Quantitative market survey of non-woody plants sold at Kariakoo Market in Dar es Salaam, Tanzania

Posthouwer, C.; Veldman, S.; Abihudi, S.; Otieno, J.N.; Andel, T.R. van; Boer, H.J. de

Quantitative market survey of non-woody plants sold at Kariakoo Market in Dar es Salaam, Tanzania

Chantal Posthouwer[a,b,*], Sarina Veldman[c], Siri Abihudi[d], Joseph N. Otieno[d], Tinde R. van Andel[a,b], Hugo J. de Boer[a,c,e]

[a] Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, The Netherlands
[b] Institute of Biology Leiden, Leiden University, P.O. Box 9505, 2300 RA Leiden, The Netherlands
[c] Department of Organismal Biology, Systematic Biology, Uppsala University, Norbyv. 18D, 75236 Uppsala, Sweden
[d] Institute of Traditional Medicine, Muhimbili University of Health and Allied Sciences, United Nations Road, P.O. Box 65001, Dar es Salaam, Tanzania
[e] Natural History Museum, University of Oslo, Postboks 1172, Blindern, 0318 Oslo, Norway

ABSTRACT

Ethnopharmacological relevance: In Tanzania, traditional medicine plays a significant role in health care and local economies based on the harvesting, trade and sale of medicinal plant products. The majority of this plant material is said to originate from wild sources, and both traditional healers and vendors are concerned about the increasing scarcity of certain species.

Aim of the study: A market survey of non-powdered, non-woody medicinal plants was conducted at Kariakoo Market in Dar es Salaam, the major hub for medicinal plant trade in Tanzania, to assess sustainability of traded herbal medicine.

Materials and Methods: For this study, fresh and dried herbs, seeds and fruits were collected and interviews were conducted to obtain information on vernacular names, preparation methods, monthly sales, uses and prices. Bundles of herbal medicine offered for sale were weighed and counted to calculate the value and volumes of daily stock at the market.

Results: A total of 71 medicinal plant products belonging to 62–67 different species from at least 41 different plant families were identified. We identified 45 plant products to species level, 20 products to genus level and four to family level. Plant species most encountered at the market were *Suregada zanzibariensis*, *Myrothamnus flabellifolia* and *Sclerocarya birrea*. The major use categories reported by the vendors were ritual purposes, digestive disorders and women's health. Annual sales are estimated to be in excess of 30 t and close to 200,000 USD, and trade in herbal medicine at Kariakoo Market provides subsistence income to many local vendors.

Conclusions: A large diversity of wild-harvested plant species is traded as medicinal products in Tanzania, including species listed on CITES Appendices. Identifying and monitoring temporal changes in availability per season and from year to year will reveal which species are most affected by this trade, and help relevant authorities in Tanzania to find alternative sources of income for dependent stakeholders and initiate targeted efforts to protect threatened plant species.

1. Introduction

Herbal medicine is an important source of health care for many people in the world (Hamilton, 2004) and the global demand is growing (FAO, 2008; Srivastava, 2000). Continuing population growth and limited access to modern medicine in developing countries contribute to this increasing demand for traditional medicine (Hamilton, 2004; Schippmann et al., 2002). In Africa, the demand for traditional medicine is not just a result of the inaccessibility or high costs of western

health care, but also due to cultural preference, where traditional medicine is often deemed a more appropriate method of treatment (Marshall, 1998). The lack of incentive for cultivation and prior accessibility of resources has resulted in indiscriminate harvesting of medicinal plants from the wild, with several species becoming endangered or going extinct (De Silva, 1997; FAO, 2008). Exploitation of plant species for medicinal purposes is partly responsible for the decline of some medicinal resources (Hamilton, 2004; Schippmann et al., 2002). Loss of medicinal plant resources can have serious

consequences. Decreasing availability can affect the overall health security of people, especially in Africa (Marshall, 1998), as well as impact local livelihoods based on harvesting, trade and sale of medicinal plant species and products (Augustino and Gillah, 2005; Hamilton, 2004; McMillen, 2012; Schippmann et al., 2002).

In Tanzania, a thriving trade in traditional medicine exists in both rural and urban areas (Otieno et al., 2015). The majority of Tanzanian medicinal plant material originates from the wild (Augustino and Gillah, 2005; De Boer et al., 2005) and already 20 years ago, traditional healers and vendors of wild medicinal plants noted an increased scarcity of certain traded species (Marshall, 1998). It is important to conserve medicinal plant resources to ensure future access to herbal medicine and to preserve dependent livelihoods. In order to investigate which wild species are vulnerable for overharvesting and should be prioritized for conservation, it is important to know which species are traded and in what quantities. Market surveys are essential for conservation and development planning (Van Andel et al., 2012), as markets are an elemental part of the trade structure for wild medicinal plants and provide a snapshot of a country's medicinal flora (Kool et al., 2012; Marshall, 1998; Mati and De Boer, 2011). Markets also reflect the main health concerns, illnesses and saliency of traditional medicine in local communities (Van Andel et al., 2012).

Market surveys based on vendor interviews have been conducted for several markets in Tanzania (Augustino and Gillah, 2005; Kaguongo, 2012; McMillen, 2008, 2012). However, not all surveys include collection of botanical voucher material for accurate matching of vernacular names to scientific ones. This is particularly important in Tanzania where folk taxa do not always correspond one-to-one with scientific plant names and plants may be traded under trade names in a variety of local languages (Otieno et al., 2015). Market surveys based on collecting and identifying plant material have not been done before in Tanzania, so a verifiable overview of the medicinal plant species traded in this country does not exist.

