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Are weeds an enemy or a multipurpose resource? An ethnobotanical perspective

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Are weeds an enemy or multipurpose resource? An ethnobotanical perspective independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

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Abstract

Modern conventional agriculture relies on high input monoculture farming of few domesticated food crops, resulting in decreased dietary diversity and poor nutritional security in the diets of people in developing countries. Weedy species of plants are mostly regarded as harmful to the effectivity of agriculture, yet they represent an easily accessible source of nutrition for rural population. This review investigates the role and importance of weedy species in the tropics, where malnutrition poses a threat to the lives of local people. Sixty-seven species of edible weedy species used as food source in the tropics were extracted from available literature, documenting their distribution, plant part used, mode of consumption, nutritional benefits and antinutritional properties. It was found that most edible weeds contain nutrients and vitamins essential to the human body, and therefore are suitable for supplementing the carbohydrate-based diets of rural people in the tropics. The aspect of traditional medicinal uses was also reviewed, concluding that most of the edible weedy species reported are valued in indigenous traditional medicines for the treatments of various diseases. The results indicate that weeds form integral parts of food baskets of people in the tropics, where indigenous knowledge of wild edible flora remains vivid.

Key words: agrobiodiversity, agroecology, ethnobotany, food, human nutrition, weed, wild edible plants

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1. Introduction

It is perceived that, in general, weeds are wild plants that emerge and dwell in areas where they are not desired. Weeds often interfere with the objectives of humans by invading agricultural areas and competing for resources with cultivated crops, thus reducing the overall productivity of the land (FAO 1986; Maroyi

2013). Therefore, weeds are, by definition, considered to be an undesirable feature of the landscape. What makes weeds so unpleasant and controversial from the human point of view is their mix of distinctive characteristics, making them hard to manage and allowing them to occupy almost any habitat. Among those traits there is fast growth and high reproductive rates, competitiveness, endurance, and their overall disruptive nature (James John et al. 1991; Westbrooks 1998). These attributes are mostly rare to cultural modern-day crops, due to the lengthy and precise process of cultivation under controlled conditions while implementing different techniques like selective breeding, genetic modification, and other mechanisms typical for intensive agriculture (Smýkal et al. 2014). Some wild plants which have not been selected for further cultivation, therefore, preserve these features formed by natural selection that favour them over domesticated plants in the task of the survival of the fittest. These species became the competitors of modern crops in the agronomical fields, and modern humans began to feel threatened. This attitude peaked during the midst of the twentieth century, when increasing human population putting pressure on food security became to raise concern (Ameen & Raza 2018).

Some significant changes needed to be met for food production to keep pace. The sector has shifted from a relatively simple, low input farming towards intensive high input farming systems. This movement of change in agricultural practices became known as the Green Revolution. Among established innovations, there was extensive fertilizer utilization, irrigation efficiency improvement, heavy machinery (reducing the need for human labour), and, finally, heavy pesticide and herbicide use (Ameen & Raza 2018). These last two innovations were perhaps the driving forces for a major shift in the perception of wild-growing plants. As the increase of yields and overall efficiency of main food crops became the target, agriculture shifted towards monocropping - occupying a large area with a single crop (Ameen & Raza 2018). In this type of production, a high frequency of pests and weeds is inevitable. Any subject causing potential yield decrease and soil depletion was thus to be eradicated.

Opposite to traditional agriculture, Green Revolution agriculture focuses on cereal grain monocultures. These extensively produced grains have helped to raise many people from starvation. However, many have been affected by malnutrition and iron or vitamin-A deficiency (Pawera & Polesný 2015). Malnutrition related issues became to be one of the leading causes of children deaths in developing counties (Buttel 1995). Additionally, according to Shiva (2000), the weed control approach of massive pesticide and herbicide implementation has increased the likelihood of health issues in some rural communities with poor education and farming practices, such as high usage of chemicals combined with scarce use of protective gear.

To conclude the aspects mentioned above, the concept of weeds is currently mainly analysed from a cash-crop threatening perspective, adopting an approach of suppression. Other attitudes have long been scarcely taken into consideration. Considered from a different point of view, most of those wild plants are edible and often exhibit valuable nutritional and medicinal properties. According to Duke's Handbook of Edible Weeds, approximately one in ten plants on Earth is a weed, and out of 18 most obnoxious weeds, 89% are edible (Duke 2001).

