CHARACTERIZATION AND DOMESTICATION POTENTIAL OF WILD YAM IN KENYA

BY

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DECLARATION

Declaration by the Candidate

This thesis is my original work and has not been submitted for any academic award in any institution; and shall not be reproduced in part or full, or in any format without prior written permission from the author and/or University of Eldoret.

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Declaration by the Supervisors

This thesis has been submitted with our approval as the University supervisors.

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DEDICATION

In memory of my mother, Kimooi Amdany and father, Chemwetich Chemjor
Who could not live to witness my achievements.

To Margaret Kimooi Amdany and Luka Cheptoris Miningwo
My aunt and uncle, my guardian parents, my all time source of inspiration.

To my wife, Valentine Chepkoech and children, Jimmy Kibet and Bill Yegon
Each of whom has brought new insight to the meaning of life.

ABSTRACT

Over four million people in Kenya, are faced with severe hunger and malnutrition caused by frequent drought. Wild yam (*Dioscorea spp*.) has been used as famine food by many communities. There is potential for domestication of the drought tolerant wild yam to improve food and nutritional security in various communities. This study investigated on the wild yams in selected parts of Kenya, with the objective of identifying the more productive and nutritious accessions that can be used for food and prevent malnutrition. Thirty one wild yam accessions were collected from selected localities in seven Counties which included Kombosang (KB1), Moigutwo (MB1), Kasaka (KB2a and KB2b), Mormorio (MB2a and MB2b), Bossei (BBa, BBb and BBc), Kapkwang (KB3a, KB3as, KB3b and KB3c) and Katimok Forest (KB4a and KB4b), Kolol (KEa, KEb and KEc), Turesia (TE, TEs1 and TEs2), Kapseret Forest (KUa, KUb and KUc), Chepsangor (CNa), South Nandi Forest (SNa and SNb), Nyakomisaro Stream (NK), Lugusi (LKa) and Kaya Tsolokero (KKa and KKb). Three cultivated yam accessions; Mathia (MN), Mogoi (MT) and St Mary's, Kitale (ST) were also collected and used as control. The accessions were locally and botanically identified. Their response to domestication was assessed in the net-house and field experiments. Internode and vine lengths, number of leaves per plant, number and fresh weight of tubers and bulbils per plant were assessed. The tubers were analysed for nutrient and secondary metabolite composition. The data obtained were analysed statistically and the differences of means were adopted as significant at $P \leq 0.05$. The wild yam accessions comprised four species, *D. schimperiana* Kunth. (KB1, MB1, MB2, KB3a, KE1, TE, KUa, CNa, NK and LKa), *D. bulbifera* var. *bulbifera* (KB4a, KEc, KUb, BB and KKb) and *D. quartiniana* var. *quartiniana* (KB2, KB3b, KEb and KUc) and *D. dumetorum* L. (KKa). The cultivated accessions were *D. bulbifera* var. *anthropophagorum* (ST) and *Dioscorea alata* L. (MT and MN). Wild *D. schimperiana* Kunth., *D. bulbifera* and *D. dumetorum* were used for famine food. *Dioscorea quartiniana* tubers were considered non-edible. *Dioscorea schimperiana* and *D. quartiniana* were used to treat various ailments. All the wild yam accessions produced significantly heavier tubers than the cultivated accessions in the net house. In the field, KEa, MB1 and MB2 produced significantly heavier tubers per plant compared to the control (MB2C) while the cultivated type (MN) did not form tubers. Whereas MB1, KEa, TE, KUb and CNa formed bulbils in the net-house plants, only KEa produced bulbils in the field. The wild yam tubers contained high levels of proteins, lipids and carbohydrates. The tubers also had the highest levels of K compared to the other mineral elements. Generally, the tubers had high levels of P, Na, K, Ca, Mg, Fe and Zn that were comparable to the cultivated types. The wild yam tubers also had high quantities of alkaloids, flavonoids, saponins and tannins that were similar to those of cultivated type (MN), but were within the allowable limits for consumption. The results show that diverse wild yam species exist in various geographical locations in Kenya. Kenyan wild yams have high potential for domestication outside their natural environments. Edible and non-edible yam tubers contained high amounts of nutrients and secondary metabolites. *Dioscorea schimperiana* and *D. bulbifera* could be incorporated to food crop systems. *Dioscorea schimperiana*, *D. quartiniana* and *D. bulbifera* accessions could have medicinal value because of their high secondary metabolites.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA - analysis of variance

cm - centimeter

FAO - Food and Agriculture Organization (Rome)

g - gram

ha - hectare

Hr - hour

IITA - International Institute of Tropical Agriculture

IPGRI - International Plant Genetic Resources Institute

kg - kilogram

L - litre

M - molar

m - metre

mg - milligram

mM - millimolar

ml - milliliter

r.p.m - revolution per minute

ppm - parts per million

USDA - United States Department of Agriculture

w/v - weight by volume

µg - microgram

µM - micromole

% - percent

^{O}C - degrees Celsius

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CHAPTER ONE

INTRODUCTION

1.1 Background Information of Yams

Yams (*Dioscorea spp.*) are herbaceous or woody climbing annual or perennial tuber-bearing plants with distinct annual cycle of growth (IITA, 2006; Adesuyi, 1997). They belong to the genus *Dioscorea* in the family Dioscoreaceae, order Dioscoreales (Tamiru *et al*., 2008; APG III, 2009). The genus *Dioscorea* has over 600 species that are distributed worldwide (Asiedu and Sartie, 2010; Couto *et al*., 2018), about 90 species in continental Africa (Magwe´-Tindo *et al*., 2015) and over 10 species in Kenya (FTEA, 2012) including the cultivated types, *D. rotundata* Poir., *D. minutiflora* Engl., *D. bulbifera* L., *D. dumetorum* (Kunth) Pax., *D. alata* L. and *D. cayenensis* Lam. (Muthamia *et al*., 2014; Atieno *et al*., 2020) and the wild yam types, *Dioscorea odoratissima* and *Dioscorea gilettii* (Milne-Redhead, 1963), *Dioscorea kituiensis* (Wilkin *et al*., 2009), *D. dumetorum, Dioscorea hirtiflora* ssp. *orientalis*, *Dioscorea asteriscus, Dioscorea schimperiana* Kunth., *Dioscorea quartiniana* var. *quartiniana, Dioscorea dumetorum* and *Dioscorea sansibarensis* (FTEA, 1952-2012; Dino, 2013; Muthamia *et al*., 2014).

Furthermore, most of the yam species still grow in their natural environments while a few have undergone domestication process. Subsequently, seven which include *Dioscorea rotundata* Poir (White yam), *D. cayenensis* (Yellow yam), *D. alata* (Water yam), *D. bulbifera* (Aerial yam), *D. esculenta* (Chinese yam), *D. praehensilis* (Bush yam) and *D. dumetorum* (Bitter yam/trifoliate yam), have been domesticated in West Africa and Asia and are the most consumed (Jayakody *et al*., 2007). Domestication leads to disappearance

of wild traits, after several clonal generations (Chikwendu and Okezie, 1989). The clonal selection from the germplasm with large tubers during domestication produces cultivars very similar to those of established crops or even new varieties. Actually, there is considerable species and varietal diversity of the *Dioscorea spp.* due to the continuous process of domestication from related wild yam species (Dumont and Vernier, 2000).

Yams are widespread in the tropical regions, mostly in West Africa, South East Asia and Tropical America (Asiedu and Sartie, 2010; Couto *et al*., 2018), with some species occurring in the temperate ecosystems (Eka, 1998). Apparently, the wild yam species are found in specific habitats within their natural environments that include moist and dry forest, woodland, wooded grassland, bushland, bushed grassland and semi-desert scrub (Dino, 2013; Gucker, 2009). Yams can grow and survive in a range of altitudes, from lowland to highland ecological zones, depending on the species and/or sub-species (Gucker, 2009). Yams vary in their response to drought. Water stress and high temperatures may be tolerated by some superior yams, but such condition in their early stages of growth can cause high mortality (Thomas *et al.,* 2006). Unfortunately, the wild yam species are increasingly threatened with extinction due to habitat loss caused by deforestation, reafforestation and climate change among others. Fortunately, on the other hand, the cultivated yam which were derived from domestication, have been cultivated and spread the world over.

Different yams may require varying soil conditions for optimum growth and production. In fact, cultivated yam is mostly a crop of the lowlands and grows well in loamy and sandy loam soils with low salinity (Muthamia *et al*., 2013). It responds well to manuring.

Gravel or rocky soil hinders tuber penetration (Muthamia *et al.*, 2013). Yams particularly *D. esculenta* does well in average soil pH 6.2 (Beyerl, 2001), but soil pH of 5.5-6.5 is optimum range for yam growth. *Dioscorea alata* yam can grow well in permeable clay soils but poorly in infertile sandy soils (Gucker, 2009). In its native habitats, *D. bulbifera* occurs in loam or loose clay soils (Gucker, 2009). High organic matter in the soil promotes vine and tuber growth (Gucker, 2009). In their early stages, yam displays rapid growth, which has been associated with mobilizing of starch reserve in the previous tuber (Dounias, 2001) and absorption of nutrients and water from its rhizosphere through its numerous roots. The rhizosphere is of paramount importance for ecosystem services, such as carbon and water cycling, nutrient trapping, crop production, and carbon uptake and storage (Adl, 2016). Rhizosphere exudates serve as communicating molecules to initiate biological and physiological interactions between the soil microbiome and the plant roots by influencing the chemical and physical properties of the soil and the soil microbial community, inhibiting growth of competing plant species, facilitating beneficial symbioses, e.g. with nitrogen-fixing bacteria, mycorrhizal fungi and by preventing pathogenic bacterial, fungal and insect attacks (De-la-Peña and Loyola-Vargas, 2014)). Some plant species have the ability to modify their rhizospheres, thereby enhancing nutrient availability, which they absorb and use for their growth and development. Yams could be one of such plants.

In addition, yam is an important food and medicinal plant used by approximately 300 million people in the world (Dansi *et al*., 2013). Actually, for a long time, yam has been a valuable nutritional and economic crop in the world's tropical and sub-tropical regions

(Sharma and Bastakoti, 2009; Nayaboga *et al*., 2014). Evidently, West Africa contributes 95% of the world's yam production (Hamadina *et al*., 2012; Dansi *et al*., 2013), with Nigeria alone producing 68% of the world's yams. Further, *D. alata, D. pentaphylla* and *D. bulbifera* have edible starch rich tubers and are most cultivated yams worldwide (Sheikh *et al*., 2013). The tubers of the cultivated types such as *D. alata, D. bulbifera* and *D. schimperiana* and the wild *D. hirtiflora* are sources of food and cash income for many low income farmers (Leng *et al*., 2019; Zulu *et al*., 2019). Yams are important globally for food security (FAO, 1991), including Kenya where they are preferred food security crop in the drier areas, especially in eastern, central, western and coastal regions (Maundu *et al*., 1999). However, yam production in Kenya is low because its use for food has rapidly declined. The factors affecting production of yams in Kenya include lack of knowledge on appropriate production methods, lack of healthy planting materials, lack of supporting policies by the government and easy access of traditional starchy staples such as maize (Maina, 2008). Generally, yam takes 7-10 months to mature in the field (Maundu *et al*., 1999; Gucker, 2009).

Yam tubers contain substantial amounts of mineral elements; iron, calcium, phosphorus, potassium, sodium, magnesium, copper, manganese, zinc and sulphur (Abara *et al*., 2003; Deb, 2002; Walsh, 2003), carbohydrates, crude protein, crude fat, crude fiber and ash, vitamin B6 and vitamin C (Shih-Chuan *et al*., 2015; Walsh, 2003). In addition, local communities have used the different yam species for different purposes. For example, *Dioscorea spp*. Have been used to treat warts, curing gastritis, as health food and herbal medicinal ingredients in traditional Chinese medicine (Maneenoon *et al*., 2008; Kadiri *et*

al., 2014). Raw tuber of *D. pentaphylla* L. against diphtheria in cattle (Sharma and Bastakoti, 2009). Tubers of *D. oppositifolia* L. are used in the treatment of swellings, scorpion stings, and snake bites (Dutta, 2015). *Discorea hispida* Dennst. is used as an antidote to arrow poison (Edison *et al*., 2006; Mishra *et al*., 2008). *Discorea bulbifera* is used against tuberculosis, a wild food for management of HIV and cultivated by Luhya community in some parts of Western Kenya for measles treatment ((Nabatanzi, 2016; Maundu *et al*., 1999). While there has been a large amount of research directed to Kenyan major cereal food crops such as maize, rice, millet and sorghum, little has been devoted to traditional crops such as yams. Therefore, there is need to identify, characterize, domesticate and use the indigeous wild yam to improve food and nutritional security in Kenya.

1.2 Statement of the Problem

A large pool of genetic wild yam resources exist in the wild environments. Despite their bitter taste due to presence of unknown phytochemicals, drought tolerant wild yam species have traditionally been harvested for food and herbal medicine by many communities during dry spells. Habitat loss that is occasioned by human activities threatens the yams with extinction. Furthermore, there is limited knowledge on the diversity, nutrient and domestication of the existing wild Kenyan yams. Therefore, there is the need to identify, characterize and determine the potential for domestication of wild yams in Kenya.

1.3 Justification

Most yam species and varieties are tolerant to drought; and the fresh tubers are available throughout the dry seasons, assuring households of reliable source of food for varying times of the year. The rural dwellers in many parts of Kenya have experienced famine resulting from poor or total crop failure because of frequent drought. Wild yam has been used for food by different communities due to its availability even during periods of severe drought. Furthermore, different yam species have been exploited for traditional herbal medicine to treat various ailments. Moreover, yam is also rich in nutrients and secondary metabolites that can be used to improve health status of the rural poor. Therefore, this study provides knowledge on the existing yam species in Kenya, their organic and mineral nutrient, secondary metabolite levels and response to domestication. The study therefore provides a basis for future breeding programs and gives recommendations for the potential yams that can be incorporated into existing food crop and food systems.

1.4 Objectives

1.4.1 General objective

To characterize and evaluate potential for domestication of the wild yams towards improving food and nutritional security in Kenya.

1.4.2 Specific objectives

1. To assess the yam species and spatial diversity in selected parts of Kenya.
2. To determine the ethnobotanical uses of Kenyan wild yams.

3. To determine the chemical status of rhizosphere soil of wild yams in the selected parts of Kenya.
4. To assess growth and production of Kenyan wild yam accessions under controlled conditions.
5. To determine levels of selected primary and secondary metabolite, and mineral composition of Kenyan wild yam tubers.

1.5 Study Hypotheses

The following hypotheses were advanced in the study;

1. There are many yam species in Kenya.
2. There are many uses of wild yams in selected parts of Kenya.
3. Soils sourced from the rhizosphere of different yam accessions have varied levels of chemical components.
4. The wild yams can grow well under controlled conditions.
5. The wild yams have varied levels of organic and mineral components.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and Diversity of Yams

2.1.1 Origin of yam

Yams are diverse (over 600) species and varieties of the plant genus; Dioscorea, that may have originated mainly in the tropics, with a few from the warm temperate ecologies (Eka, 1998). The established yam originated in Southeast Asia, West Africa, and Tropical America, which are also considered the main centers of domestication, growing and diversity of yams (Kumar *et al*., 2017). More specifically, *D. villosa* L. is native to North America (Avula *et al*., 2014). The cultivated species, *D. esculenta* (Lour) Burk. originated from China. *Dioscorea dumetorum*, *D. cayenensis* and *D. rotundata* originated in tropical West Africa while *D. bulbifera* L. is native to Asia, tropical Africa, and Northern Australia (Kumar *et al*., 2017). *Dioscorea alata* originated in south Asia (Tamiru, 2008). Whereas some of the species have been domesticated for a long time, there still exist a pool of wild yam species and varieties from which some communities access material for further domestication or use as source of either food or phytochemicals.

2.1.2 Taxonomy of yams

Yam is a common name for a variety of monocotyledonous, herbaceous, climbing plants in the genus Dioscorea (Coursey, 1967). Based on morphological characters, the genus Dioscorea is further classified into sections (Burkill, 1960), most importantly the direction of twining of the growing vine on the support (Coursey, 1967). The most

recognized sections in the genus include; Enantiophyllum, Lasiophyton, Combilium, Opsophyton and Macrogynodium (Coursey, 1967).

The vines of species in the Section Enantiophyllum comprising D. *alata*. *D. cayenensis, D. opposita, D. japonica* and *D. rotundata,* twine in anticlockwise (right) direction on their support and all are edible (Burkill, 1960). The vines of the other Sections; namely Opsophyton (*D. bulbifera*), Lasiophyton (*D. pentaphylla*, *D. dumetorum* and *D. hispida*), Combilium (*D. esculenta*), Macrogynodium (*D. trifida*) and Macroura (*D. sansibarensis* Pax.) twine in clockwise (left) direction. Species in the Enantiophyllum Section form a single large tuber that weigh 5 - 10 kg, and a single 2 - 3 m long vine (Burkill, 1960).

The yams in the Lasiophyton Section are distinguished by a cluster of medium sized tubers that are fused together (Burkill, 1960). *Dioscorea esculenta,* the only member of the Combilium Section, has short vines (Burkill, 1960) and produces many small tubers. The species in Macrogynodium section are characterized by a cluster of smaller tubers when compared with those of Combilium section.

The yam species may be composed of varieties/sub-species that have not been adequately researched and characterized. Similarly, only a few out of the over 90 yam wild species found in continental Africa (Magwe´-Tindo *et al*., 2015), have been identified in Kenya, hence the need to intensify identification of indigenous yam species to broaden the existing knowledge on genetic diversity.

2.2 Anatomy and Morphology of Yam

2.2.1 Anatomy of yam tuber

The yam underground and aerial tubers are formed from the hypocotyl and vine axils respectively (Shewry, 2003; Epping, 2020). The anatomy of yam tuber or bulbil is made up of four concentric layers: Cork periderm - the outermost layer of the yam tuber, a thick layer of cork cells that covers the inner pigmented flesh, the cortex (Raman *et al.*, 2014). The skin is made up of several cork layers and a band of lignified sclerenchyma. The cork cambium shows two layers of elongated parenchyma. Cortex is a layer immediately beneath the cork periderm, comprising thin-walled compact cells arranged in 6-8 layers with very little stored starch (Epping, 2020). Meristematic layer is constituted by the elongated thin-walled cells under the cortex. Sprouts are initiated from cells of this layer. Ground tissue comprises the central portion of the tuber, formed by thick-walled cells, flled with starch grains, with a small number of irregularly distributed vascular bundles. Many idioblasts containing calcium oxalate embedded in mucilage are usually common in the cortex and ground tissue (Epping, 2020). The starch grains are oval, elliptic or shell-shaped, 10–39 µm long and 7-29 µm wide (Raman *et al*., 2014).

2.2.2 Morphology of yam plant

Yam plant is characterized by the presence of root and climbing vine. Generally, yams have weak rooting system (Gucker, 2009; Padhan and Panda, 2020). Yam plants produce fibrous roots and underground/root tubers, storage organs of carbohydrates (Padhan and Panda, 2020). Early in the growing season sprouted yam tubers and bulbils develop thick, longer unbranched roots from their corms that superficially grow in the soil, and later,

thinner, shorter, branching, fibrous roots from the tuber (Gucker, 2009; Coursey, 1967; Kumar *et al*., 2017). Usually, the roots growing from the tubers are thin and short (Coursey, 1967). The members of the genus *Dioscorea* greatly vary in the number, shape and size of tubers, characters that are genotype and species dependent (Gucker, 2009).

There is significant variation in the shoot forms among *Dioscorea spp* (Gucker, 2009). Yams have variable climbing vines (Hahn *et al*., 1987) that lack tendrils, and thus grow by twining around a neighboring physical supporting objects. Vines of some species have prickles/wings which support twining and protect the stem against foraging animals (Gucker, 2009; Epping, 2020). Prickles are more pronounced in wild than cultivated yams (Onwueme, 1978). Vine shape of most species are cylindrical, but *D. alata* comprises of stellate, rectangular or polygonal structures with angular extension forming a four-sided cross section (Onwueme, 1978). Yams vary in vine length which may range from 1.5 m for dwarf varieties to over 30 m for tall varieties (Gucker, 2009; Onwueme, 1978). Some species of yam may also possess hairy vines.

Yam leaves are simple or compound, cordate, or acuminate with long petioles. Leaf shape could be lobed, palmate, trifoliate, or more leaflets could exist in some species (Gucker, 2009; Padhan and Panda, 2020). Leaf arrangements could be alternate, opposite or both and occur on the same stem depending on the plant species and stage of growth. For instance, *D. rotundata* has simple cordate leaves oppositely arranged on the nodes. *Dioscorea dumetorum* has trifoliate leaves while *D. pentaphylla* has digitate leaves with five leaflets. Leaves consist of reticulate veins, unserrated lamina and are non-pubescent

(Onwueme, 1978; Gucker, 2009). Leaf anatomy is characterized by presence of stomata on the lower leaf epidermis (Gucker, 2009). However, *D. bulbifera* have few stomata occurring on the upper leaf epidermis (Onwueme, 1978).

Dioscorea spp produce very small flowers, if any (Gucker, 2009; Onwueme, 1978). Flowering in several yam species is erratic, sparse or completely absent in some genotypes thereby limiting yam hybridization (Epping, 2020; Gucker, 2009). They produce sticky pollen and the small openings of the female flowers limit wind pollination (Gucker, 2009). Bisexual flowers occur on the same spike e.g. in *D. rotundata* but in *D. cayenensis*, only male flowers are present (Hahn, 1987; Tu, 2002). *D. alata* form few pistillate flowers and many staminate accessions used in hybridization (IPGRITA, 1997). Yam produce inflorescence type of flowers (Gucker, 2009). The florets of staminate inflorescence flowers are 1 to 3 mm in diameter, sessile and produced on spikes subtended by small bracts. The number of florets on each raceme is variable. At least one spike is formed at a leaf axil and usually droops downwards (Gucker, 2009; Hahn, 1987; Tu, 2002). The perianth is slightly connate at the base and consists of three light-green sepals and a corolla of three light-yellow petals. Sepals and petals are usually similar in size and colour. The androecium consists of two whorls of each stamen. Pistillate flowers measure about 0.5 cm long, and are borne on axillary spikes. The perianth consists of three green sepals and three yellow-green petals. The sepals and petals are lobed above the ovary or otherwise they resemble those in staminate flowers. The ovary is inferior and trilocular with each locule containing two ovules. The placentation of the ovary is axial, and continues to

develop into a capsule, whereas the perianth dries out during maturation (Gucker, 2009; IPGRITA, 1997). The structure and shape of complete flowers are similar to pistillate flowers except for the presence of two whorls of stamens as in staminate flowers. It is presumed that complete flowers are merely advanced forms of pistillate flowers in which the staminodes develop into functional stamens (Gucker, 2009). Prevalence of staminate flowers has been observed in imperfect sex separation (IPGRITA, 1997).

Dioscorea rotundata which originated from true seeds possess a high frequency of flowering at 80% and a ratio of staminate to pistillate flowers of approximately 1:1, with 4% of the plants monoecious and presenting large number of flowers per plant (Gucker, 2009; Onwueme, 1978). Yams in West Africa reach more than 50% flowering, and the flowering genotypes exhibit a high staminate to pistillate ratio of 40:1 (IPGRITA, 1997) and monoecious to pistillate ratio of 5:1 (Gucker, 2009). Reduction of sex organ primordia of most species results in unisexuality (Gucker, 2009). Hormonal treatment reduces sexuality in certain conditions (Gucker, 2009; Tu, 2002). Erratic flowering pattern and sex ratios in yams are influenced by ecological factors including light intensity, ratio of day to night length, soil mineral balance, length of vegetative to reproductive phase and genetic factors (Gucker, 2009; IPGRITA, 1997). The intensity of flowering differs among yam genotypes ranging between nonflowering and profuse flowering. Usually it is highest in staminate than in pistillate plants of *D. rotundata* and *D. alata*. Overally, the male plants are more in number than the female plants.

Yam is a short-day plant with diverse photoperiod requirements for flowering (Gucker, 2009; Tu, 2002). Quality and sett size of planting materials and time of planting play crucial roles in flowering time. Yam setts are pieces obtained by cutting the mother or whole yam. An investigation into the effect of planting dates and types of setts on flowering in Ibadan, Nigeria, showed that setts of *D. rotundata* planted in January and April, flowered in early and late June, respectively (Gucker, 2009). However, yam fruits are rare and, if produced, are often sterile (Gucker, 2009). Yam seeds are winged (Tu, 2002). Morphological characters have been organized into morphological descriptors and used to identify the different yam species and/or sub-species/varieties (IPGRITA, 1997), hence provides inexpensive method of identifying new yam species.

2.3 Biological Cycle and Physiology of Yam

Biological cycle in yams relates to seasonal variation in tuber sizes and quality (Dounias, 2001). Afer physiological maturity stage which normally coincides with the driest season of the year, yam plant consists of an underground tuber and/or aerial tubers. The start of rainy season marks the starting point for the formation of a new single aerial vine (Gucker, 2009). It is important that the new vine apical meristem enables it to grow rapidly to reach the canopy (Dounias, 2001). If the vine fails to reach the canopy and gets exposed to light, the yam plant will not photosynthesize to enable renewal of tuber reserves and, both vegetative and sexual reproduction for plant regeneration will not occur (Dounias, 2001). One of such yam is *Dioscorea praehensilis* whose vine, and the tubers are annually renewed (Di Giusto *et al*., 2017).

During the driest season of the year, the plant consists of an underground tuber, whose stored reserves fuel the growth of a single vine to the canopy when growth conditions become favorable (Di Giusto *et al*., 2017). The growing yam vine obtains energy, nutrients and protein from the tubers which progressively degenerate until the vine leaves are fully developed (McKey *et al*., 2010; Di Giusto *et al*., 2017). Also, the rapid growth could be enhanced by absorption of water and mineral ions from the soil by the corm and the numerous tuber roots. However, the availability of the nutrients in the soil is influenced by the soil conditions including soil acidity and alkalinity (Dakora and Philips, 2002).

The yam vine usually does not branch but bears only reduced leaves termed cataphylls, until it reaches sunlit conditions (Dounias, 2001; Di Giusto *et al*., 2017) positioned upto 30 m or more above the ground. The plant then develops leaves covering the canopy vegetation. The developed leaves photosynthesize over several months and from this stage, photosynthesis supply photosynthates that are transported to the roots where they are used for the growth of the new tubers (Dounias, 2001). The tubers formed in the initial stages of development are fragile, superficially buried. Also at this time, the plant becomes sexually active (Dunias, 2009; Di Giusto *et al*., 2017). Most of the tubers superficially grow in the soil while a few grow deeply (over 1 m depth) into the soil (Kumar *et al*., 2017; Padhan and Panda, 2020).

Yams have elaborate defense mechanisms against herbivory (Dounias, 2001; Di Giusto *et al*., 2017). Some produce prickles on stem and others produce nectar in glands located near the apical meristem, to attract ants which use the nectar and in turn protect the stem

apex from foraging insects (Dounias, 2001). The tubers formed in the early stages of growth and development contain high phytochemical contents for protection against pests (Dounias, 2001).

Finally, after the end of the long rainy season, the yam shoots wither and dry when the new tuber is fully developed. Immature tubers are nutritionally deficient, unpalatable and not suitable for consumption during vine growth and tuber renewal (Dounias, 2001). The mature tubers undergo dormancy until the onset of the next wet season, stimulating the growth of a new vine and tuber from the dormant tuber (Dounias, 2001). The mature, dry capsules formed by some yams dehisce and release winged seeds which are dispersed by wind. The appropriate period for yam tuber harvesting is after the vines have withered and dried, when the tubers are fully filled and dormant. Yam tubers may be dormant for up to 16 weeks (Di Giusto *et al*., 2017) and during that time, they can be harvested for consumption. This annual cycle of renewal of the shoot and root tuber is the central feature of the morphology, physiology and phenology of the yam. However, there is limited documentation on Kenyan yam life cycle; and the appropriate time for harvest is not well documented.

2.4 Ecology of Yams

Yams can inhabit varied environments from low to high ecological zones, depending on the species or varieties (Gucker, 2009; Wagner *et al.*, 1999). In the world, yams have been domesticated and cultivated in mainly three parts of the world: West Africa, parts of East-Central and Southern Africa, which are responsible for about 95% of the world yam

production; South-East Asia including China, Japan and Oceania, and the Caribbean; and Mexico and parts of Central America (FAO, 1999). Although yams are found in tropical and temperate climates, sub-tropical to tropical climate is the most suitable for yam growth and production (Gucker, 2009). Generally, yams grow best at moderate to high temperatures (Thomas *et al.,* 2006). Most yam species require a 7 - 10 month growing period (Coursey, 1967) and persist in dormant state through the dry spell. They require an average annual rainfall of 1,110 - 1,500 mm (Thomas *et al*., 2006). But long period of rainfall in the growing season optimize yam growth and production especially for *D. alata*, but yams are also sensitive to waterlogging (Thomas *et al.,* 2006). Some yams like *D. esculenta* are more tolerant to forest ecosystems with low light intensities (Beyerl, 2001).

Different yams may require varying soil conditions for optimum growth. High tuber yields require high potassium levels (Thomas *et al.,* 2006). In addition, *D. esculenta* occurs on silt loam in alluvial habitats (Tu, 2002), and also in habitats with rocky soils (Gucker, 2009). According to Maundu *et al*., (1999), *Dioscorea dumetorum* (Kunth) Pax, *Dioscorea minutiflora* Engl. and *Dioscorea bulbifera* var. *anthropophagorum* (A. Chev.) Summerh. (cultivated) occur in Kenya. Although the species and spatial diversity of yams have been described, there is scanty information on wild yam ecology in Kenya.

2.5 Yam Rhizosphere

The rhizosphere comprises the soil volume that is influenced by the root and parts of root tissues, and the soil covering the root where physical, chemical and biological properties

have been altered by root growth and activity (Badri and Vivanco, 2013). The rhizosphere is made the endorhizosphere: the portions of the root cortex and endodermis where microbes and mineral ions reside in the apoplastic space; the rhizoplane, the middle zone beneath the epidermis and mucilage; and the ectorhizosphere, the outermost zone which extends from the rhizoplane out into the bulk soil (McNear Jr, 2013; Badri and Vivanco, 2013). In other plants, strongly adhering dense layer consisting of root hairs, mucoid material, microbes and soil particles termed rhizosheath is found (McNear Jr, 2013). In general, the rhizosphere is the root surrounding where plants interact with other plants, herbivores and microorganisms (Bais *et al*., 2006).

The rhizosphere is critical in influencing water and carbon cycling, carbon uptake and storage, nutrient trapping and crop production (Adl, 2016). The nutrients most limiting to plant growth are nitrogen and phosphorus. Phosphorus and nitrogen are essential elements which play major roles in plant growth, development and determination of yield of crops (Nyoki and Ndakidemi, 2018). The concentration of nutrients and micro-organisms in the rhizosphere is higher than in the bulk soil (Nyoki and Ndakidemi, 2018). Interactions between roots and soil during plant growth induce variation in chemical properties between the rhizosphere soil and the bulk soil (Makoi *et al*., 2014; Nyoki and Ndakidemi, 2018). The changes in the rhizosphere may be caused by root uptake of nutrients and secretion of exudates by roots, and/or microbial activity (Makoi *et al*., 2014; Nyoki and Ndakidemi, 2018). For instance, during the early stages of growth, yam plants are characterized by presence of numerous roots that are associated with enhanced absorption of water and nutrients leading to the rapid growth of their vines. Relatively,

some yam species have formed symbiotic relationships with micro-organisms to enhance acquisition of the essential nutrients. For example, three endophytic bacteria were reported present and effective in phosphate solubilization and biological nitrogen fixation and production of indol-acetic acid (IAA) in the rhizosphere of white yam plants (*Dioscorea rotundata* Poir). Ouyabe *et al.*, (2019) identified *Brukholderia spp*., *Bacillus altitudinis*, *Enterobacter bugandensis* as the main species among 47 other nitrogen fixing bacteria isolated from yam rhizosphere. Furthermore, Ouyabe *et al.*, (2019) classified *Bacillus cereus* and *Pseudomonas aeruginosas*, obtained from the yam rhizosphere region, as the best isolates to fix atmospheric nitrogen, Indol-acetic acid production, ammonia (NH_3).

Rhizosphere soils also are rich in root exudates and play a major role in nutrient mobilization (Dakora and Philips, 2002) as compared to the bulk soil. The rhizosphere is strongly influenced by plant metabolism through the release of carbon dioxide (CO_2) and secretion of photosynthates. The root exudates account for 5-21% of total photosynthetically fixed carbon. There are many chemicals secreted by plant roots and microorganisms such as sugars, organic acids, amino acids, flavonols, flavonoids, phenolic compounds, exopolysaccharides, antibiotics glucosinolates, indole compounds, fatty acids and proteins into the rhizosphere (Weston *et al*., 2013; Li *et al*., 2013; Talboys *et al*., 2014; Zhang *et al*., 2014; Badri *et al*., 2013; Makoi *et al*., 2014; Nyoki and Ndakidemi, 2018).

