Ethnobotanical survey of medicinal plants used for the treatment of diabetes in Uganda

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Ethnobotany Research and Applications 26:56 (2023) - http://dx.doi.org/10.32859/era.26.56.1-14
Manuscript received: 30/08/2023 – Revised manuscript received: 20/10/2023 - Published: 24/10/2023

Research

Abstract

Background: Type 2 Diabetes Mellitus (DM) is increasingly becoming a global health problem. In Uganda, DM prevalence rate has more than doubled in the last decade. Although management options for DM are various including conventional medicine, physical exercise and diet, use of traditional medicine has increasingly gained traction. However, there is little information about the medicinal plants used for managing DM in Uganda and it is against this background that this study was conducted.

Methods: An ethnobotanical survey was conducted in the four regions of Uganda represented by 24 districts. Information was collected from 197 traditional medical practitioners (TMPs) who were selected using purposive and snowball sampling techniques and interviewed using semi-structured questionnaires. Data was presented using descriptive statistics and quantitatively analysed using the use value (UV) and ANOVA and principal component analysis.

Results: A total 71 medicinal plant species belonging to 44 families were mentioned by the TMPs as being used in the management of DM. The Fabaceae and Moraceae accounted for the highest number of plant species. Although woody and wildly occurring plants accounted for the highest number of plants listed in the management of diabetes, the most frequently used plants were herbaceous and domesticated plant species. An indication that TMPs frequently use plants that are available and easy to access. There was high similarity in the plant species mentioned by TMPs in the Eastern-Northern regions and those in the Central-Western regions and this is perhaps due to the similarities in climatic and ethnic factors experienced by these regions.

Conclusion: This study contributes to the wealth of knowledge on medicinal plants used to manage DM in the world. It underscores the significance of plant species towards human health and ultimately the need to conserve them. Further research should be carried out to validate the antidiabetic potential of the mentioned medicinal plant species in this study.

Keywords: Type 2 Diabetes mellitus, Traditional Health Practitioners, Medicinal plants, Uganda.

Background

Diabetes mellitus type II (DM) is a chronic metabolic disorder marked by abnormalities in lipid, carbohydrate and protein metabolism. The global prevalence of DM has significantly reached epidemic levels, especially in low and middle income countries (IDF 2021). DM is a major contributor to the very large rise in the rate of non-communicable diseases affecting developed as well as developing nations (Boutayeb *et al*., 2010). The rapid increase in diabetic cases in developing countries has largely been attributed to the epidemiological transition, demographic and nutrition changes (Jakovljevic & Getzen 2016; Kengne *et al*. 2013). DM is characterized by an array of dysfunctions including hyperglycemia resulting from the combination of resistance to insulin action, inadequate insulin secretion, and excessive or inappropriate glucagon secretion (American Diabetes Association 2009).

Due to its chronic nature, DM requires long-term medical attention to limit the development of its devastating complications and to manage them when they do occur. Since DM is considered to be one of the most psychologically and behaviorally demanding of the chronic diseases, it requires frequent self-monitoring of blood glucose, dietary modifications, exercise, and administration of medication on schedule (Ciechanowski *et al*. 2001; Melikian *et al.* 2002). DM is unique due to its cross-cutting nature, impacting multiple organ systems and increasing the risk for other communicable and non-communicable diseases. Hence, DM presents serious health and economic issues for most sub-saharan African countries if it is not promptly managed.

The prevalence of DM has risen significantly globally but more so in sub-saharan Africa. As a matter of fact, sub-saharan Africa is the only region in the world where the number of adults with diabetes is expected to increase by more than 100% (134%) by 2045, the rest of the world is less than 100% (IDF 2021). In Uganda specifically, the number of people with DM more than doubled in a span of 10 years, having risen from 307,900 in 2011 to 716,000 in 2021 and it accounted for 1,057 and 10,416 deaths in 2011 and 2021 respectively (IDF 2021). Relatedly, the cost of managing DM per person per annum in Uganda has increased three-fold in the last ten years, i.e., from 80 USD in 2011 to 227.4 USD in 2021 (IDF 2021). These statistics suggest that DM presents a growing health burden in Uganda which requires integrated management approaches.

Diabetes is managed using several approaches ranging from conventional to traditional methods and these are geared towards keeping blood glucose levels within normal limits. Most conventional antidiabetic drugs are in form of insulin and antihyperglyceamic agents (Feingold 200). However, these conventional drugs are expensive and often unavailable in most developing countries including Uganda (Kibirige *et al.* 2017; Mendis 2007; Obakiro *et al.* 2021), besides being associated with adverse side effects (Sinha *et al.* 1996). Furthermore, despite the improvement in the conventional diabetic drugs overtime, the newer ones are not without side effects including hepatocellular injury, exacerbation of renal diseases, blood dyscrasias, gastrointestinal irregularities, hypoglycemias, hypersensitivity reactions, weight gains, and lactic acidosis (Chaudhury et al., 2017).

The challenges associated with conventional antidiabetic drugs are partly responsible for the increased use of complementary and alternative medicine including herbal drugs. The high patronage of herbal medicine is also due to a combination of factors including confirmed therapeutic evidence of the herbal remedies as well as the belief that natural products pose no health risk (Nyeko *et al.* 2016; Skalli & Jordan 2017; van Andel & Carvalheiro 2013). This has resulted in wide socio-cultural acceptance of herbal drugs.