Green Revolution agriculture relies on large-scale high input techniques, such as heavy machinery and high utilisation of agrochemicals. Consequently, these practices were not adopted in countries with poorer assets, technology, market infrastructure and natural conditions, represented by sub-Saharan Africa or areas of South Asia. The agricultural model of these regions is mainly focused on self-sustaining household production and small-scale local trade, rather than large-scale commercial production (Pingali 2012). These and most other tropical regions are still facing poverty and underdevelopment at the beginning of the 21st century (Balls 2001). 40 out of 47 countries listed on FAO's list of low-income food-deficit countries lie in the tropics (FAO 2021). Populations of these countries often suffer hidden hunger, a state of undernourishment resulting from a lack of nutrient-rich food, often causing preventable health damage, such as eye disorders caused by the lack of beta-carotene in Asia, where people's diets are dominated by rice (Pawera & Polesný 2015). Vitamin A, iron, zinc, and iodine deficiencies are among the most common in populations of low and middle-income countries (Lowe 2021). Edible weedy plants are an easily accessible source of nutrients and therefore have a great potential in assessing such issues in food-deficit countries. They form an essential part of the rural diet, not only in times of food scarcity when the conditions for modern crop cultivation are unfavourable (Cruz-Garcia & Price 2012). However, their use is on decrease, mainly due to the loss of traditional knowledge (Turner et al. 2011) and global changes in the agricultural approach (Pawera & Polesný 2015). This thesis, therefore, aims to review data regarding these vulnerable areas of the tropics, where nutrition providing edible weedy plants represent a unique potential in ensuring food security and combating malnutrition.

2. Aims of the Thesis

The aim of this thesis is to review and evaluate available data on the use of tropical edible weed species. Broader aspects of weedy species in relation to ethnobotanical knowledge, human nutrition, antinutritive properties and agroecology will be discussed. The output of this review is a list of weedy species reported to be used for food purposes in the tropics.

3. Methodology

A systematic literature review was done through electronic research on Scopus, Web of Knowledge, JSTOR, CAB Abstracts from their inception until January 2022, and a manual search of relevant bibliographies. Due to the scarcity and geographical limitations of research regarding the topic of edible weeds (further listed as “EWs”), the research focus for the review was expanded to include articles concerning wild edible plant species (further listed as “WEPs”). Primary search terms used were ‘edible weed’ and ‘wild edible plants’. No restriction on the language of publication was applied. Results were selected based on their geographical field of research. To specify the research within the WEPs articles, the species extracted from WEPs sources were limited to those which matched with species included in at least one of the EWs sources. Species found in EWs sources were not imposed to such conditions of reciprocity. To assure the relevancy of the results, a minimum of two sources per each species considered in this analysis was set. Species’ weed statuses were further validated with the Global Compendium of Weeds (2007). A list of weedy plants previously reported to be used for food uses in tropical countries was created. The International Plant Name Index (2004) web-based database has been used to determine the correct spelling of full plant scientific names. Further searches were undertaken using the names of individual plants with edible uses reported in available literature. Thorough database research has proved that the topic of WEPs receives more scientific attention than the topic of EWs, therefore more data on WEPs was found than on EWs.

3.1. The geographical focus

This thesis adopts a widely accepted definition of the tropics, which states that the tropics are the regions situated within the area between the Tropic of Cancer and the Tropic of Capricorn (National Geographic Society 2011), as illustrated in Figure 1. Tropics occupy about 36 % of Earth’s landmass and are home to approximately one-third of the total population. (National Geographic Society 2011). Tropical areas fall under Köppen-Geiger climate classes of tropical rainforest, tropical monsoon, tropical savannah, and arid desert (Beck et al. 2018). The tropical rain belt dominates tropical regions’ climatic characteristics, a string of rainfall oscillating between the Tropics of

Cancer and Capricorn (Dixit 2021). Regions of tropical rainforest, monsoon and savannah typically experience two seasons - dry and wet. The bulk of the year's precipitation falls during wet seasons, when the average monthly rainfall surpasses 60 mm (Peel et al. 2007). Dry seasons' precipitation rates are below 60 mm (Peel et al. 2007) and the land is subjected to several drought. Most areas of the tropics belong to this category of dry-wet climate. The regions of the arid desert experience lack of precipitation and excess evaporation, with mean monthly temperatures above 18 °C (Woodward 2019). Desert areas experience less than 250 mm of yearly rainfall and local temperatures oscillate between reaching more than 40°C during summer days and dropping below 0°C on winter nights (Woodward 2019). The Saharan desert, along with the Arabian desert on the Arabian Peninsula and the Sechura desert on the eastern coast of Peru would be the three main areas of desert climate found in the tropical region (Peel et al. 2007).

