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*Article*

# Socio-Economic Value and Availability of Plant-Based Non-Timber Forest Products (NTFPs) within the Charcoal Production Basin of the City of Lubumbashi (DR Congo)

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**Abstract:** The overexploitation of forest resources in the charcoal production basin of the city of Lubumbashi (DR Congo) is reducing the resilience of *miombo* woodlands and threatening the survival of the riparian as well as urban human populations that depend on it. We assessed the socio-economic value and availability of plant-based non-timber forest products NTFPs in the rural area of Lubumbashi through ethnobotanical (100 respondents) and socio-economic (90 respondents) interviews, supplemented with floristic inventories, in two village areas selected on the basis of the level of forest degradation. The results show that 60 woody species, including 46 in the degraded forest (Maksem) and 53 in the intact forest (Mwawa), belonging to 22 families are used as sources of NTFPs in both villages. Among these species, 25 are considered priority species. NTFPs are collected for various purposes, including handcrafting, hut building, and traditional medicine. Moreover, the ethnobotanical lists reveal a similarity of almost 75%, indicating that both local communities surveyed use the same species for collecting plant-based NTFPs, despite differences in the level of degradation of the *miombo* woodlands in the two corresponding study areas. However, the plant-based NTFPs that are collected from *miombo* woodlands and traded in the urban markets have significant economic value, which ranges from 0.5 to 14.58 USD per kg depending on the species and uses. NTFPs used for handicraft purposes have a higher economic value than those used for other purposes. However, the sustainability of this activity is threatened due to unsustainable harvesting practices that include stem slashing, root digging, and bark peeling of woody species. Consequently, there is a low availability of plant-based NTFPs, particularly in the village area where forest degradation is more advanced. It is imperative that policies for monitoring and regulation of harvesting, and promoting sustainable management of communities' plant-based NTFPs priority, be undertaken to maintain their resilience.

**Keywords:** traditional knowledge; forest degradation; socio-economic value; non-timber forest products; *miombo* woodlands

## 1. Introduction

Forests are ecosystems that provide numerous services to the human population, including the supply of timber, fuelwood, and various non-timber forest products (NTFPs) [1]. NTFPs are goods of biological origin other than timber, derived from forests, other wooded lands, and trees outside forests, that directly or indirectly support people's livelihoods [2,3]. These products include fodder, materials for hut building and crafts, traditional medicines, and agricultural equipment [3–6], NTFPs play a crucial role in ensuring food security and contributing to the survival of riparian and urban human populations [7,8]. In fact, studies by Refs. [3,9,10] reveal that more than one-third of the world's population, and over 75% of the rural and even urban populations in developing countries, rely on NTFPs for their nutritional and medicinal needs. It has been established that NTFPs are especially important in reducing the vulnerability of poor populations by providing food during times of scarcity as well as raw materials for nutritional supplements [9]. One of the distinctive features of NTFPs is their accessibility, even to people without arable land and/or sufficient income [11].

However, the overexploitation of forest resources, supported by the poverty of an ever-growing human population coupled with rapid urbanization, is leading to an increase in deforestation and forest degradation [12,13]. As a result, there has been a decline in the abundance of numerous plant species that are a source of NTFPs in Sub-Saharan Africa [14]. Recent studies have pointed out the threats posed by human activity on forest ecosystems and on the availability of NTFPs in *miombo* woodlands [15–17]. These threats should be taken seriously in regions where there is limited forest law enforcement and where poor communities rely heavily on forest resources for their survival. The living conditions of the poor are closely linked with the state of the environment, but poverty can also be the root cause of environmental degradation. This creates a vicious cycle where poverty and environmental degradation reinforce each other, as seen in the Democratic Republic of the Congo (DRC) [18].

Several studies have been conducted on ethnobotany and the utilization of plant-based NTFPs by local communities in the DRC [11,19–21], and particularly in the Katangese Copperbelt Area in the southeastern part of the country [22,23] where *miombo* woodlands predominate and account for almost 70% of the former Katanga Province [24] and 12% of the Lubumbashi plain [25]. Notably, in Haut-Katanga Province, over 80% of the population live predominantly in rural areas and rely heavily on forests for their survival [21]. However, human activity in the form of agriculture and charcoal production has caused significant regression of *miombo* woodlands in the Lubumbashi region [16]. As a result, an estimated deforestation rate of 1.41% of *miombo* woodlands was reported in Haut-Katanga Province between 2000 and 2010 [24].

On the one hand, the basic features of slash-and-burn agriculture, such as limited levels of agricultural investment, low productivity, and poor quality of inputs (fertilizers, seeds, etc.), low levels of supervision in the agricultural sector [26,27], and high levels of pollution (air, soil, and water) due to mining activity, have contributed to a decline in the abundance of *miombo* woodland patches [28–30]. On the other hand, the widespread use of charcoal as the primary source of cooking fuel among households in the city of Lubumbashi is contributing to deforestation and degradation of *miombo* woodlands [31]. This depletion of wood resources is worsening the already existing poverty of rural populations, who rely on NTFPs for their subsistence and to improve their standard of living [14]. In fact, in the rural areas around Lubumbashi, people depend heavily on the forest for their protein, medication, energy, construction materials, and income [22]. As rural populations seek to secure their livelihood in a weak economy by any means necessary, they often pay little heed to the sustainability of resources while resorting to collection practices that could lead to the complete disappearance of *miombo* woodlands around the city of Lubumbashi.

Moreover, the increasing deforestation of *miombo* woodlands is undermining the resilience of forests and their ability to provide ecosystem services, especially NTFPs, to local populations [32]. For instance, it is negatively impacting the availability and distribution of NTFP source species around villages [33]. Currently, the future of these forest resources is cause for concern in the Lubumbashi region [34], as *miombo* woodlands are among the most threatened woodland ecosystems and should be prioritized for conservation efforts [35].

However, only a few studies have investigated the availability of plant-based NTFPs in the face of increasing human pressure on forest resources [23]. Consequently, there is limited information on the sustainability of harvesting practices for plant-based NTFPs in the Lubumbashi region. This information gap could hinder efforts to conserve forest resources sustainably [36] and the *miombo* woodlands as a whole. Yet, the conservation of forest resources, which remains a major challenge for scientific communities [37], can be achieved through the integration of social, cultural, and economic values that local communities associate with these forest resources [38]. Indeed, assessing the socio-

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economic and cultural value of NTFPs and their impact on the livelihoods of rural and urban populations in a region is crucial for promoting policies that support their sustainable management, monitoring, and regulation [5]. Such measures can help identify priority NTFPs—namely those with high commercial, ethnobotanical and frequency of use value, multiple uses, and those that are rare or vulnerable—and develop focused conservation or sustainable exploitation measures [39].

Thus, the present study was initiated to investigate the availability and socio-economic value of plant-based NTFPs in the rural area of Lubumbashi city, known as a “charcoal production basin.” It tested the following hypotheses: (i) the floristic diversity of the woody species that are sources of NTFPs used by riparian populations is low in degraded *miombo* woodlands due to the scarcity of such species; (ii) regardless of the village area, local communities’ NTFP-harvesting practices are less sustainable, and contribute to the degradation and low availability of forest resources, including NTFPs; and (iii) plant-based NTFPs harvested in the rural area of Lubumbashi have significant socio-economic importance, as evidenced by their high value on the urban market.

## 2. Materials and Methods

### *2.1. Study Area*

This study was carried out in the rural area of Lubumbashi (Figure 1), the main city of Haut-Katanga Province, DRC.