The relevance of botanical sources for managing diabetes is seen by evidence from several studies that have deliberately profiled the different plant species used traditionally in DM management, e.g. (Amuri *et al.* 2018; Bading Taika *et al.* 2018; Chege *et al*. 2015; Diallo *et al.* 2012; Ezuruike & Prieto 2014; Farzaei *et al.* 2015; Katemo *et al.* 2012; Salihu Shinkafi *et al.* 2015; Ssenyange *et al.* 2015; Telli *et al*. 2016). Despite the growing significance of DM to Uganda's populace and the healthy economy, a few studies have profiled alternative DM approaches, particularly plant species used in managing DM: Rutebemberwa *et al.* (2013) in Bugiri District and Ssenyange *et al.* (2015) in Central Uganda. Yet, effective management of any disease and improved patient outcomes requires integration management of both conventional and traditional measures (Ampomah 2022; WHO 2018). Moreover, profiling of traditionally used medicinal plant species is a crucial step in identification of new chemical entities for various diseases. For example, the main antidiabetic drug metformin is originally from *Galega officinalis* Linn which was herbal drug for diabetes in medieval Europe (Bailey & Day 2004).

Uganda has high floral diversity due to geographical and climatic variations and this diversity varies according to ethnicities. Uganda has a rich plant diversity with about 5406 native vascular plant species so far known to exist (Davis *et al.* 1994). Relatedly, there is rich diversity of traditional medical practices as well as medicinal plants across the country as evidenced

from previous studies (Asiimwe *et al.* 2021; Kakudidi *et al.* 2016; Lamorde *et al.* 2010; Namukobe *et al.* 2011; Tabuti *et al.* 2010; Tugume *et al.* 2016). As such, in order to get a clear picture of plant species used in the management of DM in Uganda, one has to atleast consider the different ethnic groups or agroecological zones. Additionally, profiling of medicinal plants which are used for managing diabetes highlights the importance of these plants and eventually raises their conservation value. This is important in the face of increased landuse changes and habitat loss that put some of the wild plants at risk of extinction. Therefore, the aim of this study was to document medicinal plants used for the management of DM in the major ethnic regions of Uganda with the purpose of justifying the need for their conservation. We hypothesized that there will be variation in the plant species used by TMPs to manage diabetes due to variations in floral diversity and culture in the four main regions of Uganda.

Materials and Methods

Study area

This study was done in 24 districts representing the four main regions (Central, Western, Eastern and Northern) in Uganda which are generally clustered by similarities in culture and climatic conditions (Figure 1). The central region has the highest human population, followed by the Eastern followed by the Western and lastly the Northern region. The central region is more urbanized while rapid urbanization has been reported in the Northern and Western regions (Tumwesigye *et al.* 2023). Uganda is a multilingual, culturally diverse country (Kabananukye & Kwagala 2007; Otiso 2006) with significant climatic, geological and altitudinal variations from north to the south and from the west to the east (Groves 1934; Hamilton 1975). Relatedly, the country has high vegetational diversity and variations in utilization of this vegetation (Davis *et al.* 1994; Keay *et al.* 1965). The vegetation in Uganda is broadly classified as heath and moor land, forest, forest-savanna mosaic, thicket, woodland, savanna, steppe, bushland, swamps, and post-cultivation communities (Langdale-Brown *et al.* 1964). Uganda's vegetation varies according to the geology and soils, climate, altitude, fire, and human influences (Kalema & Bukenya-Ziraba 2005). Uganda is largely an agrarian country where about 80% of the population derive their livelihoods from natural resources (Moyin *et al*. 2002; Shechambo *et al.* 2002). Plants are some of the natural resources that contribute significantly to people's livelihoods in Uganda by providing food, medicine, cultural functions, tourism etc.

Data collection

The survey was conducted from October 2019 to August 2020. With the help of local government officials in each district, we purposively identified the key respondents who were the traditional medical practitioners (TMPs). Using the snowball sampling technique, the first identified TMP then directed us to the next TMP who fit our selection criteria. For this study, a TMP was "a person who is recognized by the community as a herbalist who uses various plants to treat diseases and has been in the practice for more than five years". We targeted TMPs who were based in rural areas and those who were aged 20 years and above. The number of participants selected per district was based on their reputation and ability to display good knowledge about herbal medicine. Direct interviews using semi-structured questionnaires based on standard ethnobotanical methods (Shahabuddin *et al.* 2003) were conducted with traditional medical practitioners (TMPs) from selected districts representing different regions in Uganda (Figure 1). Voluntary verbal prior informed consent was sought from the TMPs before commencing the interview. Prior to the commencement of the interview, we also explained the purpose of the study to the respondent and assured him or her that the data collected would only be used for academic purpose.

For each respondent, we recorded personal demographic information on age, level of education, main source of income, how many years as a herbalist, origin of his knowledge as a herbalist. We further collected data on plants used in the treatment of DM i.e., name of the plant, the plant parts used, and whether the mentioned plant species is cultivated or not. Interviews were conducted in the local languages depending on the origin of the TMPs. Most TMPs mentioned the local names of the plant species, and these were interpreted by the local guides and cross checked by the botanist.

Plant identification and collection

Some of the plant species, especially the cultivated plants were easily identified by the TMP and the botanists. For plant species whose local names could not be easily understood by the survey team, the TMP moved with survey team to the field and with the help of the botanist, identified them or collected the samples for later identification. In addition to those plant species that could not be identified in the field, the NaFORRI botanist also collected voucher specimen for some of the plant species that were mentioned by TMPs for preservation. Plant species which could not be identified in the field were taken to the NaFORRI Herbarium for identification. Correctness of scientific names of species were also checked according to Tropicos: http://www.tropicos.org and the World Flora Online.