The aim of this study was to identify non-powdered, non-woody, fresh and dried medicinal and ritual plants sold at Kariakoo Market, the main medicinal plant market in Dar es Salaam, the largest city of Tanzania. Additional research questions were: 1) What are the major use categories for the marketed species?; 2) What are the salient diseases associated with these plants?; 3) Which species are sold most frequently?; 4) What is the volume and value of herbal medicine sold at Kariakoo Market?; 5) Are species sold that are listed on the Convention on International Trade of Endangered Species (CITES) Appendices or on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species?

2. Methods

This research was reported following the recommended standards for conducting and reporting ethnopharmacological field studies (Weckerle et al., 2017).

2.1. Study area

Fieldwork was conducted in April-May 2015 at Kariakoo Market in Dar es Salaam, the largest city in Tanzania. In 2015, Dar es Salaam was inhabited by 5.1 million people (CIA, 2017). Kariakoo Market is the main medicinal plant market in this city, with the largest number of stalls and vendors (Kaguongo, 2012). Besides Kariakoo Market, Dar es Salaam accommodates several herbalist shops, individual stalls and ambulant sellers of herbal medicine throughout the city. Additionally, there are several shops exclusively selling dried herbal medicine imported from the Middle East or a combination of Tanzanian and Arab medicinal products.

2.2. Quantitative market survey

This study was part of a larger project on monitoring trade in Tanzanian wild-harvested plants (Veldman et al., 2014, 2017). Our market survey followed methods used in Ghana (Van Andel et al., 2012), Benin (Quiroz et al., 2014) and Gabon (Towns et al., 2014). Non-powdered medicinal plant products (fresh and dried bundles of medicinal plants) available at the market were purchased, weighed (per sales unit) and processed into herbarium vouchers using standard collecting methods (Martin, 2004). Since not all products could be weighed, the average weight was used when more bundles of the same species were collected. We interviewed market vendors to obtain information on vernacular names, preparation methods, uses and prices. In addition, the vendors were asked to estimate their weekly or monthly sales of plant material. If the vendors consented, full-stall inventories were performed in which we counted all sales units per non-powdered plant product in each stall and estimated its volume by using the average weight of sales units per species. If the vendors did not agree with us counting all their bundles, they were asked to make an estimation of their wares. Additional stock kept behind the stalls was also included. For every plant product we calculated the volume at which they were present at the market as daily stock. The ethnicity, gender, education, religion and age of the vendors were also recorded. All 15 market stalls that sold non-powdered, non-woody medicinal plants were inventoried. All vendors were Tanzanian males, and belonged to the Kwere (11), Sambaa (2), and Luguru (1) ethnic groups, while the ethnicity of one vendor was not divulged. All vendors were between 25 and 50 years old. The interviews were held by author SA in Swahili, who translated to English on the spot or transcribed the details of the interview later.

Uses were documented based on what the informants told us. The term uses is used synonym for the term use reports. A use or use report is defined as an application mentioned by one interviewee for a specific plant. The use reports where divided into sixteen categories, based on how this was done in similar studies (Quiroz et al., 2014; Towns et al., 2014; Van Andel et al., 2012). Ailments related to the digestive system, such as increasing appetite, constipation and stomach ache, were listed as 'digestive disorders', health issues related to the female reproductive system, such as infertility or menstrual pain, were listed as 'women's health', and diseases not recognized by western medicine, such as against bad dreams or to make someone love you, were listed as 'ritual'. In some cases we deviated from the classifications made by similar studies, mainly when it seemed we would be overinterpreting the data. Fever and convulsions can for example be symptoms of malaria, however, since we are not sure about this, we decided to indicate these as separate categories. To ensure that it is clear how we classified the use reports into categories, an overview was made listing all use reports that were grouped in each category (Appendix B).

A substantial part of the plant products collected at the market were dried, mouldy, chopped up or infested by insects or rodents. Very few bundles of plants contained flowers or fruits. To facilitate the identification of these materials, additional voucher materials were collected with the help of one of the market vendors in a disturbed/woodland area close to Mpingo village (Chalinze), where medicinal plants were harvested for the market. These, often fertile, vouchers were used as reference material to identify the sterile market samples.

2.3. Data analysis

Herbarium vouchers were identified in the herbarium of Naturalis Biodiversity Center (L) in Leiden, using relevant literature (Arbonnier, 2004; Flora of Tropical East Africa, 1952–2012; Fox, 1982; Van Wyk et al., 2009) and by comparison with herbarium specimens from eastern Africa. Plant species that were difficult to identify to family level were first identified by matching their vernacular names with scientific names, using literature to get identification leads (Abihudi, 2014;

Kaguongo, 2012; Kokwaro, 2009; Maundu et al., 1999; PROTA, 2015).

Several vouchers for which no species level identification was possible in the herbarium were analyzed using DNA barcoding. Plant products sold at the market belonging to the genera *Aloe* and *Vanilla* could not be exported to the Netherlands for identification as we initially lacked a CITES export permit for these vouchers. The *Aloe* products were therefore identified by means of DNA barcoding. DNA was extracted using an adapted Carlson Yoon extraction protocol (Carlson et al., 1991). Approximately 0.02 g sample was pulverized using a Mini-Beadbeater (BioSpec Products) in 2 ml tubes filled for ¼ part with silica beads. 70–100 µl water phase was transferred to a GFX gel band purification kit MicroSpinTM column with 500 µl capture buffer for further purification in accordance with the manufacturers manual (GE healthcare). The tDNA was dissolved in 70–100 µl 10 mM TrisHCl solution for downstream reactions and long-term storage. DNA of the nrITS, matK and rbcL regions was amplified for DNA barcoding making use of the primers and PCR protocols described in Sun et al. (1994) for nrITS, in Ford et al. (2009) and Dunning and Savolainen (2010) for matK and in Levin et al. (2003) Kress et al. (2009) for rbcL. The PCR reactions were performed in 96-well plates (200 µl) in a total reaction volume of 25 µl containing 15.25 µl ddH2O, 2.5 µl DreamTaq reaction buffer (Thermo Scientific), 0.5 µl 25 mM dNTP, .16 µl 2% acetylated Bovine Album Serum (Promega), 0.125 µl DreamTaq polymerase (Thermo Scientific) and 2.5 µl 5pmol of the forward and reverse primer. 10 µl PCR product was cleaned using 3 µl 8 × diluted ExoSAP-IT (Thermo Scientific) by running it on a PCR machine at 37 °C for 15 min and 80 °C for 15 min. The cleaned PCR products were sent for sequencing to Macrogen Europe (Amsterdam, The Netherlands), using EZ-SEQ labels and following their protocol for sample preparation. The obtained sequences were assembled using Geneious 10.1.3 (Ripma et al., 2014) and identified using BLAST (Altschul et al., 1990) as implemented on NCBI GenBank. In general a minimum percentage identity match of 97% was used for identification up to species level. In case of lower values or in case of multiple top hits with the same score a genus or family level identification was made instead.