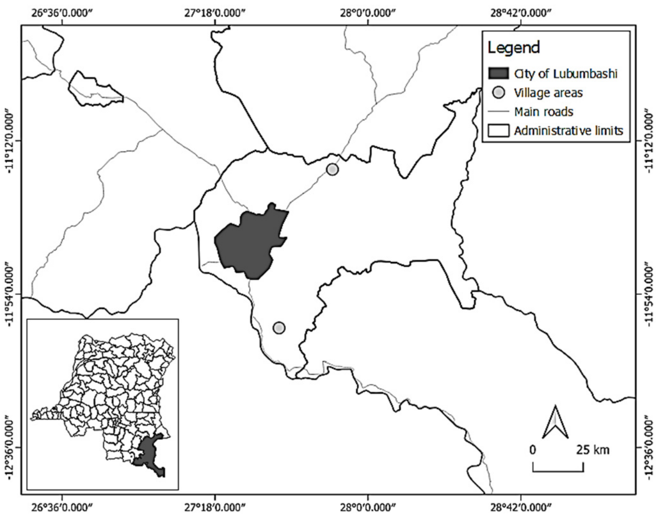


**Figure 1.** Lubumbashi City (gray polygon) and its rural area (the white area around Lubumbashi city). The gray dot refers to the villages covered by this study. The geographical coordinates used for this cartography were taken from the royal courts of the respective villages. Ethnobotanical surveys, including floristic inventories, were conducted in the two villages (Maksem and Mwawa), while commercial surveys were organized in Lubumbashi city’s markets.

The study area belongs to the CW climate type, as classified by the Koppen system [40], characterized by the alternation of a rainy season (November to March) and a dry season (May to September) separated by two transitional months (April and October). The average annual temperature is approximately 20°C [22], and the total annual rainfall is nearly 1,270 mm. However, there has been a decline in the number of rainy days since the early 2000s [41]. Situated at an altitude between 1,200 m and 1,300 m and at 11°40′ S latitude – 27°29′E longitude, *miombo* woodlands established on ferralsol [42] are the pristine vegetation of the rural area of Lubumbashi [43]. This pristine vegetation is currently undergoing regression due to human activity [44], as the population of the Lubumbashi rural area is largely poor, living on less than 1.25 USD per day [45], and engaged in natural resource exploitation activities such as shifting agriculture, charcoal production, illegal timber exploitation, (artisanal) mining, and small (informal) trade [18,46]. In addition to these

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activities, the harvesting of NTFPs remains a subsidiary activity, and serves as a means of generating income or providing self-consumption for the local communities [22].

### *2.2. Methods*

#### 2.2.1. Village selection and population sampling

Two village areas (Maksem and Mwawa) within an 80-km radius of Lubumbashi, in the charcoal production basin, were chosen for this survey. These village areas were identified as significant charcoal production sites by charcoal sellers during pre-surveys on urban markets. Moreover, despite being identified as areas of intense human activity, these village areas were selected based on the extent of forest degradation and their proximity to main roads (Table 1). The level of *miombo* woodland degradation was established based on the community's perception of the differences in deforestation and forest degradation levels between both village areas [18]. The accessibility of a village area was determined by the condition of the road leading to it. For example, a village area with degraded forests is more accessible with a macadamized road than a village area with intact forests, where the road is almost impassable and prone to flooding during the rainy season. As there was a lack of statistical data on the number of people engaged in NTFP harvesting, which is a subsidiary activity, the snowball method was utilized for this study, as recommended by Ref. [47]. At the end of each interview, respondents were asked to provide the name and contact information of another person involved in NTFP harvesting [48]. Using this method, 100 individuals (50 per village area) were selected in the main village of each of the two village areas. The survey was conducted between August 3 and September 26, 2022.

**Table 1.** Geographic location, forest status, accessibility of the village area, and sample size within the selected villages. M: Male; F: Female.

| Village areas | Latitude | Longitude | Forest status | Accessibility | Surveyed (%) | | Total |
|---|---|---|---|---|---|---|---|
| | | | | | M | F | |
| Maksem (n=50) | S 11,32998 | E 27,83755 | Degraded | Close/very good | 66 | 34 | 100 |
| Mwawa (n=50) | S 12,05379 | E 27,59325 | Nearly intact | far/bad | 70 | 30 | 100 |

#### 2.2.2. Ethnobotanical data collection

The semi-directive individual interview method, as described by Ref. [12], involved the use of both open-ended and closed-ended questionnaires. This approach allowed the interviewees' discourses to be partly oriented around different themes previously defined and recorded in the questionnaire [49]. The data collected during these surveys included information on the source species of NTFPs and their uses, useful organs, and harvesting practices. Through this information, the importance and social value of these species were determined, as well as the sustainability of the harvesting practices employed [5]. The identification of plant species cited in vernacular names by the respondents was made possible through the utilization of existing flora (Flora of Zambia, Flora of Zimbabwe, and Worldflora) as well as specialist books, manuals, and various identification guides [22,50–52]. Moreover, field trips with some of the respondents allowed for the identification of certain species cited and described in the local language by the communities. However, herbaceous species were excluded from the study due to the chosen period of floristic inventories corresponding with the dry season in the Lubumbashi rural area, during which many herbaceous species disappear due to water stress.

#### 2.2.3. Economic value of commonly used miombo woodland NTFPs

To assess the economic value of commonly harvested plant-based NTFPs in *miombo* woodlands [53], research was conducted into all NTFP sellers in 14 markets in Lubumbashi city. Finally, sellers of plant-based NTFPs not harvested from *miombo* woodlands and animal-based NTFP sellers were removed from the database. Therefore, this study focused on 90 sellers of plant-based NTFPs.

2.2.4. Floristic inventories of plant-based NTFP species

The impact of forest degradation on the frequency and, consequently, the availability of plant species used for NTFPs was investigated by installing 24 inventory plots in both village areas [54]: half of the plots (12) in Maksem degraded forest and the other half (12) in Mwawa intact forest, as suggested by Ref. [55]. Plot dimensions were determined based on previous studies [55,56] that indicated that 50 m × 20 m, or 1,000 $m^2$, is adequate for conducting floristic studies in *miombo* woodlands. In these plots, all woody individuals with a diameter at breast height (dbh) ≥ 5 cm were inventoried and measured using forest tape [55]. Unknown woody species were collected, pressed, and preserved as herbarium specimens for later identification using flora, specialist books, manuals, and identification guides, which were used to identify species found on ethnobotanical lists.

2.2.5. Data Analysis

To determine the most commonly used plant-based NTFPs by population, the citation frequency ($C_f$) was calculated using the ethnobotanyR package in R software version 4.2.1. This was based on data collected from ethnobotanical surveys. This approach was supported by the assumption that the species of NTFPs that are most frequently cited by respondents are the most used [14]. The equation used to determine citation frequency is as follows (Equation 1):

$$C_f = \frac{S}{N} \times 100 \quad (1)$$

where s represents the number of people citing the species and N represents the total number of people surveyed. As $C_f$ approaches 0, the species can be considered weakly utilized, while an $C_f$ approaching 100 indicates that the species is heavily utilized.

In addition, diversity indices (Shannon's and Simpson's indices; Pielou equitability) were calculated and a diversity t-test conducted to compare the floristic diversity [32] between both village areas using the database from the floristic inventories. The software used for this analysis was Past version 4.11. Simpson's index describes the probability that a second individual encountered in a forest is the same species as the previous one, while Shannon's index indicates the species heterogeneity of a plant community and the distribution patterns of individuals within those species [55]. Pielou's equitability is the ratio of the observed diversity to the maximum possible diversity, and can be affected by the total number of species inventoried [32]. To compare the diversity indices for both village areas, a diversity t-test was conducted to determine if there was a statistical difference between them [32].