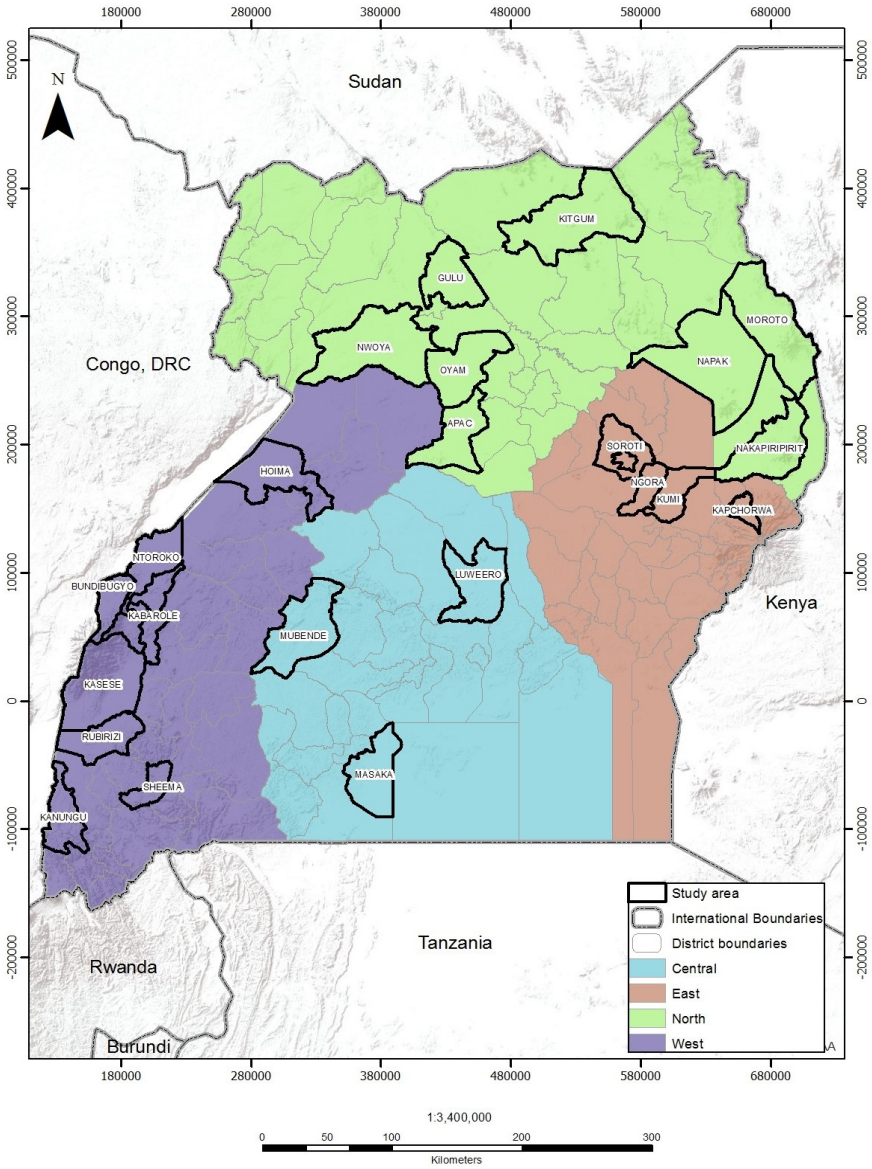

Figure 1. Map showing 24 districts representing the four regions of Uganda where the survey was conducted

Data analysis

The data obtained from the survey was entered into SPSS version.20. Data was summarized into percentages and proportions and presented using descriptive statistics. The relative importance of tree species mentioned by the TMPs was calculated using the use value (UV) (Phillips & Gentry 1993, Hoffman & Gallaher 2007) according to the formula:

$$UV = \Sigma U/n$$

where, UV is the use value of a species; ΣU the total number of mentions per species; n the number of respondents. The variation and comparisons of classifications of plant species were analysed using analysis of variance (ANOVA). Similarity or dissimilarity in the plant species mentioned by TMPs from different regions was examined using Principal Component Analysis (PCA) and the elbow method was used to determine the optimal number of clusters.

Results

TMPs Sociodemographics

A total of 197 TMPs including 55 women were interviewed after they consented. The age range of the TMPs was 30-75 years and majority had attained secondary education (47%), while 27% had attained tertiary education and 26% were primary level certified. The years of practice as herbalists ranged from 8-40 years. The main/primary source of income for most TMPs was

subsistence farming (68%) followed by small business such as retail shops (21%) and the rest were formally employed or retired public servants.

TMPs source of knowledge about herbal medicine for DM

Majority (84%) of TMPs claimed that they acquired the knowledge about herbal medicine by helping their grandparents, parents and close relatives. Only 1% mentioned that they had a good background in chemistry and ended up venturing in that field. Some of the TMPs (5%) mentioned tha they are guided by the spirit on which plants to select in case of any disease.

TMPs knowledge about DM and their mode of operation

With the exception of TMPs from Karamoja region (i.e., Napak, Moroto and Nakapiripirit) (12%), the rest of the respondents understood what DM was, and referred to it as "*sukali* or *cukali or sugar*". Table 1 shows the signs and symptoms used by TMPs to identify diabetic patients. TMPs cited 17 signs and symptoms and the signs that were cited by majority of the respondents across the different regions were: concentrated yellow urine, frequent urination, swelling of legs and slow healing of wounds (Figure 2).

