The Role of exotic medicinal plants in the treatment of modern diseases: A study at public markets on a global scale

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Research

Abstract

Background: It is important to understand treatment strategies for modern illnesses that arise from social and environmental transformation associated with the process of modernization, including those that are new or becoming more common, in order to understand how local medical systems are evolving and facing the challenges associated with diagnosing and treating these diseases. Moreover, changes brought about by modernization, such as urbanization, may influence both the knowledge and the availability of resources for treating these diseases, including the use of exotic plants, which are becoming increasingly accessible in the context of globalization, particularly through local public markets, thereby enhancing access to such resources. The present study aimed to investigate the representation of exotic species in the treatment of modern diseases and whether the rate of urbanization explains the proportion of exotic and native species used in treatments for these diseases provided in local public markets of medicinal plants on a global scale.

Methods: A systematic review was conducted, following the PRISMA protocol, of studies on local public markets, to assess whether traded exotic species are preferentially used in the treatment of modern diseases compared to other ailments. We also examined whether the local rate of urbanization influenced the composition of traded exotic species compared to native species for the treatment of modern diseases. We used odds ratios, random-effects models, and simple linear regressions to analyze the data.

Results: Our findings suggest that traded exotic species are equally likely to be used to treat both modern and other diseases. Furthermore, the rate of urbanization does not influence the composition of traded exotic species for the treatment of these diseases when compared to native species.

Conclusions: Local public markets present complex dynamics that make them more homogeneous, which may explain the same proportion of exotic and native species used to treat modern diseases, as well as the same proportion of exotic species treating modern diseases and other diseases.

Keywords: medicinal plants; modern diseases; local public markets; medical systems; globalization; urbanization.

Background

The process of modernization began in 17th-century Western Europe, intensified during the Industrial Revolution, and subsequently expanded on a global scale (Corbett *et al.* 2018). This phenomenon has transformed the environment by driving urbanization, deforestation, pollution, and climate change (Martine & Alves 2015, Mashi & Shuaibu 2018). It has also altered cultural habits within society. For instance, it has fostered sedentary lifestyles characterized by increased consumption of processed foods and greater ease of daily mobility (Gurven & Lieberman 2020), while simultaneously generating pressure to achieve a healthy and idealized body. This issue has become a major global mental health concern (Rodgers *et al*. 2023).

Excessive connectivity, productivity demands, the pervasive influence of social media, and heightened competitiveness have likewise contributed to the rising incidence of mental disorders (Koutsimani et al. 2019, Lopes et al. 2022). These transformations have been linked to the emergence and progression of various conditions, classified in the literature as modern diseases owing to their direct association with modernization (Gurven & Lieberman 2020, Fernandes et al. 2020, Souza 2020).

Mismatch diseases have spread globally alongside modernization. This phenomenon occurs when rapid environmental changes driven by human activity outpace the body's biological adaptive capacity, creating a misalignment between organism and environment (Corbett *et al*. 2018, Gurven & Lieberman 2020, Manus 2018). Research indicates that the human body reflects evolutionary adaptations suited to the lifestyle of our hunter-gatherer ancestors, which was characterized by natural diets, high levels of physical activity, and intermittent exposure to environmental stressors. The transition to urbanized societies, marked by high-calorie diets, sedentary behaviors, and reduced contact with nature, has exacerbated this biological mismatch (Corbett *et al*. 2018, Gurven & Lieberman 2020, Griffiths & Bourrat 2023). Consequently, conditions such as diabetes, cancer, and cardiovascular illnesses, which account for more than half of global mortality and morbidity, have become increasingly prevalent (Corbett *et al*. 2018, Gurven & Lieberman 2020).

In addition to mismatch diseases, modernization has facilitated the emergence of illnesses that vary across time and space, being present in a given environment at one moment and absent at another (Silva *et al*. 2022). Such illnesses arise or resurface due to environmental and cultural transformations resulting from human activity. They are often linked to environmental degradation, climate change, and altered interactions between humans, animals, and pathogens. Examples include emerging diseases such as SARS-CoV-2 (the virus responsible for "Covid-19"), and reemerging diseases such as monkeypox (Andersen *et al.* 2020, Fernandes *et al.* 2020, Patterson 2016, Zhou *et al*. 2020).

It is important to emphasize, however, that framing these conditions solely through biological or behavioral lenses, whether related to cultural changes or environmental transformations, risks a reductionist understanding of health. Such an approach tends to depoliticize the role of structural and social determinants in health and disease. Poverty, racism, forced displacement, economic inequalities, and unequal access to healthcare services are among the many factors that profoundly shape the distribution and impact of disease (Bailey *et al.* 2017, Stanaway *et al*. 2019, Singer *et al.* 2017). For instance, in the case of climate-related and zoonotic diseases, communities in the Global South are disproportionately affected despite contributing the least to environmental degradation (Romanello *et al*. 2021, WHO 2022).

These modern diseases pose serious risks to populations, including threats to life, increased morbidity, and significant sequelae (Fernandes *et al*. 2021, Gurven & Lieberman 2020, Souza 2020). They typically involve a complex array of symptoms, including common ailments such as coughs, diarrhea, influenza, and inflammation, which complicates diagnosis (Feijó *et al.* 2012, Fernandes *et al.* 2021, Gomes *et al.* 2019).

Moreover, modernization does not advance at the same pace in all regions (Corbett *et al*. 2020). Consequently, the occurrence and impact of modern diseases may vary across localities. The frequency and distribution of diseases differ according to the cultural, environmental, and socioeconomic context of each setting, whether at the regional, national, or global level (Adachi *et al*. 2022, Carmo *et al*. 2003, Corbett *et al*. 2018, Gaddy 2020). Thus, certain diseases may be unknown in some areas but not in others, or more prevalent in some regions and less common in others.

As modern diseases progress, globalization facilitates the exchange of information and resources for their treatment through local public markets, the internet, and migration (Abreu 2015, Leonti 2013, Leonti *et al.* 2015, Fonseca & Balick 2018). Historically, the dissemination of resources via human migration occurred at a slower pace, dating back to the colonial era. Over time, this process led to the worldwide distribution of certain resources owing to their commercial, nutritional, and therapeutic value (McBride *et al.* 2020, Voeks 2013). However, globalization has markedly accelerated this exchange, influencing both the composition and knowledge of resources in local pharmacopoeias (Fonseca & Balick 2018, Vandebroek & Balick 2012, Leonti *et al.* 2015).

