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Ethnobotanical survey of antidiabetic plants used by Maasai traditional practitioners in Monduli District, Arusha, Tanzania

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ABSTRACT

Traditional medicines, particularly medicinal plants, are valuable sources of antidiabetic therapy for many rural populations. However, there is limited documentation of the plants used by rural traditional healers, including the Maasai traditional practitioners (MTPs) in Tanzania. This study aims to document the traditional knowledge and antidiabetic plants used by MTPs in Monduli District, Arusha, Tanzania. An ethnobotanical survey was conducted from January to July 2024 among 55 MTPs in Monduli District, Arusha, Tanzania. The majority (70.9%) of MTPs had over 20 years of traditional experience of practice. The MTPs diagnose diabetes through signs and symptoms, and they identified physical inactivity (36%), high blood pressure (19%), and unhealthy diet (16%) as key risk factors for the development of diabetes. More than half (58.2%) of MTPs treat 1–10 diabetic patients per month. The study identified 41 species belonging to 21 plant families. The family Fabaceae represented the highest number of species (17%), followed by Combretaceae, Lamiaceae, Rutaceae, and Solanaceae (7%). The most frequently cited antidiabetic plants were *Rhamnus staddo* (RFC = 0.56, FL = 80.6), *Zanthoxylum chalybeum* (RFC = 0.49, FL= 85.2), *Physalis peruviana* (RFC = 0.49, FL = 77.8), *Albizia anthelmintica* (RFC = 0.47, FL= 80.8), and *Pappea capensis* (RFC = 0.47, FL = 69.2%). Roots (41%) and barks (31%) were the most harvested plant parts. Decoction was the primary method of remedies preparation with oral administration being preferred route. This study highlights the extensive antidiabetic knowledge of MTPs in the treatment of diabetes using medicinal plants. Of the 41 identified plants, over 81.5% have demonstrated promising antidiabetic activity in preclinical studies; however, further research is needed to isolate their bioactive compounds and elucidate their mechanisms of action.

Introduction

Diabetes mellitus is a group of metabolic disorders characterized by hyperglycemia, resulting from insufficient insulin production in pancreatic cells or the inability of body cells to utilize the produced insulin [1]. Over a period of time, uncontrolled diabetes may cause damage to body organs and cause health complications such as kidney failure, heart disease, diabetic foot disease, low vision, and nerve damage [1,2]. Diabetes affects many people worldwide, irrespective of their continent, age group, and gender [2]. According to the International Diabetes Federation's 10th edition of Diabetes Atlas, over 537 million adults (aged 20–79 years)

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worldwide were living with diabetes in 2021. This number is projected to rise to 1.3 billion by 2050 unless effective interventions are implemented [3]. Over three quarter (80%) of people affected with diabetes are living in developing countries [3]. The global mortality rate from diabetes and its complications has increased from 4.2 million in 2019 to 6.7 million in 2021 [1,2]. The number of diabetes cases is expected to grow by 46% due to population increase in many developing countries, including Tanzania [3]. Currently, approximately 3 million individuals are affected with diabetes in Tanzania [3]. The age-adjusted prevalence of diabetes among adults aged 20–79 years has risen from 9.1% in 2012 to 10.3% in 2021 [2,4].

To address the growing trends of diabetes, it is crucial to focus on prevention, early screening, prompt diagnosis, and continuous care with regular monitoring and evaluation [5]. The treatment of this disorder has predominantly depended on pharmacological therapies. However, the current available antidiabetic drugs, such as metformin, sulfonylureas, and pioglitazone, are associated with adverse health effects. These include gastrointestinal discomfort, hypoglycemia, bladder cancer, heart failure and weight gain [6,7].

Natural products, particularly plant-derived products, have gained significant interest as key sources of antidiabetic therapy in all around the world as potential alternatives to conventional antidiabetic drugs [7]. More than 80% of people, especially in rural areas, rely on traditional medicine as their first choice for antidiabetic therapies. This preference is due to its availability, affordability, and perceived fewer side effects [8,9]. In Tanzania, traditional medicine is also widely used to manage diabetes. Over 77.1% of diabetic patients use medicinal plant therapies [8]. Despite the numerous indigenous plants used in rural Tanzanian communities to treat diabetes, their use is poorly documented. Additionally, these plants may be declining due to the introduction of modern drugs, urbanization, and climate change [9]. The Maasai, a pastoralist community found in Northern Tanzania and Southern Kenya, are renowned for their traditional use of medicinal plants to address various health issues [10]. Despite this, there is a lack of comprehensive research on the specific plants they use for managing diabetes, as well as on how these remedies are prepared, the dosages used, and their methods of administration. Traditional knowledge, including the use of medicinal plants for diabetes, is often passed down orally from older generations to younger ones. If not properly documented, this valuable knowledge may be lost [13–15]. To address this gap, this study was conducted to identify and document the antidiabetic plants used by MTPs in Monduli District and explore how well these traditional practices align with current scientific evidence. This documentation is essential not only for the preservation of indigenous knowledge but also for the identification of potentially valuable medicinal plants which traditional uses are threatened by overharvesting and evolving inheritance practices within the Maasai community.

Materials and methods

Description of the study site

This study was conducted in the Monduli District Council-Arusha region located in Northern Tanzania (Fig.1). The study site was purposefully selected because it is among the original lands of the Maasai community in Tanzania. Monduli District Council is one