After identification, the annual volume and value were calculated following the method described by Towns et al. (2014). In addition, the conservation and trade status of each species was checked using the International Union for Conservation of Nature Red List of Threatened Species (IUCN, 2017) and the Appendices of the Convention on International Trade of Endangered Species (CITES, 2017a). Nomenclature follows The Plant List (2013). To put the results of this study into perspective, the findings were compared with those of other market surveys in Tanzania (Abihudi, 2014; Augustino and Gillah, 2005; Kaguongo, 2012; McMillen, 2008; Otieno et al., 2015), Benin (Quiroz et al., 2014), Gabon (Towns et al., 2014), Ghana (Van Andel et al., 2012) and Kenya (Delbanco et al., 2017; Muriuki et al., 2012; Njoroge, 2012). Literature was consulted to find out whether any new uses were reported for the species sold at Kariakoo Market (Abihudi, 2014; Augustino and Gillah, 2005; Hedberg and Hedberg, 1982; Hedberg et al., 1983a, 1983b; Ibrahim and Ibrahim 1998; Kaguongo, 2012; Moshi et al., 2009, 2010, 2012).

During the market survey, different plant parts such as roots, bark, leaves, fruits and seeds were collected. This study focused exclusively on leaves, fruits and seeds that contained sufficient distinguishable characters to be identified using morphology. The identification of fragmented material, such as wood, bark, roots and powdered medicine, requires targeted approaches such as DNA barcoding (Ghorbani et al., 2017; Veldman et al., 2014) that are outside the scope of this specific paper but will be published elsewhere.

2.4. Ethics

We followed the International Society of Ethnobiology's Code of Ethics (2006) and complied with Tanzanian national regulations. This included obtaining research permits, plant export permits and gaining

Fig. 1. Kariakoo Market stall where powdered (jars on the left), fresh and dried leaves (foreground right) and bark, wood and roots (background right) is sold.

permission from the Bagamoyo and Kibaha district offices to collect plants from the wild. All informants were asked to read and sign a consent form in Swahili that explained the nature of our research (or read out to analphabetic informants). All informants received a small financial compensation for their participation in this study and voucher samples were purchased from their market stalls.

3. Results

3.1. Market characteristics

In the spring of 2015, Kariakoo Market consisted of 49 stalls where herbal medicine was sold. The market also had several stalls specialised in imported Arab medicine, stalls with only powdered plant material in glass and plastic jars, stalls with fresh plant material and stalls where both powdered and non-powdered herbal medicines were sold (Fig. 1). Besides plant material, animal products such as dried starfish, shells and powdered bones were offered for sale at some market stalls. The market is open every day of the week throughout the entire year, although individual market stalls may be closed during the weekend and holidays. Vendors of neighbouring market stalls sometimes stand in for each other to keep stalls running every day.

3.2. Floristic diversity and salient diseases

At the market we encountered 71 medicinal plant products belonging to 62–67 different species from at least 41 families. We were able to identify 45 plant products to species level, 20 products to genus level and four products only to family level. Two products were unidentifiable to family level. The total list of encountered plant products together with their vernacular names, languages, uses, volumes and value is made available as a supplementary data file that can be found in the online version of this article (Appendix A).

The vendors reported 285 different uses for their medicinal plants, belonging to sixteen use categories, of which the three major are: ritual purposes (e.g. to become attractive, to be loved and to protect against evil spirits or bad dreams), digestive disorders (e.g. belly ache and stomach ulcers) and women's health (e.g. infertility). Ailments mentioned for less than 2% of the medicinal plant species were categorised as other (Fig. 2). A more detailed table of the use categories and the salient diseases associated with the medicinal plants is made available as a Supplementary data file, which can be found in the online version of this article (Appendix B). Uses that were not previously reported in literature were found for the majority of the species sold at Kariakoo Market. Uses that were previously reported in literature are indicated
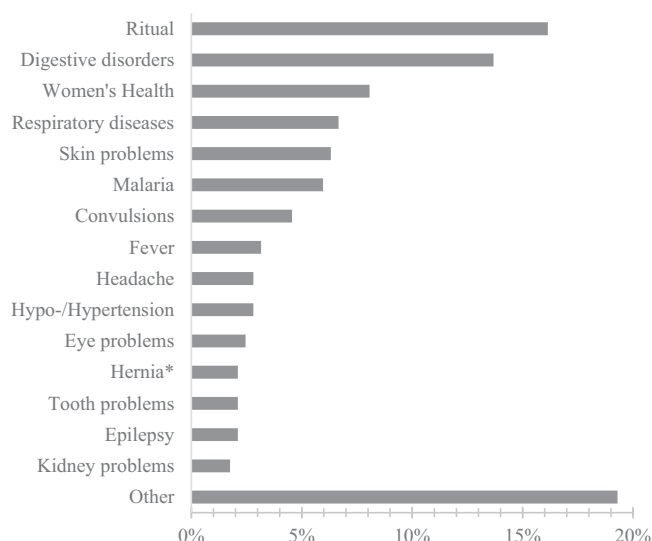
Fig. 2. Use categories for medicinal plant species sold at Kariakoo Market. This figure shows the percentage of uses reported by the vendors for each category. Vendors reported 285 different uses in total. *Not clear whether informants meant hernia or stomachache prevalent in male patients.

with the specific reference in Appendix A.