This dynamic can add complexity to medical systems, particularly those that employ medicinal plants to treat disease, since they require knowledge of symptoms, diagnosis, and appropriate treatment, which may be unfamiliar to local populations (Gomes *et al.* 2019, Feijó *et al.* 2015, Silva *et al.* 2021). We argue that exotic species are often prioritized in the treatment of modern diseases because they are more readily accessible in the context of globalization. When introduced into a system, such species bring culturally validated information constructed by other cultures through processes including the observation of symptoms, plant experimentation via associations, and trial and error until treatment efficacy is confirmed (Feijó *et al.* 2012, Kleinman 1978, Medeiros *et al.* 2017). It is important to stress that medical systems are dynamic and capable of creating, modifying, and adapting knowledge to address such diseases (Ferreira Júnior *et al*. 2018). However, from an evolutionary perspective, it is more advantageous to seek information on culturally validated plants for these diseases than to generate new knowledge (Rendell *et al*. 2010).

Urbanization may also influence the use of exotic plants in the treatment of modern diseases. It is a complex economic, social, and environmental process that unfolds over short periods, bringing profound transformations to lifestyles, social organization, and natural landscapes (Arjona-García *et al.* 2021). Urbanization alters land use through deforestation and the conversion of natural areas into human settlements. Furthermore, it can directly affect knowledge of and access to natural resources by distancing people from the natural environment and weakening cognitive and experiential connections with nature (Arjona-García *et al*. 2021, Mashi & Shuaibu 2018, Pochettino *et al*. 2012).

Research suggests that populations living in proximity to areas with greater plant resource availability, such as rural environments, and who engage in nature-related activities, tend to possess more extensive knowledge of local resources. This may encourage the use of native species, as such areas, unlike urban centers, are more likely to preserve a greater diversity of native plants that remain accessible to communities (Arjona-García *et al*. 2021, Bortolotto *et al.* 2015, Reyes-García *et al*. 2005, Silva *et al*. 2018). Conversely, urbanization may restrict access to areas rich in native resources, as urban populations tend to become more distant from such environments, thereby affecting both their knowledge of and access to these resources (Arjona-García *et al.* 2021).

Although urban areas may contain green spaces, such as forest restoration projects aimed at improving air quality and regulating temperature, or urban horticulture initiatives, these areas often feature a predominance of exotic species. This is largely due to the greater adaptability of these species to disturbed environments (Andrade & Massi 2024, Dylewski *et al*. 2023, Tartaglia & Aronson 2024). Urbanization facilitates access to exotic resources through multiple channels, such as local public markets, which can broaden knowledge of these resources. In addition to reflecting the native flora, these markets showcase species from other regions (Arjona-García *et al*. 2021, Pochettino *et a*l. 2012, Silva *et al.* 2019).

Local public markets constitute key environments for understanding the dynamics of plant use in the treatment of modern diseases. They reflect a region's cultural and biological diversity, serving as valuable sources of information on the prevalence and use of particular plant species in local medical systems (Cavalcanti & Albuquerque 2013, Leonti 2013, Monteiro *et al.* 2010). The exchange of knowledge in these spaces can facilitate the adoption of medicinal plants in local medical systems, including exotic species, which may be introduced to diversify treatment options or to address therapeutic gaps (Abreu 2015, Leonti 2013, Vandebroek & Balick 2012). In this way, information about plants used to treat modern diseases can be readily disseminated through these markets.

The present study, based on a systematic review, investigated the representation of exotic species in the treatment of modern diseases, as well as the patterns that may explain the incidence of exotic and native species in medicinal plant treatments within local public markets on a global scale. To this end, we tested the following hypotheses: (H1) The commercialization of exotic species is favored in the treatment of modern diseases, with the expectation that (P1) a higher proportion of exotic species are commercialized for such purposes than for other conditions. We further hypothesized that (H2) the rate of urbanization positively affects the commercialization of exotic species in comparison with native species used to treat modern diseases. Accordingly, we expect that (P2) the higher the rate of urbanization, the greater the proportion of exotic species sold for the treatment of modern diseases compared with native species.

Materials and Methods

The research was conducted through a systematic review, following the PRISMA recommendation (Moher *et al.* 2015) (see Figure 1). The review aimed to identify and select ethnobiological articles on the commercialization of medicinal plants in local markets, including open-air and closed establishments, on a global scale. The following keyword combinations were used: "Medicinal plants + market", "Ethnobotany + market", "Ethnopharmacology + market", and "Medicinal plants + traditional market". These searches were conducted in July 2023 using Google Scholar, Scopus, and Web of Science, all recognized for their extensive journal coverage. The subsequent stages of the systematic review were carried out between August 2023 and March 2024, as detailed below.

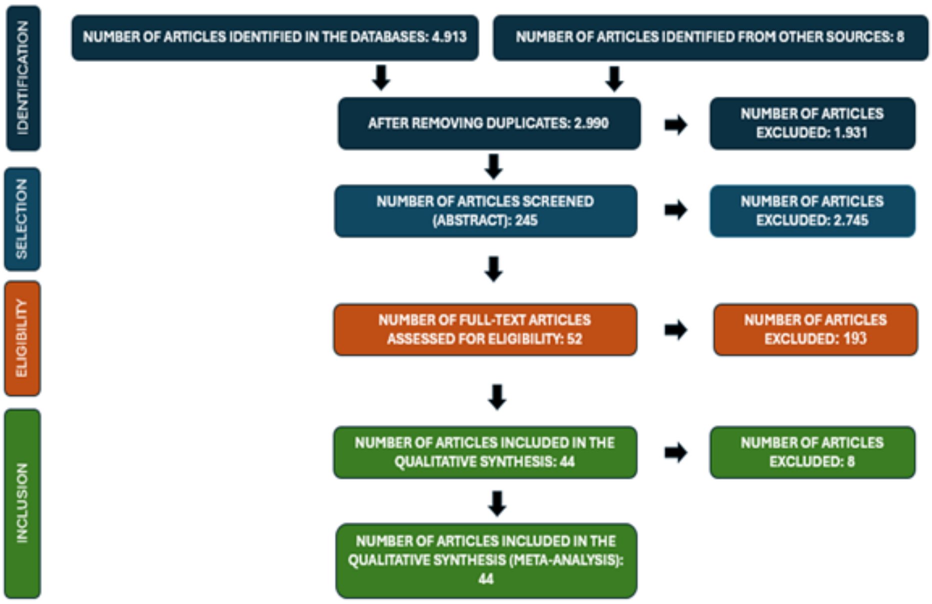

Figure 1. PRISMA Protocol Flowchart, showing each stage of the systematic review, in which we included eligible studies for the construction of the database for the present study.