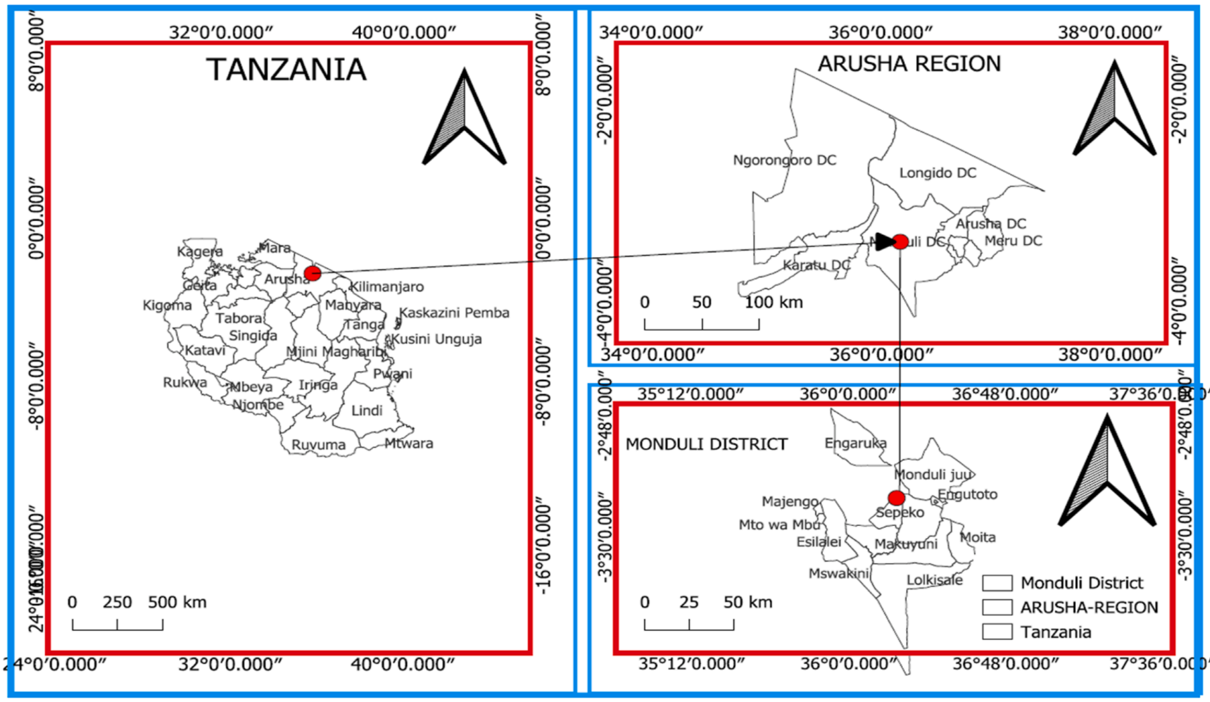

Fig. 1. A map of Tanzania indicating the location of study area, Monduli District-Arusha.

among the seven councils of the Arusha Region situated between latitude and longitude 03°18′10.44″S and 36°26′43.08″E, respectively. It is bordered to the north by Longido District, to the east by Arusha Rural District, to the south by the Manyara Region, and to the west by Ngorongoro District and Karatu District [12]. The district has three divisions (Manyara, Makuyuni, and Kisongo) with 20 wards and 62 villages. The district covers an area of 6993 km^2, of which 6290.62 km^2 is an island, 128.38 km^2 is covered with water, 3983.855 km^2 is grazing land, 1055.475 km^2 is arable land and 374.965 km^2 is forest land. Monduli is among the driest districts in Tanzania, with warm climates in low altitude and cool climates in high altitude areas. Temperatures range from 20 °C to 35 °C, while rainfall ranges from $<$ 500 mm to 900 mm in lowlands and high elevations. The climate is divided into the highlands, flat and rolling plains, and the Rift Valley. Approximately 105,547.5 hectares are potentially arable land, and 87,632.5 hectares (13.65%) are under cultivation.

According to the 2022 National Population Census, the total population was 227,585, of which 104,742 were male and 122,843 were female [13] Over 97% of the population is engaged in livestock keeping and agriculture as the main economic activities [14]. The major ethnic groups are the Maasai (40%) and Waarusha (20%), whose main economic activities are livestock keeping and farming. The Maasai live a unique life in a highly distinctive manner, such as cultural dietary practices, dressing, pastoral activities, and self-care management in human and cattle conditions [15].

Community engagement and participant selection

Before data collection, meetings were held with village leaders to explain the objectives of the study and the criteria for participant selection. Verbal and written informed consent were obtained from all participants prior to their involvement in the study. Participants were selected using purposive sampling, targeting individuals with extensive knowledge of traditional medicinal practices for treating diabetes. The inclusion criteria were: Maasai traditional healers, clan elders, traditional birth attendants, and adults aged 30 years or older with long-standing experience in traditional medicine. Exclusion criteria include non-Maasai traditional healers, traditional healers who engage in witchcraft practices, and individuals under the age of 30 years.

Data collection

An ethnobotanical survey was conducted from January to July 2024 in 13 Maasai villages located in Monduli District, Northern Tanzania. A total of 55 participants who met the study criteria and consented to participate were included in the study. Data collection employed a semi-structured questionnaire derived from a previously published article [16] with minor modifications to align with the objectives and context of the current study. These modifications included the categorization of respondents into specific age groups, the inclusion of traditional healers, traditional birth attendants, and elders knowledgeable in traditional practices, and the addition of questions related to potential overdose and specific precautions taken during treatment, particularly those based on the patient's age group, gender, and underlying health conditions.

The questionnaire gathered information on socio-demographic characteristics, awareness of diabetes, traditional medicine practices, names of antidiabetic plants, plant parts used, methods of preparation, modes of administration, and dosage. It was originally prepared in English and translated into Swahili. For participants who could not understand Swahili, a Maasai translator interpreted the questions into Maa. All responses were recorded in English and handled with strict confidentiality.

Identification and voucher specimen

After the analysis of survey data, the researcher and botanist undertook a field visit with a guide from a traditional healer to identify and collect plant specimens mentioned by the participants during the survey. Two specimens for each plant were collected, assigned voucher numbers, and pressed. Drying and mounting of plant specimens were done at Tanzania Plant Health and Pesticides Authority (TPHPA), Arusha, Tanzania. The specimens were stored at the TPHPA National Herbarium-Arusha and NM-AIST herbarium, Arusha, Tanzania.

Data analysis

Survey data were coded into Microsoft Excel version 2013, cleaned, and exported into Statistical Package for the Social Sciences (SPSS) version 21.0 for analysis. Descriptive statistics were conducted to determine the proportions, percentages, and frequencies of the collected information.

Total use value (UVs): The assessment of ethnobotanical relevance, as reported by traditional healers, was conducted using a method adapted from a previously established approach [10].

$$\text{Total use value}(\text{UVs}) = \frac{\sum \text{UVis}}{\text{ni}}$$

where $\mathbf{UV_{is}}$ represents the Use Value of each species mentioned by each MTPs while **n** represents the number of interviews carried out for one informant.

Fidelity level (FL): FL represents the proportion of MTPs who independently cited a species for the same primary use, relative to all informants who mentioned that species for any purpose. FL was calculated following the method as described previously [16].

$$\text{Fedelity level (FL \%)} = \frac{\text{Np}}{\text{N}} \times 100$$

Where **Np** is the number of MTPs that claim the use of a plant species for treating diabetes, and **N** is the total number of MTPs that use the plant species for any use.

