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Utilization of non-timber forest products as alternative sources of food and income in the highland regions of the Kahuzi-Biega National Park, eastern Democratic Republic of Congo

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ABSTRACT

In developing countries, studies on sustainable preservation of forests (including non-timber forest products NTFPs) have been poorly carried out for promoting alternative income generating activities (IGA) to alleviate pressure on praised resources by local communities living close by protected areas. This study aimed at (1) inventorying NTFPs exploited by local communities around the Kahuzi Biega National Park (KBNP), (2) assessing their therapeutic values and nutritional contributions, and (3) analyzing their rural and urban market values to determine their potential as alternative income sources as well as the major constraints in their exploitation. Individual interviews were conducted with 790 rural and urban households in Kabare, Walungu, Kalehe, and Bukavu City, eastern Democratic Republic of Congo (DRC) coupled with focus group discussions with key stakeholders around KBNP. Street vendors, restaurants, hotels, and market owners were also interviewed on uses, awareness of the nutritional and therapeutic values, and factors hindering NTFPs wide use in Bukavu urban environments. Physicochemical analyses were also conducted on main NTFPs to determine their nutritional values. Results showed that local populations around KBNP exploit at least 55 NTFPs, mainly for self-consumption as food, feed, and medicine. NTFPs represent the second most important income source around KBNP, accounting for 23.3 % of total households' income after agriculture that generates 25.7 % of total households' income. Income from NTFP trade was primarily used for food supply (29 %), investment in small businesses (19.6 %), children's education (17.7 %), and healthcare expenses (5.1 %). These NTFPs had varying nutritional values (in terms of proximate composition, essential minerals, and bioactive compounds). *Solanum nigrum* (24.9 %), *Termitomyces robustus* (18.0 %), *Amaranthus viridis* (17.6 %), and *Piper nigrum* (16.9 %) are valuable sources of proteins while *Zingiber officinale* (25.5 %), *T. robustus* (15.4 %) and *P. nigrum* (14.3 %) are rich in dietary fibres. *Piper nigrum* (37.0 and 128.3 mg/kg) and *Basella alba* (35.1 and 108.7 mg/kg) had the highest zinc and iron contents, respectively. Some of the most nutritious NTFPs, such as *S. nigrum, Dioscorea* spp., and *P. nigrum* had high contents in anti-nutritional elements and should be processed properly to maximize bioavailability. Besides, NTFPs created employment opportunities for collectors, vendors, supermarkets, hotels, and restaurants both in rural and urban areas. Though varying with rural communities, the main challenges in the NTFP value chain were low market values (48.6 %), short shelf life (22.5 %), and excessive taxation (19.1 %) while in urban areas, seasonality (36.9 %), scarcity (17.7 %), and prohibiting high prices (17.7 %) were the major limiting factors. This study highlights the significant role played by NTFPs in providing healthy and nutritious food and income for households surrounding the KBNP, and thus emphasizes the necessity for their

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promotion as alternative income sources and healthy diets to alleviate poverty and hidden hunger around the KBNP.

1. Introduction

Forests are important ecosystem service providers (Pohjanmies et al., 2017; Aznar-Sánchez et al., 2018). They play at least 100 different forest services that can be grouped under the following categories: (i) food, timber and fuel production; (ii) water conservation and regulation; (iii) nutrient retention; (iv) carbon sequestration; (v) biodiversity protection; (vi) climate regulation; (vii) ecotourism; and (viii) spiritual and traditional value (Aznar-Sánchez et al., 2018). In rural tropical areas, forests (including non-timber forest products NTFPs) represent a key source of food, economic, social, ecological, and cultural values for forest dependent people (Sardeshpande and Shackleton, 2019; Nerfa et al., 2020; Maua et al., 2020; Kazungu et al., 2020; Talukdar et al., 2021; Shackleton and de Vos, 2022; Chervier et al., 2024). However, forests' gradual degradation, particularly in developing countries, poses a threat to sustainable development and effective poverty alleviation efforts (Kazungu et al., 2020; Feng et al., 2022; Shapiro et al., 2023).

Globally, it has been estimated that forest cover decreases at a rate of 0.18 % yearly since 2000, leading to a scarcity of forest products and services' provision to local communities living and depending on such forest resources (Wolf et al., 2021; Feng et al., 2022). Rapid population growth, expansion of farmland and urbanization areas, and climate change have been listed as the major drivers of change that threaten worldwide forest system sustainability (Aznar-Sánchez et al., 2018). One of the direct consequences of a rapid population growth is the unbalance between the food demand and the food supply that results in food insecurity, particularly in disadvantaged areas. For instance, it has been hypothesized that precarious socioeconomic situations in forest-adjacent areas is one the main causes of deforestation and forest degradation in developing countries (Muafor et al., 2015; Tyukavina et al., 2018; Kazungu et al., 2020; Hartley, 2021). Therefore, improving local communities' incomes and food security around protected areas would be one of the effective approaches for maintaining the existing primary vegetation in those disadvantaged areas (Kazungu et al., 2020).

Collection and trade of non-timber forest products (NTFPs) have already proven effective in improving communities' livelihood (Loubelo, 2012; Suleiman et al., 2017; Delgado et al., 2022). They are used as food, traditional medicine, and raw materials in various sub-products, such as cosmetics (Loubelo, 2012; FAO, 2014; Talukdar et al., 2021; Zhu et al., 2021). In developing countries, it has been estimated that more than three-fourths of the populations are dependent on NTFPs for their nutrition and primary healthcare (Brack, 2018; Talukdar et al., 2021). NTFPs have significant economic value, providing ~25 % of income of ~1 billion people (Delgado et al., 2022). In some countries, it has been proven that "wild" fruits, leaves, or vines, etc. could contribute up to 14–44 % of household incomes in forest-adjacent areas (Ao et al., 2021; Zhu et al., 2021). NTFPs are even much valuable in tropical areas where ~300 million people living close by tropical forests rely on NTFPs for some or all of their income (Bharucha and Pretty, 2010). It is noteworthy that NTFPs ensure food security by providing emergency food during lean periods and serving as a safety net against seasonal uncertainties and household vulnerability to external shocks (Loubelo, 2012; Suleiman et al., 2017; Talukdar et al., 2021; Shackleton and de Vos, 2022). Besides, NTFPs are very nutritious and could help alleviate hunger if fully exploited (Sardeshpande and Shackleton, 2019). For instance, several studies across the Congo basin reported the presence of bioactive compounds, such as enzymes, pigments, and polyphenols, and anti-oxidant, anti-inflammatory, cardioprotective, immune-boosting, anti-cancer, anti-diabetic, gastroprotective, anti-anemia, and anti-diarrheal functional properties among NTFPs and other traditional foods consumed by forest adjacent tribes (Bukatuka et al., 2016; Fundu et al., 2023; Fungo et al., 2023). These authors indicated that low use of these foods by local communities, owing to the lack of awareness of their nutritional and therapeutic values, is often associated with acute shortcomings in macro and micronutrients. In central Africa alone, as many as 500 species of plants and 85 species of animals are collected from forests and savannas and play a major contribution to the household's food security and economy (Sardeshpande and Shackleton, 2019). NTFPs would, therefore, present an opportunity for riparian populations who exploit them on subsistence basis, if they are promoted at the income-generating activity (IGA) status.

Based on the above economic and food significances, special attention should be given to their sustainable management and valorization, when considering their significant contribution to the informal economic sector (Loubelo, 2012; Endamana et al., 2016; Mugido and Shackleton, 2019; Talukdar et al., 2021). Past studies carried out have suggested the utilization of NTFPs as alternative sources of food and income for the benefit of local communities whose livelihood depends on threatened NTFPs (Mhuji et al., 2018; Thammanu et al., 2021). That necessity is high in regions of lower agricultural potential (Mugido and Shackleton, 2019). Derebe and Alemu (2023) suggested that for food security, poverty reduction, and improved livelihoods, particularly in rural regions, it is crucial to promote NTFPs, enhance harvesting policies, and improve their processing methods.

The Democratic Republic of Congo (DRC) is a biological hotspot, being the 5th most biodiverse country on earth (Counsell, 2006) and hosting almost half of Africa's rainforests. However, the country faces unprecedented development challenges, making it the second largest hunger crisis in the world after Yemen and among the five poorest nations in the world (World Bank, 2023). In 2022, nearly 62 % of Congolese, around 60 million people, lived on less than $2.15 a day. About one out of six people living in extreme poverty in Sub-Saharan Africa lives in DRC (World Bank, 2023). This precarious socioeconomic situation has increased the populations' reliance on natural resources for their livelihoods, including forests (Hartley, 2021; Muvatsi et al., 2021; Karume et al., 2022; Nsevolo et al., 2023). Destructive activities include deforestation for mining, wood fuel, overexploitation of natural resources for human food and/or other essential needs (Spira et al., 2019; Karume et al., 2022). Reports showed that at least 70 % of the Congolese population directly depends on the forest for food, medicine, wood for construction, etc. (Termote et al., 2011). Consequently, ~16 million ha of forest area has been lost between 2000 and 2014 and ~1.31 million ha of natural forest were deforested in 2020 only, emitting ~854 million tons of CO_2 (Hartley, 2021; Karume et al., 2022; Shapiro et al., 2023; Chervier et al., 2024). This situation makes the DRC both the main contributor to forest loss in the region in recent years (~69 %) while the country hosts the largest proportion of the Congo basin forests, about 60 % (Tyukavina et al., 2018; Chervier et al., 2024).

In response to the above challenges, there are governmental and non-governmental initiatives to reduce deforestation in DRC, but wide poverty among populations hinders such efforts (Spira et al., 2019; Karume et al., 2022). Nevertheless, the country committed to reducing its greenhouse gaze emission (whose more than 80 % are associated with deforestation) by 17 % from 2021 to 2030, if external financing of ~ $21.6 billion is provided to allow the country reduce its heavy dependence on forests (Hartley, 2021). To reach such a commitment implies that the DRC government enforces existing forest exploitation policies while at the same time providing alternative livelihood means to its resource-poor populations, to sustainably reduce pressure on forest ecosystems (Tyukavina et al., 2018; Shapiro et al., 2023). Despite their enormous intrinsic biodiversity, the Congolese forests are the least documented in Africa, not only in terms of their potential for industrial timber exploitation, but also in terms of socioeconomic and cultural value to the local populations (firewood, medicine, shelter, tools, game, caterpillars, mushrooms, honey, WEPs, dyes, cultural and spiritual values, etc.) (Termote et al., 2011; Fungo et al., 2023).

Promoting traditional food resources, such as NTFPs around forest reserves, could assume an important role, in particular those which are cheap, ecofriendly, abundant, and easily renewable in tackling (Nsevolo et al., 2023). Fewer existing past studies showed that DRC harbors a huge diversity of NTFPs, including edible insects (Nsevolo et al., 2022, 2023; Ishara et al., 2022, 2023; Malasi et al., 2024), wild edible plants (Termote et al., 2011; Mondo et al., 2021; Fungo et al., 2023), edible mushrooms (Kamalebo et al., 2018; Kamalebo and De Kesel, 2020), bushmeats (De Merode et al., 2004; Van Vliet et al., 2012; 2019), etc. that could be valorized to alleviate hunger and poverty in rural DRC. For instance, Van Vliet et al. (2019) showed that bushmeat was the main protein source for both urban and rural populations in northeastern DRC, with an estimated trade volume of ~103–145 tons of bushmeat yearly. Analyses of the wild food value chain showed that such NTFPs were an effective means for wealth accumulation, far above the agriculture since stakeholders were market-oriented (over 90 % of both bushmeat and fish production is sold at market) with the highest outcome in the lean season when agricultural commodities are scarce (Van Vliet et al., 2012). In these lean season periods, the population obtain both income and food from NTFPs which also add diversity to local diets, providing proteins, vitamins, and minerals not provided by crops (Muvatsi, Kahindo and Snook, 2018; Fungo et al., 2023).