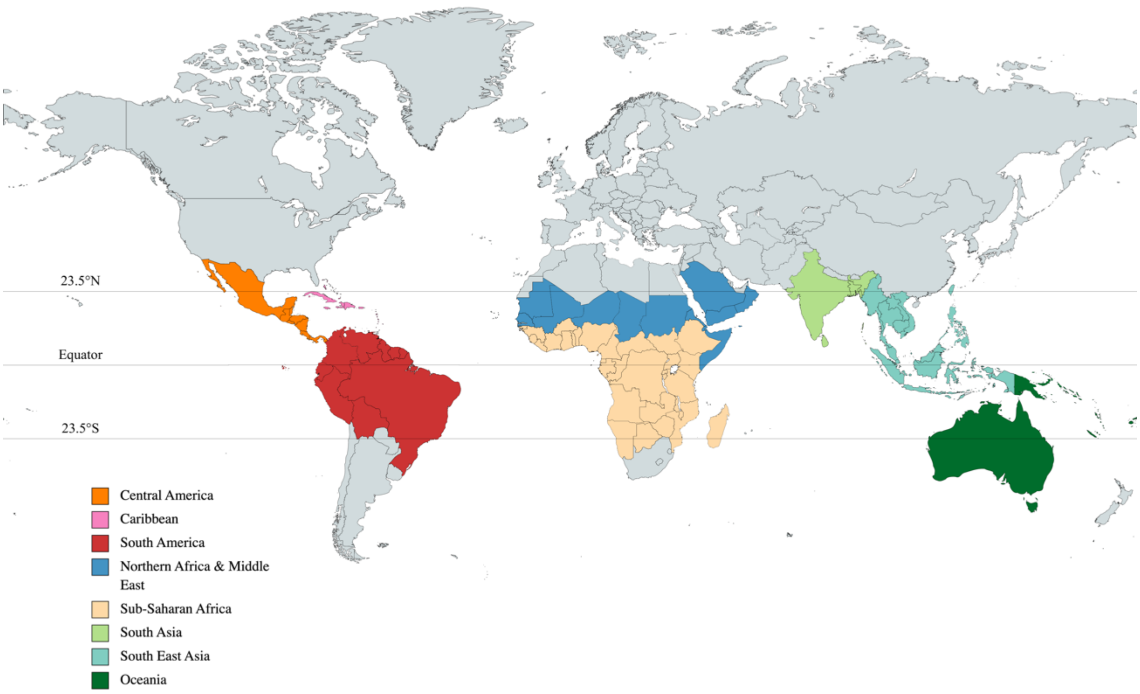

Figure 1 Map of the tropical countries of the world *(Source: author's own work)*

Sources for research were selected to equitably cover the geographical area of tropical regions of Asia, Africa, and America. Some limitations were met in the process of collecting related documents. Several regions seem to receive more scientific attention and therefore were subjected to more research than others. The most eminent areas of this occurrence were India and Mexico. In order to minimise bias, the number of sources related to these regions had to be limited. Another limitation was the lack of available data in other regions, especially regarding EWs. This issue was most prominent in the region of tropical Americas, where the only obtained data on EWs were from Mexico. This information is important to point out as it is likely that it affected the objectivity of the results of this study.

4. Literature Review

4.1. Diversity of weeds

"Weed" is a term used for describing plants, yet it bears no botanical significance. It is a label used depending on the context in which the considered plant is put. A general definition of the term would be that a plant is a weed when emerging in a situation where it is not wanted (Duke 2001; Zimdahl 2007). That implies plants spontaneously growing in agricultural fields, intruding the artificially maintained unformal pattern of the currently cultivated crop. It this context and regarding crop-rotation farming, even a self-set plant from a seedling remaining from previous crop season would be considered as weedy. This interpretation is however irrelevant to the focus of this review. The target of this work is to document different perspectives and uses of wild botanical species, which are commonly considered as useless and rather intrusive.

Weeds can be found across many botanical families; however, three of them (Poaceae, Asteraceae and Cyperaceae) account for almost half (43%) of total world's most problematic weed flora (Holm 1978). Only two species of Poaceae and one species of Cyperaceae was reported in our list of weeds used as food sources in the tropics (Table 1). However, it is rather probable that this occurrence may be due to regional disbalance in used sources. It would be incorrect to assume that only a few weedy species of Poaceae and Cyperaceae possess edible properties. Additionally, the fact that the family of Poaceae is the family of many of the most important human foodcrops (rice, maize, wheat, sugar cane) rather suggests that many of its wild genera would also be edible (Zimdahl 2007).

Nevertheless, the results are likely to reflect regional preferences towards consuming weedy species of the Amaranthaceae, Fabaceae, and Asteraceae families, as those were the families of most species reports (11, 9, 6, respectively). A total of 67 vascular edible weedy species were reported based on our analysis (Table 1).

