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Ethnobotanical study of plants used in management of diabetes mellitus in Eastern Uganda

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ABSTRACT

Ethnopharmacological relevance: Diabetes mellitus (DM) is the fourth leading cause of morbidity and mortality among non-communicable diseases affecting about 422 million people worldwide and an estimated 1.5 million deaths directly attributed to diabetes each year with a prevalence of approximately 4.1% in Uganda. The disease is on an unprecedented rise in developing countries yet access to conventional diabetes medication is a huge challenge due to limited resources. Moreover, the current management and treatment options are life-long, expensive and associated with undesirable side effects. Consequently, there is widespread use of complementary and alternative medicines, mostly herbal medicines in the management of DM in Uganda.

Aim of the study: To conduct an ethnobotanical study about medicinal plants for the management of DM in Eastern Uganda, a resource-limited area with rich plant biodiversity.

Materials and methods: An ethnobotanical survey was conducted in eight districts of Eastern Uganda. Eighty-six TMPs were interviewed using semi-structured questionnaires. Data on screening of DM, medicinal plant harvesting, herbal medicine preparation, packaging, posology and toxicities were generated. Data analysis was conducted using SPSS software version 26.

Results: Sixty-one plant species belonging to 38 families and 59 genera were used by the TMPs in the preparation of herbal remedies for the management of symptoms of DM. The most commonly used plant species were *Kigelia africana, Tamarindus indica, Aloe vera, Erythrina abyssinica, Entada abyssinica, Carica papaya,* and *Maytenus senegalensis*. The most frequently used life forms were trees (63.2%) and herbs (20%) belonging to families Fabaceae (11.4%) and Asteraceae (10%). Roots and leaves were the most used plant parts harvested predominantly from the wild. Most herbal remedies were prepared as decoctions and administered orally with no reported toxicities.

Conclusion: A wide range of medicinal plants are used by TMPs for management of diabetes in Eastern Uganda. Scientific evaluation of the antidiabetic potential, phytochemistry and toxicology of these remedies is needed to validate their use and inform the production of improved herbal medicines or discover novel molecules for effective management of DM.

1. Introduction

Diabetes mellitus (DM) is a group of heterogeneous disorders characterized by hyperglycemia and glucose intolerance resulting from insulin deficiency, impaired effective insulin action or both (Ozougwu, 2013). Diabetes was the direct cause of 1.5 million deaths in 2019 and

List of abbreviations: BUFHS, Busitema University Faculty of Health Sciences Research and Ethics Committee; DM, Diabetes mellitus; GLP-1, Glucagon like peptides; ICF, Informant Consensus Factor; LMICs, Low-and middle-income countries; SSA, Sub-Saharan Africa; TMPs, Traditional medicine practitioners.

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48 percent of all diabetes-related deaths occurring below the age of 70. The disease was also linked to 460,000 kidney disease deaths and 20% of all cardiovascular deaths (Global Burden of Disease Collaborative Network, 2020). Over 463 million adults aged 20–79 years worldwide are reported to be living with diabetes and this represents around 9.3% of the global adult population (Sun et al., 2022). An increasing burden of the disease has been reported over years with a global prevalence rising from 108 million in 1980 to approximately 537 in 2020 million adults (Ogurtsova et al., 2022). This trend is expected to reach 700 million by 2045 (Sun et al., 2022). Africa where 75% of the population remains undiagnosed is facing a rapid rise in prevalence of the disease which is estimated to be 19.8 million (L. Guariguata et al., 2014; Chiwanga et al., al.,2016). In Uganda, the prevalence of diabetes mellitus and impaired glucose tolerance is approximately 4.1% and 6.6%, respectively (Bahendeka et al., 2016; Mayega et al., 2013; Ministry of Health Uganda, 2014) and rapidly rising with the numbers expected to increase by 166.9% between 2013 and 2035 exceeding many other countries (L. Guariguata et al., 2014).

Conventional treatment of DM involves the use of injectables including insulins and Glucagon-like peptides (GLP-1) agonists, as well as oral hypoglycemic agents but undesirable side effects, decreasing efficacy, inaccessibility, expensiveness, lifelong therapy and high secondary treatment failure rates are the major drawbacks (Chaudhary et al.,2017). In Uganda, the median cost per prescription at a diabetic clinic is estimated at $11.34 and the majority of the patients cannot afford these out-of-pocket costs (Obakiro et al., 2021a). The use of complementary and alternative therapies is on unprecedented rise with over 80% of the world population depending on traditional medicines for management of several ailments especially for diabetes mellitus. This is attributed to the affordability, availability, perceived effectiveness and cultural acceptability of traditional medicine (Suntar, 2020). In various traditional medical systems of many cultures around the world, particularly in developing nations like Uganda, medicinal plants have long been used to manage diabetes (Gang et al., al.,2023). Although the actual statistics are unknown, a significant proportion of DM patients use both conventional and traditional medicines to manage DM in Uganda.

Eastern Uganda is the poorest region in Uganda with the majority of its people relying on traditional medicine for primary health care (Sreekeesoon and Mahomoodally, 2014; Tabuti et al., 2010). Additionally, the region has a characteristic topography and soil chemistry with mountainous areas in the Elgon and Sebei regions alongside the grasslands in Teso and Busoga regions which gives a unique rich biodiversity that is utilized in traditional medicine. The abundant flora in the region attracts traditional medicine practitioners from different parts of the country to harvest from it for the preparation of herbal remedies (Walusansa et al., 2022; Ssenku et al., 2022). Due to these factors, Eastern Uganda represents a promising region for investigating the use of plants in the management of diabetes mellitus. Ethnobotanical studies play a crucial role in documenting and preserving traditional knowledge about the use of medicinal plants, providing valuable insights into their therapeutic properties, safety profiles, and cultural significance.

Ethnobotanical studies conducted elsewhere have reported various plant species used in the preparation of herbal remedies for the management of DM. However, there is limited documentation of medicinal plants used for DM in Uganda yet the country has a very rich plant biodiversity (Ssenyange et al., 2015). Traditional and complementary medicines are an integral part of the countries' health care system with a legal framework enshrined in the Traditional and complementary medicine Act, 2019. Therefore, this study aimed to document the knowledge about medicinal plants used by TMP to prepare herbal medicines for the management of DM in selected districts of Eastern Uganda. This study aims to guide scientists in discovering novel molecules for diabetes treatment and has highlighted the cultural significance of traditional medicine and preserving ethnomedicinal practices for evidence-based herbal remedies.