Unfortunately, most of the studies on NTFPs in DRC only focused on their inventory, use, and diversity conservation, and did little on value chain analysis, value-addition options, and on increasing awareness on nutritional and medicinal values of NTFPs; prompting their neglect, especially among youths, elite, and urban populations (Mondo, 2023). However, without structuring the value chain, developing sub-products that meet the population preferences, and implementing enabling environments, population living close by forests would never yield maximum benefits from NTFP exploitation, making a utopia the transition from forest-overreliance to off-forest income-generating activities (Van Vliet et al., 2012, 2019). In fact, past studies elucidated the link between the income level and the inclination to rely on wild food: poorer households eat NTFPs more frequently than wealthier households (Van Vliet et al., 2012; Spira et al., 2019; Fungo et al., 2023). This means that the pressure on DRC forests would decrease if the population income improves to the level of facilitating purchase of alternative items. Although the potential of NTFPs to contribute to poverty alleviation is recognized in the country's Poverty Reduction Strategy Papers (Termote et al., 2012), there is still a huge gap of knowledge in this sector. This study will complement previous studies by contributing not only to the inventory of food NTFPs but also in increasing awareness of the NTFP stakeholders on the potential of NTFPs as food security and income generating sources and on the nutritional and therapeutic properties of most popular NTFPs.

Documentation on the NTFPs value chain, their contribution to local community income, and their nutritional composition is limited in South-Kivu province (eastern DRC), a region harboring tremendous forest resources and protected reserves, among which the Kahuzi Biega National Park (KBNP) and the Itombwe National Reserve (Cuni-Sanchez et al., 2019; Spira et al., 2019; Chuma et al., 2021). KBNP is a UNESCO World Heritage Site under threat (Simpson and Pellegrini, 2023) that is driven partly by the precarious socioeconomic situation of the population surrounding the KBNP, characterized by a high unemployment rate, limited arable land, and low agricultural productivity that exacerbate poverty and food insecurity (Maass et al., 2012; Simpson and Pellegrini, 2023). In fact, this precarious situation has led the population to engage into destructive activities such as illegal mining, uncontrolled tree logging for charcoal production and timber, bushfires to expand cultivable land, poaching of protected animal species, and the collection of endangered plant species (Cuni-Sanchez et al., 2019; Spira et al., 2019).

To reduce pressure on available forest resources in eastern DRC, it would be necessary to find alternatives that can improve households' livelihoods by promoting IGAs around protected areas. NTFPs represent one of the most important forest products upon which local communities rely on and its uses is driven by demographic profile of forest dependent users. We hypothesized that promoting NTFPs at the IGA status would help alleviate food insecurity and poverty as NTFPs appear to be accepted and collected by local communities around KBNP. It is noteworthy that collecting and trading NTFPs are legal activities encouraged under the 2002 DRC forest code adopted through Law No. 11/2002 to encourage sustainable management and socioeconomic benefits to local communities (Muvatsi et al., 2018; Cuni-Sanchez et al., 2019). Such a promotion will complement existing initiatives by the park managers, such as the distribution of farm inputs and equipment, seeds, small job creation, etc. that still struggle to alleviate population pressure on the forests. It is noteworthy that in South-Kivu, there is scarcity of knowledge on the number of NTFPs used by communities surrounding KBNP and to what extent local communities depend on NTFPs to meet their livelihood. Besides, knowledge on the nutritional and medicinal values of NTFPs used by communities surrounding KBNP tends to be poorly captured by policy-makers, especially to promote healthy diets and traditional medicines (Mondo, 2023). Furthermore, the potential use of NTFPs as IGA in both rural and urban areas of South-Kivu is poorly assessed as well as factors undermining the use of such NTFPs by communities surrounding KBNP (Mondo, 2023). As recommended by Van Vliet et al. (2019), a value chain analysis for NTFPs is important to infer recommendations that could improve the business environment, the horizontal and vertical linkages between actors and the marketing issues, as well as ensuring ecological, economic, and social sustainability. This study tends to fill those gaps by providing empirical evidences on how NTFPs contribute to food security and wealth creation around protected forest areas of South-Kivu. Such information will be valuable in decision-making process to allow governmental agencies account for such products in setting strategic development goals and devise effective promotion approaches to unlock NTFP full potential for food security and wealth creation around KBNP.

This study aimed at (1) inventorying NTFPs exploited by local communities around the Kahuzi Biega National Park, (2) assessing their therapeutic values and nutritional contributions, and (3) analyzing their rural and urban market values to determine their potential as alternative income sources as well as major constraints in their exploitation.

2. Materials and methods

2.1. Study area

This study was conducted in the riparian areas of the KBNP, South-Kivu province, eastern DRC. This park is a UNESCO World Heritage Site under threat due to the anthropic pressure (Spira et al., 2019). It is recognized as a UNESCO World Heritage Site since 1980 due to its ecological significance and rich biodiversity. In fact, it is the most important protected area for the conservation of the endemic Grauer's gorilla (Spira et al., 2019; Cuni-Sanchez et al., 2019). Among threats faced by the KBNP are artisanal mining, hunting of protected animal species (including endangered lowland gorillas and elephants), massive deforestation for timber and firewood, increased bushfire, collection of endangered plant species, farmland expansion, and presence of armed groups and militia that hinders conservation efforts and limits the park rangers' mobility and access to the site (Mondo, 2023). Most of these threats are consequences of the precarious socioeconomic status of the populations surrounding the KBNP, especially among autochthonous Batwa pygmies (Mitchell and Wagner, 2023). In addition to this extreme poverty, there is alarming nutritional status with high incidence of food insecurity due to long-term armed conflicts, declining agricultural production, and looting of livestock (Maass et al., 2012). Consequently, ~30 % of households in South-Kivu can only afford one meal a day, with a significantly low consumption of animal protein, fruits and vegetables with their high contents of micronutrients (Maass et al., 2012). There are several initiatives by local and international organizations seeking to reduce anthropic pressure on that site by providing alternative income generating sources to its riparian populations. This research project, partly supported by the German Cooperation (GIZ), is a contribution to such initiative. The study focused on indigenous communities (including autochthonous pygmies) who permanently interact with the forest environments. Surveys in rural areas covered three zones: Kaniola (in the Walungu territory), Miti (in the Kabare territory), and Bunyakiri (in the Kalehe territory). These three zones were selected based on their proximity to KBNP and the high population reliance on NTFPs (Fig. 1). Besides, surveys in urban areas took place in the Bukavu City where NTFPs collected in rural areas are processed and commercialized. Major characteristics of the surveyed zones are provided in Table 1.

The KBNP was established in 1970 with an initial size of 60,000 ha. In 1975, the government expanded the park's size to ~600,000 ha to connect the high-altitude gorilla populations with those in the lowland forest, which was not previously part of the park. This expansion involved the relocation of thousands of households from their habitats. The KBNP spans across the administrative territories of Kabare, Walungu, Kalehe, Shabunda, and Walikale (in North-Kivu).

In terms of ecological importance, the KBNP is home to a wide range of animal, plant, bird, and insect species, which thrive in its interconnected ecosystems, contributing to its rich biodiversity (Spira et al., 2019). Additionally, many rivers, including Murhundu, Cikumbi, Mpungule, Mushuva, and Bidagarha, originate from the KBNP before pouring their waters into the Lake Kivu.

Located on the western slope of the mountains in eastern DRC, ~ 50 km from the Bukavu city and the western part of the Lake Kivu, the KBNP lies within a range of bioclimatic zones (Table 1). The park is between two dense humid forests, namely the equatorial forest and the montane forest. However, the dominant climate is primarily mountainous, with a bimodal rainfall regime: a dry season going from June to August and a rainy season from September to May. In the lowlands of the park, average temperatures can reach up to 20 °C, while in the highlands; temperatures average ~15 °C.

Overall, the KBNP corridor experiences a mountainous tropical climate with abundant rainfall, ranging from 1750 to 2000 mm per year (Simpson and Pellegrini, 2023). The park encompasses various vegetation types, including the transitional forest (found at altitudes ranging from 1400 to 2600 m), the equatorial rainforest (extending from ~850 to 1400 m in altitude), the bamboo and *Podocarpus* forests (at altitudes between 2600 and 3200 m), and the alpine and Poromo zones (ranging from 3200 to 3308 m in highlands). This study was conducted in areas surrounding the highland part of this national park.

2.2. Sample selection and survey data collection

Since the exact number of target populations was unknown, a probabilistic saturation sampling technique was used to define the sample size in each selected zone as directed by Pires (1997). In this sampling technique, the survey only ceases when interviews or observations of new participants no longer reveal new information. In rural areas around KBNP, only households whose members were directly involved in NTFPs harvesting and/or marketing were sampled using the snowball method, with one respondent leading to the next (Etikan et al., 2016). Overall, individual interviews were conducted with 490 rural households during the periods of 15 May to 29 June 2019, 29 June to 09 August 2022, and 10–14 January 2023. Miti (Kabare), Kaniola (Walungu) and Bunyakiri (Kalehe) were selected based on secondary data as the zones where NTFPs are widely exploited around the KBNP. Besides, 300 randomly selected urban households were also interviewed from 1 to 15 March 2023 in Bukavu City to provide an overview on uses,

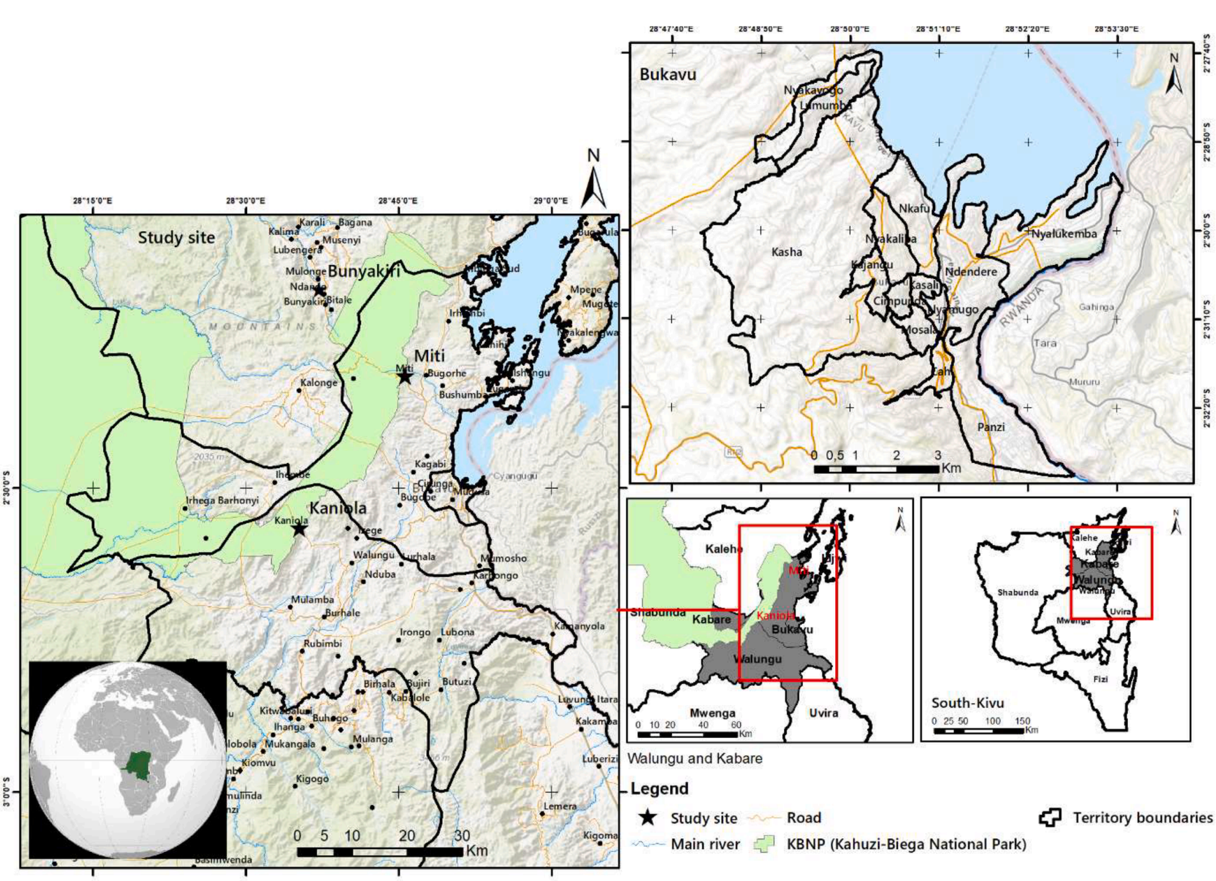

Fig. 1. Sites around Kahuzi-Biega National Park covered by the study, eastern DRC.

Table 1
Summary of the characteristics of the surveyed regions around the Kahuzi-Biega National Park.

