

Commercialization of *Aframomum* spp. in Africa: a Systematic Review of Literature and Supporting Botanical Vouchers

RONJA HERMIENE MARIA KNIPPERS^{*,1}, SANDRINE GALLOIS², AND TINDE VAN ANDEL^{*,3,4,5}

¹Utrecht University, Utrecht, The Netherlands

²Faculty of Archaeology, Leiden University, Leiden, The Netherlands

³Biosystematics group, Wageningen University, Wageningen, The Netherlands

⁴Naturalis Biodiversity Center, Leiden, The Netherlands

⁵Institute for Biology, Leiden University, Leiden, The Netherlands

*Corresponding author; e-mail: tinde.vanandel@naturalis.nl

Aframomum (Zingiberaceae) is a genus of plants native to tropical Africa that are sold on African markets as spices and traditional medicine. Not all species of *Aframomum* are equally abundant or widespread, and no overview exists of the specific species traded or the quality of the species identifications in publications referencing the sale of *Aframomum*. Through a systematic literature review, we show that 14 species of *Aframomum* are sold in 15 African countries. The majority of the studies were done in Nigeria and Cameroon and *A. melegueta* was the most frequently reported species in trade. *A. kaysarianum* was the only commercialized species with confirmed conservation issues. Our literature review shows extensive knowledge gaps regarding the commercialization of *Aframomum* in Africa. Most studies did not include herbarium vouchers, or only used market-sourced plant material, which impedes the possibilities for species verifications. Additionally, most East African countries were devoid of relevant research. These gaps can be bridged by future research in East Africa and voucher collection from living material. Information on the conservation status of traded *Aframomum* species can be obtained by population studies on wild resources and documenting local domestication efforts, as the cultivation of marketed species tends to relieve the pressure from wild resources.

Key Words: Grains of paradise, Herbarium specimens, Melegueta pepper, NTFP, Trade, Wild edible plants.

Introduction

Aframomum K.Schum. is a genus of 62 plant species in the family of Zingiberaceae that occurs in the rainforests and savanna areas of tropical Africa and Madagascar (Fischer et al. 2017; Harris and Wortley 2018). Wild *Aframomum* generally occurs in the undergrowth and along the edges of tropical forest. It is an herbaceous plant that grows to approximately 1.5 m in height (Harris and

Wortley 2018). The different species vary widely in their flower display, but all *Aframomum* species produce flask-like pods that contain aromatic, peppery seeds (Fig. 1). Species from this genus have been an important source of food and herbal medicine since antiquity. The seeds of *Aframomum*, also known as alligator pepper, melegueta pepper or grains of paradise, have been exported to Europe since the thirteenth century, where they were sold as condiment (Van Harten 1966). The extent of this trade becomes evident from maps of Africa from the 17th and eighteenth century, on which Sierra Leone, Liberia and parts of Ivory Coast are often indicated as “Grain Coast”, “Pepper Coast” or “Melegueta Coast”, referring to the grains of

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Fig. 1. Useful plant parts in the genus *Aframomum*: **A)** Fruit of cultivated *Aframomum melegueta* individual (Suriname); **B)** Fruits of *Aframomum daniellii*, wild individual, Cameroon; **C)** Open fruits of *Aframomum subsericeum*, wild individual, Cameroon; **D)** Leaves of *Aframomum subsericeum*, wild individual, Cameroon. Pictures: Tinde van Anandel (A), Sandrine Gallois (B, C, D).

paradise (Hepper 1967; Moll 1729). At present, seeds from *Aframomum* spp. have largely lost their popularity as a spice in Europe (Eyob et al. 2009), although the fruits and seeds can still be found in African food shops in migrant neighbourhoods in Paris and Brussels (Tabuna 1999; Van Anandel and Fundiko 2016). In their native range around the African equator, however, many parts of *Aframomum* spp. are available on markets and their sale has been asserted as an important local income

generator (Ingram et al. 2010; Menbere et al. 2019; Ngansop et al. 2019). The dried fruits and seeds are generally sold as a spice, while many other parts of the plants, such as the rhizomes and leaves, are used as traditional medicine for both humans and cattle (Quattrocchi 2012). Leaves of *Aframomum* spp. are also used on markets as packaging material (Ingram 2016).

The plant material of *Aframomum* spp. offered for sale in African markets is sourced from

both wild and cultivated plants. Four species of *Aframomum* are reported to be cultivated: *A. melegueta* (Roscoe) M. Schum., *A. corrorima* (A.-Braun) P.C.M. Jansen, *A. exscapum* (Sims) Hepper and *A. angustifolium* K.Schum. (FEWS NET n.d.; Furo et al. 2020; Harris and Wortley 2018; Jansen 1981). *A. melegueta*, which occurs throughout Africa's equatorial West coast, is grown as a domesticated crop in large quantities in Ghana, both as a cash crop and for subsistence use (Harris and Wortley 2018; Lock et al. 1977). *A. corrorima* is widely cultivated in Ethiopia, which alongside Kenya, Uganda, Burundi and Tanzania makes up the native range of this species (Harris and Wortley 2018). *A. exscapum* is likewise mentioned as a cultivated species by Harris and Wortley (2018), although no region of cultivation is mentioned. Lastly, *A. angustifolium* is cultivated in Ethiopia (Furo et al. 2020). Commercialized material from these species can thus be harvested from cultivated individuals, but also from wild resources, as these species still occur in the wild in the same areas. All other species sold on African markets are sourced from natural populations from tropical rainforests or savannas. In spite of the various cultivation efforts, *Aframomum* products are often regarded as non-timber forest products (NTFPs) or *produits forestiers non ligneux* (PFNL) in French. NTFPs are defined as wild products harvested from forests or other natural or disturbed vegetation types, except for industrial timber (Ticktin 2004).