2. Methods

2.1. Study design, setting and sampling

An ethnobotanical survey using a cross-sectional study design was conducted in 8 districts of Eastern Uganda namely: Kamuli, Kaliro, Pallisa, Bulambuli, Kapchorwa, Kween, Serere and Katakwi (Fig. 1). The districts were purposely sampled based on their location in rural areas with high levels of poverty and long distances to access health services. The majority of the patients in these areas use herbal medicine as either the first or second option for the management of DM.

A total of 86 TMPs were interviewed from the eight districts (on average 10 TMPs per district) using the snowball sampling technique. The TMPs were purposively selected based on their reputation in managing DM using herbal medicines in the communities. In each district, the first participant was identified through either the local council or herbalist association leadership. The first participant then helped us to identify the second who also helped us to identify the subsequent participants.

2.2. Scope of the study

The primary objective of this ethnobotanical study was to explore and document the traditional knowledge and use of medicinal plants in the management of diabetes mellitus among local communities in Eastern Uganda. The study aimed to identify plant species as well as to understand the cultural significance of herbal remedies in diabetes management. The study was conducted in Eastern Uganda, encompassing eight districts and communities representative of the region's cultural and ecological diversity. Field surveys and interviews were conducted to gather a comprehensive understanding of medicinal plants used in the management of Diabetes mellitus.

2.3. Data collection

Prior informed consent was obtained from all the participants. Data were collected from the TMPs between January and March 2023. Ethical approval was obtained for conducting the study from the Busitema University Faculty of Health Sciences Research and Ethics Committee (BUFHS-2022–40). A pilot study was conducted amongst 6 TMPs from central Uganda to pre-test the data collection tools. Data was collected using a semi-structured questionnaire with the help of research assistants who were familiar with the local language. The questionnaire included questions on the TMP biodata, knowledge of signs and symptoms of DM and names of medicinal plant species used. One focus group discussion was held with selected community members to complement the questionnaire surveys, particularly on issues of disease recognition, medicine packaging, administration and threats to medicinal plants. All the plants mentioned by TMPs to be used in the management of DM were identified and collected with the help of the TMPs in the field. Voucher specimens of each plant species were prepared and deposited at the Makerere University Herbarium for identification. The flora for tropical East Africa was used in species nomenclature. The plant names have been checked with https://wfoplantlist.org/plant-list accessed on 30 May 2023.

2.4. Data analysis

Numerical data were entered in a Microsoft Excel spreadsheet, coded, and exported to SPSS software Version 26 for analysis. Descriptive statistics using percentages and frequencies were used to summarize ethnobotanical and participant's socio-demographic data. The Informant Consensus Factor (ICF) was calculated to determine the homogeneity in the ethnobotanical information collected from the participants.

The ICF was computed using the formula (1):

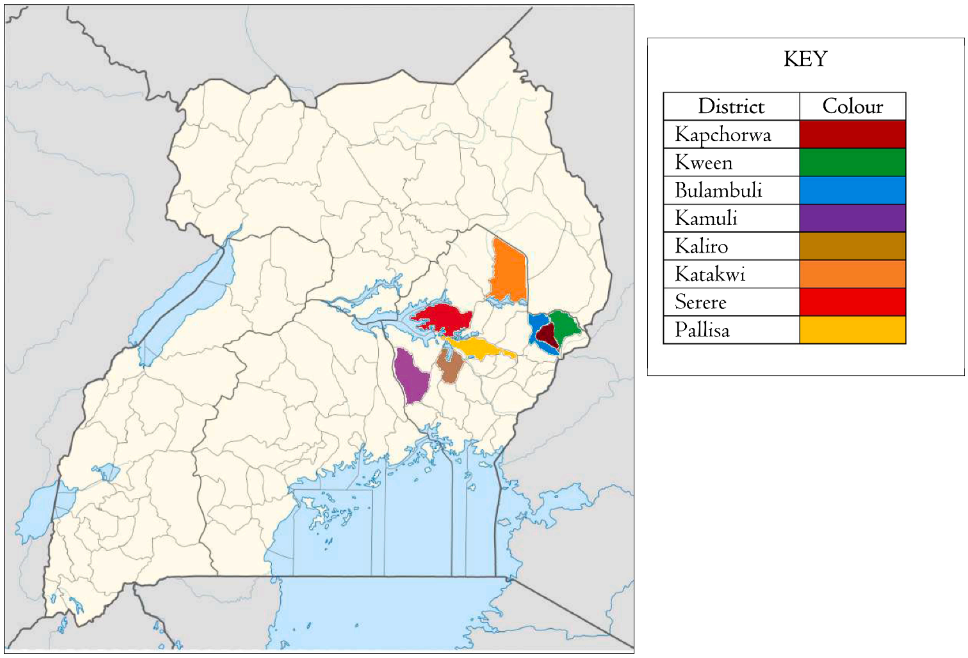

Fig. 1. Map of Uganda showing the Study districts.

$$ICF = \frac{Nur - Nt}{Nur - 1} \quad (1)$$

Where "*Nur*" refers to the total number of use reports for each disease cluster and "*Nt*" refers to the total number of species in each use category. The ICF values range from 0 to 1. High ICF values (close to 1) indicate that participants use similar medicinal plants and thus there is agreement on the medicinal plants used to treat a disease while low ICF values (close to 0) indicate that participants use many different plant species to treat a disease(Jamila and Mostafa, 2014).

3. Results

3.1. Sociodemographic characteristics

The majority of the TMP were between the ages of 41 to 60 years (46.5%). Most of them were males (67.4%), married (94.2%), primary school leavers (64%) and subsistence farmers (91.8%). Most of these participants (93.9%) acquired knowledge about medicinal plants from their relatives.

3.2. Knowledge about diabetes mellitus and treatment-seeking behaviour of patients

Diabetes mellitus was prevalent in Eastern Uganda with most of the TMPs managing an average of 60 patients annually and the majority of their patients (90%) being 30 years and above. The majority of the TMPs (82%) agreed that DM was caused by lifestyle behaviour such as lack of exercise, obesity, fatty diet, drinking of alcohol, smoking, and use of drugs among others. On the other hand, a few of the TMPs (18%) believed that it was an inherited disease transmitted along family members. All the TMPs reported that DM could not be transmitted from sick people to normal people through contact, sharing or vectors. The TMPs showed a good understanding of the signs and symptoms of DM among their clients (Fig. 2). The most reported signs and symptoms were excessive urination (21%), frequent thirst (10.1%), thorn pricks in the feet (8.4%) and excessive sweating (8.4%). The TMPs also mentioned that some patients would go to them after being diagnosed with DM by qualified health workers after conducting laboratory investigations. The TMP would also refer some of their patients to laboratories for confirmation of DM before initiation of herbal medicine, in cases where they were not certain. Upon confirmation of the disease, the TMPs revealed