Characteristics	Kabare	Kalehe	Walungu	Bukavu
Longitude Latitude	28°45′ – 28°55′ E 2°30′ – 2°50′ S	28.853° – 28.921°E 2.070° – 2.162° S	28°15 – 29°15 ʿE 2°38′ – 2°64′S	28°48′–28°54′E 2°27′– 2°34′S
Altitude (m.a.s.l)	1460–3000	1526 – 1690	980 – 2500	1428–2080
Area (km^2)	1960	5707	1800	43.3
Climate	Mountainous humid tropical climate with a bimodal rainfall pattern (*Aw3*)	Savannah tropical climate with a bimodal rainfall pattern	Mountainous humid tropical climate with a bimodal rainfall pattern (*Aw3*)	Mountainous humid tropical climate with a bimodal rainfall pattern (*Aw3*)
Annual rainfall (mm)	1300–1800	1300–1800	900–1500	1000–1500
Temperature (°C)	22.6	~19	19–23	21.6
Soils	Ferralsols and Nitisols	Nitisols, Andosols, and Ferralsols	Ferralsols	Ferralsols
Population density (inhabitants/km^2)	~347	>300	> 300	~19,800
Ethnic groups	Bashi, Bahavu, and Batwa	Bashi, Bahavu, Batwa, and Batembo	Bashi, Bahavu, and Banyindu	All (cosmopolitan)

Source : Mondo et al. (2021, 2024); Mugumaarhahama et al. (2021); Chuma et al. (2022).

awareness of the nutritional and therapeutic values, and factors hindering NTFPs wide use among urban households. These surveys involved households from all three Bukavu administrative areas, namely Ibanda, Kadutu, and Bagira. Lastly, owners and/or managers of restaurants, supermarkets and hotels, and street vendors were sampled using the snowball method, with the previous respondent recommending the next (Etikan et al., 2016). Since no secondary data existed on the exact number of these stakeholders, their sample size was determined using the probabilistic saturation sampling technique as directed by Pires (1997).

A structured questionnaire was used to collect information from households and stakeholders involved in the NTFP sector around the KBNP. The survey questionnaire consisted of the following sections: (a) socioeconomic characteristics of surveyed households, (b) economic and food contributions of NTFPs in household livelihoods, and (c) analysis of the NTFP market (value chain) as well as major constraints in exploiting NTFPs. The questionnaire was administered to the head of the household. However, in his/her absence, an adult member of the household (>18 years old) was interviewed. Prior informed consent of the respondents was taken and the study objectives were shared with them. In addition to information from households, on-site interviews with NTFP traders were conducted to gather additional information on the income generated from NTFPs and the final use of obtained profit margins. A camera was used to capture images of various inventoried products, while an observation sheet was used to collect all information related to the use of NTFPs gathered from key informants (elderly individuals, herbalists, park agents, etc.). To facilitate further analysis of nutritional values, samples of NTFPs were collected. Leaves were preserved in a notebook as herbarium specimens, liquids were stored in clean bottles, and fruits and solid products were kept dry free of water. Identification keys were used to link the vernacular names of the inventoried NTFPs to their scientific names with the assistance of a botanist.

In addition to individual interviews, three focus groups, corresponding to the three target zones, were conducted with major stakeholders (representatives of NTFP collectors, traders, potential buyers, government and park officials, etc.) of the NTFP value chain around the KBNP, using a discussion guide. The discussion guide contained a checklist from which NTFPs were ranked based on market value and market demand to determine those of potential to become an IGA once promoted. Furthermore, information related to seasonality, commercial circuit, storage and value addition options, and organizations supporting NTFPs value chains, encountered constraints, and recommendations for revitalizing this sector were discussed. Focus group information was summarized in tables or used in word forms to report consensual opinions of participants on topics mentioned above and to clarify gray zones from individual interviews' feedbacks.

In Bukavu city, a structured questionnaire was developed and coded in a Kobo Collect application. It contained questions on NTFPs as well as neglected and underutilized crops often used in urban households, awareness on their nutritional and therapeutic values, frequency of use, form of use, willingness to pay for them or their sub-products, factors hindering their wide use at the household level, etc. In addition to households, the questionnaire was also administered to other potential end-users (vendors, restaurants, hotels, and supermarkets).

2.3. Determination of the physicochemical composition of key food NTFPs

Data from the market and household surveys were used to rank NTFPs based on their relative importance (market demand and monetary value), ease of domestication, and potential as income-generating source. When two NTFPs had equal importance, the priority was given to the one assumed to be proteinous because its deficiency is a serious public health concern in eastern DRC, particularly in the study area where people could hardly afford animal proteins (Maass et al., 2012; Moumin et al., 2020). The physicochemical analyses were only conducted on the top 10 NTFPs based on the criteria above. Most relevant bioactive compounds like phenols, flavonoids, tannins, antioxidants, and carotenoids were extracted and quantified following standard procedures (AOAC, 2005; AACC, 2010). Besides, the proximate composition (moisture content, protein, fat, dietary fibers, crude ash, and carbohydrate content), mineral elements (P, K, Fe, Zn, Ca, and Mg) and other nutrients such as vitamin C were determined using standard protocols from the relevant literature as detailed below. Selected NTFPs included top leafy vegetables (*Amaranthus viridis, Basella alba, Gynandropsis gynandra,* and *Solanum nigrum*), the top spices (*Piper nigrum, Zingiber officinale*), the top fruit (*Physalis peruviana*), the top starchy tuber NTFP (*Dioscorea* spp.), the multipurpose *Moringa oleifera* and the most valued mushroom species (*Termitomyces robustus*).

The moisture content was determined using the following formula:

$$\%MC = \frac{P2 - P3}{P2 - P1} \times 100$$

Where:%MC is the percentage of moisture content, P1 is the weight of the empty porcelain dish, P2 is the weight of the porcelain dish after adding the sample and solution, P3 is the final weight of the dish after drying the sample. By substituting the values of P1, P2, and P3 into the formula, we calculated the sample moisture content.

The ash content was estimated by dry sample calcination method in a muffle furnace (Nabertherm LE 1/1) for 4–5 h at 550 °C until obtaining white ash. The ash was then cooled in a desiccator and subsequently weighed. The ash content obtained from the analysis was calculated using the following ratio:

$$Ash\ content\ (\%) = P2/P1 \times 100$$

Where P1 represents the weight of the sample before calcination, P2 represents the weight of the sample after calcination.

Total nitrogen content was determined using the Kjeldahl method (Kirk and Sawyer, 1991). The organic nitrogen in the sample was mineralized by hot sulfuric acid in the presence of an appropriate catalyst, and the formed ammonia nitrogen was displaced by a strong base and titrated in a boric acid solution. After a 2-hour resting period, the absorbance was read at a wavelength of 650 nm using a spectrophotometer. However, the total nitrogen content in a sample was calculated using the following formula:

$$Total\ nitrogen\ (\%) = ((a - b) \times v) / (w \times al \times 1000)$$

Where a is the concentration of total nitrogen in the sample solution, b is the concentration of total nitrogen in the blank reagent solution, v is the total volume at the end of the analysis procedure (i.e., 0.2 ml + 10 ml = 10.2 ml), w is the dry weight of the sample used (i.e., 0.5 g), and al is the aliquot of the sampled solution (i.e., 0.2 ml).

Crude protein content was determined using the following formula:

$$Crude\ protein\ (\%) = Total\ Nitrogen \times 6.25$$

The gross calcium and magnesium contents (Ca+Mg) were determined by complexometry using EDTA solution in the presence of Noire Eriochrome T solution as a color indicator. The magnesium content, which precipitates as magnesium hydroxide, was obtained by the difference between the calcium content and the Ca+Mg mixture content (George et al., 2013). Thus, the calcium concentration was given by the following expression:

$$Ca\ (mg/L) = (40 \times N \times V1 \times 1000) / V2$$

The Ca + Mg concentration was determined by the formula:

$$Ca + Mg\ (mg/L) = (64 \times N \times V1 \times 1000)/V2$$

The magnesium concentration in the sample was obtained by the expression:

$$Mg\ (mg/L) = (Ca + Mg) - Ca$$

Where V1 is the volume (ml) of the EDTA solution that titrated the sample filtrate to the equivalence point, V2 is the volume (ml) of the sampled filtrate, and N is the normality of the EDTA solution.

The iron and zinc were determined by atomic absorption spectrometry using an XR spectrometer as described by Rapp et al. (2017). Due to logistic constraints (limited budget), physicochemical analyses were conducted on composite samples from all sites rather than analyzing samples from each site separately.

2.4. Data analysis

Descriptive statistics was used on survey data, by calculating frequencies for qualitative variables and means followed by standard deviations for quantitative variables. Pearson's χ2 test was used to compare the independence among qualitative variables. The analysis of variance (ANOVA) was conducted on data from NTFP physico-chemical analyses while the mean separation was performed using the least significant difference (LSD) test at 5 % *p*-value threshold. All these analyses were performed using R 4.2 (R Core Team, 2020). Focus group

Table 2
Households' socioeconomic characteristics around the KBNP, eastern DRC.

Variables	*Modalities*	Zones			Total	χ^2	*p*-value
		Kabare	Kalehe	Walungu			
Sex	*Female*	56.3	52.9	52.9	54.1	2.4	*0.697ns*
	Male	43.7	47.1	47.1	45.9		
Age groups	*<30 yrs*	62.0	64.7	38.8	52.0	3.1	*0.554ns*
	30 – 45 yrs	16.9	19.6	36.9	26.7		
	45 – 55 yrs	11.3	5.9	17.5	12.9		
	>55 yrs	9.9	9.8	6.8	8.4		
Main activity	*Public service*	2.8	15.7	3.7	6.8	13.7	*<0.001****
	Agriculture	50.7	43.1	40.7	45.5		
	Small trade	8.5	9.8	40.7	18.8		
	Livestock	7.0	0.0	1.9	3.4		
	Wood operator	0.0	0.0	7.4	2.3		
	Other	31.0	31.4	5.6	23.3		
HH size	*Mean ±SD*	9.7 ± 4.3	9.6 ± 4.4	6.5 ± 2.5	8.2 ± 3.8		*0.017**
Income (CF)[§]	*Daily*	4300 ± 2062.7	3050 ± 1064.4	3555±1419.1	3635 ± 1515.4		*0.269ns*
	Monthly	129,450 ± 61,423	91,500 ± 31,933	106,650 ± 42,571	109,200 ± 45,309		*0.1409ns*
Secondary activities	*Tailor*	22.2	14.3	25.0	20.9	14.9	*<0.001****
	Timber operator	11.1	14.3	5.0	9.3		
	Nurse	11.1	21.4	0.0	9.3		
	Masonry	44.4	21.4	50.0	39.5		
	Biker	0.0	14.3	5.0	7.0		
	Restaurant	11.1	7.1	10.0	9.3		
	Veterinarian	0.0	7.1	5.0	4.7		
Marital status	*Single*	7.0	9.8	3.0	5.8	12.3	*0.015**
	Divorced	4.2	0.0	2.0	2.2		
	Married	88.7	90.2	89.1	89.2		
	Widow (er)	0.0	0.0	5.9	2.7		
Education level	*No formal education*	49.3	13.7	33.0	33.8	14.2	*<0.001****
	Primary	12.7	7.8	34.0	21.3		
	Secondary	38.0	78.4	28.2	42.7		
	University	0.0	0.0	4.9	2.2		
NPI	*1 person*	7.9	9.7	14.7	11.3	21.2	*<0.001****
	2 persons	72.9	90.3	64.9	73.1		
	3 persons	19.3	0.0	20.4	15.6		
Type of house	*Baked bricks*	16.9	9.8	12.6	13.3	8.9	*0.002***
	Wooden	74.6	90.2	72.8	77.3		
	Huts	8.5	0.0	14.6	9.3		

HH: household; §: at the time of the survey 1$ equaled 2200 Congolese Francs (CF); NPI: number of persons contributing to household income; ns, *, **, ***: not significant, significant, highly significant, and very highly significant at *p*-value thresholds of 0.05, 0.01, 0.001, respectively.

information was summarized in tables or used in word forms.