Wild *Aframomum* species are not all equally abundant and widespread. *A. angustifolium* for example is a common sight along forest edges and roadsides from Ivory Coast to Madagascar (Crook et al. 2019; Harris and Wortley 2018). Other species have a very small range, such as *A. kodmin* D.J. Harris & Wortley, or are declining in abundance due to anthropogenic threats, as is the case for *A. laxiflorum* Loes. ex. Lock (Harris et al. 2019a; Harris et al. 2019b). According to the IUCN Red List, the conservation status of *Aframomum* species ranges from Least Concern (39 species) to Vulnerable (seven species) and Endangered (ten species), alongside five species that are considered Data Deficient (IUCN 2020). The population decline of *Aframomum* species that are only found in the wild may be problematic for people who collect these species as NTFPs, but also for the survival of local wildlife. *Aframomum* fruits and leaves are an important food source for both gorillas and chimpanzees (Calvert 1985; Wrangham et al. 1994). Indeed, the clearing of vegetation along logging roads in the

Central African rainforest by timber companies has already led to a decline in *Aframomum* species along forest edges and the spread of the invasive species *Chromolaena odorata* (L.) R.M.King & H.Rob., which is not eaten by large primates (Van der Hoeven 2007).

Given the importance of *Aframomum* for both humans and wildlife, the variations in conservation status within the genus and the fact that some species are harvested from the wild while others are cultivated, it is important to assess which species of *Aframomum* are actually sold in Africa. Understanding whether the trade in *Aframomum* depends on cultivated plants, abundant wild species, or on species that are threatened or restricted in their range will help to prioritize species for sustainability assessments.

While evaluating any conservation concerns, it is important to assess to which extent the identifications of commercially harvested *Aframomum* species are based on botanical vouchers. This is essential because *Aframomum* has been frequently misidentified in herbaria (Goodwin et al. 2015). Investigating whether or not the species identifications are based on herbarium specimens will show what portion of the identifications can be verified through morphological analysis or through DNA barcoding. Many vouchers have already been revised for the recently published monograph of *Aframomum* by Harris and Wortley (2018), who combine taxonomic data with reports on range and abundance, notes on ecology and ethnobotanical practices. The authors also revised the Red List conservation status for every *Aframomum* species. The revision by Harris and Wortley (2018) has made it considerably easier to compare mentions of trade and conservation issues, thereby making this review possible.

Through a systematic literature review, we aim to assess which species of *Aframomum* are reported as being sold on African markets, in which countries these sales occur, and to what extent these observations are based on herbarium vouchers. This literature review explores whether the trade in *Aframomum* species depends on wild NTFPs or on cultivated individuals, thereby examining if the commercialization might pose a risk to the conservation of the species. Finally, we identify where the largest knowledge gaps occur and what can be done to bridge those gaps. This literature review is the first step towards a complete overview of the trade in *Aframomum* spp. in Africa and possible associated conservation concerns.

Materials and Methods

Aframomum occurs in tropical Africa from Senegal to Madagascar. In this review, we considered the sale of *Aframomum* in all African countries, both inside and outside the natural range of *Aframomum*. To retrieve literature mentioning the sale of *Aframomum* spp. in Africa we used four data sources: Web of Science (WOS), SCOPUS, Google Scholar and Prelude. We planned to search for literature through WOS, SCOPUS and Prelude only. However, after comparing the resulting publications with the hits for the aforementioned search term in Google Scholar, it became obvious that they differed substantially. We therefore felt the need to supplement our systematic literature review with a search into Google Scholar. Only the first 40 articles were assessed, as the relevance of the hits sharply declined after that point. For WOS and SCOPUS, we used the following search query: (“Aframomum” OR “Afromomum” OR “alligator pepper” OR “melegueta” OR “maniguette” OR “malagueta” OR “grains of paradise” OR “grains-of-paradise” OR “graine de paradis” OR “poivre de Guinée” OR “false cardamom” OR “korarima”) AND (“NTFP” OR “PFNL” OR “market*” OR “ethnobotan*” OR “trade” OR “spice”).

This query was used to search the title, keywords and abstract of the documents available in these databases. This included peer-reviewed articles, conference publications, reports and books. We did not include restraints concerning language or year of publication. We purposely also used the incorrect name *Afromomum*, as the genus is often misspelled in publications. A modified search query was used in Google Scholar due to its 128-character limit for search terms. The search query was as follows: “*Aframomum*” AND (“NTFP” OR “PFNL”) AND “Africa”. No other constraints were applied to this search.

The final database that we utilized in this review was the Prelude database (Baerts-Lehmann and Lehmann n.d.), which contains published and unpublished articles and reports about the use of medicinal plants in Africa. The database can be searched by plant name, country, medical symptom or reference. We searched Prelude using the search term “*Aframomum*”. No constraints regarding language or year of publication were implemented.

All unique hits that were generated using these four search engines were assessed in two rounds. In

round one, we searched for evidence of trade of any *Aframomum* species in any African country in the title, abstract, keywords, and in the main text if necessary. If there was a direct mention of sale of any species of *Aframomum* in Africa, or if the study was based on interviews where herb sellers represented the majority of the respondents, the study was passed on to round two. Publications that never identified any *Aframomum* material to species level were discarded. Likewise, publications of which the full text was not available through the internet (using the access portals of Utrecht University, Naturalis Biodiversity Center, Wageningen University and the University of Amsterdam) were rejected. In round two, we scanned the entire publications for data on sale of *Aframomum* spp. in Africa. For every study, we recorded the species name, country of sale (including market location if disclosed), presence of voucher material (including the herbarium where the voucher was deposited and the voucher number), the origin of the collected material (from living plant material or from a market), whether the material was from a wild or cultivated plant and whether the product sold on the market was called a NTFP (or PFNL). This last observation was included to identify possible instances of confusion for species that are both collected from the wild and cultivated. Additionally, we checked if the country of sale was within the natural range of the species in question according to Harris and Wortley (2018). Afterwards, we matched all species mentioned as commercialized to their IUCN Red List status and population trend, and documented geographical range and current threats (IUCN 2020). This was coupled with information on cultivation in order to be able to assess possible conservation issues for any of the *Aframomum* species (e.g., habitat loss, overharvesting), with the idea that the cultivation of marketable forest products relieves the pressure from wild resources (Ticktin 2004).