Table 1 Weed species used for food purposes in the tropics

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Aizoaceae								
Trianthema portulacastrum L.	annual succulent	(pantropical)	young shoots	cooked as vegetable		urinary disorders, oedema, headache, rheumatic pains		(Sinha & Lakra 2007; Ediriweera 2010; Blanckaert et al. 2012; Satapathy et al. 2012; Marandi & Britto 2015)
Amaranthaceae								
Alternanthera sessilis (L.) R. Br. ex DC.	perennial herb	tropical America (pantropical)	young shoots	cooked as vegetable		antioxidant, Parkinsonism, eye diseases, dysentery, wounds, menstrual disorder, malaria		(Sinha & Lakra 2007; Ediriweera 2010; Satapathy et al. 2012; Marandi & Britto 2015; Aryal et al. 2019a; Pawera et al. 2020; Daum et al. 2021; Vineeta et al. 2022)
Amaranthus hybridus L.	annual herb	tropical America (cosmopolitan)	leaves, young shoots	*quelite**, cooked as vegetable	rich in Fe, Zn, vitamin A, protein, mineral salts	antioxidant, knee pain, gastric issues	high in nitrates	(Duke 2001; Vieyra-Odilon & Vibrans 2001; van den Eynden et al. 2003; Ogoye-Ndegwa & Aagaard-Hansen 2003; Madamombe-Manduna et al. 2008; Maroyi 2011, 2013; Blanckaert et al. 2012; Turreira-García et al. 2015; Ondua et al. 2019; François Malan et al. 2020; Mateos-Maces et al. 2020; Pawera et al. 2020; Pascual-Mendoza et al. 2021; Daum et al. 2021; Kissanga et al. 2021)
Amaranthus spinosus L.	annual herb	tropical America (cosmopolitan)	leaves, young shoots	*quelite*, cooked as vegetable	source of minerals, dietary fibre, phenolic compounds, flavonoids	antioxidant, obesity, eczema, abscesses, dysuria, burns, wounds, inflammation, indigestion, laxative, diuretic	high in nitrates	(Díaz-Betancourt et al. 1999; Rajasab & Mahamad 2004; Sinha & Lakra 2007; Ediriweera 2010; Satapathy et al. 2012; Maroyi 2013; Marandi & Britto 2015; Ojelel et al. 2019; Saikia & Kumar 2020; Mateos-Maces et al. 2020; Prince et al. 2021; Nguyen et al. 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Amaranthus viridis L.	annual herb	Asia (cosmopolitan)	leaves, young shoots	*quelite*, cooked as vegetable	high protein and vitamin contents, source of Ca, Fe, P	oedema, laxative, dysentery, diabetes	toxic when in excess	(Sinha & Lakra 2007; Ediriweera 2010; Termote et al. 2010; Cruz-Garcia & Price 2012; Sharma et al. 2012; Marandi & Britto 2015; Sujarwo et al. 2016; Neamsuvan & Ruangrit 2017; Saikia & Kumar 2020; Mateos-Maces et al. 2020; Abbas et al. 2020)
Celosia argentea L.	annual herb	tropical Africa (pantropical)	leaves, young shoots	cooked as vegetable		menorrhagia, dysentery, postdelivery body ache		(Sinha & Lakra 2007; Satapathy et al. 2012; Marandi & Britto 2015; Sujarwo et al. 2016; Adegbaju et al. 2019; Ulian et al. 2020)
Celosia trigyna L.	annual herb	(tropical Africa, Arabian Peninsula)	leaves, shoots	cooked as vegetable	high protein content, source of minerals	sores, chest pains, diarrhoea, menstrual cramps		(Ogoye-Ndegwa & Aagaard-Hansen 2003; Termote et al. 2010; Maroyi 2011, 2013; Ofusori et al. 2019)
Digera muricata (L.) Mart.	annual herb	tropical Africa (Africa, Asia)	leaves, young shoots	cooked as vegetable		urinary disorders, constipation		(Sinha & Lakra 2007; Marandi & Britto 2015; Yaseen et al. 2015; Aryal et al. 2019a; Bhatti et al. 2022)
Dysphania ambrosioides (L.) Mosyakin & Clenants	annual herb	tropical America (cosmopolitan)	leaves, young shoots	*quelite*, cooked as vegetable		intestinal worms	toxic when in excess	(Tampion 1977; Kliks 1985; Vieyra-Odilon & Vibrans 2001; Turreira-García et al. 2015; Mateos-Maces et al. 2020; Pascual-Mendoza et al. 2021)
Chenopodium album L.	annual herb	Eurasia (cosmopolitan)	leaves, young shoots, seeds	leaves, young shoots as *quelite* and cooked as vegetable, seeds ground into flour	source of Fe, Zn, Ca, Mg, vitamin A, vitamin C	leukodermas, abdominal pain, gastric, seminal weakness, cardiac disorders, urinary disorders	high in nitrates, contains oxalic acid	(Díaz-Betancourt et al. 1999; Jeeva et al. 2006; Sinha & Lakra 2007; Maroyi 2011, 2013; Turner et al. 2011; Lal et al. 2012; Razzaq et al. 2013; Marandi & Britto 2015; Saikia & Kumar 2020; Mateos-Maces et al. 2020; Abbas et al. 2020; Kissanga et al. 2021)
