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Assessing the Ethnobotanical Uses, Harvesting Practices, and Conservation Awareness of *Warburgia ugandensis* in Northern Tanzania

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Abstract

Warburgia ugandensis is unsustainably harvested commercially, threatening its survival and potentially leading to local extinction in its native range areas in Northern Tanzania. Our study aimed to assess the extent of harvesting of *W. ugandensis* in Northern Tanzania, ethno-botanical uses, community perceptions of species utilization, and conservation measures across its native range in Northern Tanzania. From each of the 128 randomly selected grids, we laid down a sampling plot measuring 100 m × 100 m (1 ha) for the identification, and collection of data on the extent of harvesting of *W. ugandensis*. Additionally, we interviewed 221 respondents using open-ended questionnaires to gather data on ethno-botanical uses, perceptions of product utilization, and conservation measures. We analyzed the data using descriptive statistics and Kruskal-Wallis tests. Our findings reveal significant variation in the extent of harvesting, with Mt. Ketumbeine experiencing the most severe harvesting while Mt. Kilimanjaro holds the highest number of intact trees. Community knowledge of the medicinal uses of *W. ugandensis* was highest in Mt. Kilimanjaro, particularly for treating gastrointestinal disorders, coughs, and malaria. Perceptions of species utilization were very high in Mt. Gelai and Mt. Monduli, while Mt. Kilimanjaro, Ketumbeine, and Longido showed more variability. Awareness of *W. ugandensis* conservation measures was high in Mt. Kilimanjaro, compared to the rest of the species' native range areas. Therefore, our study findings underscore the urgent need for targeted conservation initiatives, particularly in regions like Mt. Ketumbeine and Mt. Longido, where *W. ugandensis* faces the severe extent of harvesting.

Keywords

Warburgia ugandensis, Ethnobotany, Sustainable Harvesting, Conservation

Awareness, Medicinal Plants, Northern Tanzania

1. Introduction

Medicinal plants have a central position in providing healthcare facilities for the global population [1]. A survey showed that about 80% of the world's population uses folk medicine, especially from developing countries [2]. Cultural conservatism, lack of opportunities to turn to modern medical facilities, and social-demographic aspects including the level of education, area of residence, age, and occupation are considered to be the main causes of such reliance [3]-[5]. Despite increased access to modern healthcare, medicinal plants still present a relevant solution to healthcare needs in resource-limited settings, as they are affordable and widely available [6]-[8]. While medicinal plants offer a range of alternative remedies to low-income individuals due to their affordability, they also play a vital role in creating income and employment opportunities [8] [9]. This indicates that the reliance of local communities on traditional remedies will remain very high as this reliance is linked to the pursuit of profit, which raises the question of the sustainability of these vital and threatened plant resources [6] [7].

One of the most used and widely traded medicinal plants in the community of Northern Tanzania is *W. ugandensis* [10]. It is a medicinal plant species native to East Africa [11]. Traditional healers and herbalists have used the species' bark and leaves for centuries due to their high medicinal value and potent therapeutic potential [12] [13]. *W. ugandensis* is used for the treatment of malaria, stomachache, coughs, skin diseases, and many others [14]. However, the species is facing a severe threat that may cause local extinction in many areas due to unsustainable harvesting practices [11] [15] [16]. The commercial harvesting of medicinal plant species in the pursuit of profit jeopardizes the ecological sustainability of this plant species [17] as it can lead to a decline in population, reduced reproductive success, and even local extinction [18]. Also, the natural regeneration rate and recruitment of *W. ugandensis* is low and so limited in most areas where it is found, as a result, the species has become extinct in some of its original habitats [13] [19]. The most frequently used plant parts used for various treatments are barks and roots [13]. The indiscriminate debarking of the tree species makes the plant more susceptible to fungal attacks thereby causing a significant reduction in its population, leading to a loss of biodiversity and the vital ecological services provided by the tree species [16]. *W. ugandensis* is listed as critically endangered due to excessive exploitation for commercial purposes [2] [20]. Despite the high risk of extinction due to continuing over-use, no studies documented harvesting practices, extent, and ethno-botanical uses of *W. ugandensis* across its native areas in northern Tanzania. To contribute to this information gap, our study specifically aimed to assess: 1) the extent of harvesting *of W. ugandensis* across its native range areas, 2) community knowledge of *W. ugandensis* for treating various health conditions across

its native range, 3) community perception of the level of use of the *W. ugandensis* products, and 4) community awareness of measures to ensure the sustainable conservation of *W. ugandensis.*