3. Results

3.1. Socioeconomic characteristics of surveyed households around Kahuzi Biega National Park

A higher proportion of NTFP users were women (54.1 %) than men (45.9 %), underscoring the sector's predominant association with women (Table 2). These are mainly young (<30 years old) married persons (89.2 %). Their age did not significantly differ with the study area (p>0.05). In all three-study zones, the households' livelihood means were diversified; agriculture being their primary economic activity (45.5 %), followed by small-scale trades (18.8 %), and multiple secondary activities (23.3 %). About 42.7 % NTFP users attended the secondary school, while 33.8 % had no formal education (Table 2). However, there were differences in education levels with study areas ($\chi^2 = 14.2$; $p < 0.001$), lowest literacy level being observed among autochthonous Batwa pygmies of Kabare. Majority of households (77.3 %) lived in wooden houses. It is noteworthy that the average family size across study areas was 8 members though only two persons, on average, contributed to household income. The average daily income in the study area was of 3635 Congolese francs (~$1.6), far below the international poverty line ($2.15).

Farming practices of NTFP users are summarized in Table 3. According to these results, most NTFP users grow cassava (69.5 %), common beans (11.2 %), sweet potatoes (9.9 %), and maize (6.2 %) for subsistence (86.3 %) or for market participation (13.7 %). Their farm size was ~0.63 ha. Only ~40 % households attended local farmer associations' activities. These households sourced NTFPs mainly from forests (35.1 %) and local markets (34.7 %), though there were disparities across locations ($\chi^2 = 17.8$; $p < 0.001$). Harvested NTFPs were mainly used for subsistence (87.4 %), market participation (11.2 %), and self-medication (1.3 %). Most NTFPs were directly consumed after collection with no prior processing (85.8 %). NTFPs users lived far from the markets (53.4 %), while only 18.2 % were close (Table 3). The farm-to-market distance was also high (72.3 %). Similarly, the house-to-forest distance was high for most households (79.0 %). The NTFP selling points included local markets (62.2 %), streets and roads (16.6 %), or in the neighborhood (16.1 %). The main buyers of NTFPs were local populations (39.1 %), urban people from Bukavu City (37.7 %), and people from neighboring villages or agglomerations (9.8 %).

Regardless of the locations, NTFP collectors raised low market value (34.4 %), high taxation from governmental agencies (31.5 %), uncoordinated NTFP market often favoring conflicts among stakeholders (19.10 %), high house-to-forest distance (17.98 %), and high house-to-market distance (10.11 %) as the primary factors hindering NTFP value chain around the KBNP (Table 3).

Table 3
Information on farming and NTFPs collection sources and practices among NTFP users around the KBNP.

Variables	*Modalities*	Zones					
		Kabare	Kalehe	Walungu	Total	χ^2	p-value
Crop production objectives	*Subsistence*	95.6	71.4	86.3	84.4	3.9	*0.014**
	Market participation	4.4	28.6	13.7	15.6		
Main crops	*Common bean*	19.6	0.0	11.7	11.2	7.9	*<0.001****
	Maize	0.0	0.0	14.7	6.2		
	Cassava	74.5	100.0	47.1	69.5		
	Sweet potato	0.0	0.0	23.5	9.9		
	Others	5.8	0.0	2.9	3.2		
Farm size (ha)	*Mean±SD*	0.59±0.33	0.58±0.31	0.72±0.47	0.63±0.37	–	*0.129ns*
Membership in associations	*No*	59.2	51.0	64.1	59.6	1.7	*0.525ns*
	Yes	40.8	49.0	35.9	40.4		
Utilization of NTFPs	*Subsistence*	95.8	96.1	77.2	87.4	4.2	*0.031**
	Self-medication	0.0	0.0	3.0	1.3		
	Commercialization	4.2	3.9	19.8	11.2		
Sources of NTFPs	*Own farm*	47.9	7.8	29.1	30.2	17.8	*<0.001****
	Forest	26.8	33.3	41.7	35.1		
	Market	25.4	58.8	29.1	34.7		
Level of contribution to HH	*Very high*	9.9	15.7	0.0	8.5	12.4	*<0.001****
	High	52.1	25.5	16.7	33.5		
	Moderate	22.5	31.4	46.3	32.4		
	Low	15.5	27.5	37.0	25.6		
House-to-market distance (min)	*1 – 20*	28.2	9.8	13.0	18.2	7.3	*0.014**
	20 – 60	43.7	58.8	61.1	53.4		
	> 60	28.2	31.4	25.9	28.4		
House-to-forest distance (min)	*20 – 60*	12.9	43.1	11.9	20.9	1.25	*0.132ns*
	> 60	87.3	56.9	88.1	79.0		
Prior processing before use	*Cooking before use*	0.0	7.8	15.9	8.3	9.2	*0.021**
	Direct consumption	88.7	92.2	79.3	85.8		
	Processing	11.3	0.0	4.9	5.9		
Farm-to-market distance (min)	*1 – 20*	12.7	27.5	20.6	19.6	7.5	*0.012**
	20 – 60	83.1	66.7	67.6	72.3		
	> 60	4.2	5.9	11.8	8.0		
Selling points	*Market*	33.8	78.4	74.7	62.2	8.9	*0.014**
	Neighborhood	39.4	0.0	7.4	16.1		
	Road and streets	21.1	11.8	15.8	16.6		
	Others	5.6	9.8	2.1	5.1		
Client origins	*Bukavu city*	29.6	16.0	55.3	37.7	8.7	*0.039**
	Both local and urban	11.3	24.0	9.6	13.5		
	Local population	59.2	60.0	12.8	39.1		
	Neighboring village	0.0	0.0	22.3	9.8		

NTFP: Non-timber forest product; HH: household; ns, *, **, ***: not significant, significant, highly significant, and very highly significant at p-value thresholds of 0.05, 0.01, and 0.001, respectively. SD: standard deviation.

3.2. Inventory of NTFPs and their common uses around KBNP

3.2.1. NTFPs in Kaniola (Walungu)

Firewood, medicinal herbs, fruits and nuts, leafy vegetables, bushmeat, gums, and mushrooms were the main products collected in the forest by the Walungu population. Woods were the most sought-after, including *Canna indica* (19.9 %) and *Ficus* spp. (16 %). The most frequently sought-after medicinal herbs were *Cenesio maranguensis* (12.7 %) and *Pleiocarpa pycnantha* (8.3 %), while *Cyphomandra batacea* was the most sought-after (16.6 %) among wild fruits. *Solanum nigrum* (11 %), *Basella alba* (11 %), and *Amaranthus viridis* (8.3 %) were the most popular NTFP leafy vegetables. In this area, fodder was not sought after in the forest. The rainy season was favorable for most of these products; only wood, honey, and bushmeat were available all year round regardless of the season. NTFP collection was mainly a male activity (79 %), with women accounting for only 29 %, and the latter going to the park mainly in the search for leafy vegetables (93 %) or gums (40 %). Youths were the most involved in NTFP collection, with 58 % of collectors aged between 14 and 20 years old. Elderly persons go to the forest mainly for medicinal herbs (40.6 %), fruits and nuts (26.5 %), and woods (9.8 %).

3.2.2. NTFPs in Miti (Kabare)

Autochthonous populations living in Miti primarily sought NTFPs such as firewood, medicinal herbs, fruits and nuts, leafy vegetables, bushmeat, gums, honey, and mushrooms. Among the wood species, *Alstonia boonei* (20.7 %), *Macaranga neomildbraedii* (17.2 %), *Albizzia gummifera* (11.8 %), and *Hagenia abyssinica* (11.2 %) were the most commonly collected. For medicinal herbs, *Alstonia boonei* (19.6 %) and *Cenesio maranguensis* (10 %) were the most popular among autochthonous populations of Kabare. The target fruits and nuts included *Cyphomandra batacea* (10.9 %), *Aframomum laurantii* (8.7 %), and *Myrianthus holstii* (5.4 %), while the predominant leafy vegetables were *Solanum nigrum* (9.8 %), *Basella alba,* and *Amaranthus viridis* (6.5 %). Among the animal species targeted as bushmeat, squirrels / *Urocitellus columbianus* (3.3 %), *Cercopithecus* spp. (8.8 %), and *Rattus* spp. (2.2 %) were the most mentioned. As for mushrooms, the available species were *Schizophyllum commune, Auricularia* spp., and *Lactarius deliciosus*. As for Walungu, fodder is not sought after in the park by Kabare's inhabitants.

Wood, honey, and bushmeat were available throughout the year, while other NTFP categories, such as fruits and nuts, gum, medicinal herbs, mushrooms, and leafy vegetables, were abundant only during the rainy season. As for Walungu, NTFP collection was primary a men's activity in Kabare, who accounted for 98 % of collectors. Women were more involved in harvesting leafy vegetables (22.8 %), mushrooms (20 %), and medicinal herbs (15.7 %). NTFP collection was mainly conducted by teenagers (83 %), other age categories represented only 16 % of collectors and the latter were more interested in firewood (6.5 %), honey (9.9 %), bushmeat (12 %), and leafy vegetables.

3.2.3. NTFPs in Bunyakiri (Kalehe)

Firewood was the most harvested NTFP from forests (49.3 %), with *Alstonia boonei* (40.7 %) and *Albizzia gummifera* (17.8 %) as the most targeted wood species. Medicinal herbs included *Alstonia boonei* (17.3 %) and *Cenesio maranguensis* (12.8 %), while for fruits and nuts, *Cyphomandra batacea* (13.9 %), *Aframomum laurantii* (7.7 %), and *Myrianthus holstii* (4.4 %) were the most popular. Common leafy vegetables were *Solanum nigrum* (9.8 %), *Basella alba* (6.5 %), and *Amaranthus viridis* (6.5 %). Other food NTFPs included bushmeat (mainly *Cercopithecus* spp.), gums, honey, and mushrooms. As in the other two territories, livestock fodder was not a priority for forest dwellers.

Fruits and nuts, gums, medicinal herbs, mushrooms, and vegetables were abundant in the rainy season. Honey and its by-products (e.g. bee wax, bee pollens, royal jelly, propolis, etc.), bushmeat (*Urocitellus columbianus, Rattus* spp., *Cercopithecus* spp., *Apodemus sylvaticus*, etc.) were available all year round regardless of the season. Men were the most involved in NTFP exploitation in Kalehe (91.4 %). The youths (14–20 year old) were the most involved in collecting NTFPs (82.3 %). Those above 20 years old represented only 17.7 % and went to the forest mainly for bushmeat (12 %), honey (9.9 %), leafy vegetables (6.5 %), and mushrooms (2.2 %). Table 4 summarizes the various NTFPs collected in the study areas and their common uses. Some photographs of popular NTFPs around the KBNP are presented by Fig. 2.

Across surveyed areas, NTFPs contributed up to 10, 11, and 38.5 % of household income in Kabare, Kalehe, and Walungu, respectively, relatively lower than the agriculture (20, 50, and 23.8 % income contributions in Kabare, Kalehe, and Walungu, respectively). Similarly, mean food contributions across these three zones were 52.5 % for the agriculture versus 24.5 % for NTFPs (Table 5). We also found that agriculture contributed 26.7 % of medicinal herbs versus 22 % for NTFPs collection. It is noteworthy that households devoted large share of their time to agriculture (~ four days a week), whereas they allocated an average of two days a week on NTFPs. In addition to NTFPs, households collected embers (71 %), sticks (2.9 %), planks, and ores (1.55 %).

3.3. Nutritional values of most popular NTFPs collected around KBNP

In addition to direct contributions to food, income, and medicine, NTFPs are valuable sources of nutrients that could help fight against hidden hunger around KBNP (Tables 6–9). Most NTFPs are made of water, *Basella alba* having the highest moisture content (94 %) while local wild yams had the least water content (58 %). Yams (*Dioscorea* spp.) had the highest carbohydrates (81 g/100 g of the dry weight) while *Gynandropsis gynandra* had the least concentrate ion in carbohydrates (4 g/100 g). *Moringa oleifera* was the fattiest among the top 10 NTFPs (17 %) and *Physalis peruviana* was the least concentrated in fat (0.20 g/100 g). *Solanum nigrum* (24.9 %), *Termitomyces robustus* (18 %), *Amaranthus viridis* (17.6 %), and *Piper nigrum* (16.9 %) are valuable sources of proteins while *Zingiber officinale* (25.5 %), *Termitomyces robustus* (15.4 %) and *Piper nigrum* (14.33 %) are rich in dietary fibres (Table 6).