Furthermore, an assessment was conducted on the availability of plant-based NTFPs in both village areas using dendrometry parameters such as the diameter structure of individuals, species density (N; Equation 2), relative density (RD; Equation 3), frequency (F; Equation 4), and relative frequency (RF; Equation 5) of the different source plant species of NTFPs [55,56]. The relative density and relative frequency were calculated using the entire floristic inventory database, while other dendrometry parameters (diameter structure, density, and frequency) were based only on the inventoried NTFP source species. Density is a measure of the number of individuals per unit area (hectare), while relative density shows the proportion of individuals of a specific species in relation to the total number of individuals in a forest. Frequency expresses the probability of a woody species appearing in each floristic inventory plot, while relative frequency is the proportion of a species out of all plant species [55,56]. The dendrometry package for R was used for these calculations. While dendrometry parameters approach 0, the species can be considered less available.

$$N = \frac{Number\ of\ the\ species'stems\ by\ plot}{plot\ area\ (by\ hectare)} \quad (2)$$

$$RD = \frac{Number\ of\ the\ species'stems}{Number\ of\ all\ stems} \times 100 \quad (3)$$

$$F = \frac{Number\ of\ plots\ in\ wich\ the\ species\ is\ present}{Number\ of\ all\ plots} \quad (4)$$

$$RF = \frac{The\ species\ frequency}{Sum\ of\ all\ frequencies} \times 100 \quad (5)$$

Finally, Jaccard's similarity index (Equation 6) [57] was calculated to compare plant species lists derived from the ethnobotanical surveys with the lists obtained from the floristic inventories conducted in each village:

$$J = a / a + b + c \quad (6)$$

where J is Jaccard's index; in the case of this study, a is the total number of species listed or inventoried in both village areas; and b and c are the number of species listed or inventoried, respectively, in one of the two village areas.

## 3. Results

### *3.1. Ethnobotanical knowledge and floristic diversity of woody plant species that serve as NTFP sources in miombo woodlands, as cited by respondents*

Ethnobotanical surveys of *miombo* woodlands were conducted in both riparian villages, revealing that 60 woody species served as sources of NTFPs, including 46 in the degraded forest (Maksem) and 53 in the intact forest (Mwawa). These species belong to 44 genera (Maksem: 36, and Mwawa: 40) and 22 families (Maksem: 18, and Mwawa: 20), of which the Fabaceae were most widely used as a source of NTFPs. Of these species, 22 versus 27 were used in hut building, 9 versus 16 for food, 32 versus 29 for traditional medicine, 19 versus 19 for handicrafts, and 12 versus 3 for traditional rituals in Maksem and Mwawa, respectively. Overall, *Acacia sieberiana*, *Albizia adianthifolia*, *Albizia antunesiana*, *Bobgunnia madagascariensis*, *Cassia abbreviata*, *Entandrophragma delevoyi*, *Isoberlinia* spp., *Lannea discolor*, *Sterculia quinqueloba*, *Strychnos cocculoides*, *Terminalia mollis*, and *Uapaca kirkiana* were the species most in demand for harvesting of plant-based NTFPs. Specifically, *S. cocculoides* and *U. kirkiana* were the species mainly used for food purposes in Maksem and Mwawa villages, respectively. Almost one-fifth of the Maksem local community used *A. antunesiana*, while the same fraction of the Mwawa local community used not only the aforementioned species but also *B. madagascariensis*. In addition, the Maksem and Mwawa communities used *Isoberlinia* spp. and *U. kirkiana*, respectively, as the most common species for hut building. *Sterculia quinqueloba* was the most widely used species in traditional rituals in Maksem, while in Mwawa, *A. sieberiana*, *E. delevoyi*, and *L. discolor* were used for this purpose. Finally, *C. abbreviata* and *T. mollis* were the most widely used species in traditional medicine in Maksem and Mwawa, respectively. Some species, such as *A. adianthifolia* and Annona senegalensis, served multiple purposes for the local communities of both villages. All parts of plants were harvested for traditional medicine (barks, roots), food (fruits), and hut building (stems or cord) or handicraft creation (stems). Further details are summarized in Table 2, below.

The Simpson's diversity index, showing the diversity for the ethnobotanical lists of the two villages, was 0.9588 and 0.9562, while the Shannon's index was 3.42 and 3.44, for Maksem and Mwawa, respectively. Pielou's equitability was 0.8931 and 0.867 for Maksem and Mwawa villages, respectively. The fact that these values are similar indicates that the floristic diversity of these two ethnobotanical lists is similar, as confirmed by the diversity t-test carried out on these indices ($p > 0.05$). Jaccard's similarity index showed that the ethnobotanical lists of both areas had a similarity of almost 65.38%, indicating that the local communities of both villages used the same species for collecting plant-based NTFPs (Table 2).

Notably, more than three-fourths and more than half of the local community in Maksem village and Mwawa village, respectively, are increasingly collecting the stems, roots, and bark of woody species. In addition, fruit were only collected by almost 20% and over 25% of the community in Maksem and Mwawa, respectively. When it comes to harvesting NTFPs, more than three-fourths of both local communities used slashing and plucking as harvesting practices. (Table 2).

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**Table 2.** Ethnobotanical list of woody species sources of NTFPs collected from *miombo* woodlands in the rural area of the city of Lubumbashi. Cf: Frequency of citations; Mak: Maksem village; Mwa: Mwawa village; Ba: Bark; Ro: Root; St: Stem; Le: Leaf; Fr: Fruit; Pe: Peeling; Sl: Slashing; Pl: plucking; Di: Digging; Fo: Food; Ha: Handicraft; Bu: Building; Tr: traditional rituals; Tm: Traditional medicine. -: species was not mentioned by the respondents in the corresponding village area.

