MORPHOLOGICAL CHARACTERIZATION OF CULTIVATED AND WILD YAM (*DIOSCOREA* SPP) IN MALAWI

Wezi E. Msowoya-Mkwaila*

Wisdom J. Changadeya*

and Aggrey J. D. Ambali**

Abstract

Root and tuber crops are an important source of food and cash worldwide. In Malawi, the potential of yams in crop diversification to achieve food security has long been identified. Collections of cultivated yams have been made and conserved ex-situ but the accessions have not been fully characterized. This study used IPGRI(1997) yam descriptors and a key by Hanon et al., (1995) to characterize cultivated and wild yams (*Dioscorea spp*) collections in order to generate morphological profiles of the yams which can be used in the domestication and enhancement of the species. A total of 80 wild and 43 cultivated yam accessions were collected and assessed. Initial assessment of the yam collections showed that there is a considerable species diversity of yams in the wild and cultivated yams are well established though at small scale in the farms. Principal Component Analysis produced eight distinct groups of the yams with one group constituting all cultivated yams and the other seven groups representing different wild yams. Cluster Analysis revealed that the cultivated yams are highly similar (70%) but they are not duplicates except accession MSYC18 and MSYC 23. All the cultivated yam accessions

* Department of Biological Sciences, University of Malawi, Chancellor College, Zomba, Malawi

** NEPAD African Biosciences Initiative, Policy Alignment and Programme Development Directorate, NEPAD Agency, c/o CSIR Building 10F, Meiring Naude Road, Brummeria, Pretoria, Republic of South Africa

in the study were identified as belonging to the species *D. alata*, the winged yam. The cultivated species classified earlier as *D. rotundata* and *D. bulbifera* were therefore misidentified. The yams were thus morphologically diverse with wide spectrum of characters that can be exploited by plant breeders.

Keywords: cultivated yams, wild yams, morphological characterization, descriptors

 # Corresponding author: Wisdom Changadeya,

Introduction

The economy of Malawi hinges on the agricultural sector. Maize, rice, millet and sorghum are the major cereal crops while cassava, potatoes, yams and sweet potatoes are the major root and tuber crops of importance for food and cash. Maize contributes 80% of the daily food calories and occupies approximately 76% of the total cultivable land and 25% of the population is dependent on root and tuber crops (Malawi Government, 1999).

Roots and tubers have potential to improve household cash income and food security due to their flexibility in mixed farming systems (Gadgil, 2001). In rural Malawi, household land holding capacity is very low at less than 2.0 ha per household rendering intercropping a real option (Malawi Government, 1999). Orkwor *et al.* (1991) suggested that yams can be easily intercropped with sweet potato and other crops.

The shift from subsistence to commercial based agriculture and changing land use patterns is increasing the pressure on genetic resources of such neglected crops like yams leading to an increased awareness of the need to conserve and increase sustainable utilization of these resources. Because of climatic, economic and social changes that are occurring at an ever-increasing rate, the role of plant genetic resources for agriculture (PGRFA) in eliminating poverty and providing food security is even more significant (Cooper *et al.*, 1998). This realization has led to a number of programmes aimed at the conservation of PGRFA.

The National Herbarium and Botanical Gardens of Malawi (NHBGM) has documented nine species of yams (*Dioscorea*) growing wildly in the country (NHBGM, 2002) while preliminary yam surveys of 1998 to 2001 showed establishment of cultivated yams in the country (Gondwe *et al.*, 2003). There is also a 1998 collection of yams at Bvumbwe Agricultural Research Station (BARS) which though, not exhaustive, has shown some variability and could constitute some adapted accessions. Matus *et al.*, (1999) argued that collections that have not been systematically characterized often contain duplicated accessions, many unique or rare types, emphasizing the need to characterisize collections.

Given the potential of yams in the diversification of Malawi' agricultural systems, genetic diversity assessment provides a basis for future breeding and management programmes. This necessitated a study to characterize yams in Malawi with an aim of generating a morphological profile of wild and cultivated yams (*Dioscorea spp*), which can be used in the domestication and enhancement of the species. The study used morphological descriptors partly because morphological characters have been used to identify cultivated yams before in Malawi (Gondwe et al., 2003) and are easy to use and are accessible for resource poor institutions compared to use of molecular markers which require expensive equipment and expert training.

Material and Methods

Germplasm Collection

A preliminary survey was carried out to identify the different cultivated species of yams present in Malawi in all the Agricultural Development Divisions (ADDs) (Figure 1). Identification was carried out using keys prepared by the International Plant Genetic Resources Institute (IPGRI, 1997) for the cultivated yam species and a key provided by Hanon *et al.* (1995) for the wild yams.