Relative frequency of citation (RFC): RFC represents the local importance of each plant species and is calculated using the following formula [12].

$$RFC = \frac{FC}{N}$$

Where **FC** denotes the number of MTPs reporting the use of particular species and **N** is the total number of informants.

Ethical approval

Ethical approval for conducting this research was obtained from the Northern Tanzania Health Research Ethics Committee (KNCHREC00012/01/2024) and Monduli District Council (HW/MON/R5/1 VOL IX/250). Oral and written informed consent were obtained from each participant before conducting the interview.

Results

Socio-demographic characteristics of the study participants

As illustrated in Table 1, the study enrolled 55 MTPs, comprising 46 (84%) males and 9 (16%) females, and a majority or 24 (44%) were aged >60 years. The 95% of the MTPs were married, 90.9% were Christian, and 36% had attained primary education. All participants (100%) practiced agro-pastoralism as their main economic activity. According to the data presented in Table 1, >45% of

Table 1
Socio-demographic characteristics of the study participants.

Variable	Frequency n (%)
Gender:	
Male	46 (84%)
Female	9 (16%)
Age group:	
30–45 years	12 (22%)
46–60 years	19 (34%)
>60 years	24 (44%)
Marital status:	
Married	52 (95%)
Divorced	1 (1%)
Widow	2 (4%)
Religion:	
Christian	50 (90.9%)
Muslim	1 (1.8%)
No religion	4 (7.3%)
Ethnicity:	
Maasai	55 (100 %)
Occupation:	
Agro-pastoralist	55 (100%)
Education level:	
No education	25 (46%)
Primary education	20 (36%)
Secondary educ	10 (18%)
Maasai Traditional Practitioner groups:	
Traditional healers (TH)	23 (41.8%)
Traditional birth attendants (TBA)	7 (12.7%)
Traditional Knowledgeable Leader (TKL)	25 (45.5%)
Year of experience:	
0–5 years	6 (10.9%)
6–10 years	6 (10.9%)
11–15 years	1 (1.8%)
16–20 years	3 (5.5%)
> 20 years	39 (70.9%)
Ways of acquiring traditional knowledge:	
Inherited from parents/orpul training	55 (100%)
Attended any training on traditional practices:	
Yes	10 (18.2%)
No	45 (81.8%)

the MTPs were traditional knowledge leaders, while 41.8% were traditional healers, and 12.7% were traditional birth attendants with knowledge of medicinal plants. More than 39 (70.9%) of the MTPs had over 20 years of experience in traditional practices, and all had inherited their knowledge from their ancestors (Table 1). Only 18.2% of the MTPs had received additional formal training in traditional medicine practice.

Traditional knowledge and diabetic awareness among MTPs

As shown in Fig. 2, the levels of traditional knowledge on diabetes treatment among MTPs were categorized as low (total scores < 9), medium (total score $= 9$), and high (total scores > 9). The results indicated that 36.4% of MTPs possessed low levels of traditional knowledge, 27.3% had medium levels, and 36.4% demonstrated high levels of knowledge related to diabetes treatment (Fig. 2). Furthermore, over half, 34 (61.8%), of the MTPs reported that diabetes was rare among the Maasai community, and 49 (81.1%) relied on signs and symptoms for diagnosing diabetic patients (Table 2). Most of MTPs or 32 (58.2%) treated 1–10 diabetic patients per month. The MTPs identified several risk factors associated with the development of diabetes, including physical inactivity (36%), high blood pressure and high blood cholesterol (19%). All MTPs noted that they were not recommending patients to use herbal remedies alongside pharmaceutical drugs. According to results indicated in Table 2, MTPS were also able to identify reasons for not recommending herbs with pharmaceutical drugs, such as death (69%), excessive vomiting (16%), severe diarrhea (8%), and reduced drug effectiveness (7%).

Relationship between socio-demographic characteristics and traditional knowledge of MTPs

The relationship between socio-demographic characteristics and traditional knowledge among MTPs was examined using correlation analysis. As presented in Table 3, gender demonstrated a very weak negative correlation with traditional knowledge ($r = -0.058, p = 0.676$), which was not statistically significant. Similarly, age ($r = 0.191, p = 0.162$), education level ($r = 0.054, p = 0.615$), and years of experience in traditional practices ($r = 0.190$, $p = 0.164$) all showed weak positive correlations with traditional knowledge; however, none of these associations were statistically significant. In contrast, marital status exhibited a moderate positive correlation ($r = 0.372$, $p = 0.005$) that was statistically significant, suggesting that married individuals are more likely to possess or engage with traditional knowledge related to medicinal plants for managing diabetes. Additionally, the MTPs group variable demonstrated a statistically significant negative correlation with traditional knowledge ($r = -0.410, p = 0.002$), indicating that certain practitioner groups may have less knowledge of or access to traditional medicinal practices for diabetes treatment.

Diversity of medicinal plants used in the treatment of diabetes

A total of 41 antidiabetic plant species, representing 21 plant families, were identified and recorded in this study, as presented in Table 4. Mostly utilized medicinal plants for treating diabetes includes *R. staddo* (RFC = 0.56, UV = 0.51, FL = 80.6), *Z. chalybeum* (RFC = 0.49, UV = 0.23, FL = 85.2), *P. peruviana* (RFC = 0.49, UV = 0.09, FL = 77.8), *A. anthelmintica* (RFC = 0.47, UV = 1.5, FL = 80.8), *P. capensis* (RFC= 0.47, UV= 0.65, FL= 69.2), *E. axillare* (RFC = 0.43, UV = 0.33, FL = 83.3), *A. nilotica* (RFC = 0.40, UV = 0.85, FL = 77.3), *A. volkensii* (RFC = 0.30, UV = 0.67, FL = 70.6), *C. schefflera* (RFC = 0.30, UV = 0.67, FL = 64.7), *V. simplicifolia* (RFC = 0.29, UV = 0.34, FL = 62.5) and *R. ussambaransis* (RFC = 0.27, UV = 0.16, FL = 60). As depicted in Fig. 3, the family Fabaceae, with seven species, represented the highest number of species (17%), followed by Combretaceae, Lamiaceae, Rutaceae, and Solanaceae, each with three species (7%). The families Apocynaceae, Asteraceae, Euphorbiaceae, Meliaceae, Myrsinaceae, and Rhamnaceae each had two species (5%).