| N° | Species | Families | Cf (%) n=50 | | Organs | | Harvesting practices | | Mains uses | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mak | Mwa | Mak | Mwa | Mak | Mwa | Mak | Mwa |
| 1 | *Acacia polyacantha Wild.* | Fabaceae | 2 | .- | Ba, Ro | - | Pe, Di | - | Tm | - |
| 2 | *Acacia sieberiana DC* | Fabaceae | 2 | 2 | Ro | Ro | Di | Di | Tm | Tr |
| 3 | *Afzelia quanzensis Welw.* | Fabaceae | 14 | 4 | St, Le | St | Sl, Pl | Sl | Ha, Bu, Tr | Ha |
| 4 | *Albizia adianthifolia (Schumach.) W. Wight* | Fabaceae | 10 | 40 | Ba, Ro, St | Ba, Ro, St | Pe, Di, Sl | Pe, Di, Sl | Ha, Tm | Ha, Bu, Tm |
| 5 | *Albizia antunesiana Harms* | Fabaceae | 50 | 22 | Ro, St | Ba, Ro, St | Di, Sl | Pe, Di, Sl | Ha, Bu, Tm | Ha, Bu, Tm |
| 6 | *Albizia versicolor Welw. Ex Oliv.* | Fabaceae | 18 | - | Ro, St | - | Di, Sl | - | Ha, Tm | - |
| 7 | *Anisophyllea boehmii Engl.* | Anisophilleaceae | 46 | 54 | Ba, Fr | Ba, Fr, St | Di, Pl, Sl | Pe, Pl, Sl | Fo, Tm | Fo, Bu, Tm |
| 8 | *Annona senegalensis Pers.* | Annonaceae | 10 | 16 | St | Ba, Fr, Ro, St | Sl | Pe, Pl, Di, Sl | Ha, Bu, Tm | Fo, Ha, Bu, Tm |
| 9 | *Bobgunnia madagascariensis (Desv.) J.H. Kirkbr. & Wiersama* | Fabaceae | 16 | 42 | Ba, Ro, St | Ba, Ro, St | Pe, Di, Sl | Pe, Di, Sl | Bu, Tr, Tm | Ha, Bu, Tm |
| 10 | *Brachystegia boehmii Taub.* | Fabaceae | 10 | 24 | Ba, St | Ba, St | Pe, Sl | Pe, Sl | Bu | Ha, Bu, Tm |
| 11 | *Brachystegia floribunda Benth.* | Fabaceae | - | 2 | - | Ba | - | Pe | - | Bu |
| 12 | *Brachystegia spiciformis Benth.* | Fabaceae | 20 | 16 | Ro, St | Ba, St | Di, Sl | Pe, Sl | Ha, Bu, Tm | Bu, Tm |
| 13 | *Cassia abbreviata Oliv.* | Fabaceae | 28 | 4 | Ba, Ro | Ba, Ro | Pe, Di | Pe, Di | Tm | Tm |
| 14 | *Combretum molle Engl. & Diels* | Combretaceae | 8 | 8 | Ba, Ro, St | Ba, Ro, St | Pe, Di, Sl | Pe, Di, Sl | Ha, Bu, Tm | Ha, Bu, Tm |
| 15 | *Diospyros mespiliformis Hochst. Ex A. DC.* | Ebenaceae | - | 2 | - | Ba, Ro | - | Pe, Di | - | Tm |
| 16 | *Diplorhynchus condylocarpon (Müll. Arg.) Pichon* | Apocynaceae | 20 | 6 | Ba, Ro, St | Ba, Ro | Pe, Di, Sl | Pe, Di | Ha, Bu, Tm | Tm |
| 17 | *Entandrophragma delevoyi De Wild.* | Meliaceae | - | 2 | - | Ba, Ro | - | Pe, Di | - | Tr |
| 18 | *Erythrina abyssinica Lam. Ex DC.* | Fabaceae | - | 14 | - | Ba, Ro, St | - | Pe, Di, Sl | - | Ha, Tm |
| 19 | *Erythrophleum africanum (Welw. Ex Benth.) Harms* | Fabaceae | 2 | 10 | Ba | St | Pe | Sl | Bu | Ha, Bu |
| 20 | *Faurea saligna Harv.* | Proteaceae | 4 | 2 | St | St | Sl | Sl | Bu | Bu |
| 21 | *Ficus stuhlmannii Warb.* | Moraceae | 2 | 1 | Le | St | Pl | Sl | Tr | Tr |
| 22 | *Ficus sycomorus L.* | Moraceae | 10 | 2 | Ba, St | St | Pe, Sl | Sl | Ha, Tr, Tm | Ha |
| 23 | *Ficus sp* | Moraceae | - | 2 | - | St | - | Sl | - | Bu |
| 24 | *Garcinia huillensis Welw.* | Clusiaceae | 4 | 18 | Fr | Ba, Ro | Pl | Pe, Di | Fo | Fo, Tm |
| 25 | *Hexalobus monopetalus (A. Rich.) Engl. & Diels* | Annonaceae | 2 | - | Fr | - | Pl | - | Fo | - |
| 26 | *Hymenocardia acida Tul.* | Phyllanthaceae | 10 | 4 | Ba, Ro, St | Ro, St | Pe, Di, Sl | Di, Sl | Ha, Tr, Tm | Bu, Tm |
| 27 | *Isoberlinia spp* | Fabaceae | 56 | 20 | Ba, St | Ba, Ro, St | Pe, Sl | Pe, Di, Sl | Ha, Bu, Tm | Ha, Bu, Tm |

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| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 28 | *Julbernardia globiflora (Benth.) Troupin* | Fabaceae | 8 | - | Ba, St | - | Pe, Sl | - | Bu | - |
| 29 | *Julbernardia paniculata (Benth.) Troupin* | Fabaceae | 30 | 22 | Ba, St | Ba, Ro, St | Pe, Sl | Pe, Di, Sl | Ha, Bu, Tm | Ha, Bu, Tm |
| 30 | *Landolphia kirkii Dyer ex Hook. F.* | Apocynaceae | 2 | 12 | Ro | Fr | Di | Pl | Tm | Fo |
| 31 | *Lannea discolor (Sond.) Angl.* | Anacardiaceae | 6 | 4 | Le, St | Ro, St | Pl, Sl | Di, Sl | Ha, Tr, Tm | Ha, Tr, Tm |
| 32 | *Marquesia macroura Gilg* | Dipterocarpaceae | 4 | 6 | St | St | Sl | Sl | Ha, Bu | Ha, Bu |
| 33 | *Monotes katangensis (De Wild.) De Wild.* | Dipterocarpaceae | - | 2 | - | St | - | Sl | - | Bu |
| 34 | *Ochna schweinfurthiana F. Hoffm.* | Ochnaceae | 2 | - | Ba | - | Pe | - | Tm | - |
| 35 | *Olax obtusifolia De Wild.* | Olacaceae | - | 2 | - | St | - | Sl | - | Bu |
| 36 | *Parinari curatellifolia Planch. Ex Benth.* | Chrysobalanaceae | 26 | 52 | Ba, Fr, Ro, St | Ba, Fr, Ro, St | Pe, Pl, Di, Sl | Pe, Pl, Di, Sl | Fo, Bu, Tm | Fo, Bu, Tm |
| 37 | *Pericopsis angolensis (Boulanger) Meeuwen* | Fabaceae | 22 | 30 | Ro, St | Ro, St | Di, Sl | Di, Sl | Ha, Bu, Tr, Tm | Ha, Bu, Tm |
| 38 | *Piliostigma thonningii (Schumach.) Milne-Redh.* | Fabaceae | 12 | 2 | Ba, Ro | Ba, Ro | Pe, Sl | Pe, Di | Bu,Tr, Tm | Bu,Tm |
| 39 | *Pseudolachnostylis maprouneifolia Pax* | Phyllanthaceae | - | 4 | - | Ba, St | - | Pe, Sl | - | Bu, Tm |
| 40 | *Psorospermum febrifugum Spach* | Hypericaceae | - | 2 | - | Ro | - | Di | - | Tm |
| 41 | *Pterocarpus angolensis DC.* | Fabaceae | 46 | 18 | Ba, Ro, St | St | Pe, Di, Sl | Sl | Ha, Bu, Cu, Tm | Ha, Bu |
| 42 | *Pterocarpus tinctorius Welw.* | Fabaceae | 60 | 4 | Ba, Ro, St | St | Pe, Di, Sl | Sl | Ha, Bu, Tm | Ha, Bu |
| 43 | *Rothmannia engleriana (K. Schum.) Keay* | Rubiaceae | 2 | - | Le | - | Pl | - | Tr | - |
| 44 | *Securidaca longepedunculata Fresen.* | Polygalaceae | 16 | 6 | Le, Ro | Ro | Pl, Di | Di | Tr, Tm | Tm |
| 45 | *Sterculia quinqueloba (Garcke) K. Schum.* | Malvaceae | 26 | 2 | Ba, Le, Ro, St | Ba, Le | Pe, Pl, Di, Sl | Pe, Pl | Bu, Tr, Tm | Bu |
| 46 | *Strychnos innocua Delile* | Loganiaceae | - | 6 | - | Fr | - | Pl | - | Fo |
| 47 | *Strychnos pungens Soler.* | Loganiaceae | - | 2 | - | Ro | - | Di | - | Tm |
| 48 | *Strychnos spinosa Lam.* | Loganiaceae | 12 | 6 | Fr, Ro | Fr, Ro | Pl, Di | Pl, Di | Fo, Tm | Fo, Tm |
| 49 | *Strychnos cocculoides Baker* | Loganiaceae | 48 | 60 | Fr, Ro | Fr, Ro | Pl, Di | Pl, Di | Fo, Tm | Fo, Tm |
| 50 | *Strychnos sp* | Loganiaceae | 2 | 4 | Ro | Ro | Di | Di | Tm | Tm |
| 51 | *Syzygium cordatum Hochst. Ex C. Krauss* | Myrtaceae | - | 2 | - | Fr | - | Pl | - | Fo |
| 52 | *Syzygium guineense DC.* | Myrtaceae | - | 6 | - | Fr | - | Pl, Sl | - | Tm |
| 53 | *Terminalia mollis M.A. Lawson* | Combretaceae | 24 | 32 | Ba, Ro, St | Ba, Ro | Pe, Di, Sl | Pe, Di | Ha, Bu, Tm | Tm |
| 54 | *Thespesia garckeana F. Hoffm.* | Malvaceae | 8 | 22 | Fr | Fr, St | Pl | Pl, Sl | Fo | Fo, Ha |
| 55 | *Uapaca kirkiana Müll.Arg.* | Phyllanthaceae | 46 | 68 | Fr, Ro, St | Fr, St | Pl, Di, Sl | Pl, Sl | Fo, Bu, Tm | Fo, Ha, Bu |
| 56 | *Uapaca nitida Müll.Arg.* | Phyllanthaceae | 2 | 8 | Fr, St | Fr, St | Pl, Sl | Pl, Sl | Fo, Bu | Fo, Bu |
| 57 | *Uapaca pilosa Hutch.* | Phyllanthaceae | - | 6 | - | Fr | - | Pl | - | Fo |
| 58 | *Ximenia sp* | Olacaceae | 2 | 2 | St | St | Sl | Sl | Ha | Bu |
| 59 | *Zanha africana (Radlk.) Exell* | Fabaceae | 2 | - | Ro | - | Di | - | Tm | - |
| 60 | *Zanthoxylum chalybeum Engl.* | Fabaceae | 22 | 28 | Ro | Ba, Ro, St | Di | Pe, Di, Sl | Tm | Ha, Tm |