We visualized the results of this systematic literature review in two maps. The first map was made in R v3.6.3, with the packages “ggplot2” and “rnatuarearth”. We used the coordinates of 51 *Aframomum* species that were listed as human observations or preserved specimens by the Global Biodiversity Information Facility (www.gbif.org). The second map was assembled using Photopea (<http://www.photopea.com>). The pie chart was drawn up in Excel and bar plots were also made in R v3.6.3, using the package “ggplot2”.

Results

SOURCED PUBLICATIONS AND SELECTION

In total, 280 unique peer-reviewed articles, books and (conference) reports were generated through the searches in WOS, SCOPUS, Google Scholar and Prelude (Table 1). Some studies arose through multiple search engines, hence the number of publications generated through the four engines is higher than the number of combined unique publications from all four search engines.

The full text of 50 out of the total of 280 articles in round one could not be accessed through the internet or via the library staff of the four Dutch research institutes. These publications were therefore not included in our analysis. From the remaining 230 publications, 70 studies were retrieved that yielded the data used in our analysis. A complete overview of all data extracted from these references can be found in Appendix S.1. The remaining 160 publications were discarded because they did not mention the sale of at least one species of *Aframomum* in Africa.

AVAILABILITY AND QUALITY OF VOUCHER MATERIAL AND COMMERCIALIZATION LOCALITY

Only 51 of the 62 *Aframomum* species reported by Harris and Wortley (2018) were listed in GBIF as herbarium vouchers and/or human observation (Fig. 2). All *Aframomum* species occur in the wild, but four of them are also cultivated.

Among the 70 selected publications, only 28 reported that they had produced voucher material that was deposited at an herbarium. Twelve studies collected their plant specimens from living material (either from wild or from cultivated individuals), 11 studies collected their specimens from a market, one study collected vouchers from both living material and a market and four studies did not specify where

they obtained their voucher material (Fig. 3). Vouchers made from market material included whatever parts of the plants were for sale, e.g., dried fruits or seeds. Of the 28 publications that documented the creation of herbarium vouchers, seven did not report voucher numbers. The remaining 42 articles did not produce vouchers of any sort.

The 70 publications that were reviewed in this study yielded 15 countries with documented sales of at least one species of *Aframomum*: Angola, Benin, Burundi, Cameroon, Congo-Brazzaville, Democratic Republic of the Congo, Egypt, Equatorial Guinea, Ethiopia, Gabon, Ghana, Ivory Coast, Liberia, Nigeria and Sierra Leone. In total, 14 of the 62 recognized species of *Aframomum* were reported to be sold in these countries (Fig. 4). Additionally, there was mention of two species – *A. grana-paradisii* (L.) K.Schum. and *A. hanburyi* K.Schum. – that are no longer accepted. *A. hanburyi*, mentioned as sold in Equatorial Guinea and Ghana (Lock et al. 1977; Sunderland and Obama 1999), has been recognized as a synonym of *A. daniellii* (Hook.f.) K.Schum. and was treated as such in this review. *A. grana-paradisii* was mentioned in one study from Cameroon (Dibong et al. 2011). Because it is a name that represents a group of vouchers of differing species (Harris and Wortley 2018), we could not assign this specimen to a recognized species in this review.

The amount of documented *Aframomum* species for sale and the presence of vouchers for those species differed substantially between countries (Fig. 4). Most of the studies presenting data on the commercialization of *Aframomum* took place in Nigeria and Cameroon. These countries also yielded the highest diversity of traded species. We found 31 publications that addressed the sale of *Aframomum* spp. in Nigeria, mentioning five species, while 16 publications yielded information on the sale of *Aframomum* spp. in Cameroon, totalling 11 species. Two of the five species identifications reported from Nigeria were supported by vouchers

TABLE 1. NUMBER OF PUBLICATIONS GENERATED IN ROUND ONE AND REVIEWED IN ROUND TWO FROM ALL FOUR SEARCH ENGINES, INCLUDING THE TOTAL NUMBER OF PUBLICATIONS PER ROUND

Search engine/database	Number of unique publications in round one	Number of unique publications in round two
WOS	43	9
SCOPUS	111	45
Prelude	126	19
Google Scholar	40*	11
Total	280	70

*203 hits in total. Only the first 40 articles were reviewed, as hits became irrelevant after that