2. Methods

2.1. Study Area

The area lies within the Maasai steppe between 2.500˚, 4.00˚S, and 35.90˚, 37.80˚E (**Figure 1**), has a mean annual rainfall of 686.7 mm, and follows the bimodal patterns [21], with long rains between March and April and short and little rains between November and December [22]. The mean monthly minimum and maximum temperatures are 18˚C and 30˚C, respectively. The topography ranges from gently undulating plains of 600 m to 5895 m above sea level, with Mount Kilimanjaro being the highest peak [23] [24]. The montane forests that dominate the highlands give way to grasslands and savannas as one descends to lower elevations, with the vegetation varying accordingly based on height, rainfall, and edaphic factors [25] [26]. The soil is rich in nutrients and mostly volcanic in origin, making the highlands in this region ideal areas for agriculture [27] [28]. The area comprises various land use categories, such as national parks, Forest Reserves, croplands, grazing land, and settlements [22]. Northern Tanzania holds 4,218,189 people, according to the Population and Housing Census [29], with the Maasai community making up most of the surveyed area.

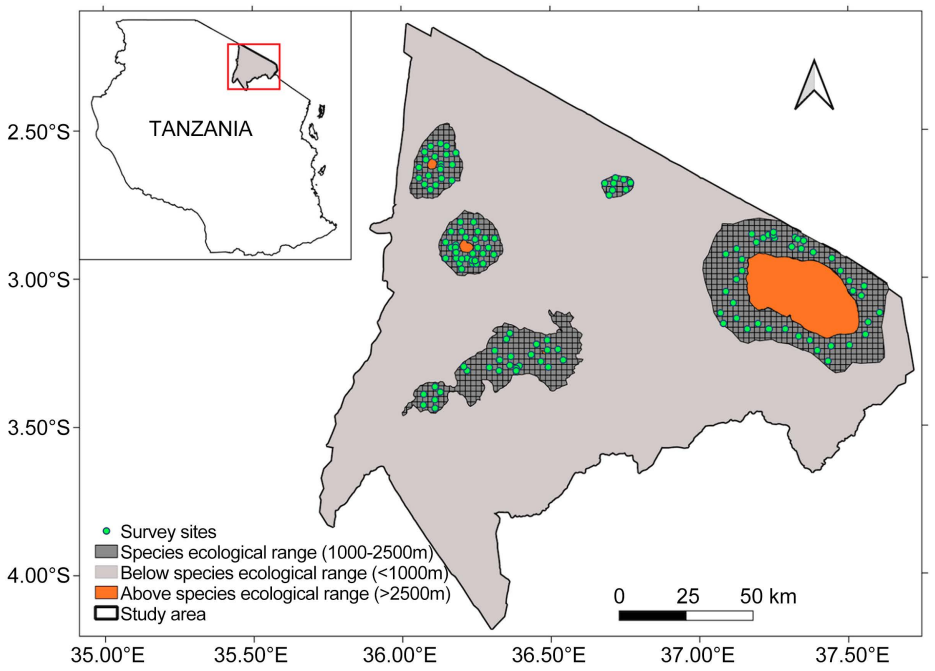

Figure 1. Map of the study area in Northern Tanzania depicting the ecological range of *W. ugandensis* across its native habitats. The species' ecological range (1000 - 2500 m above sea level) is highlighted, along with areas below (<1000 m) and above (>2500 m) the species' ecological range. Survey sites (green points) are distributed across stratified sampling grids within the identified ecological range. The inset shows the study area's location within Tanzania.

2.2. Data Collection

We generated contour lines from the digital elevation model using Quantum Geographical Information System (QGIS version 3.32.1) to delineate the ecological range of *Warburgia ugandensis* (1000 - 2500 m a.s.l, Figure 1). We then applied stratified random sampling techniques, stratifying the potential ecological range of *W. ugandensis* across its native range areas (Mt. Kilimanjaro, Mt. Ketumbeine, Mt. Monduli, Mt. Gelai, and Mt. Longido) into square grids measuring 2 km × 2 km (Figure 1). Using QGIS version 3.32.1, we randomly selected a total of 128 grids for sampling.