Piper nigrum (37.0 and 128.3 mg/kg) and *Basella alba* (35.1 and 108.7 mg/kg) had the highest zinc and iron contents, respectively (Table 7). *Moringa oleifera* had the highest concentration in potassium (690.1 mg/100 g) while *Piper nigrum* had the least concentration in potassium (13.5 mg/100 g). The magnesium contents were highest for *Solanum nigrum* (247.6 mg/100 g) and *Dioscorea* spp. (200.5 mg/100 g). On the other hand, *Moringa oleifera* and *Gynandropsis gynandra* had the highest calcium contents, 790 and 456.2 mg/100 g, respectively (Table 7). *Dioscorea* yams had the highest carotenoid content (114.5 μg/g). Other NTFPs with high contents in carotenoids were *Physalis peruviana* (69.6 μg/g) and *Moringa oleifera* (66.5 μg/g). The vitamin C was highest in *Moringa oleifera* (80.7 mg/100 g) compared to other NTFPs. *Physalis peruviana* (67.9 mg/100 g), *Basella alba* (63.2 mg/100 g), *Gynandropsis gynandra* (63 mg/100 g) and *Dioscorea* spp. (61.3 mg/100 g) had the highest contents in antioxidants (Table 8). Total phenolic compounds were highest in *Dioscorea* spp. (487.6 mg/g). Other NTFPs with high contents included *Piper nigrum* (338.4 mg/g) and *Moringa oleifera* (261.2 mg/g). We found more flavonoids in *Basella alba* (420.4 mg/100 g), *Gynandropsis gynandra* (372.4 mg/100 g), and *Moringa oleifera* (290.0 mg/100 g) (Table 8).

We found more phytates in *Solanum nigrum* (84.53 mg/100 g) and *Dioscorea* spp. (72.5 mg/100 g) than other NTFPs, while mushroom *Termitomyces robustus* had almost no phytates (0.92 mg/100 g). *Piper nigrum* had the highest concentration in oxalates (223.2 mg/100 g) and *T. robustus* had the least oxalate concentration (0.57 mg/100 g). Lastly, *Dioscorea* spp. had the highest tannin concentration (123.2 mg/100 g) far above all other NTFPs (Table 9). Physico-chemical compositions of local mushroom species are provided in Table S1. Of the nine mushroom species, *A. cornea* and *S. communis* (24 %) were the most proteinous while *A. rubescens* was the least proteinous (12 %). The vitamin content ranged from 3.2 to 4.6 mmol L^{-1} while phosphorous (10.0 – 164.2 ppm), potassium (1287.5 – 4724.5 meq L^{-1}), and dry matter content (11.8 –

Table 4
Main NTFPs exploited around Kahuzi Biega National Park, eastern DRC.

Scientific name	Local name	Product type	Organ used	Usages			
				Food/feed	Medicine	Wood	Sales
–	Buhache	Plant	Leaves, stem	–	+	+	–
–	Namaruti	Plant	Fruits	+	–	–	+
–	Fumbire	Animal	Whole animal	+	–	–	+
Acanthus pumbens	Magwerhe	Plant	Barks	–	+	–	+
Aframomum laurantii	Ntolo	Plant	Fruits	+	–	–	+
Albizzia gummifera	Mushebeye	Plant	Leaves, stem, bark	–	+	+	–
Aloe vera	Cigaka	Plant	Leaves	–	+	–	+
Alstonia boonei	Kitangondo	Plant	Leaves, bark, stem, roots	–	+	+	–
Amanita rubescence	Koba	Mushroom	Whole mushroom	+	–	–	–
Amaranthus viridis	Ntedebuka	Plant	Leaves, stem	+	–	–	+
Apis melifera	Manyagu	Insect	All parts	+	+	–	+
Apodemus sylvaticus	Nandi/Fuko	Animal	All parts	+	–	–	–
Auricularia auricula juda	Bitere	Mushroom	All parts	+	–	–	+
Basella alba	Nderema	Plant	Leaves	+	+	–	+
Bidens pilosa	Kashisha	Plant	Leaves	+	+	–	–
Bunaeopsis aurantiaca	Milanga	Insect	Whole insect	+	+	–	+
Bridelia micrantha	Mujimbu	Plant	Barks	–	+	–	+
Canna indica	Bulengo	Plant	Stem	–	–	+	–
Cantherellus luteopunctus	Dodwa	Mushroom	Whole mushroom	+	+	–	+
Cercopithecus spp.	Kima	Animal	Whole animal	+	+	–	+
Cleistanthus ripicola	Luchacha	Plant	Leaves	–	+	–	+
Cyathula uncinulata	Igwarha	Plant	Leaves	–	+	–	–
Cyperus latifolius	Muchacha	Plant	Stem	–	–	+	+
Cyphomandra batacea	Liprini	Plant	Fruits	+	+	–	+
Dioscorea spp.	Birongo, Bihama	Plant	Tubers	+	+	–	+
Ekebergia benguelensis	Sirita	Plant	Leaves, fruits, stem, roots	–	+	+	+
Euphorbia hirta	–	Plant	Leaves	–	+	–	–
Gouania longipetala	Muvula	Plant	Leaves	–	+	–	+
Gryllotalpa longipennis	Nkwananzi	Insect	Whole insect	+	–	–	–
Gynandropsis gynandra	Muhole	Plant	Leaves	+	+	–	+
Hagenia abyssinica	Muzuzi	Plant	Stem	–	–	+	–
Helix spp.	Konokono	Animal	Whole animal	+	–	–	–
Imbrasia oyemensis	Tukumombo	Insect	Whole insect	+	–	–	+
Lactarius pelliculatus	Budodwa	Mushroom	Whole mushroom	+	–	–	–
Lactarius deliciosus	Bwamalungwe	Mushroom	Whole mushroom	+	–	–	–
Lebrunia buchai	Buchai	Plant	Barks, fruits, stem, roots	–	+	+	+
Lentinus squarrosulus	Bujana	Mushroom	Whole mushroom	+	–	–	–
Macaranga neomildbraediana	Muchacha	Plant	Barks, fruits, stem, roots	–	+	+	–
Marasmius arborescens	Butalyabalume	Mushroom	Whole mushroom	+	+	–	–
Marasmius bekolocongoli	Bujana	Mushroom	Whole mushroom	+	–	–	–
Milletia dura	Nchunguri	Plant	Stem	–	–	+	+
Moringa oleifera	Moringa	Plant	Bark, seed, leaf, oil, stem, roots	+	+	+	+
Myrianthus preussi	Chamba	Plant	Fruits	+	+	–	+
Newtonia buchananii	Lukundu	Plant	Barks, fruits, stem, roots	–	+	+	–
Passiflora edulis	Maracuja	Plant	Fruit	+	+	–	+
Physalis peruviana	Mbuma	Plant	Fruits, leaves	+	+	–	+
Piper nigrum	Ketchu	Plant	Seeds	–	+	–	+
Pleiocarpa pycnantha	Kitangondo	Plant	Leaves, bark, stem, roots	–	+	+	–
Pleurotus spp.	–	Mushroom	Whole parts	+	+	–	+
Ricinus communis	Mbonobono	Plant	Fruit	+	+	–	+
Sapium ellipticum	Mukalakala	Plant	Stem	–	–	+	–
Schizophyllum commune	Bukoko	Mushroom	Whole parts	+	+	–	+
Senecio maranguensis	Mubazibazi	Plant	Leaves	–	+	–	+
Solanum nigrum	Mulunda	Plant	Leaves	+	+	–	+
Termitomyces robustus	Bihumyo	Mushroom	Whole parts	+	+	–	+
Termitomyces microcarpus	Bushwa	Mushroom	Whole parts	+	+	–	+
Urocitellus columbianus	Chihule	Animal	Whole animal	+	–	–	+
Zingiber officinale	Tangawisi	Plant	Rhizome	+	+	–	+

+: indicates product use; -: indicates product non-use.

32.7 %) fluctuated much among local mushroom species (Table S1).

3.4. Potential of NTFPs as IGA using value chain analysis in South-Kivu rural and urban areas

3.4.1. NTFP value chain analysis in the vicinity of Kahuzi Biega National Park

The study showed that there were existing NTFP selling points across surveyed zones (Table 10): the primary selling points being the local markets (60.6 %), roadsides (20.0 %), or the neighborhood (19.4 %). The average daily income per household from NTFPs was 3379.3 FC (~ 2.1 US$). NTFPs were purchased by locals (46.7 %), urban inhabitants from the Bukavu City (38.33 %), and those from neighboring villages or agglomerations (15.0 %). Three quarters of the rural population (74.4 %) indicated that access to the forest required a permit from KBNP officers but only 24.4 % of NTFP users were aware of the regulatory texts; the information was mainly disseminated by the public environmental agencies and the park security officers (Table 10). Regarding taxes, only 40.6 % of NTFP collectors and merchants paid the tax, with 74.3 % paying it to the local chiefdom tax officers and 25.7 % to public environmentalists. The average tax per day was 100 FC (~ 0.06 US$).

The purpose of harvesting, collecting, or gathering NTFPs was

Fig. 2. Pictures of some NTFPs used by populations around KBNP, eastern DRC.

Table 5
Contribution of NTFPs vs. agriculture to household income and food security around KBNP, South-Kivu, eastern DRC.

Contributors	Financial contribution (%)				Food contribution (%)				Medicinal contribution (%)			
	Kabare	Kalehe	Walungu	Mean	Kabare	Kalehe	Walungu	Mean	Kabare	Kalehe	Walungu	Mean
NTFP (%)	10.0 ± 5.0	11.0 ± 9.0	38.5 ± 21.0	23.3 ± 22.1	31.8 ± 27.5	31.1 ± 27.1	17.8 ± 16.3	24.5 ± 20.7	43.3 ± 11.5	10.0 ± 9.4	11.0 ± 9.4	22.0 ± 0.5
Agriculture (%)	20.0 ± 2.0	50±30.0	23.8 ± 11.7	25.7 ± 15.9	46.1 ± 24.1	54.6 ± 24.5	56.5 ± 22.0	52.5 ± 24.0	–	26.7 ± 16.5	–	26.7 ± 16.5
Others non-farm activities (%)	60.0 ± 5.0	35.0 ± 25.0	32.9 ± 16.7	40.0 ± 20.0	30.6 ± 15.7	18.3 ± 12.6	34.8 ± 28.4	27.8 ± 19.0	27.8 ± 19.0	27.0 ± 19.6	29.6 ± 16.0	28.0 ± 19.0

NTFP: Non-timber forest product.

Table 6
Proximate composition of the top 10 food NTFPs in eastern DRC.

N	Species	Moisture content (%)	Carbohydrates (g/100 g)	Fat (g/100 g)	Crude protein (%)	Dietary fibres (%)	Crude ash (g/100 g)
1	*Amaranthus viridis*	92.82 ± 0.07	66.25 ± 0.21	1.88 ± 0.16	17.63 ± 0.21	6.21 ± 0.02	15.22 ± 0.11
2	*Basella alba*	94.10 ± 0.36	5.14 ± 1.34	1.19 ± 0.26	2.77 ± 0.03	1.17 ± 0.11	–
3	*Gynandropsis gynandra*	81.80 ± 1.19	4.09 ± 0.26	1.12 ± 0.04	4.82 ± 0.26	5.81 ± 0.36	–
4	*Dioscorea* spp.	58.18 ± 1.22	80.75 ± 0.42	0.53 ± 0.07	4.42 ± 0.18	2.44 ± 0.58	2.57 ± 0.27
5	*Moringa oleifera*	74.50 ± 0.19	11.30 ± 0.12	16.90 ± 0.93	13.60 ± 0.17	4.51 ± 0.01	–
6	*Physalis peruviana*	78.95 ± 2.01	12.66 ± 0.04	0.20 ± 0.07	1.43 ± 0.36	4.69 ± 0.10	2.09 ± 0.68
7	*Piper nigrum*	88.52 ± 0.01	46.06 ± 0.08	8.20 ± 0.08	16.86 ± 0.07	14.33 ± 0.05	4.08 ± 0.00
8	*Solanum nigrum*	84.70 ± 0.01	53.51 ± 0.01	4.60 ± 0.01	24.90 ± 0.02	6.81 ± 0.01	10.18 ± 0.02
9	*Termitomyces robustus*	93.46 ± 0.06	63.62 ± 0.14	2.22 ± 0.01	18.04 ± 0.08	15.38 ± 0.01	2.13 ± 0.25
10	*Zingiber officinale*	84.98 ± 0.04	38.35 ± 1.13	3.72 ± 0.03	5.09 ± 0.09	25.5 ± 0.04	3.85 ± 0.61

Values are means ± SD. Data on NTFP leafy vegetables are sourced from Bahati (2022). Moisture content was calculated on a wet basis while carbohydrate, fat, crude protein, dietary fibres and crude ash were calculated on dried basis.