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*3.2. Socio-economic values of the main NTFPs collected in each village area*

In the different markets of Lubumbashi city, the economic value of the NTFPs collected mostly from the *miombo* woodlands varied according to their different uses, ranging from 0.5 to 14.58 USD per kg. NTFPs used for handicraft purposes had a higher economic value than those used for other purposes. A considerable proportion of these NTFPs did not have economic value and were mainly consumed for personal use. Of the NTFPs that did have economic value, the value of those used as food was low, ranging between 0.5 and 2.5 USD per kg of fruit. For those used in handicraft, their economic value varied depending on the type of handicraft (pestles, mortars, handles, mixers, tam-tams, sieves), and ranged from 0.84 to 14.58 USD per kg. NTFPs collected for hut building had a similar price regardless of the species collected, amounting to approximately 0.83 USD per kg of stem. Finally, the price of NTFPs collected for use in traditional medicine was determined by the size of the root or bark, with an average value of 9.25 USD per kg of root or bark (Table 3)

**Table 3.** Socio-economic values of the top-five most-harvested NTFPs in *miombo* woodlands according to their different uses. NTFPs collected for self-consumption are excluded from this table. $C_f$: Frequency of quotation. -: species was not mentioned by the respondents in the corresponding village area. Average weight of a mixer = 0.24 kg; handle = 0.80 kg; pestle = 1.78 kg; mortar = 8.78 kg; juvenile stem = 3 kg.

| N° | Species | Village areas ($C_f$%) ; n=50 | | Economic value (USD) |
|---|---|---|---|---|
| | | Maksem | Mwawa | |
| | | Food use | | |
| 1 | *A. boehmii* | 21 | 27 | 2.5/kg |
| 2 | *S. cocculoides* | 23 | 28 | 0.5/kg |
| 3 | *U. kirkiana* | 22 | 31 | 0.57/kg |
| | | Handicraft use | | |
| 4 | *A. adianthifolia* | - | 12 | 1.88/kg of Handle or 0.84/kg of pestle |
| 5 | *A. antunesiana* | 16 | 8 | 1.88/kg of Handle or 0.84/kg of pestle |
| 6 | *A. versicolor* | 9 | - | 1.88/Handle |
| 7 | *A. senegalensis* | - | 5 | 1.88/Handle |
| 8 | *B. madagascariensis* | - | 12 | 1.88/kg (Handle) or 0.84/kg (pestle) |
| 9 | *Isoberlinia spp* | 13 | 4 | 1.43 -14.58/kg of art |
| 10 | *P. angolensis* | - | 5 | 1.43 -14.58/kg of art |
| 11 | *P. angolensis* | 8 | 7 | 1.43 -14.58/kg of art |
| 12 | *P. tinctorius* | 12 | - | 1.43 -14.58/kg of art |
| | | Use in hut building | | |
| 13 | *A. antunesiana* | 12 | - | 0.83/kg of stem |
| 14 | *B. madagascariensis* | - | 9 | 0.83/kg of stem |
| 15 | *B. boehmii* | - | 11 | 0.83/kg of stem |
| 16 | *B. spiciformis* | - | 7 | 0.83/kg of stem |
| 17 | *E. africanum* | - | 4 | 0.83/kg of stem |
| 18 | *Isoberlinia spp* | 26 | 4 | 0.83/kg of stem |
| 19 | *J. paniculata* | 10 | 7 | 0.83/kg of stem |
| 20 | *P. angolensis* | - | 11 | 0.83/kg of stem |
| 21 | *P. angolensis* | 20 | - | 0.83/kg of stem |
| 22 | *P. tinctorius* | 24 | - | 0.83/kg of stem |
| 23 | *U. kirkiana* | - | 12 | 0.83/kg of stem |
| 24 | *U. nitida* | - | 4 | 0.83/kg of stem |
| | | Use in traditional medicine | | |
| 25 | *B. madagascariensis* | - | 12 | 9.25/kg of Root or Bark |
| 26 | *C. abbreviata Oliv.* | 14 | - | 9.25/kg of Root |
| 27 | *S. longepedunculata* | 7 | - | 9.25/kg of Root |

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| | | | | |
|---|---|---|---|---|
| 28 | *T. mollis* | 10 | 16 | 9.25/kg of Root or Bark |
| 29 | *Z. chalybeum* | 11 | 12 | 9.25/kg of Root |

*3.3. Availability of woody plant species NTFP sources in both forest habitats*

Almost all woody-species NTFP source individuals inventoried in both ecosystems (degraded forest: Maksem, and intact forest: Mwawa) had a diameter at breast height (dhp) that varied between 5 cm and 45 cm. In Maksem, almost all individuals were found in the low diameter class (5–15 cm). whereas in Mwawa, the inventoried individuals were distributed in all diameter classes with an acceptable number of individuals. That diametric structure of Mwawa forest presents an inverted J-curve, indicating a multispecies, ecologically stable habitat with high regeneration potential (Figure 2).

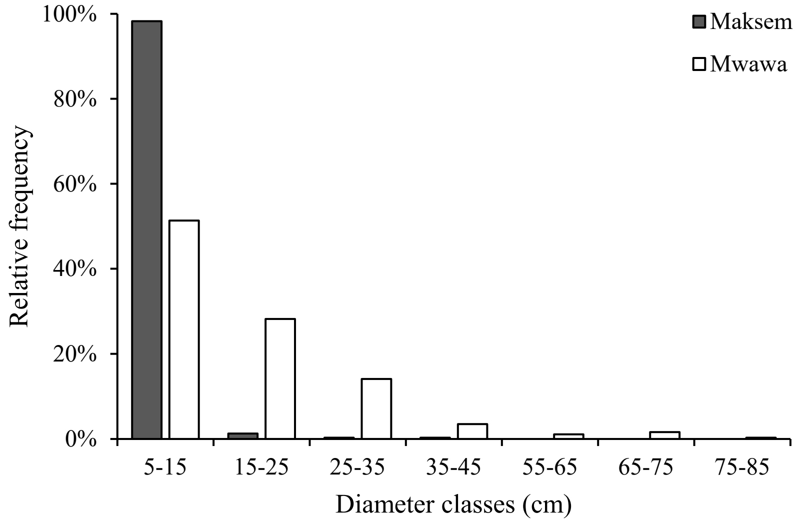


**Figure 2.** Diameter structure (cm) of NTFP source species inventoried around two villages: Maksem (degraded forest) and Mwawa (intact forest).