In each randomly selected grid, a sampling plot measuring 100 m × 100 m (1 ha) was established to identify *W. ugandensis* trees and assess the extent of harvesting for each tree encountered during the survey. Additionally, we administered open-ended questionnaires to 221 respondents living near the sampled plots after obtaining their consent. We translated the questions into Maa and Chagga, the primary languages of the Maasai and Chagga communities in Northern Tanzania. The questionnaires explored the community's knowledge of *W. ugandensis* for treating various health conditions, their perceptions of the usage level of *W. ugandensis* products, and their awareness of conservation measures necessary to ensure the sustainable management of *W. ugandensis*.

2.3. Data Analysis

We entered the data into a Microsoft Excel spreadsheet, coded and organized it, and then exported it to R software version 4.3.2 for analysis. We used the Kruskal-Wallis test to analyze variations in the extent of harvesting across the native range areas of *Warburgia ugandensis*. Additionally, we applied descriptive statistics to summarize the frequency of responses regarding community knowledge of *W. ugandensis* for treating various health conditions, community perceptions of the level of use of *W. ugandensis* products, and community awareness of conservation measures necessary for its sustainable management across its native range areas (Mt. Kilimanjaro, Mt. Ketumbeine, Mt. Gelai, Mt. Longido, and Mt. Monduli).

3. Results

3.1. Harvesting Practices of *W. ugandensis* across Its Native Range Areas in Northern Tanzania

We recorded the highest number of trees (248) in Mt. Ketumbeine, which also exhibited the most extensive harvesting, with significant numbers of totally debarked trees (115), vertical bark-stripped trees (80), and root-cut trees (16) (Table 1). In contrast, we recorded the highest number of intact trees (124) in Mt. Kilimanjaro out of the total 169 trees documented in this area, surpassing other native range areas of the species. The Kruskal-Wallis test revealed a highly significant difference in the extent of root cutting among these regions ($p < 0.001$), indicating that this unsound harvesting practice is particularly concentrated in areas such as Mt. Ketumbeine. Other types of harvesting, such as vertical bark stripping, ring

debarking, and topping, appeared more evenly distributed across the native range areas of *W. ugandensis*, suggesting that these practices either occur uniformly or that the differences observed result from random variation (Table 1). Overall, the data suggest that *W. ugandensis* trees face varying levels of harvesting depending on the native range areas, with root cutting being particularly concentrated in certain areas, which might require targeted conservation efforts (Table 1) (Figure 2).

Table 1. Summarizes the counts of *W. ugandensis* trees subjected to various harvesting practices and the number of intact trees across its native ranges.

Native ranges	Vertical bark stripping	Root cutting	Ring debarked	Topped	Total Debarked	Total Intact	**Overall Total**
Kilimanjaro	39	0	0	6	45	124	**169**
Longido	9	1	0	4	14	8	**22**
Monduli	23	0	1	4	28	76	**104**
Gelai	6	0	1	0	7	16	**23**
Ketumbeine	80	16	4	15	115	133	**248**
Overall Total	**157**	**17**	**6**	**29**	**209**	**357**	**566**
Kruskal-Wallis test	H = 6.23, df = 4, p = 0.182	H = 21.40, df = 4, p = 0.001	H = 5.05, df = 4, p = 0.2821	H = 3.24, df = 4, p = 0.517	H = 8.17, df = 4, p = 0.085	H = 3.98, df = 4, p = 0.407	H = 4.64, df = 4, p = 0.325