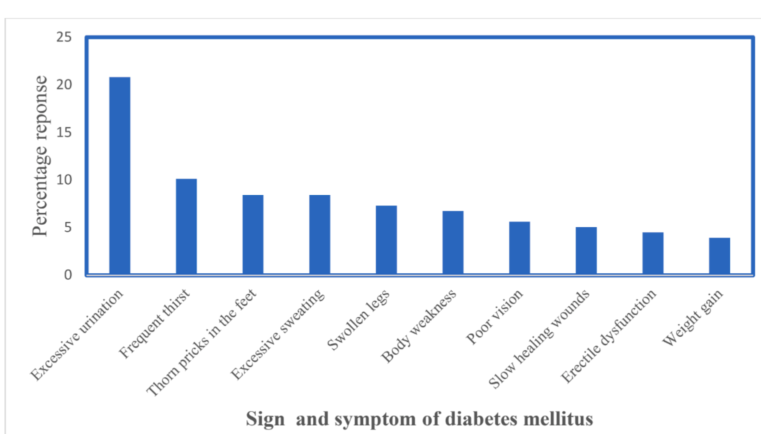

Fig. 2. Reported signs and symptoms of diabetes mellitus by herbalists in Eastern Uganda.

that those who cannot afford conventional medicines and those who believe in natural medicine seek traditional medicine as their first option. However, some of those who go to health facilities come back to traditional medicine while others continue with conventional medicine alongside traditional medicine.

3.3. Plant species used in the preparation of herbal remedies for the management of diabetes mellitus in Eastern Uganda

Sixty-one plant species belonging to 38 families and 59 genera were mentioned by TMP in 8 districts of eastern Uganda for the management of symptoms of DM (Table 1). Of the reported species, seven plant species were mentioned by five or more TMP. These are; *Kigelia africana* (9), *Tamarindus indica* (7) *Aloe vera* (7), *Erythrina abyssinica* (6), *Entada abyssinica* (5), *Carica papaya* (5), *Maytenus senegalensis* (5). Fabaceae (11.4%), Asteraceae (10%), and Apocynaceae (5.7%) were the most represented plant families (Fig. 3). Most of the inventoried plant species were trees (63.2%), and herbs (20%) (Fig. 4).

The Informant Consensus Factor (ICF) for DM calculated in this study was 0.53. A high ICF (close to 1) indicates strong agreement among the TMPs in the medicinal plants used in the management of a disease. This usually happens in communities where there is sharing of knowledge about herbal medicine such as in herbal medicine association groups. A low ICF (close to 0) indicates that the TMPs use different plants to prepare herbal medicine for a certain disease. This is characteristic of communities where there is restricted sharing of indigenous knowledge.

3.4. Herbal medicine preparation and administration for the management of diabetes mellitus

The majority of the TMPs (92.8%) collected the medicine plants from the wild and a few (7.2%) from around their homesteads. The roots (33.6%) were the most commonly used plant part, followed by the leaves (28.4%) and stem bark (21.6%) (Fig. 5). The major mode of preparation of herbal medicine was decoctions (67.1%). The oral route was the predominant route of administration of herbal medicines. The topical route was only used in the case of treating wounds caused by DM. Generally, there were a lot of inconsistencies in the doses administered and dosing intervals and duration of treatment. For liquid formulations, doses were largely determined using “cups” of volume 0.5 L. Depending on the concentration of the herbal medicine, quantities ranged between 0.25 – 1 L taken two or three times a day for a period of one to three weeks. The majority of the TMP (87.2%) prepared their medicine without adding any excipients such as preservatives. They believed that among the plant species used, there were those with preservative properties although they could not specify them. Other TMP said they would add *Eucalyptus species* (9.3%) and honey (3.5%) purposely for the preservation of their herbal medicine. In most cases, the herbal medicine was prepared when needed with a maximum duration of storage of about two weeks. Plastic bottles (0.5 −1 L) and small jerricans (1–3 L) were the most used packaging materials for liquid forms while polythene bags were used to store powder forms. All the TMP reported that their herbal medicine was relatively safe with no reported side effects with the exception of the bitter taste in some products.

3.5. Challenges to medicinal plants in Eastern Uganda

The herbalists lamented that medicinal plants are at risk of extinction. Apart from some medicinal plants being rare species, others are getting endangered due to anthropogenic activities such as cutting of trees for charcoal burning and construction, over-cultivation and grazing, quarrying (in the Sebei region) and settlement and climate change, particularly prolonged droughts. Eastern Uganda’s ecosystems are under increasing pressure due to deforestation, land degradation, and habitat destruction. These activities disrupt the natural habitats of medicinal plants, leading to the loss of plant species and threatening their survival. The high demand for medicinal plants for both traditional and commercial purposes has led to overharvesting, resulting in the depletion of certain plant populations. Unsustainable collection practices can adversely affect the long-term availability and efficacy of medicinal plants. Climate change impacts, such as unpredictable weather patterns, altered rainfall, and rising temperatures, directly affect the distribution and growth of medicinal plants. Climate-related disruptions can lead to changes in plant phenology, making it challenging for communities to find and utilize specific plants at certain times of the year.

The traditional knowledge of medicinal plants is often passed down orally through generations. However, as younger generations seek modern lifestyles and education, there is a risk of losing this valuable knowledge, leading to the underutilization and neglect of indigenous remedies. Many traditional remedies are based on empirical knowledge and have not been extensively studied or scientifically validated. The lack of formal documentation and research on the medicinal properties of specific plants hampers their integration into modern healthcare practices. Due to the limited access to modern healthcare facilities, the demand for traditional medicine, including medicinal plants, remains high in Eastern Uganda. However, a lack of appropriate healthcare infrastructure may hinder the effective integration and utilization of these remedies.

4. Discussion

The study found that several medicinal plant species (61) were used in the preparation of herbal remedies for DM in Eastern Uganda. Among the reported plant species, although the majority of them had been previously reported to be used in the management of DM by communities outside Uganda, some of the plant species were reported for the first time (Table 1). In a study conducted in central Uganda, a total of eighteen plant species were reported to be used in the management of DM (Ssenyange et al., 2015). Out of these, eight plant species have also been reported in this study. The high number of plant species reported in our study could be attributed to the higher numbers of districts studied and hence large agroecological zones covered. But also, there is more use of traditional medicine in Eastern Uganda than in Central Uganda attributed to the higher level of poverty and limited access to health services in the region. The inability to access primary health care services forces patients to seek intervention from traditional medicine practitioners whose services are readily available, affordable with ‘claimed’ efficacy and safety (Tabuti et al., 2010).