A total of 1,059 individuals (Maksem: 444; Mwawa: 615) were inventoried, belonging to 57 species (Maksem: 34; Mwawa: 47); 39 genera (Maksem: 26; Mwawa: 35), and 21 families (Maksem: 15; Mwawa: 21). Of the total, 785 (Maksem: 397; Mwawa: 388) individuals were sources of NTFPs. These individuals belonged to 40 woody species (Maksem: 27; Mwawa: 33), 28 genera (Maksem: 21; Mwawa: 25), and 13 families (Maksem: 11; Mwawa: 13). The NTFP source individuals represented 74.13% (Maksem: 89.41%; Mwawa: 63.09%) of the total forest, while the NTFP source species accounted for 70.41% (Maksem: 79.41%; Mwawa: 70.21%) of all inventoried woody species.

The density of species per hectare varied between 0.83 and 107.5 individuals. It ranged from 0.83 to 92.5 individuals (mean: 13.19 ± 22.85) and from 0.83 to 107.5 (mean: 10.86 ± 19.2) individuals in the Maksem and Mwawa forests, respectively. Relative density varied between 0.21 and 24.34% and from 0.16 to 20.98% in Maksem and Mwawa forests, respectively. *Isoberlinia* spp. and *B. spiciformis* had high density in both forests, with individuals of these species representing nearly a quarter of the total individuals in each forest.

The probability of species being found in all floristic inventory plots (or the frequency species) varied between 0.08 to 1. The frequency of species in the Maksem forest ranged from 0.08 to 0.83 (mean: 0.31 ± 0.21), and from 0.08 to 1 (mean: 0.32 ± 0.26) in the Mwawa forest. In addition, *A. adianthifolia*, Ficus sycomorus, *Julbernardia paniculata*, and *Parinari curatellifolia* had a high probability of being found in all floristic inventory plots. Notably, *F. sycomorus*, *J. paniculata* and *P. curatellifolia* had a near-100% probability of being inventoried in all floristic inventory plots in Maksem degraded forest, while *A. adianthifolia* had a similarly high probability in the Mwawa intact forest. The relative frequencies of species varied between 0.55 and 7.75%, ranging from 0.78 to 7.75% (mean: 2.86 ± 1.92)

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and from 0.55 to 6.59% (mean: 2.13 ± 1.70) in Maksem and Mwawa forests, respectively. *Julbernardia paniculata* and *B. spiciformis* represented around 10% of all species in each forest (Table 4).

When comparing the floristic diversity between both surveyed forests, the Simpson's diversity index was 0.8537 for the degraded forest (Maksem) and 0.8668 for the intact forest (Mwawa). In addition, Shannon's index was 2.452 for Maksem and 2.739 for Mwawa. The diversity t-test, applied to the Shannon diversity index, indicated a significant difference between both forests ($p < 0.01$). Finally, Jaccard's similarity index indicated that both floristic inventory lists have 50% similarity.

**Table 4.** Woody plant species sources of NTFPs inventoried in the *miombo* woodlands around the two villages. Maksem (Mak): degraded forest and Mwawa (Mwa): intact forest. -: species was not inventoried during floristic inventories in the corresponding village's forest.