The tubers of *Dioscorea rotundata, Dioscorea cayenensis* and *Dioscorea dumetorum* contain secondary metabolites especially flavonoids and saponins, which are sources of resistance against herbivory by beetles (*Heteroligus meles* Bilb.).

The compounds that are released can cause dissolution of primary minerals and precipitation or crystallization of secondary compounds and/or minerals and eventually transformation of mineral components in the rhizosphere (Makoi *et al*., 2014), and also modification of the rhizosphere soil pH. For example, the exuded organic acid anions have the ability to change the pH of their rhizospheres, and enhance availability of nutrients such as P, K, Ca, Mg, Zn and Ca among others, which are usually fixed in unavailable forms under acidic conditions (Dakora and Phillips, 2002; Sivakumar *et al*., 2009; Prashar *et al*., 2013). Furthermore, the organic acid anions such as citrate, oxalate and malate, are able to form stable complexes with Al (Ma *et al.,* 2004; Ahkamia *et al*., 2017) and protect the root tip from Al toxicity (Nyoki and Ndakidemi, 2018). Again, plants respond differently to N deficiency depending on the form in which nitrogen occurs in the soil. Ammonium has a positive charge, and thus the plant expels one proton (H^+) for every NH_4^+ taken up resulting in a reduction in rhizosphere pH. When supplied with NO_3^-, the plant releases bicarbonate (HCO_3^-) which increases rhizosphere pH. Similarly, rhizosphere soil pH can be modified through root secretion of the alkaline anions OH^-, HCO and metal ion chelators **(**Hassan *et al*., 2017**)**. Again, due to pH changes in the rhizosphere, *Cyclopia genistoides,* a tea-producing legume indigenous to South Africa, increased nutrient availability in its rhizosphere by 45-120% P, 108-161%

potassium (K), 120-148% Ca, 127-225% Mg and 117-250% boron compared with bulk soil (Dakora and Philips, 2002).

Furthermore, Jones *et al*., (2009) described loss of root cap and dermal cells, insoluble mucilage, soluble root exudates, volatile organic carbon, and death and lysis of root cells as the major processes of rhizosphere deposition termed rhizodeposition. Metabolites secreted from roots change depending on the developmental stage of the plant (Chaparro *et al*., 2013; Ziegler *et al*., 2013; De-la Peña *et al*., 2014).

Within the rhizosphere, a complex set of inter- and intraspecies communications and food web interactions that significantly influence carbon flow and transformation occur (Ahkamia *et al*., 2017). For example, different nematodes which include *Pratylenchus coffeae, Merlinius incognita, Merlinius brevidens, Rotylenchulus reniformis*, *Helicotylenchus dihystera* and *Heteroligus meles* Bilb. among others, that feed on yam tubers and reside in the rhizospheres of different species of yam, have been documented (Abdulsalam *et al.*, 2021; Okoroafor and Iborida, 2017). Also, the release of large amounts of organic carbon by the plant roots promotes microbial diversity and activity (Bais *et al*., 2006; Vandenkoornhuyse *et al*., 2015; Mendes *et al*., 2012). The type and composition of root secretion can alter the microbial diversity of the rhizosphere, favoring the growth of microorganisms that can benefit plant health and crop productivity. For example, Plant Growth Promoting Rhizobacteria (PGPR) are prevalent in the rhizosphere soil in which they facilitate solubilization of mineral nutrients, fixation of nitrogen and disease suppression (Nyoki and Ndakidemi, 2018). Furthermore, root exudates serve as energy sources for microorganisms and act as chemical attractants and

repellents, thus promotes rhizosphere interactions. The exudates also initiate biological interactions between the soil microbes and the plant roots by influencing the soil chemical and physical properties and the soil microbial community; inhibiting growth of competing plant species, facilitating beneficial symbioses, preventing bacterial, fungal and insect attacks (De-la-Peña and Loyola-Vargas, 2014)). Ouyabe *et al*., (2019) identified *Brukholderia spp., Bacillus altitudinis* and *Enterobacter bugandensis* as the main species among 47 other nitrogen fixing bacteria isolated from yam rhizosphere.

In the rhizosphere, plants interact with pathogen through roots. Thus, the rhizosphere acts as a preventive microbial buffer zone that protects against infection (Baetz and Martinoia, 2014). Also, root-exuded compounds prevent the growth of harmful microbes (Li *et al*., 2013).

Despite the significance of the rhizosphere in promoting plant and microbial interactions, plant growth and production, and more importantly aiding the plant to mitigate effect of plant stresses including drought, little information is known on yam rhizosphere. The present study was done to assess the rhizosphere chemical compositional profile of wild yam accessions in different parts of Kenya to establish levels of selected macronutrients that would inform future yam rhizosphere research on root exudates, microbial interactions, and fertilizer regime when the wild yam accessions were to be domesticated.

2.6 Ethnobotany of Yam

A few yam species produce edible tubers, while majority produce non-edible tubers. Subsequently, yams tubers have been treated as health food and traditional medicine. Although many yam species produce bitter tubers, due to the presence of diverse secondary metabolites/phytochemicals, traditional skills are used in many communities across the world to remove the bitterness (Sheikh *et al*., 2013). Yam can be consumed boiled, pounded, mashed, fried, baked, roasted (Adetoro, 2012). They can be eaten raw or dried, ground into flour and stored for future use. The flour can also be moistened, molded, boiled and eaten with soup (Okwu and Ndu. 2006). Yams may also be processed into fermented flour. Processing can alter the content of phytochemicals as well as their bioactivities.

Herbal preparations of yam are used in traditional medicine (Maneenoon *et al*., 2008; Dutta, 2015; Sharma and Bastakoti, 2009), fish poison (Burkill, 1960), against ectoparasites (Maneenoon *et al*., 2008). *Discorea hispida* Dennst. is used as an antidote to arrow poison (Edison *et al*., 2006; Mishra *et al*., 2008).

In Kenya, different yam species are cultivated in Central and Eastern Kenya for food and income (Muthamia *et al*., 2014). There is limited literature on non-food uses of yam yet yam in Kenya is increasingly becoming a neglected plant genetic resource. Hence, the need to determine the indigenous knowledge on use of different yam species by Kenyan indigenous communities.

2.7 Metabolite Composition of Yam Tubers

2.7.1 Primary metabolites

Yam tubers are rich in starch. Yam tuber dry matter consists largely of carbohydrates (upto 77.5 %), whereas crude protein, crude fat, crude fiber and ash contents are up to 7.9%, 1.2%, 1.8% and 3.8% respectively (Shih-Chuan *et al*., 2015). The water content of fresh yam is about 70% (Deb, 2002). The amino acid profiles found in yams include Arginine leucine, threonine, lysine valine, methionine, cysteine, among others (Deb, 2002). In addition, yams contain vitamin C (up to 24.7 mg/100g dry weight (Abara *et al*., 2003).

2.7.2 Secondary metabolites

Yam tubers are rich in medicinal properties due to the presence of diverse secondary metabolites, also referred to as phytochemicals (Sheikh *et al*., 2013. The yam tuber stores food and many secondary metabolites, some of the secondary metabolites are antinutritional factors (Sheikh *et al*., 2013). Common among these substances are the phenolics, flavonoids, alkaloids, saponins, terpenoids, cyanogenic glycosides and vitamins such as carotenoids and tocopherols (Eleazu *et al*., 2013). Mucilage of yam tubers contains soluble glycoprotein and dietary fibre, in addition to saponins, phytosterols, glycans, diosbulins, (+)-ß-eudesmol and paeonol (Shih-Chuan *et al.*, 2015). Many researches have reported presence of high amounts phytochemicals in *Dioscorea* species. For example *D. alata, D. bulbifera, D. dumetorum, D. cayenensis, D. rotundata* among others (Lawal *et al*., 2014; Okoroafor amd Iborida, 2017).

The phytochemicals have diverse roles in plants including colour and attraction of agents of pollination and seed dispersal, defense and protection against pathogens or environment (Eleazu *et al.,* 2012). Thus, they are also referred to as bioactive compounds. Phytochemicals limit the use of many plants for food as they can adversely affect consumers (Eleazu *et al.,* 2012). High levels of the substances may interfere with absorption or assimilation of nutrients. Reduction of the phytochemicals can be achieved through different hydrothermal treatments, which could also enhance the palatability and digestibility of the yams (Eleazu *et al.,* 2012). Despite their anti-nutritive properties, phytochemicals induce varied biochemical and pharmacological actions when ingested by animals including humans (Lawal *et al*., 2014).

Yam saponins remain stable during thermal processing and under light exposure (Shih-Chuan *et al.,* 2015). However, they can be hydrolyzed by glucosidases after crushing of tubers (Shih-Chuan *et al*., 2015). Saponins from yams are precursors for the chemical synthesis of birth control pills, progesterone and estrogen (Podolak *et al*., 2010) and corticosteroidal hormones which improve fertility in males (Igile *et al*., 2013). Saponins enhance antimicrobial activity against pathogenic microbes and serve as natural antibiotics, which help the body to fight fungal and yeast infections (Sodipo *et al.,* 2000). Saponins lower vitamins and some minerals, such as zinc and iron, in tubers through formation of insoluble complexes (Igile *et al*., 2013), hence controlling microbes that utilize these vitamins and minerals for their metabolism (Adeosun *et al.,* 2016). Although ingestion of high saponin concentrations could cause hemolysis of blood, they also lower cholesterol and prevent cancer.

Alkaloids are the largest group of secondary metabolites and are the most efficient therapeutic plant secondary metabolites, comprising basically of nitrogen bases synthesized from amino acid building blocks. Alkaloids and their synthetic derivatives are used as basic medicinal agents because of their analgesic, antispasmodic and antibacterial properties (James *et al*., 2012).

Flavonoids are important class of polyphenols in the plant kingdom. Structurally, they are made of more than one benzene ring (James, 2012). They are potent water soluble antioxidants. In addition, flavonoids have also been reported to possess antimicrobial and anti-inflammatory properties (Igile *et al*., 2013). Alkaloids and flavonoids are responsible for the antifungal activities in higher plants.

Tannins are secondary metabolites that bind to proteins and are potent inhibitors of enzymes. Tannin rich plants are used as healing agents. The large amounts of tannins in the extracts of the peels of the varieties of yams are in the healing of wounds and burns (Okwu and Ndu, 2006). Formulations based on tannin-rich plants have been valuable treatment of diseases like leucorrhoea, rhinnorhoea, healing of wounds and diarrhoea.

Terpenoids are widespread and chemically diverse groups of bioactive compounds in plants (Omojate *et al*., 2014) of which quite a number have been isolated from yams, including *D. bulbifera,* and have been shown to have antibacterial and antiprotozoal properties (Adeosun *et al*., 2016; Omojate *et al*., 2014). The presence of terpenoids in the yam extracts could enhance their potency against any bacterial infections (Sheikh *et al.,* 2013). Phenolic compounds such as phenolic acids, flavonoids and many other polyphenols, function as antioxidants (Zielinski and Kozlowska, 2008). In particular,

plant phenols possess a considerable range of bioactive properties which are not only broadly classified as nutritional but pharmacological, anti-microbial among others (Zielinski and Kozlowska, 2008).

Yams have exhibited many beneficial physiological activities such as hypoglycemic, antioxidative, antitumor, antibacterial and antimutagenic activities in humans and animals due to presence of diverse bioactive components.

Most secondary metabolites including carotenoids, saponins and flavonoids are antioxidants. They lower cholesterol, inhibit and decrease tumor formation, decrease inflammation and protect against cancer and heart diseases (Onimawo and Akubor, 2012). The high carotenoid levels in yams leads to increased β-carotene which functions as a free-radical-trapping agent and singlet oxygen quencher and have anti-mutagenic, chemo-preventive, photoprotective and immune enhancing properties (Krishan *et al.*, 2012; Sanful *et al.,* 2013).

Adeniyi *et al.,* 2010 reported that plant extracts containing bioactive agents with antimicrobial properties have been found useful in treating bacterial and fungal infections. Several studies have shown hypoglycemic, antimicrobial, and antioxidant activities of yam extracts (Adeosun *et al.,* 2016). Yams may stimulate the proliferation of gastric epithelial cells and enhance digestive enzyme activities in the small intestine (Simões *et al.,* 2009). The varied antibacterial activity recorded for *D. bulbifera* organs including whole tuber, bulbils and yam peels could be attributed to different metabolites constituted by these plant parts (Adeosun *et al.,* 2016), following the fact that these phytochemicals are routinely described as the major antibacterial factors found in plant

(Simões *et al.*, 2009). According to Adeosun *et al.*, (2016), the ethanolic extract of the peel of *D. bulbifera* demonstrated better inhibitory efficacy against etiologically significant bacteria including *Pseudomonas aeruginosa, Klebsiella pneumonia, Escherichia coli, Streptococcus pneumonia, Micrococcus luteus, Proteus vulgaris and Staphylococcus aureus*, for the fact that the peels of the yam tubers could be more enriched with several bioactive chemicals. The general believe that plant extracts are more effective against gram positive than gram-negative bacteria (Suffredini *et al.*, 2006), is contradicted by report findings by Adeosun *et al.*, (2016) that both gram-positive and gram-negative isolates tested against the yam extract were inhibited at concentrations ranging between 125 µg/ml and 500 µg/ml. Following the report of (Kuete *et al.*, 2012), the significant activity displayed by the yam tubers also reinforce the hypothesis that *D. bulbifera* could be explored as potential antimicrobial drug. Moreover, Kuete *et al.*, (2012) also emphasized that active compounds from *D. bulbifera* are substrates of multi-drug resistant (MDR) bacteria efflux pumps, suggesting a possible use as an inhibitor in the fight against these strains.

According to the report of Okoroafor and Iborida, (2017), the antibacterial activity of ethanolic extract of the *D. bulbifera* tubers is associated with the presence of terpenoids and flavonoids in the tubers that are also linked to membrane disruption and formation of complex with bacterial cell wall (Pandey and Kumar, 2013). Generally, foods rich in beneficial phytochemicals are significantly valuable in promoting overall health and preventing infections (Okoroafor and Iborida, 2017).

2.8 Mineral Composition of Yam Tubers

They also contain substantial amounts of minerals such as iron, calcium, phosphorus, potassium, sodium, magnesium, copper, iron, manganese, zinc and sulphur (Abara *et al*., 2003; Deb, 2002). The compositional nutrient profiles of the Kenyan yams will be reported in this current study.

2.9 Domestication of Wild Yams

For thousands of years, yams have undergone domestication process and have been cultivated in their regions of origin, mostly in tropical and sub-tropical regions, resulting to many ecotypes (Sesay *et al*., 2013). Where cultivated, yams have been incorporated into the social and cultural life of the people and have significant contribution to food security, medicine and commercial value particularly in rural areas (Kambaska *et al*., 2009; Dansi *et al*., 2013). Domestication enhances traits that are desirable to farmers and consumers, including ease of harvest, enhanced taste and nutritional levels. Furthermore, domestication selects against traits that increase the plant's defensive or reproductive success in natural environments. Consequently many domesticated crops have reduced fitness, or in some cases, an inability to survive outside of cultivation (Purugganan and Fuller, 2011).

Selection can be unconscious or conscious (Jensen *et al*., 2012). In unconscious selection, likely the driver of many early domestications, the act of moving plants from the wild into man-made environments alters selection pressures, leading to increased fitness of phenotypes that have low fitness in the natural environment. Human management, creates further selection pressures (Fuller *et al*., 2010; Jensen *et al*., 2012). In conscious

selection, desirable phenotypes are selected, while less desirable phenotypes are neglected or actively removed until their frequency decreases in the population (Zohary, 2004).

The cultivated species of yams resulted from domestication which was preceded by *in situ* propagation by the forest hunting and food gathering societies particularly in West Africa (Dounias, 2001). In the process of exploiting the wild yam, the gathering communities, ensure the maintenance of the wild yam tuber heads in the soil by reburying after harvesting the fleshy parts. This practise is common among some communities in West Africa, Philipines, Central Africa, Tanzania among others (Dounias, 2001). These processes have been described as protocultivation. In several communities, harvesting of wild yam tubers is regulated by religious prohibitions (Purugganan and Fuller, 2011). The plant is kept within its original environment in order to respond to the seasonal mobility of forest dwellers (Dounias, 2001). Alternatively, local communities in West Africa transplant individual wild yam plants into their home gardens (Coursey, 1967). Yam domestification is still practised by local farmers (Mignouna and Dansi, 2003). Small scale farmers obtain new cultivars mainly from neighbours or collecting tubers from the forest or fallows. The ability of the new domesticate to adapt to the local environment would determine its adoption. According to farmers, some of the newly domesticated accessions start to produce tubers that are morphologically similar to those of cultivated varieties 3-6 years after cultivation (Purugganan and Fuller, 2011). However, yam domestication practises have been on the

decline, particularly where the yam production is majorly market-driven (Jensen *et al*., 2012).

Successful domestication has been reported to be associated with gene regulation and expression (Jensen *et al*., 2012; Akakpo *et al*., 2017). For example, the genes that have been associated with domestication of wild yam include genes involved in formation of adventitious roots (Sánchez *et al*., 2007; Heo *et al*., 2011), early stages of starch biosynthesis and storage (Baroja-Fernández *et al*., 2012). Adaptation of the cultivated yam led to the selection of genes that enable efficient photosynthesis with increasing light and heat intensity (Akakpo *et al*., 2017**)**.

Existing literature indicates that *D. minutiflora, D. alata, D. bulbifera, D. dumetorum* among others are cultivated in Kenya (Muthamia *et al.*, 2014), but there is no information on their domestication in Kenya. In addition, presence of diverse wild yam species in different floristic regions in Kenya have been reported. In spite of the existence of these wild yams that have been used by local communities for food, there is no evidence of attempt to domesticate them in Kenya. In view of the current climate change, food insecurity, habitat loss due to agricultural intensification and deforestation among others, wild yam is increasingly faced with threats of extinction. Hence, there is need to intensify conservation of indigenous yam species through domestication and in turn improve food security.

2.10 Yam Production

Yams are primarily cultivated for their edible tubers, which are sources of both food and planting material (Coursey, 1967; Hahn, 1995, Deb, 2002). The tubers are rich in starch and considered a major contributor to food security in West Africa (Zannou, 2006).

The world yam production and area under cultivation have been on the rise (FAO, 2011). The world's yam production in 2010 was 48.7 million tons (Abasi *et al.*, 2013). Total African production rose by 14 million with East African production rising by 18 thousand tons. *Discorea alata, D. bulbifera* and *D. pentaphylla* are the most worldwide cultivated true yams (Sheikh *et al.*, 2013). Among the six species commonly found in West Africa, *D. rotundata* is the most widely grown and generally considered to be the best in terms of food quality, thus commanding the highest market value (Markson *et al*., 2010; Otegbayo *et al.*, 2001; Ike and Ononi, 2006; Otoo and Asiedu, 2008). In Nigeria, different species including *D. rotundata, D. cayenensis, D. bulbifera* and *D. dumetorum* are commercially produced; and *D. esculenta* is cultivated in lesser quantity for domestic use (Otoo and Asiedu, 2008). *Discorea bulbifera* which is regarded as food for the poor and eaten mainly during food scarcity, is grown in the Western and Eastern regions of Nigeria (Deb, 2002). It is less preferred probably due to its taste and variable size of the bulbils when compared to other yam types (Igbokwe *et al.*, 2016). In India, out of the 26 yam species reported, only *D. alata* is cultivated, and the remaining species grow wild (Kumar *et al.*, 2017).

Contrary to the global and regional trends, Kenya yam production has been on a decline with the production decreasing by over 6000 tons between l999 and 2009 (FAO, 2011). Maundu *et al.,* 1999 reported yam as a neglected crop in Kenya although there are some areas in central highlands where yam cultivation is still on going with the major species being *D. minutiflora* Engl. *D. bulbifera* (Maundu *et al.,* 1999).

In Kenya, wild yam is used by the different ethnic groups as food during times of drought and famine, and to a lesser extent as traditional medicine (Muthamia *et al*., 2013). However, there is no evidence of attempts by local farmers or researchers to domesticate or characterize it for food and medicinal use. There is the need for research on cultivated and wild yams to improve their production and enhance food security especially in drought prone areas. This study addresses this concern.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Sites

The wild and cultivated yam accessions that were used in the study were collected from selected and georeferenced localities in nine Counties of Kenya. The localities that contained wild yam species included Kombosang, Moigutwo, Kasaka, Mormorio, Bossei, Kapkwang and Katimok Forest (Baringo), Kolol and Turesia (Elgeyo-Marakwet), Kapseret Forest (Uasin Gishu), Chepsangor and South Nandi Forest (Nandi), Lugusi (Kakamega), Nyakomisaro Stream (Kisii) and Kaya Tsolokero (Kilifi), whereas the localities with cultivated yam included Mathia (Nyeri) and, Mogoi and St Mary's, Kitale (Trans-Nzoia). The map of the selected localities and a brief description of the yam accessions and their localities of collection are presented in Figure 1 and Table 1 respectively. The localities were chosen based on history of yam presence (FTEA 1952-2012 and observations.

The net-house experiments were carried out at the University of Eldoret Biological Sciences' net house, situated in latitude 0°35'1.96"N and longitude 35°18'33.26"E. It stands on an altitude of 2,152 m above sea level. The yam proximate and mineral element analyses were conducted in Chemistry Laboratory while the yam soil rhizosphere analysis was done in Soil Science Laboratory, University of Eldoret. The University is located 9 Km northeast of Eldoret town in Uasin Gishu county, Kenya.

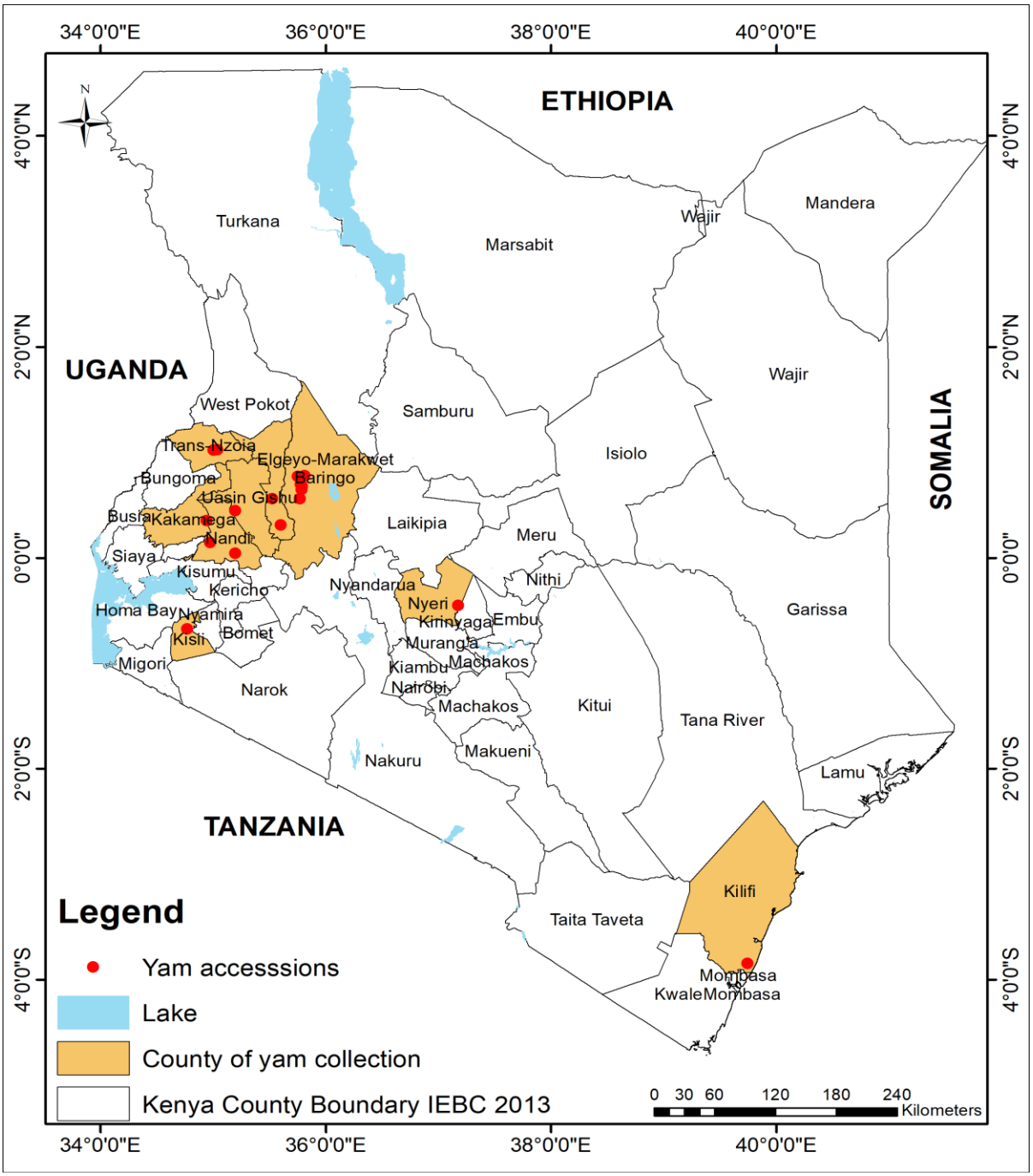

Figure 1. A map of Kenya indicating the localities and Counties where the wild yam accessions were observed and their samples collected.

Table 1. Brief description of Kenyan yam accessions and their localities of collection: * indicates yam-like accession

Yam accessions		Collection site	County			Altitude (m)
Code	**Type**			**Latitude**	**Longitude**	
KB1	Wild	Kombosang	Baringo	0°46'26.07"N	35°44'52.66"E	1297
MB1	Wild	Moigutwo	Baringo	0°46'51.27"N	35°48'38.95"E	1814
MB2a	Wild	Mormorio	Baringo	0°41'55.52"N	35°46'27.99"E	1655
MB2b	Wild	Mormorio	Baringo	0°41'55.52"N	35°46'27.99"E	1655
KB2a	Wild	Kasaka	Baringo	0°43'1.03"N	35°46'38.02"E	1455
KB2b	Wild	Kasaka	Baringo	0°43'1.03"N	35°46'38.02"E	1455
BBa	Wild	Bossei	Baringo	0°43'1.03"N	35°46'38.02"E	1650
BBb	Wild	Bossei	Baringo	0°43'1.03"N	35°46'38.02"E	1650
BBc	Wild	Bossei	Baringo	0°43'1.03"N	35°46'38.02"E	1650
KB3a	Wild	Kapkwang	Baringo	0°38'54.31"N	35°47'3.17"E	2110
KB3as	Wild	Kapkwang	Baringo	0°38'54.31"N	35°47'3.17"E	2110
KB3b	Wild	Kapkwang	Baringo	0°38'54.31"N	35°47'3.17"E	2110
KB3b	Wild	Kapkwang	Baringo	0°38'54.31"N	35°47'3.17"E	2110
KB4a	Wild		Baringo	0°31'45.65"N	35°45'42.55"E	2234
KB4b	Wild	Katimok Forest	Baringo	0°31'45.65"N	35°45'42.55"E	2234
KB4c*	Wild		Baringo	0°31'45.65"N	35°45'42.55"E	2234
KEa	Wild		Elgeyo-Marakwet	0°33'42.70"N	35°31'28.48"E	1782
KEb	Wild	Kolol	Elgeyo-Marakwet	0°18'45.65"N	35°35'52.69"E	1882
KEc	Wild	Kolol	Elgeyo-Marakwet	0°18'45.65"N	35°35'52.69"E	1882
TE	Wild	Turesia	Elgeyo-Marakwet	0°17'11.39"N	35°34'58.46"E	1868
TEs1	Wild	Turesia	Elgeyo-Marakwet	0°17'11.39"N	35°34'58.46"E	1868
TEs2	Wild	Turesia	Elgeyo-Marakwet	0°17'11.39"N	35°34'58.46"E	1868

Table 1. Continued

Yam accessions		Collection site	County			Altitude (m)
Code	**Type**			**Latitude**	**Longitude**	
KUa	Wild		Uasin Gishu	0°2'36.76"N	35°11'38.47"E	2003
KUb	Wild		Uasin Gishu	1°1'19.97"N	35° 0'12.08"E	2003
KUc	Wild	Kapseret Forest	Uasin Gishu	0°27'4.62"N	35° 12'0.42"E	1987
CNa	Wild		Nandi	0°21'5.99"N	34°56'28.61"E	1638
CNb*	Wild	Chepsangor	Nandi	0°21'5.99"N	34°56'28.61"E	1638
SNa	Wild	South Nandi Forest	Nandi	0°8’43.09”N	34°58’11.03”E	1867
SNb	Wild	South Nandi Forest	Nandi	0°8’43.09”N	34°58’11.03”E	1867
SNc*	Wild	South Nandi Forest	Nandi	0°8’43.09”N	34°58’11.03”E	1867
LKa	Wild		Kakamega	0°40'22.70"S	34°46'4.83"E	1831
LKb*	Wild	Lugusi	Kakamega	0°40'22.70"S	34°46'4.83"E	1831
NK	Wild	Nyakomisaro Stream	Kisii	0°26'59.55"S	37°10'32.09"E	1629
MT	Cultivar	Mogoi	Trans-Nzoia	1° 1'29.21"N	35° 2'13.33"E	1874
ST	Cultivar	St Mary’s, Kitale	Trans-Nzoia	Trans-Nzoia	North Rift	1855
MN	Cultivar	Mathia	Nyeri	0°26'59.55"S	37°10'32.09"E	1868
KKa	Wild	Kaya Tsolokero	Kilifi	3°50’45.40”S	39°44’35.89”E	148
KKb	Wild	Kaya Tsolokero	Kilifi	3°50’47.64”S	37°44’38.85”E	136
KKc*	Wild	Kaya Tsolokero	Kilifi	3°50’47.64”S	37°44’38.85”E	136

The field experiments were conducted at Mormorio in Baringo County, situated in latitude 0°41'55.52"N and longitude 35°46'27.99"E and stands on an altitude 1655 m above sea level. The phytochemical analysis of the yam tubers was carried out in the Chemistry Laboratory, Kisii University.

3.1.1 Kombosang and Moigutwo

Kombosang and Moigutwo are located in Kaboskei Kerio and Kaboskei locations in Barwessa and Bartabwa wards respectively, both in Baringo North sub-county. Kombosang and Moigutwo are located about 21 km and 24 km North-West and North of Kabartonjo town respectively. Kombosang and Moigutwo lie on the north-west and southern slopes of Mesente-Kapkurukwo range respectively. Kombosang is situated in lower Midland (UM 5) and Moigutwo in Upper Midland (UM 4) zones (Jaetzold, 2010). They stand on altitude of between 1250 - 1850m. One yam wild species was common in the two sites. The localities are inhabited by the Tugen community.

3.1.2 Kasaka and Mormorio

Kasaka and Mormorio are villages in Kasaka sub-location in Kabartonjo ward, Baringo North sub-county in Baringo County. Kasaka and Mormorio are located 14km and 13km North-West of Kabartonjo town on the western scarps of Tugen Hills. The two localities are separated by Ngarau range/ridge where Mormorio lies on the southern and Kasaka on the northern sides of the ridge. They are situated in Upper Midland (UM 4) zone (Jaetzold, 2010) and stand on an altitude of between 1450 - 1655m. Wild yam species were found in the natural thickets mostly on the southern side of Ngarau range and one

species is mostly widespread in Kasaka. The localities are inhabited by the Tugen Community.

3.1.3 Bossei

Bossei is located in Kapkiamo sub-location, Kelyo location, in Kabartonjo ward, Baringo North sub-county in Baringo County. It is located 8 km North-West of Kabartonjo town on the western scarps of Tugen Hills. It is situated in Upper Midland (UM 4) zone (Jaetzold, 2010) and stands at an altitude of between 1650 m. A wild yam (BB) species was found in the moist riverine forest in Summet Spring. The locality is also inhabited by the Arror sub-tribe of Tugen Community.

3.1.4 Kapkwang and Katimok Forest

Kapkwang and Katimok Forest are also located in Kabartonjo Ward. Kapkwang and Katimok Forest are located 2 km and 1 km North-West and South of Kabartonjo town respectively. Kapkwang is situated in Upper Midland (UM 3) and Katimok Forest in Lower Highland (UH 2) zones (Jaetzold, 2010). They stand on an altitude of between 2000 - 2234m. Acessions KB3a, KB3as and KB3b were found in uncultivated land in western dry and rocky slopes of Kapkwang.