Table 7
Mineral composition of the top 10 food NTFPs in eastern DRC.

N	Species	Zinc (mg/kg)	Iron (mg/kg)	Iodine (µg/kg)	Potassium (mg/100 g)	Magnesium (mg/100 g)	Calcium (mg/100 g)
1	*Amaranthus viridis*	9.53 ± 0.22	17.71 ± 1.51	–	33.58 ± 0.11	72.32 ± 0.21	57.34 ± 0.21
2	*Basella alba*	35.14 ± 0.23	108.74 ± 0.29	1.77 ± 0.23	493.80 ± 4.33	70.42 ± 1.31	80.22 ± 3.56
3	*Gynandropsis gynandra*	14.34 ± 0.12	81.39 ± 0.37	0.85 ± 0.05	297.40 ± 6.23	71.38 ± 1.54	456.2 ± 7.26
4	*Dioscorea* spp.	6.10 ± 0.14	5.50 ± 1.41	–	475.10 ± 3.58	200.5 ± 0.71	103.51 ± 1.41
5	*Moringa oleifera*	2.24 ± 0.01	29.82 ± 0.03	0.21 ± 0.08	690.10 ± 8.61	155.3 ± 3.01	790.00 ± 9.52
6	*Physalis peruviana*	0.15 ± 0.05	0.54 ± 0.05	–	256.32 ± 2.20	20.04 ± 0.08	17.80 ± 0.12
7	*Piper nigrum*	37.04 ± 0.57	128.31 ± 4.11	–	13.48 ± 0.34	2.41 ± 0.05	10.28 ± 0.75
8	*Solanum nigrum*	0.07 ± 0.01	13.01 ± 0.01	–	42.89 ± 0.02	247.59 ± 9.01	17.33 ± 0.03
9	*Termitomyces robustus*	0.93 ± 0.04	2.55 ± 0.07	–	158.32 ± 0.04	13.17 ± 0.06	47.47 ± 0.08
10	*Zingiber officinale*	0.92 ± 0.41	8.00 ± 0.21	–	71.55 ± 1.21	91.32 ± 2.11	88.40 ± 0.97

Values are means ± SD. Data on NTFP leafy vegetables are sourced from Bahati (2022).

Table 8
Vitamins and other nutrients of the top 10 food NTFPs in eastern DRC.

N	Species	Carotenoids (µg/g)	Vitamin C (mg/100 g)	Antioxidants (mg/100 g)	Total Phenolic Compounds (mg/g)	Flavonoids (mg/100 g)
1	*Amaranthus viridis*	15.43 ± 0.36	32.44 ± 0.27	18.12 ±0.73	11.38 ±0.04	0.49 ± 0.01
2	*Basella alba*	38.79 ± 2.40	27.73 ± 4.17	63.21 ± 0.35	130.32 ± 6.31	420.42 ± 57.02
3	*Gynandropsis gynandra*	25.41 ± 8.26	33.67 ± 6.73	63.00 ± 0.21	121.18 ± 2.00	372.40 ± 7.41
4	*Dioscorea* spp.	114.54 ± 7.26	28.53 ± 1.19	61.34 ± 7.54	487.56 ± 9.62	63.91 ± 2.58
5	*Moringa oleifera*	66.52 ± 3.24	80.71 ± 3.66	36.93 ± 0.04	261.23 ± 4.06	290.04 ± 7.12
6	*Physalis peruviana*	69.55 ± 0.72	39.68 ± 0.15	67.85 ± 1.89	135.34 ± 0.65	5.93 ± 0.74
7	*Piper nigrum*	11.37 ± 1.03	1.59 ± 0.24	22.53 ±0.68	338.4 ± 1.41	2.14 ± 0.59
8	*Solanum nigrum*	18.73 ± 1.13	34.81 ± 0.03	4.49 ± 0.29	67.84 ± 2.61	64.31 ± 6.18
9	*Termitomyces robustus*	8.17 ± 0.02	3.66 ± 0.11	53.05 ± 0.38	121.69 ± 0.03	15.74 ± 0.14
10	*Zingiber officinale*	2.36 ± 0.03	9.04 ± 0.01	73.52 ± 1.24	44.57 ± 0.01	45.77 ± 5.23

Values are means ± SD. Data on NTFP leafy vegetables are sourced from Bahati (2022).

Table 9
Anti-nutritional elements of the top 10 food NTFPs in eastern DRC .

N	Species	Phytates (mg/100 g)	Oxalates (mg/100 g)	Tannins (mg/100 g)
1	*Amaranthus viridis*	1.17 ± 0.03	35.4 ± 1.01	0.39 ± 0.01
2	*Basella alba*	7.44 ± 0.27	19.91 ± 2.69	7.34 ± 1.14
3	*Gynandropsis gynandra*	7.23 ± 0.36	22.91 ± 0.88	5.55 ± 1.32
4	*Dioscorea* spp.	72.54 ± 1.78	67.10 ± 9.23	123.20 ± 1.13
5	*Moringa oleifera*	15.32 ± 0.15	10.48 ± 0.08	10.37 ± 1.04
6	*Physalis peruviana*	33.65 ± 0.06	21.49 ± 3.69	18.82 ± 0.42
7	*Piper nigrum*	1.17 ± 0.02	223.20 ± 8.71	22.11 ± 0.80
8	*Solanum nigrum*	84.53 ± 1.02	78.56 ± 1.45	50.74 ± 3.02
9	*Termitomyces robustus*	0.92 ± 0.00	0.57 ± 0.25	0.29 ± 0.12
10	*Zingiber officinale*	39.41 ± 1.15	23.11 ± 2.02	5.89 ± 0.03

Values are means ± SD. Data on NTFP leafy vegetables are sourced from Bahati (2022).

mainly for self-consumption (46.7 %) and sale (51.7 %). Most households harvesting NTFPs had good relationships with the park's eco-guards. The main challenges faced while collecting and marketing NTFPs were unsatisfactory selling prices (48.6 %), rapid product deterioration due to lack of proper conservation techniques (22.5 %), and excessive taxation (19.1 %). NTFPs were commonly sold in piles (67.6 %), wholesale (36.1 %), and very rarely by piece (2.2 %). Other raised constraints regardless of the location included the NTFP seasonality and scarcity (67.6 %), harassment by armed rebels (16.5 %), and the road safety issues (15 %) (Table 10).

Disparities among community locations were observed for most variables ($p < 0.05$). For instance, more people had legal access to forest in Kaniola in Walungu territory (53.3 %) than Miti (20.0 %) and Bunyakiri (3.3 %) in Kabare and Kalehe territories, respectively. Residents of Bunyakiri transaction NTFPs mainly from the market (80.0 %) while Miti autochthonous pygmies exchange forest products among themselves within their neighborhoods (43.3 %). A third of NTFP users in Kaniola belongs to a cooperative while this is not a common practice in the other two sites. Besides, these Kaniola NTFP stakeholders easily accessed urban market (66.7 %) than those in Miti (30 %) and Bunyakiri

Table 10
NTFPs value chain analysis around Kahuzi Biega National Park, eastern DRC.

Variables	Modalities	Bunyakiri	Kaniola	Miti	Mean (%)	*P*-value
Permit access	*No*	96.7	46.7	80.0	74.4	***
	Yes	3.3	53.3	20.0	25.6	
Selling points	*Market*	80.0	65.0	36.7	60.6	
	Neighborhood	5.0	10.0	43.3	19.4	***
	Roadside	15.0	25.0	20.0	20.0	
Existing NTFP users' cooperative	*No*	100.0	61.7	98.3	86.7	
	Yes	0.0	38.3	1.7	13.3	***
Income from NTFP sales ($)	*Means±SD*	2.2 ± 1.6	2.1 ± 0.7	2.0 ± 1.6	2.1 ± 1.3	*ns*
Origin of clients	*Bukavu City*	18.3	66.7	30.0	38.3	***
	Neighborhood	61.7	20.0	58.3	46.7	
	Surrounding villages	20.0	13.3	11.7	15.0	
Awareness on legal texts	*No*	100.0	61.7	65.0	75.6	
	Yes	0.0	38.3	35.0	24.4	***
Information channel	*Environment department*	0.0	84.6	20.0	50.0	
	Park guard	0.0	15.4	80.0	50.0	**
Operating fee	*No*	55.0	46.7	76.7	59.4	
	Yes	45.0	53.3	23.3	40.6	**
Tax collectors	*Environmental agents*	18.5	24.2	42.9	25.7	*ns*
	Chiefdom agents	81.5	75.8	57.2	74.3	
Daily tax amount ($)	*Means±SD*	0.08 ± 0.09	0.07±0.08	0.08 ± 0.09	0.07± 0.08	*ns*
Purpose of NTFP exploitation	*Self-consumption*	45.0	0.0	95.0	46.7	
	Self-medication	0.0	5.0	0.0	1.7	***
	Market participation	55.0	95.0	5.0	51.7	
Relationships with park eco-guards	*Good*	98.3	88.3	53.3	80.0	
	Bad	1.7	11.7	46.7	20.0	***
Challenges§	*Rapid product deterioration*	23.7	28.3	14.8	22.5	
	High taxation	33.9	3.3	20.4	19.1	***
	Forest-to-market distance	1.7	26.7	0.0	9.8	
	Unsatisfactory selling price	40.7	41.7	64.8	48.5	
	Product seasonality	50.0	88.7	66.7	67.6	
	Collection risks	20.0	7.5	19.3	15.9	
	Rebel harassment	30.0	3.8	14.0	16.5	
Selling unit	*Wholesale*	28.3	38.3	41.7	36.1	
	Pieces	0.0	6.7	0.0	2.2	*
	Heap	71.7	55.0	58.3	61.7	

ns, *, **, ***: not significant, significant, highly significant, and very highly significant at *p*-value thresholds of 0.05, 0.01, and 0.001, respectively. SD=standard deviation. §: for this variable, households were allowed multiple responses.

(18.3 %). None of the stakeholders in Bunyakiri knew about forest access regulatory texts but third of those in the other two sites were aware of the regulatory texts (Table 10). Park eco-guards seemed to interact more with the Batwa pygmies of Miti, hence facilitating their access to regulatory texts while in Walungu the information on the regulatory texts was acquired from the public agencies in charge of the environmental conservation. Another area of disparities among community locations is the NTFP collection purposes: subsistence motivated Bunyakiri (45 %) and Miti inhabitants (95 %) while those in Kaniola were market-oriented (95 %). Challenges for NTFP value chain were dominated by product seasonality (50 %), low market value (40.7 %), and high taxation (33.9 %) in Bunyakiri. In Kaniola, market seasonality (88.7 %), low market value (41.7 %), and rapid product deterioration (28.3 %) were the top three challenges faced by the NTFP value chain. On the other hand, Miti stakeholders raised market seasonality (66.7 %), low market value (64.8 %), and high taxation (20.4 %) as the top three factors limiting NTFP value chain in their area (Table 10).

3.4.2. NTFP value chain analysis in Bukavu city

Socio-demographic characteristics of respondents in Bukavu city are provided in Table S2. These included owners of hotels, restaurants, markets, households, supermarkets, and street vendors. Regardless of the NTFP subsectors, respondents were mostly married middle age adults. A third of them (37.1 %) had a secondary school level, a quarter (24.9 %) attended the university, a fifth (20.05 %) had no formal education, while 12.6 % had primary school level. It is noteworthy that the education level varied significantly with the intervention sector ($p < 0.001$). The proportion of stakeholders with lower education level was highest among street vendors (61 % had no formal education) than other value chain phases' stakeholders where most people had attended at least secondary school education. Actors involved in the NTFP sector had diversified income-generating activities. Household work was their main activity (36.9 %), followed by small businesses (31.3 %), and the private sector (17.1 %). Only 11 % of them had salaried activity. Results in Table S3 show that 51 NTFPs (including neglected and underutilized crops) are used in hotels and restaurants, markets, households, supermarkets, and by street vendors in Bukavu City. Of these, 46 NTFPs were used for food while 36 of them were also attributed therapeutic virtues.