Most plant products were harvested from Pwani region (mainly from Bagamoyo and Kibaha district), while other popular harvest regions were Tanga, Morogoro and Arusha (Fig. 3). All harvesting locations reported by the vendors are mentioned in the online Supplementary data file (Appendix A). The majority of plant products was harvested by the market vendors themselves, particularly the products that could be collected from the surroundings of Dar es Salaam. However, some of the vendors bought products from people who harvested the products for them. Sometimes the vendors harvested together with someone who knew the area better and knew where the trees (especially the rare ones) could be found. Some vendors received large quantities of bags with fresh powders from middlemen. Other vendors received the material in non-powdered form and powdered it themselves in their storage units, which were not always located at the Kariakoo Market.

3.3. Frequencies and volumes

Plant species encountered on at least four of the 15 market stalls are listed in Table 1. *Suregada zanzibariensis* Baill. was sold at 10 stalls on the market, while *Cassytha filiformis* L. and *Pupalia lappacea* (L.) Juss. were encountered in almost half of the market stalls. The daily volumes and quantities of the most popular species are shown in Table 2. *Suregada zanzibariensis* and *Myrothamnus flabellifolia* Welw. were plant species sold in greatest bulk together with the highest amount of sales units per year. The annual volumes and quantities of the most popular species are shown in Table 3 together with their values. Frequency, amount of sales units and volume are shown, as occasionally sold species can make up a large part of the bulk volume. For example, the heavy fruits of *Kigelia africana* (Lam.) Benth. were only encountered in two stalls, but due to their heavy weight, they made up the greatest annual bulk and daily stock. In contrast, the light leaves of *S. zanzibariensis* were sold much more frequently but represented much less volume.

None of the most frequently encountered species in separate market stalls or species sold at the market in high quantities or volumes were listed on CITES Appendices or on the IUCN Red List of Threatened Species (CITES, 2017a; IUCN, 2017).

3.4. Annual sales and prices

The total annual value of non-woody and non-powdered herbal medicine sold at Kariakoo Market was estimated to be nearly 200,000 USD. Individual species sold at the market with the highest annual sales were *S. zanzibariensis*, *M. flabellifolia* and *Sclerocarya birrea* (A.Rich.) Hochst. (Table 3). The cheapest plant products per kg sold at the market were the heavy fruits of *Cocos nucifera* L. (0.98 USD/kg) and *K. africana* (1.21 USD/kg). The most expensive plant product sold at the market were the seeds of *Sorghum bicolor* (L.) Moench, sold at one market stall for 177 USD per kg and with an average price of 103 USD per kg. This *Sorghum* cultivar was not used as staple food (like the other cultivars sold for much lower prices at the food markets), but rather used in very small quantities, in elaborated rituals and in specific medicine for skin problems and stomach ulcers. The leaves of *Landolphia* sp. CP142, also used for stomach ulcers, were also quite expensive (109 USD/kg), probably because they had to be brought from a large distance (see Appendix A).

3.5. Threatened species

Even though many *Aloe* species are CITES-listed, the species that we encountered at the market, *Aloe vera* (L.) Burm.f., is not. All *Vanilla* products sold at the market are CITES-listed, considering that all species belonging to this family (Orchidaceae) are listed on the CITES Appendices since 1975 (CITES, 2017b). None of the identified species were listed on the IUCN Red List of Threatened species, but it is possible that some of the products that we were unable to identify are either IUCN- or CITES-listed.

4. Discussion

4.1. Importance and sustainability of the trade in herbal medicine

We estimated that at least 30 t (30,916 kg) of herbal medicine is sold in the form of dried and fresh leaves, fruits and seeds at Kariakoo Market, Dar es Salaam, each year producing an annual turnover of nearly 200,000 USD (calculated at 198,062 USD). However, these figures do not include the more heavy woody products (wood, bark and roots) and powdered herbal medicine. We used our rough data on these products and estimated that over 68 t of roots, wood and bark, and at least 100 t of powdered herbal medicine is sold annually. As a result, the total trade in medicinal plants at Kariakoo Market is much higher, and it provides subsistence income to vendors in the city, as well as to harvesters in the more rural areas.

The sustainability of plant harvesting depends on several factors, such as the plant part that is harvested (Schmidt et al., 2011) and the vegetation type from which the plant is harvested (Peters, 1996). Collection of leaves, fruits or seeds is considered to be more sustainable than the harvest of wood, roots or bark, which in most cases will lead to the death of a plant (Cunningham, 1993; Van Andel and Havinga, 2008). In addition, plants harvested from disturbed areas or weedy vegetation are more common and thus less susceptible to declining resources than rare plants harvested from vulnerable vegetation types in protected areas (Van Andel and Havinga, 2008). Plant species listed on the International Union for Conservation of Nature Red List (IUCN, 2017) and the Convention on International Trade of Endangered Species list (CITES, 2017a) cannot be harvested sustainable as their position on these lists already indicates their vulnerability, with the exception of species listed by the IUCN as "least concern". The only IUCN Red Listed or CITES Appendix-listed species on the market were *Vanilla* specimens, which were not sold in substantial amounts. However, the bulk of medicinal plant products sold at Kariakoo Market consisted of powdered and entire pieces of roots, wood and bark harvested from wild sources and possibly from protected areas. Therefore, further research, including DNA analysis of samples difficult to identify using

Fig. 3. Map of Tanzania. The grey areas show the most popular harvest regions according to plant vendors. Adapted from Wikimedia Commons (2015).

morphology alone, will focus on the determination of the potential threat of trade and commercialisation of medicinal plant resources in Tanzania.