Plant parts used to make herbal formulations

Fig.4 shows that MTPs use a variety of plant parts, including bark, fruits/seeds, leaves, roots, and stems, in the preparation of antidiabetic treatments. The most commonly used plant part were the roots (41%), followed by the bark (31%), leaves (19%), and

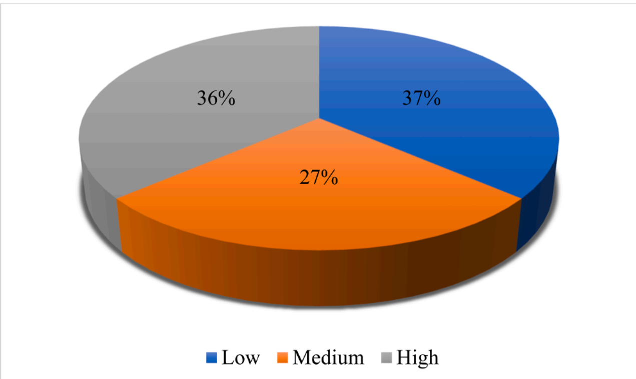

Fig. 2. Traditional knowledge levels among MTPs for diabetes treatment.

Table 2
Diabetes awareness among MTPs in Monduli District-Arusha, Tanzania.

Variable	Frequency n (%)
How common are diabetic cases in this community (Maasai):	
Common	21 (38.2%)
Rare	34 (61.8%)
Ways of diagnosing diabetes:	
Signs & symptoms	49 (81.1%)
Patient history	4 (7.3%)
Evidence from the hospital	2 (3.6%)
The average number of patients attended in a month:	
1–10 patients	32 (58.2%)
11–20 patients	20 (36.4%)
>20 patients	3 (5.5%)
Factors associated with diabetes:	
High blood cholesterol	5 (16%)
Physical inactivity	11 (36%)
Unhealthy eating	5 (16%)
High blood pressure	6 (19%)
Excess bodyweight	4 (13%)
Advice patient to use herbs and pharmaceutical drugs concurrently:	
Yes	0
No	55 (100%)
Reasons for not recommending patients to use herbs and pharmaceutical drugs concurrently:	
Death	42 (69%)
Excessive vomiting	10 (16%)
Excessive diarrhea	5 (8%)
Reduce drug effectiveness	4 (7%)

Table 3
Relationship between socio-demographic characteristics and traditional knowledge of MTPs.

Variables	Sub-groups	Level of traditional knowledge			Correlation coefficient	*p*-values
		Low (total scores < 9)	Medium (total scores = 9)	High (total scores > 9		
Gender	Male	16	13	17	−0.058	0.676
	Female	4	2	3		
Age	30–45	6	3	3	0.191	0.162
	45–60	8	4	7		
	>60	6	8	10		
Marital status	Married	18	15	19	0.372**	0.005
	Divorced	1	0	0		
	Widow	1	0	1		
Education level	No education	6	10	9	0.054	0.615
	Primary education	7	4	9		
	Secondary education	3	4	3		
Years of experience	0–5 years	4	1	1	0.19	0.164
	6–10 years	2	3	1		
	11–15 years	0	0	1		
	16–20 years	1	1	1		
	>20 years	13	10	16		
Maasai practitioners' groups	Traditional healers	9	4	10	−0.410**	0.002
	Traditional birth attendant	2	2	3		
	Knowledgeable elders/ leaders	9	9	7		

** Correlation is significant at the level of *p* value <0.01; *Correlation is significant at the level of *p* value <0.05.

fruits/seeds (6%) (Fig. 4).

Growth form of the antidiabetic plants

As illustrated in Fig. 5, the main life forms of the antidiabetic plant species were trees (45%), shrubs (28%), herbs (22%), and climbers (5%).

Table 4
Medicinal plants commonly used by MTPs in treating diabetes in Monduli District, Arusha, Tanzania.

Family name	Botanical name	Local name	PU	Preparation	Dose	MOD	GRF	HAT	CT	FL %	RFC	UV	C. No
Aloeaceae	*Aloe volkensii*	Osukuroi	LV	Two drops of leaf sap are added to one glass of water or fresh milk.	One glass taken three times per day	Oral	HB	Wild	17	70.6	0.31	0.67	WPR88
Anacardiaceae	*Lannea schweinfurthii*	Orpande	BK, RT	Dried and powdered bark/roots are boiled in 2 L of water, and the decoction is taken	1/2 L taken three times per day	Oral	TR	Wild	5	40	0.09	0.2	WPR51
Apocynaceae	*Carissa spinarum*	Olamuriaki	ST, RT	Stem/root powder is boiled in 4 L of water, and the remaining 3 L decoction is added to the animal broth.	1/2 L taken three times per day	Oral	SH	Wild	11	36.4	0.2	0.39	WPR16
	Secamone parvifolia (oliv.) Bullock.	Osinandei	RT	Pound roots and boil with 2 L of water; then the decoction is taken	1/4 L taken three times per day	Oral	CL	Wild	4	25	0.07	0.31	WPR08
Asteraceae	*Conyza pyrrhopappa* Sch.Buip.ex A. Rich.	Oltisia	LV, RT	The leaves are crushed and soaked in water, and the infusion is taken. Roots are dried, and the fine powder is boiled in water	1/2 L taken twice per day	Oral	SH	Wild	3	66.7	0.05	0.07	WPR35
	Sphaeranthus bullatus Mattf.	Orkipirelekima	LV	The leaves are crushed, dried, ground into a fine powder, and then boiled in water.	Taken frequently	Oral	HB	Wild	5	80	0.09	0.02	WPR46
Combretaceae	*Terminalia brown* Fresen.	Orbukoi	BK	The barks are pounded, dried, and ground into a fine powder, then boiled with water, and the decoction is taken.	Taken frequently	Oral	TR	Wild	8	37.5	0.14	0.03	WPR57
	Combretum molle G. Don.	Ormaroroi-orok	BK, RT	Decoction	1/4 tea cup taken three times per day	Oral	TR	Wild	10	40	0.18	0.04	WPR44
Euphorbiaceae	*Croton dichogamus* Pax.	Enjanipus	BK, RT	The barks and roots are pounded, dried, and ground into fine powder. Then, the powder is boiled with water/added to animal broth	1/2 L taken once after every three days	Oral	SH	Wild	5	60	0.09	0.07	WPR38
	Croton macrostamchyus Delile.	Oloiyapyap	LV	Fresh leaves are sliced and cooked as a vegetable	None	Oral	TR	Wild	5	40	0.09	0.2	WPR21
	Croton scheffleri	Enjani-emburkel	ST	Decoction	One tea cup taken once per day	Oral	SH	Wild	17	64.7	0.31	0.69	WPR66
Fabaceae	*Acacia xanthophloea* Benth.	Olerai-eibor	BK, RT	Decoction	1 L taken once per day	Oral	TR	Wild	3	66.7	0.05	0.11	WPR27
	Erythrina abyssinica	Oloponi	BK	Decoction	1/2 tea cup taken three times per day	Oral	TR	Wild	12	58.3	0.22	0.45	WPR19
	Acacia nilotica (L.) Willd. Ex Del.	Orkilorit	BK, RT	Barks and root powder are added to 2 L of hot water, and the decoction is filtered. The decoction is mixed with animal broth	1 cup taken once per day for seven days	Oral	TR	Wild	22	77.3	0.40	0.82	WPR26
	Senna didymobotrya (Fresen.) Irwin & Barneby	Ormapinu/ Osenetoi	LV	The leaves powder is soaked in hot water, and the infusion is taken.	1/4 L taken three times per day	Oral	TR	Wild	4	50	0.07	0.04	WPR22
	Acacia garadii/ thomasaii	Ormermenyi	BK, RT	The bark/roots powder is boiled with 3 L of water until it remains 1.5 L of decoction.	1/4 L twice per day	Oral	TR	Wild	2	40	0.04	0.11	WPR42
	Indigofera arrecta	Emuimbi	RT	The roots are dried and ground, the powder is boiled in 5 L of water, and the decoction is taken.	One tea cup taken three times per day	Oral	HB	Wild	1	100	0.02	0.05	WPR85