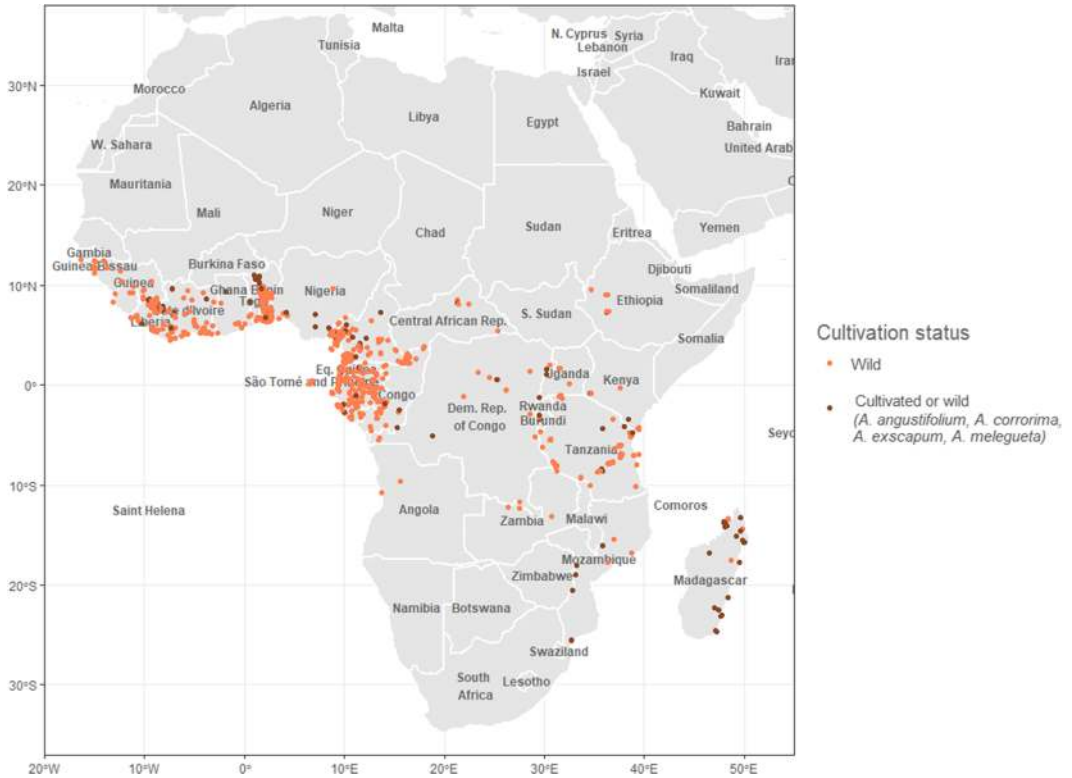


Fig. 2. Map showing the localities of herbarium specimens and human observations of the 51 *Aframomum* species that are listed by GBIF in Africa. Coordinates obtained from GBIF.org (GBIF Occurrence Download: <https://doi.org/10.15468/dl.au26mk>, 22 January 2021).

(Fig. 5B). Among the 11 species of *Aframomum* documented as being sold in Cameroon, nine were based on voucher specimens (Fig. 5C). All other

countries were represented by five studies or less. Eight countries (Burundi, Congo-Brazzaville, Egypt, Equatorial Guinea, Gabon, Ivory Coast,

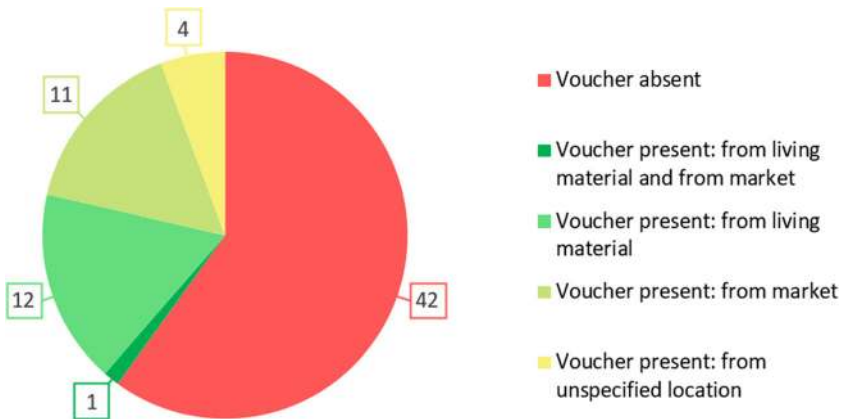


Fig. 3. Voucher presence and collection locality in the 70 publications that reported the commercialization of *Aframomum* species in Africa.

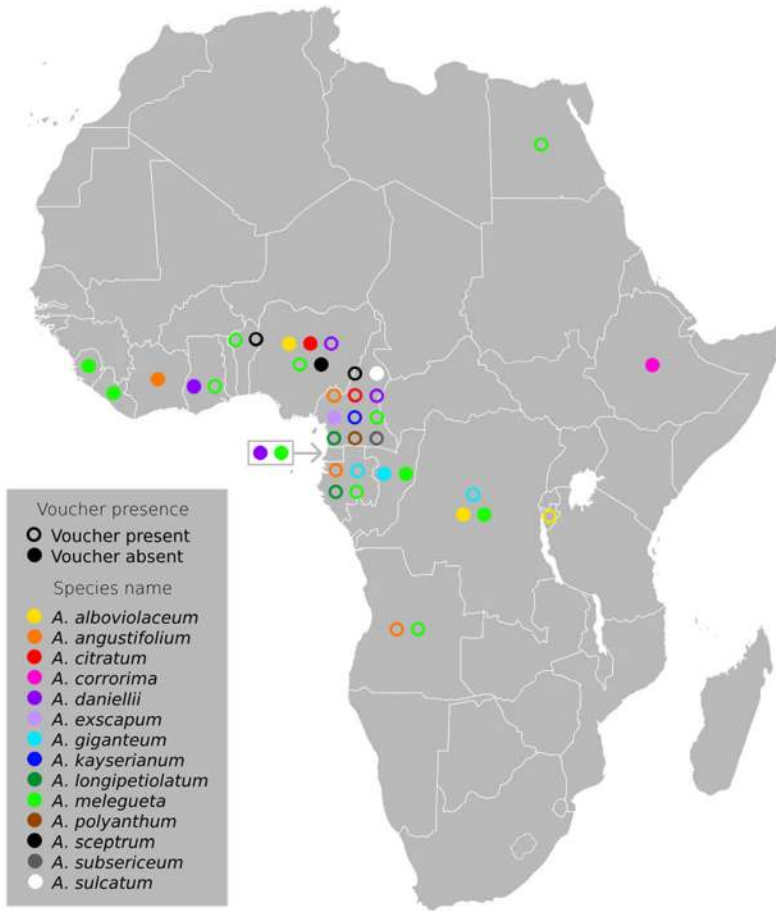


Fig. 4. Map of Africa depicting the sale of *Aframomum* species per country, for the 14 commercialized species mentioned in the reviewed literature. Open circles indicate that there was at least one voucher present for every commercialized species.

