ababa. He then joined Hawassa University in 2006 and graduated with Bachelor of Science degree in Horticulture in 2008. He was employed in Mizan-Tepi University in Sept., 2008 and serving as graduate assistant. After two years of service, he joined Hawassa University in Sept., 2010 for MSc study and graduated with Masters of Science degree in Horticulture in March 2013.

After two and half years of service in Mizan-Tepi University as a lecturer, he again joined Hawassa University in Oct., 2015 for a PhD study. He is still serving in Mizan-Tepi University as a lecturer and researcher. He has 11 publications, 3 of which are part of this PhD work. Having saying these, I invite the candidate to present his PhD dissertation entitled "*Diversity of Cultivated and Wild Yams (Dioscorea spp.) in Southwest Ethiopia Based on Farmers Management Practices, Agro-Morphological Traits, and Nutritional Composition*".