| N° | Species | Families | Density /ha | | Relative Density (%) | | Frequency | | Relative Frequency (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mak | Mwa | Mak | Mwa | Mak | Mwa | Mak | Mwa |
| 1 | *A. polyacantha* | Fabaceae | - | - | - | - | - | - | - | - |
| 2 | *A. sieberiana* | Fabaceae | - | - | - | - | - | - | - | - |
| 3 | *A. quanzensis* | Fabaceae | - | - | - | - | - | - | - | - |
| 4 | *A. adianthifolia* | Fabaceae | 4.17 | 17.5 | 1.1 | 3.41 | 0.25 | 0.83 | 2.33 | 5.49 |
| 5 | *A. antunesiana* | Fabaceae | 10.83 | 11.67 | 2.85 | 2.28 | 0.5 | 0.58 | 4.65 | 3.85 |
| 6 | *A. versicolor* | Fabaceae | - | - | - | - | - | - | - | - |
| 7 | *A. boehmii* | Anisophylleaceae | 2.5 | 6.67 | 0.66 | 1.3 | 0.08 | 0.42 | 0.78 | 2.75 |
| 8 | *A. senegalensis* | Annonaceae | 1.7 | - | 0.43 | - | 0.17 | - | 1.55 | - |
| 9 | *B. madagascariensis* | Fabaceae | 1.7 | 5.83 | 0.43 | 1.14 | 0.17 | 0.42 | 1.55 | 2.75 |
| 10 | *B. boehmii* | Fabaceae | 2.5 | - | 0.65 | - | 0.17 | - | 1.55 | - |
| 11 | *B. floribunda* | Fabaceae | - | - | - | - | - | - | - | - |
| 12 | *B. spiciformis* | Fabaceae | 15.83 | 107.5 | 4.17 | 20.98 | 0.5 | 1 | 4.65 | 6.59 |
| 13 | *C. abbreviata* | Fabaceae | - | - | - | - | - | - | - | - |
| 14 | *C. molle* | Combetaceae | 0.83 | 3.33 | 0.22 | 0.65 | 0.08 | 0.25 | 0.77 | 1.65 |
| 15 | *D. mespiliformis* | Ebenaceae | - | - | - | - | - | - | - | - |
| 16 | *D. condylocarpon* | Apocynaceae | 13.33 | 15.83 | 3.51 | 3.09 | 0.58 | 0.58 | 5.43 | 3.85 |
| 17 | *E. delevoyi* | Fabaceae | - | - | - | - | - | - | - | - |
| 18 | *E. abyssinica* | Fabaceae | - | - | - | - | - | - | - | - |
| 19 | *E. africanum* | Fabaceae | - | 5.83 | - | 1.13 | - | 0.33 | - | 2.2 |
| 20 | *F. saligna* | Proteaceae | - | - | - | - | - | - | - | - |
| 21 | *F. stuhlmannii* | Moraceae | - | - | - | - | - | - | - | - |
| 22 | *F. sycomorus* | Moraceae | 0.83 | - | 0.21 | - | 0.83 | - | 0.78 | - |
| 23 | *Ficus sp* | Moraceae | - | 0.83 | - | 0.16 | - | 0.08 | - | 0.55 |
| 24 | *G. huillensis* | Clusiaceae | - | - | - | - | - | - | - | - |
| 25 | *H. monopetalus* | Annonaceae | 0.83 | - | 0.22 | - | 0.08 | - | 0.78 | - |
| 26 | *H. acida* | Phyllanthaceae | - | 0.83 | - | 0.16 | - | 0.08 | - | 0.55 |
| 27 | *Isoberlinia. Spp* | Fabaceae | 92.5 | 15.83 | 24.34 | 3.09 | 0.67 | 0.75 | 6.2 | 4.94 |
| 28 | *J. globiflora* | Fabaceae | 24.17 | - | 6.35 | - | 0.42 | - | 3.88 | - |
| 29 | *J. paniculata* | Fabaceae | 75 | 4.17 | 19.74 | 0.81 | 0.83 | 0.17 | 7.75 | 1.1 |
| 30 | *L. kirkii* | Apocynaceae | - | 1.67 | - | 0.32 | - | 0.08 | - | 0.55 |
| 31 | *L. discolor* | Anacardiaceae | - | 5 | - | 0.98 | - | 0.33 | - | 2.2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 32 | *M. macroura* | Dipterocarpaceae | - | 17.5 | - | 3.41 | - | 0.25 | - | 1.65 |
| 33 | *M. katangensis* | Dipterocarpaceae | - | 7.5 | - | 1.46 | - | 0.41 | - | 2.75 |
| 34 | *O. schweinfurthiana* | Ochnaceae | 5.83 | - | 1.54 | - | 0.42 | - | 3.88 | - |
| 35 | *O. obtusifolia* | Olacaceae | - | 2.5 | - | 0.48 | - | 0.17 | - | 0.55 |
| 36 | *P. curatellifolia* | Chrysobalanaceae | 0.83 | 6.67 | 0.21 | 1.3 | 0.83 | 0.41 | 0.78 | 2.75 |
| 37 | *P. angolensis* | Fabaceae | 1.7 | 10.83 | 0.44 | 2.11 | 0.17 | 0.58 | 1.55 | 3.85 |
| 38 | *P. thonningii* | Fabaceae | - | 0.83 | - | 0.16 | - | 0.08 | - | 0.55 |
| 39 | *P. maprouneifolia* | Phyllanthaceae | - | 4.16 | - | 0.81 | - | 0.17 | - | 1.1 |
| 40 | *P. febrifugum* | Hypericaceae | - | - | - | - | - | - | - | - |
| 41 | *P. angolensis* | Fabaceae | 10 | 20.83 | 2.63 | 4.07 | 0.58 | 0.58 | 5.42 | 3.85 |
| 42 | *P. tinctorius* | Fabaceae | 19.17 | - | 5.04 | - | 0.58 | - | 5.42 | - |
| 43 | *R. engleriana* | Rubiaceae | - | - | - | - | - | - | - | - |
| 44 | *S. longepedunculata* | Polygalaceae | - | - | - | - | - | - | - | - |
| 45 | *S. quinqueloba* | Sterculiaceae | - | - | - | - | - | - | - | - |
| 46 | *S. innocua* | Loganiaceae | - | - | - | - | - | - | - | - |
| 47 | *S. pungens* | Loganiaceae | - | 0.83 | - | 0.16 | - | 0.08 | - | 0.55 |
| 48 | *S. spinosa* | Loganiaceae | 3.33 | 5 | 0.88 | 0.33 | 0.25 | 0.17 | 2.33 | 1.1 |
| 49 | *S. cocculoides* | Loganiaceae | - | 3.33 | - | 0.65 | - | 0.33 | - | 2.2 |
| 50 | *Strychnos sp* | Loganiaceae | - | 4.17 | - | 0.81 | - | 0.33 | - | 2.2 |
| 51 | *S. cordatum* | Myrtaceae | - | - | - | - | - | - | - | - |
| 52 | *S. guineense* | Myrtaceae | - | 0.83 | - | 0.16 | - | 0.08 | - | 0.55 |
| 53 | *T. mollis* | Combretaceae | 0.83 | - | 0.21 | - | 0.08 | - | 0.78 | - |
| 54 | *T. garckeana* | Malvaceae | - | - | - | - | - | - | - | - |
| 55 | *U. kirkiana* | Phyllanthaceae | 11.67 | 17.5 | 3.07 | 3.41 | 0.41 | 0.75 | 3.88 | 4.94 |
| 56 | *U. nitida* | Phyllanthaceae | 3.33 | 10 | 0.88 | 1.95 | 0.17 | 0.42 | 1.55 | 2.75 |
| 57 | *U. pilosa* | Phyllanthaceae | - | - | - | - | - | - | - | - |
| 58 | *Ximenia sp* | Olacaceae | - | - | - | - | - | - | - | - |
| 59 | *Z. africana* | Fabaceae | - | - | - | - | - | - | - | - |
| 60 | *Z. chalybeum* | Rutaceae | - | - | - | - | - | - | - | - |

A Jaccard similarity index of more than 50% was observed between the lists of ethnobotanical surveys and floristic inventories conducted in both forests. This means that the woody species inventoried as NTFP sources represent almost half of the species listed in the ethnobotanical survey for both village areas. Specifically, in Maksem and Mwawa forests, the comparison between ethnobotanical and floristic inventories lists resulted in 53.84% versus 53.85% similarity, respectively.

## 4. Discussion

### *4.1. Ethnobotanical knowledge and floristic diversity of woody species NTFP sources harvested from miombo woodlands and used by riparian populations in village areas.*

The ethnobotanical surveys revealed a list of around sixty woody species, with nearly fifty species in each village. These results demonstrate that the riparian communities of the *miombo* woodlands have proven knowledge of species, as stipulated by Ref. [58] for the riparian communities of *miombo* woodlands in Tanzania. The rich ethnobotanical lists found in this survey highlight the important role played by NTFPs in the daily lives of riparian communities [19], particularly in *miombo*

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woodlands [22]. However, the diversity of traditional knowledge and the floristic diversity of NTFP source species in the living environment will influence the number of NTFP source species reported by local community members [59]. It has been found that the diversity of NTFPs and their varied uses by different communities is related to these communities' habits and customs, which can differ greatly from one community to another [59], as we revealed for two riparian communities in Lubumbashi (Table 2). The ethnobotanical lists have a similarity rate of roughly 75%, even in the face of varying levels of degradation in the *miombo* woodlands between the two village areas. This can be attributed to the fact that local riparian communities usually belong to the same ethnic group and share similar customs and habits [22]. This result corroborates those of Refs. [14,60], which suggest that increased interaction among ethnic groups in the same geographic area may impact their knowledge of woody species.

However, the similarity between the two ethnobotanical lists may also indicate that the local community in the village areas with degraded forests are continuing to harvest NTFPs as they would in intact forests, even by utilizing seedlings, to meet their NTFP needs. This practice may decrease the forest's ability to regenerate.

### *4.2. NTFP-harvesting practices used in the two villages, and organs collected*

The harvesting practices for plant-based NTFPs have low sustainability, and may be having negative impacts on the *miombo* woodlands. Indeed, slashing the stems of woody individuals contributes to a direct reduction in the density of the forest, particularly for the populations of woody species that are sources of NTFPs [4]. Additionally, this harvesting practice contributes to forest degradation and reduces the capacity of forests such as the *miombo* woodlands to provide ecosystem services to dependent riparian and urban communities. This practice also contributes to a loss of plant biodiversity [61] in the *miombo* woodlands, which possess significant floristic diversity with a high rate of endemism [35]. Harvesting stems from seedlings (woody individuals with dhp < 10 cm) compromises the future of the forest, as these seedlings constitute the adult individuals of the future [6]. This may explain the high forest degradation and lower biodiversity of plant-based NTFPs observed in Maksem village area, where the most common harvesting practice used is slashing. In contrast, plucking of fruits remains the most common harvesting practice in the Mwawa village area (Table 2). This method is more sustainable and has a lower negative impact on the forest's future and the environment [4]. However, research conducted in South Africa has indicated that wild fruit resources have declined due to excessive harvesting [62]. Excessive harvesting and exportation of fruits from the forest will ultimately compromise its capacity for regenerative growth.