In Bukavu city, NTFPs were either sold raw or after value-addition. For example, wild fruits are sold in heaps in the form of ripe fruits or processed into juice. We noted that NTFPs price varied with the selling point's location, they are expensive in Ibanda compared to the other two municipalities for most NTFPs (Table 11). There are known NTFP selling points across Bukavu city, most of the transactions being done by households for consumption and medication (57.7 %). The NTFP value chain is dominated by retailers (96.9 %), with no significant differences among municipalities. Daily income did not vary with municipalities and was generally low, 38 % of vendors being unable to reach 10,000 CF a day (~4.54 US$ but which is still higher than 3 US$ a day, the national minimum daily wage in DRC) and only 8.8 % could surpass 40,000 CF a day (18.18 US$). The majority of urban respondents raised several factors hindering NTFPs commercialization and use in Bukavu city. These factors included the products' seasonality (36.9 %), rarity or limited access (17.7 %), short shelf life (5.9 %), change in the eating habit among urban dwellers with most people preferring imported processed products (5.1 %), prohibiting high prices (17.7 %), lack of awareness about NTFPs nutritional and therapeutic values (9.0 %), absence of processed NTFPs or their by-products (5.5 %), and loss of cultural values among youths (2.4 %). These stakeholders suggested the introduction of improved post-harvest techniques to prolong the NTFP

Table 11
Common NTFPs sold at Bukavu city's local markets and their market values in Congolese francs (at the time of the survey, 1 US$ equaled 2200 Congolese Francs (CF)).

Species	Unit	Acquisition and utilization forms	Origin	Bagira	Ibanda	Kadutu	$\bar{Y}$±SD
Passiflora edulis	Heap	*Ripe fruits, fresh (as dessert), and juice*	*Market*	1400±480	2000±650	2000±680	1750±660
Cyphomandra batacea	Heap	*Ripe fruits, fresh (as dessert)*	*Market*	2000±820	2200±830	2100±800	2000±810
Physalis peruviana	Heap	*Fresh, powder, and spice*	*Market*	–	3000±1650		3000±1650
Piper nigrum	100 g	*Flour (condiment spice)*	*Market*	1300±600	2180±800	1000±300	1650±850
	Heap	*Grains*	*Market*	1300±300	2000±200	2000±300	1640±820
Zingiber officinale	100 g	*Powder, spice, and juice*	*Market and street vendors*	2000±500	1400±400	1500±400	1500±450
	Heap	*Rhizome*	*Kabare*	1650±550	2200±930	1550±650	1800±780
Termitomyces robustus	Heap	*Fresh and vegetable*	*Kabare and street vendors*	5000	5000	5000	5000
Apis mellifera honey	Liter	*Fresh and tea*	*Market and Kabare*	20,000	20,000	20,000	20,000
Amaranthus spp.	Heap	*Fresh*	*Market*	1670±550	1950±300	1500±420	1780±450
Solanum nigrum	Heap	*Fresh and vegetable*	*Market*	1250±250	1500±430	1500±500	1480±430

$\bar{Y}$: mean, SD: standard deviation.

shelf life (22.4 %), to regulate NTFP prices at local markets (32.6 %), to implement well-defined marketing points (7.5 %), and to encourage value-addition to develop more attractive by-products (37.6 %) as the main strategies in enhancing NTFP value chain and use in urban areas of eastern DRC (Table 12).

3.4.3. Perceptions of urban households on the therapeutic values of main NTFPs marketed in Bukavu city

Information on the therapeutic values of most popular NTFPs in Bukavu city are provided in Table 13. Most households believed that NTFPs are rich sources of nutrients and medicine that bring several health benefits to the population, including the prevention or management of several diseases: angina, hypoglycemia, hypertension, ascariasis, flu, hernia, stomach-ache, prostate diseases, inflammations, urinary complications, anemia, cutaneous diseases, poison or food intoxication, intestine troubles, liver disease, etc. Some therapeutic virtues were known by almost all the populations such as the potential of *Gynandropsis gynandra* in relieving coughs (100 %), *Solanum* spp. (Kashongwe) in treating stomachache especially among newborn babies (82 %), *Cyphomandra batacea* in treating anemia (77 %), *Piper nigrum* in alleviating coughs (73 %), *Passiflora edulis* in improving digestion (66.6 %), *Ricinus communis* in preventing hemorrhoid (63 %). Further studies are necessary on these NTFPs to elucidate nutraceuticals and bioactive compounds acting in treating illnesses.

4. Discussion

4.1. The variety of NTFPs inventoried and used as source of food and medicine by communities surrounding KBNP

NTFPs are already accepted commodities among rural populations in eastern DRC, and hence, any intervention on them would boost local economies at all levels (De Merode et al., 2004; Mondo et al., 2021; Ishara et al., 2022, 2023). However, effective interventions would require that these products are inventoried, their uses and virtues are known, and their potentials as IGA are assessed (Termote et al., 2011; Van Vliet et al., 2019; Nsevolo et al., 2023). The current study inventoried more than 55 NTFPs exploited in three riparian zones of the Kahuzi-Biega National Park, in eastern DRC. These included insects, plant- and animal-based NTFPs, and mushrooms that are either used raw, dry, or processed into powder or juice to extend their shelf life or to attract urban markets (including households, hotels, supermarkets, and restaurants). The list of NTFPs elaborated in this study is far from being exhaustive, given the huge ethnic diversity and ecologies characterizing zones around the KBNP (Mitchell and Wagner, 2023). Such a huge diversity of NTFPs has also been reported in other parts of DRC where 166

Table 12
NTFP market value chain information in Bukavu city.

Variables	Modalities	Bagira	Ibanda	Kadutu	Mean (%)	*P*-value
Selling points	*Hotel and Restaurant*	18.52	15.46	17.33	17.00	0.425*ns*
	Market	20.99	15.46	20.00	18.58	
	Household	56.79	58.76	57.33	57.71	
	Supermarket	0.00	4.12	0.00	1.58	
	Street vendor	3.70	6.19	5.33	5.14	
Daily income from sales (CF[a])	*< 10,000*	27.27	37.93	51.72	38.46	0.474*ns*
	>40,000	6.06	10.34	10.34	8.79	
	10,000–20,000	30.30	24.14	17.24	24.18	
	21,000–30,000	21.21	24.14	20.69	21.98	
	31,000–40,000	15.15	3.45	0.00	6.59	
Type of vendors	*Retailer*	100.00	100.00	89.47	96.88	0.298*ns*
	Wholesaler	0.00	0.00	5.26	1.56	
	Intermediary trader	0.00	0.00	5.26	1.56	
Challenges	*Lack of processed sub-products*	2.47	5.15	9.09	5.49	0.013*
	Availability (scarcity)	13.58	26.8	10.39	17.65	
	Preference of imported products	3.70	8.25	2.60	5.10	
	Short shelf life	7.41	4.12	6.49	5.88	
	Unawareness of the NTFP virtues	6.17	7.22	14.29	9.02	
	Loss of cultural values	3.70	2.06	1.30	2.35	
	Prohibiting high prices	20.99	12.37	20.78	17.65	
	Seasonality	41.98	34.02	35.06	36.86	
Recommendations	*Develop NTFP by-products*	17.28	19.59	31.17	22.35	0.002**
	Implement conservation methods	45.68	30.93	37.66	37.65	
	Sales outlets throughout the city	2.47	16.49	1.30	7.45	
	Reduce market prices	34.57	32.99	29.87	32.55	

[a] At the time of the survey, 1 US$ equaled 2200 Congolese Francs (CF), ns, *, **, ***: not significant, significant, highly significant, and very highly significant at *p*-value thresholds of 0.05, 0.01, and 0.001, respectively.

Table 13
Population awareness on NTFP therapeutic and nutritional virtues in Bukavu city, eastern DRC.

NTFP species	Bukavu inhabitants' perceptions on NTFP medicinal and nutritional properties
Passiflora edulis	Treats angina (33.3 %), improves digestion (66.6 %), aperitif (20 %), vitamin-rich (46.7 %), fights insomnia (26.7 %), treats anemia (20 %)
Cyphomandra batacea	Treats angina (15.5 %), improves digestion (15.7 %), provides vitamins (21.5 %), treats anemia (77 %)
Imbrasia oyemensis	Fights malnutrition (40.0 %), proteineous (80 %)
Physalis peruviana	Treats stomachache (85.3 %), improves digestion (25.4 %), vitamin-rich (25 %), treats earache (23 %)
Piper nigrum	Treats stomachache (18.7 %), angina (20.6 %), and coughs (73 %)
Moringa oleifera	Treats stomachache (18.6 %), vitamin-rich (50 %), skin rejuvenation (50 %), wound healing (31 %), it prevents cutaneous disorders (20 %) and stomach acidity (33 %)
Dioscorea spp.	Improves digestion (33 %), anti-malaria (33 %), diabetes prevention (50 %), prostatitis prevention (33 %)
Apis mellifera honey	Treats stomachache (16.7 %), poison (24 %), burns and wounds (15 %)
Zingiber officinale	Treats coughs (16 %), improves digestion (17.4 %), treats poison (17 %), backache (16 %)
Ricinus communis	Treats hernia (36 %), hemorrhoid prevention (63 %)
Bunaeopsis aurantiaca	Proteinous (100 %)
Gynandropsis gynandra	Boosts immunity (50 %), cough relief (100 %), diabetes prevention
Termitomyces spp.	Vitamin-rich (22 %), proteinous (17 %), stroke prevention (28 %), treats sexual disorder (25 %), skin disorders (25 %), and backache (50 %)
Solanum spp. *(Kashongwe)*	Treats stomachache (82 %)
Aloe vera	Treats stomachache (17.1 %)
Amaranthus spp.	Vitamin-rich (24.5 %)
Solanum nigrum	Treats stomachache (26.8 %), improves digestion (28.6 %), prevents anemia (30.3 %), diabetes prevention (27.5 %)
Basella alba	Facilitates childbirth (48 %), treats rheumatism (34 %)

Values in parentheses represent the proportion of households that listed that particular therapeutic virtue. Only properties recognized by more than 15 % of households were considered reliable. Lab experiments are necessary to confirm these perceptions by NTFP users.

wild edible plant species (Termote et al., 2011), 148 edible insects (Nsevolo et al., 2023), 34 bush meats (Van Vliet et al., 2019), and 78 species of edible macrofungi (Kamalebo and De Kesel, 2020) were previously identified.

Some NTFPs (*Piper nigrum, Solanum nigrum*, essential oils from serpents and plants, spices, etc.) are popular even among urban populations, showing that they play significant roles in households' diets and medication in South-Kivu, and thus helping diversify the population food. In fact, food diversification has been regarded as an essential strategy in fighting hidden hunger in eastern DRC (Mondo et al., 2021) where micronutrient deficiencies are high, especially among women and children (Maass et al., 2012; Moumin et al., 2020; Irakiza et al., 2021). Of the identified NTFPs, fruits are the most widely consumed NTFP group in eastern DRC, but in different forms; they are consumed either as pulp, seed, nut, juice, or the whole fruit as our study indicated. Besides, they are also part of diabetic patients' diets, helping to control blood sugar levels (Mondo et al., 2021). Leafy vegetables, that come second, are consumed in the form of vegetables and condiments (Bahati, 2022). Among these, the African nightshade (*Solanum nigrum*), *Basella alba,* and *Amaranthus viridis*, which are available all year round, are the most consumed, and thus contribute in maintaining food security during lean seasons. Such observation of the wide use of leafy vegetables in eastern DRC was previously reported by Bahati (2022) who identified up to 20 leafy vegetables in Walungu, one of the zones covered in this study. In other parts of DRC, Fundu et al. (2023) identified 169 leafy vegetables that are commonly collected by the western DRC populations, several of which are rich in proteins of good biological value: lipids with unsaturated fatty acids, vitamins, and minerals. Other inventoried NTFPs were bush meat, gums, and mushrooms that provide human bodies with certain vitamins for a healthy balance (Van Vliet et al., 2019; Fundu et al., 2023). In eastern DRC, De Merode et al. (2004) estimated that bushmeat, fish, and wild plants contributed 3.1 %, 6.2 %, and 9.6 %, respectively, to the total value of the food consumed in the household. Similar observations on the huge NTFP diversity were made in other parts of the world and highlighted the NTFP potential to improve local communities' livelihoods, especially during lean season when agricultural production is low (De Merode et al., 2004; Biloso and Lejoly, 2006; Verina et al., 2010; Shackleton and de Vos, 2022). These essential contributions of NTFPs to populations' livelihoods (household income, subsistence needs, and health care, as well as providing multiple social and cultural values) throughout the year were ascertained by several other scholars (Suleiman et al., 2017; Zhu et al., 2021; Talukdar et al., 2021; Derebe and Alemu, 2023).