Studies were selected for inclusion in the database based on the following criteria: they were written in English, as the universal language of science; they were peer-reviewed; they presented original research data (categorized as "research articles"); and they listed species and their therapeutic targets (diseases). The studies were then imported into a Microsoft Excel spreadsheet and refined according to exclusion criteria. These criteria encompassed studies with a different thematic focus, studies addressing only single species or disease, articles presenting only lists of the most commercialized species, systematic reviews, and studies that did not collect botanical material (voucher samples) for species identification in herbaria.

Each study included in the database was also assessed for risk of bias related to sample quality and methodology. Studies were classified as having a low, moderate, or high risk of bias according to an adaptation of Medeiros *et al.* (2014). Only studies assessed as having a low or moderate risk of bias were considered eligible for inclusion. Following this process, 44 articles covering the period from 2000 to 2023 were included in the database (see Table 1).

The extracted information included: authors, scientific names of medicinal species, species families, therapeutic indications, market names, and complete addresses, including the cities and countries in which the studies were conducted.

Table 1. Author(s), name, city, and countries where the analyzed local public markets are located.

AUTHORS	COUNTRY	MARKETS
Ahmad *et al*. (2017)	Pakistan	Commercial Market - Punjab; Market of Rawalpindi - Punjab; Cantt Market Murree - Punjab; Kotli Sattian – Punjab.
Albuquerque *et al*. (2007)	Brazil	São José Market in Recife.
Amiri & Joharchi (2013)	Iran	Markets of Mashhad City.
Asra *et al*. (2023)	Indonesia	Angso Duo Market and Talang Banjar Market in Jambi city.
Betti (2002)	Camaroon	Markets of Yaoundé.
Bitu *et al*. (2015)	Brazil	Mercados do Crato – Região do Cariri.
Bussmann (2016)	Bolivia	Rodriguez Market - La Paz; Calle Market - Santa Cruz; El Alto Market – La Paz.
Bussmann *et al*. (2018)	Colombia	Bogotá Makets: Armenia Market, Boyacá Market, Central de Corabastos Market, El Carmen Market, Fontibón Market, Girardot Market, Kennedy Market, La Concordia Market, La Perseverancia Market, Las Cruces Market, Las Ferias Market, Lucero Market, Municipality of Pacho Market (Cundinamarca), Paloquemao Market, Plaza del 12 de Octubre Market, Plaza del 7 de Agosto Market, Plaza del Quirigua Market, Restrepo Market, Samper Mendoza Market, San Benito Market, San Carlos Market, Santander Market, Trinidad-Galán Market and Plaza del 20 of Julio Market.
Delbanco *et al*. (2017)	Kenya	Markets in Marsabit town and Moyale town.
Ferreira *et al*. (2021)	Brazil	Public markets in seven municipalities of the state of Paraíba: João Pessoa, Sapé, Guarabira, Solânea, Monteiro, Patos, and Itaporanga.
Hanlidou *et al*. (2004)	Greece	Herbal market of Thessalonik - Solania.
Hilonga *et al*. (2018)	Tanzania	Markets in the cities: Arusha, Morogoro, Mbeya, Mwanza, and Dodoma.
Idu *et al*. (2010)	Nigeria	Mida, Itoku, Adatan, Kuto, and Lafenwa markets in Abeokuta, Ogun State, Nigeria.
Idu *et al*. (2014)	Nigeria	Markets of Abeokuta City – Ogum.
Iskandar *et al*. (2020)	Indonesia	Market of Karangwangi Village - Southern Cianjur, West Java.
Jin *et al*. (2018)	China	Traditional medicinal markets at the Dragon Boat Festival in Jianghua, Hunan Province.
Jusu & Sanchez (2013)	Sierra Leone	Markets in the cities of Freetown, Bo, Kenema, Golahun, and Gegbwema.
Karousou & Deirmentzoglou (2010)	Cyprus	Markets in the citys of Nicosia, Limassol and Paphos.
La cruz *et al*. (2014)	Peru	Mayorista Market in Challwa – Huaraz; Central Market of Carhuaz – Carhuaz; Model Market of Yungay – Yungay.
Lee *et al*. (2008)	China	Markets in Honghe Prefecture - Yunnan province.
Lev & Amar (2000)	Israel	Markets in Israel.
Li *et al*. (2017)	China	Markets of Chaoshan – Guangdong.
Liu *et al*. (2021)	China	Kaili market – Guizhou.
Mati & Boer (2011)	Iraq	Qaysari Market – Erbil.
Monteiro *et al*. (2011)	Brazil	Free Fairs in Caruaru city.
Mwaura *et al*. (2020)	Kenya	Markets in Kajiado, Narok and Nairobi counties.
Nanagulyan *et al*. (2020)	Armenia	Market of Yerevan city.
Nguyen *et al*. (2019)	Vietnam	Markets in districts of Son La province.
Oliveira *et al*. (2021)	Brazil	Open market in the city of Oeiras, semiarid region of Piauí.
Ouédraogo *et al*. (2020)	Burkina Faso	Markets in the cities: Ouagadougou, Ouahigouya, Fada N'Gourma, Dédougou, Bobo Dioulasso, and Léo.