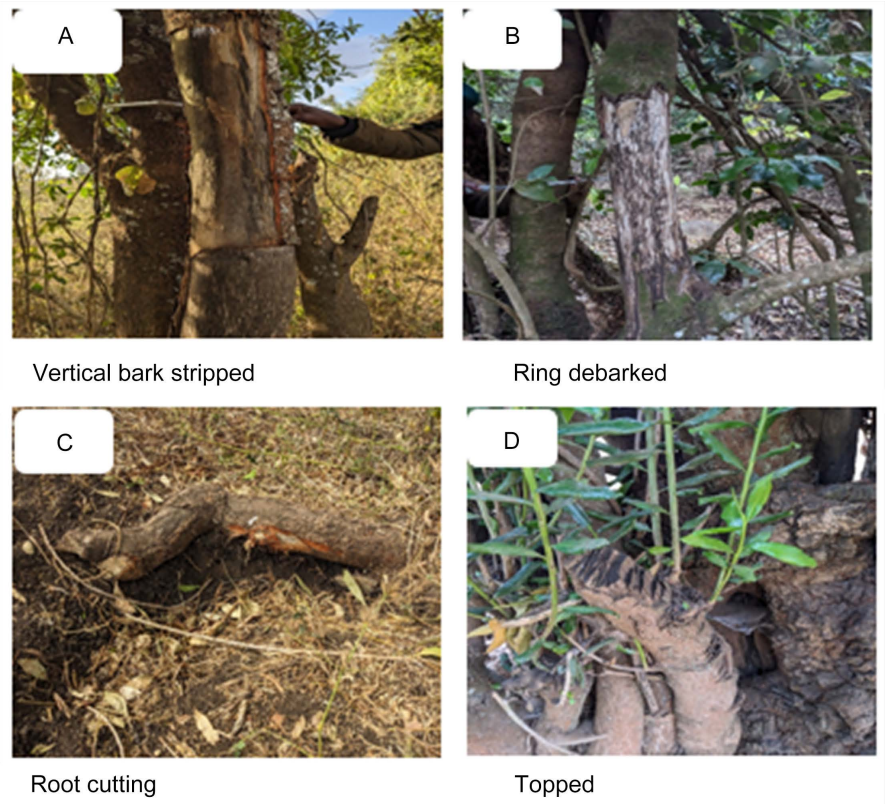

Figure 2. (A)-(D) shows the observed existing harvesting practices of *W. ugandensis* across its native range areas.

3.2. Community Knowledge of *W. ugandensis* for Treating Various Health Conditions across Its Native Range Areas

Our results (Table 2) demonstrate the diverse knowledge of *Warburgia ugandensis* used for treating various health conditions across its native range areas (Mt. Gelai, Mt. Ketumbeine, Mt. Kilimanjaro, Mt. Longido, and Mt. Monduli). We found that respondents most commonly reported using *W. ugandensis* to treat gastrointestinal disorders, with Mt. Kilimanjaro having the highest number of responses (83), followed by Mt. Ketumbeine (59) and Mt. Gelai (43). Knowledge of its use for treating coughs was also prominent, particularly in Mt. Kilimanjaro (83 responses), but significantly lower in Mt. Longido, where only two respondents mentioned it.

We observed widespread knowledge of using *W. ugandensis* for malaria treatment in Mt. Kilimanjaro (52 responses), Mt. Ketumbeine (45), and Mt. Gelai (33). However, fewer respondents in Mt. Monduli (16) and Mt. Longido (10) reported this knowledge. Additionally, we found that knowledge of its use for post-partum discharge was concentrated in Mt. Kilimanjaro and Mt. Ketumbeine, with minimal awareness reported in other areas.

For treating toothache, respondents in Mt. Kilimanjaro and Mt. Ketumbeine exhibited the highest levels of awareness, while other areas showed little to no recognition. Knowledge of treating pneumonia with *W. ugandensis* was limited, with only a few respondents in Mt. Gelai, Mt. Longido, and Mt. Monduli reporting its use. Similarly, awareness of its use for asthma was the least common, with only small numbers of respondents in Mt. Longido and Mt. Monduli reporting this application. These findings underscore regional variations in the traditional knowledge of *W. ugandensis* across its native range.

Table 2. Knowledge of *W. ugandensis* for treating various health conditions across its native range areas.

Diseases	Mt. Gelai	Mt. Ketumbeine	Mt. Kilimanjaro	Mt. Longido	Mt. Monduli
Gastrointestinal	43	59	83	17	19
Cough	7	45	83	2	12
Malaria	33	45	52	10	16
Post-partum discharge	2	42	42	0	2
Toothache	3	39	66	0	1
Pneumonia	4	0	0	3	5
Asthma	0	0	0	4	1

3.3. Community Perception of the Level of Use of the *W. ugandensis* Products

The results depict the perception of the level of use of *W. ugandensis* products across different species' native range areas (Table 3). Respondents' perception of the level of use of species' products was high in Mt. Kilimanjaro with (64) report-

ing very high use of the species' products while in Mt. Gelai all of the (43) respondents reported very high use of the species' products. None of the respondents reported "High" or "Moderately high" usage of the species products in Mt. Monduli and Mt. Gelai suggesting a widespread perception of very high species utilization in these areas. The reported results indicate that *W. ugandensis* products are highly valued and widely used in these regions. In contrast, the perception at Mt. Ketumbeine and Mt. Longido shows some variation. At Mt. Ketumbeine, while the majority of respondents (49) also perceive the usage as Very high, 8 respondents rated the usage as moderately high and 1 as High. This indicates a slightly more varied perception of the usage levels, though still predominantly very high. At Mt. Longido, the perception is more dispersed, with 12 respondents indicating Very high usage, 4 reporting moderately high, and 1 indicating High. This suggests that while *W. ugandensis* products are still widely used, the extent of this usage varies compared to the other sites.