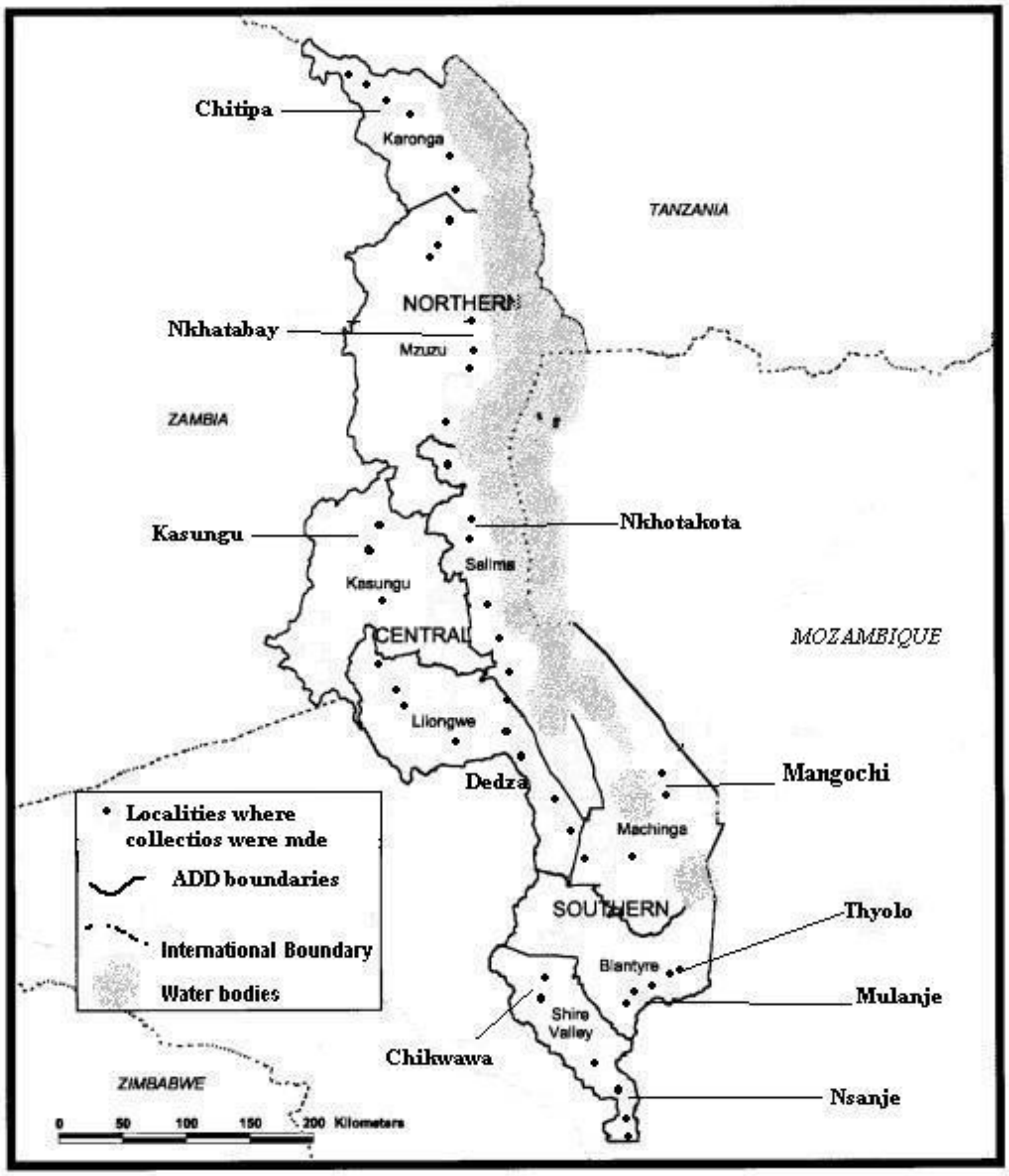

Figure 1: Cultivated Yam Collection: Map of Malawi showing ADDs and the places where cultivated yams were collected

Tubers of cultivated yam were collected from farmers in yam growing areas in five of the eight ADDs of the country. Collection from the three other ADDs had been made in 1998 and 2001, prior to the study. Primary identification was done based on donor farmer descriptions since the vegetative part of the plant had dried up at that time of the year, (October). Tubers were labelled and description of the habitat documented.

Wild yam germplasm was collected based on, but not restricted to, records of the NHBGM. A sample of 2 to 3 tubers was collected from each site (between 5-8 sites per district depending on availability). Passport data included accession number (unique identifier), scientific name, local name and habitat description were recorded on site. Included in this study were some accessions collected prior to the study in 1998 and 2001 which were maintained at Bvumbwe Agricultural Research Station (BARS) (Table 1).