4.2. Reference voucher collection

In order to provide reliable identifications for deteriorated market samples, additional voucher collection with market vendors was essential. Dar es Salaam is a multi-ethnic city, and under-differentiation (use of a single name for different species), or over-differentiation (use of several names for a single species) of vernacular names is common

(Otieno et al., 2015). As these local names are not documented sufficiently with vouchers specimens in the literature, voucher collection is essential in any ethnobotanical survey in this setting.

4.3. Prices and availability

It is often stated that prices of medicinal plant products depend on resource availability, plant accessibility and local demand (Cunningham, 2001). This did not seem to apply directly at Kariakoo Market, where prices of the products were determined by the weight of the sales units (i.e. the most expensive plant products were sold in small

Table 1
Most frequently sold plant products (> 25% of the stalls).

Species	Product	Number of stalls	Frequency (%)
Suregada zanzibariensis	Leaves	10	67
Cassytha filiformis	Whole plant	7	47
Pupalia lappacea	Fruits	7	47
Ehretia amoena	Leaves	6	40
Solanum sp. (CP50, CP72)	Leaves	6	40
Uvaria sofa	Leaves	6	40
Myrothamnus flabellifolia	Leaves	5	33
Abrus precatorius	Leaves	4	27
Diospyros fischeri	Leaves	4	27
Ocimum lamiifolium	Leaves	4	27
Sclerocarya birrea	Leaves	4	27

Table 2
Plant species available in greatest bulk and with the highest amount of sales units in present daily stock.

Species	Product	Daily market stock (units)	Total weight daily stock (kg)
Suregada zanzibariensis	Leaves, seeds	964	20
Myrothamnus flabellifolia	Leaves	460	43
Pupalia lappacea	Fruits	287	46
Ehretia amoena	Leaves	230	24
Solanum sp. (CP50, CP72)	Leaves	226	19
Uvaria sofa	Leaves	221	14
Cissus rotundifolia	Leaves	216	29
Abrus precatorius	Leaves	216	12
Sclerocarya birrea	Leaves	213	31
Lannea schweinfurthii	Leaves	200	18
Ocimum americanum	Leaves	151	11
Solanum incanum	Fruits	125	1
Diospyros fischeri	Leaves	97	24
Chenopodium opulifolium	Leaves, seeds	76	4
Murraya koenigii	Leaves	50	4
Cassia afrofistula	Leaves	29	5
Crossopteryx febrifuga	Leaves	28	4
Kigelia africana	Fruits	22	89

volumes and the cheapest plant products were sold in large volumes). However, some of de vendors mentioned that prices increased for plant products that were more difficult to obtain (e.g. the vendors had to travel a great distance) or when they thought the buyer or patient was rich. This was also the case in Tanga, where factors such as the perceived power of the medicinal plant product, the relationship of the consumer to the vendor, how busy the vendor is, and the perceived

wealth of the consumer mainly determined the price. Demand and availability did not influence the price in most cases (McMillen, 2008).

4.4. Comparison with other studies on medicinal plant markets

There are both similarities and differences between our research and previous studies on the medicinal plant markets in Tanzania (Abihudi, 2014; Augustino and Gillah, 2005; Kaguongo, 2012; McMillen, 2008, 2012; Otieno et al., 2015). In our study, the traded medicinal plants at Kariakoo Market were mostly used for ritual purposes, digestive disorders and women's health. A pilot market study by Abihudi (2014) reported the most commonly treated diseases in Dar es Salaam to be impotence, hernia, malaria and stroke, whereas in Tanga the most salient diseases treated with herbal medicine were colic, malaria and food allergies. The most used medicinal plants to treat those diseases were *Zanthoxylum chalybeum* Engl., *Zanha africana* (Radlk.) Exell, *Hymenaea verrucosa* Gaertn. and *Cassia abbreviata* Oliv. According to Abihudi (2014), only ten percent of the conditions mentioned by the vendors were related with psycho-spiritual conditions, a much lower percentage than what we found. None of the most frequently mentioned species listed by Abihudi (2014) were found at Kariakoo Market. Augustino and Gillah (2005) listed women's health and hernia as most important use category in the Morogoro district, and women's health and abdominal pains in the Iringa district. They did not report any plants used for ritual purposes.

Kaguongo (2012) found that *C. abbreviata*, *Z. chalybeum* and *Z. usambarense* (Engl.) Kokwaro were the most mentioned species. A later study by Otieno et al. (2015) focusing on vernacular names used for herbal medicine reported 19 species that were mentioned by 10 or more herbalists. The overlap between these 19 most cited species and the most frequently sold species recorded here (Table 1) is 36% at genus level; the species available in greatest bulk (Table 2) is 28%; and with the species sold in greatest bulk (Table 3) is 21%. A possible explanation for the difference in medicinal species and use categories between our market survey and the previous studies in Tanzania, could be that our study exclusively focused on leaves, fruits and seeds, while other studies also included roots and bark (Abihudi, 2014; Kaguongo, 2012; Otieno et al., 2015).

Medicinal plants sold at markets in Benin (Quiroz et al., 2014), Gabon (Towns et al., 2014) and Ghana (Van Andel et al., 2012) were mainly used for women's health and ritual purposes, which are also major important categories in our study. However, very few of the popular plant species sold at these West and Central African markets were found during our survey. The only species that Kariakoo shared with the markets in Benin were *Abrus precatorius* L., *Cassytha filiformis* and *Ocimum americanum* L., while in Ghana the markets also sold *S.*

Table 3
Plant species sold in greatest bulk and/or with the highest amount of sales units per year.