Table 3. Perception of the level of use of the *W. ugandensis* products.

Native areas	High	Moderately high	Very high
Mt. Kilimanjaro	14	6	64
Mt. Gelai	0	0	43
Mt. Ketumbeine	1	8	49
Mt. Longido	1	4	12
Mt. Monduli	0	0	19

3.4. Community Awareness of Measures to Ensure the Sustainable Conservation of *W. ugandensis*

Results in (**Table 4**) present an overview of various community measures implemented across species' different native range areas to ensure the sustainable conservation of *W. ugandensis*. Results show that Mt. Kilimanjaro leads in all four categories: awareness of sustainable harvesting practices, planting *W. ugandensis* in homesteads, control of *W. ugandensis* products, and protection of its natural habitat, with the highest number of respondents mentioning these activities. Mt. Ketumbeine follows closely behind, showing strong respondents' awareness across these areas, although not as pronounced as in Mt. Kilimanjaro. Mt. Gelai also demonstrates moderate respondents' awareness of these conservation measures, particularly in raising awareness and planting in homesteads. However, the engagement in Mt. Longido and Mt. Monduli is considerably lower across all categories, indicating a need for increased efforts in these regions to bolster the sustainable conservation of *W. ugandensis*. The differences in awareness across the sites highlight the varying levels of conservation awareness and practices, with Mt. Kilimanjaro setting a strong example, while Mt. Longido and Mt. Monduli may benefit from targeted conservation initiatives.

Table 4. Community awareness of measures to ensure the sustainable conservation of *W. ugandensis*.

Study site	Awareness of sustainable harvesting practices	Planting *W. ugandensis* in homestead	Control of *W. ugandensis* products	Protection of *W. ugandensis* habitat
Mt. Gelai	37	30	29	32
Mt. Ketumbeine	48	42	44	52
Mt. Kilimanjaro	73	62	60	55
Mt. Longido	5	10	12	11
Mt. Monduli	14	15	10	10

4. Discussion

The unsustainable harvesting practices of *W. ugandensis* across its native ranges in Northern Tanzania pose a significant threat to its survival, with root cutting being particularly severe in regions like Mt. Ketumbeine. Our findings reveal regional variations in harvesting intensity and community knowledge of the species' medicinal uses. While gastrointestinal disorders, malaria, and coughs are commonly treated ailments, unique applications like post-partum discharge treatment highlight the diverse ethnobotanical knowledge associated with *W. ugandensis*. Community perceptions indicate a high reliance on the species, reflected in its over-utilization and the widespread sale of its products in local markets. Despite these challenges, strong awareness of conservation measures in areas like Mt. Kilimanjaro suggests a promising foundation for promoting sustainable practices.

4.1. Harvesting Practices of *W. ugandensis*

Our findings reveal that *W. ugandensis* faces extensive unsustainable harvesting practices, such as root cutting and vertical bark stripping, particularly in Mt. Ketumbeine. These results align with studies by [30] [31], who reported similar unsound practices for other medicinal plants, including *Warburgia salutaris*, in Southern Mozambique and Kenya, respectively. Both studies highlighted vertical bark stripping as the most prevalent practice, which is consistent with our findings. However, while [32] [33] emphasized that root cutting disrupts nutrient and water absorption and increases plant mortality, our study uniquely identified Mt. Ketumbeine as a hotspot for such practices, indicating localized harvesting pressures. In contrast to the findings by [34], which suggested that unsustainable harvesting is equally distributed across regions, our study showed significant spatial variation. For example, Mt. Kilimanjaro, with its protective status as a national park, exhibited the highest number of intact trees, demonstrating the effectiveness of conservation interventions. These differences highlight the role of protected areas in mitigating unsustainable harvesting, as observed in studies on medicinal plants [35] [36].