In addition to food NTFPs, there were several medicinal plants and products that were searched for from the forest owing to difficult access to healthcare services in these remote areas. Besides, most populations around KBNP are poor and thus unable to cover modern medical expenses (Spira et al., 2019; Mitchell and Wagner, 2023). Similar findings were reported in the southwestern Central African Republic where populations largely rely on self-medication using medicinal non-woody plant species (Endamana et al., 2016). Previous reports estimated that ~80 % of the populations in developing countries use NTFPs as their primary source of healthcare due mainly to their inability to access modern medication (FAO, 2008; Brack, 2018). Various medicinal herbs and their different parts (leaves, barks, roots, etc.) were used in traditional medicine practiced by indigenous and non-indigenous communities in that part of DRC. Of these herbs, the most commonly used were *Senecio maranguensis* and *Alstonia boonei*. Based on local community perception, these medicines are effective as they heal much faster than modern drugs. For example, *Alstonia boonei* herbs are used to treat stomachache (amoeba) and its bark is used to cure hernia. *Cyathula uncinulata* is used to treat intestinal worms. *Cyphomandra batacea* and *Aframomum laurantii* are the most widely harvested fruits and are believed to possess laxative virtues (its ability to rid the intestine of foreign substances). Kirthika and Janci Rani (2020) reported the presence of bioactive compounds, such as enzymes, pigments, and polyphenols, and anti-oxidants, anti-inflammatory, cardioprotective, immune-boosting, anti-cancer, anti-diabetic, gastroprotective, anti-anemia, and anti-diarrheal functional properties among NTFPs consumed by Irula tribes of South India. These authors noted that reduced consumption of these NTFPs was associated with acute shortcomings in macro and micronutrients in the most vulnerable age groups. Further studies are necessary to comprehend the active ingredients conferring curative power to such NTFPs and to determine the appropriate application doses to prevent intoxication deriving from substance abuse, as previously recommended by Mondo et al. (2021) and Fundu et al. (2023).

Another common use of NTFPs in eastern DRC included fuelwood (*Canna indica, Newtonia buchananii, Alstonia boonei, Macaranga neomildbraediana, Albizzia gummifera*) in these local communities where firewood is the only source of cooking energy. This search for firewood from forest reserves has been reported in other studies in developing countries where access to electricity is limited (Suleiman et al., 2017; Talukdar et al., 2021; Njenga et al., 2021). Suleiman et al. (2017) showed that the collection of firewood and medicinal plants are jointly carried out in most part of Africa by both men and women. Unfortunately, with rapid population increase, there would be rapid logging of trees for firewood, thus leading to forest covers' degradation (Kyaw et al., 2020; Hartley, 2021).

4.2. Physicochemical composition of main NTFPs and their importance as source of food and medicine around KBNP

This study showed that NTFPs are very nutritious, implying that they hold tremendous potential to improve the population's nutritional status as they provide proteins, dietary energy, essential minerals, etc. For instance, some species exploited around KBNP such as *Solanum nigrum, Termitomyces robustus, Amaranthus viridis*, and *Piper nigrum* proved to be valuable sources of proteins that lack in most population diets in eastern DRC due to extreme poverty (Maass et al., 2012), while *Zingiber officinale, T. robustus* and *P. nigrum* are rich in dietary fibres that could facilitate digestion (Bahati, 2022). *Piper nigrum* and *Basella alba* had the highest zinc and iron contents, respectively. It is noteworthy that these two micronutrients are crucial for human health and wellbeing (Garg et al., 2018). In fact, iron and zinc deficiencies are common nutritional deficits worldwide, with important roles on neurologic functions (poor memory, inattentiveness, and impulsiveness), finicky appetite, and mood changes (sadness and irritability) (Granero et al., 2021). For such a reason, there are several programs promoting biofortified foods, rich in provitamin A, zinc, and iron in the world, including eastern DRC (Bouis, 2018; Garg et al., 2018; Moumin et al., 2020). Past experiences showed that lack of awareness of the nutritional values of indigenous foods, including NTFPs, was a primary factor of their neglect and underutilization (Kirthika and Janci Rani, 2020; Mondo et al., 2021; Mondo, 2023). We hypothesized that increasing the population's awareness on NTFP values would change their attitude towards NTFPs and thus boost consumption even among urban dwellers. The more these products are consumed, the higher the income would be for NTFP collectors, and the better the nutritional status of the entire population would become. Such evidence, brought by the current study, was still missing and should be exploited to promote wide use of NTFPs in eastern DRC. Besides, knowing NTFPs' nutritional composition would boost their use in local industries as they will be used either as supplements to enrich existing foods or serve as a substitute to import products to reduce food prices and importation dependency that undermines the country's food sovereignty and foreign reserves (Irakiza et al., 2021; Karume et al., 2024; Mondo et al., 2024). For example, Irakiza et al. (2021) successfully used local mushroom to fortify breads for which wheat flour was substituted by cassava flour to reduce wheat import in eastern DRC. The use of locally available resources would also reduce vulnerability of Congolese economies and food security to international shocks as it has been the case during the Russia invasion of Ukraine (Karume et al., 2024). Lastly, this study highlighted the importance of considering the anti-nutritional elements present in some NTFPs (*S. nigrum, Dioscorea* spp., and *P. nigrum*) such as phytates, oxalates and tannins, and calls for actions to devise preparation and cooking methods that maximize nutrient bioavailability. In fact, anti-nutritional elements are biological components present in foods that reduce nutrient uptake or utilization, leading to impaired gastrointestinal functions and metabolic performance (Samtiya et al., 2020; Duraiswamy et al., 2023).

4.3. Potential of NTFPs as an alternative IGA in both in rural and urban areas of South-Kivu

From our findings, NTFPs were the second most important income source after agriculture around KBNP. We realized that households involved in NTFPs collection had 50 % more daily income than the general population mean (2.1 vs.1.6 US$). This 50 % income increase could be attributed to the fact that NTFP collectors were also farmers, meaning that NTFP exploitation was for them a means of diversifying their income sources (Ao et al., 2021; Zhu et al., 2021). Another hypothesis explaining high income for NTFP collectors as compared to farmers is that NTFP collectors are primarily market-oriented while farmers are more motivated by subsistence. De Merode et al. (2004) showed that although agriculture yields 53 % of household production in northeastern DRC, only 12 % of it is sold at the market while up to 90 % of NTFPs (especially bushmeat and fish) are sold at the market. Similar observation was made by Delgado et al. (2022) who demonstrated that NTFPs use can generate higher revenues than other productive land use options, such as timber extraction or livestock production, if the resources from which they derive from are sustainably managed. Same conclusion was reached by Van Vliet et al. (2019) who showed that bushmeat provided an income of about USD 400 yearly for forest dwellers in northeastern DRC. Financial resources from NTFPs sustain livelihoods in those forest-adjacent areas since these were primarily used to meet households' basic needs: food supply, investment in small businesses, healthcare expenses, and children's education, given the lack of better job opportunities (De Merode et al., 2004; Van Vliet et al., 2012, 2019). These results agreed with those of Derebe and Alemu (2023) in the Horn of Africa who showed that by selling NTFPs, farmers were able to meet their basic needs and those of their families (purchase of medicines, kerosene, soap and clothes; construction of houses; payment of dowry and school fees). This economic return from NTFPs was even higher in urban areas of Bukavu, ranging from ~4.54 to 18.18 US$ a day, largely surpassing the national minimum wage in DRC which is 3 US$ a day.

However, NTFP market in eastern DRC is still poorly structured; the main selling points being local markets, streets, and the neighborhood. Factors hindering this sector value chain in the study area are mainly product seasonality, low market value, rapid product deterioration, and high taxation in rural areas of South-Kivu. In Bukavu, top challenges are the products' seasonality, rarity or limited access, short shelf life, preferences of the urban population for imported processed products, prohibiting high prices, lack of awareness about NTFPs nutritional and therapeutic values, absence of processed NTFPs or their by-products, and loss of cultural values among youths. Similar reports were made by Termote et al. (2011, 2012) and Van Vliet et al. (2019) showing poor NTFP market structuring in northeastern DRC due to several socioeconomic and structural factors such as lack of transport and market infrastructure, lack of storage space, illegal taxes (including fines and bribes), lack of access to credit, insufficiency of NTFPs to purchase, and low purchasing power of consumers. Besides, limited value-addition efforts have been made to develop processed products that can attract youth and urban populations, meaning that collectors and vendors are not yet yielding maximum benefits from exploiting NTFPs (Nsevolo et al., 2023; Mondo, 2023).

5. Conclusion and recommendations

In addition to providing shelter for plant and animal biodiversity, forests provide numerous ecosystem services for people living in rural and urban areas of the South-Kivu. This study showed that the KBNP is a biological hotspot, with more than 55 NTFPs used as food and medicine by surrounding populations, with a predominance of wild fruits and leafy vegetables. Results showed also that these NTFPs are valuable sources of proteins, dietary energy, and essential minerals. Of these NTFPs, *S. nigrum, T. robustus, A. viridis*, and *P. nigrum* are valuable sources of proteins while *Z. officinale, T. robustus*, and *P. nigrum* are rich in dietary fibres. *Piper nigrum* and *Basella alba* had the highest zinc and iron contents, respectively. Such nutritional information is a valuable asset for extension services and other stakeholders encouraging wide use of NTFPs in eastern DRC either for direct consumption or through use in local industries to improve the population's nutritional status. This study also provided evidence that NTFPs could improve the livelihood of local communities through commercialization, since NTFPs' collectors had 50 % more daily income than the average population around KBNP (2.1 vs. 1.6$) and its returns in urban areas significantly surpassed the national minimum daily wage in DRC (~4.54 to 18.18 US$ a day vs. 3 US$). We also found that populations are already aware of the medicinal virtues of most NTFPs marketed in their area, prompting interest in them. Therefore, NTFPs could play a significant role in providing healthy and nutritious food and in wealth creation for households surrounding the KBNP if major constraints raised by stakeholders, namely low market values, short shelf life, excessive taxation, and seasonality, are addressed. To unlock the full potential of NTFPs as sources of food, medicine, and wealth around KBNP, the following recommendations should be considered:

(1) Provide training and capacity-building programs to local communities on sustainable harvesting, processing, and marketing techniques for NTFPs. This empowers communities to make informed decisions and maximize the value of NTFPs while preserving forest ecosystems.

(2) Stimulate local communities involvement in decision-making processes related to NTFP management and utilization. Encourage community participation in sustainable forest management practices and the development of NTFP-based enterprises.

(3) Promote value addition and product diversification of NTFPs to enhance their market competitiveness and economic viability. This can include processing NTFPs into higher-value products such as extracts, essential oils, herbal supplements, and handicrafts.

(4) Advocate for supportive policies and legal frameworks that recognize the importance of NTFPs in sustainable forest management and provide incentives for their conservation and sustainable use.

(5) Establish monitoring and evaluation mechanisms to track the impact of NTFP promotion initiatives on forest conservation, livelihood improvement, and socioeconomic development. This helps identify successful strategies and areas for improvement.

(6) Invest in research and development to understand the nutritional, medicinal, and economic potential of various NTFPs. This includes studying their domestication, market value, demand, and potential uses in different industries.

Finding

Not applicable.

CRediT authorship contribution statement

Jean M. Mondo: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Géant B. Chuma:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Matthieu B. Muke:** Investigation, Writing – review & editing, Data curation, Formal analysis. **Bienfait B. Fadhili:** Investigation, Writing – review & editing, Data curation, Formal analysis. **Jacques B. Kihye:** Investigation, Writing – review & editing, Data curation, Formal analysis. **Henri M. Matiti:** Investigation, Writing – review & editing, Data curation, Formal analysis. **Caroline I. Sibomana:** Methodology, Writing – review & editing. **Léon M. Kazamwali:** Methodology, Writing – review & editing. **Napoléon B. Kajunju:** Methodology, Writing – review & editing. **Gustave N. Mushagalusa:** Writing – review & editing, Supervision, Project administration. **Katcho Karume:** Writing – review & editing, Supervision, Project administration. **Hwaba Mambo:** Writing – review & editing, Project administration, Funding acquisition. **Rodrigue B. Ayagirwe:** Writing – review & editing, Supervision, Project administration. **Alphonse Z. Balezi:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

The data can be available on a reasonable request.

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Supplementary materials

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