Petrakou *et al*. (2019)	Greece	Markets of Peloponeso.
Randriamiharisoa *et al*. (2015)	Madagascar	Markets of Antananarivo.
Rasethe *et al*. (2019)	South Africa	Informal Herbal Medicine Markets of the Limpopo Province.
Rios *et al*. (2017)	Ecuador	Markets of Loja Province.
Shah *et al*. (2020)	Pakistan	Matta Bazzar, Swat district - Khyber Pakhtunkhwa; Topi Bazzar district - Khyber Pakhtunkhwa; Qissa Khawni Bazzar, Peshawar district - Khyber Pakhtunkhwa; Punjabi Bazar, kurram district - Khyber Pakhtunkhwa; Main Bazzar, Mardan district - Khyber Pakhtunkhwa; Main Bazar, Dir Upper district - Khyber Pakhtunkhwa; Chwok Bazzar, Bannu district - Khyber Pakhtunkhwa.
Shah *et al*. (2021)	Pakistan	Market of Bunnu district - Khyber Pakhtunkhwa.
Silalahi *et al*. (2015)	Indonesia	Tradicional Kabanjahe Market – Sumatra.
Sulaini & Sabran (2018)	Malaysia	Local Markets in Batu Pahat, Johor.
Suma *et al*. (2017)	India	Thilagar Thidal Market - Tamil Nadu.
Uzun & Bozdag (2022)	Turkey	Grand Bazaar Market.
Uzun & Koca (2020)	Turkey	Markets of Kahramanmaraş Grand Bazaar - Kahramanmaras.
Zahoor *et al*. (2021)	Pakistan	Markets in Punjab province.
Zangh *et al*. (2020)	Myanmar	Markets of the Mandalay Region, Magway Region, Yangon Region and Nay Pyi Taw Union Territory.
Zangh *et al*. (2022)	China	Markets in the Lijiang area.

Biogeographic origin of species

To standardize the scientific names of the species, a review was performed on World Flora Online (WFO 2022). Regarding the biogeographic origin of the species, the national level was considered; that is, whether they are exotic or native to the countries in which they are sold. The origin of a species may be defined at different scales - region, ecosystem, country, or continent (Medeiros *et al.* 2017). Accordingly, we reviewed the species on websites with extensive biodiversity databases, including the International Union for Conservation of Nature (IUCN) (https://www.iucnredlist.org/) (IUCN 2022), the Missouri Botanical Garden (https://www.missouribotanicalgarden.org/) (Missouri Botanical Garden 2021), the Royal Botanic Gardens, Kew (POWO) (http://www.plantsoftheworldonline.org/) (POWO 2022), and Reflora (https://reflora.jbrj.gov.br/) (Flora e Fungos do Brasil 2022). Four species were not recognized in any of the databases and were therefore excluded from this study.

Classification of modern diseases

A bibliographic search was conducted using the keywords "modern diseases" or "diseases of modernity" in the same search engines used to identify studies on local public markets: Google Scholar, Scopus, and Web of Science. Modern diseases were classified according to literature supporting this category. These diseases are associated with modern advancements and include newly emergent diseases (such as SARS-CoV-2 and Zika) as well as diseases that have progressed and become more prevalent (such as depression, anxiety, and cancer) (Corbett *et al*. 2020, Griffiths & Bourrat 2023, D'avila 2020, Gurven & Lieberman 2020, Silva *et al.* 2019).

The analysis included studies from 2000 to 2023, aligning with the timeframe of research on local public markets included in the review. This period marks the beginning of the new century and a phase of significant global expansion characterized by accelerating urbanization and intensifying social and environmental changes. Consequently, the incidence of diseases associated with these changes has increased, including pandemics (Baker *et al.* 2022, Martine & Shuaibu 2018, Yocoub *et al.* 2011).

A total of 41 studies were identified that addressed the topic, specifying modern diseases, their emergence, and their impact on society. These studies were used to classify modern and non-modern diseases in the local public markets examined (Table 1). Diseases were categorized according to body systems using the ICD-11, a classification system developed by the World Health Organization (WHO 2023). It serves as a global standard for the identification and classification of diseases, health conditions, and other causes of death. Due to the lack of scientific evidence and the absence of an official classification, our analyses did not consider cultural diseases related to beliefs, such as the evil eye (Rios *et al.* 2017).

Georeferencing of markets and urbanization rate

The location of the local public markets was extracted from the pair of coordinates (LAT/LONG) on Google Earth and imported into ArcGIS Pro (Personal User license) (ESRI 2022) using the Geographic Coordinate System WGS 84. Based on the georeferenced location of the markets, the corresponding table was updated with the following attributes: market name, country, administrative region (city/province), quantity of exotic and native species sold for the treatment of modern diseases, number of exotic and native species sold for the treatment of other diseases, total population, and urban population of the district or province in which the market was located.

To calculate the urbanization rate of the district or province, the standard formula was applied: Urban Population / Total Population × 100 (UN 2018), using the Raster Calculator tool in ArcGIS Pro. Data on total and urban populations were collected from the official websites of the demographic agency of the respective countries, corresponding to the locality nearest to the market coordinates, which could be at the city or provincial level, depending on data availability.

Not all studies on commercialization of medicinal plants were included at this stage because some authors studied more than one market in different locations but provided a general species table without specifying which species corresponded to which market, making it impossible to identify the exact location of commercialization. In other cases, the information provided in the text was insufficient to determine precise market locations. In such instances, we contacted the authors by email to obtain further details. Ultimately, 20 articles were included, enabling the analysis of 74 local public markets at this stage.

Data analysis

To assess whether the proportion of commercialized exotic species is greater for the treatment of modern diseases than other conditions, we first analyzed the proportion of native and exotic species used to treat modern and other diseases. For each study, we calculated the effect size based on the Odds Ratio (OR), a case-control measure that estimates the likelihood of exotic and native species being used to treat modern and non-modern diseases. Modern diseases were the case, and non-modern diseases were the control. We then applied a random effects model to analyze whether heterogeneity existed among the study results. In this analysis, we considered that certain species tend to be repeated in medical systems. This occurs frequently with exotic species, as some of these species are widely traded globally. By contrast, the composition of native species in medical systems tends to be more heterogeneous, which could mask the data. Thus, measuring the effect of exotic and native species on modern diseases provided a clearer analytical framework.

To test the hypotheses of the second research question, we established the urbanization rate as the predictor variable and considered the proportion of exotic species sold for the treatment of modern diseases relative to native species as the response variable. For comparison, we also analyzed the predictor variables for the proportion of exotic species sold for the treatment of other diseases. In the R programming environment, we conducted a simple linear regression analysis to assess the relationship between the predictor variable and the outcome.

Results

Modern diseases identified in the literature and observed in markets

According to the reviewed literature on modern diseases, mismatch diseases such as cancer, depression, diabetes, and hypertension have been extensively studied. These diseases are frequently identified as some of the leading causes of rising mortality and morbidity in contemporary society (see Figure 2). Furthermore, these conditions are associated with long-term sequelae that significantly impair quality of life. Many of the diseases classified as modern have treatments available through local public healthcare systems (see the supplementary material for further details).