The moderate informant Consensus Factor (0.53) implied that the TMPs in Eastern Uganda have limited sharing of indigenous knowledge related to medicinal plants used in the management of DM. Although DM has existed for a long time, its burden in Uganda has been previously low and of less public health concern. The rapid increase in diabetic patients in the last decade has triggered TMPs to search for more natural products to manage the disease. Those who have succeeded in discovering potential natural therapeutics are not willing to share with others due to the financial benefit associated. There are also over 15 tribes in Eastern Uganda each with its own language and cultural beliefs. The geographical differences in the region also cause some flora to be absent in certain districts/regions (Schultz et al., 2020). Hence it is highly likely that different plant species are used in the preparation of herbal medicines for DM by the TMPs. We could not easily calculate the scores from the preference ranking and paired comparison tests because of the relatively low informant consensus factor (Yimam et al., 2022).

The most harvested plant parts were roots followed by leaves. Even in DR.. Congo, roots (41.3%) and leaves (28.6%) were the most used plant parts in the preparation of herbal remedies for DM (Amuri et al., 2017). Harvesting of roots is associated with increased loss of plant species because roots regenerate slowly compared to leaves and yet many herbalists don’t follow the good harvesting practices. This could probably pose a threat to the sustainable use of these plants and thus investigations into other aerial plant parts such as leaves and stembark

Table 1
Medicinal plants used in Eastern Uganda for treating diabetes mellitus.

SN	Scientific name	Local Name (Language)	Family	Voucher Number	Plant form	Part used	Frequency of mention	Previous reports	Phytoconstituents responsible
1	*Abrus precatorius* L.	Kasitisiti (Ls)	Fabaceae	OSB001	H	R	1	China (Qian et al., 2022; Noor et al., 2022)	luteolin, abrectorin, orientin, isoorientin, and desmethoxycentaviridin-7-O-rutinoside, glycyrrhizin, abrusoside A to D, abrusogenin and abruquinones D, E and F(Nwanosike et al.,2016)
2	*Ageratum conyzoides* L.	Namirembe (Ls)	Asteraceae	OSB002	H	L, R	1	Cameroon(Nyunaï et al., 2009), Uganda (Ssenyage et al., 2015)	flavonoids, tannins, terpenoids and/or coumarins(Nyunaï et al., 2009)
3	*Albizia coriaria.* Welw. ex Oliv.	Omugavu (Lg)	Fabaceae	OSB004	T	SB, R	1	Uganda (Ssenyange et al., 2015)	Alkaloids, phenols, saponins, flavonoids, cardiac glycosides, tannins, terpene(Omara et al., 2021)
4	*Aloe vera* (L.) Burm.f.	Ekikaka (ls), Kigaji (Lg), Rotichekokwa (Sa)	Asphodelaceae	OSB058	H	L	7	Pakistan(Ahmad et al., 2009)	alkaloids, saponins, tannins, flavonoids, terpenoids, coumarins, glycosides, Xanthoproteins, glycosides, steroids, phenols(Sharma et al., 2014)
5	*Alstonia boonei* De Wild.	Mubadangalabi (Ls)	Apocynaceae	OSB003	T	SB	1	(Adotey et al., 2012)	Polyphenols; vitamin E stigmasterol, Phytol and phytol acetate(Oyebode et al., 2019)
6	*Annona muricata* L.	Musitaferi (Ls)	Annocaceae	OSB011	T	L	3	Uganda(Y. Gavamukulya et al., 2017)	hexadecanoic acid, β-Sitosterol, Hydroxylamine, O-decyl-(Verengai et al., 2017)
7	*Aristolochia elegans* Mast.	Nakesero (Lg)	Aristoloceae	OSB007	H	R	1	Mexico(Monroy-Ortiz et al., 2013)	No reports
8	*Artocarpus heterophyllus* Lam.	Fene (Ls / Lg)	Moraceae	OSB008	T	S	1	India(Prakash et al., 2009), Uganda (Ssenyage et al., 2015)	quercitrin flavonoid, artocarpesin, norartocarpetin, and oxyresveratrol (Prakash et al., 2009)
9	*Aspilia africana* (Pers.) C.D. Adams	Makayi (Lg)	Asteraceae	OSB009	H	L	1	Nigeria(Essiett and Akpan, 2013)	alkaloids, tannins, flavonoids, glycosides, and saponins(Essiett and Akpan, 2013)
10	*Aspilia polycephala* S. Moore	Namkejir (Sa)	Asteraceae	OSB013	H	R, L	3	Reported for the 1st time	
11	*Azadirachta indica* A.Juss.	Muharubaine (Kiswahili)	Melaiceae	OSB052	T	L	3	Libya(Eid et al., 2017)	quercetin-3-O-β-D-glucoside, myricetin-3-O-rutinoside, quercetin-3-O-rutinoside (also known as rutin), kaempferol-3-O-rutinoside, kaempferol-3-O-β-D-glucoside and quercetin-3-O-α-L-rhamnoside(Atangwho and Ani, 2011)
12	*Balanites aegyptiaca* (L.) Delile	Ecomai (At)	Zygophyllaceae	OSB012	H	S	1	Cameroon(Yougouda et al., 2018)	No reports
13	*Bidens pilosa* L.	Namijikong (Sa), Sere (Lg)	Asteraceae	OSB059	H	R, L	3	Benin(Sanoussi et al., 2015)	No reports
14	*Broussonetia papyrifera* (L.) Vent.	Mukulaido	Moraceae	OSB014	T	SB, R	1	China(Haldar and Dadure, 2021)	Papyriflavonol A, Kazinol A, Brossoflurenone A(Ryu et al., 2010)
15	*Cannabis sativum* L.	Endaye (Ls)	Canabeceae	OSB015	H	L	1	South Africa(Levendal and Frost, 2006)	Cannabidiol, vanillin, apocynin, methyl palmitate, and syringaldehyde(Levendal and Frost, 2006)
16	*Carica papaya* L.	Omupapali Omusadha (Ls)	Caricaceae	OSB024	T	L	5	Nigeria(Bamisaye et al., 2013)	phenolic acids, chlorogenic acid, flavonoids, alkaloids, steroids and quinones(Esther Juárez-Rojop et al., 2012, 2014)
17	*Carissa edulis* Vahl	Omutwoga (Ls)	Apocynaceae	OSB017	S	R	2	Nigeria(Ojerinde et al., 2021a)	rhamnetin-3-β-Dglucopyranoside, peonidin-3-rutinoside, malvidin-3-O-β-D-(6″-acetylglucoside)(Ojerinde et al., 2021b)
18	*Catharanthus roseus* (L.) G.Don	Rose (English)	Apocynaceae	OSB019	H	L, Fl, WP	4	India(Retna and Ethalsha, 2013)	Ajmalicine, flavonoids, terpenes, and glycosides(Retna and Ethalsha, 2013; Vega-Ávila et al., 2012)