Table 1. Yam Accessions collected by BARS

Accession Codes	District	Species identified as
1998 Yam accession collection		
BAR1	Thyolo	*D. rotundata*
BAR2	Mulanje	*D. rotundata*
BAR3	Thyolo	*D. cayenensis*
BAR4	Zomba	*D. rotundata*
BAR5	Mulanje	*D. alata*
BAR6	Thyolo	*D. alata*
2001 Yam accession collection		
MUN2	Mkumba, Mangochi	*D rotundata*
MUN4	Malekano, Mangochi	*D rotundata*
MUN12	Mponda Karonga	*D. bulbifera*
MUN14	Mwenitete, Chitipa	Unidentified
MUN17	Nyambwawi, Nkhatabay	Unidentified
MUN18	Nyambwawi, Nkhatabay	Unidentified
MUN22	Kasungu ADD	*D. rotundata*
MUN23	Kasungu ADD	*D. rotundata*

Source: Gondwe *et a.l*, 2003

Morphological Data Collection

A total of 43 accessions of *Dioscorea alata* were collected from seven districts in four ADD's The accessions were grown at Bvumbwe Agricultural Research Station where data using IPGRI Descriptors for Yam (*Dioscorea spp*) were collected from three to four plants per accession on stems, leaves, and tuber traits. The descriptors, both qualitative and quantitative were recorded but only those that had differing states were used in the analysis. A total of 60 descriptors were used in the analysis. Quantitative data were recorded as average of the three to four plants sampled. Characterization descriptors were recorded firstly on young plant (at twenty days after emergence) then the same characters on mature plants (just before senescence), and data on tubers was collected at harvesting. No data was collected on inflorescences because all the accessions in both the wild and cultivated accessions did not flower.

Data handling and Statistical Analysis

Descriptive statistical analysis (i.e mean, standard deviation, maximum and minimum) was applied on the quantitative descriptors to estimate and describe the performance of the different accessions based on each character.

Pearson's Correlation coefficient was calculated to estimate the degree of association among the different quantitative characters analyzed. The significance of the coefficients was calculated at $P \leq 0.05$ using the t- test (Sokal and Rholf, 1969)

The qualitative data was recorded on a nominal scale and was transformed into a binary data matrix. The traits that had only two categories of description (e.g. absence/presence traits) were scored normally in the binary matrix using a method developed by Benesi (2002), in which traits with more than two categories of description e.g. wing colour were coded by considering the whole range of diversity of that trait and scored against that particular class. For example, the colour or wings ranges from 1 = green, 2 = green with purple and 3 = purple. If an accession had green wings, 1 was scored against SWC1 = green, and 0 for SWC2 = green with purple edge, and 0 for SWC3 = purple (Benesi, 2002).

Using the program NTSYS-pc version 2.1(Rohlf, 2001), Principal Component Analysis (PCA) was performed to assess morphological diversity. The accessions were then plotted on the Principal Component Axes to see if any patterns emerged on proximity of the accessions.

The binary matrice generated using Benesi, (2002) method on qualitative data of cultivated accession only was analysed using NTSYS pc version 2.1 (Rohlf, 2001). Pair wise similarity matrices were computed by Simple Matching coefficient (SM) (Sokal and Michener, 1958) and used to construct dendrograms from Sequential Agglomerative Hierarchical and Nested (SAHN) clustering method using the Unweighted Pair Group Method with Arithmetical Averages (UPGMA) (Sneak and Sokal, 1973) in order to identify unique morphotypes and duplicates

Results and Discussion

Germplasm collection

A total of 43 accessions of cultivated *Dioscorea alata* known by several local names *(Chilazi, Mpama, Viyao or Mapeta*) were collected from seven districts spread throughout the country suggesting that cultivated yams are a well established crop in the country though grown at small scale and relied upon only during times of famine. A total of 80 accessions of wild yams belonging to eight species, were collected from nine districts of the south and central Malawi where the collection mission concentrated (Table 2). The ease with which the diversity of yams were found in the wild in the selected districts of collection, implied that wild yams are wide spread and conserved (*in situ*) in the bushes of the country.

Table 2. Wild yam accessions collected from various districts in Malawi

Species	Number of accessions
D. dumetorum	**41**
D. schimperiana	**23**
D. odoratissima	**4**
D. quartiniana	**5**
D.hylophila	**2**
D.sansibarensis	**1**
D. bulbifera	**3**
D.cochlear-apiculata	**1**

The most abundant species of wild yam was *D. dumetorum* which made up more than 50% of the collection, (41 accessions). *D.schimperiana* also occurred in abundance in most districts in

Malawi constituting 29% of the collection. The collection mission established that there is still considerable species diversity of wild yams in Malawi (Table 2). All the species reported by the NHGBM were found. However some of their habitats have been destroyed thus their abundance has been negatively affected. The destruction of their habitats also affected other species associated with *Dioscorea* such as *Anona senegalensis*, and *Cochorus olitorius* whish are valuable as famine food sources besides being part of the ecosystem.