Species	Product	Annual sale (units)[a]	Annual volume (kg)	Average value per kg (USD)	Annual sale (USD)
Suregada zanzibariensis	Leaves, seeds	> 63851	> 4251	5.38[b]	> 31687
Myrothamnus flabellifolia	Leaves	25905	3078	16.97	52239
Sclerocarya birrea	Leaves	17832	2462	3.84	9458
Abrus precatorius	Leaves	17380	1000	9.17	9171
Solanum sp. (CP50, CP72)	Leaves	> 17049	> 1404	6.07	> 8519
Cissus rotundifolia	Leaves	16620	2210	3.69	8151
Lannea schweinfurthii	Leaves	15600	1388	5.51	7651
Pupalia lappacea	Fruit	> 14880	> 2344	4.43	> 10387
Uvaria sofa	Leaves	> 12760	> 797	8.39	> 6685
Diospyros fischeri	Leaves	> 5996	> 1432	2.10	> 3000
Ocimum americanum	Leaves	4875	309	10.72	3310
Ehretia amoena	Leaves	3813	339	7.22	2445
Kigelia africana	Fruit	1800	7310	1.21	8828

[a] Greater than symbols are used when we were unable to measure or weigh all stock.
[b] The average value per kg for *S. zanzibariensis* was calculated excluding one product (with an annual value of 8000 USD), because we were unable to weigh this product.

bicolor and *O. americanum*. None of the species traded at Kariakoo Market were encountered at the market in Gabon. The large difference in floristic composition between the Kariakoo Market and markets in West and Central Africa may be caused by the strong floristic and cultural differences between West, Central and East Africa.

None of the species traded in northern Kenya were sold at Kariakoo Market either (Delbanco et al., 2017). The only species that Kariakoo shared with other surveyed markets in Kenya were *Solanum incanum* L. (Njoroge, 2012) and *K. africana* (Muriuki et al., 2012). Medicinal plants traded in northern Kenya were mainly used for respiratory diseases, bone and joint pain, stomachache and women's health. These uses, except for bone and joint pain, were also important in our study. Although the vegetation of Kenya and Tanzania share more species, the little overlap in floristic composition between Kariakoo market and Kenyan markets may be explained by the fact that our study exclusively focused on leaves, fruits and seeds, whereas the other studies also included roots and bark.

The average price per kg of herbal medicine in Tanzania (5.8 USD/kg) was much lower than in the West African markets. In Gabon, the average price for medicinal plants was the highest with 56 USD/kg, followed by Benin (21 USD/kg) and Ghana (8.2 USD/kg). Just like in Tanzania, the cheapest plant product sold at the market in Ghana was *K. africana*. In the other West African markets, the most expensive plant products were also ritual items sold in small volumes, such as the seeds of *Operculina macrocarpa* (L.) Urb. (34–220 USD/kg) in Benin or inflorescences of *Streptogyna crinita* P.Beauv. (1869 USD/kg) in Gabon. Even though the cheapest and most expensive plant products sold at the West African and Tanzanian markets differ from each other, all vendors sold the most expensive plant products in small volumes and the cheapest plant products in large volumes. In northern Kenya, the most frequently traded species were priced between 2 and 9 USD/kg. The most expensive product were the seeds of *Lepidium sativum* L., which were used for bone and joint pain, fever, respiratory diseases and stomachache (Delbanco et al., 2017). The other studies in Kenya (Muriuki et al., 2012; Njoroge, 2012) did not report any prices for herbal medicine.

5. Conclusion

Our study shows that a large diversity of wild-harvested plant species is traded as medicinal products in Tanzania, including species listed on CITES Appendices. The estimated 30 t of fresh and dried leaves, fruits and seeds sold at Kariakoo Market in 2015 provide a substantial source of income and traditional health care for the inhabitants and play an important role in spiritual wellbeing, women's health and in treating digestive disorders. When roots, wood, bark and powdered medicinal products are also taken into account, the estimated annual turnover of the medicinal plant market would be even higher (almost 200 t annually). Therefore, analyzing the trade in these products is necessary to give a more complete overview of the medicinal plant trade at Kariakoo Market. In addition, identifying and monitoring temporal changes in availability per season and from year to year will reveal which species are most affected by this trade, and help relevant authorities in Tanzania find alternative sources of income for dependent stakeholders and initiate targeted efforts to protect threatened plant species.

Acknowledgements

Funding

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jep.2018.04.039.

References

Abihudi, S., 2014. Documentation and identification of medicinal plants trade in Tanzania by means of DNA barcoding (MSc Thesis). Muhimbili University of Health and Allied Sciences, Dar-es-Salaam.

Altschul, S.F., Gish, W., Miller, W., Myers, E.W., Lipman, D.J., 1990. Basic local alignment search tool. J. Mol. Biol. 215 (3), 403–410.

Arbonnier, M., 2004. Trees, Shrubs and Lianas of West African Dry Zones. Margraf Publishers GmbH, Weikersheim.

Augustino, S., Gillah, P.R., 2005. Medicinal plants in urban districts of Tanzania: plants, gender roles and sustainable use. Int. For. Rev. 7, 44–58.

Carlson, J.E., Tulsieram, L.K., Glaubitz, J.C., Luk, V.W.K., Kauffeldt, C., Rutledge, R., 1991. Segregation of random amplified DNA markers in F1 progeny of conifers. Theor. Appl. Genet. 83, 194–200.

CIA, 2017. Central Intelligence Agency. The world factbook. Tanzania. ⟨https://www.cia.gov/library/publications/resources/the-world-factbook/geos/print_tz.html⟩ (Accessed 24 September 2017).

CITES, 2017a. Convention on International Trade in Endangered Species of Wild Fauna and Flora. ⟨http://checklist.cites.org/⟩ (Accessed 24 September 2017).