3.1.5 Kolol and Turesia

Kolol and Turesia are located in Tambach and Turesia locations of Keiyo North and Keiyo South Sub- counties respectively, in Elgeyo-Marakwet County. Kolol is located 20 km South-East of Iten town and Turesia is 40 km South-East of Eldoret town. Both sites are situated in Upper Midland (UM 4) zone (Jaetzold, 2010) along the Elgeyo-Marakwet

escarpment. They are located on elevations between 1750 - 1900m. The yam species were found in natural woodland vegetation, roadsides and as weeds in cultivated environments. The residents of Elgeyo-Marakwet County are mainly from the Keiyo community.

3.1.6 Kapseret Forest

Kapseret Forest is a national forest reserve in Kapseret Sub-county, Uasin Gishu County. It is located 10 km West of Eldoret town. It is situated in Lower Highland (LH 2) zone (Jaetzold, 2010). The site stands at 2000 m above sea level. It receives an annual rainfall of 2100 mm, which is evenly distributed between March and November. The temperature ranges between 8 ^{o}C to 25 ^{o}C. Soils are well-drained, dark humic nitisols that are generally fertile (Jaetzold, 2010). More than two different yam species were found in and around and outside the forest.

3.1.7 Chepsangor

Chepsangor is in Nandi Hills Sub-county of Nandi County. It is located 16 km West of Nandi Hills town. It is in Upper Midland (UM 4) zone (Jaetzold, 2010) and stands at an altitude of 1638 metres above sea level. The soils are coarse-grained, excessively drained sandy soils. Yam species are found in natural thickets, roadsides and growing as weeds in cultivated environments. The locality is also inhabited by mainly the Nandi Community.

3.1.8 South Nandi Forest

South Nandi Forest lies west of Kapsabet town and south of the main Kapsabet-Kaimosi road. The area receives high rainfall, 1,600-900 mm/year, and is drained by the Kimondi and Sirua rivers. The landscape is gently undulating with well-drained, moderately fertile soils (BI, 2022). South Nandi is transitional between the lowland forests of West and Central Africa and the montane forests of the central Kenya highlands, and forms part of the western rainforest region and the easternmost fragment of the Guinea-Congolian phytogeographical region (BI, 2022). Two wild yam species (SNa and SNb) were discovered and collected in the forest near Chepkumia Primary School.

3.1.9 Nyakomisaro Stream

Nyakomisaro Stream originates from Nyakomisaro village and runs through the eastern side of Kisii town in Kisii County. Kisii County is characterized by high and reliable rainfall (1200 - 2100 mm per year), with mean temperatures between 16^{o}C - 18^{o}C and stands at an altitude of between 1800 m - 2165 m. The soils are well drained, dark red humic nitisols. It is located in Upper Midland (UM 4) agro-ecological zone (Jaetzold, 2010). Wild yam was found at Nyakomisaro Stream riparian/riverine at Kisii University and Nyambera Primary school near Daraja Moja. The locality is inhabited mainly by the Kisii community.

3.1.10 Lugusi

Lugusi is located in Lugari sub-county in Kakamega County. It is situated about 10km West of Turbo town. It is located in Upper Midland (UM 3) zone (Jaetzold, 2010) and stands at an altitude of 1831 m above the sea level. The site receives an annual rainfall of

1800 mm, which is evenly distributed. Soils are well-drained, deep brown sandy soils (Jaetzold, 2010). A wild yam species was found in the locality. The locality is inhabited by mainly the Bukusu/Luhya Community.

3.1.11 Mogoi and St Mary's, Kitale

Mogoi and St Mary's are located in Trans-Nzoia County**.** They are characterized by high and reliable rainfall, with mean temperatures between 25 ^{o}C - 30 ^{o}C and stand at an altitude of between 1855 - 1904 m above sea level. The soils are well-drained, dark red rhodic ferralsols. It is located in Upper Midland (UM 3) agro-ecological zone (Jaetzold, 2010). Two different cultivated yam species were found in farmers' gardens. The farmers were from Kikuyu Community.

3.1.12 Mathia

Mathia is situated in Karatina Sub-county, Nyeri County. The site receives an average 1900 mm annual rainfall. The soils are well-drained, dark reddish brown nitisols. It is situated in Upper Midland agro-ecological zone. Some farmers in this zone were found to grow only one yam species in their gardens. The farmers were also from Kikuyu ethnic community.

3.1.13 Kaya Tsolokero

Kaya Tsolokero is one of the sacred forests of the Mijikenda in the coastal region of Kenya. It is located in Junju village, Junju location, South Kilifi sub-county, Kilifi County. The area of the forest is 35 hectares, exhibiting an evergreen vegetation with

very thick forest and a variety of floral diversity. Two wild yam species and a yam-like species were found in the forest.

3.2 Species and Spatial Diversity of Kenyan Wild Yam

3.2.1 Identification of the yam accessions

Identification of wild and cultivated yam specimens in each locality involved guidance by experienced local elders who were knowledgeable on yams. Each yam species/sub-species encountered in a locality were named, photographed and their shoot samples were collected for further identification. Scientific identification of the yam accessions was carried out using available keys for yam (Hamon *et al*., 1995; Wilkin 1999, 2001; Wilkin *et al*., 2009, 2010), and the assistance of taxonomists from University of Eldoret and the East African Herbarium at the National Museum of Kenya. The voucher specimens were deposited in the University of Eldoret Herbarium.

3.2.2 Coding of the yam accessions

Identified plants per yam species/sub-species/locality, nine plants were sampled and treated as an accession. Each yam accession was then coded by the initial character of its collection locality and County. Where the first letter of a collection locality is the same as the one for the previous locality, a numerical value was added followed by a lowercase alphabetical letter only if the species were more than one per locality. For example, one and two yam species were collected from Kombosang and Kasaka localities respectively. The two localities are in Baringo County. Hence, the accessions were coded as KB1

(Kombosang, Baringo County) and, KB2a and KB2b (Kasaka, Baringo County) as indicated in Table 1.

3.2.3 Morpho-physiological characterization of the yam accessions

Morpho-physiological data that were used to characterize the yam accessions were recorded based on the descriptors defined by IPGRI/IITA, (1997), using nine (9) plants per accession. The data focused on 42 morpho-physiological characters that were organized into twelve general characters. The morphological characters that were observed and recorded included colour, hairiness, prickles distribution, plant organ type, growth habit, twining, shape, stipules, organ arrangement and surface texture of the stems, leaves, flowers, bulbils and underground tubers as shown in Appendix 1. The physiological characters included growth cycle and tuber flesh colour change after oxidation. The characters were observed and recorded for yam plants *in situ* and used for further identification and determination of relationships among the accessions.

3.2.4 Spatial diversity of wild yam

Data on collection localities, altitudes, geographic coordinates and habitat types were recorded in order to establish the distribution of yam according to habitat and geographic locations in selected Counties in Kenya.

3.3 Ethnobotanical Uses of Yam

Interviews were conducted on selected community members, mainly the elders, living in the selected localities, to determine their indigenous knowledge on yams. The interviews

were conducted using a questionnaire (Appendix 2) with emphasis on naming, uses and distribution of yam in their localities. The proportion (in %) of respondents that were knowledgeable of yam species in each locality, was calculated as:

$$\%R = \frac{n}{N} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where;

i. *%R=percentage number of knowledgeable respondents;*
ii. n*=number of respondents knowledgeable of yam per locality;*
iii. N *=total number of respondents in all the localities.*

3.4 Collection of Yam Accession Rhizosphere Soil and Tuber Samples

The rhizosphere soil samples of each selected yam plant per accession were collected according to a modified method of Bulgarelli *et al*., (2012). The underground tuber(s) of each yam plant were carefully excavated. Soil aggregates that were bound to the tuber and roots were removed and the resultant soil was then collected and kept in separately labeled bags. Rhizosphere soil of the same accession in a locality were aggregated into a composite and kept in separately labeled bags from other composites. The tuber head of each accession was excised and reburied in its hole for conservation of the yam. Then, the tubers of each accession were put in separately labelled bags. Bulbils, where they occurred, were also separately collected. Their collection sites were then georeferenced using GPS and the respective co-ordinates and altitudes were recorded (Table 1). The collected tubers of each accession were transported to the University of Eldoret and

Mormorio experimental sites for planting, while the rhizosphere soils were transported to the Soil Science laboratory to establish their chemical compositional profiles.

3.5 Rhizosphere Soil Analysis

The soils collected from the rhizosphere of the yam accessions were analyzed to establish the pH and chemical constituents.

3.5.1 Determination of rhizosphere pH

Rhizosphere soil pH was determined with pH meter in a 1:2.5 (w/v) soil: water suspension as recommended by Okalebo *et al.,* (2002). Fifty ml distilled water was added to 20 g of air-dried soil. The mixture was stirred thoroughly for ten minutes and allowed to settle for 30 minutes. Then the pH of the supernatant was measured.

3.5.2 Digestion of Soil Samples for Chemical Analysis

The total nitrogen and phosphorus determination in soils was done after wet digestion as recommended by Okalebo *et al*., (2002). Wet digestion reagents were prepared from analytical grade chemicals[1]. Air dried soil samples were sieved through a 0.25mm/ (25μ) sieve. Then 300 mg of each sample were put in clean digestion tubes and mixed with 4.4 ml of digestion reagent. Blanks containing 4.4 ml of the digestion reagent were run as a check. The mixture was heated to 70°C for one hour, followed by 360°C for two hours in a Kjeldahl digester (CSB 204 - Gerhardt). The contents were cooled and topped to 50 ml with distilled water.

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[1] (0.42 g of selenium powder was mixed with 14 g of lithium sulphate and placed in 350 ml of 30% H_2O_2. The suspension was thoroughly mixed and 420 ml of concentrated H_2SO_4 was carefully added while cooling in ice bath. The resultant reagent was stored in bottles at 2 - 4 ^{0}C)

3.5.3 Nitrogen

The nitrogen content in soil samples was determined using ammonium distillation and titration method (Okalebo *et al*., 2002). Steam distillation apparatus was set up and steam was passed through for 30 minutes. Steam blank was checked by collecting 50 ml distillate and titrated with N/140 HCl[2].

Ten (10) ml aliquot of the final sample digest was placed in reaction chamber and mixed with 10 ml of 40% NaOH[3]. Distillation was done and the distillate was collected in 5 ml of 1% boric acid[4] containing four drops of mixed indicator[5]. After the indicator turned blue, distillation was continued for an additional 2 minutes.

The distillate was titrated with the N/140 HCl to definite pink end point. Blank distillation and titration were also carried out. Distillation of an aliquot of standard 100 ppm ammonium sulphate solution was carried out to determine recovery. The percentage nitrogen in soil samples was calculated using the equation described by Okalebo *et al*., (2002):

$$\%\text{N} = \frac{(a-b)\ \times v\ \times 100}{1000 \times w \times al \times 1000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Where:

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[2] 8.1 ml concentrated HCl was put in 1 litre of distilled water to make 0.1 N HCl: 73 ml of the 0.1N HCl was diluted to 1 litre to make the **N/140 HCl**.
[3] 400 g NaOH was dissolved in distilled water and diluted with water to 1 litre to make **40% NaOH**.
[4] (**1% boric acid**: 10 g was dissolved in distilled water and diluted to 1 litre)
[5] 0.99 g bromocresol green, 0.066 g methyl red and 0.011 g thymol blue were dissolved in 100 ml ethanol to form the **mixed indicator.**

i a = concentration of N in the solution,

ii. b = concentration of N in the blank,

iii. v = total volume at the end of analysis procedure, iv. w = weight of the dried sample

iv. al = aliquot of the solution taken.

3.5.4 Olsen phosphorus

Three (3) g of air dried soil was mixed with 50 ml of the Olsen extracting solution (1M Sodium bicarbonate at pH 8.5)[6] and shaken on a reciprocal shaker (Gallenkamp-CAT 101400.XXZ.C) for 30 minutes. The suspension was filtered through the Whatman No.42 paper, and the filtrate was used for Olsen P determination.

Ten (10) ml of P standard solutions or the sample filtrates were pipetted into 50 ml volumetric flasks, and mixed with 5 ml of 0.8 M boric acid[7]. Then 10 ml of ascorbic acid reagent was added and solution was diluted to 50 ml with distilled water. The contents were stoppered, mixed well, and allowed to stand for 1 hour. The absorbance was measured with a spectrophotometer (Spectronic 21D, Milton Roy) at 880 nm. Standard absorbance readings were used to prepare a standard curve, which was used to convert sample absorbance into apparent concentration (ppm).

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[6] **Sodium bicarbonate, 0.5 M of pH 8.5:** 42 g of NaHCO3 was dissolved in 1 litre of distilled water. The pH was adjusted to 8.5 using 1 M sodium hydroxide solution. **1 M NaOH** is prepared by dissolving 40 g of NaOH in 1 litre of distilled water).

[7] **8 M boric acid -** 49.4 g of boric acid powder was dissolved and diluted to 1 litre with distilled water.

3.5.5 Organic carbon

Organic carbon was determined by the sulphuric acid and aqueous potassium dichromate digestion as described by Okalebo *et al*., (2002). The cooled digestate was transferred to 100 ml conical flask. Diphenylamine indicator (0.3 ml) was added and titrated with 1 M ferrous sulphate solution to definite end point which was indicated by colour change from greenish to brown. The titre was recorded and corrected for 2 reagent blanks (T). The organic carbon content in the soil samples was then calculated as;

$$\%\mathrm{C} = \frac{\mathrm{T} \times 0.2 \times 0.3}{\mathrm{Sw}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

Where:

i. $\mathrm{T} = \mathrm{titre}$,

ii. $\mathrm{Sw} = \mathrm{sample\ weight}$.

3.6 Effect of Cultivation on Growth and Production of Wild Yam

3.6.1 Preparation of yam tubers for planting

Dioscorea schimperiana (KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa) and *D. bulbifera* (KUb) accessions whose planting materials were adequately available, were grown in net-house and field in order to determine their potential for cultivation. A cultivated type, *D. alata* (MN) accession, was included as a check. *Dioscorea schimperiana* tubers of each accession were cut into mini tubers called setts that weighed 150 g or above, according to method by Asfaw, (2016) and O’Sullivan, (2010). The setts were sprouted in dark rooms at the experimental sites. Accession MN planting materials

were pieces of woody rhizomes prepared and recommended by yam farmers. The KUb tubers were whole tubers that weighed 150 g or less.

3.6.2 Net-house experiments

The eleven wild yam accessions which included KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK, LKa and KUb were grown in a net-house, with 75% shade. Each sprouted tuber was transferred to a growth pouch filled with forest soil, and accessions of the same species from the same collection site were replicated three times. Cultivated type, MN was included as a check. Each plant was watered with 2 litres of water in the morning and 2 litres in the evening. Each plant was staked. Data on internode length at 1m height, vine length and number of leaves per plant were recorded at mid and physiological maturity. The underground tubers were manually extracted from the growth pouches, and the bulbils were picked from the vines, after the shoots had dried up. The number and fresh weight of tubers and bulbils per plant were recorded. The tubers were placed in separate labeled paper bags and transported to the laboratory for further analysis.

3.6.3 Field experiments

Five wild yam accessions including KB1, MB1, MB2, KEa and CNa that have been used for food by the local communities were planted in an experimental plot at Mormorio village, in order to assess their potential for domestication under open field conditions. MN was also included as a check. The yam tubers were planted to 2 feet deep holes applied with organic manure, spaced at 1m between rows and 1m between plants according to a method by Asfaw, (2016) and O'Sullivan, (2010). Accession MB2C that

was collected from the bushes neighboring the experimental plot was planted in shallow holes without manure application and treated as control. The experiment was laid out in a randomized complete block design where plants were raised in two blocks and within each block, each accession was planted in plots measuring 4x3 m then replicated three times. One month after planting, weeding and staking were carried out. Each yam plant was staked using dry sticks to provide support and stimulate vine and leaf development to enhance photosynthesis. Three plants per plot were randomly tagged for data collection. Data on internode length at 1m height, vine length and number of leaves per plant were recorded at mid and physiological maturity. The underground tubers were manually dug out, and the bulbils were picked from the vines, after the shoots had dried up. The soil was washed off the tubers. The number and fresh weight of tubers and bulbils per plant were also assessed and recorded. The tubers were placed in separate labelled paper envelopes and transported to the laboratory for analysis.

3.7 Determination of Primary Metabolite Composition of Yam Tubers

3.7.1 Tuber sample preparation

The harvested tubers were washed with water and carefully peeled. The peeled tubers of the wild yam accessions, including KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa, appeared red on the upper and yellow on the lower portions; which corresponded to the head and middle portions of the tuber. Each tuber was sectioned into two at the boundary of the two colours and placed in separate labeled envelopes. The peeled whole tubers and bulbils of KUb and MN had uniformly light yellow colour, whereas KEb had creamy colour, and were treated as whole tubers. Accession KEb was

collected from its natural habitat in Elgeyo-Marakwet County, when the other accessions had been harvested from the net-house and field experiments. It was a different species from the other accessions. The peeled tubers were then subjected to proximate analysis to determine the primary metabolites including, proteins, lipids, carbohydrates, moisture, ash and crude fibre contents.

3.7.2 Moisture content

The moisture content of the tubers was measured using the method of Association of Official Analysis of Chemists (A.O.A.C, 1990). Two grams of each of the tuber head, middle or whole tuber of the yam accessions was placed in a crucible and heated at 105 ^{o}C, until a constant weight was obtained. The moisture content of each sample was calculated as shown below;

$$\%\ \text{Moisture} = \frac{W2 - W3}{W2 - W1}\ X100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

Where:

i. w_1= initial weight of empty crucible,

ii. w_2 = weight of crucible + sample before drying,

iii. w_3= final weight of crucible + sample after drying.

The peeled tubers were cut into small pieces and dried at 65 ^{o}C until constant weight was attained. The dried pieces were then milled using a locally fabricated milling machine to fine flour which was sieved through 1mm sieve, packed in airtight bottles and stored before analysis.

3.7.3 Crude protein

Crude protein was analysed using the method of A.O.A.C, (1990). Two grams of each tuber flour and 20 ml of distilled water were placed into a Kjeldahl digestion flask. It was stirred and allowed to stand for 20 minutes. A tablet of selenium catalyst was added followed by 20 ml of concentrated sulphuric acid. The flask was heated on the digestion block at 100 ^{o}C until the digest became clear. The flask was cooled and the content was transferred into 50 ml volumetric flask and diluted to the mark with distilled water.

Ten ml of the digest was transferred into another Micro-Kjeldahl flask and connected to the distilling outlet of the Kjeldahl distillation unit. A conical flask containing 5 ml of boric acid indicator was placed under the condenser outlet. Ten ml of 40% sodium hydroxide solution was added to the content in the Kjeldahl flask. The contents were distilled and distillate was collected in 5 ml of boric acid. The nitrogen in the distillate was determined by titrating with 0.01 M of H_2SO_4 until the end point was obtained when the colour of the distillate changed from green to pink. The percentage nitrogen was calculated and multiplied by 6.25 to obtain the value of the crude protein (A.O.A.C, 1990).

$$\% \text{ Nitrogen} = \frac{(Vs - Vb) \text{ X Na X } 0.01401}{W} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where:

i. Vs = titre value of the sample,

ii. Vb = volume of acid required to titrate,

iii. Na = normality of acid,

iv. W = weight of sample in grams.

3.7.4 Crude lipid

Lipid content of the tubers of each accession was determined using the Soxhlet extraction method. Ten gram of each of the flour samples were wrapped with a filter paper and placed in a thimble. The thimble was covered with cotton wool and placed in the extraction column that was connected to a condenser. Two hundred (200) ml of n-Hexane was used to extract the lipid as described by A.O.A.C. (1990).

$$\% \text{ Lipid} = \frac{w2 - w3}{ws} \; X \; 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6)$$

Where:

i. w_2 = weight of filter paper and sample before extraction,

ii. w_3= weight of filter paper and sample after extraction,

iii. w_s= weight of sample.

3.7.5 Crude fibre

Crude fibre content was determined using the method of A.O.A.C. (1990). Five grams of each of the flour sample and 200 ml of 1.25% H_2SO_4 were heated for 30 minutes and filtered with Whatman filter paper No. 42 in a Buchner funnel. The residue was washed with distilled water until it was acid-free. The residue was boiled in 1.25% NaOH for 30 minutes. It was filtered and washed several times with distilled water until it was

alkaline-free. It was then rinsed once with 10% HCl, twice with ethanol and three times with petroleum ether. The resultant residue was placed in a crucible and dried at 105^{o}C in an oven overnight. The residue was cooled in a desiccator, then ignited in a muffle furnace at 550^{0}C for 90 minutes. The crude fibre content was calculated as:

$$\%CF = \frac{W2 - W3}{W1} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where:

i. %CF = percentage crude fibre,
ii. W2= weight of filter paper and sample before extraction,
iii. W3 =weight of filter paper and sample after extraction.

3.7.6 Ash content

The ash content of the tubers was done using the method of A.O.A.C (1990). Two grams of each of the tuber flour was placed in a crucible and ignited in a muffle furnace at 550^{o}C for 6 hours. The ash was then cooled in a desiccator and weighed at room temperature. The ash content was calculated using the formula;

$$\%Ash = \frac{Wa}{Ws} \times\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (8)$$

Where:

i. wa = weight of ash,
ii. ws = weight of original sample.

3.7.7 Carbohydrate content

The carbohydrate content was determined by subtracting the total percentage of moisture, protein, lipid, fibre and ash contents from 100 according to Otitoju, (2009);

$$\%C = 100 - (\%P + \%M + \%A + \%CF) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where:

i. %C= percent carbohydrate,
ii. %P= percent protein,
iii. %M= percent moisture,
iv. %A= percent ash,
v. %CF= percent crude fibre.

3.8 Determination of secondary metabolite contents

3.8.1 Alkaloid concentration

The alkaloid concentration in the yam tubers was determined by the ammonium hydroxide precipitation using the method described by Harborne, (1998). Five grams of the tuber flour was weighed into a 250 ml beaker and 200 ml 10% acetic acid in ethanol was added, thoroughly shaken and covered to stand for 4 hours. It was then filtered through Whatman filter paper No. 42 and the extract was concentrated using a water bath to 50 ml. Concentrated ammonium hydroxide was added drop-wise to the extract until the precipitation was complete. The precipitate was allowed to settle, and was collected by filtration and then weighed. The concentration of alkaloids was calculated as:

$$A = \frac{Wap - Wp}{Sw} \text{ x } 100 \ldots \ldots \ldots (10)$$

Where;

A= alkaloids content,

Wap=weight of alkaloid +filter paper,

Wp=weight of filter paper

Sw=sample weight

3.8.2 Flavonoid concentration

Flavonoid content was determined according to the method described Boham and Kocipai, (1994). Ten (10) g of the tuber sample was extracted repeatedly with 100 ml of 80% aqueous methanol at room temperature. The whole solution was filtered through Whatman filter paper No. 42. The extract was transferred into a crucible and evaporated into dryness over a water bath and weighed to a constant weight. Flavonoid content was calculated as:

$$F = \frac{Wfd - Wd}{Ws} \text{ x } 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (11)$$

Where:

i. F=flavonoid content
ii. W_{fd} =weight of flavonoid + evaporation dish,
iii. W_d =weight of empty evaporation dish,
iv. Ws=sample weight.

3.8.3 Tannins concentration

The tannin content of the yam tubers was determined by Folin Denis spectrophotometric method (Harbone, 1998; Kirk and Sawyer, 1998). Five (5) g of the tuber flour was mixed with distilled water in the ratio of 1:10 (w/v). The content was stirred for 30 minutes at room temperature and filtered through a whatman No. 42 filter paper. A standard tannin solution was prepared[8]. Two (2) ml of the standard tannic acid solution and 2 ml of distilled water were separately placed 50ml volumetric flask to serve as standard and reagent blank respectively. Then 2 ml of each of the tuber sample extract was put in 50 ml flask. Thirty five (35) ml distilled water, 1ml Folin Denis reagent[9] and 2.5 ml of saturated Na_2CO_3 solution[10] were added. Each flask was then diluted to the 50ml mark with distilled water and incubated for 90 minutes at room temperature. Their absorbance was measured at 760 nm in the spectrophotometer (New Shimadzu UV-1800 Double Beam). Tannin content was calculated as;

$$T = \frac{At \times Cs \times Vt}{Ws \times As \times Va} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where;

i. T=tannins content

ii. Ws = weight of sample,

iii. At = absorbance of test sample,

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[8](**Tannic acid standard solution**: 100 mg of tannic acid was dissolved in 1 litre of water. Fresh solution was prepared for each determination (1 ml = 0.1 mg of tannic acid).

[9](**Folin-Denis reagent:** To 750 ml of water, 100 g of sodium tungstate ($Na_2WO_4.2H_2O$), 20 g of phosphomolybdic acid and 50 ml of 85% phosphoric acid ($H_3 PO_4$) were dissolved. The mixture was refluxed for 2 hrs, cooled to 25 ^{0}C and dilute to 1000 ml with distiiled water)

[10](**Saturated sodium carbonate solution**: To 100 ml of water, 35 g of anhydrous sodium carbonate was added, dissolved at 70 ^{o}C and cooled overnight. The clear liquid was decanted before it was used)

iv. As = absorbance of standard tannic acid solution,

v. Cs = concentration of standard tannic acid solution,

vi. Vt = total volume of extract,

vii. Va = volume of extract analyzed.

3.8.4 Saponins concentration

Saponin content was determined by the method of Obadoni and Ochuko, (2001). Five (5) g of tuber sample was mixed with 50 ml of 20 % ethanol. The sample was heated with continuous stirring over a hot water bath for 4 hours at 55°C. The mixture was filtered and the residue re-extracted with another 50 ml of 20 % ethanol. The combined extracts were reduced to 10 ml over water bath at 90°C. The concentrate was transferred into a separating funnel, and 20 ml of diethyl ether was added and shaken vigorously. The aqueous layer was recovered while the ether layer was discarded. The purification process was repeated. Fifteen (15) ml of n-butanol was added, and the combined n-butanol extracts were washed twice with 10 ml of 5% aqueous sodium chloride. The remaining solution was heated over water bath. The samples were dried in the oven to a constant weight and the saponin content was calculated using the formula;

$$S = \frac{Ws + Wds - Wed}{Sw} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Where:

i. S=saponins content,

ii. Ws=weight of saponin,

iii. Wds=weight of dish and saponin,

iv. Wed=weight of empty dish,

v. Sw=tuber sample weight.

3.9 Determination of mineral elements in yam tubers

3.9.1 Tuber sample digestion

The dry flour of each accession weighing 300 g were placed in a labelled, clean and dry digestion tube. To each digestion tube, 4.4 ml digestion mixture containing 0.42 g of selenium powder, 14 g of lithium sulphate, 350 ml of 30% H_2O_2 and 420 ml of concentrated H_2SO_4 was added as described by Okalebo *et al.,* (2002). Digestion was done at 360 ^oC for 2 hours and the contents were cooled. Twenty five ml of distilled water was added and mixed well until no more sediment dissolved. The mixture was allowed to cool and topped to 50 ml mark with water and mixed well. The digests were allowed to settle and the clear supernatant was used to assess the chemical composition of the yam tubers.

3.9.2 Total phosphorus

Total phosphorus was assessed using ascorbic acid procedure as described by Okalebo *et al*., (2002). Five ml of digest solution was pipetted into a volumetric flask and twenty ml of distilled water was added followed by 10 ml of the ascorbic acid reducing agent and topped to 50 ml with distilled water. The covered mixture was well shaken and allowed to stand for one hour to permit full colour development. Then the absorbance was read at 880 nm in a spectrophotometer (Spectronic 2ID, Milton Roy). The mean blank value was subtracted from the samples to give the corrected reading. Standard P

concentrations[11], 0.0, 0.2, 0.4, 0.8, 1.0 and 1.2 ppm were prepared and mixed with the ascorbic acid reducing agent. The absorbance was read at 880 nm, and a standard curve was plotted using absorbance readings of standard P solutions and used to determine P concentration for each sample.

3.9.3 Potassium

The potassium content was anaylsed with flame photometer (Jenway no. PFP7, UK). Two (2) ml of the tuber digest solution was placed into a 50 ml volumetric flask, topped to 50 ml mark with distilled water and mixed well. The solutions, starting with the standards, sample and blank were aspirated directly into the flame photometer at 766.5 nm and the absorbance readings recorded. The amount of potassium present in the sample solution was read from the calibration curve prepared by plotting galvanometer/transmission readings against potassium concentrations, following the operation instructions given for flame photometer.

3.9.4 Sodium

Two ml of the digested sample solution was placed into a 50 ml volumetric flask. It was topped to mark with distilled water and mixed well. The sample solutions were aspirated starting with the standards, sample and blank solutions directly into the flame photometer (Jenway no. PFP7, UK) at 766.5 nm and the absorbance readings recorded. The amount of sodium present in the sample solution was read from the calibration curve prepared by plotting galvanometer/instrument readings against sodium concentrations, following the operation instructions given for flame photometer.

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[11] **Standard phosphorus, 1000 ppm P** - 1.097 g dry KH_2PO_4 was dissolved and made to 250 ml with distilled water. Ten (10) ml of 1000 ppm P solution was diluted with distilled water to 1 litre to make 10 ppm P,

3.7.5 Calcium

Ten ml of the digested sample solution was put into a 50 ml volumetric flask. Ten ml of 0.15% lanthanum chloride[12]was added and topped to the mark with distilled water and stirred well. The standard, blank and sample solutions were aspirated into atomic absorption spectrophotometer at wavelength 422.7 nm. A calibration curve of the standard readings was used to read the concentration of calcium in the sample and blank solutions.

3.9.6 Magnesium

Five millilitres of the wet-digested sample solution was put in a 50 ml volumetric flask, filled to the 50 ml mark with distilled water and thoroughly mixed. The Mg standard series, the blank and sample solutions were aspirated into the flame of atomic absorption spectrophotometer (Spectra AA-200, Australia). The concentration of the magnesium in the standard series, sample and the blank solutions were measured. The concentration of the sample and the blank solutions were read from a calibration curve of the standard readings.

3.9.7 Iron

The diluted sample, blank digests and the standard series were aspirated into the atomic absorption spectrophotometer (Spectra AA-200, Australia) that was calibrated for iron measurement at a wavelength of 248.3 nm and their absorbance were recorded. The Fe content was determined against the Fe standard curve that was plotted from the readings of the Fe standard series.

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[12] Lanthanum chloride, $LaCl_3 \cdot 7H_2O$, 0.15%. 1.5 g of lanthanum chloride was dissolved in distilled water and diluted to 1 litre

3.9.8 Zinc

The diluted sample, blanks digests and the standard series were aspirated into the atomic absorption spectrophotometer (Spectra AA-200, Australia) that was calibrated for zinc measurement at a wavelength of 213.9 nm and the absorbances were recorded. The Zn content was determined against the Zn calibration curve that was plotted from the readings of the standard series.

3.10 Data analysis

Past 4.03 software.was used to analyse physio-morphological characterisation data. The data were coded into numerical values and subjected to multivariate and principal component analyses (PCA) to identify the most discriminating morphological character. From the correlation matrix, data were generated for the principal component factor analysis. A dendrogram was generated based on a hierarchical cluster analysis using paired group (UPGMA). A presence (+) or absence (-) matrix was performed for the spatial diversity for each species. SPSS (version 21 Premium) was used to analyze the indigenous knowledge, rhizosphere soil chemical, tuber primary and secondary metabolite, and mineral composition, growth and yield attributes data. Descriptive statistics (percentages) were calculated to determine the proportion of respondents knowledgeable of yam local name and uses. The rhizosphere soil chemical, tuber primary and secondary metabolite, and mineral composition, growth and yield attributes data were subjected to analysis of variance and the differences of means were adopted as significant at $P \leq 0.05$. Post-hoc separation of means was done using Tukey's test (Zar, 1984).

CHAPTER FOUR

RESULTS

4.1 Species and Spatial Diversity of Wild Yam in Kenya

4.1.1 Local naming and scientific identification of the yam accessions

The 31 wild yam accessions were classified into four species; *D. schimperiana* Kunth., *D. bulbifera* L., *D. quartiniana* var. *quartiniana,* and *D. dumetorum* (Kunth) Pax. The three cultivated yam accessions belonged to two species; *Dioscorea alata* L. (MN and MT) and *Dioscorea bulbifera* var. *anthropophagorum* (ST). *Discorea schimperiana* Kunth. included accessions KB1, MB1, MB2a, KB3a, KB4b, KEa, TE, KUa, CN1a, CN2a, NK and LKa (Table 2, Figure 2). However, accessions KB3as, KB3c, TEs1 and TEs2 were morphotypes of *D. schimperiana* Kunth (Figure 3). Apparently, KB3as and TEs1 had green prickled vines and large leaves that folded downwards at their apex and green inflorescence, thus were considered *D. schimperiana* ssp 1. KB3c had dark brown vines without prickles, and leaves that folded upwards, were considered ssp 2, whereas TEs2 was similar to KB3c except that it had prickled vine and dark brown inflorescence and was considered ssp 3 of *D. schimperiana* (Figure 3). The *D. schimperiana* Kunth. was also known by different local names by the respondents of the communities in the different localities. For instance, it was identified as *Nyakanwo* (Tugen), *Yakanwet* (Keiyo/Nandi), *Omotabararia* (Abagusi) and *Limbama* by Bukusu/Luhya (Table 3). Despite some phenotypic differences in their tuber and shoot systems, KB3as, TEs1 and TEs2 were identified by same local names, *Nyakanwo* and *Yakanwet* by Tugen and Keiyo ethnic groups respectively (Figure 3, Table 2).