Morphological characterization

Quantitative Descriptors

Quantitative morphological characters showed wide variations among the accessions (Table 3) with more variations among the wild species evidenced by a standard deviation of 0.54 compared to 0.16 in the cultivated yams. This observation also showed that there is considerable morphological variation among cultivated yams since the study only collected a single species of cultivated yams (*Dioscorea alata)* against eight species of the wild yams. Other studies in Kenya have shown morphological variability among cultivated yams (Mwirigi et al. 2009). It is known that farmers use specific distinguishing characters to identify their yam varieties (Muthamia et al. 2008).

Table 3: Mean, standard error, maximum and minimum for the quantitative traits evaluated

	Wild Yam (n=80)				Cultivated Yam (n=53)			
Descriptor	**Mean**	**Std Error ±**	**Max**	**Min**	**Mean**	**Std Error ±**	**Max**	**Min**
Stem Diameter	0.74	0.06	2.5	0.2	0.82	0.02	1	0.5
Internode length	14.43	0.72	30	5	8.67	0.30	12	5
Number of internodes to 1st branch	1.36	0.19	10	1	1.39	0.19	10	0
Number of branches	3.93	0.46	13	0	1.91	0.15	4	0
Number of stems/plant	1.69	0.13	6	1	1.50	0.07	2	1
Leaf length	18.01	1.11	47	4	18.40	0.62	30	11
Leaf width	18.74	1.17	50	3.8	9.56	0.31	16	5
Number of leaves	17.31	1.46	60	2	22.56	1.10	50	10
Number of nodes to	1.69	0.14	8	1	1	0	1	1

first leaf

On average, accessions of cultivated yams had thicker stems than the wild species while wild yam species had longer internodes (Mean=14.43cm) with many variations since they were different species (Table 3). Generally branching occurred at near the base of the plant in both types of yams. However there were more variations in the wild yams. For instance, branches occurred high up on the stems of some of the accessions of *D. odoratissima* and *D. dumetorum.* This means that some of the plants belonging to these species were bushy at the top of the stake. When growing in the wild they form a thick canopy at the top. In contrast, branching occurred at the base in *D.schimperiana, D. sansibarensis and D. quartiniana.*

Wild yams had more branches per plant than cultivated yams. Wild yam species had larger leaves compared to cultivated yams (Table 3). These leaves emerged right after germination in all the accessions except in *D. bulbifer*a where the leaves emerged while the plant was 4 internodes high. On average, cultivated yams had more leaves per plant, at thirty days after emergence while wild yams had fewer leaves. *D. bulbifera* and *D. odoratissima* had the highest number of leaves among the wild yams while the *D. cochleari- apiculat*a and *D. quartiniiana* had very few leaves (Data not shown).

Pearson's Correlation Coefficient analysis

Table 4 shows Pearson' correlation coefficients among quantitative descriptors that were significant at $P \leq 0.05$. There was negative correlation between the number of internodes and the stem diameter. Accessions with more internodes had thinner stems. Such plants also had fewer branches and smaller leaves as shown by the decreasing leaf length and leaf width. This relationship occurred in both cultivated and wild yams. Negative correlation was also observed between the length of internodes and the number of leaves. As the length of internodes decreased, the number of leaves increased. This was probably because with long internodes there are only a few points where leaves appear on the stems, consequently, the leaves are few and far spaced. This was more pronounced among cultivated yams (Table 3).

Internode length was also negatively correlated with stem diameter. This observation meant that plants with thinner stems had longer internodes. They also had fewer leaves. This was consistently observed among wild yams (Table 3). There was also a negative relationship between the number of branches, and leaf length (Table 3; 4). The accessions, mainly wild, with more branches had leaves that were short. In essence the length of leaves is a measure of the leaf area size since leaf length and leaf width of *Dioscorea* species are proportional, (Degras, 1993) such that as the number of branches increased, the leaves grew smaller.

Table 4: Correlation coefficients between quantitative descriptors. Coefficients not shown were not significant at P≤ 0.05

	SDM	SIL	SNI	SBR	SNM	LLG	LWD	LNM	NFL
SDM	1.000								
SIL	-0.282	1.000							
SNI	-0.487	_	1.000						
SBR	_	_	-0.419	1.000					
SNM	_	_	_	_	1.000				
LLG	_	_	-0.528	-0.148	_	1.000			
LLW	_	_	-0.589	_	_	_	1.000		
LNM	-0.347	-0.503	_	0.010	_	_	-0.099	1.000	
NFL	_	_	_	_	_	_	_	_	1.000

SDM=Stem diameter (cm); SIL=Internode length (cm); SNI=Number of internodes to first branching; SBR= Number of branches; SNM=Number of stems per plant; LLG=Leaf length (cm); LWD= Leaf width (cm); LNM=number of leaves at thirty days; NFL=number of internodes to first leaf

The numbers of internodes on a stem were negatively correlated with the number of branches especially among cultivated yams. The longer plants (with more internodes) had fewer branches and shorter and narrower leaves. This seems to indicate that the height of the plants compensated for the smaller leaves. There was a low positive correlation, though not specific to either cultivated or wild yams, between the number of branches and the number of leaves since more branches meant more internodes per plant. The number of leaves however was negatively correlated to internode length, stem diameter and number of branches. This meant that plants with short internodes, thin stems and few branches had more leaves which were also narrower in width i.e. small leaves.