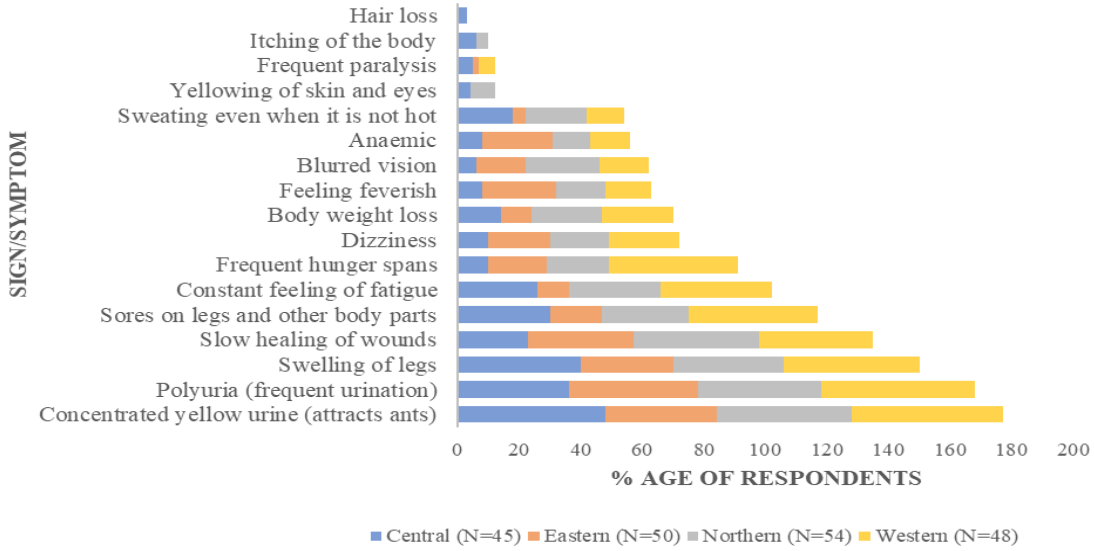

Figure 2. Signs and symptoms used to identify DM by TMPs from different regions of Uganda.

The mode of operation varied among TMPs, whereby some TMPs insisted that patients should present laboratory test results before they could start herbal medication (Figure 2). Other TMPs relied on signs and symptoms before starting to administer the herbal medication (Figure 2). Majority of the TMPs advised their patients to terminate the conventional drug before starting to use the herbal drug (Figure 3). Furthermore, some TMPs encouraged their patients to go for laboratory tests so as to ascertain whether the herbal drug is working or not.

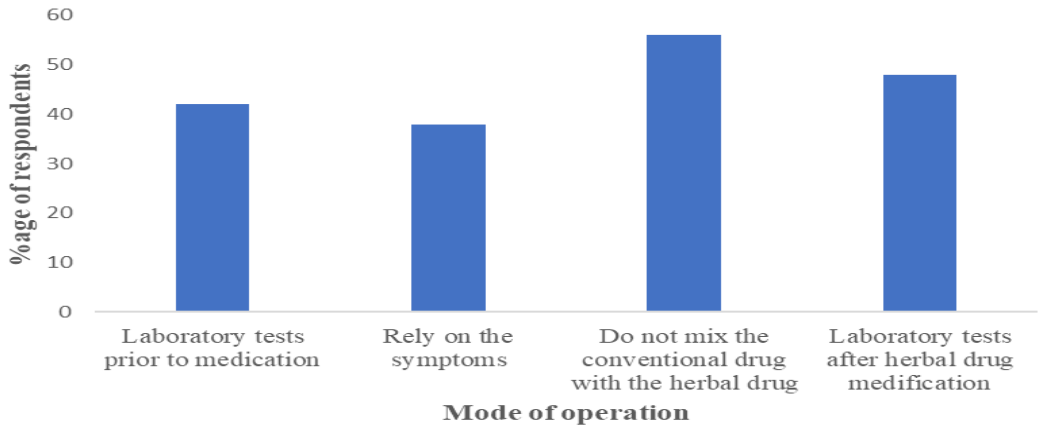

Figure 3. TMPs mode of operation while managing DM

Plant species used by TMPs for treating DM

The TMPs mentioned 71 plant species representing 44 families as being used in the management of DM (Table 1). The plant species mentioned in the four regions did not vary significantly ($p>0.05$). The family Fabaceae had the highest number of plant species (nine) followed by the Moraceae (five) and Bignoniaceae and Asteraceae (four). The rest of the families had less than four plant species.

There was high similarity in the plant species mentioned by TMPs in Eastern and Northern Uganda and then high similarity in the species mentioned by TMPs in Central and Western Uganda (Figure 4). There was high dissimilarity in plant species mentioned by TMPs as shown by the Eastern-Northern group and the Central-Western group (Figure 4.). Furthermore, the clusters attest to the similarity of plant species mentioned in the Central-Western group and those in the Eastern-Northern group.