(*continued on next page*)

Table 4 (*continued*)

Family name	Botanical name	Local name	PU	Preparation	Dose	MOD	GRF	HAT	CT	FL %	RFC	UV	C. No
	Albizia anthelmintica Brongn.	Emukutani	BK, RT	The barks and roots decoction are added into 1 L of animal broth	1/2 cup taken twice per day	Oral	TR	Wild	26	80.7	0.47	1.2	WPR76
Flacourtiaceae	*Trimeria grandifolia*	Oledet	BK, RT	The bark/roots are crushed and boiled with water, and then decoction is taken	1/4 cup of tea taken three times per day	Oral	SH	Wild	6	83.3	0.11	0.22	WPR17
Gentianaceae	*Enicostema axillare* (Lam) A.Raynal	Enjani-engusero	LV	Fresh leaves are chewed once per day. The leaves are dried, ground and the powder is added to tea/water	1/4 L taken once per day	Oral	HB	Wild and farm	24	83.2	0.44	0.33	WPR75
Lamiceae	*Leonotis mollisima*	Orbibiai	LV	Fresh leaves are chewed twice per day. The powder of leaves is boiled with water, and the infusion is taken	½ tea cup taken twice per day	Oral	HB	Wild and farm	2	50	0.04	0.07	WPR53
	Plectranthus Sp	Orkaukau	LV	Chew the leaves and swallow the juice. The leaves are crushed and soaked in cold water, and the infusion is taken.	1/2 L taken twice per day and then used again after five days	Oral	HB	Wild	3	33.3	0.05	0.07	WPR37
	Ocimum gratissimum Forssk.	Ormanyinyikwai	LV	Fresh leaves are crushed and boiled in water The leaves are dried and ground, and then the powder is added to the tea	Taken frequently	Oral	SB	Wild	5	40	0.09	0.12	WPR18
Meliaceae	*Turraea robusta* Gürk.	Enjanie-ngahe	BK, RT	Fresh bark and roots/the powder of bark and roots are boiled with water. Then, animal broth is added to the decoction	1/2 L taken twice per day	Oral	TR	Wild	14	57.1	0.25	0.45	WPR06
	Azadirachta indica A. Juss.	Ormwarubaini	BK, LV	The bark/leaves are dried, and the powder is boiled in water. Fresh milk/honey is added into the decoction to neutralize bitterness	1/2 L taken three times per day	Oral	TR	Wild and farm	10	30	0.18	0.09	WPR36
Myrisinaceae	*Embelia schimperi* Vatke.	Olchani-onyoikie	RT	Roots decoction is added to animal broth	1 L taken once per day	Oral	SB	wild	11	54.5	0.2	0.54	WPR02
	Morella salicifolia	orkitalaswa	BK	The barks are crushed and boiled with water	1/2 tea cup taken once per day	Oral	TR	Wild	5	20	0.09	0.16	WPR03
Oleaceae	*Olea europeae*	Oloirieni	BK, RT	The bark, stem, and barks are pounded and boiled with water, and the decoction is taken	1/2 L taken twice per day	Oral	TR	Wild	10	20	0.18	0.42	WPR11
Plumbaginaceae	*Commicarpus plumbagineus* Standl.	Orng'eriandus	BK	The barks are dried, ground and the powder is boiled with 6 L of water	One tea cup taken three times per day for 21 days	Oral	HB	Wild	1	100	0.01	0.09	WPR33
Polygonaceae	*Rumex usambarensis* (Dammer)	Engaisijoi	RT	The roots are sliced, dried, and ground, then the powder is boiled in water	1/4 L taken twice per day	Oral	HB	Wild and farm	15	60	0.27	0.16	WPR30
Rhamnaceae	*Helinus mystacinus* (Aiton) Steud.	Olesupeni	BK	Fresh barks are crushed and boiled with water, then the decoction is added to the animal broth	1/2 L taken twice per day	Oral	CL	Wild	10	60	0.18	0.62	WPR09
	Rhamnus staddo A.Rich.	Engokola	RT	Decoction	One tea cup taken twice per day	Oral	TR	Wild	31	0.52	0.56	80.6	WPR10
Rutaceae	*Zanthoxylum chalybeum* Engl.	Oloisuki	BK, RT	Decoction	1/4 L taken twice per day	Oral	TR	Wild	27	85.1	0.49	0.27	WPR07
	Vepris simplicifolia	Orgilai	RT	Fresh bark is pounded and boiled with water	3/4 L twice per day	Oral	TR	Wild	16	62.5	0.29	0.35	WPR05
	Harrisonia abyssinica Oliv.	Endululu	BK, RT	The powder of dried bark/roots is boiled with water. Then, the decoction is added to the animal broth.	1/2 L taken twice per day	Oral	SB	Wild	8	37.5	0.14	0.33	WPR67