Principal Component Analysis

Principal Component Analysis (PCA) was performed on all the descriptors. The qualitative descriptors were converted into class ranges (Eigen Analysis of the evaluated traits with the first four principal axes, C1, C2, C3, C4; Data not shown) according to Degras, (1993). The linear transformation performed by this method generated a new set of weighted combinations of the original variables given in Table 5.

Table 5: PCA analysis of the qualitative evaluated traits with the first four principal axes, PCA1, PCA2, PCA3, PCA4 (Qualitative evaluated traits; Data not shown)

	PCA1	PCA2	PCA3	PCA4
Eigen value	39.50	14.15	11.27	6.50
% Variation explained	30.62	14.85	8.74	5.09
%Variation accumulated	30.62	45.47	54.21	59.31

The scree test revealed that the first four PCAs were the most important accounting for 59.31% of all the underlying variation (Table 5). Dansi et al., (1999) demonstrated that in yams the general appearance of the plant and the tuber are of great importance in cultivar identification. The variations depicted by PCA 1 which accounted for 30.6% (Table 5) of all the total variance was caused by presence of wings on stem and petiole, length and number of stem, absence of hair or spines on the stems, type and colour of leaves' veins and margins, colour of petioles, position of leaves, number and shape of tubers per hill, presence of anchor roots on the tuber, position of roots on the tuber, position of branching of the tuber and presence of cracks on the tuber This principal component generally differentiated cultivated yam from the wild yams.

Colour of stems, absence of wax on stems, length of stems, number of branches per stem, length of internodes, length of leaves, colour and type of leaves, presence of hair on leaves and stems, absence of corms on tubers, number of roots on the tubers, position of roots on the tubers, thickness of tuber and tuber flesh colour accounted for the 14% variation observed in PCA2 (Table 5).

PCA3, which explained 8.74% (Table 5) of the total variation, was based on the following; length of stem, colour of stems, number of branches, type of leaves, colour of leaf margins, arrangement of leaves on the stem, colour of mature leaves, shape of mature leaf edges, length of petioles, number of tubers per hill, seasonality of tuber formation, branching of tubers, colour of tubers, presence of corms and amount of gum released by tubers.

Variations depicted by PCA4 were caused by; absence of wings on stems, absences of hairs on stems, presence of spines on stems, thickness of stems, length of internodes, colour of petioles, absence of spines on the petioles, type of leaves, shape of tubers, number of tubers and skin thickness of tubers.

Figure 3 shows a graphic illustration of Principal Component Analysis. The analysis grouped the accessions into eight distinct groups which in effect represented accurately actual species investigated in this study. All the wild yams were grouped in their respective species group by the analysis.

Group 1 was composed of all cultivated yam accessions which belonged to the species *D. alata*. This finding was contrary to the current BARS classification of cultivated yam accessions which shows that accessions BAR1, 2, 4 and MUN2, 4, 22 and 23 belong to the species *D. Rotundata* (Table 1) yet they are cultivated yams and this study grouped them among *D. alata* accessions. These accessions were identified by BARS as *D. rotundata* based on their tuber shape. *D. rotunndata* has cylindrical tubers with rounded or pointed ends, smooth brown skins and white flesh. The accessions assumed the rounded elongate shapes of *D. rotundata* and thus misleading the investigators. *D. alata* is known to present distortion in shapes of tubers. Degras, (1993) argued tuber shape is not a reliable means of identification of D. *rotundata* or *D. alata*. Other traits, like wings and stem cross section, should be used to classify these yams accordingly. Based on present analysis, these accessions should be classified as belonging to the species *D. alata*.

Accession BAR3 was identified as *D. cayenensis* by BARS (Table 1) probably because of the tuber flesh colour, but this study grouped BAR3 among *D. alata*. Accession MUN12 was classified as *D.bulbifera* (Table 1) on account of aerial bulbils that were collected. *D.bulbifera* distinguishes itself from all other species by producing large kidney-shaped aerial bulbils weighing up to 200g. Occasionally *D. alata* produces small fusiform bubils that are shed and sprout when the conditions are favourable, (Degras, 1993). MUN12 germplasm was collected as bulbils and this led to the misclassification. However this accession has winged stems and produced small aerial bulbils weighing not more than 15g only in the second season. Accession MUN12 therefore belongs to winged yam, *D. alata* based on this study.