Chenopodium berlandieri Moq.	annual herb	(Europe, North America)	leaves; young shoots	*quelite*, cooked as vegetable	high protein and vitamin contents, source of Ca, Fe, P	antibacterial, antiscorbutic tonic, diuretic	high in nitrates	(Vieyra-Odilon & Vibrans 2001; Blanckaert et al. 2012; Mateos-Maces et al. 2020)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Ouret lanata (L.) Kuntze.	woody perennial herb	(Africa to tropical Asia)	leaves, rhizomes	cooked as vegetable		urinary disorders, asthma, snake bite, abortion inducement		(Jeeva et al. 2006; Sinha & Lakra 2007; Ediriweera 2010; Marandi & Britto 2015; Vineeta et al. 2022)
Apiaceae								
Centella asiatica (L.) Urb.	perennial herb on damp soils	tropical Asia (pantropical)	whole plants	cooked as vegetable, chutney	source of minerals	memory power increase, stomachic, constipation, liver tonic, gastric acidity, asthma, leprosy, psoriasis, hair growth, associated with neurodegenerative prevention research		(Sinha & Lakra 2007; Ediriweera 2010; Cruz-Garcia & Price 2012; Satapathy et al. 2012; Lal et al. 2012; Marandi & Britto 2015; Chiroma et al. 2019; Hunter et al. 2019; Saikia & Kumar 2020; Nguyen et al. 2021)
Eryngium foetidum L.	perennial herb	(tropical America)	leaves	prepared as chutney; condiment	source of carotenoids	antioxidant, antimicrobial, common cold, cough, fever, cardiovascular disorders, diuretic		(Lévi-Strauss 1952; Khare 2004; Marandi & Britto 2015; Turreira-García et al. 2015; Hunter et al. 2019; Mateos-Maces et al. 2020; Anju et al. 2021; Pascual-Mendoza et al. 2021)
Asteraceae								
Bidens pilosa L.	annual herb	tropical America (pantropical)	young leaves, young shoots	*quelite*, cooked as vegetable	rich in protein, P, Cu, B	wounds, ulcers, immunological disorders, digestive disorders, infectious ailments, cancers, metabolic syndrome		(Díaz-Betancourt et al. 1999; Vieyra-Odilon & Vibrans 2001; Ogoye-Ndegwa & Aagaard-Hansen 2003; Madamombe-Manduna et al. 2008; Maroyi 2011, 2013; Marandi & Britto 2015; Mateos-Maces et al. 2020; Jayasundera et al. 2021; Gumisiriza et al. 2021; Daum et al. 2021; Kissanga et al. 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Galinsoga parviflora Cav.	annual herb	tropical America (cosmopolitan)	young leaves, young shoots	*quelite*, cooked as vegetable	rich in Fe, Cu			(Vieyra-Odilon & Vibrans 2001; Madamombe-Manduna et al. 2008; Maroyi 2013; Mateos-Maces et al. 2020; Pascual-Mendoza et al. 2021; Kissanga et al. 2021)
Hypochaeris radicata L.	perennial herb	Morocco (cosmopolitan)	leaves, rhizomes	leaves eaten raw or cooked as a vegetable; rhizomes ground		antioxidant, anti-inflammatory		(Díaz-Betancourt et al. 1999; Turner et al. 2011; Nyerges 2017; Hwang et al. 2019)
Sonchus oleraceus L.	annual herb	Europe (cosmopolitan)	leaves, rhizomes	leaves as *quelite* or raw, rhizomes cooked as vegetable		antimicrobial properties, Anemia, cervical cancer		(Díaz-Betancourt et al. 1999; Vieyra-Odilon & Vibrans 2001; Madamombe-Manduna et al. 2008; Turner et al. 2011; Blanckaert et al. 2012; Maroyi 2013; Petropoulos et al. 2019; Abbas et al. 2020; Pascual-Mendoza et al. 2021; Gumisiriza et al. 2021)
Taraxacum sect. *Taraxacum* F.H.Wigg	perennial herb	Eurasia (cosmopolitan)	leaves, flowers, taproots	leaves as *quelite* or cooked as vegetable, flowers eaten raw, taproots boiled or picked	high in vitamins A, B and C, lecitin, Fe, P, K	diuretic, jaundice		(Díaz-Betancourt et al. 1999; Duke 2001; Clare et al. 2009; Benoliel & Orsen 2011; Turner et al. 2011; Petropoulos et al. 2019)