Moreover, the harvesting of roots, stems, and bark of woody species may be considered harmful due to the fact that they play a crucial role in the survival of plant species [63] and the integrity of forest ecosystems [7], especially in the *miombo* woodland ecoregion, which are characterized mainly by the alternation of dry and rainy seasons [22]. Excessive harvesting of individual roots by digging negatively impacts their stability and ability to absorb water and minerals from the soil. Additionally, bark harvesting disrupts the circulation of sap and leaves the plant more vulnerable to aggressors and diseases that could lead to desiccation [4,64].

### *4.3. Socio-economic values of NTFPs collected in miombo woodlands and sold in urban and peri-urban markets*

Most of the NTFPs harvested from *miombo* woodlands have high economic value, with prices in urban markets confirming the findings of other researchers [4,19,22,39] who have shown the importance of NTFPs in daily life. Rural and urban communities rely on these NTFPs for their livelihood, especially for those without arable land or sufficient income [11,65]. However, NTFPs used for food have a lower economic value, as urban populations in Lubumbashi are increasingly opting for manufactured food substitutes.

Furthermore, the exceptionally high economic value of NTFPs for artisanal use and hut building may motivate members of local communities, particularly those in poverty, to overharvest the forest resources for their own survival. This phenomenon can lead to forest degradation, deforestation, and

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the disappearance of several plant species [4]. Combined with the proximity of a village to a road and its accessibility (facilitating the transport of NTFPs, along with various other forest products, to urban markets)—as in the case of Maksem village—this accentuates the overexploitation of forest resources and can lead to the rapid degradation of the forest.

*4.4. Availability of woody species as sources of NTFPs in the areas around the two villages: Maksem (degraded forest) and Mwawa (intact forest).*

The availability of woody species as sources of NTFPs is low, particularly in the degraded Maksem forest. This low availability is due to factors such as low floristic diversity, low density, low frequency, and low dhp of woody individuals that serve as sources of NTFPs. Excessive human activity and unsustainable harvesting practices may be the main causes of this situation [66]. These results corroborate those of previous studies, such as that conducted by Ref. [54] in *miombo* woodlands in Mozambique, where less-disturbed habitats had higher diversity, density, and dhp of woody individuals. This demonstrates that overexploitation of *miombo* woodlands can lead to the depletion of forest resources, specifically those related to NTFPs. Human activity—essentially agriculture, wood-energy production, and particularly activity related to the harvesting of NTFPs—is one of the factors driving deforestation and degradation of *miombo* woodlands in the peri-urban and rural areas of Lubumbashi city [16,17]. In addition, the low availability of woody individuals (sources of NTFPs) in the Lubumbashi region could be attributed to deforestation and forest degradation as a result of urbanization [67–69], intensive mining activity, and soil pollution by trace metals, as demonstrated by previous studies [28,29]. Climate change in the region could also be a contributing factor to its forest degradation [18].

*4.5. Implications of the results for the sustainability of miombo woodland ecosystem services*

NTFPs play a crucial role in the survival of riparian and urban communities [20], as evidenced by the ethnobotanical lists provided by community members in this survey (Table 2). However, due to the low production capacity of the agricultural system and the effects of climate change, these communities rely heavily on forest resources for their survival, contributing to forest degradation [6,14], especially in *miombo* woodlands [70]. This rapid degradation of *miombo* woodlands is leading to a reduction in the availability of NTFPs in the rural area of Lubumbashi, and it is endangering both the forest and the communities that depend on it. Domesticating woody species that are sources of NTFPs would represent an alternative solution [71]. Domestication can play a crucial role in maintaining biodiversity, particularly in the case of NTFP source species found in natural environments [72]. With domestication and the establishment of nurseries for NTFP woody species, it is possible to reduce human pressure on forest resources [73] and allow woody species to naturally reconstitute forest stands. The strategy would require the identification of priority NTFP woody species [14,39,54]. For example, Ref. [74] successfully domesticated *miombo* woodland woody species, namely U. kirkiana, P. curatellifolia, S. cocculoides, and Sclerocarya birrea (A. Rich.) Hochst., in South Africa to counteract the excessive collection of NTFPs in natural areas. Nonetheless, implementing a monitoring system can enable the identification of priority NTFP source species, which can serve as a foundation for conservation efforts [39,75,76].

In addition, to mitigate the low availability of NTFP woody species in degraded *miombo* woodlands highlighted in the present study's findings (Table 4), one option is the enrichment of degraded forests. This could be achieved through reforestation using woody species native to *miombo* woodlands [77]. This approach would help maintain the forest's structure, composition (floristic diversity), and function in the region [18,78]. However, research conducted by Ref. [32] indicates that native *miombo* woodland species regenerate poorly and grow slowly, slowing down the reforestation and enrichment of forest ecosystems. Therefore, an alternative solution would be to use exotic multipurpose species such as Acacia auriculiformis A. Cunn. ex Benth [79,80]. These exotic species have already been used elsewhere, and have produced desirable outcomes on the Bateke plateau [81] as well as in the Lubumbashi region (Mukoma and Kikonke) in the DRC.

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NTFPs harvested from *miombo* woodlands hold economic value for both local and urban communities, as they serve as a source of income and generate economic benefits [14], as indicated by the results in this study (Table 3). However, this economic value could lead to their overexploitation, as harvesting regulation is weak and monitoring systems are lacking [82]. Thus, implementing a certification system for NTFPs sold on the market is a necessary step, as noted by Ref. [79]. This certification process plays a crucial role in enhancing the economic value and sustainability of forest resources, especially NTFPs [83]. This certification would enable the identification of sustainably harvested NTFPs on the market, encouraging harvesters, sellers, and consumers to adopt environmentally responsible practices [84].

The harvesting practices for NTFPs—particularly slashing—remain unsustainable and compromise the *miombo* woodlands' regeneration capacity. Unfortunately, many local community members continue to use unsustainable harvesting practices, as indicated by the results of this study (Table 2). These practices contribute to forest degradation and reduce the ecosystem services that these forests provide to rural communities [14]. To mitigate this, it is essential to regulate the exploitation of woody species by reforming forest resource exploitation legislation [82]. Tanzania has already attempted to regulate *miombo* woodland exploitation by reforming woody species harvesting legislation and setting a minimum cutting diameter below which individuals should not be harvested, thereby promoting the sustainable exploitation of woody forest resources [15]. However, the key to implementing these standards for forest resource exploitation lies in educating and sensitizing local communities to their adoption.

## 5. Conclusions

This study examined the socio-economic value and availability of plant-based NTFPs in the rural area of Lubumbashi by means of ethnobotanical and socio-economic interviews, supplemented with floristic inventories in two village areas, each characterized by contrasting forest conditions (degraded and intact). Results revealed that ethnobotanical lists of the tree species used by the riparian communities as source of NTFPs were similar (almost 75%) despite the evident contrasts in the degradation of the *miombo* woodlands in both village areas. The study identified 60 tree species, including 46 in the degraded forest and 53 in the intact forest, as the sources of NTFPs within both village areas, highlighting 25 priority species. Furthermore, the study demonstrated that the practices utilized for harvesting plant-based NTFPs in the *miombo* woodlands were unsustainable. These practices, including slashing, digging, and peeling, accounted for nearly three-quarters of all survey citations and, as a result, are causing significant forest degradation. Finally, it was found that NTFPs harvested in the *miombo* woodlands had a non-negligible economic importance, playing an essential role in the life of rural and urban communities. Economic values ranged from 0.5 to 14.58 USD per kg depending on the type of NTFP (species and use), forming one of the primary sources of income for households in both study areas. Thus, it is crucial that the monitoring, harvesting regulation, and sustainable management of plant-based NTFPs be given priority, thus maintaining the capacity of *miombo* woodlands to provide ecosystem services to local communities.

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