(*continued on next page*)

Table 4 (*continued*)

Family name	Botanical name	Local name	PU	Preparation	Dose	MOD	GRF	HAT	CT	FL %	RFC	UV	C. No
Salvadoraceae	*Salvadora persica* L.	Oremit	BK, ST	Decoction	1/4 L taken once after 14 days	Oral	TR	Wild	8	62.5	0.14	0.42	WPR82
Santalaceae	*Osyris lanceolata* Hochst.& Stend.	Olosesiai	RT	The roots are crushed and boiled in water.	1/4 tea cup taken three times per day	Oral	SB	Wild	5	20	0.09	0.18	WPR61
Sapindaceae	*Pappea capensis* Eckl. & Zeyh.	Endimigomi	BK	The bark is dried, ground to a fine powder, and boiled in water	One tea cup taken per day	Oral	TR	Wild	26	69.2	0.47	0.62	WPR39
Solanaceae	*Solanum incanum* L.	Oltulelei/ Endulelei	RT	Fresh/dried roots are crushed and boiled with 1 L of water until remain1/2 L of the decoction.	Adult: 1/2 L tea cup taken twice per day. Child:1 teaspoon taken twice per day	Oral	SB	Wild	3	33.3	0.05	0.05	WPR23
	Physalis peruviana L.	Tamtam	FR, LV	Fruits are consumed/crushed, and the juice is filtered.Leaves are chewed	One tea cup taken three times per day	Oral	HB	Wild	27	77.7	0.49	0.09	WPR48
	Withania somnifera L. Dunal	Olesayeti	LV, RT	The roots are boiled with water, and fresh milk is added to the decoction	One tea cup taken three times per day	Oral	SB	Farm	13	81.8	0.24	0.42	WPR27

Abbreviations used: PU=Part used, MOD=Mode of administration, GRF=Growth form, HAT=Habitat, CT=Citation, UV=Use value, C.No=Collection number LV= Leaves, BK=Bark, RT= Root, FR=Fruit, ST=Stem, TR= Tree, HB=Herb, SB=Shrub, CL=Climber, FL = Fidelity level, RFC= Relative frequency of citation.

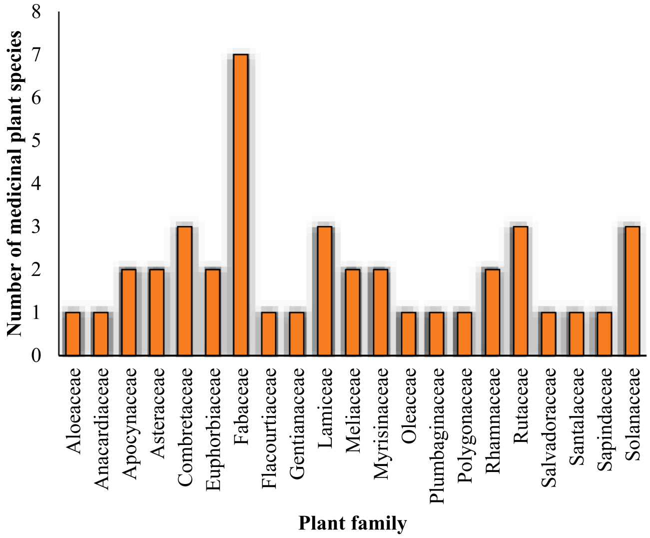

Fig. 3. Families of plants used in treating diabetes by MTPs in Monduli District, Arusha, Tanzania.

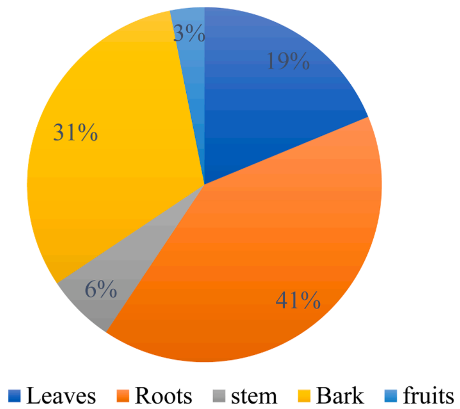

Fig. 4. Common plant parts used in treating diabetes in Monduli District, Arusha, Tanzani.

Discussion

Traditional knowledge plays a crucial role in healthcare, particularly for rural populations in developing countries. In the current study, >39 (70.9%) of the MTPs had over 20 years of experience in traditional medicinal practices, with all of them having inherited their knowledge from their ancestors. Similar experiences were observed in previous studies conducted on the same ethnic group in

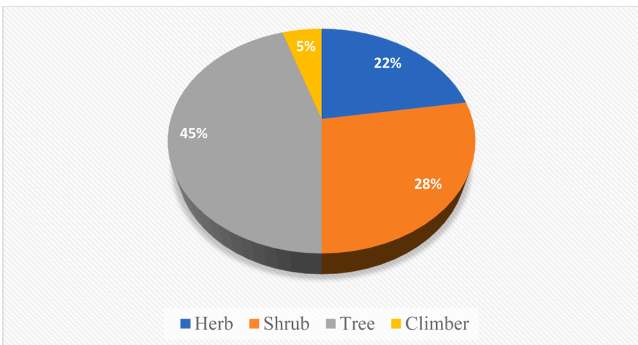

Fig. 5. Growth forms of medicinal plants used in treating diabetes by MTPs in Monduli District,Arusha, Tanzania.

different parts of Kenya and Tanzania [12,14,16,48,55]. The strong traditional healing practices exemplified by MTPs are highly associated with the passing on of traditional knowledge from the older to younger generations through storytelling and traditional training/ceremonies (called *orpul* in Maa language) [12,16]. Although diabetes was reported to be uncommon among the Maasai community, 58% of MTPs reported treating 1–10 diabetic patients who sought care within one month. These findings align with previous studies in Ilkisonko and Southern Kajiado districts in Kenya [14,48], but contrast with reports from Nyeri County, Kenya, where fewer diabetic patients sought traditional care [18]. The high number of diabetic patients seeking care from MTPs in Monduli district can be largely attributed to their extensive experience in ethno-medicine, which is passed down from elders as they grow and mature from childhood [12,14,48]. Furthermore, the MTPs in this study had a thorough understanding of diabetes, including its causes, symptoms, diagnostic methods, management, and treatment approaches. However, only marital status and Maasai traditional groups showed significant correlation with socio-demographic characteristics of MTPs. Signs and symptoms of diabetes were used mostly by 49 (81%) traditional healers as a primary diagnostic method of diabetes. These findings align with studies in Southwest Nigeria and Tanzania [19,27,83], in contrast to those in Kenya, where traditional healers use modern diagnostic methods, like laboratory blood sugar tests, to confirm diabetes before initiating treatment [10]. In addition, the MTPs identified physical inactivity (36%), high blood pressure (19%), unhealthy diet (16%), high blood cholesterol (16%), and excess body weight as risk factors for the development of diabetes. These findings are consistent with those reported by traditional healers in Narok County, Kenya [10]. Despite their low level of education, all MTPs were aware of the harmful effects of combining conventional antidiabetic drugs with traditional therapies. The adverse outcomes identified, including death (69%), severe vomiting (16%), diarrhea (8%), and drug interactions (7%), align with those reported by traditional healers in a previous study in Kenya [20].