Table 2. The local and botanical names of the yam accessions and the proportion of knowledgeable respondents in the selected localities in Kenya

No	Yam accession				Ethnic group	
	Code	**Type**	**Botanical name**	**Local name**		**Locality**
1	KB1	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Kombosang
2	MB1	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Moigutwo
3	KB2a	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Kasaka
4	MB2a	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Mormorio
5	BBa	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Bossei
6	KB3a	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Kapkwang
7	KB3as	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Kapkwang
8	KB3c	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Kapkwang
9	KB4b	Wild	*Dioscorea schimperiana* Kunth.	*Nyakanwo*	Tugen	Katimok Forest
10	KEa	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Keiyo	Kolol
11	TE	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Keiyo	Turesia
12	TEs1	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Keiyo	Turesia
13	TEs2	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Keiyo	Turesia
14	KUa	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Nandi	Kapseret Forest
15	CNa	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Nandi	Chepsangor
16	SNa	Wild	*Dioscorea schimperiana* Kunth.	*Yakanwet*	Nandi	South Nandi Forest
17	NK	Wild	*Dioscorea schimperiana* Kunth.	*Omotabararia*	Abagusi	Nyakomisaro Stream
18	LKa	Wild	*Dioscorea schimperiana* Kunth.	*Limbama*	Luhya/Bukusu	Lugusi
19	KB4a	Wild	*Dioscorea bulbifera* var. *bulbifera*	*Nyakanwo*	Tugen	Katimok Forest

Table 2. Continued

No	Yam accession				Locality	Ethnic group
	Code	**Type**	**Botanical name**	**Local name**		
20	KEc	Wild	*Dioscorea bulbifera* var. *bulbifera*	*Yakanwet*	Keiyo	Kolol
21	KUb	Wild	*Dioscorea bulbifera* var. *bulbifera*	*Nyakanwo*	Nandi	Kapseret Forest
22	BBc	Wild	*Dioscorea bulbifera* var. *bulbifera*	*Nyakanwo*	Tugen	Bossei
23	KKb	Wild	*Dioscorea bulbifera* L. variant 1		Chonyi	Kaya Tsolokero
24	ST	Cultivar	*Discorea bulbifera* var. *anthropophagorum*	*Gikwa*	Kikuyu	ST Mary's, Kitale
25	KB2b	Wild	*Discorea quartiniana* var. *quartiniana*	*Sekawet*	Tugen	Kasaka
26	MB2b	Wild	*Discorea quartiniana* var. *quartiniana*	*Sekawet*	Tugen	Mormorio
27	BBb	Wild	*Discorea quartiniana* var. *quartiniana*	*Sekawet*	Tugen	Bossei
28	KB3b	Wild	*Discorea quartiniana* var. *quartiniana*	*Sita/sekawet*	Tugen	Kapkwang
29	KEb	Wild	*Discorea quartiniana* var. *quartiniana*	*Sakawat*	Keiyo	Kolol
30	KUc	Wild	*Discorea quartiniana* var. *quartiniana*		Nandi	Kapseret Forest
31	SN2b	Wild	*Discorea quartiniana* var. *quartiniana*		Nandi	South Nandi Forest
32	KKa	Wild	*Dioscorea dumetorum* (Kunth) Pax.	*Riga*	Chonyi	Kaya Tsolokero
33	MT	Cultivar	*Discorea alata*	*Gikwa*	Kikuyu	Mogoi
34	MN	Cultivar	*Discorea alata*	*Gikwa*	Kikuyu	Mathia

Figure 2. Shoots of wild yam species observed in situ in different Counties; *D. schimperiana* Kunth (MB2a, KB3a, KEa), *D. quartiniana* var. *quartiniana* (KUc and MB2a), *D. dumetorum* (Kunth) Pax. (KKa), *D. bulbifera* var. *bulbifera* (BBc, KUb) and a cultivated *D. alata* (MN).

Figure 3. Stems, leaves and floral parts of *D. schimperiana* Kunth. morphological variants (KB3as, TEs1, TEs2).

Moreover, *D. bulbifera* var. *bulbifera* included the wild yam accessions, KB4a, KUb, KEc, BBc and KKb (Table 2; Figure 2). Similar to *D. schimperiana*, the *D. bulbifera* accessions, BB, KB4a, KEc, KUb and KKb also showed morphological differences among themselves. Accessions BB, KB4a, KEc and KUb which were found in North Rift region of Kenya, had golden brown irregular or oblong underground tubers, prickled stem base, pink stem, grey round or oval bulbils and were *D. bulbifera* var. *bulbifera*, while KKb that was found in the Coastal region, had grey, round underground tuber, non-prickled purple stem base, green stem above the base, dark purple angular or bean shaped bulbils and was considered a new variety/sub-species of *D. bulbifera*. Accession ST, the cultivated type was identified as *D. bulbifera* var. *anthropophagorum.* The Tugen, Keiyo and Nandi respondents gave *D. bulbifera* var. *bulbifera* the same local name as *D. schimperiana* Kunth; Nyakanwo (Tugen) and Nyakanwet (Keiyo and Nandi). However, Chonyi respondents in Kilifi County did not know its indigenous name, whereas the cultivated type of *D. bulbifera* was locally named *Gikwa* by respondents of Kikuyu ethnic group.

Dioscorea quartiniana var. *quartiniana* included KB2b, BBb, KB3b, KEb, KUc and SN2b accessions that were locally known as *Sekawet* or *Sita* by Tugen respondents in Kasaka, Mormorio, Bossei and Kapkwang localities in Baringo County (Table 2). Keiyo informants in Kolol locality in Elgeyo-Marakwet County named it *Chepkawat*/*Sakawat*, but it was unknown to the respondents in both Nandi and Uasin Gishu Counties. In addition, *D. dumetorum* (Kunth) Pax. (KKa) was named *Riga* or *Mriga* by Chonyi ethnic group in Kaya Tsolokero. *D. alata* (MN and MT)

was referred to as *Gikwa* by Kikuyu respondents in Mogoi, and Mathia, in Trans-Nzoia and Nyeri Counties respectively.

Finally, yam-like plants including KB4c*, CNb*, SNc*, LKb* and KKb*, characterized with prickled vines and leaf morphology that closely resembled *D. alata* L but had bi-stipular tendrils (Figure 4) were encountered in Baringo, Nandi, Kakamega and Kilifi Counties. They were botanically identified as *Smilax aspera* L.

4.1.2 Characterization of yam using morphological characters

1. Principal component analysis (PCA)

The PCA showed that the first four principal components, whose Eigen values were over 0.2, together contributed 99.12% of the overall variance (Table 3). This 99.12% variance was contributed by eighteen (Table 4) out the 42 traits used to describe the yam accessions (Appendix 1). The first principal component (PC 1) accounted for 88.31% of the total variance (Table 3). It was characterized by high positive loadings (factor-variate correlations) on base colour and above base colour (Table 4). The PC 2 determined by base colour, hairs (absence/presence), hairiness, plant type, surface texture, growth habit and flesh colour explained only 6.85% of the overall variance. The third PC was related to above base colour, hairs, hairiness, plant type, surface texture, growth habit, organ arrangement, shape, growth cycle, flesh colour (upper), flesh colour (lower), tuber flesh colour 5 mins after dissecting which accounted for 2.678% of the total variation. Moreover, the fourth factor was influenced primarily by hairs, hairiness, surface texture, growth habit, organ arrangement, growth cycle, tuber flesh colour (upper), tuber flesh colour (lower), colour change after oxidation, flesh colour 5 mins after oxidation explaining only 1.29% of the variation.

Figure 4. Yam-like wild plants, *Smilax aspera*; KB4c* (Baringo County), CN1b* and CN2b* (Nandi County) and cultivated yam, *D. alata*, MN (Nyeri County).

Table 3. Eigen values and share of total variance and principal components of the characters of the yam accessions

Parameters	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Eigen value	17.64	1.37	0.53	0.26
Variance (%)	88.31	6.85	2.67	1.29
Cumulative (%)	88.31	95.16	97.83	99.12

Table 4. Correlations between characters and principal components (PC)

Character	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Base colour	**0.506**	**0.773**	-0.166	-0.286
Above base colour	**0.856**	-0.477	**0.114**	0.094
Hairs	0.004	**0.136**	**0.105**	**0.173**
Hairiness	0.009	**0.274**	**0.201**	**0.341**
Base prickles	-0.025	0.088	0.030	-0.012
Above base prickles	0.007	0.006	-0.090	-0.142
Plant/organ type	0.036	**0.120**	**0.250**	0.087
Surface texture	0.023	**0.134**	**0.218**	**0.225**
Growth habit	0.001	**0.116**	**0.171**	**0.144**
Twining direction	0.021	0.025	-0.009	0.003
Organ arrangement	0.053	0.056	**0.150**	**0.199**
Organ shape	-0.056	-0.035	**0.752**	-0.634
Growth cycle	-0.004	0.031	**0.218**	**0.262**
Stipules	-0.003	-0.053	0.019	-0.014
Flesh colour (upper)	0.020	**0.108**	**0.232**	**0.272**
Flesh colour (lower)	-0.020	0.046	**0.162**	**0.162**
Flesh colour change after oxidation	-0.002	0.020	**0.167**	**0.163**
Flesh colour 5 mins after oxidation	0.039	0.069	**0.125**	**0.164**

Values in bold indicate the most relevant characters (>0.1) that contributed most to the variation of the particular component.

2. Yam Accession Clustering on basis of morphological characteristics

The dendrogram identified two main clusters of the 34 yam accessions as represented by the accession codes (Figure 5). The first cluster contained 27 accessions, and the second, 7 accessions. The 27 accessions in the first cluster formed two sub-clusters. These included the sub-cluster 1 (I), which comprised 18 accessions of *Dioscorea schimperiana* Kunth. (KB3a, KB4b, SNa, TE, LKa, NK, CNa, KEa, KUa, KB1, BBa, KB2b, MB1, MB2a and KB3c) and *D. schimperiana* variants (TEs1 and KB3as, TEs2).

The sub-cluster 1 (II) were composed of the *D. bulbifera* var. *bulbifera* (KB4a, BBc, KEc, KUb), *D. bulbifera* L. variant (KKb), the cultivated, *D. bulbifera* var. *anthropophagorum* (ST), *D. dumetorum* (Kunth) Pax. (KKa) and *D. alata* L. (MN and MT). However, some accessions such as TES2, TES1, KB3as and KB3c in sub-cluster 1 (I), and ST and KKb in sub-cluster 1 (II), were distantly separated from the other accessions of the same sub-cluster.

Furthermore, the second cluster produced two sub-clusters that were composed of seven accessions (Figure 5). Cluster 2 (A) is made up of *Dioscorea quartiniana* var *quartiniana* (KB2a and KUc) and sub-cluster 2 (B), which is composed of *Dioscorea quartiniana* var. *quartiniana* (KEb, MB2b, BBb, KB3b and SNb).

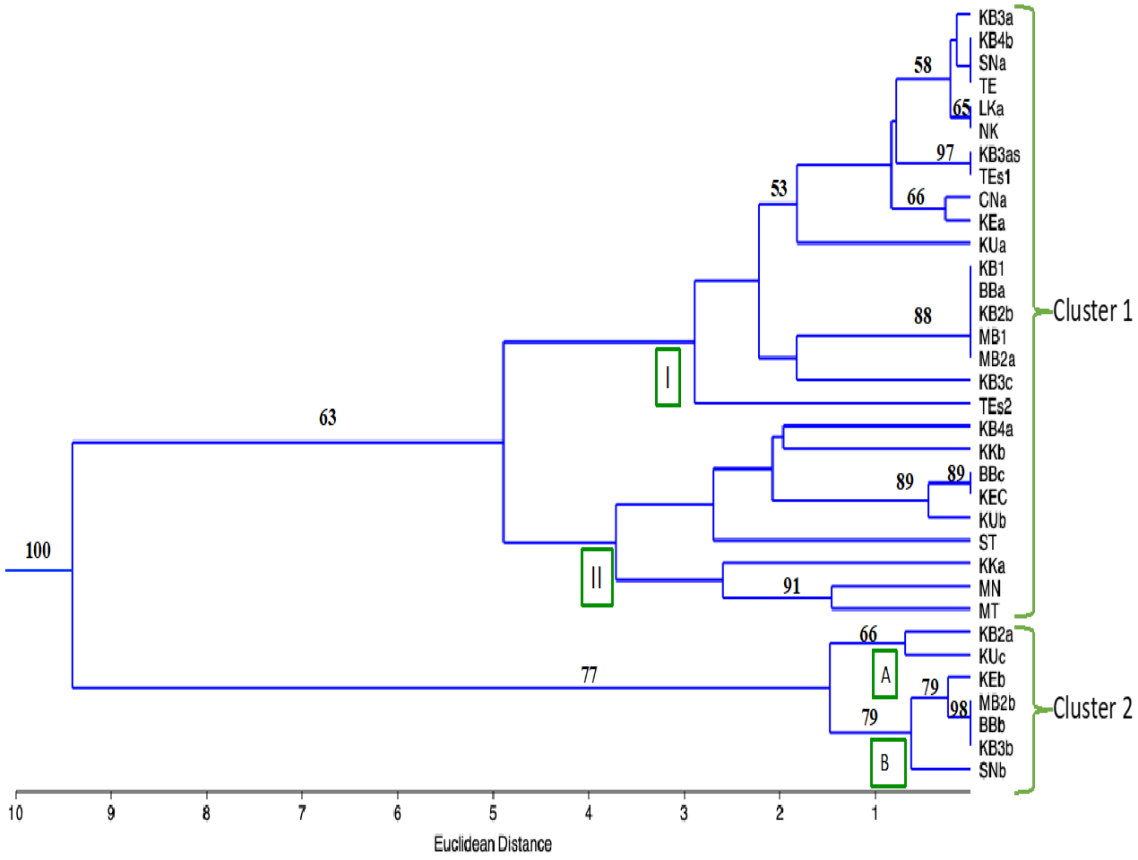

Figure 5. Dendrogram illustrating the relationship among yam accessions based on morphological characters.

Key:

Cluster 1 (I) *Dioscorea schimperiana* Kunth. (KB3a, KB4b, SNa, TE, LKa, NK, KB3as, TEs1, CNa, KEa, KUa, KB1, BBa, KB2b, MB1, MB2a, KB3c and TEs2). **Cluster 1 (II)** *D. bulbifera* var. *bulbifera* (KB4a, BBc, KEc, KUb), *D. bulbifera* L. variant (KKb), *D. bulbifera* var. *anthopophagorum* (ST), and *D. dumetorum* (KKa), *D. alata* (MN and MT). **Cluster 2 (A)** *Dioscorea quartiniana* var *quartiniana* (KB2a and KUc). **Cluster 2 (B)** *Dioscorea quartiniana* var quartiniana (KEb, MB2b, BBb, KB3b and SNb).

4.1.3 Distribution of the wild yam species in Kenya

The different wild yam species occupied specific habitats that were categorized into four; moist/wet deep forest, forest edges and outskirts, dry and rocky slopes and moist/wet riverine forest (Table 5). *Dioscorea schimperiana* Kunth. was present in all the four habitats that were distributed in fourteen out the fifteen localities in six Counties that comprised Kombosang, Moigutwo, Mormorio, Kapkwang and Katimok Forest (Baringo), Kolol and Turesia (Elgeyo-Marakwet), Kapseret Forest (Uasin Gishu), Chepsangor and South Nandi Forest (Nandi), Nyakomisaro Stream (Kisii) and Lugusi (Kakamega). It was absent in Kaya Tsolokero in Kilifi County. It occured in an altitude between 1297 - 2110 m above the sea level.

Discorea quartiniana var. *quartiniana* also occured in all the four habitats but in seven out of the fifteen localities that included, Kasaka, Mormorio and Kapkwang (Baringo County) and Kolol (Elgeyo-Marakwet), Kapseret Forest (Uasin Gishu County) and South Nandi Forest (Nandi County). It inhabited areas with an altitude range of 1455 - 2003 m above the sea level.

Dioscorea bulbifera var. *bulbifera* occurred mostly in moist/wet or dry deep forest and forest edges in Katimok, Kapseret and Kaya Tsolokero forests in Baringo, Uasin Gishu and Kilifi Counties respectively. In addition, a few plants grew over indigenous riverine forests in Kiptebeng'wo and Summet Springs in Kolol and Bossei localities in Baringo and Elgeyo-Marakwet Counties respectively.

Table 5. Distribution of wild yam species according to habitats in the selected localities: plus (+) indicates the presence of a species and minus (-) indicates its absence.

Code	Species	Habitat			
		Deep forest	**Forest edges/outskirts**	**Rocky slopes**	**Riverine forest**
KB1	*Dioscorea schimperiana* Kunth.	-	-	+	+
MB1	*Dioscorea schimperiana* Kunth.	-	-	+	+
KB2a	*Dioscorea schimperiana* Kunth.	-	-	+	+
MB2a	*Dioscorea schimperiana* Kunth.	-	-	+	+
BBa	*Dioscorea schimperiana* Kunth.	-	-	+	+
KB3a	*Dioscorea schimperiana* Kunth.	-	-	+	+
KB3as	*Dioscorea schimperiana* Kunth.	-	-	+	+
KB3c	*Dioscorea schimperiana* Kunth.	-	-	+	+
KB4b	*Dioscorea schimperiana* Kunth.	-	+	+	-
KEa	*Dioscorea schimperiana* Kunth.	-	+	+	+
TE	*Dioscorea schimperiana* Kunth.	-	+	+	+
TEs1	*Dioscorea schimperiana* Kunth.	-	+	+	+
TEs2	*Dioscorea schimperiana* Kunth.	-	+	+	+
KUa	*Dioscorea schimperiana* Kunth.	-	+	+	+
CNa	*Dioscorea schimperiana* Kunth.	-	-	+	+
SNa	*Dioscorea schimperiana* Kunth.	+	+	+	+
NK	*Dioscorea schimperiana* Kunth.	-	+	+	+
LKa	*Dioscorea schimperiana* Kunth.	-	+	+	-
BBc	*D. bulbifera* var. *bulbifera*	-	+	-	+
KB4a	*D. bulbifera* var. *bulbifera*	+	+	-	-

Table 5. Continued.

Code	Species	Habitat			
		Deep forest	**Forest edges/outskirts**	**Rocky slopes**	**Riverine forest**
KEc	*D. bulbifera* var. *bulbifera*	-	+	-	+
KUb	*D. bulbifera* var. *bulbifera*	+	+	-	-
KKb	*Dioscorea bulbifera*	+	+	-	-
KB2b	*D. quartiniana* var. *quartiniana*	-	-	+	+
MB2b	*D. quartiniana* var. *quartiniana*	-	-	+	+
BBb	*D. quartiniana* var. *quartiniana*	-	+	+	+
KB3b	*D. quartiniana* var. *quartiniana*	-	-	+	+
KEb	*D. quartiniana* var. *quartiniana*	-	-	+	+
KUc	*D. quartiniana* var. *quartiniana*	-	-	+	+
SNb	*D. quartiniana* var. *quartiniana*	+	+	+	+
KKa	*Dioscorea dumetorum* Pax	+	+	-	-

It occurred in an altitude range of 1882 - 2003 m above sea level. *Dioscorea dumetorum* was available in the moist deep forest and dry forest edges of Kaya Tsolokero in Kilifi County, at an altitude of 136 m above sea level.

4.2 Ethnobotanical Uses of Yam by Indigenous Communities in Kenya

The ethnic communities used the six yam species identified in this study for different purposes (Table 6). Notably, a half (50%) of all the respondents reported wild yam tubers (Figures 6 and 7) to have been used as famine food. Specifically, 10.0%, 2.5% and 37.5% of all the respondents reported *D. bulbifera*, *D. dumetorum* and *D. schimperiana* tubers to have been useful famine food (Table 7). Again, 2.5% of Nandi respondents noted *D. schimperiana* to have been vital in diabetes tratment and wound dressing while 12.5% of Tugen respondents affirmed the use of *D. schimperiana* in treatment of sterility in humans. Although *D. quartiniana* was reported poisonous, 7.5% of the Tugen respondents reported it useful in treatment of gonorrhoea.

Of the 50% knowledgeable respondents on wild yam as famine food, 20% and 12.5% were from Tugen and Keiyo ethnic groups (Table 7), while the rest were Abagusii (2.5%), Chonyi (2.5), Luhya/Bukusu (2.5) and Nandi (2.5). Moreover, the 10% of the respondents who reported *D. quartiniana* tubers as non-edible, included 2.5% and 7.5% respondents from Keiyo and Tugen communities espectively. Of the 7.5% of all the respondents that reported *D. alata* and *D. bulbifera* var. *anthropophagorum* as regular food, all were members of Kikuyu ethnic community, where 5.5% and 2.5% respectively, reported *D. alata* and *D. bulbifera* var. *anthropophagorum* were used as regular food.

Table 6. The indigenous uses and the proportion of respondents knowledgeable of the uses of yam species

Yam uses	**The yam species and the percentage (%) of respondents knowledgeable of the yam uses**						Total
	D. bulbifera var. *bulbifera*	*D. dumetorum* (Kunth) Pax (Wild)	*D. schimperiana* Kunth. (Wild)	*D. alata* L.(cultivar)	*D. bulbifera* var. *anthropophagorum*	*D. quartiniana* var. *quartiniana*	
Famine food	**10.0**	**2.5**	**37.5**	0.0	0.0	0.0	**50.0**
Regular food	0.0	0.0	0.0	**5.0**	**2.5**	0.0	**7.5**
Income generation	0.0	0.0	0.0	**2.5**	0.0	0.0	**2.5**
Poisonous	0.0	0.0	0.0	0.0	0.0	**10.0**	**10.0**
Diabetes treatment	0.0	0.0	**2.5**	0.0	0.0	0.0	**2.5**
Gonorrhoea treatment	0.0	0.0	0.0	0.0	0.0	**7.5**	**7.5**
Pain reliever	0.0	0.0	**2.5**	0.0	0.0	0.0	**2.5**
Sterility treatment (Humans)	0.0	0.0	**12.5**	0.0	0.0	0.0	**12.5**
Sterility treatment (Livestock)	0.0	0.0	**2.5**	0.0	0.0	0.0	**2.5**
Wound dressing	0.0	0.0	**2.5**	0.0	0.0	0.0	**2.5**
Total	**10.0**	**2.5**	**60.0**	**7.5**	**2.5**	**17.5**	**100.0**

Table 7. The proportion (%) of respondents in different ethnic communities that were knowledgeable of yam uses

Yam uses	Percentage (%) of knowledgeable respondents per ethnic group							Total
	Abagusi	Chonyi	Keiyo	Kikuyu	Luhya/Bukusu	Nandi	Tugen	
Famine food	**2.5**	**2.5**	**12.5**	0.0	**2.5**	**10.0**	**20.0**	**50.0**
Regular food	0.0	0.0	0.0	**7.5**	0.0	0.0	0.0	**7.5**
Income generation	0.0	0.0	0.0	**2.5**	0.0	0.0	0.0	**2.5**
Poisonous	0.0	0.0	**2.5**	0.0	0.0	0.0	**7.5**	**10.0**
Diabetes treatment	0.0	0.0	0.0	0.0	0.0	**2.5**	0.0	**2.5**
Gonorrhoea treatment	0.0	0.0	0.0	0.0	0.0	0.0	**7.5**	**7.5**
Pain reliever	**2.5**	0.0	0.0	0.0	0.0	0.0	0.0	**2.5**
Sterility treatment (Humans)	0.0	0.0	0.0	0.0	0.0	0.0	**12.5**	**12.5**
Sterility treatment (Livestock)	0.0	0.0	0.0	0.0	**2.5**	0.0	0.0	**2.5**
Wound dressing	0.0	0.0	0.0	0.0	0.0	**2.5**	0.0	**2.5**
Total	**5.0**	**2.5**	**15.0**	**10.0**	**5.0**	**15.0**	**47.5**	**100.0**

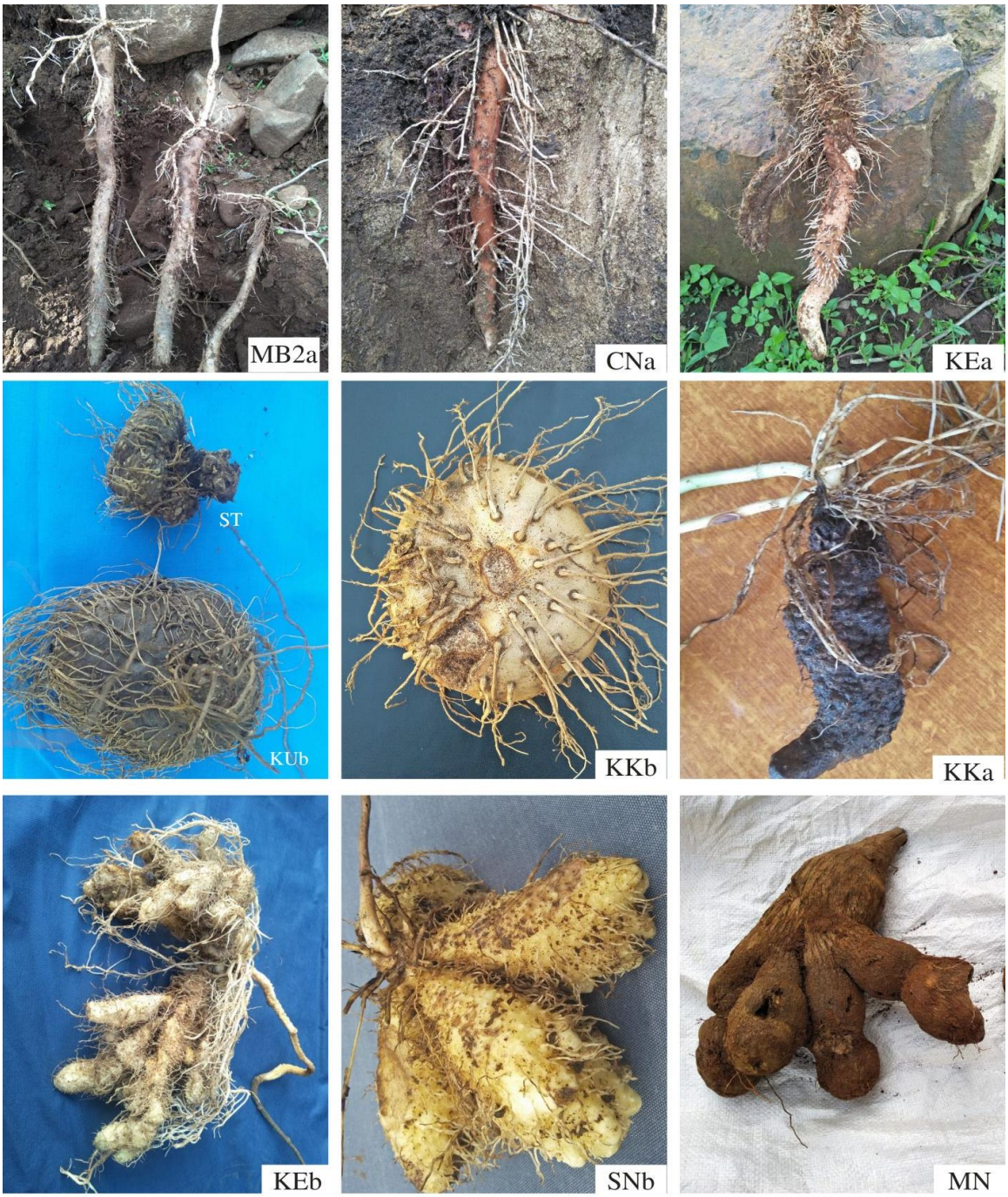

Figure 6. Wild yam tubers of *D. schimperiana* (MKB2a, CNa, KEa), *D. bulbifera* var *anthropophagorum* (ST), *D. bulbfera* var. *bulbifera* (KUb, KKb), *D. dumetorum* (KKa), *D. quartiniana* var. *quartiniana* (KEb, SNb) and *D. alata* (MN).

Figure 7. Yam bulbils formed by plants in situ, *D. schimperiana* (KB3as, CNa, KUa, NK), *D. bulbifera* var. *anthropophagorum* (ST), *D. bulbfera* var. *bulbifera* (KEc, KKb), *D. quartiniana* var. *quartiniana* (KB2a, KUc).

However, none of the Nandi respondents knew whether *D. quartiniana* var. *quartiniana* tubers were edible or not. Moreover, the proportion of knowledgeable respondents on the uses of yam as herbal medicine was low and varied according to communities Table 4). Thus, very few (2.5%) of Abagusii Luhya/Bukusu and Nandi respondents reported use of *D. schimperiana* Kunth. in pain relief, sterility treatment in livestock, and diabetes treatment and dressing respectively. Relatively, a higher proportion (12.5%) of Tugen respondents affirmed the use of *D. schimperiana* in treatment of sterility in humans. Although *D. quartiniana* var. *quartiniana* was reported as non-edible, 7.5% of the Tugen respondents reported that a small piece of its tuber has been boiled with other herbs and used in treatment of gonorrhoea. Generally, a few respondents were knowledgeable on the uses of the wild yam, while majority were not knowledgeable.

4.3 Chemical Composition of Rhizosphere Soils of Kenyan Wild Yam Species

The pH of the soils sampled from the rhizosphere of the different wild yam species in their habitats across seven Counties in Kenya ranged from neutral to acidic (Table 8). Except accessions MB2 (pH 6.0) and KEa (pH 5.9), whose rhizosphere soils were moderately acidic (pH 5.7 - 6.2), soils from the rhizosphere of the other accessions belonging to *D. schimperiana* including KB1 (6.5), MB1 (6.4), KB3a (6.6), TE (6.7), CNa (6.5), NK (6.4), LKa (6.4), and D. *bulbifera,* KUb (6.3), were mildly acidic to neutral (pH 6.2-7.2).

Table 8. **The chemical composition of rhizosphere soils of Kenyan yam species**

Yam Accession		**Rhizosphere soil**			
Species	**Code**	**pH**	**% C**	**Olsen P**	**% N**
Dioscorea schimperiana	KB1	6.5	3.85±0.15^{fg}	16.9±1.22^{c}	0.21±0.01^{ef}
Dioscorea schimperiana	MB1	6.4	1.53±0.02^{i}	10.65±0.69^{de}	0.11±0.01^{g}
Dioscorea schimperiana	MB2	6.0	3.76±0.10^{fg}	5.03±0.43^{f}	0.2±0.00^{ef}
Dioscorea schimperiana	KB3a	6.6	4.11±0.05^{f}	26.45±0.97^{b}	0.23±0.01^{de}
Dioscorea schimperiana	KEa	5.9	4.94±0.12^{cd}	7.27±0.78^{ef}	0.27±0.02^{cd}
Dioscorea schimperiana	TE	6.7	5.77±0.04^{b}	**35.23±1.33^{a}**	**0.36±0.01^{b}**
Dioscorea schimperiana	CNa	6.5	3.09±0.08^{h}	24.65±1.68^{b}	0.17±0.01^{f}
Dioscorea schimperiana	NK	6.4	4.63±0.14^{de}	4.2±0.68^{f}	0.31±0.01^{c}
Dioscorea schimperiana	LKa	6.4	4.53±0.09e	5.47±1.52^{f}	0.22±0.01^{de}
Dioscorea bulbifera	KUb	6.3	**7.47±0.02a**	26.65±1.77^{b}	**0.48±0.02^{a}**
Dioscorea alata	MT	6.2	5.14±0.05c	13.2±1.15^{cd}	0.29±0.01^{c}
Dioscorea alata	MN	5.1	3.49±0.05g	16.41±1.28^{c}	0.24±0.01^{de}

Values after ± denotes Standard Error.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

Additionally, the rhizosphere soil pH of most samples derived from *D. schimperiana* namely; KB1 (6.5), MB1 (6.4), KB3a (6.6), TE (6.7), CNa (6.5), NK (6.4), LKa (6.4) were similar as the pH of rhizosphere soil from the wild *D. bulbifera* accession, KUb (6.3) and the cultivated *D. alata*, MT (6.2) which were mildly acidic to neutral (pH 6.2 - 7.2). Only MN (5.1) rhizosphere was strongly acidic (pH≤5.6).