Liberia and Sierra Leone) were only represented by one study. Congo-Brazzaville, Equatorial Guinea, Ethiopia, Ivory Coast, Liberia and Sierra Leone lacked any voucher material for the species that were sold there.

Among the 14 species of *Aframomum* that we encountered in this review, *A. melegueta* was most frequently mentioned as being sold on African markets (Fig. 4; Fig. 5A). The sale of *A. melegueta* was reported in 48 studies from 12 countries that produced 18 vouchers, followed by *A. daniellii* (13 mentions from four countries and four vouchers) and *A. citratum* K.Schum. (eight mentions from two countries and three vouchers). All other species were mentioned five times or less (Fig. 5A). Three

of the 14 species of *Aframomum* that were identified as being sold in Africa were not supported by any vouchers: *A. exscapum* and *A. sulcatum* K.Schum. were only mentioned in one publication. *A. corrorima*, however, was mentioned in five studies from Ethiopia (Fig. 5A; Table S.1). These identifications were said to be based on examinations by expert botanists or were simply said to be verified at a laboratory or herbarium.

RANGE OF COMMERCIALIZED *AFRAMOMUM* SPECIES

Four *Aframomum* species were encountered on markets outside of their natural or cultivated range

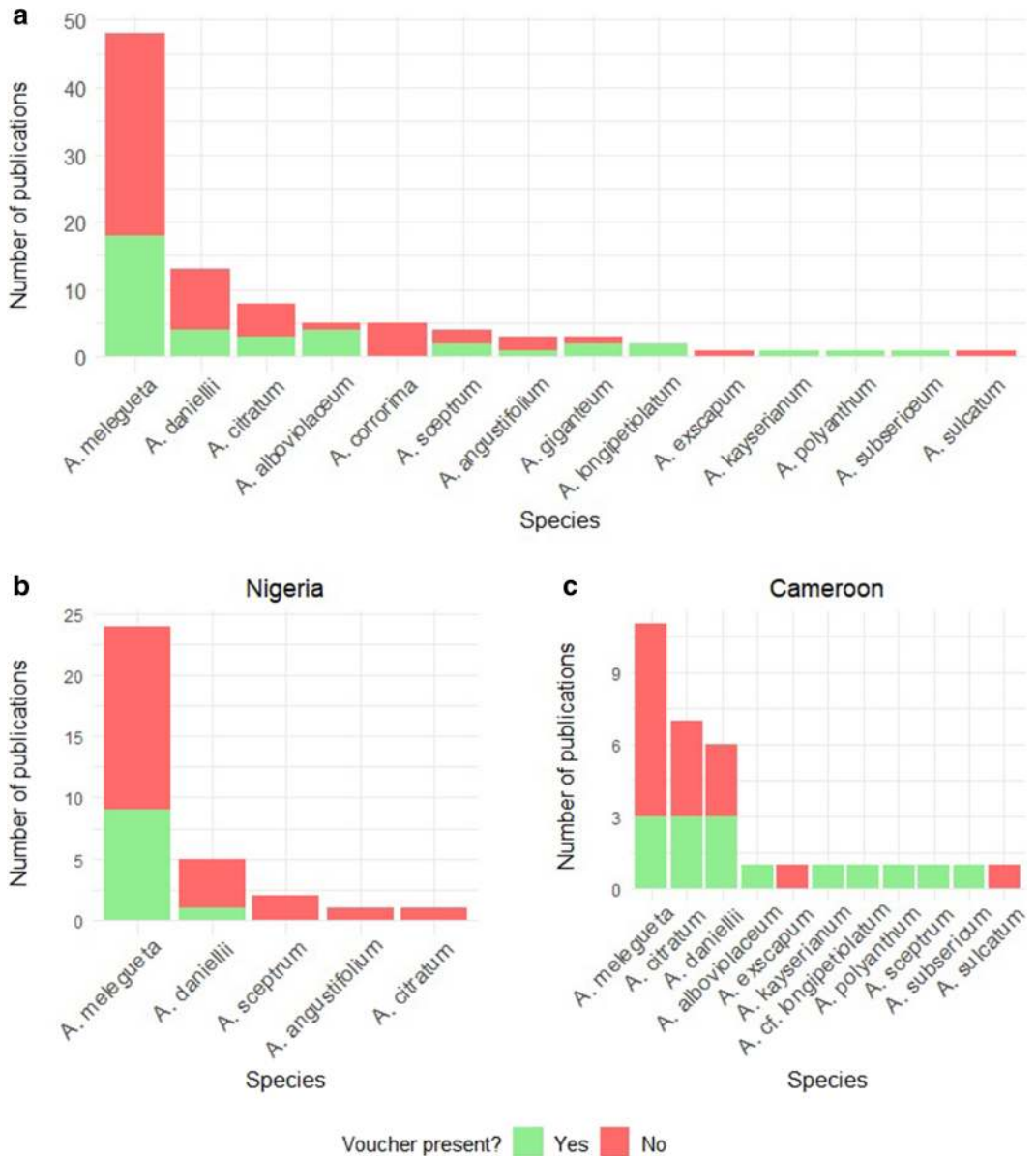


Fig. 5. Number of publications mentioning the sale of different *Aframomum* species in: **A)** all 70 publications resulting from the systematic literature review; **B)** publications referencing the sale of *Aframomum* spp. in Nigeria; and **C)** publications referencing the sale of *Aframomum* spp. in Cameroon.

(Fig. 4; Appendix S.2). *A. melegueta* was found to be sold in Egypt (El-Halawany et al. 2012), which is far outside of its range that stretches from Guinea to the Democratic Republic of the Congo and Angola (Appendix S.2; Harris and Wortley 2018).