Tridax procumbens (L.) L.	perennial herb	tropical America (pantropical)	leaves	*quelite*, cooked as vegetable	source of Ca, Mg, K, Na, Se, carotenoids	liver disorders, gastritis, heartburn, blisters, high blood pressure, bronchial catarrh, malaria, dysentery, diarrhea, stomach-ache, headache		(Sinha & Lakra 2007; Madamombe-Manduna et al. 2009; Wani et al. 2010; Nallella et al. 2013; Jayasundera et al. 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Basellaceae								
Basella alba L.	vine perennial herb	tropical Asia (Africa)	leaves, rhizomes	raw, cooked as a vegetable	rich in Fe, vitamin A	anti-diabetic, anti-inflammatory, antioxidant, tuberculosis treatment, insomnia		(Ogoye-Ndegwa & Aagaard-Hansen 2003; Marandi & Britto 2015; Neamsuvan & Ruangrit 2017; Ojelel et al. 2019; Aryal et al. 2019a; Borelli et al. 2020; Sagar et al. 2022; Vineeta et al. 2022)
Brassicaceae								
Brassica rapa L.	biennial herb	Mediterranean (cosmopolitan)	leaves, flowers, young shoots, seeds	cooked as a vegetable, pickled, seeds ground	source of Ca, Se	antiarthritic, muscle relaxant, wound disinfection	contains glucosinolates	(Díaz-Betancourt et al. 1999; Vieyra-Odilon & Vibrans 2001; Turner et al. 2011; Maroyi 2013; Mateos-Maces et al. 2020; Pascual-Mendoza et al. 2021; Salehi et al. 2021; Cámara-Martos et al. 2022)
Raphanus raphanistrum L.	annual herb	Europe (cosmopolitan)	leaves, young shoots, rhizomes	leaves, shoots, rhizomes as *quelite*, leaves eaten raw	source of vitamin E, polyunsaturated fatty acids, phenolic compounds	fungal infection treatment		(Vieyra-Odilon & Vibrans 2001; Turner et al. 2011; Iyda et al. 2019; Pascual-Mendoza et al. 2021; Anand et al. 2022)
Cleomaceae								
Cleome gynandra L.	annual herb	(pantropical)	leaves, young shoots	cooked as vegetable, sun-dried		anti-inflammatory, worm Infestation, malaria, fungal diseases, cancer		(Ogoye-Ndegwa & Aagaard-Hansen 2003; Sinha & Lakra 2007; Madamombe-Manduna et al. 2009; Ediriweera 2010; Maroyi 2011, 2013; Marandi & Britto 2015; Hunter et al. 2019; Mateos-Maces et al. 2020; Ulian et al. 2020; Daum et al. 2021; Chand et al. 2022)
Cleome monophylla L.	annual herb	tropical Africa (India)	leaves, young shoots	cooked as vegetable	source of micronutrients	anti-inflammatory, antirheumatic, antidermatotic, treatment of bile enlargement		(Kumari & Kumar 2001; Khare 2004; Odhav et al. 2007; Madamombe-Manduna et al. 2009; Maroyi 2013; Marandi & Britto 2015; Daum et al. 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Cleome viscosa L.	annual herb	tropical Asia (pantropical)	young shoots	cooked as vegetable		headache, swellings, stomachic, malaria, skin disorders, ulcer, earache		(Sinha & Lakra 2007; Ediriweera 2010; Satapathy et al. 2012; Lal et al. 2012; Dhanam & Elayaraj 2014; Marandi & Britto 2015; Chand et al. 2022)
Caryophyllaceae								
Drymaria spp.	annual herb	tropical America (pantropical)	whole plants	cooked as vegetable		headache, throat pain, fever, cough, pneumonia		(Díaz-Betancourt et al. 1999; Vieyra-Odilon & Vibrans 2001; Madamombe-Manduna et al. 2008; Vineeta et al. 2022)
Spergula arvensis L.	annual herb	Eurasia (cosmopolitan)	leaves, young shoots, seeds	leaves, shoots as *quelite* or cooked as vegetable, seeds ground	source of Mg, Na, P	antibacterial, antifungal, laxative, diuretic		(Wilman & Riley 1993; Vieyra-Odilon & Vibrans 2001; Sinha & Lakra 2007; Marandi & Britto 2015)
Commelinaceae								
Commelina benghalensis L.	perennial herb	Eurasia (pantropical)	leaves, young shoots, rhizomes	cooked as vegetable		antioxidant, laxative, leprosy, snake bite, swelling, cancer, skin diseases, tinea corporis		(Sinha & Lakra 2007; Lal et al. 2012; Kanta Sahu et al. 2013; Marandi & Britto 2015; Gumisiriza et al. 2021; Daum et al. 2021; Vineeta et al. 2022)
Commelina diffusa Burm.f.	perennial herb	Eurasia (pantropical)	leaves	cooked as vegetable		antibacterial, veneral diseases, diarrhea, tuberculosis, cramps		(Díaz-Betancourt et al. 1999; Duke 2001; Balemie & Kebebew 2006; Blanckaert et al. 2012; Frankova et al. 2021)
Commelina zambesica C.B. Clarke	perennial herb	Africa (Africa)	young shoots, seeds	cooked as vegetable				(Madamombe-Manduna et al. 2009; Maroyi 2013)