The rhizosphere soils of different yam species also contained varying levels of carbon (Table 9). For example, *D. bulbifera* (KUb) rhizosphere soils contained a significantly higher level of carbon than those from *D. schimperiana* and *D. alata* (MT and MN) accessions. Among the *D. schimperiana* accessions, only TE rhizosphere soils had significantly higher carbon relative to *D. alata*. MB1 and CNa rhizosphere soils had significantly lower C levels than soils from the rhizosphere of the cultivated species, MT and MN.

Furthermore, the rhizosphere soil carbon significantly varied among *D. schimperiana* accessions. Thus, TE rhizosphere soils had significantly higher carbon levels than the other *D. schimperiana* accessions including KB1, MB1, KB3a, CNa, NK and LKa. KEa. MB1 had the lowest rhizosphere C (1.53%).

The rhizosphere soils of the yam species also exhibited varying levels of Olsen P. *Dioscorea schimperiana* (TE, CNa and KB3a) and *D. bulbifera* (KUb) rhizosphere soils contained significantly higher Olsen P compared to the rhizosphere soils of the *Dioscorea alata*, MT and MN. *Dioscorea schimperiana* MB2, KEa, NK and LKa had significantly lower Olsen P compared to MT and MN.

The rhizosphere of TE, had significantly higher contents of Olsen P compared to the other *D. schimperiana* accessions such as KB1, MB1, KB3a, CNa, NK and LKa. The nitrogen concentration in rhizosphere soil of the different yam accessions also showed significant ($P \leq 0.05$) variation (Table 9). For instance, of the three species, *D. bulbifera*, KUb and *D. schimperiana*, TE rhizosphere soils had significantly higher N content compared to the N content in rhizospheres of the *D.alata*, MT and MN. *Dioscorea schimperiana* accession, TE had significantly higher rhizospheric soil nitrogen among the *D. schimperiana* accessions. CNa and MB1 had the lowest N content.

4.4 Growth and Production of Wild Yam Under Cultivation

4.4.1 Net-house Cultivation

All the net-house grown yam accessions sprouted (Table 9; Figure 8) and formed healthy shoots that varied in internode and vine lengths, and number of leaves (Figure 9). For example, the yam species produced internodes that significantly varied in length (Table 9). *Dioscorea schimperiana* accessions, KEa, TE and KUa had significantly longer internodes than *D. alata*, MN. *Dioscorea bulbifera* (KUb) had similar internode length as most of *D. schimperiana* and *D. alata* accessions. Moreover, *D. schimperiana* KEa and TE internodes were significantly longer than the other *D. schimperiana* accessions including KB1, MB1, CNa, NK and LKa. KB1 had the shortest internodes relative to the other accessions. The accessions varied significantly in the number of leaves produced in the net-house.

Table 9. Growth attributes of wild yam under net-house cultivation

Yam accession	Internode length (cm)	No. of leaves	Vine length (cm)
KB1	9.1±0.3^{c}	82.7±3.3^{c}	101.3±3.1^{d}
MB1	10.6±0.8^{bc}	94.9±13.1^{bc}	182.9±32.8^{b}
MB2	12.0±1.3^{a-c}	**144.8±14.8^{ab}**	137.4±20.5^{b-d}
KB3a	11.4±0.6^{a-c}	128.1±4.2^{a-c}	128.6±4.2^{b-d}
KEa	**14.6±0.4^{a}**	**173±3.6^{a}**	184.6±27.5^{b}
TE	**14.3±0.7^{a}**	**159.2±9.3^{a}**	159.7±9.3^{bc}
KUa	**13.1±0.5^{ab}**	**175.9±7.5^{a}**	176.6±7.5^{b}
KUb	12.1±0.6^{a-c}	**157.3±8.5^{a}**	157.9±8.5^{bc}
CNa	11.0±1.3^{bc}	132.7±17.6a-c	133.4±17.7^{b-d}
NK	10.4±0.4^{bc}	99.3±6.5^{bc}	99.9±6.4^{cd}
LKa	11.4±0.3^{a-c}	98.9±13.0^{bc}	110.6±8.2^{b-d}
MN	11.2±0.5^{bc}	85.1±2.5^{c}	**422.4±15.0^{a}**

Values after ± denotes Standard Error.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

Figure 8. Sprouted yam tubers which were prepared as planting materials, *D. schimperiana* (CNa, KEa, MB2, MB1 and KB1), *D. bulbifera* (KUb and KEc) and *D. alata* (MN).

Figure 9. Net-house wild and cultivated yam accessions grown in Growth Pouches; *D. schimperiana* Kunth. (KEa, TE), *D. alata* L. (MN).

Dioscorea schimperiana (KEa, TE, KUa and MB2), and *D. bulbifera* (KUb) produced statistically similar number of leaves but were significantly higher than *D. alata* (MN) and the rest of *D. schimperiana,* KB1, MB1, NK and LKa accessions (Table 10). All the *D. schimperiana* and *D. bulbifera*, KUb accessions grew significantly shorter vines compared to the *D. alata*, MN. Among the *D. schimperiana* accessions, KUa, KEa and MB1formed significantly longer vines compared to their counterparts, with KB1 and NK producing the shortest vines, measuring less than a metre in length.

All the net-house grown wild and cultivated yam accessions formed tubers (Table 10; Figure 10). On the average, each accession of *D. schimperiana* (KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa) and *D. bulbifera* (KUb) formed one tuber per plant, a significantly lower number when compared with 3 tubers formed by *D. alata*, MN accession. The net-house *D. schimperiana* accessions formed coiled root tubers (Plate 8) that were different from the normally elongated/vertical types formed by *D. schimperiana* plants (Plate 4). The *D. bulbifera* (KUb) produced normal fibrous oval shaped tubers. On the contrary, the *D. alata*, MN accessions formed small spined tubers (Figures 9 and 10; Table 10).

The tuber fresh weight/plant ranged from 56.9±1.9 to 415.2±20.2 g (Table 10). All the wild yam accessions of *D. schimperiana* (KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa) and *D. bulbifera* (KUb), produced significantly heavier tubers than the cultivated type, D. alata (MN), and KEa accession of *D. schimperiana* produced significantly heavier tubers compared to *D. bulbifera* (KUb) accession (Table 10).

Table 10. The production attributes of wild and cultivated yam accessions at 7 months after planting in the net-house

Yam accession	Tuber number/ plant	Bulbil number/plant	Tuber fresh wt(g)/plant	Bulbil wt (g)/plant
KB1	1±0c	0±0e	300.4±9.5c-e	0±0e
MB1	1±0c	5±0d	**415.2±20.2a**	6.6±0.4d
MB2	1±0c	0±0e	297.1±12.3c-e	0±0e
KB3a	1±0c	0±0e	318.6±18.7b-e	0±0e
KEa	1±0c	**9±0a**	**383.9±18.0ab**	**11.9±0.5b**
TE	1±0c	**7±0b**	**361.1±27.1a-c**	**11.1±0.5b**
KUa	1±0c	0±0e	294.2±14.0c-e	0±0e
KUb	1±0c	6±1c	342.6±19.8b-e	**14.5±0.9a**
CNa	1±0c	**9±0a**	287.1±16.1de	8.1±0.4c
NK	1±0c	0±0e	257.4±16.6e	0±0e
LKa	1±0c	0±0e	275.0±14.4de	0±0e
MN	**3±0a**	0±0e	67.8±2.4f	0±0e

Values after ± denotes Standard Error.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

Figure 10. Extracted root tubers of net-house grown yam accessions, *D. schimperiana* (MB1 and KB1, KEa, TE, LKa, CNa and KUa), *D. bulbifera* (KUb) and *D. alata* (MN).

Scale 1:20

Figure 11. Bulbils formed by net-house grown wild yam plants, *D. schimperiana* (MB1, KEa and TE) and *D. bulbifera* (KUb).

Of the *D. schimperiana* accessions, MB1, KEa and TE significantly produced heavier tubers than KB1, MB2, KB3a, KUa, CNa, NK and LKa. Furthermore, the net-house yam species formed bulbils on axils of their vines. Among the ten accessions of *D. schimperiana*, four namely, MB1, KEa, TE and CNa, and the D. bulbifera (KUb) accession, formed bulbils (Figure 11).

Dioscorea schimperiana, KEa and CNa plants developed significantly many bulbils relative to *D. bulbifera* (KUb) and *D. schimperiana*, MB1. Accession KUb of D. bulbifera produced significantly heavier (14.5±0.99 g) bulbils when compared to *D. schimperiana* KEa, TE, CNa and MB1 bulbils (Figure 11). *Dioscorea schimperiana* accessions KEa and TE formed heavier bulbils than CNa and MB1. Accession MB1 relatively produced the lightest bulbils (6.6±0.4 g). Generally, it was observed that the D. bulbifera, cultivated type, in St Mary's, Kitale produced larger bulbils than the wild D. bulbifera accessions.

4.4.2 Field cultivation

The five (5) field-grown *D. schimperiana* accessions showed significantly varied vegetative growth (Table 11; Figure 12): KEa had the longest, and MN the shortest internodes. However, MB2, KEa and CNa that were planted 2 feet deep holes had significantly longer internodes compared to the MB2C, that were planted in 20 cm deep holes and MN. Generally, the *D. schimperiana* accessions had significantly longer internodes compared to the control, MB2C and the cultivated *D. alata* accession, MN (Table 11).

Table 11. Vegetative growth attributes of Kenyan wild and cultivated yam accessions under field conditions

Yam accession	Growth attributes		
	Internode length (cm)	**No. of leaves**	**Vine length (cm)**
KB1	11.7±0.5^{de}	39±7^{b}	196.1±9.5^{b-d}
MB1	14.7±0.8^{bc}	**47±11^{ab}**	**261.7±16.5^{a-c}**
MB2	**16.2±1.0^{ab}**	39±5^{b}	205.4±16.1^{b-d}
KEa	**17.6±0.4^{a}**	**63±11^{ab}**	**271.7±29.9^{ab}**
CNa	**16.3±0.7^{ab}**	35±5^{b}	180.0±9.2^{cd}
MB2C	12.7±0.5^{cd}	34±6^{b}	139.1±14.8^{d}
MN	9.8±0.4^{e}	**85±18^{a}**	**295.2±22.5^{a}**

± denotes Standard Error.

Values with the same letter (s) in a column are not significantly different at $P \leq 0.05$, according to Tukey's test.

Figure 12. Vines of field grown wild yam accessions, *D. schimperiana* (KEa) with bulbils, and cultivated, *D. alata* (MN).

All the *D. schimperiana* and *D. alata* accessions formed leaves in the field grown plants. However, none of the *D. schimperiana* accessions including KB1, MB2 and CNa had significantly higher number of leaves per plant compared to the *D. alata*, except MB1 and KEa that showed similar number of leaves as MN accession. All the *D. schimperiana* accessions had similar number of leaves as MB2C (Table 11, Figure 12). MN produced the highest number of leaves/plant while MB2C the lowest.

The field grown *D. schimperiana* accessions formed single vines that varied in length and ranged from 139.1±14.8 to 295.2±22.5 cm (Table 11, Figure 12), but not as long as when they were growing in their natural habitats (Figure 2). Of the *D. schimperiana* accessions, none had significantly longer vines than MN. However, MB1 and KEa had similar vine length as MN. MB1 and KEa produced significantly longer vines than KB1, MB2, CNa and MB2C. Generally, the *D. schimperiana* accessions significantly produced longer internodes, but shorter vines and lesser number of leaves when compared with *D. alata* accession.

All the field-grown *D. schimperiana* accessions including KB1, MB1, MB2, KE, CNa and MB2C formed tubers (Table 12, Figure 13) while *D. alata*, MN did not. The accessions KB1, MB1, MB2, KE and CNa produced single elongated root tubers that were less fibrous than MB2C but similar in number as MB2C (Figure 13). Moreover, the accessions produced tubers that exhibited significant variation in tuber weight and ranged from 178.4±10.3 to 365±18.5 g. Accessions KEa, MB1 and MB2 produced significantly heavier root tubers/plant compared to KB1 and MB2C.

Table 12. The production attributes of wild and cultivated yam accessions at 7 months after planting in the field

Yam accession	Production attributes			
	Tuber No/plant	Bulbil No/plant	Tuber wt (g)/plant	Bulbil wt (g)
KB1	1±0[a]	0±0[b]	227±17.3[c]	0±0[b]
MB1	1±0[a]	0±0[b]	287.5±4.5[b]	0±0[b]
MB2	1±0[a]	0±0[b]	277.2±13.6[b]	0±0[b]
KEa	1±0[a]	**1±0.2[a]**	**365.0±18.5[a]**	**5±1.0[a]**
CNa	1±0[a]	0±0[b]	306.9±6.3[b]	0±0[b]
MB2C	1±0[a]	0±0[b]	178.4±10.3[c]	0±0[b]
MN	0±0[b]	0±0[b]	0±0[d]	0±0[b]

Values after ± denotes Standard Error.

Zero values indicates absence of tubers.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

Figure 13. Excavated tubers of field grown wild yam accessions, *D. schimperiana* (KEa, CNa, MB1, MB2 and MB2C).

Figure 14. Partially excavated root tubers of different yam accessions in situ; *D. schimperiana* (MB2, KEa, NK and CNa) and D. quartiniana var. *quartiniana* (KEb) tubers revealing the effect of rocky soils and neighbouring tree roots on tuber growth.

However, all the *D. schimperiana* accessions formed slender, heavily fibrous and elongated/vertical underground tubers in their natural habitats than when they were in cultivation (Figures 13; 14). Except a few KEa plants that formed bulbils (Table 12; Figure 12), the other *D. schimperiana* accessions including KB1, MB1, MB2, CNa and MB2C did not form bulbils in field-grown plants. The bulbils were small and weighed 5.0±1.0 fresh weight (Figure 12).

Although the field-grown plants of KB1, MB1, MB2 and CNa accessions did not produce bulbils, they produced many larger bulbils when they were growing in the wild (Figure 7). Again, *D. alata*, MN did not produce bulbils in the field grown plants.

The field and net-house results showed significant differences in growth and production of the wild and cultivated yam accessions. *Dioscorea schimperiana* accessions grew taller in the field than in the net-house. However, except KB1 that produced lesser number of leaves, MB1, KEa and CNa produced a higher number of leaves in net-house plants compared to field-grown plants. Again, except CNa, the rest of *D. schimperiana* accessions produced heavier underground tubers per plant than the field-grown accessions. In addition, all the net-house and field grown *D. schimperiana* accessions produced single underground tubers/plant. Only KEa formed a higher number and heavier bulbils in some net-house compared to the field-grown counterparts. In addition, MB1 and CNa produced bulbils in net-house, but not in the field. *Dioscorea alata*, MT and MN exhibited a higher growth and production in net-house plants relative to the field grown plants. They produced more than one underground tubers in the net-house per

Growth Pouch, but did not produce tubers in the field. Finally, MT and MN did not produce bulbils in the net-house and field experiments.

4.5 Primary Metabolite Composition of Wild and Cultivated Yam Tubers

4.5.1 Primary metabolite Composition of the net-house grown wild and cultivated yam tubers

The yam accessions contained substantial amounts of moisture, which ranged from 45.45± 1.26 % to 79.82 ± 0.64 %). Most of the *D. schimperiana* and the *D. bulbifera* (KUbB and KUbR) accessions had significantly lower moisture content when compared with *D. alata* (MN) in the net-house grown plants (Table 13). However, only *D. schimperiana* (CNaH) had similar moisture content as *D. alata* (MN). The net-house grown *D. schimperiana*, *D. bulbifera* and *D. alata* contained significantly higher moisture content than the wild *D. quartiniana* accession. The moisture content was significantly different between the head (Red) and middle (Yellow) sections of *D. schimperiana* accessions (Figure 15). Accessions LKa, KEa, CNa and KB1 had significantly higher moisture content in their head than middle sections whereas NK and MB2 had significantly higher moisture in their middle sections. MB1, MB2, TE, KEa and KB3a did not show any significant difference in their moisture content between their head and middle sections (Table 13). *Dioscorea bulbifera* contained significantly a higher moisture content in its underground (KUbR) than aeral (KUbB) tubers.

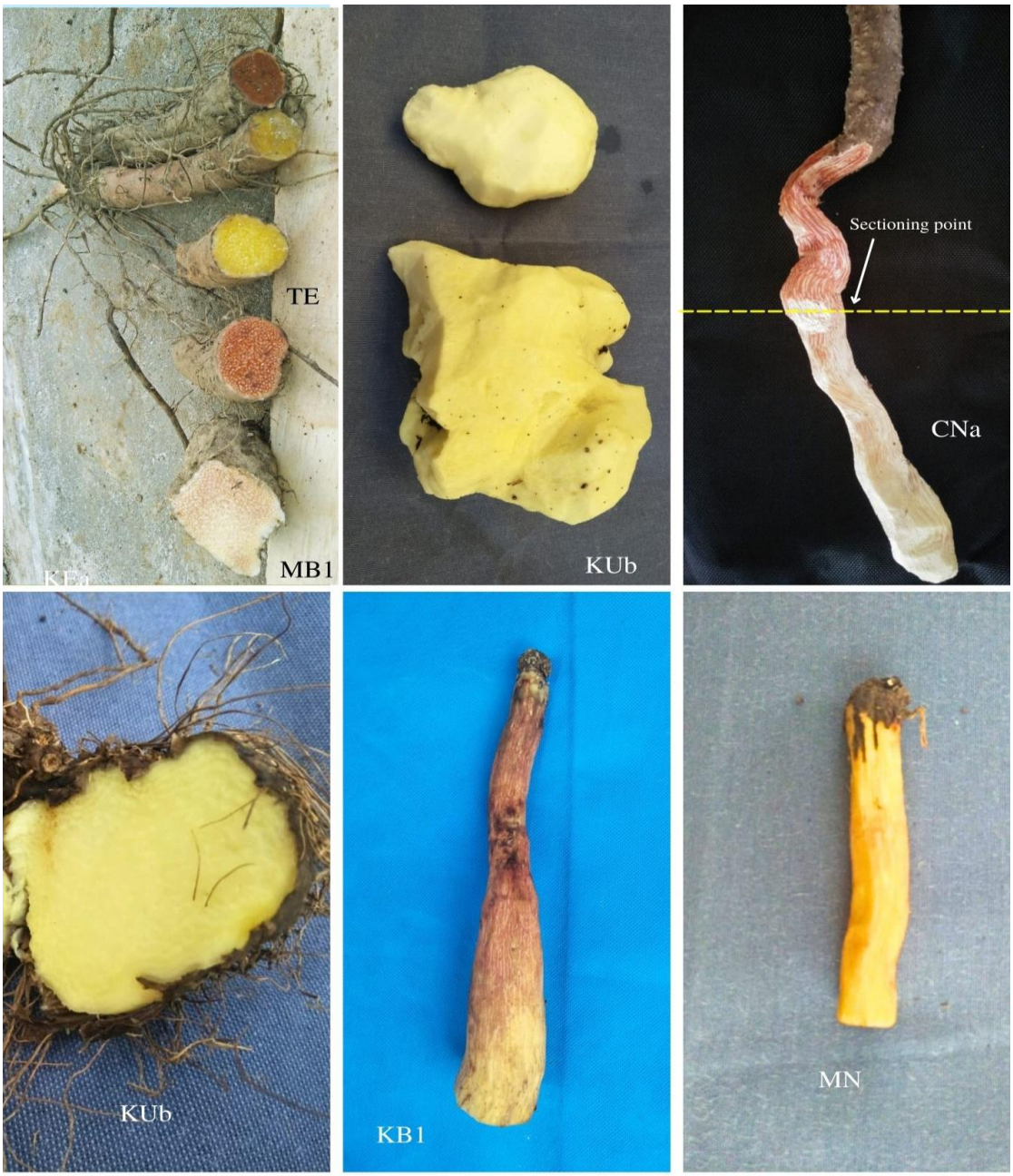

Figure 15. Peeled or sectioned tubers of *D. schimperiana* Kunth. (TE, MB1, CNa and KB1) accessions showing the pigmented portions; head (red) and middle (yellow), *D. bulbifera* L. (KUb) and *D. alata* L. (MN) whole tubers, uniformly pigmented yellow.

Table 13. Primary metabolite composition in tubers of net-house grown wild and cultivated yam accessions

Yam Accessions	Primary metabolite composition (%)					
	Moisture	**Ash**	**Crude protein**	**Crude fibre**	**Lipid**	**Carbohydrate**
LKa**H**	55.09±0.46^{i}	0.33±0.03^{g}	6.99±0.12^{bc}	1.92±0.2^{a}	2.45±0.08^{c-e}	33.22±0.66^{b}
LKa**M**	46.32±0.89^{j}	0.82±0.38d^{-g}	5.58±0.07^{f}	2.31±0.26^{a}	1.75±0.1^{e}	**43.22±1.07^{a}**
MB1**H**	67.23±0.59^{f-h}	0.55±0.03^{g}	5.64±0.39^{f}	2.78±0.45^{a}	**7.02±0.29^{a}**	16.78±0.31^{d-h}
MB1**M**	66.46±0.41^{f-h}	1.51±0.01^{a-c}	5.86±0.03^{ef}	2.17±0.09^{a}	6.28±0.11^{ab}	17.72±0.48^{c-g}
MB2**H**	69.47±0.41^{c-f}	1.06±0.04^{b-f}	6.18±0.26^{d-f}	2.67±0.45^{a}	6.63±0.16^{ab}	13.99±1.01^{g-k}
MB2**M**	72.26±0.75^{b-e}	0.72±0.04^{e-g}	5.42±0.24^{f}	3.1±0.17^{a}	2.07±0.29^{de}	16.43±0.82^{d-h}
KB3a	70.45±0.36c-f	1.05±0.08b-f	5.91±0.22d-f	2.98±0.24a	3.47±0.24b-e	16.14±0.46e-i
KB3a	67.9±0.22fg	1.33±0.08a-d	9.73±0.16bc	2.95±0.29a	6.98±0.51a	11.12±0.24jk
KEa**H**	72.77±0.52^{b-e}	0.7±0.03^{fg}	6.39±0.1^{d-f}	2.92±0.08^{a}	2.23±0.21^{c-e}	14.99±0.45^{f-j}
KEa**M**	67.74±1.94^{fg}	1.34±0.02^{a-d}	8.8±0.16^{c}	2.52±0.49^{a}	1.42±0.18^{e}	18.19±2.23^{c-g}
THE	66.72±0.42^{f-h}	**1.74±0.01^{a}**	7.21±0.08^{d}	2.42±0.12^{a}	2.02±0.49^{de}	19.89±0.57^{c-e}
TE**M**	63.20±1.06^{h}	1±0.09^{c-f}	6.07±0.05^{d-f}	2.14±0.31^{a}	6.3±0.31^{ab}	21.29±1.00^{bc}
NK**H**	45.46±1.26^{j}	1.61±0.04^{ab}	5.44±0.38^{f}	2.17±0.15^{a}	5.43±0.14^{a-c}	**39.91±1.34^{a}**
NK**M**	72.92±0.73^{b-d}	0.58±0.11^{fg}	6.11±0.26^{d-f}	2.51±0.17^{a}	3.73±1.66^{a-e}	14.15±0,97^{g-k}
KUa**H**	69.36±0.43^{d-f}	1.07±0.06^{b-f}	5.30±0.20^{f}	1.86±0.16^{a}	3.6±0.17^{b-e}	18.81±0.44^{c-f}
KUa**M**	68.8±0.23^{d-f}	0.3±0.03^{g}	9.82±0.07^{de}	2.46±0.2^{a}	2.08±0.22^{de}	16.54±0.57^{d-h}
CNa**H**	**75.88±1.43^{ab}**	0.62±0.05^{fg}	8.69±0.69^{c}	2.16±0.09^{a}	2.55±0.17^{c-e}	10.09±0.98^{k}
CNa**M**	68.72±0.76^{ef}	1.02±0.26^{c-f}	**10.34±0.11^{ab}**	2.7±0.13^{a}	4.3±1.55^{a-e}	12.93±0.94^{h-k}
KB1**H**	74.25±0.24^{bc}	0.74±0.0^{e-f}	6.98±0.04^{de}	2.81±0.41^{a}	5.33±0.07^{a-d}	5.41±0.44^{l}
KB1**M**	68.88±0.23^{d-f}	1.08±0.01^{b-f}	**11.46±0.52^{a}**	3.2±0.18^{a}	3.85±1.71^{a-e}	16.01±1.73^{e-i}
KUb**R**	74.71±0.73^{b}	1.29±0.1^{a-e}	7.05±0.08^{de}	3.02±0.03^{a}	2.18±0.07^{c-e}	11.74±0.62^{i-k}
KUb**B**	63.35±0.68^{h}	1.51±0.04^{a-c}	5.81±0.01^{ef}	2.7±0.07^{a}	5.18±0.16^{a-d}	21.45±0.80^{c}
MN	**79.82±0.64^{a}**	1.03±0.01^{b-f}	5.16±0.13^{f}	2.82±0.21^{a}	6.6±0.06^{ab}	4.56±0.50^{l}
KEb	67.9±0.22^{fg}	1.33±0.08^{a-d}	9.73±0.16^{bc}	2.95±0.29^{a}	**6.98±0.51^{a}**	11.12±0.24^{jk}

Key: **H** at the end of *D. schimperiana* codes denotes tuber head/upper portion; **M**-middle portion; **R**- denotes root tuber, **B**- bulbils in *D. bulbifera.*

KEb- collected from the wild habitat.

± denotes Standard Error.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

The yam accessions varied significantly in ash content that ranged from 0.30±0.03% to 1.74±0.01% (Table 13). Only *D. schimperiana* TE, produced significantly a higher ash content in its tuber compared to the cultivated *D. alata*, and the wild *D bulbifera* accessions collected from the net-house grown plants and *D. quartiniana* (KEb) collected from its natural habitat. Among the *D. schimperiana* accessions, TE significantly produced the highest ash content in its head section compared to the others, while KUa, LKa and MB1 produced the lowest (Table 13). Accesssions TE, NK and KUa contained significantly higher ash content in their head than middle sections, and MB1 and KEa had significantly higher ash content in their middle sections. In addition, there was no significant difference in ash content between the root tubers and bulbils of *D. bulbifera*.

Furthermore, the yam accessions had varied amounts of crude protein. The levels of the crude protein in the in the net-house grown yams ranged from 5.42% to 11.46 %. Therefore, some accessions of *D. schimperiana* (KB1, CNa and KEa) and *D. bulbifera* (KUbR) had significantly higher crude protein content compared to *D. alata* (MN) accessions. Only *D. schimperiana* (KB1M) had significantly a higher protein content than *D. quartiniana* (KEb). Among the *D. schimperiana* accessions, LKa and KB1 had significantly higher crude protein content in their head compared to their middle sections. KEa, KUa and CNa had significantly lower crude protein levels in their tuber head. Additionally, MB1, MB2, TE and NK contained similar levels of crude protein between their head and middle sections. There was no significant difference in protein content between the root tubers and bulbils of *D. bulbifera*.

All the yam accessions produced appreciable amounts of crude fibre that ranged from 1.86±0.16% to 3.2±0.18% in their fresh tubers. However, the levels did not significantly differ among the different accessions or species, and between the head and middle sections of *D. schimperiana* accessions or root and bulbils of *D. bulbifera*.

Furthermore, the yam accessions formed significant levels of crude lipid, which varied from 1.48±0.18% to 7.02±0.29% (Table 13). Thus, *D. schimperiana* (MB1) and *D. quartiniana* KEb) significantly produced the highest crude lipid while LKa and KEa the lowest. Although the crude lipid contents were the highest in MB1 and KEb, they were statistically similar to *D. alata* (MN). *Dioscorea bulbifera* (KUbR) and *D. schmperiana* (CNaH, KUaM, TEH, KEaM, MB2M and LKa) produced significantly lower lipid contents thsn *D. alata*. Among the the *D. schimperiana* accessions, only MB2 had exhibited higher lipid contents in the tuber head than the middle section, while TE had a higher crude lipid in its middle section.

The fresh tubers of the yam accessions possessed varied amounts of carbohydrates that ranged between 4.56% and 43.22% (Table 14). For example, the tubers of *D. schimperiana* and *D. bulbifera* accessions contained higher contents of carbohydrates compared to the cultivated type, *D. alata* (MN), but some of the *D. schimperiana* accession tubers were significantly higher in carbohydrates than *D. bulbifera* and *D. quartiniana*. Furthermore, out of the ten net-house grown *D. schimperiana* accessions only NK tubers had the highest carbohydrate content in their head sections compared to its middle section, while LKa and KB1 accumulated higher carbohydrate content in their

middle sections. Bulbils of of *D. bulbifera* (KUbB) exhibited higher carbohydrate contents than the root tubers.

4.5.2 Primary metabolite composition of the field-grown wild yam

The field grown *D. schimperiana* accessions including, KB1, MB1, MB2, KEa, CNa and the control (MB2C), also had substantial amounts of proximate components. However, *D. alata* (MN) accession did not form tubers, hence the zero values (Table 14). Fresh tubers of CNa middle section significantly accumulated the highest amount of moisture compared to the control (MB2HC) and the other *D. schimperiana* accessions (Table 14). Apparently, CNa and KB1 significantly produced a higher moisture content in their middle than head sections, in the field. Accession MB1 had the lowest moisture content. Only KEa had significantly higher moisture content in the head than middle tuber.

The accessions produced substantial amount of ash. The middle section of KB1 produced significantly higher content of ash compared to the other accessions and control. The ash content ranged from 1.05±0.08 to 2.52±0.01%. MBI and CNa had significantly higher ash content in the middle section than head section of their tubers that were also similar to the ash content of the control. KB1, MB2 and KEa had similar ash content in the head and middle sections. Generally, the wild yam accessions had significantly higher ash content than the control.

Table 14. Primary metabolite composition in tubers of field grown wild and cultivated yam accessions

Yam accessions	Primary metabolite composition (%)					
	Moisture	**Ash**	**Crude protein**	**Crude fibre**	**Lipid**	**Carbohydrate**
KB1**H**	66.93±0.78^{cd}	1.79±0.17b-d	**11.98±0.20a**	3.13±0.07a	4.5±1.55a-c	11.67±0.72bc
KB1**M**	72.13±1.86b	1.66±0.06d	**12.57±0.16a**	2.96±0.57a	5.15±0.07ab	5.52±2.4d
MB1**H**	65.74±0.69cd	1.58±0.01de	4.88±0.17de	3.13±0.21a	**6.27±0.14a**	**18.4±0.85a**
MB1**M**	64.95±0.72d	**2.51±0.01a**	4.77±0.02de	2.90±0.22a	**6.19±0.12a**	**18.68±0.86a**
MB2**H**	64.97±1.92d	2.00±0.12bc	4.44±0.07e	2.90±0.08a	**6.89±0.08a**	**18.8±0.84a**
MB2**M**	68.29±0.58b-d	2.06±0.03b	4.66±0.09de	3.02±0.57a	**6.2±0.06a**	15.76±1.10ab
KEa**H**	70.10±0.29bc	1.73±0.04cd	4.37±0.13e	3.63±0.17a	1.8±0.09cd	**18.37±0.37a**
KEa**M**	71.66±0.75b	1.71±0.03cd	5.32±0.10d	3.44±0.08a	2.30±0.23b-d	15.58±0.85ab
CNa**H**	67.26±0.53cd	1.32±0.05e	8.05±0.04b	2.95±0.19a	3.77±1.24a-c	16.66±1.87ab
CNa**M**	**75.98±0.33a**	1.64±0.05d	6.72±0.47c	2.68±0.11a	4.2±0.86a-c	8.79±1.16cd
MB2**HC**	70.45±0.36bc	1.05±0.08f	5.91±0.22d	2.98±0.24a	3.47±0.24a-c	16.14±0.46ab
MB2**MC**	67.9±0.22 cd	1.33±0.08e	9.73±0.16b	2.95±0.29a	**6.98±0.51a**	11.12±0.24bc
MN	0±0e	0±0f	0±0f	0±0b	0±0d	0±0e

Key: **H** at the end of *D. schimperiana* codes denotes tuber head/upper portion; **M**-middle portion; and **C** - the control.

± denotes Standard Error.

Zero values in MN indicates absence of tubers.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

The tubers of field grown accessions had appreciable amounts of crude protein, which ranged from 4.37±0.13 to 12.57±0.16%. Accession KB1, contained significantly higher protein content compared to the MB2 control and the other *D. schimperiana* accessions. KEa and control middle section of tubers had significantly higher proteins than their head sections. However, there was no significant variation between the *D. schimperiana* treatments and the control. MB1 and MB2 tubers had significantly elevated lipid content than KEa. Accessons KB1, MB1 and MB2 did not show significant difference in their protein content, between the head and middle sections of their tubers.

Furthermore, the tubers of all the accessions produced a considerable amount of crude fibre that ranged from 2.68±0.11 to 3.63±0.17%. The crude fibre content was similar in the head and middle sections of tubers of *D. schimperiana* accessions and the control.