(continued on next page)

Table 1 (*continued*)

SN	Scientific name	Local Name (Language)	Family	Voucher Number	Plant form	Part used	Frequency of mention	Previous reports	Phytoconstituents responsible
19	*Cissampelos mucronata* A. Rich.	Kavamagombe (ls) / Maswi (lugwere)	Menispermaceae	OSB020	H	R	2	South Africa(De Wet and Van Wyk, 2008)	Isococlaurine(He et al., 2021)
20	*Citrus limon* (L.) Burm.f.	Ndimnyondet (Sa)	Rutaceae	OSB021	T	L, F	4	Zimbabwe(Verengai et al., 2017)	limettin, limonin, chrysoeriol, p-coumaric acid, scoparin, vitexin, chrysoeriol-7-O-glucoside, and hesperidin in addition to friedlin, lupeol, behenic acid, β-sitosterol and stigmasterol mixture and β-sitosterol-O-glucoside(Oyebadejo and Solomon, 2019; Verengai et al., 2017)
21	*Conyza sumatrensis* (Retz.) E.Walker	Kafumbe (Lg)	Asteraceae	OSB022	H	L	1	Reported for the 1st time	No reports
22	*Cupressus lusitanica* Mill.	Torogionted (Sa)	Cupressaceae	OSB023	T	L	1	Reported for the 1st time	No reports
23	*Elaeodendron buchananii* (Loes.) Loes.	Mbaluka	Celasteraceae	OSB018	T	SB	1	Reported for the 1st time	No reports
24	*Entada abyssinica* Steud. ex A.Rich.	Mwolola (Lg) Mushembut (Sa), Musambamaadi (Ls)	Fabaceae	OSB016	T	R	5	Amuri et al., 2018	No reports
25	*Erythrina abyssinica* Lam. ex DC.	Muyirikiti (Ls)	Fabaceae	OSB025	T	SB	6	DR.. Congo(Amuri et al., 2017)	No reports
26	*Euphorbia hirta* L.	Kasandasanda (Lg)	Euphorbiaceae	OSB026	H	WP	1	Bangladesh(Nyeem et al., 2017)	No reports
27	*Garcinia buchananii* Baker	Musaali (Lg)	Clusiaceae	OSB027	T	SB	1	Kenya(Chinsembu, 2019)	No reports
28	*Hoslundia opposita* Vahl	Enfodo (Ls), Kamunye (Lg)	Lamiaceae	OSB028	S	L	2	Burkina faso(Regina et al., 2015)	alkaloids, tannins, flavonoids, cardiac glucosides(Akolade et al., 2014)
29	*Indigofera circinella* Baker f.	Enfuni ensadha (Ls)	Fabaceae	OSB029	H	R	1	Reported for the 1st time	No reports
30	*Ipomoea batatas* (L.) Lam.	Eikabalyabili (Ls), Lumonde (Lg)	Convolvulaceae	OSB030	H	L	1	India(Panda and Sonkamble, 2012)	glycoprotein, anthocyanins, alkaloids, and flavonoids(Akhtar et al., 2018)
31	*Kigelia africana* (Lam.) Benth.	Maberebere (Lg) Gufungo (Lu) Naibeere (Ls) Edodoi (At) Yago (Lo)	Bignoniaceae	OSB031	T	F	9	South Africa(Fagbohun et al., 2020)	Phenolic, Coumarins,sterols, triterpenes,diterpenes, Quinones, iridoids,alkanes(Fagbohun et al., 2020)
32	*Lantana latifolia* Tausch	Kapanka (Lg)	Verbenaceae	OSB032	S	L	1	Reported for the 1st time	No reports
33	*Maesopsis eminii* Engl.	Musizi (Lg)	Rhamnaceae	OSB033	T	SB	1	Indonesia(Situmorang et al., 2015)	No reports
34	*Mangifera indica* L	Omuyembe (Lg)	Anacardiaceae	OSB034	T	L, SB	1	India(Wauthoz et al., 2007)	mangiferin, rhamnetin, catechin, epicatechin, iriflophenone 3-C-β-D-glucoside, gallic acid phenolics, flavonoid compounds.(Wauthoz et al., 2007)
35	*Maytenus senegalensis* (Lam.) Exell	Omuwaiswa (Ls), Eteba (At)	Celasteraceae	OSB035	T	R	5	Tanzania(Moshi and Mbwambo, 2002)	alkaloids, flavonoids, saponins, tannins and steroidal compounds(Mann et al., 2014b)
36	*Maytenus undata* (Thunb.) Blakelock	Chepkatet (Sa)	Clestraceae	OSB036	T	R	1	Nigeria(Mann et al., 2014b)	friedelin, epifriedelanol (2), taraxerol, 3-oxo-11α-methoxyolean-12-ene-30-oic acid (4), 3-oxo-11αhydroxyolean-12-ene-30-oic acid and 3,11-dihydroxyolean-12-ene-30-oic acid(Mann et al., 2014b)
37	*Mondia whitei* (Hook.f.) Skeels	Mulondo (Lg)	Apocynaceae	OSB037	H	R	1	Togo(Kpodar et al., 2015), Uganda (Ssenyage et al., 2015)	No reports
38	*Moringa oleifera* Lam.	Moringa (All)	Moringaceae	OSB038	T	SB, L & S	2	Nigeria(Edoga et al., 2013)	alkaloids, quinine, saponins, flavonoids, tannin, steroids, glycosides(Gupta et al., 2012)
39	*Musa paradisiaca* L.	Empumumpu ya kidozi (Ls)	Musaceae	OSB039	T	Fl	2	India(Shruthi, 2019)	Acyl steryl glycosides, triterpenes, Hemiterpenoid glucoside (1,1-dimethylallyl alcohol), syringin,

(continued on next page)

Table 1 (*continued*)