A. sulcatum was found to be sold in Nigeria (Ajiboye et al. 2016; Kayode et al. 2008), while this species is said not to cross the Dahomey Gap (Harris and Wortley 2018). Fruits of *A. cf. longipetiolatum* Koechlin were reportedly sold by

Baka foragers to spice traders in southeast Cameroon (Gallois et al. 2020), even though this species is known to be endemic to Gabon (Harris and Wortley 2018). Finally, Dibong et al. (2011) mention the sale of *A. exscapum* – written as *A. excapum* – on a market in Douala, Cameroon, although according to Harris and Wortley (2018) it does not occur further east than Ivory Coast.

CONSERVATION STATUS OF COMMERCIALIZED *AFRAMOMUM* SPECIES

All but two of the 14 *Aframomum* species that were found to be sold in Africa are classified as Least Concern on the IUCN Red List (Table 2). All known cultivated species are classified as Least Concern, with the exception of *A. melegueta*, which is classified as Data Deficient because the species has been cultivated and subsequently naturalized throughout tropical Africa and its natural range can therefore no longer be established (Harris et al. 2019c). *A. kaysirianum* is classified as Endangered, due to its restricted range and forest loss in Cameroon and Nigeria (Harris et al. 2019d). This species was reported as being sold on Cameroonian markets by a single study (Dzoyem et al. 2014).

LC = Least Concern, EN = Endangered, DD = Data Deficient.

From the species that are classified as Least Concern, *A. sceptrum* and *A. subsericeum* have decreasing population trends. The wild population trends of all other species are either stable or unknown, including those species that can be found in cultivation. Interestingly, for more than half of all species found to be sold in Africa, no data exists on their population or conservation status (Table 2).

Discussion

This systematic literature review provides relevant insights into the current knowledge on trade and conservation issues within the genus of *Aframomum*, and revealed extensive knowledge gaps on the taxonomic identification of the commercialized *Aframomum* specimens. In this study we have tried to amass all research on commercialization of *Aframomum* in Africa, but information may have been missed from the 50 publications of which the full text was not available online or through university libraries. We also excluded information on the commercialization of *Aframomum* in Africa that was mentioned on labels of herbarium specimens

collected on markets that were never featured in any publication. A search through the Naturalis Bioportal (<https://bioportal.naturalis.nl>) yielded a specimen that was collected on a Nigerian market, but this voucher was never mentioned as such in a publication (Fig. 6). The extraction of similar label data, lying hidden in numerous digitalized and non-digitalized herbaria worldwide, would take years.

RANGE, COMMERCIALIZATION AND CONSERVATION OF *AFRAMOMUM* SPP. IN AFRICA

Among the 14 species of *Aframomum* traded in 15 African countries, *A. melegueta* was encountered most frequently and in the most countries. This is not surprising, given that *A. melegueta* has been cultivated and traded internationally for centuries, thereby potentially extending its range (Harris and Wortley 2018; Lock et al. 1977; Van Harten 1966). Interestingly, two studies from Nigeria and the Democratic Republic of the Congo indicated that material of *A. melegueta* sold on the markets was collected from the wild (Bakwaye et al. 2013; Kayode et al. 2008). If this information from market vendors is correct, this suggests that although most material of *A. melegueta* sold on markets comes from cultivated individuals, this species may still be locally collected from the wild as a NTFP. This knowledge, coupled with the fact that *A. melegueta* was mentioned as a rare wild species in Nigeria (Olanipekun et al. 2016), indicates that local conservation issues for wild *A. melegueta* may be present.

Our systematic literature review also yielded three publications in which *A. melegueta* was labelled as an NTFP even though the material for sale was said to come from cultivated sources (Appendix S.1; Guedje et al. 1998; Ingram and Schure 2010; Towns et al. 2014). This shows that the term NTFP is not always well understood and that care should be taken when this term is encountered. Due to this confusion, it is of utmost importance to clearly separate wild-sourced and cultivated material of *A. melegueta* sold on markets when examining conservation threats and assessing the harvest sustainability of this species. If the commercialized material comes from cultivated individuals, the risk of overharvesting wild resources is limited, although natural *Aframomum* populations may still be threatened by deforestation.

The second *Aframomum* species sold in Africa that might be experiencing conservation threats is *A. kaysirianum*: the only commercialized species