In the present study, a variety of antidiabetic botanical species utilized by the MTPs in Monduli District were documented. A total of 41 antidiabetic plants, derived from 21distinct plant families, were collected, identified, and reported within the Monduli District. The plant families Fabaceae, Combretaceae, Lamiaceae, Rutaceae, and Solanaceae were the most commonly used in treating diabetes by MTPs. This finding is consistent with studies conducted previously in Tanzania [12] and Kenya [21], which highlighted Fabaceae, Solanaceae, Lamiaceae, and Rutaceae as the most predominant plant families used by the Maasai ethnic group to treat various human conditions, including diabetes. The high species diversity within these families highlights both the biological richness and the cultural significance of these plants in traditional healthcare systems for managing a range of ailments [12]. Furthermore, the presence of natural protected forests such as the Monduli Mountains Forest Reserve, Lendikinya Forest Reserve, and Losimingori Forest enhances the availability and accessibility of these medicinal plants [21]. These forest ecosystems play a key role in supporting the continued use of species from these plant families, contributing to the frequency of their use reports in traditional medicine. The most medicinal plants frequently utilized by MTPs in this study include *R. staddo, Z. chalybeum, P. peruviana, A. anthelmintica, P. capensis, E. axillare, A. nilotica, A. volkensii, C. schefflera, V. simplicifolia,* and *R. ussambaransis.* As illustrated in Table 4, approximately 66% of the antidiabetic plants used by MTPs in Monduli district are also used by other traditional healers worldwide to treat various human conditions, including diabetes. However, the current research revealed a significantly larger number of medicinal plants for treating diabetes compared to those previously identified in Kenya (14 plants) [10], South Africa (15 plants) [22], Morocco (22 plants) [23], and Uganda (27 plants) [24]. The MTPs primarily harvested roots (41%) for traditional antidiabetic remedies, followed by stem barks (31%), similar to practices observed by traditional healers across various parts of Africa [11–12]. The preference for using roots in the preparation of antidiabetic herbal remedies may be due to the higher concentration of phytoconstituents in roots and their ability to preserve bioactive compounds long after harvesting [25]. In addition, the Maasai prefer roots because they can be dried, stored, and used during harsh conditions, such as droughts, without losing their potency or requiring fresh materials [26]. However, this may be unsuitable and may threaten the availability of some potential plant species in the future [26]. This is in contrast with previous studies [23], which reported leaves and fruits as the most commonly utilized plant parts for the formulation of antidiabetic herbal medicine. Harvesting leaves and fruits is considered environmentally friendly, as it does not harm the plant [27].

Moreover, the literature review revealed promising antidiabetic potential from 21 plant species) (81.5% as demonstrated in either *in vitro* or *in vivo* studies (Table 4). The active compounds isolated from *Z. chalybeum, P. peruviana, E. axillare, E. schimpheri, W. somnifera, C. molle, A. indica, O. europaea, O. gratissimum,* and *P. zeylanicum* have demonstrated antidiabetic activities through various mechanisms. These activities include α-amylase and α-glucosidase inhibition [24,26,52,65], antioxidant and antilipidemic activities [29], DPP-4 inhibition activity [30], improved glucose transport, increased insulin sensitivity, enhanced insulin secretion by pancreatic β-cells [31], and enhanced GLUT4 translocation [32]. This further supports the traditional use of these medicinal plants by traditional healers for treating diabetes [Table 5].

The current study identified six medicinal plants that were cited for the first time by MTPs in Monduli District, Arusha, Tanzania. These plants include *L. schweinfurthii, S. didymobotrya, C. pyrrhopappa, L. mollissima, R. usambarensis,* and *A. anthelmintica*. However, no scientific research has yet been conducted to confirm their antidiabetic potential. Several studies have reported the presence of potential phytochemical constituents in these plants, such as phenols, alkaloids, flavonoids, tannins, saponins, and terpenoids [22,30,24,42,73], which may exert various antidiabetic activities through different mechanisms. The phytochemical compounds identified in the antidiabetic herbs used by MTPs in Monduli District support their traditional use in treating diabetes. However, further scientific research is needed to assess their antidiabetic potential, which could serve as a foundation for developing novel antidiabetic medications.

Conclusion

This study highlights the strong traditional knowledge of MTPs in treating diabetes, with 41 medicinal plants identified. Literature indicates that 81.5% of these plants show promising antidiabetic properties *in vitro* or *in vivo* studies. However, further research is

Table 5
Literature review and cross-referencing of medicinal plants used by MTPs in treating diabetes in Monduli District, Arusha, Tanzania.