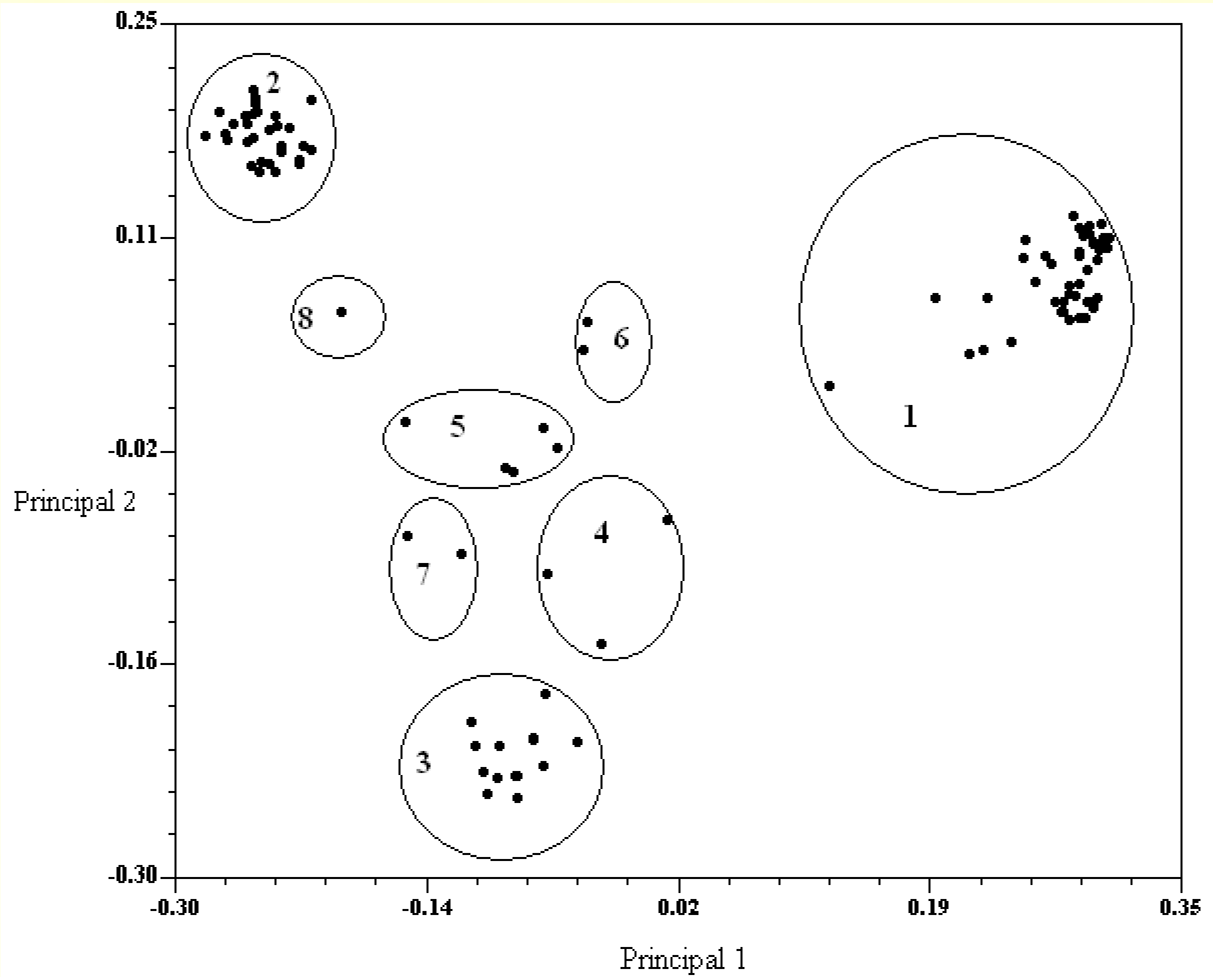

Figure 2: Graphic illustration of the Principal Component Analysis of the *Dioscorea* accessions based on PCA1 and PCA2.

1 = *D. alata*, 2 = *D. dumetorum*, 3 = *D. schimperana*, 4 = *D. odoratissima*, 5 = *D. quartiniana*, 6 = *D. bulbifera*, 7 = *D. sansibarensis* and *D. hylophila*.

This finding means that all the collection missions taken in 1998, 2000 and 2002 yielded *D. alata* accessions only. Further, Asiedu et al, (1997), reported that IITA supplied *D. rotundata* seeds to Malawi in 1992. The seeds were never released to farmers hence *D rotundata* should not be with farmers officially. The grouping of all cultivated yam into species *D. alata* is in line with the morphological characteristics of this species; mainly the presence of a set of four wings on the entire stem which cause the stem to be quadrangular in cross-section.

Cluster Analysis

In order to investigate intraspecific variation among cultivated yams, cluster analysis was performed (Figure 3). The analysis identified four groups of accessions (Figure 3). There was no association between the clustering pattern and eco-geographical distribution of the accessions as the accessions appeared mixed. The accessions were highly similar at 70% level of similarity nevertheless very distinct morphotypes were identified except for MSYC18 and MSYC 23 which were duplicates with similarity of 100% (Figure 3).

Cluster 1 contained accession BAR3 only. This accession shares the least similarity with the rest at 70% and is a unique morphotypes probably because of high level of anthocyanins which give the entire plant purple coloration in the stems, leaves and tubers.