About diseases whose occurrence varies over time and space, temporal analysis reveals the presence of various illnesses, including those that have led to pandemics, such as dengue, SARS, MERS, Zika, and H1N1. For further details, please refer to the supplementary material.

Exotic species used in the treatment of modern diseases

When analyzing our first hypothesis, we discovered that the proportions of exotic and native species commercialized for treating modern diseases do not differ significantly from those used for other diseases in the examined studies ($Q = 52.7652$, $p = 0.1461$). This finding suggests that the proportion of exotic species is similar for both types of diseases ($OR = 0.9877$; 95% $CI = 0.9127$ to 1.0685; $p = 0.7567$). However, this result does not support our initial hypothesis (Figure 2).

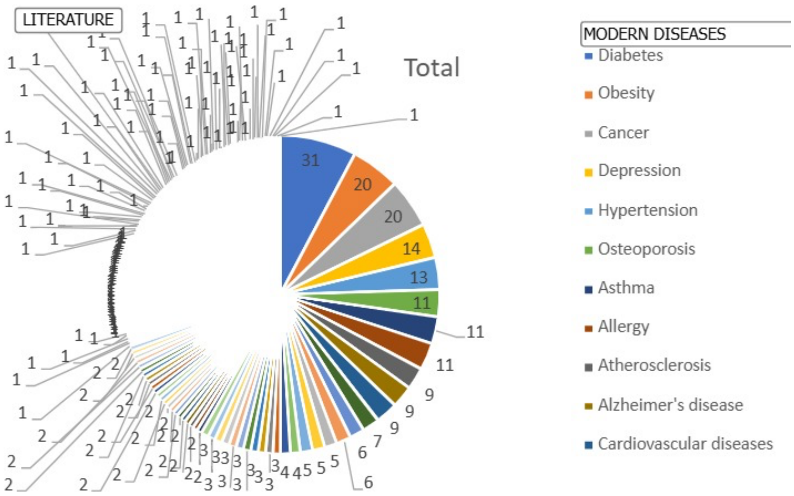

Figure 2. Distribution of literature studies on modern diseases. The image highlights the frequency with which modern diseases are addressed in scientific publications.

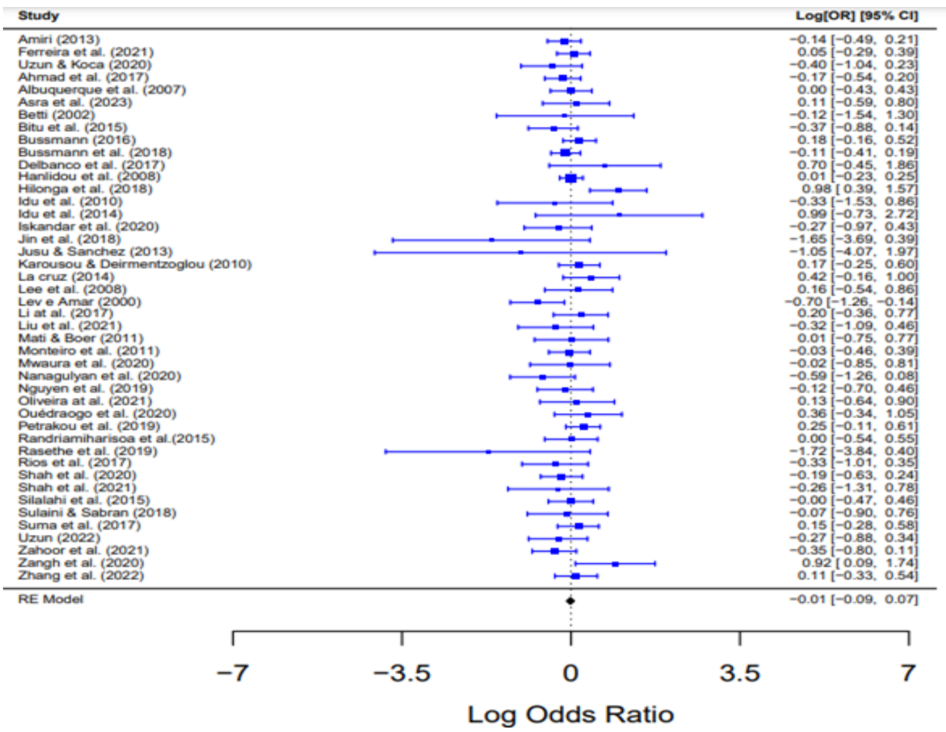

Figure 3. Forest plot showing the odds ratios (OR) and 95% confidence intervals (95% CI) for the proportion of exotic versus native species marketed for the treatment of modern diseases and other diseases. Each line represents an individual study, with the central point indicating the OR for that study, and the horizontal bars representing the 95% CI. The dotted vertical line indicates the combined OR for all studies (OR = 0.9877; 95% CI = 0.9127 to 1.0685), suggesting no significant difference in proportions between the analyzed groups (p = 0.7567).

Influence of the urbanization rate on the commercialization of exotic species for the treatment of modern diseases

Regarding Hypothesis 2, we did not observe a significant relationship between urbanization rates and the proportion of native species relative to exotic species (p = 0.91; Figure 3). A lack of relationship was also observed between the urbanization rate and the proportion of exotic to native species for the treatment of other diseases (p = 0.40). Thus, the urbanization rate does not explain the commercialization of exotic species compared to native species for treating modern diseases or other diseases.