CITES, 2017b. The CITES species. ⟨https://cites.org/eng/disc/species.php⟩ (Accessed 24 September 2017).

Cunningham, A.B., 1993. African medicinal plants: setting priorities at the interface between conservation and primary health care. People and Plants working paper 1. UNESCO, Paris.

Cunningham, A.B., 2001. Applied Ethnobotany: People, Wild Plant Use and Conservation. Earthscan, London.

De Boer, H.J., Kool, A., Broberg, A., Mziray, W., Hedberg, I., Levenfors, J., 2005. Antifungal and anti-bacterial activity of some herbal remedies from Tanzania. J. Ethnopharmacol. 96, 461–469.

De Silva, T., 1997. Industrial utilization of medicinal plants in developing countries. In: Bodeker, G., Bhat, K.K.S., Burley, J.P.V. (Eds.), Medicinal Plants for Forest Conservation and Health Care. FAO Publishing, Rome, pp. 116–129.

Delbanco, A.S., Burgess, N.D., Cuni-Sanchez, A., 2017. Medicinal plant trade in Northern Kenya: economic importance, uses and origin. Econ. Bot. 71 (1), 13–31.

Dunning, L.T., Savolainen, V., 2010. Broad-scale amplification of matK for DNA barcoding plants, a technical note. Bot. J. Linn. Soc. 164, 1–9.

FAO, 2008. Food and Agriculture Organization. Trade in Medicinal Plants. Raw Materials, Tropical and Horticultural Products Service Commodities and Trade Division Economic and Social Department. FAO, Rome.

Flora of Tropical East Africa, 1952. In: Beentje, H.J. (Ed.), Flora of Tropical EastAfrica. Kew Publishing, Richmond.

Ford, C.S., Ayres, K.L., Haider, N., Toomey, N., Van-Alpen-Stohl, J., Kelly, L., Wikstrom, N., Hollingsworth, P.M., Joel-Duff, R., Hoot, S.B., Cowan, R.S., Chase, M.W., Wilkinson, M.J., 2009. Selection of candidate DNA barcoding regions for use on land plants. Bot. J. Linn. Soc. 159, 1–11.

Fox, F.W., 1982. Food from the Veld: Edible Wild Plants of SouthernAfrica: Botanically Identified and Described. FAO Publishing, Peaslake.

Ghorbani, A., Saeedi, Y., De Boer, H.J., 2017. Unidentifiable by morphology: dna barcoding of plant material in local markets in Iran. PloS One 12 (4), e0175722.

Hamilton, A.C., 2004. Medicinal Plants, Conservation and Livelihoods. Biodivers. Conserv. 13, 1477–1517.

Hedberg, I., Hedberg, O., 1982. Inventory of plants used in traditional medicine in Tanzania. I. Plants of the families Acanthaceae-Cucurbitaceae. J. Ethnopharmacol. 6, 29–60.

Hedberg, I., Hedberg, O., Madati, P.F., Mshigeni, K.E., Mshiu, E.N., Samuelsson, G., 1983a. Inventory of plants used in traditional medicine in Tanzania. II. Plants of the families Dilleniaceae-Opiliaceae. J. Ethnopharmacol. 9, 105–128.

Hedberg, I., Hedberg, O., Madati, P.F., Mshigeni, K.E., Mshiu, E.N., Samuelsson, G., 1983b. Inventory of plants used in traditional medicine in Tanzania. Part III. Plants of the familie Papilionaceae-Vitaceae. J. Ethnopharmacol. 9, 237–260.

International Society of Ethnobiology Code of Ethics, 2006. ⟨http://ethnobiology.net/code-of-ethics/⟩ (Accessed 18 July 2015).

IUCN, 2017. International Union for the Conservation of Nature Red List of Threatened Species. ⟨http://www.iucnredlist.org/⟩ (Accessed 24 September 2017).

Kaguongo, M., 2012. Conservation of Wild-harvested Medicinal Plant Species in Tanzania: Chain and Consequence of Commercial Trade on Medicinal Plant Species (MSc Thesis). Uppsala University, Uppsala.

Kokwaro, J.O., 2009. Medicinal Plants of East Africa. University of Nairobi Press, Nairobi.

Kool, A., De Boer, H.J., Rydberg, A., Kruger, A., Abbad, A., Björk, L., Martin, G., 2012. Molecular Identification of Commercialized Medicinal Plants in Southern Morocco. PLoS One 7 (6), e39459.

Kress, W.J., et al., Erickson, D.L., Jones, F.A., Swenson, N.G., Perez, R., 2009. Plant DNA barcodes and a community phylogeny of a tropical forest dynamics plot in Panama. Proc. Natl. Acad. Sci. USA 106, 18621–18626.

Levin, R.A., Wagner, W.L., Hoch, P.C., Nepokroeff, M., Pires, J.C., Zimmer, E.A., Sytsma, K.J., 2003. Family-level relationships of onagraceae based on chloroplast rbcL and ndhF data. Am. J. Bot. 90 (1), 107–115.

Marshall, N.T., 1998. Searching for a Cure: Conservation of Medicinal Wildlife Resources in East and Southern Africa. Traffic International, Cambridge.

Martin, G.J., 2004. Ethnobotany: a Methods Manual. Earthscan, London.

Mati, E., De Boer, H.J., 2011. Trade and Commercialization of Herbal Medicine in the Qaysari Market, Kurdish Autonomous Region, Iraq. J. Ethnopharmacol. 133, 490–510.

Maundu, P.M., Ngugi, G.W., Kabuye, C.H.S., 1999. Traditional Food Plants of Kenya, Kenya Resource Centre for Indigenous Knowledge (KENRIK), Nairobi.

McMillen, H.J., 2008. Conserving the Roots of Trade: Local Ecological Knowledge of Ethnomedicines from Tanga, Tanzania Markets (Ph.D Thesis). University of Hawai'i, Manoa.