Cluster 2 consisted of other morphotypes (BAR2, MUN2 and MUN14) with 82% similarity with accessions in cluster 3 and 4. These accessions most distinguishing feature was numerous roots on the entire tuber which gave it a prickly appearance.

Accessions in cluster 3 had unique long rough tubers that had small nodes to indicate the direction of branching with an exception of MSYN 7 which had long cylindrical tubers with no indication of branching.

Most of the accessions belonged to cluster 4. These accessions had the typical characteristics of *D. alata*. The stems were of intermediate thickness (1-1.5cm in diameter), had green wings with purple margins.

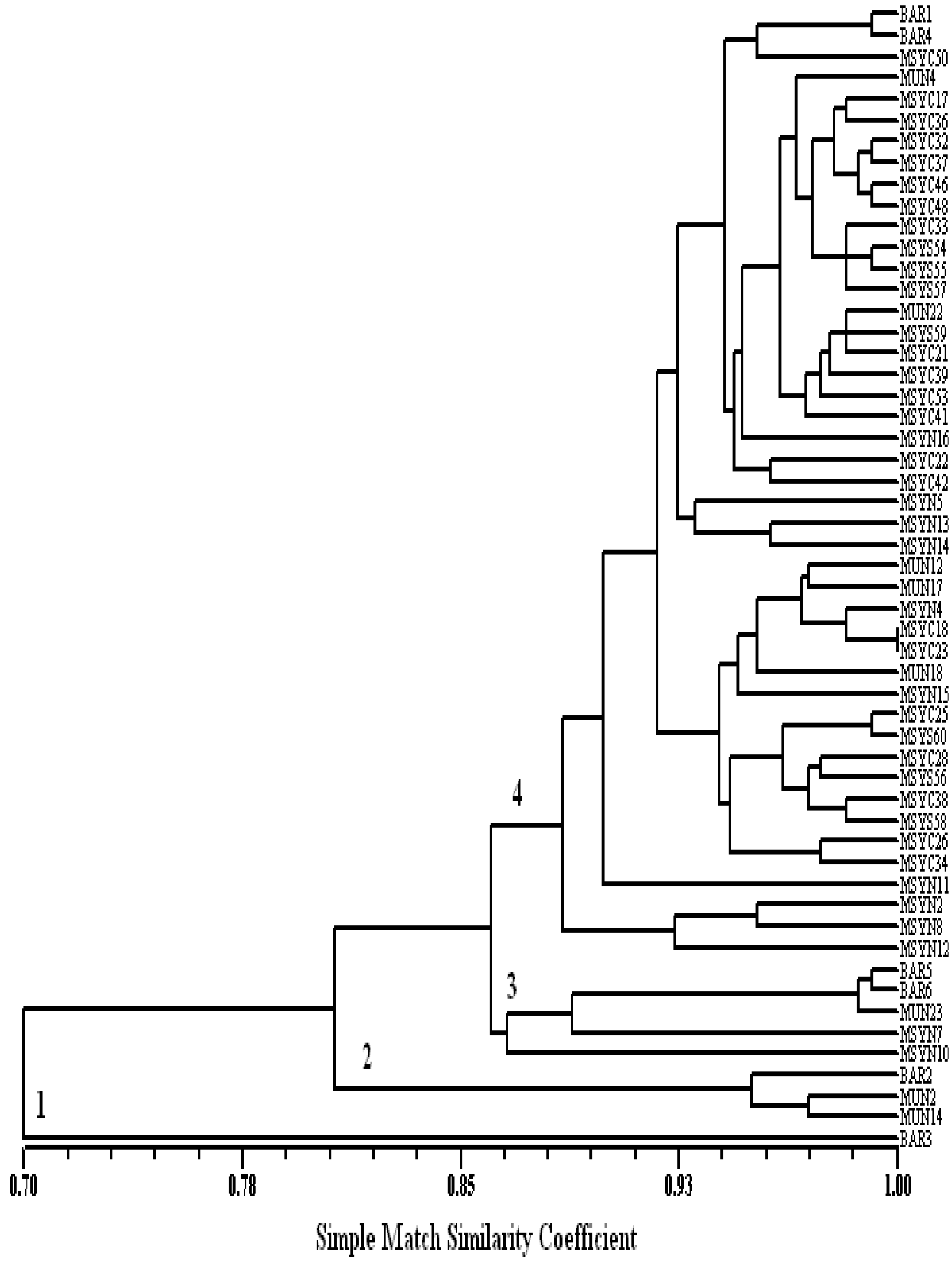

Figure 3: Dendrogram obtained by cluster analysis of cultivated accessions based on UPGMA.