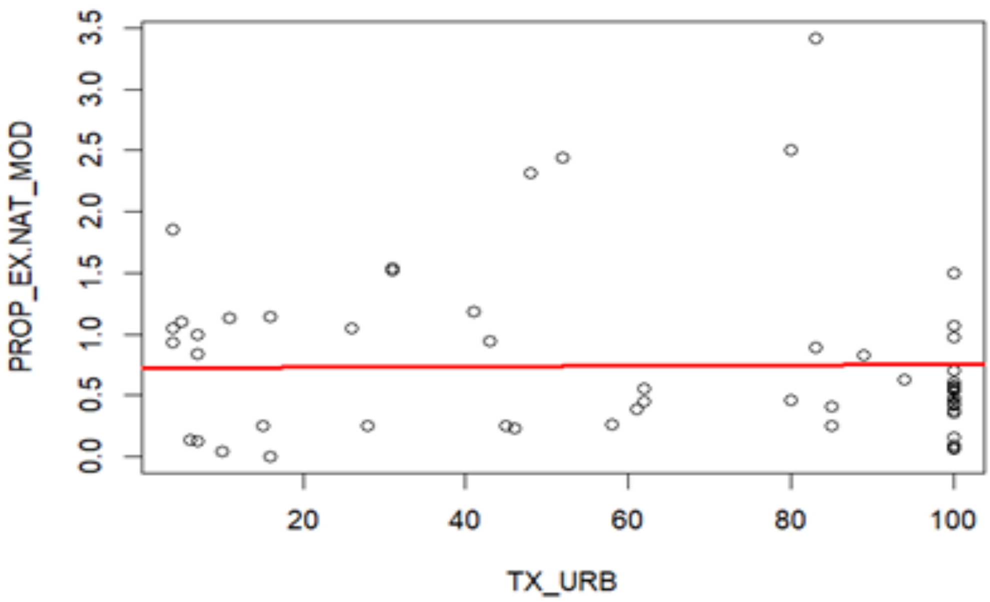

Figure 4. shows the result of the simple linear regression analysis to determine whether the urbanization rate explains the number of exotic species commercialized in the studied markets for treating modern diseases (R^2 = 0.06524, p = 0.9125).

Discussion

Our findings refute the hypothesis (H1) that exotic species are favored for the treatment of modern diseases. This suggests that modern and non-modern diseases are equally likely to be treated with exotic species. To better understand these results, it is important to recognize that markets function as a "showcase" of local resources and knowledge. They are also dynamic, incorporating species from other cultures through regional and global exchanges, which may render them more homogeneous (Monteiro *et al.* 2010). Although information integration has accelerated in recent times, facilitating the exchange of resources between populations, many medicinal species now widely commercialized were introduced during the colonial period. Over time, these species became extensively used for disease treatment and acquired cultural significance at the local level (Fonseca & Balick 2018, McBride *et al*. 2020, Voeks 2013). This historical process may also have contributed to the homogenization of medicinal plant species traded in markets.

From a local perspective, modern diseases may be unfamiliar to certain medical systems. However, their symptoms can resemble those of non-modern diseases. Consequently, traders and patients use commercialized plants to treat these conditions based on symptom similarities. This generates overlap in the plants employed to treat modern and other diseases (Feijó *et al.* 2012, Ferreira Júnior *et al.* 2016, Silva *et al.* 2021). Such patterns have been reported in various studies of traditional and local communities (Cock & Van Vuuren 2020, Cock *et al.* 2018, Ferreira Júnior *et al.* 2016), including those involving more recent modern diseases such as Covid-19 (Cavalcanti *et al.* 2020, Pavão *et al.* 2020, Silva *et al.* 2021).

It is therefore often more advantageous to replicate pre-existing, culturally validated information about plants and their therapeutic targets (Rendell *et al.* 2010), especially as many modern diseases have gradually been incorporated into medical systems, rather than generating entirely new information for their treatment. As experts on medicinal plants, local vendors may engage in experimental practices with commercially available species. They can build therapeutic knowledge based on the characteristics of particular diseases and subsequently disseminate this information within the local community (Ferreira Júnior *et al.* 2016, Monteiro *et al*. 2010). Another possibility is that exotic species introduced through intercultural exchanges to treat modern diseases may also be tested for other local diseases. Such species may persist within medical systems due to their adaptive traits, including efficacy, ease of local adaptation, and accessibility (Ferreira Júnior *et al.* 2016, Medeiros *et al.* 2017).

Regarding the second hypothesis, which examined how urbanization rates in market locations influence the knowledge and use of exotic and native plants for treating modern diseases, the results provided no support. This indicates that factors such as urbanization rate do not explain the presence of exotic and native species in the market for the treatment of modern diseases. The same result was observed in the case of other diseases. We believe that other factors may shape the dynamics of exotic plant selection, including migration flows (Vandebroek and Balick 2012) and the degree of population isolation, itself influenced by port dynamics. Although we lack sufficient data set to explore these aspects in greater depth, we suggest that future studies should address them.

Our results contrast with previous research in local communities, which has shown that urbanization influences both knowledge of and access to exotic food and medicinal resources (Arjona-García *et al.* 2021, Bortolotto *et al.* 2015, Reyes-García *et al.* 2005). These studies demonstrate that urban expansion transforms the natural environment, leading to loss of native vegetation and reduced areas for collecting and managing plant resources. As a result, populations become increasingly distanced from such resources. At the same time, the introduction of exotic species may be facilitated by markets, the internet, and migration (Abreu *et al.* 2015, Arjona-García *et al.* 2021, Reyes-García *et al.* 2005).

To interpret our findings, it is essential to acknowledge that public markets are dynamic spaces where the trade of exotic and native species for therapeutic purposes is facilitated. Markets selling medicinal plant resources are typically located in urban centers, serving not only local populations but also rural communities and residents of neighboring town. This broadens their reach and importance in healthcare systems (Rios 2017, Tinitana *et al.* 2016). However, their urban location distances them from primary forests, the main source of native resources. Traders are thus compelled to cultivate species in disturbed environments or rely on external suppliers to maintain a steady supply (Albuquerque *et al.* 2007, Towns *et al.* 2014). This scenario may favor the trade of exotic plant resources.

Nevertheless, although urbanization reduces traders' direct access to native resources while facilitating the introduction of exotic species, alternative strategies are often employed to ensure a continuity of native species supply. One such strategy is cultivating in readily accessible areas. For instance, Van Andel and Havinga (2008) observed in Surinamese markets that over 80% of traded species were native, yet fewer than half were collected directly from forests. Instead, many were cultivated in nearby villages, agricultural fields, and urban gardens, and subsequently harvested for sale.

Similarly, Towns *et al.* (2014) found that increasing distance from primary forests often led to the cultivation of native species in adjacent areas. Their study further revealed that some species regarded as extinct in the wild were being maintained and managed through cultivation, thereby ensuring their continued availability in urban markets. Thus, just as exotic species expand into urban areas owing to their adaptability and ease of cultivation (Gama *et al*. 2018, Santos *et al.* 2014, Schneider 2007), native species may also be cultivated and adapted for commercial purposes in these environments (Van Andel & Havinga 2008).