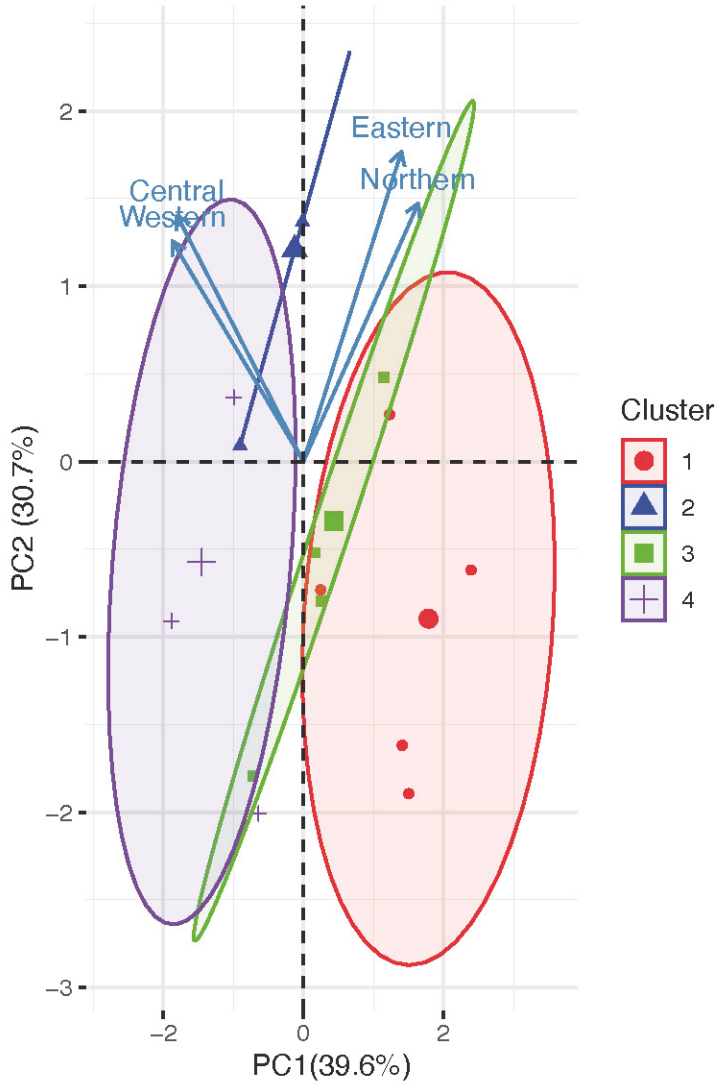

Figure 4. PCA plot showing clusters of plant species used by TMPs from different regions of Uganda

Plant parts used, growth forms and habitat

The various plant parts were used for managing DM, however leaves (34%) and stem bark (29%) were mostly used followed by fruits (12%), roots (12%) and seeds (10%) while flowers and bulbs accounted for the remaining 2%. There were several instances where more than one part of the same plant species was used (Table 1). Woody plants accounted for the highest proportion (76%) of plant species used to manage diabetes compared to herbaceous plants which accounted for 24%. However, herbaceous plants had higher UV (mean 0.44±0.19) indicating that they were mentioned by the highest number of informants compared to woody plants (mean 0.16±0.11) ($F_{1,69}=55.6$, $p=0.00$) (Table 1). The highest proportion of plant species used in management of diabetes are not cultivated (54%), followed by cultivated plants (34%) and lastly those which are both cultivated and wildly occurring (13%) (Table 1). However, the UV of cultivated plant species (0.29±0.2) was higher than that of wild plant species (0.19±0.15) ($F_{1,69}=7.4$, $p=0.008$).

Table 1. Medicinal plant species used to manage DM in selected district in Uganda

Family	Scientific name	Plant part used	Region*	Habitat	Plant form	Use Value	Voucher no.
Amaranthaceae	*Amaranthus viridis* L.	L	C, E, N, W	Both	Herb	0.69	NC
Amaryllidaceae	*Allium cepa* L.	Bulb	C, E, N, W	Cultivated	Herb	0.50	NC
Anacardiaceae	*Anacardium occidentale* L.	L, SB	E, N	Cultivated	Tree	0.15	NC