SN	Scientific name	Local Name (Language)	Family	Voucher Number	Plant form	Part used	Frequency of mention	Previous reports	Phytoconstituents responsible
									(6S, 9R)-roseoside, benzyl alcohol glucoside, (24R)−4α, l4 α,24-trimethyl-Sacholesta-8,25 (27)-dien-3β-o1(Zafar and Akter, 2011)
40	*Opuntia stricta* (Haw.) Haw.	Edagal	Cactaceae	OSB040	H	L	2	Zambia(Prashar et al., 2018)	trans-linalool oxide, cis-linalool oxide, and linalool(Prashar et al., 2018)
41	*Ozoroa insignis* Delile	Ketikapchewor (Sa)	Anacardiaceae	OSB041	S	L	1	Senegal(Diop et al., 2022)	No reports
42	*Persea americana* Mill.	Avocado (All)	Lauraceae	OSB042	T	SB, L, Se	4	Nigeria(Antia et al., 2005) Uganda (Ssenyage et al., 2015)	alkaloids, saponins, unsaturated steroids and triterpenoids (Leucoanthocyanins), cyanogenic glycoside(Antia et al., 2005)
43	*Phoenix reclinata* Jacq.	Omusansa	Arecaceae	OSB043	T	S	1	Ethiopia(Mekuanent et al., 2015) Uganda (Ssenyage et al., 2015)	No reports
44	*Phyllanthus amarus* Schumach. & Thonn.	Ngorinet (Sa)	Phyllanthaceae	OSB044	T	R	4	Thailand(Phumthum and Balslev, 2018)	Coumarin, Flavonoid Naphtoquinone, Alkaloid, anthracene derivative saponin, lignan, triterpene, Tanins, triterpene(Sèlidji et al., 2018)
45	*Physalis peruviana* L.	Entutunu ennene (Lg)	Solanaceae	OSB045	H	WP	1	Uganda(Kasali et al., 2021b)	polyphenols, flavonoids, alkaloids, saponins, tannins, anthocyanins, mucilages, cardiac glycosides, coumarins and betalains(Fokunang et al., 2017)
46	*Piliostigma reticulatum* (DC.) Hochst.	Ekirama (Lg)	Fabaceae	OSB046	T	R	1	Nigeria (Ajayi et al., 2019)	No reports
47	*Psidium guajava* L.	Eppera (Lg)	Myrtaceae	OSB047	T	F, L	1	Mexico(Díaz-de-Cerio et al., 2017)	No reports
48	*Psilotrichum ellioti.* Bak	Mukasa (Lg)	Amaranthaceae	OSB048	H	WP	1	Reported for the 1st time	No reports
49	*Psorospermum febrifugum* Spach	Kanzironziro (Lg)	Chenopodiaceae	OSB049	S	SB	1	Reported for the 1st time	No reports
50	*Punica granatum* L.	Mukomamawanga (Lg)	Punicaceae	OSB050	S	R	1	Pakistan(Ali et al., 2017)	polyphenols, flavonoids, sterols, polyterpenes, pyrrolizine alkaloids (Maphetu et al., 2022)
51	*Ricinus communis* L.	Manuet (Sa)	Euphorbiaceae	OSB051	T	R	1	India(Rana et al., 2012)	Alkaloids (ricinine (and N-demethylricinine), flavones (glycosides kaempferol-3-O-β-D-Xylopyranoside, kaempferol-3-O-βD-glucopyranoside, quercetin-3-O-β-D-xylopyranoside, quercetin-3-O-β-D-glucopyranoside, kaempferol-3-O-βrutinoside and quercetin-3-O-β-rutinoside)(Kumar, 2017)
52	*Rytigynia neglecta* (Hiern) Robyns	Lakatetwet (Sa)	Rubiaceae	OSB006	T	R	3	Reported for the 1st time	No reports
53	*Sarcocephalus latifolius* (Sm.) E. A.Bruce	Mutamatama	Rubiaceae	OSB053	T	R, L	1	Sudan(Eisawi et al., 2022)	No reports
54	*Sida alba* L.	Akeyoyeyo akatono (Lg)	Malvaceae	OSB054	S	L	1	Reported for the 1st time	No reports
55	*Spathodea campanulata* P. Beauv.	Kifabakazi (Ls)	Bignoniaceae	OSB055	T	SB, R	2	Kenya, Guinea, Ivorycoast(Padhy, 2021)	ursolic acid, tomentosolic acid, 20β-hydroxyursolic acid, verminoside, specioside, spathoside, kaempferol, and β-sitosterol-3-acetate(Padhy, 2021)
56	*Steganotaenia araliacea* Hochst.	Ebusubus (At)	Apiaceae	OSB056	T	R	1	Eriteria(Demoz et al., 2015)	No reports
57	*Syzygium cumini* (L.) Skeels	Jambula (Lg)	Myrtaceae	OSB057	T	SB	1	India(Ayyanar and Subash-Babu, 2012), Uganda (Ssenyage et al., 2015)	anthocyanins, glucoside, ellagic acid, isoquercetin, kaemferol and myricetin, jambosine, antimellin(Ayyanar and Subash, 2012)

(*continued on next page*)

Table 1 (*continued*)

SN	Scientific name	Local Name (Language)	Family	Voucher Number	Plant form	Part used	Frequency of mention	Previous reports	Phytoconstituents responsible
58	*Tamarindus indica* L.	Aryawat (Sa) Omukooge (Lg)	Fabaceae	OSB005	T	F, SB, L	7	Uganda, Kenya(Havinga et al., 2010)	linonene and benzyl benzoate, n-hexacosane, eicosanoic acid, βsitosterol, (+)-pinitol. octacosanyl ferulate, 21-oxobehenic acid, apigenin, catechin, procyanidin B2, along with taxifolin, eriodictyol and naringenin(Meher et al., 2014)
59	*Tylosema fassoglensis* (Kotschy ex Schweinf.) Torre & Hillc.	Kiyugeyuge (Ls)	Fabaceae	OSB010	H	WP, R	3	Zimbabwe(Maroyi, 2023)	No reports
60	*Urena lobata* L.	Mutamatama	Malvaceae	OSB060	T	R	1	Nigeria(Omonkhua and Onoagbe, 2010)	alkaloids, flavonoids, saponins and tannins(Islam et al., 2015)
61	*Zea mays* L.	Kasoli (Lg)	Poaceae	OSB061	H	F	1	China(Li et al., 2004)	No reports

Key: **Plant parts**; F: Fruit, R: Root, SB: Stem bark, Fl: Flower, WP; Whole plant; S: Seed,.
Language; Lg: Luganda, Ls: Lusoga, At: Ateso, Sa: Sabiny, Lu: Lugishu, Lo: Luo.
Plant form; T: TREE, H: Herb, S: Shrub.

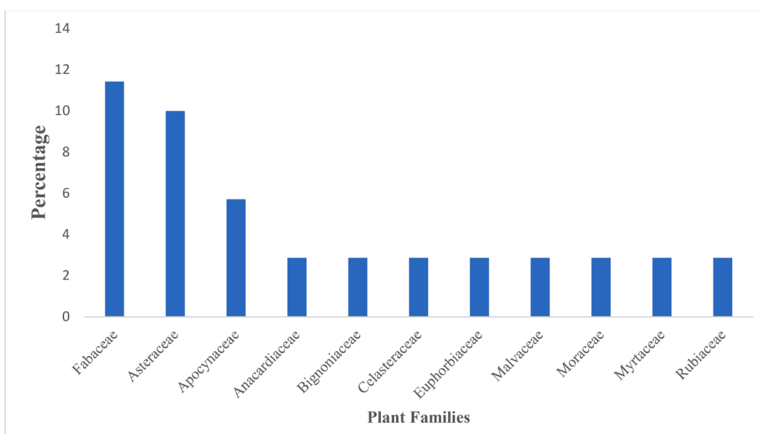

Fig. 3. Distribution of plant species used in the management of diabetes mellitus in Eastern Uganda in the different botanical families.