The accessions also had varied levels of lipid content, ranging from 1.8±0.09 – 6.98±0.51%. MB1 and MB2 had significantly higher lipid content than KEa, but similar as the lipid content in the control.

The tubers of all the tested accessions contained carbohydrates that ranged from 5.52±2.4% - 18.80±0.84%. There was no significant difference in carbohydrate contents between the treatments and the control However, accessions MB1, MB2 and KEa recorded the highest carbohydrate content. KB1 and CNa had significantly higher carbohydrate content in their tuber head compared to the middle sections.

4.6 Secondary Metabolite Composition of Tubers of Kenyan Wild and Cultivated Yam Accessions

4.6.1 Secondary metabolite composition in net-house grown yam

The secondary metabolite concentration in the yam tubers is presented in Table 15. *Dioscorea bulbifera* accessions, KUbR and KUbB had significantly higher concentrations of alkaloids than the *D. alata* (MN), *D. quartiniana* (KEb) and *D. schimperiana* accessions. However, KEb had similar alkaloid concentrations as MN. The tuber head and middle portions of *D. schimperiana,* KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa had significantly lower alkaloid concentrations compared to the MN accession (Table 15).

Although the head portion contained higher alkaloid concentration than the middle portion of the tubers of KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa accessions, there was no significant alkaloid variation between the head and middle portions of the same tuber.

There was significant difference in flavonoid contents among the accessions (Table 18). *Dioscorea schimperiana* (KEa, KUa, NK and LKa) and *D. bulbifera* (KUbR and KUbB) had significantly higher flavonoid concentration than *D. quartiniana* (KEb) and *D. alata* (MN). Moreover, the accessions also had substantial amounts of tannins, but only *D. bulbifera*, KUbR and KUbB had significantly higher concentration of tannins compared to the cultivated types, MN.

Table 15. The tuber secondary metabolite concentration in the net-house grown wild and cultivated yam accessions

Yam accession	Secondary metabolite composition (mg/100 g)			
	Alkaloids	**Flavonoids**	**Tannins**	**Saponins**
KB1**H**	0.43±0.05^{de}	1.91±0.52^{c}	1.54±0.37^{c}	**14.07±0.41^{bc}**
KB1**M**	0.31±0.03^{e}	0.94±0.05^{c}	3.43±1.05^{c}	0.74±0.14^{ef}
MB1**H**	0.71±0.12^{de}	1.95±0.47^{c}	2.89±0.72^{c}	0.90±0.01^{d-f}
MB1**M**	0.43±0.06^{de}	1.91±0.06^{c}	4.61±0.58^{c}	2.94±0.26^{d-f}
MB2**H**	0.67±0.16^{de}	1.8±0.13^{c}	4.3±0.38^{c}	0.96±00^{d-f}
MB2**M**	0.39±0.07^{e}	1.50±0.19^{c}	2.93±0.76^{c}	0.43±0.04^{ef}
KB3a**H**	0.62±0.08^{de}	1.81±0.06^{c}	8.08±0.06^{c}	8.96±1.07^{c-e}
KB3a**M**	0.39±0.06^{e}	2.23±0.35^{c}	1.76±0.35^{c}	0.94±0.03^{d-f}
KEa**H**	0.4±0.04^{e}	**8.48±0.52^{a}**	6.15±1.03^{c}	3.56±0.09^{d-f}
KEa**M**	0.32±0.12^{e}	0.92±0.02^{c}	1.93±0.22^{c}	2.60±1.05^{d-f}
KEb	1.63±0.08^{bc}	**6.05±0.25^{b}**	6.74±0.67^{c}	9.59±2.17^{cd}
TE**H**	0.6±0.11^{de}	0.98±0.01^{c}	1.79±0.41^{c}	0.09±0.01^{f}
TE**M**	0.39±0.07^{e}	2.38±0.34^{c}	1.73±0.42^{c}	0.41±0.02^{ef}
KUa**H**	0.58±0.11^{de}	6.43±0.55^{ab}	2.47±0.28^{c}	0.19±0.01^{ef}
KUa**M**	0.39±0.07^{e}	0.89±0.05^{c}	1.52±0.83^{c}	0.46±0.05^{ef}
KUb**R**	**2.15±0.18^{ab}**	**8.05±1.38^{ab}**	**27.22±1.3^{a}**	**22.44±3.96^{ab}**
KUb**B**	**2.4±0.36^{a}**	**6.73±0.43^{a-c}**	**15.27±2.86^{b}**	**29.01±2.45^{a}**
CNa**H**	1.14±0.30^{cd}	5.90±0.37^{b}	7.67±0.75^{c}	**18.41±1.83^{b}**
CNa**M**	0.46±0.04^{de}	0.87±0.06^{c}	1.77±0.37^{c}	7.07±0.57^{c-f}
NK**H**	0.78±0.12^{de}	**6.96±0.30^{ab}**	1.88±0.45^{c}	0.71±0.25^{ef}
NK**M**	0.54±0.11^{de}	0.95±0.02^{c}	2.14±0.69^{c}	4.37±1.55^{d-f}
LKa**H**	0.7±0.12^{de}	**6.53±0.93^{ab}**	9.51±0.34^{c}	0.44±0.27^{ef}
LKa**M**	0.56±0.11^{de}	0.96±0.01^{c}	1.35±0.33^{c}	0.56±0.04^{f}
MN	1.52±0.21^{bc}	0.89±0.05^{c}	1.83±0.31^{c}	8.39±4.93^{c-f}

Key: **H** added at the end of *D. schimperiana* codes denotes tuber head/upper portion; **M**-middle portion; **R**- denotes root tuber, **B**- bulbils in *D. bulbifera.* **KEb**- collected from the wild habitat.

Values after ± denotes Standard Error.

Zero values in MN indicates absence of tubers.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

The head and middle portions of KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa, and the whole tuber of KEb had similar amounts of tannins as the cultivated types, MN. There was no significant variation between the head and middle portions of the tubers of *D. schimperiana* KB1, MB1, KB3a, KEa, TE, KUa, CNa, NK and LKa.

There was significant variations in the distribution of the flavonoids between the head and middle portions of the tubers of some *D. schimperiana* accessions, hence the head portions of KEa, KUa, CNa, LKa and NK had significantly higher levels of flavonoids than their middle portions.

The wild yam accession KUbR, KUbB, tuber head portions of KB1 and CNa contained significantly higher levels of saponins compared to MN, and the other wild yam accessions. TE tubers had significantly the lowest saponin content. Of the *D. schimperiana* accessions, only KB1 and CNa had significantly higher saponin concentration in their tuber head portions than in their middle portions. Although the head portions of MB1, MB2, KB3a, KEa, TE, KUa, NK and LKa had higher saponin concentrations than their middle portions, the differences between the two portions of the tubers were not statistically significant.

4.6.2 Secondary metabolite composition of field grown yams

The metabolite concentration in field grown yams is presented in Table 16. The head portions of MB1 tubers had significantly higher levels of alkaloids than the tubers of the control (MB2C) and other accessions. KB1 middle portion recorded the lowest (0.36±0.13 mg/100 g) alkaloid content.

Table 16. The tuber secondary metabolite concentration in the field grown Kenyan wild and cultivated yam accessions

Yam accession	Secondary metabolite composition (mg/100 g)			
	Alkaloids	**Flavonoids**	**Tannins**	**Saponins**
KB1**H**	0.47±0.15^{b}	2.33±0.43^{c}	1.84±0.29^{d}	2.94±0.26^{c}
KB1**M**	0.36±0.13^{b}	0.98±0.05^{c}	3.23±1.05^{cd}	0.74±0.14^{c}
MB1**H**	**0.82±0.12^{a}**	1.98±0.38^{c}	2.78±0.72^{cd}	**12.08±0.51^{a}**
MB1**M**	0.53±0.06^{b}	1.95±0.06^{c}	2.61±0.58^{bc}	0.90±0.01^{c}
MB2**H**	0.69±0.16^{b}	2.3±0.13^{c}	2.1±0.18^{b-d}	2.96±0.01^{c}
MB2**M**	0.35±0.07^{b}	1.60±0.19^{c}	2.09±0.76^{cd}	0.46±0.04^{c}
KEa**H**	0.71±0.08^{b}	1.91±0.06^{c}	**7.05±0.04^{a}**	3.56±0.09^{c}
KEa**M**	0.43±0.07^{b}	2.13±0.3^{c}	2.76±0.45^{cd}	0.96±0.03^{c}
CNa**H**	0.49±0.04^{b}	**9.15±0.61^{a}**	**5.99±1.03^{ab}**	**8.96±1.07^{b}**
CNa**M**	0.38±0.12^{b}	2.9±0.02^{c}	2.53±0.22^{cd}	2.60±1.05^{c}
MN	0.0±0.0^{b}	0.0±0.0^{c}	0.0±0.00^{d}	0.0±0.0^{c}
MB2**HC**	0.7.±0.07^{b}	7.38±0.55^{b}	3.73±0.42^{cd}	6.8±0.23^{b}
MB2**MC**	0.63±0.11^{b}	3.2±0.34^{c}	2.87±0.28^{cd}	3.59±0.01^{c}

Key: **H** added at the end of *D. schimperiana* codes denotes tuber head/upper portion; **M**-middle portion; and **C** - the control.

Zero values in MN indicates absence of tubers.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

The alkaloid contents ranged from 0.36±0.13 - 0.82±0.12 mg/100 g. The accessions produced flavonoids that ranged from 0.98±0.05 mg/100 g to 9.15±0.61 mg/100 g. Accession CNa tuber heads contained significantly higher flavonoid contents than the control and the other accessions. CNa tuber heads had significantly higher flavonoids than their middle portions (Table 16).

Accesions KB1, MB1, MB2, KEa tuber heads, and CNa middle portion had flavonoid levels that were similar to levels in the MB2C tuber head portion but less than levels in its middle portion (Table 16). The control (MB2) had lower levels of flavonoids in the head than its middle portion.

Furthermore, the tannins present in the yam accessions varied significantly and ranged between 1.84±0.29 and 7.05±0.04 mg/100 g. KEa and CNa tuber head portions produced significantly higher tannin contents compared to the control. Again, KEa and CNa tuber head portions produced significantly higher tannin contents compared to their middle portions. KB1, MB1, MB2, KE (M) and CNa (M) had similar tannin contents as the control, and in addition, there was no significant difference between the tuber head and middle portions of these accessions.

The field grown accessions had considerable amounts of saponin that varied significantly among the accessions. The saponin content among the accessions ranged between 0.46±0.04-12.08±0.51 mg/100g. The head tuber portions of KB1 and KEa were significantly higher in saponins than the control and the other accessions.

Similarly, only KB1 and CNa had significantly higher saponins in their tuber heads than middle portions. Accessions KB1, MB1, MB2 and CNa head and middle, and KEa middle portions of their tubers, had similar saponin contents as the head and middle portions of the MB2C tubers.

4.7 Mineral Element Composition of Wild and Cultivated yam

4.7.1 Mineral element composition of net-house grown wild and cultivated yams

All the yam accessions contained P, Na, K, Ca, Mg, Fe and Zn mineral elements (Table 17). Despite the presence of these mineral elements in all the accessions, there was significant differences in the levels of some elements among the species and between the head and middle sections of *D. schimperiana* accessions. *Dioscorea schimperiana* (KB1 and TE), *D. bulbifera*, wild type (KUbR and KUbB) and *D. quartiniana* (KEb) accessions had significantly higher P levels compared to *D. alata* (MN) and most of *D. schimperana* accessions. Furthermore, none of the *D. schimperiana* accessions had significantly higher P levels in their tuber heads compared to their middle sections. However, only KB1 had significantly higher P levels in their tuber middle section than head section.

The tubers of the yam accessions significantly varied in Na content. *Dioscorea bulbifera* (KUbR and KUbB) tubers accumulated the highest Na content compared to the other wild and cultivated yam accessions. *Dioscorea quartiniana* (KEb) significantly accumulated higher Na content compared to the other wild types except KUb.

Table 17. The mineral element composition of net-house grown Kenyan wild and cultivated yam accessions

Yam accession	Mineral element content (mg/100 g)						
	P	**Na**	**K**	**Ca**	**Mg**	**Fe**	**Zn**
KB1**H**	0.21±0.01b-d	1.75±0.03d-f	161.07±4.8a	0.19±0h	**0.38±0a**	**3.73±0.18a**	**0.13±0a**
KB1**M**	**0.25±0a**	1.83±0.08c-f	150.97±7.82a	2.58±0.06cd	**0.31±0ab**	**3.83±0.31a**	**0.11±0ab**
MB1**H**	0.18±0e-h	1.95±0.03c-e	133.55±26.37a	1.05±0.01g	0.18±0c-g	1.81±0.04c-e	0.08±0cd
MB1**M**	0.17±0f-i	1.75±0.03d-f	135.78±10.65a	1.19±0.03f	0.17±0d-g	2.18±0.14c-e	0.08±0cd
MB2**H**	0.15±0.01g-j	2.17±0.09c	118.87±5.92a	1.69±0.02e	0.19±0c-g	2.3±0.16b-e	0.07±0d
MB2**M**	0.18±0.01d-g	2.21±0.12c	148.18±11.09a	1.76±0.04e	0.20±0.01b-e	2.25±0.04b-e	0.07±0d
KB3a**H**	0.16±0.01f-i	2.00±0.01c-e	133.19±22.19a	1.16±0.03f	0.18±0c-g	1.58±0.20de	0.08±0.01cd
KB3a**M**	0.17±0.01f-j	2.00±0.05c-e	128.40±11.56a	1.26±0.03f	0.18±0.01c-g	1.17±0.01e	0.09±0.01b-d
KEa**H**	0.17±0f-i	1.83±0.06c-e	116.71±2.80a	1.8±0.04f	0.19±7c-g	2.93±0.49e	0.08±0.01b-d
KEa**M**	0.17±0f-i	1.98±0.05c-e	115.02±0.57a	0.85±0.02f	0.14±0e-g	1.19±0.02e	0.08±0cd
THE	**0.22±0a-c**	2.18±0.06c	153.2±0a	1.21±0.06f	0.27±0b-d	1.49±0.04e	0.08±0cd
TE**M**	**0.20±0b-e**	1.75±0.03d-f	166.89±71.66a	2.11±0.02d	0.22±0b-e	1.45±0.07e	0.09±0b-d
KUa**H**	0.17±0.01f-i	1.86±0.03c-f	136.34±11.46a	1.15±0.01f	0.17±0d-g	1.18±0.01e	0.08±0.01cd
KUa**M**	0.19±0.01f-i	2.0233±0.4c-f	160.45±43.02a	1.2±0.01f	0.18±0d-g	1.44±0.24e	0.08±0cd
KUb**R**	**0.22±0a-c**	**4.66±0.03a**	125.7±26.24a	2.31±0.03cd	0.21±0b-e	2.25±0.09b-e	**0.13±0a**
KUb**B**	**0.22±0a-c**	**4.38±0.07a**	175.87±30.97a	2.39±0.08bc	0.20±0c-f	**3.50±0.03ab**	**0.13±0a**
CNa**H**	0.18±0d-g	1.7±0d-f	108.31±9.03a	0.32±0.02h	0.22±0.01b-e	**3.14±0.05a-c**	0.09±0b-d
CNa**M**	0.18±0.01d-g	2.07±0.19cd	145.68±2.43a	1.33±0.05f	0.28±0.02bc	**3.73±0.04a**	0.09±0b-d
NK**H**	0.14±0.01ij	1.71±0.14d-f	122.65±11.23a	1.80±0.23e	0.10±0.03g	2.09±1.03c-e	0.07±0.02d
NK**M**	0.14±0.01j	1.7±0d-f	133.32±6.58a	0.80±0.03gh	0.14±0e-g	2.55±0.16a-e	0.08±0cd
LKa**H**	0.16±0f-j	1.51±0f	115.04±14.59a	0.86±0.01f	0.16±0.01e-g	1.84±0.04c-e	0.09±0b-d
LKa**M**	0.15±0h-j	1.46±0.03f	120.24±2.17a	1.58±0.01e	0.17±0d-g	1.15±0.23e	0.09±0b-d
MN	0.09±0k	1.75±0.03d-f	148.71±0.56a	2.45±0.01bc	0.18±0.01c-g	1.58±0.07de	0.09±0b-d
KEb	**0.25±0.01a**	**3.70±0.15b**	**133.32±8.52a**	**3.66±0.04a**	**0.38±0.09a**	2.41±0.22b-e	**0.11±0ab**

Key: **H** added at the end of *D. schimperiana* codes denotes tuber head/upper portion; **M**-middle portion; **R**- denotes root tuber, **B**- bulbils in *D. bulbifera.* **KEb**- collected from the wild habitat.

Values after ± denotes Standard Error.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

Except TE that had significantly higher content of Na in its head (2.18±0.06 mg/100g) than middle (1.75±0.03 mg/100 g) section, the rest of the *D. schimperiana* accessions did not show significant difference between the tuber head and middle section.

Potassium was the highest (175.87±30.97 mg/100 g) of all the mineral elements in all the yam accessions, followed by Na, Fe, Ca, Mg, P and Zn. The phosphorus levels ranged from 0.07 - 0.25 mg/100g of tuber sample. Although K was the highest, there was no significant difference in K contents among the yam accessions.

The Ca content of the yam accession tubers significantly varied and ranged from 0.19±0.02 - 3.66±0.04 mg/100g (Table 17). *Dioscorea quartiniana* (KEb) had the highest (3.66±0.04) Ca content in its tubers compared to the *D. schimperiana, D. bulbifera* and *D. alata* accessions. *Dioscorea schimperiana* (KB1) tuber head had the lowest (0.19±0.02 mg/100g). The cultivated *D. alata*, MN had significantly higher Ca content compared to its counterpart MT. Furthermore, the tuber head and the middle sections of the *D. schimperiana* accessions exhibited significant difference in Ca levels. For instance, KB1, MB1 and CNa had significantly higher Ca levels in the middle section than the head section of their tubers. TE, NK and LKa had significantly higher Ca content in their tuber heads than middle sections, while KB3a, KEa and KUa had similar content of Ca in their heads and middle sections.

The yam accession tubers had Mg contents that significantly varied among the wild and cultivated types. The Mg content ranged between 0.10±0.03 mg/100g and 0.38±mg/100g. *Dioscorea schimperiana* (KB1) and *D. quartiniana* (KEb) had significantly higher Mg

contents in their tubers than *D. alata* (MN and MT) accessions. Most of *D. schimperiana* and *D. bulbifera* (KUbR and KUbB) accessions had no significant diference between with *D. alata* accessions. There was no significant difference in Mg content between the tuber head and middle sections in all the *D. schimperiana* accessions (Table 17).

Furthermore, the yam accessions had Fe contents that varied significantly from 1.15±0.23 to 3.83±0.03 mg/100g (Table 16). *Dioscorea schimperiana* (KB1 and CNa) and *D. bulbifera* (KUb) significantly exhibited higher levels of Fe when compared with *D. alata* (MN and MT) accessions. However, *D. quartiniana* and most of *D. schimperiana* accessions had no significant difference with MN and MT. Also the tuber head and middle sections in all the D. *schimperiana* accessions had no significant difference in Fe contents.

Zinc levels in the tubers were the lowest of all the mineral elements tested, but again they significantly varied among the accessions. For example, *D. schimperiana* (KB1) head and middle sections, *D. bulbifera* (KUbR and KUbB) showed significantly higher Zn content than the MN and MT accessions while *D. quartiniana* (KEb) and most of *D. schimperiana* accessions had similar Zn contents as MN. KB1 significantly showed higher Zn content than the rest of *D. schimperiana* accessions but all did not show significant difference in Zn content between their tuber head and middle sections. Generally, Zn content ranged from 0.07±0 - 0.13±0 mg/100 g.

4.7.2 Mineral element composition of the field grown wild and cultivated yam

The tubers of field grown yams had high levels of mineral elements, which included P, Na, K, Ca, Mg, Fe, and Zn (Table 18). The cultivated yam (*D. alata*) did not produce tubers in the field, hence the Zero (0) values. Tubers of all the tested wild yam accessions accumulated P contents that ranged from 0.15±0.01 - 0.26±0.04 mg/100 g. There was no significant difference in P content between the head and middle sections, and among the accessions (Table 18). The Na content in the yam accessions significantly varied but ranged from 1.74±0.01 to 2.22±0.08 mg/100g (Table 18). MB2 head section had significantly the highest Na content compared to the other accessions, while CNa head section had the lowest. KB1, MB1, KEa and CNa tubers contained similar levels of Na.

All the yam accessions had produced similar amounts of K that ranged from 110.81±5.08 to 180.18±30.59 mg/100g. The yam accession tubers had Ca contents that ranged from 0.88±0.38 to 2.11±0.02mg/100g. CNa head section had significantly the highest Ca content and KEa middle section the lowest. KB1, MB1 and MB2 had similar amounts of Ca. The Mg content in the tubers ranged from 0.17±0.0 to 0.28±0.01 mg/100g. KB1 and CNa had the highest content of Mg while MB1 had the lowest. Furthermore, the accession tubers produced Fe contents that ranged from 1.73±0.03 to 3.72mg/100g. CNa had the highest content of Fe compared to the control and the other accessions that had similar amounts of Fe, in tuber head and middle portions. The yam accessions had the lowest levels of Zn compared to the other elements. Only KB1 had significantly higher Zn content relative to the control. The other accessions had similar amounts of Zn as the control.

Table 18. Mineral content of the field grown Kenyan wild and cultivated yam accessions

Yam accession	Mineral elemnt content (mg/100 g)						
	P	**Na**	**K**	**Ca**	**Mg**	**Fe**	**Zn**
KB1**H**	0.24±0.03[a]	1.92±0.07a-c	150.80±4.29a	1.67±0.31ab	0.26±0.06ab	3.29±0.57a-c	**0.15±0a**
KB1**M**	0.26±0.04[a]	2.06±0.17a-c	150.41±6.9a	1.65±0.44ab	0.28±0.01a	3.63±0.26ab	**0.14±0.01a**
MB1**H**	0.20±0.03[a]	1.81±0.04bc	180.18±30.59a	1.14±0.08ab	0.19±00ab	1.73±0.03c	0.10±0b
MB1**M**	0.2±0.03[a]	1.79±0.10bc	130.50±10.26a	1.33±0.05ab	0.17±0.00b	2.2±0.15a-c	0.09±0.01b
MB2**H**	0.17±0.03[a]	2.22±0.08a	110.81±5.08a	1.25±0.2ab	0.28±0.00ab	1.91±0.92a-c	0.08±0.01b
MB2**M**	0.2±0.03[a]	2.15±0.04ab	140.85 ±10.81a	1.42±0.45ab	0.22±0.00ab	2.53±0.17a-c	0.10±0.01b
KEa**H**	0.2±0.03[a]	1.99±0.06a-c	130.33±6.59a	1.81±0.22ab	0.24±0.02ab	1.85±0.04bc	0.1±0.01b
KEa**M**	0.2±0.03[a]	2.05±0.04a-c	120.85±1.1a	0.88±0.38bc	0.19±0.00ab	1.74±0.09c	0.1±0.01b
CNa**H**	0.21±0.04[a]	1.74±0.01c	150.32±00a	**2.11±0.02a**	0.28±0.04ab	**3.72±0.04a**	0.10±0.01b
CNa**M**	0.2±0.02[a]	2.01±0.08a-c	160.69±16.71a	1.33±0.05ab	0.27±0.01ab	3.01±0.47a-c	0.1±0.01b
MB2**HC**	0.15±0.01[a]	2.13±0.04ab	120.31±6.51a	1.71±0.03ab	0.20±0.01ab	2.04±0.47a-c	0.08±0.01b
MB2**MC**	0.19±0.01[a]	**2.21±0.08a**	150.13±9.55a	1.75±0.04ab	0.23±0.00ab	2.26±a-c	0.1±0.01b
MN	0±0[b]	0±0d	0±0b	0±0c	0±0c	0±0d	0±0c

Key: **H** added at the end of *D. schimperiana* codes denotes tuber head/upper portion; **M**-middle portion; and **C** - the control.

Values after ± denotes Standard Error.

Zero values in MN indicates absence of tubers.

Values with the same letter(s) in a column are not significantly different ($P \leq 0.05$), according to Tukey's test.

CHAPTER FIVE

DISCUSSION

5.1 Species and Spatial Diversity of Wild Yam in Kenya

5.1.1 The local naming and identity of wild yam accessions

The present study has shown that the thirty one wild yam accessions which were collected across seven Counties in Kenya belonged to four species that included *D. schimperiana* Kunth., *D. bulbifera* L., *D. quartiniana* A. Rich. and *D. dumetorum* (Kunth) Pax. However, *D. schimperiana* Kunth. is a highly variable species being characterized with presence of three morphotypes (KB3as and TEs1, KB3c, TEs2) while *D. bulbifera* L. was divided into wild, *D. bulbifera* var. *bulbifera* (BBc, KB4a, KEc and KUc), cultivated, *D. bulbifera* var. *anthropophagorum* (ST) and *D. bulbifera* unknown morphotype/variant (KKb) that has not been reported. Apparently, scanty information on *D. schimperiana* Kunth. and *D. bulbifera* L. is available in Kenya. The existence of these variants suggested polymorphism in yam species. Relatively, the morphotypes could have resulted from the fact that two yam species inhabited varied habitats and Counties. The study therefore suggests existence of diverse yam wild species and varieties or sub-species. Thus, there is need for molecular characterization to determine the relationships and identities of these wild yams.

Relatively, other wild yam species that have been identified and reported in Kenya include *Dioscorea odoratissima* which was found in Malaba forest (Milne-Redhead, 1963), *Dioscorea gilettii* that was identified near Moyale in northern Kenya and in Southern Ethiopia (Milne-Redhead, 1963, 1975) and *Dioscorea kituiensis,* that has been

reported in woodlands of Kitui and some parts of Meru in Eastern Kenya (Wilkin *et al.,* 2009).

The results also indicate that the same wild yam plants were known by different local names even among members of the same ethnic group. For example, despite them belonging to Kalenjin ethnic community, the Tugen, Keiyo and Nandi local name of *D. schimperiana* is either *Nyakanwo* or *Yakanwet*, names that sound slightly different. Also members of Kipsigis, a sub-group of Kalenjin living in Kericho County in South Rift region of Kenya, refer to *D. schimperiana* tubers as *Yagniat* (Kabuye, 1986).

Although some of the respondents could identify and name the wild yam, they could not discriminate different species and instead assign them the same names. Consequently, *D. bulbifera* and *D. schimperiana*, were assigned the same local name, *Nyakanwo* by Arror/Tugen or *Yakanwet* by Keiyo and Nandi ethnic communities. Assigning the same name to different species could be attributed to the inability of individuals to distinguish the differences existing between the species, owing to close morphological similarities among them. Similar findings were reported by Muthamia *et al*., (2014) where *Dioscorea odoratissima* and *Dioscorea alata* were locally named *Emodo* by members of Teso ethnic group.

The results further showed that only a smaller proportion, below 7% of the members of community in the different localities could identify and name wild yam. This finding signals that indigenous knowledge of wild yam is at risk of disappearance in many Kenyan communities. This could be due to lack of current use of wild yam by these

communities although it had been harvested for food and/or medicine, and the disappearance of wild yam in most of the localities due to habitat loss.

Apparently, local naming and generally indigenous knowledge of yams (Folk taxonomy) by local communities in Kenya, mirrors trends of local naming of yam in many parts of the world. For example, *D. bulbifera* that has been named *Nyakanwo* (Tugen), *Yakanwet* (Nandi), *Omotabararia* (Abagusi) and *Limbama* (Bukusu/Luhya) in the respective Baringo, Elgeyo-Marakwet, Uasin Gishu/Nandi, Kisii and Kakamega Counties, is named *Pita aalu* by local communities in India (Kumar *et al*., 2017). Although the folk taxonomy is important in identification, naming and preservation of indigenous knowledge of yam, it could not distinguish closely similar members of different species or sub-species, hence the use of botanical system of nomenclature.

But still, botanic identification of the wild yam in this particular study was not easy since many yam-like plants were discovered including KB4c*, CN1b*, CN2c* and LKb*. Distinguishing yam from these yam-like plants in the field, was also difficult since they share similar shoot morphological characterisics that are confusing, hence required an experienced taxonomist to identify them. In fact, Plagen, (2015) observed the same yam-like plants in Tugen hills and identified them as *Dioscorea abyssinica*, but actually they were *Smilax aspera.* Nonetheless, the folk taxonomy and botanical nomenclature have been applied the world over in the study of *Dioscorea spp* (Kumar *et al*., 2017).

In conclusion, four wild yam species were identified; *D. schimperiana, D. bulbifera, D. quartiniana* and *D. dumetorum.* The four morphological variants were considered new

sub-species/varieties of *Dioscorea schimperiana* and *D. bulbifera*. Therefore, the present yam wild species status in Kenya comprise, *D. schimperiana, D. quartiniana, D. dumetorum, D. bulbifera, D. gillettti, D. asteriscus, D. odoratissima* and *D. kituiensis.*

5.1.2 Morpho-physiological characterization of yam

Morphological characters that had a significant role in discriminating between the yam accessions/species in this present study were base colour, above base colour, plant/organ type, shape, surface texture and tuber flesh colour (upper) and tuber flesh colour (lower), prickles, stipules and twining direction while the physiological traits were oxidation colour of the tubers and growth cycle. These results are in agreement with those obtained by Atieno *et al*., (2020) that morphological variability score on the first principal component (PC 1) was highly correlated to leaf position and tuber flesh colour. Moreover, a number of researchers reported similar results. For instance, Jyothy *et al*., (2017) concluded that morphological variability score on the PC 1 correlated with characters associated to tuber shape and tuber flesh colour. Mwirigi *et al*., (2009) reported that PC 2, PC 3 and PC 4 were mainly correlated with characters related to leaf position and tuber flesh colour. Similarly, Sheikh and Kumar, (2017) explained that variability scores on PC 1 were highly correlated to stem colour.

From the dendrogram, morpho-physiological characterisation of Kenyan yams from nine Counties indicated close relatedness of most accessions despite their geographic locations being widely separated. For example, MT that was found in North Rift and MN in Central Kenya clustered together despite their localities being widely dispersed. Both accessions were *D. alata* species. Similarly, ST cultivated type that was found in Trans-

Nzoia County, were in the same sub-cluster with the wild types, KEc, KUb and BB, found in Elgeyo-Marakwet, Uasin Gishu and Baringo Counties respectively. Apparently, all were accessions of *Dioscorea bulbifera*. However, KB4a and KKb, also *D. bulbifera* accessions found in Baringo and Kilifi Counties, were in the same sub-cluster suggesting they are more closely related but both are less similar to ST, KEc, KUb and BBb, implying they could be of different genotypes, hence different sub-species/varieties.

Although it is found in the coastal region and belonging to *Dioscorea bulbifera*, KKb is closely related to KUc, KEb, SNb, KB3b and MB2b which are *Dioscorea quartiniana* accessions found in the North Rift region. Notably, KB2a, a *D. quartiniana* accession in North Rift region is closely related to KKa, a *D. dumetorum* accession found in the Coastal region, possibly because both twine to the left and possess compound leaves. In spite of the wide geographical distribution of *D. schimperiana*, all of its accessions clustered in the same cluster in the dendrogram.

Generally, in sub-cluster 1 (I), TES2, TES1, KB3as and KB3c were distantly separated from the other accessions, despite them belonging to same species, *D. schimperiana* Kunth. Similarly, *D. bulbifera* var. *anthropophagorum* (ST) and KKb were also distantly separated from the other accessions in sub-cluster 1 (II). Therefore, TES2, TES1, KB3as and KB3c, and KKb could possibly be new varieties/sub-species that have not been previously been documented within *D. schimperiana* Kunth. and *D. bulbifera* L. Furthermore, *D. alata, D. bulbifera, D. quartiniana* and *D. dumetorum* accessions were grouped together in the dendrogram, depicting close relatedness among the four yam species. The close relatedness among the four species could be due to cross-pollination

and sexual recombination, geographical and environmental influence, and possibly mutation, which could have also resulted in the emergence of the variants (morphotypes) in *D. schimperiana* and *D. bulbifera*. Also, Burns and Bottino, (1989), explained that significant morphological variation within and between the various species may be attributed to cross-pollination and sexual recombination, and mutation.