Family	Scientific name	Plant part used	Region*	Habitat	Plant form	Use Value	Voucher no.
Anacardiaceae	*Mangifera indica* L.	L, FR, SB	C, E, N, W	Cultivated	Tree	0.46	NC
Annonaceae	*Annona senegalensis* Pers.	L, SD, SB	N	Cultivated	Tree	0.22	BK0529
Annonaceae	*Annona muricata* L.	L, FR	C, E	Cultivated	Tree	0.23	NC
Annonaceae	*Monodora myristica* (Gaertn.) Dunal	FR, SD	C, W	Not cultivated	Tree	0.07	NC
Apocynaceae	*Carissa edulis* (Forssk.) Vahl	F, SB, RT	C, E, N	Not cultivated	Shrub	0.07	BK0527
Araliaceae	*Polyscias fulva* (Hiern) Harms	SB	C, W	Not cultivated	Tree	0.06	NC
Asclepiadaceae	*Mondia whitei* (Hook.f.) Skeels	SB	C, E, W	Not cultivated	Shrub	0.22	NC
Asphodelaceae	*Aloe vera*	L	C, E, N, W	Both	Herb	0.29	NC
Asteraceae	*Ageratum conyzoides* L.	L	C, N, W	Not cultivated	Herb	0.17	NC
Asteraceae	*Crassocephalum vitellinum (Benth.)* S. Moore	L, SB	C, N, W	Not cultivated	Herb	0.40	NC
Asteraceae	*Sonchus oleraceus* L.	L	C, W	Not cultivated	Herb	0.30	NC
Asteraceae	*Vernonia amygdalina* Delile	L	C, E, N, W	Not cultivated	Shrub	0.38	NC
Bignoniaceae	*Kigelia africana* Lam. Benth.	FR, RT	C, E, N	Not cultivated	Tree	0.30	BK0528
Bignoniaceae	*Markhamia lutea* (Benth.) K. Schum.	SB	C, E	Both	Tree	0.11	NC
Bignoniaceae	*Spathodea campanulata* P. Beauv.	SB	C, E, W	Not cultivated	Tree	0.17	NC
Bignoniaceae	*Stereospermum kunthianum* Cham.	SB	E, N, W	Not cultivated	Tree	0.15	BK0533
Burseraceae	*Canarium schweinfurthii* Engl.	L, SB	C, E, W	Cultivated	Tree	0.06	NC
Canellaceae	*Warburgia ugandensis* Sprague	L	C, W	Both	Tree	0.37	NC
Cannabaceae	*Trema orientalis* L. Blume	SB	E	Not cultivated	Tree	0.08	NC
Caricaceae	*Carica papaya* Linn.	L, SD, RT	C, E, W	Cultivated	Tree	0.08	NC
Clusiaceae	*Symphonia globulifera* L.f.	SB	C, W	Not cultivated	Tree	0.10	NC
Combretaceae	*Combretum molle* R.Br. ex G. Don	L, SB, RT	E, N	Not cultivated	Tree	0.10	NC
Cucurbitaceae	*Cucurbita maxima* Duchesne	L, FR	C, E, N, W	Cultivated	Herb	0.57	NC
Cucurbitaceae	*Momordica charantia L.*	FR	E, N	Both	Herb	0.13	NC
Cupressaceae	*Cupressus lusitanica* Mill.	L	W	Cultivated	Tree	0.07	NC
Euphorbiaceae	*Croton macrostachyus* Hochst. ex Delile	L, SB, RT	C, W	Not cultivated	Tree	0.17	NC

Family	Scientific name	Plant part used	Region*	Habitat	Plant form	Use Value	Voucher no.
Euphorbiaceae	*Sapium ellipticum* (Hochst.) Pax	L	C, W	Not cultivated	Tree	0.22	NC
Fabaceae	*Albizia coriaria* Welw. ex Oliv.	SB, RT	C, E, N	Both	Tree	0.38	BK0525
Fabaceae	*Albizia glaberrima* (Schumach. & Thonn.) Benth.	SB	C, E, N, W	Not cultivated	Tree	0.08	BK0530
Fabaceae	*Cajanus cajan* (L.) Millsp.	L, SD	N	Both	Shrub	0.25	NC
Fabaceae	*Entada abyssinica* Steud.ex A.Rich.	L, SB, RT	C, N, W	Not cultivated	Tree	0.10	BK0531
Fabaceae	*Erythrina abyssinica* Lam.	FL, SB	C, E, N, W	Not cultivated	Tree	0.22	NC
Fabaceae	*Mimosa pudica* L.	L, SD	C, E, N, W	Not cultivated	Herb	0.52	NC
Fabaceae	*Piliostigma thonningii* (Schumach.) Milne-Redh.	RT, SB	C, W	Not cultivated	Tree	0.15	BK0524
Fabaceae	*Tetrapleura tetraptera* (Schumach. & Thonn.) Taub.	L, FR, RT	C	Not cultivated	Tree	0.09	NC
Fabaceae	*Vachellia (acacia) nilotica* (L.) P.J.H. Hurter & Mabb.	L, SD, SB	E, N	Not cultivated	Tree	0.08	NC
Graminaae	*Cymbopogon citratus* Stapf	L	C, E, N, W	Cultivated	Herb	0.48	NC
Labiatae	*Leonotis mollissima* Gürke	L, SD	C, W	Not cultivated	Herb	0.48	NC
Lauraceae	*Persea americana* Mill.	L, FR, SD	C, E, N, W	Cultivated	Tree	0.17	NC
Liliaceae	*Allium sativum* L.	Bulb	C, E, N, W	Cultivated	Herb	0.48	NC
Loganiaceae	*Strychnos spinosa* Lam.	SB, RT	E, N	Not cultivated	Tree	0.08	BK0536
Malvaceae	*Abelmoschus* esculentus Moench	FR	C, E, N	Cultivated	Herb	0.45	NC
Malvaceae	*Grewia mollis* Juss.	L, SB, RT	C, E, N, W	Not cultivated	Tree	0.15	BK0534
Meliaceae	*Azadirachta indica* A. Juss.	L, SB	C, E, N, W	Both	Tree	0.53	NC
Meliaceae	*Cedrela odorata* L.	SB	C, W	Not cultivated	Tree	0.17	NC
Moraceae	*Antiaris toxicaria* (Pers.) Lesch	SD, SB	C, E, N, W	Not cultivated	Tree	0.10	BK0523
Moraceae	*Artocarpus heterophyllus* Lam.	L, SB, SD	C, E, W	Cultivated	Tree	0.08	NC
Moraceae	*Ficus glumosa* Delile	L, SB	E, N, W	Not cultivated	Tree	0.08	NC
Moraceae	*Ficus natalensis* Hochst.	SB	C, E, N	Both	Tree	0.13	BK0526
Moraceae	*Ficus sur* Forssk.	L	C, E, N, W	Not cultivated	Tree	0.13	BK0535
Moringaceae	*Moringa oleifera* Lam.	L, FR, RT	C, E, N, W	Cultivated	Tree	0.14	NC