4.2. Community Knowledge of *W. ugandensis* for Treating Various Health Conditions

Our study showed high levels of knowledge of *W. ugandensis* for treating gastro-

intestinal disorders, malaria, and coughs, particularly in Mt. Kilimanjaro. These findings corroborate studies by [12] [13] [37], which documented similar uses in East Africa. However, we also identified unique applications, such as its use for accelerating post-partum discharge, which have not been widely reported. This contrasts with [38], who suggested that traditional medicinal knowledge of *W. ugandensis* is largely homogenous across regions. The localized variations observed in our study underscore the influence of cultural and environmental factors on the ethnobotanical knowledge base. Interestingly, while studies by [39] emphasized malaria treatment as the most common medicinal use of *W. ugandensis*, our findings revealed a broader application of the species, including gastrointestinal disorders and coughs, as the dominant ailments treated. This broader scope of knowledge may reflect the integration of different cultural practices in Northern Tanzania, a dynamic also noted by [38] [40] [41] across communities in East Africa.

4.3. Perception of Species Use and Overexploitation

The perception of very high usage of *W. ugandensis* products in Mt. Gelai and Mt. Monduli aligns with findings by [10] [42], who reported high demand for the species in Kenya and Northern Tanzania, respectively. However, our study contrasts with [43], who suggested that perceptions of usage are uniformly high across regions. Our results revealed variability, particularly in Mt. Longido, where perceptions of usage were less unanimous, reflecting differences in local dependency and accessibility. The high levels of *W. ugandensis* consumption and trade, as reported in our study, corroborate findings by [10], which documented widespread trade of the species in local markets. This underscores the species' cultural and economic significance, but it also raises concerns about overexploitation, a challenge highlighted by [43] in medicinal plant commercialization.

4.4. Conservation Awareness of *W. ugandensis*

Our findings on conservation awareness demonstrated significant regional differences, with Mt. Kilimanjaro showing the highest awareness across all conservation measures. These results are consistent with studies by [44] [45], which emphasized the role of community engagement in ensuring the sustainability of threatened medicinal plants. However, our study contrasts with [36], who suggested a more uniform distribution of conservation awareness, as we observed lower awareness levels in Mt. Longido and Mt. Monduli. The promising levels of community awareness reported in Mt. Kilimanjaro reflect the effectiveness of existing conservation interventions, observed by [46] [47]. This suggests that targeted conservation education and sustainable harvesting programs could be expanded to regions like Mt. Ketumbeine and Mt. Longido, where awareness is less pronounced.

4.5. Conservation Implications

These findings reveal important considerations for developing conservation strat-

egies tailored to the needs of each region [48]. Targeted efforts in Mt. Ketumbeine, where unsustainable harvesting practices are most prevalent, could include stricter harvesting controls, community education on sustainable methods, and incentives for planting *W. ugandensis* in controlled environments [48]-[50]. Conversely, the high level of knowledge and conservation awareness in Mt. Kilimanjaro could provide a model for best practices that could be shared with less aware communities, such as those in Mt. Longido and Mt. Monduli. Enhancing awareness of the plant's ecological and cultural value and training communities in sustainable harvesting and planting techniques could help preserve *W. ugandensis* populations [51]. Furthermore, the high medicinal demand, as seen in Mt. Kilimanjaro and Mt. Gelai, underscores the need for a balanced approach to conservation that acknowledges the plant's healthcare role while preventing overexploitation.

5. Conclusion

The study findings provide important insights into the ethno-botanical uses and extent of harvesting of *W. ugandensis* across its native range areas in Northern Tanzania. It revealed a significant cultural and medicinal importance linked to the reliance of *W. ugandensis* on diverse applications. While the study underscores the diverse knowledge of high use of *W. ugandensis* products, it raises questions about its sustainability due to the prevalence of unsound harvesting practices such as vertical bark stripping, ring debarking, and root cutting that pose a significant threat to the long-term survival of *W. ugandensis.* Furthermore, the study reveals a homogenized knowledge among the respondents on the conservation measures to be taken to ensure the conservation of *W. ugandensis,* with a high proportion of respondents pointing out a need for sustainable harvesting practices, species' habitat protection, and control of species and associated products in the markets. Therefore, the study's findings highlight the need for a multifaceted approach, such as conservation education on sustainable harvesting practices of *W. ugandensis*, community-based conservation, and compliance with the laws that govern the use of medicinal plant products.

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Ethical Consideration

The research was carried out with permission from the Tanzanian Commission for Science and Technology (COSTECH), permit #: 2023-719-NA-2023-952, Tan-

zania National Parks (TANAPA), Longido, and Monduli District Councils. Respondents' verbal consent was obtained before starting an interview because the majority of them were not competent in writing as advised by village leaders. No names were gathered, and respondents' identities were numerically coded to ensure anonymity.

Conflicts of Interest

The authors declared 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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