TABLE 2. RED LIST STATUS, POPULATION TREND AND CULTIVATION DATA FOR ALL *AFRAMOMUM* SPECIES COMMERCIALIZED IN AFRICA

Species	IUCN Red List status			Reported as cultivated?	Distribution range	Threats	Source
	IUCN Red List status	IUCN pop. Trend	IUCN pop. Trend				
<i>A. albioviolaceum</i> K.Schum.	LC	Stable	No data	Widespread: mainland equatorial Africa	No major threats, tolerant to some disturbance	Harris et al. (2019e)	
<i>A. angustifolium</i> (Sonn.) K.Schum.	LC	Stable	Yes	Widespread: Equatorial Africa, Madagascar, the Seychelles	No major threats, tolerant to some disturbance	Crook et al. (2019); Furo et al. (2020)	
<i>A. citratum</i> (J.Pereira) K.Schum.	LC	Unknown	No data	Western equatorial Africa: Cameroon, Equ. Guinea, Gabon, Southern Nigeria	Habitat loss, some tolerance to disturbance	Harris et al. (2019f)	
<i>A. corrorina</i> (A.Braun) P.C.M.Jansen *	LC	Unknown, probably declining outside protected areas	Yes	Eastern equatorial Africa: Burundi, DRC, Ethiopia, Kenya, Tanzania, Uganda	Loss of habitat due to expanding agriculture and logging in part of its range	Eyob et al. (2009); Harris et al. (2019g)	
<i>A. daniellii</i> (Hook.f.) K.Schum.	LC	Stable	No data	Widespread: equatorial Africa, incl. São Tomé and Príncipe	Habitat loss in parts of its range, no major threats	Harris et al. (2019h)	
<i>A. excapum</i> (Sims) Hepper *	LC	Unknown	Yes	Western coastal Africa: Guinea, Ivory Coast, Liberia, Sierra Leone	Loss in forest cover and decline in habitat quality	Harris et al. (2019i); Harris and Wortley (2018)	
<i>A. giganteum</i> K.Schum.	LC	Unknown	No data	Western equatorial Africa: Cameroon, Congo, DRC, Equatorial Guinea, Gabon	No threats specific to this species.	Harris et al. (2019j)	
<i>A. kaysenianum</i> (K.Schum.) K.Schum.	EN	Unknown	No data	Restricted: Mountainous areas of Northern Cameroon and Southern Nigeria	Forest clearance for agriculture (in Nigeria), lower threat in Cameroon.	Harris et al. (2019d)	
<i>A. longipetiolatum</i> Koeschlin	LC	Unknown	No data	Endemic to Central and Eastern Gabon	No recorded threats to this species.	Harris et al. (2019k)	
<i>A. melegueta</i> K.Schum.	DD	Unknown	Yes	Western and Central equatorial Africa from Guinea to Uganda, incl. São Tomé and Príncipe	Identification of threats impossible; cultivation may have impacted the wild population.	Harris et al. (2019c); Lock et al. (1977)	
<i>A. polyanthum</i> K. Schum.	LC	Unknown	No data	Central equatorial Africa: CAR, Cameroon, Congo, DRC, Gabon, South Sudan, Zambia	No specific threats are known for this species.	Harris et al. (2019l)	
<i>A. sceptrum</i> K.Schum.	LC	Decreasing	No data	Western and Central equatorial Africa from Guinea to DR Congo	Local threats due to urban and agricultural expansion, logging.	Harris et al. (2019m)	
<i>A. subsericeum</i> K.Schum.	LC	Decreasing	No data	Central equatorial Africa: CAR, Cameroon, Congo, DRC, Equatorial Guinea, Gabon	Coastal areas: habitat loss due to urbanization, agriculture, mining, logging.	Harris et al. (2019n)	
<i>A. sulcatum</i> (Oliv. & D.Hanb. ex Baker) K.Schum. *	LC	Stable	No data	Western equatorial Africa: Ghana, Ivory Coast, Liberia, Sierra Leone	Habitat loss, but resilient to human disturbances.	Harris et al. (2019o)	

*Documentation of sale in Africa not backed up by herbarium voucher(s)

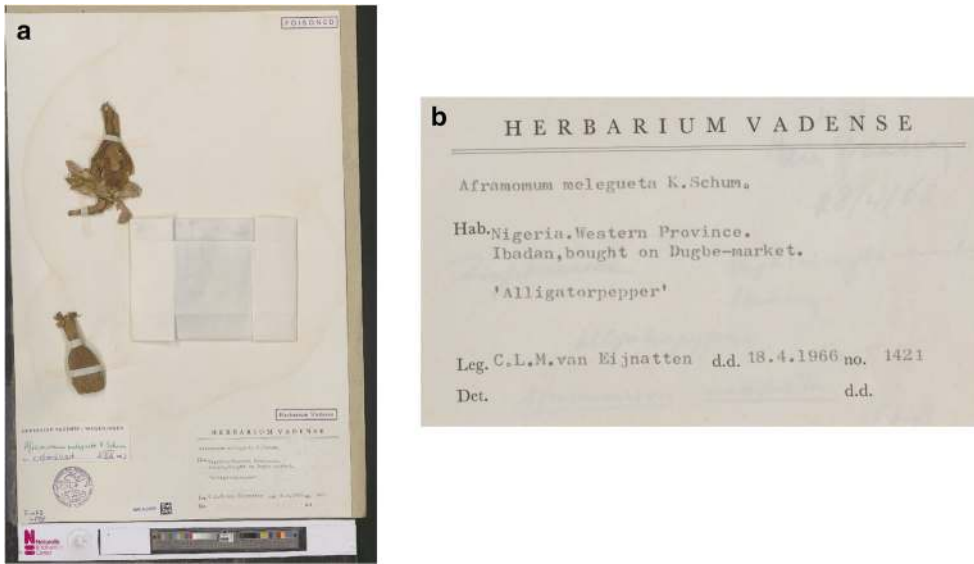


Fig. 6. **A)** Herbarium voucher (WAG.1201727) of dried fruits of *A. melegueta* from Dugbe market in Ibadan, Nigeria; **B)** a close-up of the label. Source: Naturalis Biodiversity Center.

that is Endangered according to the IUCN Red List. This is due to its restricted range in Nigeria and Cameroon and possible habitat loss through agricultural development, especially on the Obudu Plateau in Nigeria (Harris et al. 2019d). Harris et al. (2019d) suggest that the high altitude at which this species occurs in Cameroon would protect it from the bulk of forest loss in that country. Moreover, Harris and Wortley (2018) state that within its range, *A. kayserianum* is not rare. These contradictory assessments for the different countries coupled with the fact that we only found one study documenting the sale of *A. kayserianum* and no additional literature on the harvest of this species, indicates that more research is needed to assess whether or not the harvest of *A. kayserianum* for commercial purposes in Africa is sustainable. Such a venture will have to include market surveys in and around the mountainous areas of Nigeria and Cameroon, as well as expeditions to the source material as indicated by sellers, during which the local population size can be assessed. The second- and third-most mentioned commercialized species were *A. daniellii* and *A. citratum*. They occur solely in the wild and are both widespread, although *A. citratum* is described in Harris and Wortley (2018) as “not very common”. Both are labelled Least Concern by the IUCN Red List, indicating

that an imminent risk of decreasing populations or extinction through the harvesting of these species is unlikely.