5.1.3 The distribution of the wild yam species in Kenya

The outcome of this study revealed the presence of wild yams in all the fifteen selected localities. They were present in a wide range of habitats such as in moist/wet deep forest, forest edges and outskirts, rocky slopes, and wet/moist riverine forest. *Dioscorea schimperiana* and *D. quartiniana* occurred in moist/wet deep forest, forest edges and outskirts, rocky slopes, and wet/moist riverine forest habitats. This is indicative of their ability to adapt to varied environments, thus their presence in most of the localities studied. Furthermore, the presence of *D. schimperiana* in only protected environments such as riverine and catchment zones, particularly in Nyakomisaro and Lugusi, also suggests that *D. schimperiana* must have occupied most of the ecosystems in North Rift, Western and South Nyanza. Similarly, existence of *D. schimperiana, D. quartiniana, D. asteriscus* and *D. odoratissima* in Western floristic zone of Kenya has been reported (FTEA 1952-2012; Dino, 2013), but are currently non-existent or rare in the same zone. However, the current yam occurrence only in the protected habitats is because of human activities including conversion of the yam habitats into agricultural land, construction of buildings and roads and change of policy on environmental conservation. These human activities have led to habitat loss and consequently loss of wild yam species. For instance,

Nyakomisaro Stream and Lugusi in Kisii and Kakamega Counties, were the only localities with only one (*D. schimperiana*) out of the four species of wild yams discovered. These two counties have large portion of their land converted to agriculture and settlement, leaving out only the unsuitable or protected lands such as hill/catchment areas, road reserves and riverine/riparian zones. In fact, some of the riparian reserve zones have been planted with the fast growing blue gum trees, especially along the Nyakomisaro riparian. These ecosystems supported the *D. schimperiana* populations that were encountered in this study.

Harvesting of the trees could disrupt the plant community, especially if suitable non-commercial replacement trees are not maintained. Therefore, human activity in riparian areas, although controlled by law, can cause degradation to the ecosystem, such as waste dumping and cutting down of eucalyptus trees along Nyakomisaro Stream zone. Moreover, commercial tree growing in Katimok and Kapseret forests and cereal crop farming in Kombosang, Kolol and Chepsangor, have increasingly accelerated the disappearance of wild yam. Thus, with this trend, the wild yam species in Kenya face a great risk of extinction.

Dioscorea quartiniana has been reported to occur in altitudes ranging between 0 - 2280 m above sea level (Contu, 2013), hence the reason for its availability in most of the localities which also could imply that the species is present in most parts of Kenya. The findings also agree with the report that *D. quartiniana* is common and distributed in Sub-Saharan Africa, from Senegal to Sudan, throughout tropical Africa to South Africa and in Madagascar (Wilkin, 2010; Contu, 2013). Similarly, it is an extremely variable and

present in a range of forests, grassland and rocky habitats (Burkill, 1960; Contu, 2013). Despite their widespread occurrence, *D. schimperiana* and *D. quartiniana* have not been cultivated in Kenya.

Dioscorea bulbifera tended to occur in moist/wet deep forest, forest edges and outskirts, and moist/wet riverine habitats, which indicates their adaptation to moist or wet forested habitats. Furthermore, its occurrence within an altitude range of 136 - 2003 m above sea level, suggests it can inhabit low to high altitude areas. The discovery of *D. bulbifera* in some parts is noteworthy because there is no prior report on the presence of wild *D. bulbifera* in Kenya. However, *D. bulbifera* var. *anthropophagorum* has been in cultivation in central, eastern, western and coastal regions of Kenya (Muthamia *et al.,* 2014; FarmBizAfrica, 2017); Business Daily Africa, 2017; Atieno *et al*., 2020), In addition, its occurrence in the wild suggests that it could either be native or unrecorded introduction to these regions. Burkill, (1960) also pointed out the existence of *D. bulbifera* in the African wild environments.

Furthermore, in spite of its occurrence in the deep and forest edges habitats, *D. dumetorum* only occurred in Kaya Tsolokero in Kilifi County, at an altitude of 148 m above sea level. Similarly, existing information indicates the presence of *D. dumetorum* in the coastal region (FTEA. (1952-2012; Maundu *et al*., 1999; Muthamia *et al*., 2014). Hence, *D. dumetorum* is adapted to the climatic conditions of the coastal region. Apparently, *D. bulbifera* and *D. dumetorum* have cultivated relatives in Kenya, but there is no literature of domestication of the two in the country (Muthamia *et al.,* 2014;

Maundu, 1999). Generally, *D. schimperiana* and *D. quartiniana* were the most widely distributed while *D. dumetorum* is the least distributed wild yam species in Kenya.

5.2 The Ethnobotanical Uses of Yam in Kenya

The four wild and two cultivated species of yam identified in this study were ethnobotanically valuable as food and herbal medicine among the different ethnic groups in Kenya. Three of the wild yam species namely *D. bulbifera*, *D. schimperiana* and *D. dumetorum* are edible and have been valuable wild food resources especially during times of severe famine. However, *D. quartiniana* var. *quartiniana* is non-edible and considered highly poisonous especially among the Tugen and Keiyo ethnic groups. On the hand, the two cultivated yam species, *D. alata* and *D. bulbifera* were majorly used as regular/staple food and income generation especially by the Kikuyu community. Furthermore, the results also indicated that two of the wild yams namely *D. schimperiana* and *D. quartiniana* have been used as herbal medicine to treat female and male sterility, diabetes, pain and dressing wounds.

However, only a smaller proportion (< 30%) of the respondents in the study Counties, know the uses of yam compared to those who do not know, indicating that yam is currently not known by even the elderly members of local communities in Kenya. It also suggests fading away of indigenous knowledge on yam among the Kenyan communities. Furthermore, the results showed variation on the level of indigenous knowledge per locality and species. Thus, even though *D. schimperiana* was commonly used as famine food, the proportion of knowledgeable respondents was higher mostly in localities in

Baringo and Elgeyo-Marakwet than in Uasin Gishu, Kisii and Kakamega Counties. This could be attributed to the finding that until recently, *D. schimperiana* was still used as famine food, due its availability during periods of severe drought and famine, when the staple food such as cereals and pulses are not available in Baringo and lower parts of Elgeyo-Marakwet Counties.

The other counties including Uasin Gishu, Kisii and Kakamega are less affected by drought, remaining mostly food secure, thus could not source for the wild yam. Additionally, the results indicate that even a smaller proportion of the respondents knew *D. schimperiana* as being used as herbal medicine to treat; male and female sterility in humans (Arror), male and female sterility in livestock (Bukusu/Luhya), diabetes (Nandi) and alleviate headache and abdominal pains (Abagusi). Similar to the results is the report by Kabuye, (1986), that *D. schimperiana* tubers have been harvested from the neighbouring wild environments and used as famine food by *Kipsigis* community in Kericho County, but there is no information on its medicinal use. The study outcome also confirms the report by Burkill, (1960) that the native communities in tropical Africa harvest *D. schimperiana* tubers for famine food. Contrary to harvesting *D. schimperiana* from the wild environments, it has been cultivated, consumed, and considered integral for food security in Cameroon (Leng *et al.,* 2019). However, despite its use for food and medicine, *D. schimperiana* has not been cultivated and researched in Kenya, yet it is greatly faced with the risk of extinction due to the rapid destruction of its habitat in most parts of the country. Therefore, more research to assess the wild yam species status and

indigenous knowledge on Kenyan wild yam should be conducted, to recommend their conservation and habitat protection.

The results further have shown that the *D. bulbifera* var. *bulbifera*, has been harvested from its natural environment namely, Bossei, Katimok Forest, Kolol and Kapseret Forest and used as famine food. Nevertheless, very few informants, 9% and 8% of Tugen from Katimok Forest and Bossei respectively, 5% Nandi in Kapseret and 9% Keiyo in Kolol were knowledgeable on use of *D. bulbifera*. None (0%) of the Chonyi respondents in Kaya Tsolokero in Kilifi County knew the local uses of *D. bulbifera.* Similarly, the study has revealed that *D. bulbifera*, has been used as regular food especially among the Kikuyu ethnic group, in which a small proportion (7.5%) of all the respondents in all the localities studied, reported it as important regular food. Furthermore, in the recent past, some farmer's in Central and Eastern Kenya have cultivated yam majorly for income generation from sale of underground and aerial tubers (FarmBizAfrica, 2017). These results are similar to reports that many communities across the world obtain *D.bulbifera* tubers from wild or cultivated plants and use them as famine food (Kumar *et al.,* 2017; Baressa, and Itefa, 2019). However, none of the respondents in the selected localities reported use of *D. bulbifera* in traditional medicine, but globally, *D. bulbifera* has been used traditionally to cure various ailments including; relieving dysmenorrhoea, reducing acidity, against rheumatoid arthritis, in spasmodic asthma, for menopausal problems, for labor pain and the prevention of early miscarriage, for hernia, relieving the pain of child birth among many others (Kumar *et al.,* 2017; Baressa and Itefa, 2019).

The results also revealed that all the respondents, Tugen (Kasaka, Mormorio, Kapkwang) and Keiyo (Kolol) affirmed *D. quartiniana* var. *quartiniana* as non-edible, and hence considered poisonous. None of the *Nandi* respondents knew whether it is edible or non-edible. Despite *D. quartiniana* being non-edible, 5%, 4% and 3% of Tugen ethnic group in Kasaka, Mormorio and Kapkwang respectively, reported that a small piece of its tuber is boiled with other herbs and used in treatment of gonorrhea. In spite of *D. quartiniana* being treated as poisonous, it was found to possess high levels of protein, lipids, mineral element and flavonoids in this study. Also, contrary to the believe by Tugen and Keiyo ethnic groups in Kenya that *Dioscorea quartiniana* tubers are poisonous, the species has been cultivated for food in Cameroon and East Nigeria (Coursey, 1967; Contu, 2013).

The Chonyi ethnic group living in Kaya Tsolokero has also consumed *Dioscorea dumetorum*, as food during times of severe famine. *Dioscorea dumetorum* has also been cultivated in Kenya (Maundu *et al.*, 1999; Mwirigi *et al.*, 2009; Atieno *et al.*, 2020). Although it is present in the wild and cultivation along the coastal region, there is no research evidence about *D. dumetorum* domestication in Kenya. However, *D. dumetorum* is one of the wild yams that has been domesticated and cultivated in West Africa and Asia (Jayakody *et al*., 2007).

This study established that cultivated yam, *Dioscorea alata* was only popular (5.0%) among members of Kikuyu ethnic group. For instance, in Trans-Nzoia, a County inhabited by diverse ethnic groups, only members of the Kikuyu ethnic group raised a few yam plants, *D. alata* and *D. bulbifera* in their home gardens, and use them for consumption and income generation. In Nyeri County, a few members of the Kikuyu

especially the older generation, cultivated *D. alata* in their household gardens. *Dioscorea alata* is one of the well-studied yams in the world. Furthermore, the finding that *D. alata* is used for food and income generation, is similar to reports documented in literature. For example, its tubers have been used as staple food and income generation, and to a lesser extent as herbal medicine especially in Asia, West Africa and Ethiopia (Kumar *et al.*, 2017; Baressa and Itefa, 2019) among others. In summary, the results from this study reveal that the wild yams, *D. schimperiana, D. bulbifera* and *D. dumetorum* tubers are edible and have been harvested from the wild and consumed during times of severe famine. *Dioscorea quartiniana* is non-edible and treated as poisonous. Furthermore, *D. schimperiana* and *D. quartiniana* were useful traditional medicine; *D. schimperiana* has been used to treat sterility, diabetes, and relieving pain, and wound healing while *D. quartiniana* has been useful in treatment of gonorrhoea. Only a few members (<30%) particularly the elderly, in the selected localities are knowledgeable of yam. There is need to use this indigenous knowledge to promote use and conservation the wild and cultivated yams in Kenya.

5.3 The Chemical Properties of Rhizosphere Soils of Different Yam Species

The study is the first to assess the chemical compositional status of rhizosphere soils from two wild yams, *D. schimperiana* and *D. bulbifera*, and a cultivated *D. alata* accessions growing in different habitats. The results revealed that soils from rhizospheres of the yam species significantly varied in chemical composition. For instance, the pH of soils sampled from the rhizosphere of all the accessions were below pH 7, hence acidic according to Chude *et al.*, 2005 who reported that soils with pH less than 7 are considered

acidic. The results further revealed that despite their wide geographical distribution, *D. schimperiana* accessions including KB1 (6.5), MB1 (6.4), KB3a (6.6), TE (6.7), CNa (6.5), NK (6.4), LKa (6.4) rhizosphere soils were mildly acidic to neutral (pH 6.2-7.2) and MB2 (pH 6.0) and KEa (pH 5.9), were moderately acidic (pH 5.7 - 6.2) according to Estaban, (2000). The results suggest a wide range of rhizosphere soil pH for *D. schimperiana*, from moderately acidic to mildly acidic, which could also explain its presence in diverse habitats. The rhizosphere soil pH of *D. bulbifera,* KUb (6.3), is within mildly acidic to neutral (pH 6.2-7.2) suggesting it thrives well in mildly acidic or neutral soils, thus its restricted occurrence in Kenya. Accessions MN and MT, *Dioscorea alata* that were cultivated in Nyeri and Trans-Nzoia Counties that are geographically sparsed, had strongly acidic to mildly acidic rhizosphere soils respectively, suggesting *Dioscorea alata* does well acidic soils. This could explain its widespread global distribution.

Tolerance to acidity in some plant species have been studied and reported, but not in yams. Nevertheless, since all the localities where the yams were obtained, are located in tropical Kenya where soils are strongly acidic (Okalebo *et al.,* 2002), the results, therefore depict rhizosphere soil pH modification by the yam species. However, there is need to assess the chemical composition of the yam rhizospheres and compare with bulk soil in each selected locality, to determine their abilities in modifying the rhizospheres.

The results also revealed the presence in varying levels of carbon in the rhizosphere soils of all the yam accessions. Generally, the rhizosphere soils of all the yam species had moderate to high levels of organic carbon according to Okalebo *et al*., (2002) who rated >3.0% carbon in soil as being high. Additionally, the high concentration of %C in the

rhizosphere *D. bulbifera* and *D. schimperiana* when compared with *D. alata*, could be attributed to the annual degeneration and eventual degradation of the original tuber and roots in *D. bulbifera* and *D. schimperiana*, when a new tuber is growing and developing. This explanation is supported by the report by Prashar *et al.,* (2013) that the dead root is transformed into soil by rhizospheric activity making the rhizosphere a unique region distinct from the bulk soil. In addition, the higher carbon levels in rhizosphere soil of most accessions of *D. schimperiana*, and *D. bulbifera* could be associated with the numerous roots on their tubers, which might have released carbon rich exudates than the *D. alata* whose tubers lack roots. The prolonged existence characterized by the annual renewal of tubers and shedding of leaves and their subsequent decomposition could have increased carbon in the rhizosphere of *D. bulbifera* and *D. schimperiana*, as opposed to *D. alata*.

Similarly, roots of various plant species release up to 40% of their total photosynthetically fixed carbon in form of both low and high molecular weight organic acids and inorganic compounds (Vandenkoornhuyse *et al*., 2015; Mendes *et al*., 2013). The high molecular weight compounds released from the roots are the complex molecules such as mucilage, cellulose making up the majority of C. The compounds can greatly influence the chemical, physical and biological processes in the rhizosphere (Jones *et al*., 2009). Jones *et al.,* (2009) explained that the composition and amount of the released compounds are influenced by many factors including plant species, climate, insect herbivory, nutrient deficiency or toxicity, and the chemical, physical and edaphic conditions. Thus, the differences in carbon levels among the yam species could be

attributed to variation in genotypes, climatic conditions and nutrient deficiency or toxicity, and the chemical, physical and edaphic conditions. Some exudate compounds act as signaling and chemoattractant molecules that recruit beneficial microorganisms that contribute to pathogen resistance, water retention, and the synthesis of growth-promoting hormones (Berendsen *et al.,* 2012; Liswadiratanakul *et al*., 2023**)**. For example, Ouyabe *et al*., (2019) identified *Brukholderia spp*., *Bacillus altitudinis*, *Enterobacter bugandensis* as the main species among 47 other nitrogen fixing bacteria isolated from yam rhizosphere. Release and deposition of organic carbon by the plant roots, increases microbial populations and activities and subsequent flow of carbon to root associated symbionts (Walker *et al*., 2011; Bais *et al*., 2006). The microbial activity in the rhizosphere assists the plant in nutrient uptake and offers protection against pathogen attack (Berendsen *et al.,* 2012; Weinert *et al*., 2011). Therefore, it could be possible that the different yam species produce carbon rich exudates that attract different microbes, which in turn contribute to nutrient mobilization and absorption thereby promoting the rapid growth reported for yam species.

Furthermore, the results exhibit varying levels of Olsen P in the rhizosphere soils of all the yam accessions. However, KEa (7.3 ppm), MB1 (5.03 ppm), LKa (5.5 ppm) rhizospheric soils had Olsen P levels below the minimum Olsen P requirement of 10 ppm according to Okalebo *et al.,* (2002). The significant difference in rhizosphere Olsen P levels amongst the *D. schimperiana*, *D. bulbifera* and *D. alata*, and accessions of *D. schimperiana* could be due to differences in geographic, genotypic, soil type and cultivation. Thus, the significantly higher levels of Olsen P in wild yams, *D.*

schimperiana (TE, CNa, KB3a), *D. bulbifera* compared to *D. alata* could be associated with differences in species and localities. For example, *D. schimperiana* and *D. bulbifera* rhizosphere soils were obtained from plants in their natural environment while *D. alata* soils were from plants in field cultivation. Furthermore, lower P levels in *D. schimperiana* accessions, MB2, KEa, NK and LKa when compared with their counterparts, TE, CNa and KB3a, might be due to differences in their genotypes and geographical locations. The accessions were collected from a wide geographical ecology with different soil types, which might have occasioned the difference in rhizosphere Olsen P levels among the yam accessions.

The low P could be due acidic rhizospheres exhibited by most accessions in this study. Under acidic conditions, phosphate (PO_4^{3-}), the form of P absorbed by plants, is insoluble in soils, binding strongly to Ca, Al and Fe oxide depending on the nature of the soils, and soil organic matter rendering much of the P unavailable to plants. In P depleted soils or acidic soils, some plant species and/or varieties have evolved special mechanisms to obtain PO_4^{3-}. Such plants are acid tolerant. It was found in this study that most yam accessions had acidic rhizospheres, depicting that they are acid tolerant. Acid tolerance in plants have been associated with diverse mechanisms. Plants liberate PO_4^{3-} from organic sources by releasing enzymes such as acid phosphatase (Rudrappa, 2008). Plant roots can exude organic acids such as malic and citric acids into the rhizosphere, which effectively solubilize P bound in soil minerals (Rudrappa, 2008). Some plants recruit diverse microbes that help in phosphate solubilization to increase the availability of P. In particular, white yam plants (*Dioscorea rotundata* Poir.) has been reported to attract

through release of exudates to its rhzosphere, three endophytic bacteria, effective in phosphate solubilization (Sonia, 2020). Therefore, the higher levels of P in *D. schimperiana* and *D. bulbifera* rhizospheres suggest that their roots and tubers could be more efficient in exudate secretions that could attract different microbes leading to enhanced rhizosphere microbial activity and mobilization of P and other nutrients. Thus, there is the need to intensify the study of the yam rhizospheres to identify beneficial micro-organisms that would be used to improve nutrient acquisition and enhance yam and possibly other crops production.

Moreover, the results revealed the presence of N in the rhizosphere soils of all the yam accessions that ranged from low to high according to Okalebo *et al.,* (2002), who rated 0.05-0.12% N in soil as being low. Subsequently, the rhizosphere soils of KEa, TE, KUb, NK and MT had very high N (>0.25%), KB1, CNa, LKa, and MN moderate (0.12-0.25) and MB1 had low levels of N. The results showed the highest N in rhizosphere soils of *D. bulbifera*, followed by *D. schimperiana* and *D. alata*, which could be associated with species and geographical differences in influencing the rhizosphere N levels. The higher N in the wild than cultivated species suggests cultivation affects rhizosphere levels of chemical composition. The moderate to very high %N in rhizosphere soils of most *D. schimperiana*, *D. bulbifera* and *D. alata* accessions could be attributed to many factors. For instance, a number of bacteria including *Brukholderia spp., Bacillus altitudinis, Enterobacter bugandensis, Bacillus cereus* and *Pseudomonas aeruginosas*, have been identified as the main nitrogen fixing bacteria isolated from yam rhizosphere (Ouyabe *et al*., 2019; Sonia, 2020; Sivakumar *et al*., 2009). Moreover, different plant species can

release nitrogen containing root exudates including amino acids, proteins, phenolics and other secondary metabolites which are easily used by rhizopheric micro-organisms (Jones *et al*., 2009; Vandenkoornhuyse *et al*., 2015; Mendes *et al*., 2013). Some exudate compounds are signaling and chemoattractant molecules to beneficial microorganisms which contribute to water retention, and the synthesis of growth-promoting hormones (Berendsen *et al.*, 2012), contributing to increase in rhizosphere soil nitrogen. The composition and amount of the released compounds are influenced by many factors including plant species, climate, insect herbivory, nutrient deficiency or toxicity, and the chemical, physical and edaphic conditions, which could also explain the difference in N content among the yam accessions. Components in root exudates assist plants in availing nutrients by acidifying or changing the redox conditions within the rhizosphere or directly chelating with the nutrients. Moreover, plants respond to nutrient deficiency by altering root morphology, recruiting the help of microorganisms, and changing the chemical properties of the rhizosphere (Rudrappa, 2008; Amanullah, 2015). The high N in most yam species rhizosphere, could be due reduced leaching of soluble nitrate (NO_3^-), release of ammonium (NH_4^+) in clays and soil organic matter and bacterial nitrification (Rudrappa, 2008). Hence, it can be deduced that wild yams, *D. schimperiana*, *D. bulbifera* and cultivated, *D. alata*, could have mobilized higher levels %N to their rhizosphere soils through root exudate secretion and attracting nitrogen fixing micro-organisms that also synthesize growth-promoting hormones. Therefore, yam rhizosphere should be investigated for micro-organisms to establish their potential in growth and production, and biofertilizer development.

5.4 The Effect of Cultivation on Wild Yam Growth and Production

5.4.1 Effect of net-house cultivation on wild yam growth and production

The present study is the first in Kenya to assess the effect of cultivation on wild yam growth and production in order to determine its potential for domestication. The results of the net-house grown yam accessions showed that each *D. schimperiana* and *D. bulbifera* plant forms a single underground tuber. In addition, the two species formed single underground tubers in their natural habitats, implying that cultivation did not affect the number of tubers produced under net-house cultivation. However, it was observed that *D. schimperiana* and *D. bulbifera* were less fibrous compared to tubers formed by the same species in the wild environment, depicting that cultivation retards the growth of roots on tubers. The increased number of roots on tubers probably offer physical protection to the growing tuber (Dounias, 2001). On the other hand, the formation of two or more tubers by *D. alata* (MN) accessions could be attributed to the use of woody rhizomes as planting material instead of tubers. However, each tuber formed by the planted rhizome is linked to a vine, an observation that was also reported by yam farmers in Nyeri County. Furthermore, a sprouting trial experiment on *D. alata* at the University of Eldoret, resulted to the formation of a single vine. Gucker, (2009), reported similar findings on *D. alata* production in Hawaii, America. The variation in tuber weight among accessions of *D. schimperiana,* and between *D. bulbifera* and *D. alata*, could be due to genotype, species and environment effects and that *D. schimperiana* greatly respond to cultivation than *D. bulbifera* and *D. alata*. Also, size of planting material affects tuber weight (O'Sulvan, 2010). Apparently, the tuber planting material for KB3a, KUa, CNa, NK and LKa were small (70 - 150 g), thus could be the reason for their low production. Similar to

the varied tuber weights, were the fascinating varied tuber shapes displayed by the *D. schimperiana* accessions. Accessions MB1, KEa, TE and CNa formed tubers that were longer than the two feet Polythene Growth Pouches. Hindered by the Growth Pouch, the tubers coiled around the bottom of the growth pouch resulting to the different coiled shapes of tubers. Some tubers pierced through the growth pouches but their vertical growth was prevented by the concrete floor and the partitioning walls in which the Growth Pouches were confined, again growing into different shapes outside the growth pouches. This unique tuber growth characteristic in *D. schimperiana* explains the ability of tuber growth into rock crevices/cracks, thus its survival in rocky habitats, while also contributing to weathering and soil formation. Furthermore, cultivated accessions, MN produced small tubers in net-house plants whereas they produced very large tubers in established plants found in farmers' gardens in Nyeri and Trans-Nzoia Counties. This suggests that *D. alata* produces small tubers in the first season, which tend to increase in size and weight in the successive seasons. The superior performance of wild yam accessions in the net-house could be due to the appropriate agronomic treatment that included raising the plants in 2 feet Growth Pouch, supplemental watering of plants, appropriate spacing and staking of the growing plant shoots. Proper spacing/arrangement and staking exposed plants to maximum light, reducing competition for light among the accessions, and enhancing light absorption and photosynthesis. Hence, increased accumulation of starch leading to increased tuber weight. Reduced competition for light could explain the formation of shorter vines/shoots in all the net-house grown yams. It was observed that leaves were formed by net-house plants during their early stages of growth as opposed to when plants were growing in the wild. This means plants in the net-

house photosynthesized early and accumulated more starch that caused increase in tuber weights. Again, it was observed in this study that *D. bulbifera* and *D. schimperiana* tubers formed and supported growth of new tubers that lacked shoots, where the new tuber being attached to the old one, increases in size as the older gradually shrunk away.

The formation of bulbils by some plants of *D. schimperiana* (MB1, KEa, TE and CNa) and *D. bulbifera* (KUb) indicated that these species are capable of bulbil formation, but their variation in number and weight of bulbils per plant, could be related to differences in species and/or genotypes, environmental conditions and growth. Thus, the formation of larger bulbils in *D. bulbifera* than *D. schimperiana*. Also *D. schimperiana* accessions (MB1, KEa, TE and CNa) that formed bulbils, also exhibited superior growth compared to those that failed to form bulbils, suggesting that bulbil formation is also associated with health and vigorous yam growth. In addition, in their wild environment, some MB1, KB1, KB3a and NK plants formed many relatively large bulbils than in net-house grown plants. Therefore, failure of bulbil formation, or formation of few, small and lighter bulbils could be linked to cultivating these plants in the net-house, i.e outside their natural environment, hence the effects of cultivation. Additionally, the *D. schimperiana* underground tubers were significantly larger and heavier than their bulbils. However, it was discovered that a *D. schimperiana* (NK) plant in Nyakomisaro Stream in Kisii County produced many (over 150) bulbils that weighed 450 g in total while its underground tuber weighed 240 g. A wild *D. bulbifera* (KUb) plant in Kapseret Forest in Uasin Gishu County, also formed many (55) bulbils that weighed a total of 390 g and its underground tuber weighed 360 g. In contrary, cultivated type, *D. bulbifera* (ST) that was

found in St Mary's Kitale, produced many large bulbils, each weighing >250 g. In addition, a yam farmer in Murang'a reported a cultivated *D. bulbifera* plant in his farm produces a total of 20 kg per year. The results further showed that none of the plants of two accessions of *D. alata*, MT and MN formed bulbils. Similarly, none of the plants from the two collection sites in Nyeri and Trans-Nzoia Counties produced bulbils, implying that bulbil formation is rare in *D. alata* grown in Kenya. In contrast, Gucker, (2009) reported presence of bulbils in *D. alata* found in Latin America. A discovery was made that bulbils sprouted into new plants while still attached to the mother plant or when they fall on the ground. Therefore, bulbils are primarily used by the plant for reproduction or propagation. Generally, when the accessions were raised in partial shade provided by the net-house, synonymous/mimicking their natural environment, they produced heavier tubers and shorter and less leafed vines. Conclusively, cultivation seemingly causes growth of shorter vine length and less number of bulbils but increases tuber weight in wild yams. All the tested wild yam accessions exhibited improved production under cultivation. Accessions MB1, KEa, TE and CNa of *D. schimperiana* and KUb (D. *bulbifera*), exhibited significantly higher production than the other accessions, hence their greater potential for domestication.

5.4.2 Effect of field cultivation on wild yam growth and production

The field results showed significantly varied vegetative growth and production of *D. schimperiana* accessions. For example, the findings revealed that the *D. schimperiana* accessions produced longer internodes than MN, a pointer that internode length in yams differ from species to species and that *D. schimperiana* have longer internodes than *D.*

alata species. Despite the longer internodes in *D. schimperiana* compared to *D. alata* (MN) accessions, MN produced longer vines with a higher number of leaves. Apparently, *D. alata* forms more nodes with opposite leaf arrangement compared to *D. schimperiana*. Furthermore, in contrast with their growth in the wild, *D. schimperiana* accessions formed shorter internode and vines, and fewer leaves in the field grown plants. For example, during the field survey, a *D. schimperiana* (MB2) plant that grew to about 15 m was observed in the natural environment in Baringo County whereas the tallest plant of the same accession grew to 2 m in a field experiment at the same locality. The reduction in internode and vine length, and number of leaves might be because of reduced competition among the accessions for space and light in the open field, where the plants were exposed to full light. Most accessions of *D. schimperiana* produced significantly heavier tubers than the control, indicating that cultivation or full light improved production of yam. Furthermore, KEa produced heavier tubers compared to the other *D. schimperiana* accessions, depicting that response of yam to cultivation is probably genotype dependent, and the poor performance of KB1 relative to the rest of *D. schimperiana* accessions could be due to ecological differences between KB1 collection locality (Kombosang) and experimental site (Mormorio). Kombosang stands at a lower altitude and is located in upper midland (UM 4) zone while Mormorio stands on a higher altitude and located in upper midland (UM 3) zone (Jaetzold, 2010). It was observed that all the *D. schimperiana* shoots withered and dried six months after sprouting while the *D. alata* shoots persisted even through the dry season, between December and March. This observation suggests *D. alata* as a perennial plant, and although it did not form tubers in the first season, it could form them in the succeeding season(s), particularly in Mormorio

or low altitude zones. The results also indicate that *D. schimperiana* does well under cultivation in upper midland zones. In conclusion, open field cultivation favours growth and production of wild yam, *D. schimperiana*. The *D. alata* formed healthy shoots but not tubers during the first season at least in Mormorio or upper midland zones.

The results revealed that *D. schimperiana* accessions formed single elongated less fibrous tubers that grew vertically deep into the ground. In the wild, *D. schimperiana* also formed single elongated tubers that were heavily covered by fibrous roots, that cover almost the entire tuber, but very many on the upper portion of the tuber. The implication is that cultivation reduced formation of fibrous roots on the tuber. These roots are associated with absorption of water and secretion of allelochemicals for tuber protection against foraging animals such as beetles, squirrels, and roots of plants. With cultivation, these risks are reduced, hence the reduction in the number of fibrous roots. The healthy growth of shoot and lack of tuber formation in MN even after the 10 months (period documented for *D. alata* harvesting), could be related to unsuitability of the type of planting material used, although it was observed that established *D. alata* plants that grew from rhizomes produced large tubers in farmers' gardens in Nyeri County. Therefore, the failure of these accessions to form tubers even after 10 months in Mormorio in Baringo County, could largely be attributed to variation in environmental conditions between the two sites. Furthermore, although *D. alata* is cultivated mostly in Central Kenya, it is not native to Kenya, but Asia (O'Sullivan, 2010), hence could explain its low production. Similarly, Coursey, (1967) reported that underground tubers are generally small in the 1st year of growth for *D. alata* and *D. bulbifera* and large tubers may not be produced until yams

reach 3 years old. Furthermore, great variation in the growth and forms of vines, leaves, bulbils, and tubers are reported for air yams and water yams and are also likely in other species.

5.5 The Primary Metabolite Composition of Wild and Cultivated Yam Tubers

The primary metabolite components was assessed to establish the potential of Kenyan wild yam for functional food and nutritional security. The results showed substantial amounts of moisture, ash, crude fibre, protein, lipid and carbohydrates commonly referred to as proximate components, in net-house and field grown *D. schimperiana, D. bulbifera* and *D. alata*, and *D. quartiniana* collected from the wild. The variation in the metabolite component contents among the yam species might be due to the genetic, environmental factors and maturity of yams (Mulualem *et al*., 2018). Relatively, the moisture content of most of the yam accessions were consistent with the levels reported for two wild yam species in Nigeria (Afiukwa *et al.,* 2013), and 61.93% in *D. alata* (FAO, 2001) and 65 - 81% for all cultivated species (Osagie, 1992). The results were comparable to those obtained by Afiukwa and Igwe, (2015) on moisture content between 68.74±1.34% and 66.57±1.276% of *D. bulbifera* underground and aerial tubers in Nigeria. The moisture content is associated with the quantity of solid matter present, and the rate of spoilage is closely related to the amount of moisture present in the food material (Sanful *et al*., 2013). Hence, it is an indicator of perishability and storability of food materials. Cultivars with low moisture content may have a longer shelf life. However, tubers of most yam species are not highly perishable due to the presence phytochemicals in the tubers, which have been associated with antimicrobial activity.

The ash contents of the yam accessions were lower than the ash contents of two wild yam species reported by Afiukwa *et al*., (2013) which were 3.35% (okpura) and 3.15% (Ighobe) and also slightly than 1.84% reported for *D. rotundata* by Lawal *et al*., (2012). However, the results are similar compared to 0.6 - 1.7% documented for cultivated yam species in Nigeria by Osagie, (1992). The ash content gives a measure of total amount of inorganic compounds like minerals present in a sample (Osagie, 1992). The results indicate that the yam tubers could be good sources of essential minerals and trace elements as reported by Osagie, (1992).