Family	Scientific name	Plant part used	Region*	Habitat	Plant form	Use Value	Voucher no.
Myricaceae	*Myrica salicifolia* Hochst. ex A. Rich.	RT	E, W	Not cultivated	Tree	0.08	NC
Myrsinaceae	*Maesa lanceolata* Forssk.	SB	C, E, W	Not cultivated	Tree	0.23	NC
Myrtaceae	*Eucalyptus grandis* Hill ex Maid.	L	C, E, W	Cultivated	Tree	0.09	NC
Myrtaceae	*Psidium guajava* L.	L, SB	C, E, N, W	Cultivated	Tree	0.08	NC
Myrtaceae	*Syzygium cuminii* (L.) Skeels	L, FR, SB	C, E	Both	Tree	0.07	NC
Olacaceae	*Ximenia americana* L.	L, FR, SB	N	Not cultivated	Tree	0.06	NC
Phyllanthaceae	*Euphorbia hirta* L.	L, SB	C, E	Not cultivated	Tree	0.07	NC
Punicaceae	*Punica granatum* L.	FR, SD	C, N	Cultivated	Tree	0.08	NC
Rhamnaceae	*Maesopsis eminii* Engl. (NC	L, SB	E	Cultivated	Tree	0.16	NC
Rosaceae	*Prunus africana* (Hook.f.) Kalkman	L	C	Both	Tree	0.24	NC
Rubiaceae	*Craterispermum laurinum* (Poir.) Benth.	L, SB	C, W	Not cultivated	Tree	0.08	NC
Rubiaceae	*Sarcocephalus latifolius* (Sm.) E.A. Bruce	SD, RT	E, N	Not cultivated	Tree	0.10	NC
Rutaceae	*Zanthoxylum chalybeum* Engl.	L, SB, RT	W	Not cultivated	Tree	0.38	BK0532
Sapotaceae	*Vitellaria paradoxa* C. F. Gaertn.	SD	E, N	Not cultivated	Tree	0.08	NC
Solanaceae	*Solanum gilo* Raddi	L, FR	C, E, N, W	Cultivated	Herb	0.64	NC
Solanaceae	*Solanum indicum* L.	L, FR	C, E, N, W	Cultivated	Herb	0.59	NC
Zingiberaceae	*Zingiber officinale* Roscoe	RT	C, E, N, W	Cultivated	Herb	0.66	NC

Key*:* Plant part*: L represents leaves, FR-fruit, SB-Stem bark, SD-Seed, FL-Flowers, RT-Root;* Region*: C represents Central, E: Eastern, N: Northern, W: Western;* Habitat *represents where that plant was mostly sourced from by the TMPs: cultivated means that the plant species is planted, not cultivated means that the plant is sourced from the wild, both means that the plant is sourced from cultivated and wild populations;* Voucher no. *NC: Plant sample not collected*.

Discussion

This study provides information on medicinal plant species used by TMPs from various parts of Uganda to manage DM. TMPs in rural areas from the different regions of Uganda are knowledgeable about DM and diagnosing DM patients which suggests that diabetes is also a health problem in rural areas and is no longer a disease for elites as is the common myth. Furthermore, the study findings provide evidence that DM patients in Uganda are using herbal drugs as alternative medicine for diabetes which is in line with findings from previous studies (Rutebemberwa *et al.* 2013) and this also attests to the fact that about 80% of Uganda's population relies on herbal drugs for primary health care.

The herbal medicine practice in managing DM is dominated by males although there was a good proportion of females probably because it is mostly men who walk long distances to the wild to collect plant parts. Similar findings have been shown in related studies by Kamagaju *et al.* (2013) and Okello & Ssegawa (2007). Relatedly, it was evident that the youth (below 30 years) are largely missing in this enterprise (Tugume *et al.* 2016), probably because parents are not passing on knowledge to the young ones or youths are not interested in this enterprise or parents are encouraging youths to train in formal enterprises which are more financially rewarding.

Although this was not the case for all TMPs, some TMPs who participated in this study acted professionally by depending on laboratory results before administering their herbal medication for managing diabetes. This can be explained by the fact that most TMPs were learned and are responsible (judging by their age). Relatedly, it was clear that the herbal medicine enterprise was not the primary source of income for the TMPs, so they seem to be driven by their passion to indulge in this enterprise and this may explain why they are exercising care as they administer their herbal drugs.