McMillen, H.J., 2012. Ethnobotanical knowledge transmission and evolution: the Case of medicinal markets in Tanga, Tanzania. Econ. Bot. 66, 121–131.

Moshi, J.M., Otieno, D.F., Mbabazi, P.K., Weisheit, A., 2009. The ethnomedicine of the Haya people of Bugabo ward, Kagera Region, north western Tanzania. J. Ethnobiol. Ethnomed. 5, 24.

Moshi, J.M., Otieno, D.F., Mbabazi, P.K., Weisheit, A., 2010. Ethnomedicine of the Kagera Region, north western Tanzania. Part 2: the medicinal plants used in Katoro Ward, Bukoba District. J. Ethnobiol. Ethnomed. 6, 19.

Moshi, J.M., Otieno, D.F., Weisheit, A., 2012. Ethnomedicine of the Kagera Region, north western Tanzania. Part 3: plants used in traditional medicine in Kikuku village, Mulebe District. J. Ethnobiol. Ethnomed. 8, 14.

Muriuki, J., Franzel, S., Mowo, J., Kariuki, P., Jamnadass, R., 2012. Formalisation of local herbal product markets has potential to stimulate cultivation of medicinal plants by smallholder farmers in Kenya. For. Trees Livelihoods 21, 114–127.

Njoroge, G.N., 2012. Traditional medicinal plants in two urban areas in Kenya (Thika and Nairobi): diversity of traded species and conservation concerns. Ethnobot. Res. Appl. 10, 329–338.

Otieno, J., Abihudi, S., Veldman, S., Nahashon, M., Van Andel, T.R., De Boer, H.J., 2015. Vernacular dominance in folk taxonomy: a case study of ethnospecies in medicinal plant trade in Tanzania. J. Ethnobiol. Ethnomed. 11, 10.

Peters, C., 1996. The ecology and management of non-timber resources. World Bank Technical Paper 322, Washington, DC.

PROTA, 2015. Plant Resources of Tropical Africa. ⟨http://www.prota4u.info/⟩ (Accessed 18 July 2015).

Quiroz, D., Towns, A., Legba, S.I., Swier, J., Brière, S., Sosef, M., Van Andel, T.R., 2014. Quantifying the domestic market in herbal medicine in Benin, West Africa. J. Ethnopharmacol. 151, 1100–1108.

Ripma, L.A., Simpson, M.G., Hasenstab-Lehman, K., 2014. Geneious! Simplified genome skimming methods for phylogenetic systematic studies: a case study in *Oreocarya* (Boraginaceae). Appl. Plant Sci. 2 (n/a), 1400062. http://dx.doi.org/10.3732/apps.1400062.

Schippmann, U., Leaman, D.J., Cunningham, A.B., 2002. Impact of Cultivation and Gathering of Medicinal Plants on Biodiversity: Global Trends and Issues, in: Biodiversity and the Ecosystem Approach in Agriculture, Forestry and Fisheries. FAO, Rome.

Schmidt, I.B., Mandle, L., Ticktin, T., Gaoue, O.G., 2011. What do matrix population models reveal about the sustainability of non-timber forest product harvest? J. Appl. Ecol. 48, 815–826. http://dx.doi.org/10.1111/j.1365-2664.2011.01999.x.

Srivastava, R., 2000. Studying the Information Needs of Medicinal Plant Stakeholders in Europe, in: Nash, S. (Ed.), Traffic Dispatches. Traffic Europe, Brussels, 15, 5.

Sun, Y., Skinner, D.Z., Liang, G.H., Hulbert, S.H., 1994. Phylogenetic analysis of *Sorghum* and related taxa using internal transcribed spacers of nuclear ribosomal DNA. Theor. Appl. Genet. 89, 26–32.

The Plant List, 2013. Version 1.1. A working list of all plant species. ⟨www.theplantlist.org⟩.

Towns, A.M., Quiroz, D., Guinee, L., De Boer, H.J., Van Andel, T.R., 2014. Volume, value and floristic diversity of Gabon's medicinal plant markets. J. Ethnopharmacol. 155, 1–10.

Van Andel, T., Havinga, R., 2008. Sustainability aspects of commercial medicinal plant harvesting in Suriname. For. Ecol. Manag. 256, 1540–7821545. http://dx.doi.org/10.1016/j.foreco.2008.06.031.

Van Andel, T.R., Myren, B., Van Onselen, S., 2012. Ghana's herbal market. J. Ethnopharmacol. 140, 368–378.

Van Wyk, B.E., Van Oudtshoorn, B., Gericke, N., 2009. Medicinal Plants of South Africa. Briza Publications, Pretoria.

Veldman, S., Gravendeel, B., Otieno, J.N., Lammers, Y., Duijm, E., Nieman, A., Bytebier, B., Ngugi, G., Martos, F., Van Andel, T.R., De Boer, H.J., 2017. High-throughput sequencing of African chikanda cake highlights conservation challenges in orchids. Biodivers. Conserv. 26, 2029–2046.

Veldman, S., Otieno, J., Gravendeel, B., Van Andel, T.R., De Boer, H.J., 2014. Conservation of endangered wild harvested medicinal plants: use of DNA barcoding. In: Gurib-Fakim, A. (Ed.), Novel Plant Bioresources: Applications in Food, Medicine and Cosmetics. John Wiley & Sons, Ltd, Chichester, UK.

Weckerle, C.S., De Boer, H.J., Puri, R.K., Van Andel, T.R., Bussmann, R.W., Leonti, M., 2017. Recommended standards for conducting and reporting ethnopharmacological field studies. J. Ethnopharmacol. 210, 125–132.

Wikimedia Commons, 2015. Tanzania map. ⟨https://commons.wikimedia.org/wiki/File:Tanzania_map_Mercator.svg⟩ (Accessed on 9 October 2017).