Another factor motivating access primary vegetation is demand for particular local species of cultural and medicinal significance (Medeiros *et al.* 2017, Silva *et al.* 2019, Towns *et al*. 2014). Vendors therefore obtain these resources through multiple channels, such as harvesting in forested and fragmented areas cultivation, or sourcing via intermediaries without accessing these areas themselves (Van Andel & Havinga 2008, Towns *et al.* 2014, Albuquerque *et al.* 2007). These varied acquisition strategies help sustain both exotic and native species in medicinal markets.

Markets exhibit highly complex dynamics, with resources originating from multiple regions. In some cases, this diversity may surpass that of the local flora. However, this complexity may not accurately reflect local knowledge of medicinal plants or their use in treating modern diseases. It is therefore plausible that local and traditional communities present different realities which merit further investigation.

Limitations

For our systematic review, we carefully selected articles that examined the patterns of use of medicinal plants sold in global markets. While this approach has its benefits, it also has negative implications. By discarding studies with bias review, we lose valuable information. However, we recognize that this loss is less concerning than including studies with a high risk of bias. Additionally, our keywords covered numerous studies. For future systematic reviews on this topic, however, we recommend including the keyword "trade," as it may be useful for identifying studies related to the commercialization of natural resources. Another important factor is that belief-based diseases were not included in our study, highlighting the limitations of official bodies in classifying diseases grounded in local knowledge. Furthermore, the context of markets may have limited our findings since markets are biocultural complexes. The knowledge of sellers, the surrounding population, and the diversity of commercialized medicinal plants is dynamic and may not reflect local therapeutic choices for treating modern diseases due to external factors influencing the trade of these plants. Local and traditional communities may have different realities that require additional investigation.

Conclusion

From a theoretical perspective, we have advanced our understanding of the role of exotic plants in treating modern diseases in local public markets. People seek out these plants to address symptoms, resulting in noticeable similarities between exotic and native plants in the treatment of modern diseases. However, regarding the influence of urbanization on the proportion of exotic and native species used to treat modern diseases, the market context may have slightly constrained our interpretation because it does not always accurately reflect local ecological knowledge dynamics. Therefore, we recommend that future studies focus on the communities themselves. From a practical standpoint, understanding how populations adapt their medicinal plant-based medical systems to treat modern diseases in the context of ongoing environmental and lifestyle changes is crucial, as it highlights the vulnerabilities of these systems and their adaptive processes.

Declarations

List of abbreviations: PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses; IUCN - International Union for Conservation of Nature; OR - Odds Ratio measure; COVID-19 – Coronavirus disease 2019; MERS - Middle East Respiratory Syndrome; SARS - Severe Acute Respiratory Syndrome.

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Author contributions: TCS, PMM, and WSFJ provided the idea, with methodological adjustment, analyzed the data, and wrote the manuscript; MLS collected the data, with methodological adjustment, and wrote the manuscript; BFB collected the data and wrote the manuscript; LMR and JGS contributed with methodological adjustment, data analyses and wrote the manuscript; UPA assisted in the discussion and wrote the manuscript. All authors read and approved of the final manuscript.

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Appendix

Diseases of modernity, according to the literature and found in the studied markets.

Body System	Diseases of modernity according to literature	Reference	Diseases of modernity found in the markets studied
Mental, Behavioral or Neurodevelopmental Disorders	Schizophrenia, depression, anxiety, stress, attention deficit disorder, autism, insomnia, dementia, eating disorders, postpartum depression, and other psychological disorders such as obsessive-compulsive disorder, bipolar disorder, and others.	Corbett et al. (2018), Hegde (2015), Migdał & Živković (2007) Krakauer (2020) Hidaka (2012) Logan & Jacka (2014), Gurven & Liebermanb (2020), Basu &Dixit (2021), Samsel & Seneff (2013), Samsel & Seneff (2015), Zarean et al. (2021), Keohane et al. (2017), Kalia (2002), Choi et al. (2005), Blacher et al. (2016), Hahn-Holbrook & Haselton (2014), Gibbons (2016), Yacoub et al. (2011).	Stress, anxiety, depression, and insomnia.
Diseases of the Digestive System	Acid reflux, chronic heartburn, cavities, celiac disease, gallbladder disease, cholera, chronic constipation, liver cirrhosis and liver disease, Crohn's disease, irritable bowel syndrome, inflammatory colitis, acute pancreatitis, peptic ulcers, stomach ulcers, gallstones, and hemorrhoids.	Hegde (2015), Gurven & Liebermanb (2020), Samsel & Seneff (2013), Samsel & Seneff (2015) Bloom et al. (2020) Morris (2011), Gismera & Aladrén (2008), Kelsen & Wu (2012), Bernstein & Shanahan (2008), Okin & Medzhitov (2012), Waetzig & Schreiber (2003).	Acid reflux, chronic heartburn, cavities, gallbladder disease (cholecystitis), chronic constipation, liver disease, liver cirrhosis, hepatitis, scurvy, cholera, stomach diseases such as Crohn's disease, enterocolitis, irritable bowel syndrome, inflammatory colitis, peptic ulcers, hemorrhoids, gallstones, and stomach ulcers.
Cardiovascular diseases	Endothelial dysfunction, congenital heart disease in newborns, alcoholic cardiomyopathy, arrhythmias, coronary artery disease, heart failure, stroke, heart attack, sudden tissue ischemia, thrombosis, hypertension, arteriosclerosis, dyslipidemia, high cholesterol, and cardiovascular diseases in general.	Sharifi-Rad et al. (2020), Samsel & Seneff (2015), Senapati et al. (2015), Yacoub et al. (2011), Migdał & Živković (2007), Sengupta & Dutta (2021), Blacher et al. (2016), Booth et al. (2000) Gayathri et al. (2011), Okin & Medzhitov (2012), Sengupta & Dutta (2021), Krakauer, (2020),Power (2012), Gurven & Liebermanb (2020), Sudano & Gregorio (2011), Hidaka (2012), Choi et al. (2005).	Heart attack, angina, arrhythmias, coronary artery disease, hyperlipidemia, heart failure, stroke, thrombosis, arteriosclerosis, high cholesterol, and hypertension.
Infectious and parasitic	Dengue, COVID-19, influenza,	Bloom et al. (2020),	Dengue, COVID-19,