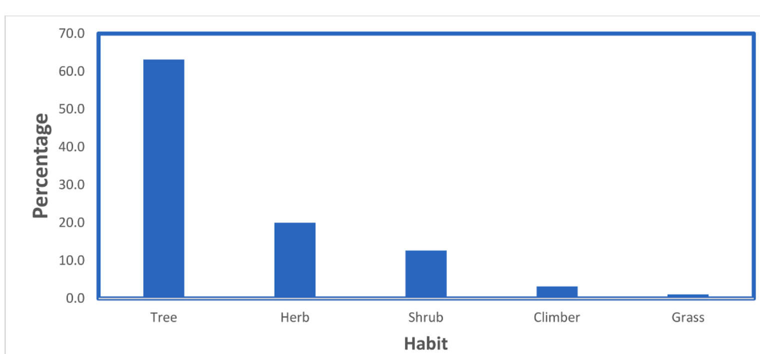

Fig. 4. Plant form (habit) of the medicinal plant species used in the management of diabetes mellitus in Eastern Uganda.

with similar bioactivity are needed. Combinations of medicinal plants (polyherbal formulations) were generally preferred to prepare herbal therapies for DM as opposed to single plants. The phytochemicals from the different plant species when combined act synergistically to bring about an enhanced pharmacological effect and hence better efficacy than when used singly (Yang et al., 2014). The oral preparations were predominant because the oral route is convenient to use (Bandaranayake, 2006). But also, probably the herbalists cannot prepare formulations to be administered by parenteral routes (Obakiro et al., 2020). Dose determination and administration was a huge challenge among the herbalists as the methods used were unreliable, inconsistent and not based on any scientific evidence. There is therefore a likely danger of either under dose or over dose the patients with likely consequences of therapeutic failure or toxicity respectively (Obakiro et al.,

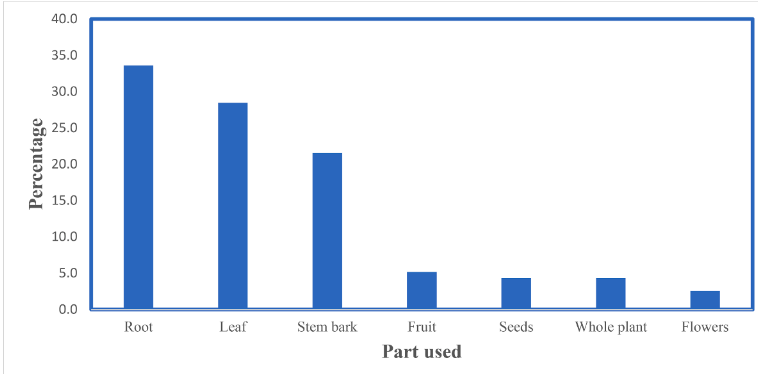

Fig. 5. Plant parts used in the preparation of herbal medicine for management of diabetes mellitus in Eastern Uganda.

2021b; Anywar et al., 2021) The packaging materials used to store the herbal medicine as well as the preparation procedure were prone to contamination by pathogenic microorganisms and toxic chemicals. Standardization of the preparation procedure, packaging and dosages of herbal medicines need to be enhanced and monitored by regulatory authorities.

Most of the plant species were from the families Fabaceae and Asteraceae. In the Democratic Republic of Congo and Tanzania, the family Fabaceae was also ranked first and second while in India family Asteraceae was ranked highest to provide medicinal plants for DM (Hussain et al., 2018; Kasali et al., 2021a; Peter et al., 2021). Biosynthetic pathways in these families are known to generate secondary metabolites with anti-hyperglycemic and antidiabetic properties (Peter et al., 2021b). Eleven of the commonly mentioned plant species have been scientifically validated and proved to possess significant anti-hyperglycemic and /or antidiabetic activity using either in *vitro* or animal models (Table 2). This implies that it is highly probable that the herbal medicine prepared by the herbalists for DM is efficacious against DM. However, since phytochemical composition can vary due to changes in soil chemistry, geography and climate, there is a need to confirm the antidiabetic activity of the plants(Karalija et al., 2022).

Loss of medicinal plants and other biodiversity is escalating globally due to climate change and anthropogenic activities (Anywar et al., 2020). Poverty in the region is the main driver of rampant deforestation that has accelerated forest loss, Uncontrolled deforestation has also contributed to prolonged droughts experienced in the region exacerbating the loss of vital medicine plants. It was also reported that charcoal burning, construction, firewood and prolonged droughts were responsible for the decline in plant diversity in Ethiopia (Yimam et al., 2022).

In a nutshell, addressing the challenges to medicinal plants in Eastern Uganda requires a holistic approach that involves community engagement, conservation efforts, scientific research, and policy interventions. Collaboration between local communities, government agencies, researchers, and conservation organizations are essential to promote sustainable practices, preserve traditional knowledge, and ensure the continued availability and effectiveness of medicinal plants for future generations.

4.1. Future perspectives of this study

The study's findings will contribute to the integration of traditional herbal medicine into mainstream healthcare systems. As evidence-based data on the efficacy and safety of specific medicinal plants becomes available, healthcare practitioners may consider incorporating these herbal remedies into diabetes management protocols. This integration can provide more comprehensive and culturally sensitive healthcare options for diabetes patients in Eastern Uganda.

Furthermore, the findings of this study may pave the way for further research into pre-clinical studies and clinical trials to validate the antidiabetic properties of specific plants reported. The development of evidence-based herbal therapies can lead to the formulation of standardized herbal products that meet quality and safety standards. These products can offer alternative or complementary options to conventional antidiabetic medications.

Documenting the medicinal plant species used for diabetes management in Eastern Uganda can also contribute to the conservation of these valuable resources. This would promote sustainable harvesting practices and cultivation of the reported medicinal plants ensuring their long-term availability and ecological preservation.

The study can serve as a foundation for capacity-building initiatives, fostering collaboration between traditional healers, herbalists, and modern healthcare practitioners. The documentation of traditional knowledge in the ethnobotanical study can empower local communities by recognizing and validating their traditional healing practices. Acknowledging the cultural significance of herbal medicine can strengthen community identity and promote the preservation of indigenous knowledge.