Cyanotis axillaris (L.) D. Don ex Sweet	creeping perennial herb	India (Asia, Australia)	leaves	cooked as vegetable		anti-inflammatory, ascites, abortions		(Sinha & Lakra 2007; M et al. 2011; Marandi & Britto 2015)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Convolvulaceae								
Ipomoea aquatica Forssk.	perennial herb growing on damp soils	tropical Asia (pantropical)	leaves	*quelite*, cooked as vegetable		anti-inflammatory, antioxidant, rheumatism, purgative, ringworm, skin issues		(Cruz-Garcia & Price 2012; Lal et al. 2012; Kanta Sahu et al. 2013; Marandi & Britto 2015; Aryal et al. 2019a, 2019b; Pawera et al. 2020; Borelli et al. 2020)
Cucurbitaceae								
Cucumis anguria L.	creeping perennial herb	south Africa (Africa, tropical America)	leaves, young shoots, fruit	leaves, young shoots cooked as vegetable; fruit eaten raw, pickled	source of minerals, vitamins	jaundice, stomach pains		(Madamombe-Manduna et al. 2009; Maroyi 2011, 2013; Daum et al. 2021)
Cyperaceae								
Cyperus esculentus L.	annual herb	Mediterranean (pantropical)	rhizomes	roasted, prepared as a beverage	source of lipids, protein, starch, fiber, vitamins, minerals	antioxidant, abscesses, bladder ailments, boils, cancer, colds, colic, hemorrhage, stomachache, ulcers		(Duke 2001; Madamombe-Manduna et al. 2009; Maroyi 2011, 2013; Yu et al. 2022)
Dennstaedtiaceae								
Pteridium aquilinum (L.) Kuhn	fern	Eurasia (cosmopolitan)	shoots, rhizomes	cooked as vegetable, raw	source of polyunsaturated fatty acids, minerals	arthritis, tuberculosis, stomach cramps, diarrhea	contains tannic acid, thiaminase, filicin	(Lévi-Strauss 1952; Moerman 1998; Termote et al. 2010; Turner et al. 2011; Wang et al. 2020; Ulian et al. 2020; Nekrasov & Svetashev 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Euphorbiaceae								
Euphorbia hirta L.	annual herb	tropical America (pantropical)	fruits	raw	source of terpenoids, alkaloids, steroids, tannins, flavonoids, phenolic compounds	antibacterial, antioxidant, urinary issues, respiratory problems, digestive problems, tumors		(Madamombe-Manduna et al. 2009; Termote et al. 2010; Saikia & Kumar 2020; Gumisiriza et al. 2021)
Fabaceae								
Cajanus cajan (L.) Millsp.	perennial herb	India (pantropical)	seeds	raw	source of protein, vitamin B	diabetes		(Cruz-Garcia & Price 2012; Sujarwo et al. 2016; Medeiros Jacob et al. 2020; Ulian et al. 2020; Pascual-Mendoza et al. 2021)
Senna tora (L.) Roxb.	perennial herb	tropical America (pantropical)	leaves	cooked as vegetable, raw		antioxidant, cough, dermatitis, skin diseases, gastrointestinal disorders, associated with neurodegenerative prevention research		(Sinha & Lakra 2007; Ediriweera 2010; Marandi & Britto 2015; Bedigian 2019; Aryal et al. 2019a; Saikia & Kumar 2020)
Crotalaria spp.	annual / perennial subshrubs	India (cosmopolitan)	leaves, flowers, shoots	*quelite*, cooked as vegetable	source of beta-carotene	antibacterial, antioxidant, insomnia, sleeplessness, stress	some species contain pyrrolizidine alkaloids	(Mateos-Maces et al. n.d.; Morton 1994; Uiso & Johns 1996; Ogoye-Ndegwa & Aagaard-Hansen 2003; Blanckaert et al. 2007; Madamombe-Manduna et al. 2009; Khan et al. 2013; Turreira-García et al. 2015; Hitziger 2016; Ojelel et al. 2019; Bedigian 2019; Ulian et al. 2020; Borelli et al. 2020; Pascual-Mendoza et al. 2021; Daum et al. 2021)
Medicago lupulina L.	biennial herb	Eurasia (cosmopolitan)	leaves, young shoots	cooked as vegetable	source of minerals	arthritis, boils, cancer, dysuria, fever, gravel, heart ailments, scurvy, tumors	under certain conditions, the plant may generate cyanide	(Duke 2001; Sinha & Lakra 2007; Marandi & Britto 2015; Darch et al. 2020)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Medicago polymorpha L.	annual herb	Mediterranean (cosmopolitan)	leaves, flowers, seeds	cooked as vegetable, raw	high protein content			(Vieyra-Odilon & Vibrans 2001; Madamombe-Manduna et al. 2008; Elamine et al. 2022)