diseases	malaria, chikungunya, Zika, H1N1, HIV, AIDS, measles, MERS, SARS, yellow fever, rabies, Ebola, leptospirosis, Lyme disease, and anthrax.	Sengupta & Dutta (2021), Ehlers & Kaufmann (2010), Herbert et al. (2009), Chemych E Lutai (2020).	influenza, malaria, chikungunya, HIV, measles, yellow fever, and rabies.
Diseases of the skin and subcutaneous tissue	Acne, eczema, lupus, and psoriasis.	Hegde (2015), Gurven & Liebermanb (2020), Herbert et al. (2009), Gawda et al. (2017), Ehlers & Kaufmann (2010).	Acne, eczema, lupus, and psoriasis.
Diseases of the blood or blood-forming organs	Anemia	Samsel & Seneff (2013).	Anemia and hypertension.
Diseases of the sistema musculoesquelético.	Ankylosing spondylitis, bunion, rickets, sarcopenia, flat feet, musculoskeletal disorders, hammer toes, and rheumatic diseases such as rheumatoid arthritis, fibromyalgia, gout, lower back pain, osteoporosis, plantar fasciitis, and spinal problems.	Ehlers & Kaufmann (2010), Gurven & Liebermanb (2020), Hahn-Holbrook & Haselton (2014), Booth et al. (2000), Hegde (2015), Yacoub et al. (2011), Zarean et al. (2021), Okin & Medzhitov (2012), Gawda et al. (2017), Deaner & Allendale (2014), Hidaka (2012).	Rickets, rheumatic diseases such as rheumatoid arthritis, fibromyalgia, and gout, lower back pain and related problems, osteoporosis, tendinitis, plantar fasciitis, and herniated discs.
Diseases of the visual system	Glaucoma & myopia syndrome.	Gurven & Liebermanb (2020).	Myopia syndrome.
Immune System Diseases	Allergies.	Sharifi-Rad Et Al. (2020), Corbett et al. (2018), Logan & Jacka (2014), Jackson (2001), Gurven & Liebermanb (2020), Prescott (2013), Ehlers & Kaufmann (2010), Okin & Medzhitov (2012), Migdał & Živković (2007), Herbert et al. (2009).	Allergies (allergic flu, allergic fever).
Diseases of the system Endocrine, nutritional, or metabolic diseases	Diabetes, thyroid problems such as Basedow-Graves' disease, Hashimoto's thyroiditis, and hypothyroidism, lactose intolerance, metabolic disorders in newborns, metabolic syndrome, obesity, and scurvy.	Kelsen & Wu (2012), Booth et al. (2000), Gayathri et al. (2011), Samsel & Senef (2015), Okin & Medzhitov (2012), Yacoub et al. (2011), Migdał & Živković (2007), Sengupta & Dutta (2021), Giannouli (2017), Gawda et al. (2017), Blacher et al. (2016), Hahn-Holbrook & Haselton (2014), Sharifi-Rad et al. (2020), Corbett et al. (2018), Hegde (2015), Krakauer (2020), Deaner & Allendale (2014), Hidaka (2012), Ginaldi et al. (2005), Power (2012), Logan & Jacka (2014), Gurven & Liebermanb (2020), Basu & Dixit (2021), Prescott (2013),	Diabetes, hypothyroidism, metabolic syndrome, obesity, and scurvy.

		Robbins et al. (2014), Patil et al. (2011), Sudano & Gregorio (2011), Samsel & Seneff (2013), Samsel & Seneff (2015), Zarean et al. (2021).	
Diseases of the respiratory system	Rhinitis, sinusitis, tuberculosis, pulmonary disorders such as asthma, chronic bronchitis, pulmonary emphysema, pneumonia, apnea, sarcoidosis, and others.	Gayathri et al. (2011), Herbert et al. (2009), Sharifi-Rad et al. (2020), Bloom et al. (2020), Ehlers & Kaufmann (2010), Godreuil et al. (2007), Senapati et al. (2015), Okin & Medzhitov (2012), Hegde (2015), Deaner & Allendale (2014), Gurven & Liebermanb (2020), Prescott (2013).	Chronic lung diseases such as asthma, chronic bronchitis, pneumonia, rhinitis, sinusitis, and tuberculosis.
Neoplasms	Adrenal incidentaloma and cancers in general.	Angeli & Terzolo (2002), Samsel & Seneff (2013), Prescott (2013), Patil et al. (2011), Kelsen & Wu (2012), Booth et al. (2000), Gayathri et al. (2011), Ehlers & Kaufmann (2010), Samsel & Senef (2015), Senapati et al. (2015), Okin & Medzhitov (2012), Gibbons (2016), Migdał & Živković (2007), Choi et al. (2005), giannouli (2017), Blacher et al. (2016), Sharifi-Rad et al. (2020), Corbett et al. (2018), Hegde (2015), Deaner & Allendale (2014), Hidaka (2012), Gurven & Liebermanb (2020), Prescott (2013).	Cancer (other types, bowel, lung, breast, and leukemia) and adrenal disorders.
Diseases of the nervous system	Carpal tunnel syndrome, multiple sclerosis, Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis.	Gurven & Liebermanb (2020), Ehlers & Kaufmann (2010), Samsel & Senef (2015), Gawda et al. (2017), Senapati et al. (2015), Giannouli (2017), Keohane et al. (2017), Sharifi-Rad et al. (2020), Corbett et al. (2018), Ginaldi et al. (2005), Samsel & Seneff (2013).	Multiple sclerosis, Alzheimer's, neuritis, and Parkinson's disease.
Disorders of the genitourinary system	Kidney diseases and urinary tract problems.	Blacher et al. (2016), Samsel & Seneff (2013), Gibbons (2016).	Bladder disease, prostate problems, kidney disease, and urinary tract problems.
Reproductive system diseases	Ovarian problems such as endometriosis, infertility, pre-eclampsia, and polycystic ovary syndrome.	Gurvena & Liebermanb (2020), Samsel & Seneff (2013).	Infertility and ovarian problems
Congenital malformations & neurological conditions	Microcephaly in Children.	Samsel & Seneff (2013).	---
Other Systems or General Conditions	Necrotizing enterocolitis and fatigue.	Kelsen & Wu (2012), Gurvena & Liebermanb (2020).	Fatigue