The evidence generated from the ethnobotanical study can inform policymakers about the significance of traditional medicine in healthcare.

5. Conclusion

A wide range of medicinal plants in Eastern Uganda with claimed antidiabetic properties are being used to prepare unstandardized herbal therapies. Scientific studies to validate the antidiabetic potential as well as the phytochemistry and toxicology of the identified plants and the herbal remedies are needed to discover novel molecules and standardization of the herbal therapies for effective management of DM.

Ethics approval and consent to participate

The protocol for this study was reviewed and approved by the Busitema University Faculty of Health Sciences Research and Ethics Committee (BUFHS-2022–40). All respondents were asked for their consent and had to sign a prior informed-consent form after the objectives and possible consequences of the study had been explained to them. The prior informed consent (PIC) was translated into five different four languages (Ateso, Sabiny, Luganda and Lusoga). Permission to access the participants for this study was granted by the local area administration.

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Table 2
Reported anti-hyperglycemic and/or antidiabetic activity of some of the identified plants species in Eastern Uganda.

Plant species	Family	Part used	Solvent	Antidiabetic activity	References
1. Aloe vera	Asphodelaceae	L	No extraction	The juice significantly reduced levels of fasting blood glucose within two weeks and of triglycerides within four weeks. /	(Babu et al., 2021; Bunyapraphatsara et al., 1996; Haghani et al., 2022)
2. Annona muricata	Annonaceae	F and L	Ethanol, Water	The leaf extracts showed hypoglycemic activity in murine models. There is a positive correlation between tannins, flavonoids and triterpenoids content and the inhibition of a-glucosidase. Flavonoids inhibit a-glucosidase through hydroxylation bonding and substitution at the b ring. This inhibition decreases carbohydrate hydrolysis and glucose absorption and inhibits carbohydrates metabolism into glucose. Additionally, glycemic index (GI) and glycemic load (GL) have been reported for *A. muricata* fruit. GI and GL are considered low for A. muricata, which agrees with its hypoglycemic potential.	(Adewole and Caxton-Martins, 2006; Y. Gavamukulya et al., 2017; Hardoko et al., 2015)
3. Carica papaya	Caricaceae	F, SB, L	Water	The aqueous leaf extract (400 mg/kg body weight) showed a significant reduction (P<0.01) in blood glucose level and serum lipid profile levels in alloxan-induced diabetic rats as compared with the control. A dose of 1000 mg/kg of papaya leaf ethanol extract is more effective in reducing blood glucose levels in diabetic Wistar mice compared to 2 mg/kg body weight of glibenclamide.	(Maniyar and Bhixavatimath, 2012) (Olikhah TI et al., 2020)
4. Catharanthus roseus	Apocynaceae,	WP	Ethanol	The ethanolic extract showed some antidiabetic effect on STZ-induced diabetes as a result of complex mechanisms of GLUT2 & 4 gene mRNA expression	(Al-Shaqha et al., 2015)
		SB	Water	The stem aqueous fraction showed the best hypoglycemic activity which was comparable to Tolbutamide.	(Vega-Ávila et al., 2012)
5. Citrus limon	Rutaceae	L	Ethanol	The ethanol and hexane extracts significantly decreased blood glucose levels, cholesterol and LDL.	(Halalsheh et al., 2022)
6. Entada abyssinica	Fabaceae	L	No extraction (Powder used)	*E. abyssinica* effects on serum glucose level and malondialdehyde levels were significant in diabetic treated compared to diabetic control (6.7 ± 0.81 vs. 16.2 ± 1.6 mmol/L and 10.08±0.61 vs. 16.44±3.00 μmol/L)	(Muhammad and Ummahani, 2014)
7. Erythrina abbyssinica	Fabaceae	SB	Water	The aqueous extract showed significant antihyperglycemic activity at a dose of 500 mg/kg in rats using the oral glucose tolerance test (OGTT) with a hyperglycemia inhibition factor of 38.5% as compared to glibenclamide (49.6%). Cohort studies showed reduced risk of type 2 diabetes associated with high intakes of dietary flavonoids from *E.abyssinica*	(Ndinteh, 2018)
8. Kigelia Africana	Bignoniaceae	F	Water	Oral &intraperitoneal administration of the aqueous and ethyl acetate leaf extract (100, 200 $300 mg/kg) caused a statistically significant dose-independent reduction in plasma glucose level in alloxan-induced diabetic mice.	(Njogu et al., 2018)
9. Maytenus senegalensis	Celastraceae	R & SB	Methanol	The crude extract showed 29.75%. reduction in fasting glucose levels compared to 27.03% reduction when glibenclimide was used. after 2 weeks	(Mann et al., 2014)
10. Persea Americana	Lauraceae	S	Water	The aqueous extract showed antidiabetic activity through inhibition of β-cell death and protein kinase B (PKB/Akt) pathways	(Ojo et al., 2022)
		L	Ethanol and water	The hydroalcoholic extract has anti-diabetic properties and possibly acts to regulate glucose uptake in liver and muscles by way of PKB/Akt activation	(Lima et al., 2012)
		L	Methanol	Methanolic extract reduced the AIP (atherogenic index of plasma) by 45%. Histopathological analyzes of the pancreas showed regeneration of islets of Langerhans. The methanolic extract was the most effective in preventing intestinal glucose uptake up to 60.90%	(Kouamé et al., 2019)
11. Tamarindus indica	Fabaceae	F, SB, L	Water	Aqueous extract of seed of T. indica had potent antidiabetogenic activity in streptozotocin (STZ)-induced diabetic male rats.	(Maiti et al., 2004)

Key: **Plant parts**; F: Fruit, R: Root, SB: Stem bark, Fl: Flower, WP; Whole plant; S: Seed.

CRediT authorship contribution statement

Samuel Baker Obakiro: Conceptualization, Funding acquisition, Writing – original draft, Investigation, Project administration. **Kenedy Kiyimba:** Data curation, Writing – original draft, Investigation, Writing – review & editing. **Tonny Wotoyitidde Lukwago:** Data curation. **Jalia Lulenzi:** Writing – original draft, Data curation. **Richard Oriko Owor:** Data curation, Writing – review & editing. **Moses Andima:** Data curation, Writing – review & editing. **Joseph Francis Hokello:** Data curation. **Carol Kawuma:** Data curation. **Gauden Nantale:** Data curation. **Dan Kibuule:** Writing – original draft, Funding acquisition. **Godwin Anywar:** Validation, Visualization, Writing – review & editing. **Paul Waako:** Writing – original draft, Funding acquisition, Supervision. **Yahaya Gavamukulya:** Writing – original draft, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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