The protein levels in the yam accessions that ranged from 5.42% to 11.46 % compare well with 7.82% protein content reported for *D. rotundata* by Lawal *et al*., (2014) and 2 - 6% for yam peel reported by Akinmutimi *et al*., (2006). However, the accessions contained protein contents higher than those reported for Ighobe (3.37%) and okpura (2.21%), 1.53%, the average protein content of *Dioscorea spp.* in the United States (Afiukwa *et al*., (2013) and 1-3% and 1.4- 3.5% reported for cultivated yam species by Coursey, (1967) and Osagie, (1992) respectively. Therefore, the wild yams are good and even have better protein content than some cultivated species. The relatively high protein content is an indicator that these wild yam species could support growth and movement, and body defense in human being.

The results revealed high lipid contents in some *D. schimperiana* (MB1) and *D. quartiniana* (KEb) accessions that could be ear-marked for lipid profiling to determine

the quality. Interestingly, most tuber crops do not store lipids in their tubers. The lipid content of most of the yam accessions were comparable to 6.01% (okpura) but many times lower than 13.03% (ighobe) as documented by Afiukwa *et al*., (2013). However, the lipid results of the wild yam accessions were higher than 0.17% for yams generally as reported in USDA National Nutrient Database, and 0.2-0.4% for common cultivated yams in Nigeria (Osiage, 1992} and 0.84% for *D. rotundata* (Lawal *et al*., 2014). The lipid content in these yam species are reasonable, and presence of lipids in foods are vital in determining their palatability (Ayo *et al*., 2013). However, tubers of most yam species are not palatable, yet results in this study have shown high lipid content in yam. The low palatability of yam tubers could therefore, majorly be attributed to their phytochemicals contents.

The crude fibre contents of the yams were consistent with 1.52% and 3.56% for okpura and ighobe wild yams. The accessions also contained fibre contents within the range reported for yams (Osage, 1992, Abara *et al.,* 2003). The fibre contents of most of the yam accessions were not significantly different from 4.1% for yams (USDA National Nutrient Database), but significantly lower for some yam accessions. Therefore, these wild yam species qualify as food considering their fibre contents. Fibre improves absorption of trace elements, lowers the absorption of cholesterol and prevents metabolic disorders such as hypertension and diabetes mellitus (Mensah *et al*., 2012).

The carbohydrate contents of the fresh yam tuber were similar to 16.4 - 31.8% for the cultivated yam tubers and 32.49% for yam peel (Osagie, 2012; Ayo *et al.,* 2018), and 12.71 to 33.95% for cultivated yam landraces in southwest Ethiopia (Mulualem *et al*., 2018). The results were also in agreement with those reported for cultivated yam (Abera, 2011). The high carbohydrate content in most of the yam accessions is an indication they could be a good source of energy for human beings.

5.6 The Secondary Metabolite Composition of Wild and Cultivated Yam Tubers

The results from this study show the presence of alkaloids, flavonoids, tannins and saponins in the tubers of the various yam accessions. The presence of alkaloids in the head and middle sections of *D. schimperiana* or whole tuber of *D. bulbifera*, *D. quartiniana* and *D. alata* accessions is consistent with the results reported by Lawal *et al*., (2014) on the presence of alkaloids in yam peel, maize chaff and bean coat. The study revealed that KUb underground (R) and bulbils (B) had significantly higher concentrations of alkaloids than the cultivated accessions MN, but research tests by Adeosun *et al.,* (2016) did not detect presence of alkaloids in *D. bulbifera* tubers. Although *D. quartiniana* (KEb) has been reported as non-edible by the local communities, its alkaloid content was similar to that of edible cultivated yams, MN. The significantly lower concentrations of alkaloids in tubers of *D. schimperiana* (KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa) in comparison to MN, could imply suitability of this species for food. The lack of significant variation in alkaloid concentration between the tuber head (red) and middle (yellow) portions of the tubers of

D. schimperiana accessions indicates that the alkaloids are proportionately distributed in the two portions of the tuber.

The results are similar to many reports indicating presence of substantial amounts of secondary metabolites in tubers of different yam species (Adeosun *et al*., 2016; Kumar *et al*., 2017; Kayode *et al*., 2017). For example, the alkaloid concentration results of the net-house grown and field grown wild yam accessions are consistent with results reported by Okoroafor and Iborida, (2017), which ranged between 0.34 - 0.97mg/5g for *D. rotundata, D. cayenensis* and *D. dumetorum.* Alkaloids have been used for over two centuries as stimulant and are active against bacteria (Madziga *et al*., 2010) and most efficient and significant therapeutic plant substance (Lawal *et al*., 2014). The presence of alkaloids in high concentrations could confer antimicrobial properties to the tubers of the yam accessions (Eleazu *et al*., 2013). Therefore, the considerable amounts of alkaloids in the tubers of the yam accessions indicates that they can elicit medicinal benefits and could be recommended for exploitation as medicine.

The results from net-house and field grown accessions show significant differences in flavonoid concentration among *D. bulbifera, D. quartiniana* and *D. schimperiana* accessions. This suggests species differences in flavonoid synthesis. Furthermore, the flavonoid differences between the underground tubers and bulbils of *D. bulbifera* (KUbR and KUbB), and head and middle portions of some *D. schimperiana* accessions suggests genotypic variation in biosynthesis and partitioning of these secondary metabolites. Majority of *D. schimperiana* accessions including KB1, MB1, MB2, TE and KB3a that

had similar flavonoid concentrations in the head and middle portions, implies that flavonoids are distributed in the tuber head and middle portions. Also, the underground tubers were higher than the bulbils in phenols, but the bulbils were higher in alkaloids, saponins and flavonoid contents (Naczk and Shahidi, 2006). Furthermore, the quantity of secondary metabolite compounds in a given species of plant material varies with a number of factors such as cultivar, environmental conditions, cultural practices, postharvest practices, processing conditions and storage (Naczk and Shahidi, 2006).

The finding that KB1, MB1, MB2 and KEa had significantly lower flavonoid concentration in field grown accessions than the control, is a pointer that full light reduces flavonoid concentration in yam. In spite of the significantly higher concentration of flavonoids in some *D. schimperiana*, *D. quartiniana* (KEb) and *D. bulbifera* (KUb) accessions, they were within the allowable limits for consumption hence may not affect their use for food. The presence of flavonoids in high concentration in some wild yam accessions is comparable to the results reported by Lawal *et al.,* (2014) on the presence of flavonoids in maize chaff, bean coat and yam peel. Additionally, results were consistent with research findings by Okoroafor and Iborida, (2017) on *D. rotundata*, *D. cayenensis* and *D. dumetorum* which ranged between 4.21 - 15.69 mg/5g. Harbone, (1998) reported higher concentration of flavonoid in both yellow and bitter yam (trifoliate yam) and that flavonoid constitutes 50 % of all known phenolic compounds. Flavonoids are the most diversified groups of phenolic compounds found in plants (Lawal *et al*., 2014). The results indicate the ability of the wild and cultivated yam species to play an important role in preventing disorders associated with oxidative stress. The functions of flavonoids

include antioxidant, protection against allergies, inflammation, free radicals, platelet aggregation, microbes, ulcers, hepatoxins, viruses and tumors (Trease and Evans, 2002; Okwu and Ndu, 2004). Additionally, Chandrasekara and Kumar, (2016) pointed out that phenols in yam tubers render several health benefits including antibacterial, anti-inflammatory and antimutagenic activities. Therefore, the considerable amounts of flavonoids in the yam accessions indicates the potential pharmacological properties embedded in their tubers.

The presence of tannins in amounts ranging from 1.35±0.33 to 127.22±11.30 mg/100 g and 1.54±0.37 and 8.08±0.06 mg/100 g in nethouse and field grown wild yam respectively, indicates the ability of wild yam accessions to synthesize tannins in their tubers. The significantly higher concentration of tannins in *D. bulbifera* (KUb) underground tubers and bulbils in nethouse plants, suggest that it was more efficient in tannin production compared to *D. alata* (MN) and *D. schimperiana* accessions. The nethouse tannin results indicated that *D. schimperiana* accessions, KB1, MB1, MB2, KB3a, KEa, TE, KUa, CNa, NK and LKa had similar tannin content in their tuber head and middle portions. Also, the tannin contents of the *D. schimperiana* accessions were similar to that of *D. quartiniana* (KEb) and the *D. alata* (MN and MT). However, in field grown accessions, the significantly higher tannin content in KEa and CNa tuber head portions relative to the control and the other accessions, is a signal that some accessions of the same species could form and store more tannins in their tuber head than middle portions.

Furthermore, the tannin results were closely similar to the results reported by Mulualem *et al.,* (2018) on yam landraces from Southwest Ethiopia, which ranged from 19.80 to 181.0 mg/100g with a mean value of 64.67 mg/100g. The results are also closely similar to the reported value for *Dioscorea rotundata* (20 mg/100 g), and tannin concentration in cultivated yams that ranged from 4.40 mg/100g for *D. cayenensis* (Pure yellow flesh) to 13.20 mg/100g for *D. alata* reported by Polycarp *et al.,* (2012). The findings are relatively similar to those of 20-255 mg/100g reported on various under-utilized yam tubers (Arinathan *et al*., 2009). Comparatively, the results of yam accessions were lower than reported values of tannins in *Dioscorea alata* that ranged from 46.5 to 180.25 mg/100g (Udensi *et al*., 2010). The levels of tannin in all yam accessions are comparable with the 9.0±0.17 g/100g reported for Bael pulp (Uttara *et al*., 2012). The yam accession tannin results were consistent with those reported by Okoroafor and Iborida, (2017), which ranged between 0.0 - 0.02mg/5g of *D. rotundata, D. cayenensis* and *D. dumetorum.* This agrees with report of Arogba, (2008), that the more coloured or pigmented a variety, the higher the tannin content.

Production and accumulation of tannins, is one of the major mechanisms by which plants defend themselves against attacks by insects (Arogba, 2008). The low tannin contents in the yam accessions could be attributed to the high protein contents reported earlier in the yam tubers, which might have formed protein-tannin complexes leading to low concentration of tannins. Tannins have been reported to form complexes with proteins and reduce their digestibility and palatability (Shajeela *et al*., 2011). However, their contents in foods are known to reduce through cooking or heat treatment, which make the

protein available (Lewu *et al*., 2010; Osagie, 1992). Tannin is non-toxic but can generate physiological responses in animals that consume them (Shajeela *et al*., 2011). Tannins have antimicrobial properties and their mode of antimicrobial activities in plants include their ability to inactivate microbial adhesions, enzymes and membrane transport proteins (Omojate *et al*., 2014). Karou *et al*., (2007) also stated that many physiological activities such as stimulation of phagocytic cells and wide range of anti-infective actions in plants have been attributed to tannins because of their molecular action of forming complexes with proteins (Karou *et al*., 2007). Tannins inhibit the growth of insect and disrupt the digestive activities in ruminant animals (Karou *et al*., 2007). The presence of tannin in the extract of *D. bulbifera* is of health benefit, following the report of (Cowan, 1999) that advocated that the consumption of tannin containing beverages especially green tea and red wine, can prevent or cure a variety of illness. Tannins play major roles as antifungal, antidiarrhoeal, antioxidant and antihemorrhoidal agents (Adeosun *et al*., 2016). The presence of tannins in the yam accessions are all indicative of the antimicrobial efficacy of the extracts of their tubers against pathogenic microbes and foraging macrobes.

The levels of saponins in net-house and field grown yams are within the saponin range obtained by Mulualem *et al*. (2018). The saponin results were consistent with results reported by Okoroafor and Iborida, (2017), and Princewill and Ibeji, (2015). The significantly higher saponin content in both underground and bulbils compared to the other accessions, is consistent with the research report by Adeosun *et al*., 2016; Eleazu *et al*., 2013). Furthermore, the higher concentration of saponin in middle portion of some are similar to the findings of Eleazu *et al*., 2013). Moreover, the male line of the yam

contains less diosgenin than the female line, which could explain the significantly lower concentrations of saponin among *D. schimperiana* accessions.

Saponins and flavonoids are factors of resistance or antifeeding to insect feeding on plants (Okoroafor and Iborida, 2017). Thus, saponin and flavonoid constitute the major ingredient of resistance of *Dioscorea dumetorum* and *Dioscorea cayenensis* to *Heteroligus meles* (Okoroafor and Iborida, 2017). Saponin has been reported to have anti-inflammatory, cardiac depressant and hyper-cholesterolemic effect (Okwu and Ndu, 2006). Saponin and steroid also have relationships with sex hormones like oxytocin which regulate the onset of labour in pregnant women and subsequent release of milk (Okwu and Ndu, 2006). This could justify the use of some wild yam species in the treatment of male and female sterility by some communities in Kenya, as indicated in this present study. Diosgenin, the aglycone part of the steroidal saponin extracted from yam, is used as precursor for the synthesis of hormones and corticosteroids which improve fertility in males (Okwu and Ndu, 2006), or simply, a principal raw material for the industrial production of steroidal drugs (Huang *et al*., 2012). Phytosterols are also useful in the pharmaceutical industry as a natural source of steroidal hormones (Prohp and Onoagbe, 2012). Diosgenin and phytosterols have been reported to exhibit hypocholesterolemic activity (Prohp and Onoagbe, 2012), through increasing biliary secretion and fecal excretion of cholesterol and decrease glucose and cholesterol absorption and liver cholesterol level (Prohp and Onoagbe, 2012; Esenwah and Ikenebomeh, 2008).

According to recent findings steroidal saponins could be a novel class of prebiotics to lactic acid bacteria and are effective in treating fungal and yeast infections in humans and animals (Huang *et al*., 2012). Some saponins like diosgenyl exert a large amount of biological functions, such as antifungal, anti-bacterial and anticancer activities. Saponins have also been reported to possess the properties of precipitating and coagulating red blood cells (Okwu and Ndu, 2006). Therefore, in medicine, *D. bulbifera* can be applied as antibleeding agent to arrest loss of blood in case of injuries Adeosun *et al*., 2016). The presence of saponins in the yams suggests that the tubers may have hypocholesterolenic effect, anticancer, antifungal, antibacterial, antibleeding activities, and useful to expectant and lactating animals and those that deliver without the expulsion of their placenta, and improves fertility in males.

The amounts of most of the secondary metabolites assessed are comparable to those documented in the literature for common edible yam species, thus the tubers of the wild yam species are good food sources. Although secondary metabolites in high concentrations especially tannins can inhibit bioavailability of nutrients and affect digestibility and palatability of foods, they can also enhance their potential for pharmacological properties (Kayode *et al.,* 2017). Generally, food rich in potentially beneficial phytochemicals are acclaimed to promote overall health and prevent disease (Okoroafor and Iborida, (2017; Adeosun *et al*., 2016). Hence, the presence of phytochemicals in the tubers of the *D. schimperiana*, *D. bulbifera*, *D. quartiniana, D. alata* is an indicator of their food and medicinal value.

5.7 The Mineral Element Composition of Wild and Cultivated Yam Tubers

The study reveals presence of major mineral (P, K, Na, Ca and Mg) and trace (Zn and Fe) elements in appreciable quantities in wild yam tubers. The mineral composition of the yam accessions were similar to findings reported in literature. The Na contents of the yam accessions were very similar to 0.14±0.10 - 0.24±0.10 mg/100g for *D. dumetorum, D. cayenensis, D. alata, D. rotundata* and *D. bulbifera* documented by Okwu and Ndu, (2006). The Na levels were slightly higher than 0.25, 0.33, 0.39 mg/100g reported for *D. rotundata, D. cayenensis* and *D. dumetorum* respectively (Okoroafor and Iborida, (2017).

The K contents of the yam accessions were significantly higher than 0.39±0.10 to 1.00±0.11 mg/100g reported for *D. dumetorum, D. cayenensis, D. alata, D. rotundata* and *D. bulbifera* by Okwu and Ndu, (2006). However, the results were similar with 145.33 ± 1.15 mg/100g and 104.00 ± 2.00 mg/100g for okpura and ighobe wild yams reported by Afiukwa *et al.*, (2012).

The Ca contents of the yam accessions were comparable to the results reported by Okwu and Ndu, (2006) for *D. dumetorum, D. cayenensis, D. alata, D. rotundata* and *D. bulbifera* which ranged from 1.20±0.10 to 2.00±0.10. They were also similar to 1.3 mg/100g, 1.70 mg/100g, 1.92 mg/100g for *D. rotundata, D. cayenensis* and *D. dumetorum* respectively (Okoroafor and Iborida, 2017). The body uses 99% of calcium for building strong healthy bones, blood clotting, and contributes to normal brain function (Afiukwa *et al*., 2012).

Mg contents of the yam accessions were slightly lower than 0.49±0.11 to 0.85±0.10 reported by Okwu and Ndu, (2006) for *D. dumetorum, D. cayenensis, D. alata*, *D. rotundata* and *D. bulbifera,* and 0.93 - 0.96 mg/100g for *D. rotundata, D. cayenensis* and *D. dumetorum* reported by Okoroafor and Iborida, (2017).

The P contents of the yam accessions were similar to results obtained by Okwu and Ndu, (2006) which ranged from 0.16±0.11 to 0.28±0.10 mg/100g for *D. alata*, 0.29±0.20 mg/100g (*D. cayanensis*), 0.36±0,10 mg/100g (*D. bulbifera*), 0.17±0.21 to 0.20±0.10 mg/100g (*D. rotundata*) and 0.26 mg/100g (*D. dumetorum*). Also, the results were closely similar to 0.21 mg/100g, 0.39 mg/100g, 0.30 mg/100g for *D. rotundata*, *D. cayenensis* and *D. dumetorum* respectively reported by Okoroafor and Iborida, (2017).

The Fe contents of the yam accessions were significantly higher than 0.55 mg/100g, 0.58 mg/100g, 0.64 mg/100g for *D. rotundata*, *D. cayenensis* and *D. dumetorum* respectively reported by Okoroafor and Iborida, (2017). However, the Fe results were within 2.00±0.005-1.61±0.032 mg/100g of underground and aerial tubers of *D. bulbifera* documented by Afiukwa and igwe, (2015).

The Zn contents of the yam accessions were similar to 0.17±0.013 mg/100g reported for aerial tubers but lower than 0.36±0.016 mg/100g for underground tubers of *D. bulbifera* documented by Afiukwa and igwe, (2015). The results were also lower than 0.22 mg/100g, 0.26 mg/100g, 0.28 mg/100g for *D. rotundata, D. cayenensis and D. dumetorum* respectively (Okoroafor and Iborida, (2017), 0.26 ± 0.00 and 0.25 ± 0.00 mg/100g for Okpura and Ighobe wild yams reported by Afiukwa *et al*., (2012).

The variations observed in mineral compositions of the yams could be attributed to genetic factors, geographical variations in soil composition of the minerals, efficiency of mineral uptake, and the analytical procedure employed (Afiukwa *et al*., (2012). The contents of the trace elements, Zn (0.25 - 0.26) and Fe in the yam accessions, are within permissible limits set by FAO/WHO, (1984), which is 27.4 ppm for Zn in edible plants. The low concentrations of the trace elements in these wild yam species indicate their food safety (Saupi *et al*., 2009).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Wild yam species; *D. schimperiana* Kunth., *D. bulbifera* var. *bulbifera*, *D. quartiniana* var. *quartiniana* and *D. dumetorum* (Kunth) Pax and, two cultivated species, *D. alata* and *D. bulbifera* var. *anthropophagorum* occur in Kenya. Among the four wild yam species, *D. bulbifera* var. *bulbifera* has not been previously reported in Kenya. *Dioscorea schimperiana* and *D. bulbifera* had variants that could be new sub-species/varieties. *Dioscorea schimperiana* and *D. quartiniana* var. *quartiniana* were the most widely distributed wild yam species, while *D. dumetorum* the least distributed in Kenya.

2. The wild types, *D. schimperiana, D. bulbifera and D. dumetorum* tubers have been harvested for famine food by several communities in Kenya. *Dioscorea quartiniana* has non-edible tubers that are regarded poisonous. *Dioscorea schimperiana* and *D. quartiniana* herbal preparations are used against sterility, diabetes, pain and gonorrhoea and, wound dressing and healing. Only a few (< 30%) members of the community, particularly the elderly, in the selected localities are knowledgeable of identity and use of wild yam.

3. The *in situ* rhizosphere soils of *D. schimperiana, D. bulbifera* and *D. alata* had moderately to mildly acidic, mildly acidic, mildly and strongly acidic rhizosphere

soils respectively. *D. schimperiana* and *D. bulbifera* rhizosphere soils had significantly higher Olsen P, N and carbon relative to *D. alata*.

4. Wild yams exhibited healthy growth and production of sizeable tubers under domestication. *Dioscorea schimperiana* (KEa, CNa, TE, MB1) and *D. bulbifera* var. *bulbifera* (KUb) performed well.
5. *Dioscorea schimperiana, D. bulbifera* var. *bulbifera* and *D. alata* tubers contain high amounts of protein, lipid and carbohydrates. *Dioscorea schimperiana* (MB1) and *D. bulbifera* (KUb) had the highest lipid content.
6. *Dioscorea schimperiana*, *D. bulbifera* var. *bulbifera*, *D. quartiniana* var. *quartiniana* and *D. alata* contain high levels of alkaloids, tannins, flavonoids and saponins. Tuber head portion had significantly higher levels of the secondary metabolites than middle sections in most of the accessions of *D. schimperiana.* The secondary metabolites levels in most of the wild yam accessions were similar with levels in cultivated species and were within the allowable limits for food quality and safety.
7. The wild yam tubers had significantly high levels of P, Na, K, Ca, Mg, Fe and Zn comparable to the cultivated yam cultivars. All the accessions had the highest potassium levels compared to the other mineral elements.

6.2 Recommendations

1. *Dioscorea schimperiana* and *D. bulbifera* comprised of morphotypes that conclusively could not be classified using the existing Keys and morphological characterization. Hence, there is the need for molecular characterization.

2. *Dioscorea schimperiana*, *D. bulbifera* and *D. dumetorum* that were used for food and had high levels of nutrients and mineral elements, are recommended as functional food for enhancing food and nutritional security.
3. Wild yam could be cultivated to improve food security in Baringo and Uasin Gishu counties. More research is needed to assess the production of the cultivated *D. bulbifera* and *D. alata* in Baringo and Uasin Gishu counties.

4. Wild yam accessions from this study should be tested for antimicrobial properties and toxicity levels as potential sources of alternative medicine.

Wild yam accessions MB1, KEb, MB2 and MN that have high lipid levels can be further assessed for the fatty acid composition.

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APPENDICES

Appendix I. Table showing morphological characteristics used to describe the Kenyan yam accessions

Morphological characters (General)	**Specific characters**	**Modalities**
Colour	Stem base colour	1-Green; 2-Purplish green; 3-Brownish green; 4-Dark brown; 5-Purple; 99-Other (Pink)
	Above base colour	1 Green; 3 Purplish green; 4 Brownish green; 5 Dark brown; 6 Purple; 99 Others (Pink)
	Petiole (Leaf base) colour	1 All green with purple base; 2 All green with purple leaf junction; 3 All green with purple at both ends; 4 All purplish-green with purple base; 5 All purplish-green with purple leaf junction; 6 All purplish-green with purple at both ends; 7 Green; 8 Purple; 9 Brownish green; 10 Brown; 11 Dark brown; 99 Other (All green with pink leaf junction)
	Leaf blade colour(above base)	1 Yellowish; 2 Pale green; 3 Dark green; 4 Purplish green; 5 Purple; 6. Dark green; 99 Other
	Peduncle colour (base)	1 Green; 2 Pale green; 3 Yellow; 4 Grey; 5 Dark brown
	Floret colour	1 Purplish; 2 White; 3 Yellowish 4. pink
	Skin colour at head of bulbil	1 Greyish; 2 Light brown; 3 Dark brown; 99 Other (Dark purple; Golden brown)
	Skin colour at lower part of bulbil	1 Greyish; 2 Light brown; 3 Dark brown; 99 Other (Dark purple; Golden brown)
	Flesh colour of bulbil	1 White; 2 Yellowish white/off-white; 3 Yellow; 4 Orange; 5 Light purple; 6 Purple; 7 Purple with white; 8 White with purple; 9 Outer purple/inner yellowish; 99 Other

Appendix I. continued

	Skin colour at underground tuber head	1 White; 2 Yellowish white/off-white; 3 Yellow; 4 Orange; 5 Light purple; 6 Purple; 7 Purple with white; 8 White with purple; 9 Outer purple/inner yellowish; 99 Other
	Skin colour at underground tuber lower part	1 White; 2 Yellowish white/off-white; 3 Yellow; 4 Orange; 5 Light purple; 6 Purple; 7 Purple with white; 8 White with purple; 9 Outer purple/inner yellowish; 99 Other
	Tuber flesh color (Upper part)	1 White; 2 Yellowish white/off-white; 3 Yellow; 4 Orange; 5 Light purple; 6 Purple; 7 Purple with white; 8 White with purple; 9 Outer purple/inner yellowish; 99 Other (Red)
Hairiness	Absence/presence of hairs on stem, leaf, flower and tubers	0 Absent; 1 Present
	Hairiness of stem, leaf petiole, leaf blade (upper), peduncle, florets and tubers	3 Sparse; 7 Dense
Prickles	Absence/presence of prickles on stem, stem base, on stem above base, leaf petiole, leaf lamina (upper), peduncle, florets and tubers	0 Absent; 1 Present
	Prickles distribution on stem base, stem above base, leaf petiole, leaf lamina (upper), peduncle, florets and tubers	0 Absent; 1 Few; 2 Many
Plant organ type	Stem type	1 Dwarf; 2 Shrub-like; 3 Climbing
	Leaf type	1 Simple; 2 Compound
	Inflorescence type	1 Spike; 2 Raceme; 3 Panicle
	Tuber type	1 Underground; 2 Rhizome; 3 Aerial
Growth habit	Stem twining	0 No; 1 Yes
	Leaf growth habit	1 Erect; 2 Horizontal; 3 Prostrate

Appendix I. continued

	Floret habit	1 Erect; 2 Horizontal; 3 Nodding; 4 Pendent
	Tuber	1Deeply buried 2 Shallowly buried
	Bulbil	1Aerial, facing downwards 2 Aerial, facing upwards
Twining	Twining direction	1 Clockwise (climbing to the Left); 2 Anti-clockwise (climbing to the right); 99 Others
Shape	Stem shape	1 Square; 2 Quadrangular; Octagonal; 4; Round; 99 Other (angular)
	Leaf shape	1 Ovate; 2 Cordate; 3 Cordate long; 4 Cordate broad; 5 Sagittate long; 6 Sagittate broad; 7 Hastate; 8 Other
	Peduncle shape	1 Square; 2 Quadrangular; Octagonal; 4; Round; 99 Other (angular)
	Tuber shape	1 Round; 2 Oval; 3 Oval-oblong; 4 Cylindrical; 5 Flattened; 6 Irregular; 99 Other
	Aerial tuber shape	1 Round; 2 Oval; 3 Irregular; 4 Elongate
Stipules	Absence/presence of stipules	0 Absent; 1 Present
Organ arrangement	Leaf arrangement on stem	1 Alternate; 2 Opposite; 3 Alternate at base/opposite above
	Floret arrangement on peduncle	1 Acropetal 2 Centripetal; 3 Other
	Bulbil arrangement on stem	1 Alternate; 2 Opposite; 3 Alternate at base/opposite above
Surface Texture	Stem surface Texture	1 Smooth; 2 Rough
	Leaf surface Texture	1 Smooth 2 Rough
	Peduncle surface Texture	1 Smooth 2 Rough
	Tuber surface Texture	1 Smooth; 2 Wrinkled; 3 Rough
Physiological character	**Yam organ**	**Modalities**
Growth (Life) cycle	Growth cycle of stem, leaves, flowers and tubers	1 Annual; 2 Perennial
Flesh colour after oxidation	Tuber flesh oxidation 5 minutes after cutting	0 No; 1 Yes
	Flesh colour after oxidation	1 Grey; 2 Purple; 3 Orange; 99 Other (Brown)

Descriptors adopted from IPGRI/IITA, (1997).

Appendix II. Questionnaire to collect information on yam in selected counties of Kenya

My name is Joseph Rotich Chemwetich, a D.Phil student in Plant Physiology at the University of Eldoret. Currently, I am undertaking a research for scholarly interest. I humbly request you to provide information as guided by this questionnaire. Your information will be treated with utmost confidentiality. Do not write your name anywhere in this questionnaire.

1. Personal data
    a. By ticking the appropriate answer, kindly indicate your age.

        41-49 yrs ( ), above 50 yrs ( )

    b. Give the name of your;

        Village ……

        Sub-location……..

        Ward…….

        County……...

        Ethnic group……..

    c. Indicate your gender; Male ( ), Female ( ).

2. Information about yam
    a. Do you know yam? Yes ( ) No ( ).
    b. Is yam similar or it is this specimen? (Life yam specimens and/or photographs).
    c. Where in your locality is yam found? .....
    d. What is the name of yam in your language/dialect?

Species	**Whole plant**	**Tuber**	**Bulbil**
D.schimperiana Kunth.			
D. bulbifera			
D. alata			
D. quartiniana A. Rich			
D. dumetorum			
Others ……			

e. Have you ever eaten or used yam? Yes ( ) No ( ).

f. From your experience, what are the local uses of yam?

Species	**Organ used**	**Local uses**
D. bulbifera		
D. alata		
D. quartiniana		
Others		

g. Is yam cultivated in you locality? Yes ( ) No ( ).

If No, why is it not cultivated? …….

h. From your experience and to the best of your knowledge, is the local yam native or exotic? .....

Appendix III. Analysed data for PCA

a. Eigen values and variance

PC	Eigenvalue	% Variance
1	17.6375	88.306
2	1.36807	6.8495
3	0.532866	2.6679
4	0.25671	1.2853
5	0.0615821	0.30832
6	0.0494916	0.24779
7	0.0384201	0.19236
8	0.0135069	0.067625
9	0.00809468	0.040528
10	0.00371461	0.018598
11	0.002395	0.011991
12	0.00054866	0.002747
13	0.00011892	0.00059538
14	8.05E-05	0.00040297
15	4.91E-05	0.00024585
16	2.96E-30	1.48E-29
17	2.16E-33	1.08E-32
18	1.55E-34	7.78E-34

b. Factor loadings

Character	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
Base colour	0.506	0.773	-0.166	-0.286	0.016	-0.168	-0.052	0.059
Above base colour	0.856	-0.477	0.114	0.094	0.023	0.104	0.019	-0.012
Hairs	0.004	0.136	0.105	0.173	0.139	0.234	-0.106	-0.112
Hairiness	0.009	0.274	0.201	0.341	0.245	0.469	-0.209	-0.212
Base prickles	-0.025	0.088	0.030	-0.012	0.288	0.224	0.712	0.151
Above base prickles	0.007	0.006	-0.090	-0.142	0.185	0.313	0.339	0.307
Plant Type	0.036	0.120	0.250	0.087	-0.719	0.056	0.362	0.066
Surface Texture	0.023	0.134	0.218	0.225	-0.035	0.218	0.030	0.039
Growth habit	0.001	0.116	0.171	0.144	-0.407	0.278	-0.237	0.300
Twining direction	0.021	0.025	-0.009	0.003	-0.027	0.045	0.082	-0.294
Arrangement	0.053	0.056	0.150	0.199	0.144	-0.216	-0.011	0.144
Shape	-0.056	-0.035	0.752	-0.634	0.124	0.022	-0.090	-0.064
Growth cycle	-0.004	0.031	0.218	0.262	0.271	-0.176	-0.164	0.584
Stipules	-0.003	-0.053	0.019	-0.014	-0.013	-0.132	-0.004	0.244
Flesh colour (upper)	0.020	0.108	0.232	0.272	0.071	-0.300	0.175	-0.252
Flesh colour (lower)	-0.020	0.046	0.162	0.162	0.016	-0.319	0.076	0.103
Colour change after dissecting	-0.002	0.020	0.167	0.163	0.005	-0.336	0.169	-0.046
Flesh colour 5 mins after dissecting	0.039	0.069	0.125	0.164	0.057	-0.092	0.155	-0.371

Appendix IV: Similarity Report

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Certificate of Plagiarism Check for Synopsis

Author Name	Joseph Rotich Chemwetich SC/D.PHIL/B/02/11
Course of Study	Type here...
Name of Guide	Type here...
Department	Type here...
Acceptable Maximum Limit	Type here...
Submitted By	titustoo@uoeld.ac.ke
Paper Title	CHARACTERIZATION AND DOMESTICATION POTENTIAL OF WILD YAM IN KENYA
Similarity	10%
Paper ID	986395
Submission Date	2023-09-27 15:18:26

Signature of Student

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