The survey highlighted 71 plant species from 44 families with Fabaceae family accounting for the largest number of species. Related studies in Uganda also attest to the fact that most medicinal plant species used for managing DM are in Fabaceae family (Asiimwe *et al.* 2021, Tugume *et al.* 2016). Much as DM is still not considered to be common in rural areas, a relatively high number of plant species were reported to manage diabetes. This is indicative of the high floral diversity and rich traditional knowledge in Uganda. The plant species with high UV in this study have antidiabetic potential as reported in previous studies, for example *Zingiber officinale* (Aderonke & Jide 2020), *Amaranthus viridis* (Girija *et al.* 2011), *Solanum gilo* (Okafor *et al.* 2016), *Azadirachta indica* (Sanni *et al.* 2019), *Mangifera indica* (Aderibigbe *et al.* 1999). These studies give credence to the use of the mentioned species by TMPs to manage diabetes and point to the great potential of using the mentioned species in the development of new drugs for diabetes. Furthermore, the plant species which were commonly used as per the high UV in this study are also known to have high therapeutic potential as evidenced from the broad range of diseases that they manage (Beristain-Bauza *et al.* 2019; Ediriweera *et al.* 2017; Saleem *et al.* 2018). An indication that these species can contribute significantly to human health improvement. The similarity in plants species used to manage DM in Eastern and Northern Uganda and for Central and Western Uganda may be due to the similarities in climatic and soil conditions, which influences the vegetation types in these areas. For instance, generally Central and Western Uganda regions receive higher amount of rainfall than Eastern and Northern Uganda regions which tend to be semi-arid (Nsubuga & Rautenbach 2018). Similarities in ethnic groupings may also explain the similarities in plant species used in the two clusters, for instance, the central-western cluster are mainly Bantu while the eastern-northern cluster are mainly Luo (Ricart-Huguet & Green 2018). This may also partly explain the dissimilarity in plant species registered in Eastern-Northern from those recorded in Central-Western Uganda. The fact that TMPs in sites with similarities in plant species tend to use similar plants for managing diabetes gives credence to pharmaceutical potential of those species towards managing diabetes.

Although the highest number of plant species listed for managing diabetes were wildly occurring or not cultivated, plant species that were mostly mentioned by TMPs according to the UV were the cultivated ones, which concurs with findings from previous studies (Zenderland *et al.* 2019). Moreover, although trees accounted for the highest number of plant species listed by TMPs, they were not mostly used to manage diabetes according to the lower UV of trees compared to that of herbaceous plants. This probably suggests that high usability is positively associated with easy access and availability. Implying that most trees or none-domesticated plants are less accessible and available due to the fact that they are slow growing in nature, less domesticated and sparsely distributed. Nonetheless, just like in previous studies, majority of the TMPs depend on the wild tree populations as the source for the plant parts (Gumisiriza *et al.* 2019; Namukobe *et al.* 2011). This also highlights the need to heighten conservation efforts for indigenous tree species through various interventions such as domestication and farmer managed regeneration.

The plant parts that were mostly used for managing diabetes were leaves and stem bark and this is in line with related studies in Uganda and elsewhere in the region (Obakiro *et al.* 2021; Tugume *et al.* 2016; Yikna & Yehualashet 2021). This is probably because leaves and stem bark are normally abundant and easy to harvest compared to roots. The other reason could be to the high regenerative ability of leaves and the fact that they are easy to process. Moreover, the dominance of the stem bark in managing DM could be due to the high yield of phytochemicals, hence may have high antidiabetic potential. Nonetheless, the high proportion of the stem bark was due to the high proportion of trees as plant forms used in managing DM.

Conclusion

Diabetes is a chronic and complex disease which pauses a health burden on populations in developing countries like Uganda. Although various conventional antidiabetic drugs have been manufactured, they are still marred with several side effects, are largely inaccessible and unaffordable to most Ugandans and in most cases their specificity renders them ineffective. As such, multiple drug therapy with herbal remedies for managing DM have gained traction. This study provides baseline information about plant species used to manage diabetes in Uganda on which further experimental investigation can be done to ascertain their antidiabetic efficacy and eventually contribute to formulation and manufacture of new diabetic drugs. Although no particular plant species were unique to a particular region, the study shows that there is variation in the medicinal plants used in the different regions of Uganda which may be attributed to the differences in climatic and ethnicity factors. This variation can be harnessed, whereby the plant species that dominate DM management in the different regions

can be combined and be used to make a polyherbal product which has high efficacy towards DM management. Relatedly, the variations in climatic and ethnic factors can be positively exploited to domesticate and conserve plant species especially the slow growing indigenous tree species in their favourable environments. Additionally, the study underscores the fact that TMPs mostly use plants that are easily available and parts that are easily harvested. Our findings show that a high proportion of plant species used to manage DM are not cultivated and therefore cannot contribute their services to humanity optimally. To this end, we recommend cultivation of indigenous tree species that were mentioned by the TMPs in order to increase their availability and accessibility.

Declarations

List of abbreviations: Diabetes mellitus (DM), Traditional Medical Practitioners (TMP), Use value (UV), National Forestry Resources Research Institute (NaFORRI).

Ethics statement:

Approval to conduct the study was obtained from the directorate of research of the National Agricultural Research Organization. In every district, permission was sought from the local government authorities prior to consulting the TMPs. Informed consent was sought verbally from each TMP before commencing the interview. Respondents were informed of the potential benefits of this study and that there was no risk involved in participating in the study.

Consent for publication: Not applicable

Availability of data and materials: The original data that support the findings of this study are available upon request from the corresponding author.

Competing interests: All authours declare no conflict of interest.

Funding: This study was funded by Government of Uganda under the Competitive Grant Scheme, Cohort V.

Authors' contributions: Moreen Uwimbabazi planned the study, designed the data collection tools, collected the data, analysed the data and wrote the manuscript; Bernadette Kabonesa was the botanist and responsible for plant identification; Samuel Ongarep collected and cleaned the data; Francis Omujal designed the data tool, analysed the data and wrote the manuscript; Hillary Agaba planned the study, supervised this work and reviewed the manuscript.

Acknowledgments

The authors acknowledge all the financial support from Government of Uganda through the Ministry of Agriculture, Animal Industry and Fisheries. We sincerely thank all the Traditional Medical Practitioners (TMPs) who participated and voluntarily offered information during the surveys. We are grateful to all the NaFORRI staff who participated at different stages of the survey.

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