EAST AFRICAN KNOWLEDGE GAP

Through our literature review a major knowledge gap was revealed for the Central African Republic, Kenya, Malawi, Mozambique, Rwanda, South-Sudan, Tanzania, Togo and Uganda. These predominantly East African countries yielded no publications on the commercialization of *Aframomum* through the channels used in this study. Undoubtedly, market surveys on spices and medicinal plants in these countries, which all possess rainforest and savanna habitat suitable for *Aframomum* spp., would yield data on sales of fruits, seeds, rhizomes or leaves. Various species, such as *A. corrorima* and *A. albiflorum* Lock, are endemic to East Africa (Harris and Wortley, 2018) and market surveys in these areas thus hold the potential to significantly contribute to the knowledge of trade in *Aframomum*. Ethiopia was the only East African country represented by more than one publication, but this country is also in need of more research into the trade in *Aframomum* spp. None of the five studies from Ethiopia produced vouchers, which raises the question if *A. corrorima* is truly the only

commercialized *Aframomum* species in Ethiopia. Given the fact that *A. angustifolium* is known to be commonly cultivated in Ethiopian home gardens (Furo et al. 2020), it would surely be found on regional markets with intensified sampling.

SPECIES IDENTIFICATION LIMITATIONS

Our systematic literature review yielded important insights regarding the reliability of the species identifications of *Aframomum* spp. sold in Africa. Strong limitations were uncovered concerning both the availability and quality of voucher material collected in the reviewed articles. More than half of the included publications did not report the creation of any kind of voucher. Their identifications were either based on the evaluation of an (unnamed) expert, or there was no mention of how the species were identified at all. The lack of traceable voucher material, makes it impossible to verify whether the species mentioned are correctly identified. This in turn hinders the design of management plans for sustainable extraction of commercialized *Aframomum* species. Especially the many studies that focused on potential pharmacological properties of *Aframomum* species without mentioning any voucher material (e.g., Ajiboye et al. 2016) should be more careful in attributing effects to certain species, as their identification cannot be checked.

The most well-represented country, Nigeria, showed that quantity and quality do not necessarily coincide. At first sight, Nigeria seemed to be

particularly well-studied. Yet, only two out of the five traded species were reported in studies that provided vouchers, thereby making species verification possible. All reported vouchers from Nigeria concerned *A. melegueta* except for one herbarium specimen of *A. daniellii* (Okeke et al. 2018). The identity of the three additional species reported to be sold in this country cannot be verified. This contrasts with our findings from Cameroon, where the species were much better represented by herbarium material. Thus, there is no clear link between the quantity of studies referencing the commercialization of *Aframomum*, and the quality of the species identifications within those publications.

For the 28 publications that did produce vouchers it would in theory be possible to verify their species identifications, which is important because *Aframomum* is frequently mis-identified in herbaria and identifications of vouchers cannot blindly be assumed to be correct (Goodwin et al. 2015). This is especially true for the vouchers from the 11 studies that used market-sourced material. These vouchers rarely contain the whole plant and the material is often already dried. An example of how such dried plant material is encountered on an African market is presented in Fig. 7. Given the fact that these parts are very difficult to identify in isolation from other tissues, identification issues can ensue when relying on morphology. This is a common problem with identifying specimens across African markets. Wares are often dried and bought from middlemen, thereby complicating



Fig. 7. Unidentified *Aframomum* fruits (indicated by red square) sold as an ingredient in a *pau de cabinda* aphrodisiac mixture in Angola. Source: Destino Venda, Wikimedia Commons

species identification (Van Andel et al. 2012). In the case of *Aframomum*, market-sourced vouchers can be accurately re-examined by DNA barcoding of specimens that have been revised and cited in Harris and Wortley (2018), after which additional vouchers can be identified through DNA analysis.

We also encountered several publications in which the authors did state that they created vouchers but in which the voucher numbers were not reported. It is impossible to revise these without contacting the author personally, shrinking the pool of verifiable vouchers even further. In the end, only 21 publications produced vouchers and made these traceable by providing voucher numbers, and just ten of those vouchers contained the whole plant. The specimens in all other studies are either unverifiable, untraceable or possibly need DNA analysis to accurately confirm the species identification.

Conclusion and Recommendations

This study offers a first overview of the trade in *Aframomum* in Africa. Among the 14 commercialized species of *Aframomum* traded in 15 African countries, *A. melegueta* was encountered most frequently and Nigeria and Cameroon were studied most intensively. Conservation concerns were found for *A. kayserianum* and possibly for wild *A. melegueta* populations. Yet, large knowledge gaps exist concerning the commercialization of *Aframomum* in almost all East African countries within the native range of *Aframomum* and the majority of sourced publications did not base their species identification on herbarium vouchers. Only 13 studies collected the whole plant from the wild or place of cultivation and three of those publications never mentioned the voucher numbers. The lack of herbarium material or reported voucher numbers means that those species identifications are not verifiable. A problematic matter, given that *Aframomum* is often misidentified in herbaria and that *Aframomum* is an important yet obviously understudied income generator throughout Africa. More detailed knowledge concerning the trade in *A. melegueta* and *A. kayserianum* will be crucial to identify to what degree the collection of these species as an NTFP poses conservation threats. Given these considerable shortcomings, we recommend that future academic endeavours investigating the commercialization of *Aframomum* spp. in Africa focus on countries within the native

range of *Aframomum* that have as of yet not been the subject of intensive study. Moreover, care should be taken to collect vouchers, preferably from living material that has been indicated by the vendors as the source plant of the marketed products. Voucher numbers and the herbarium where the vouchers are deposited should be reported in the publication. This will allow researchers to verify the identification through morphological studies using the new revision by Harris and Wortley (2018) or through DNA analysis. By simultaneously reporting the source of the material (either from the wild or from cultivated sources), as well as noting the abundance in the wild, future research could also effectively aid in the detection of further conservation issues surrounding commercialized species of *Aframomum* in Africa.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1007/s12231-021-09517-4>.

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