Scientific name	Reported traditional uses	Relevant pharmacological activity/chemical constituents
Rhamnus staddo	Used for strength/nutrient supplements, and sexually transmitted diseases [34]	Contain flavonoids and terpenoids, with α-glucosidase and α-amylase activities [35]
Zanthoxylum chalybeum	Back decoction is used to treat diabetes [20]	The active compounds (6-Benzo[1,3]dioxol-5-yl-hexa-2,5-dienoic acid isobutylamide (chaylbemide A), -Methoxy-N-(2-methoxy-phenyl)-N-methyl-benzamide (chalybemide B), and N-(2-Hydroxy-2-methyl-propyl)-3-phenyl-acrylamide (chalybemide C) exhibited α-amylase and α-glycosidase inhibitory activity [36].
Physalis peruviana	Leave infusion is used to treat diabetes [37]	The active compound quercetin-3-O-rhamnoside, 3-O-methylellagic acid, and quercetin 3-O-galactoside possess α-amylase, lipase, and β-glucosidase inhibition activities [38]
Albizia anthelmintica	Root decoction is used to treat in diabetes Tanzania [39]	Antioxidant activity from methanol leaf extracts [40]
Pappea capensis	Leaf infusions are used to treat diabetes in Kenya[41]	Hypoglycemic activity from ethylacetate leaves and stem barks extracts [33]
Enicostema axillare	Used traditionally to treat diabetes [37]	The active compound swertiamarin exhibited antidiabetic, antioxidant and antilipidemic activities [29]
Acacia nilotica	Steam bark decoction is used to treat diabetes [37]	Anti-hyperglycemic activity, improvement of insulin level, and insulin resistance [42].
Aloe volkensii	Leaf sap/gel is used to treat diabetes [23,33]	Inhibition of α-amylase enzyme activity [44]
Croton scheffleri	Root decoction is used to treat *Candida* infections [45]	No report
Rumex usambarensis	The aerial parts and roots are used to treat diabetes in Ethiopia [46]	Aqueous leaf and stem extract exhibit appetite suppressing and weight reduction effects [47]
Vepris simplicifolia	Antimicrobial activities [48]	Antimicrobial activity [48]
Turraea robusta	Used to treat malaria [49]	Antiplasmodial activities [50]
Erythrina abyssinica	Root extracts used to treat diabetes in Tanzania [51]	Flavones isolated from root extracts inhibit protein tyrosine phosphate 1B[52], hypoglycemics activity [53]
Carissa spinarum	Roots decoction is used to treat diabetes[10]	Acetonic extract exhibited antihyperglycemic and anti-hyperlipidaemic effects on alloxan-induced diabetic rats[54]
Embelia schimpheri	Worm, gonorrhoea, heartburn [45,46]	The active compound embelin (2,5-dihydroxy-3-undecyl-p-benzoquinone) possesses antioxidant and anti-inflammation effects [56]
Withania somnifera	Roots and bark extracts are used to treat diabetes [57]	Bioactive compound, withaferin-A, possess the ability to inhibit DPP-4, helping to improve insulin resistance and β-cell dysfunction [30].
Combretum molle	Leaf extract is used to treat diabetes and its symptoms [58]	The active compound mollic acid glucoside (MAG) possesses hypoglycaemic and antidiabetic properties [59]
Azadirachta indica	Leaf extract is used to treat diabetes [20]	The active compounds sitosterol, stigmasterol, and squalene possess antidiabetic activities through inhibition of α-amylase and α-glucosidase activities [28]
Olea europaea	Leaf infusion is used to treat diabetes [60]	The active compounds oleuropein and hydroxytyrosol exhibit antidiabetic activity by improving glucose transport, increasing insulin sensitivity, and facilitating insulin secretion by pancreatic β-cells [31].
Helinus mystachinus	Bark decoction is used to treat respiratory disorders [61]	β-Sitosterol and botulinic acid possess antibacterial activity [62].
Terminalia brownii	Bark decoction is used to treat diabetes [23,53]	Antihyperglycemic, hypoglycemic activities and suppression of postprandial hyperglycaemia [63]
Harrisonia abyssinica	Used to treat malaria [49]	Antioxidant [64]
Salvadora persica	Used to treat diabetes [65]	Antihyperglycemic, antihyperlipidemic,and antimicrobial activities [66]
Trimeria grandifolia	Stem bark decoction is used to treat diabetes [10]	Flavonoids, lignans, and terpenoids exhibit strong antidiabetic activities by inhibiting α-glucosidase and α-amylase [35]
Lannea schweinfurthii	Leaf extract is used to treat diabetes [58]	Antimicrobial and anti-inflammatory [67]
Sphaeranthus bulatus	Used to treat gout [12]	No report
Croton dichogamus	Polio-like symptoms, gonorrhoea, and chest pain [68]	Antimicrobial activity, anti-HIV1 potential as replication inhibitors [69]
Croton macrostachys	Root decoction is used to treat diabetes [20]	Anti-diabetic activity associated with the presence of alkaloids, flavonoids, terpenoids, and phenolic compounds [70]
Ocimum gratissimum	Leaf decoction is used to treat diabetes [60]	The active compound thymol exhibits hypoglycemic properties and stimulates pancreatic alpha-amylase activity [71]
Morella salicifolia	Stem decoction is used to treat diabetes [72]	Antihyperglycemic, α-amylase inhibitory and antioxidant activity [25,66]
Osyris lanceolata	Abdominal and sexual ailment [68].	Antioxidant activity [73]
Secamone parviflora	Used to treat Bilharzia/ Schistosomiasis[74]	No report
Senna didymobotrya	Leaf extract is used to treat diabetes [23,69]	Tannins, saponins, terpenoids, flavonoids, phenols, and alkaloids[75]
Conyza pyrrhopappa	Roots/leaves decoction is used to treat diabetes [76]	No report
Acacia xanthophloea	Pneumonia, appetite enhancer [17]	Phenols, alkaloids, and flavonoids[77]
Plectranthus sp	Leaf extract is used to treat malaria [49]	Antidiabetic and anti-hyperlipidemic activities [73,74,78]

(*continued on next page*)

Table 5 (*continued*)

Scientific name	Reported traditional uses	Relevant pharmacological activity/chemical constituents
Solanum incanum	Roots decoction is used to treat diabetes [23–50].	Antidiabetic and Antihyperlipidemic [79]
Acacia gerrardii	Gastrointestinal disorders [80]	Antioxidants [81]
Leonotis mollissima	Leaf decoction is used to treat diabetes [58]	Antibacterial [82].
Indigofera arrecta	Leaf extract is used to treat diabetes [83]	Antidiabetic [84]
Plumbago zeylanicum	Leaf extracts are used to treat diabetes [85]	The active compound plumbagin exhibits antidiabetic activities and enhances GLUT4 translocation [32].

required to confirm their efficacy and safety for human use. The study also recommends investigating the phytochemistry and anti-diabetic effects of six medicinal plants newly identified, which may contribute to the discovery of new antidiabetic therapies. Furthermore, it stresses the importance of public awareness to plant these plants in botanical gardens to preserve them for future use.

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CRediT authorship contribution statement

Wilfrida Paul Roman: Conceptualization, Methodology, Investigation, Writing – original draft. **Haikael David Martin:** Supervision, Conceptualization, Writing – review & editing. **Huda Ismail:** Writing – review & editing. **Md. Shahidul Islam:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare no competing interests.

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