Conclusions

The study found that there is considerable species diversity of wild yams in country and they are widely distributed. The yams are morphologically diverse; each species has its own distinguishing features indicating that there is a wide spectrum of characters that can be exploited by plant breeders. Cultivated yams are well established in Malawi, hence are found in all the agro-ecological zones of the country. The study has shown that all the cultivated yam accessions investigated belong to *D. alata*, the winged yam. The accessions that were classified as *D. rotundata* and *D. bulbifera* among the cultivated yams were misidentified. Although the cultivated yam accessions are highly similar (70%) but they are not duplicates except MSYC18 and MSYC 23.

Acknowledgement

This study was made possible by funds provided by the Forum on Agricultural Resources Husbandry of the Rockerfeller Foundation. We are also grateful to Mr. E.S. Kathumba of National Herbarium and Botanical Gardens of Malawi and Mr. S. Chitekwere of Bvumbwe Agricultural Research Station for their technical assistance.

References

Asiedu R, Wanyera NM, Ng SYC, Ng NQ (1997). Yams, pp. 57-66. *In:* Fuccillo, D., L. Sears and P. Stapleton (eds.) Biodiversity in Trust, Conservation and Use of Plant Genetic Resources in CGIAR Centers, Cambridge University Press, Cambridge.

Benesi IRM (2002). Native starch evaluation and analysis of genetic distance using AFLP of elite cassava (*Manihot esculenta* Crantz) genotypes from Malawi. MSc Thesis, University of Free State, Republic of South Africa. pp. 148.

Cooper HD, Spillane C, Kermali I, Anishetty NM (1998). Harnessing plant genetic resources for sustainable agriculture. Plant Genet. Resour. Newsl., 114: 1-8

Dansi A, Mignouna HD, Zoundjihekpon J, Sangare A, Asiedu R, Quin FM (1999). Morphological diversity, cultivar groups and possible descent in the cultivated yams (*Dioscorea cayenensis/D. rotundata* complex) in Benin Republic. Gen. Res. Crop Evol. 46: 371-388.

Degras L (1993). The Yam A Tropical Root Crop. The Macmillan Press, London.

Gadgil M, (2001). Poverty and Biodiversity pp 845-856 *In:* Levin S.A. (ed.) Encyclopedia of Biodiversity, Vol. 3 Academic Press, San Diego.

Gondwe WT, Ambali AJD, Luhanga R, Msowoya W, Chitekwere SF (2003). Yam (*Dioscorea* spp) germplasm evaluation for yield and quality, Department of Agricultural Research Services. In-House Scientific Conference September 1-2, 2003. Chitedze Agricultural Research Station, Lilongwe.

Hanon P, Dumont R, Zoundjihekpon R, Tio-Toure B, Hamon S (1995). Wild Yams in West Africa: Morphological Characteristics. ORSTOM.

IPGRI/IITA (1997). Descriptors for Yam (*Dioscorea* spp.). International Institute of Tropical Agriculture, Ibadan, Nigeria/ International Plant Genetic Resources Institute, Rome, Italy

Malawi Government (1999). Malawi Agricultural and Natural Resources Research Master Plan, National Research Council of Malawi, Lilongwe

Matus I, Gonzalez MI, del Pozo A (1999). Evaluation of Phenotypic variation in a Chilean collection of garlic (*Allium sativum* L.) clones using multivariate analysis Crop Genet. Resour. Newsl. 117:31-36

Mwirigi PN, Kahangi EM, Nyende AB, Mamati E (2009). Morphological variability within the Kenyan yam (Dioscorea spp). J. of Appl. Biosc. 16: 894-901.

Muthamia ZK, Ngae GN, Ateka E, Nyende AB, Mamata E (2008). Paper presented at the 10 th Biennial KARI Scentific Conference. 10th-14th November 2008. Kari headquarters, Nairobi, Kenya.

National Herbarium and Botanical Gardens of Malawi (2002). Distribution of *Dioscorea* species in Malawi. Zomba (unpublished)

Orkwor GC, Okereke OU, Ezedima FOC, Halm SK, Ezumah HC, Akobundu IO (1991). The response of yam (*Dioscorea rotundata* Poir.) to various periods of weed interference in an intercropping with maize (*Zea mays* L.), Okra (*Abelmoschus esculentus* L. Moench), and sweet potato (*Ipomea batatas* L. Lam), Proceedings of the 9th Symposium of the International Society for Tropical Root Crops 20-26 October 1991, Accra, Ghana. (Ofori, F. and S.K.Hahn, eds), ISTRC, Wageningen, Netherlands.

Rholf JR (2001). NTSYSpc Version 2.1, Numerical Taxonomy and Multivariate Analysis System, Exeter Software, New York.

Sneath PHA, Sokal RR (1973). Numerical taxonomy. Freeman, San Francisco, pp. 573.

Sokal RR, Michener CD (1958). A statistical method for evaluating systematic relationships. Univ. Kansas Sci. Bull. 38: 1409-1438.

Sokal RR, Rohlf J (1969). *Biometry*. W.H. Freeman and Company, San Francisco.