Mimosa pudica L.	creeping perennial herb	tropical America (pantropical)				anti-inflammatory, analgesic, high blood pressure, associated with CNS disorder research,	contains mimosine	(Madamombe-Manduna et al. 2008; Saikia & Kumar 2020; Castañeda et al. 2022)
Neptunia oleracea Lour.	perennial herb	tropical America (pantropical)	young leaves, shoot tips, young pods	cooked as a vegetable, raw		antioxidant, anti-inflammatory, liver problems		(Bhoomannavar et al. 2011; Cruz-Garcia & Price 2012; Pawera et al. 2020; Borelli et al. 2020)
Vicia hirsuta (L.) Gray	perennial herb	Eurasia (pantropical)	young shoots	cooked as vegetable		cancer types (breast, colon, and prostate), diabetes, and cardio-vascular disease		(Sinha & Lakra 2007; Marandi & Britto 2015; Salehi et al. 2021)
Vicia sativa L.	perennial herb	Eurasia (Europe, Asia, USA)	young shoots	cooked as vegetable		Similar properties as *V. hirsuta*		(Vieyra-Odilon & Vibrans 2001; Marandi & Britto 2015; Salehi et al. 2021)
Lamiaceae								
Leucas aspera (Willd.) Link	perennial herb	tropical Asia (Asia)	leaves, young shoots	cooked as vegetable		antioxidant, earache, sore, snake bite, jaundice, gastric trouble, dyspepsia, anorexia, fever, respiratory issues, skin issues		(Khare 2004; Sinha & Lakra 2007; Satapathy et al. 2012; Kanta Sahu et al. 2013; Dhanam & Elayaraj 2014; Marandi & Britto 2015)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Leucas cephalotes (Roth) Spreng.	annual herb	S.E. Asia (Asia)	leaves, young shoots	cooked as vegetable		anti-inflammatory, antioxidant, jaundice, cough, bronchial asthma, fever, scabies, urinary disabilities		(Khare 2004; Sinha & Lakra 2007; Marandi & Britto 2015; Aryal et al. 2019a)
Malvaceae								
Anoda cristata (L.) Schltdl.	annual herb	tropical America (cosmopolitan)	leaves, rhizomes	*quelite*, cooked as vegetable		antioxidant, type 2 diabetes, cardiovascular diseases		(Madamombe-Manduna et al. 2009; Juárez-Reyes et al. 2015; Mateos-Maces et al. 2020)
Corchorus olitorius L.	annual herb	tropical Africa (pantropical)	leaves, fruits	Leaves and fruits cooked as vegetable, dried leaves as tea		antimicrobial, antipyretic, antioxidant, gonorrhea, pre-delivery trouble		(Djah Francois & Danho Fursy Rodelec n.d.; Khare 2004; Balemie & Kebebew 2006; Sinha & Lakra 2007; Bhattacharjya & Borah 2008; Madamombe-Manduna et al. 2009; Maroyi 2011, 2013; Marandi & Britto 2015; Bedigian 2019; Daum et al. 2021)
Corchorus tridens L.	annual herb	tropical Africa (cosmopolitan)	leaves, young shoots	cooked as vegetable	high in essential fatty acids, protein content	menses problems, spermatorrhea, hepatitis, gastric pain, pneumonia		(Freiberger et al. 1998; Madamombe-Manduna et al. 2009; Maroyi 2011, 2013; Yaseen et al. 2015)
Hibiscus cannabinus L.	semi-perennial herb	Africa (Africa, Asia)	seeds	ground into flour		anti-inflammatory, anti-diabetic, antitumoral		(Madamombe-Manduna et al. 2009; Zhao et al. 2014; Ojelel et al. 2019; Daum et al. 2021; Govindarasu et al. 2022)
Onagraceae								
Ludwigia adscendens (L.) H.Hara	perennial creeping / floating herb	tropical America (pantropical)	leaves	cooked as vegetable		antioxidant, cooling, diuretic, mild laxative		(Khare 2004; Sinha & Lakra 2007; Cruz-Garcia & Price 2012; Marandi & Britto 2015; Rajiv et al. 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Oxalidaceae								
Oxalis corniculata L.	annual herb	tropical America (cosmopolitan)	leaves, fruits, flowers, rhizomes	*quelite*, cooked as vegetable, raw	source of vitamin C	antioxidant, anticancer, anthelmintic, anti-inflammatory, analgesic, antimicrobial, antifungal, diuretic, anemia, dysentery, cough, jaundice, rickets, scurvy		(Bown & Herb Society of America. 1995; Díaz-Betancourt et al. 1999; Duke 2001; Kumari & Kumar 2001; Sinha & Lakra 2007; Madamombe-Manduna et al. 2009; Ediriweera 2010; Lal et al. 2012; Marandi & Britto 2015; Saikia & Kumar 2020; Nakhuru et al. 2021; Castañeda et al. 2022)
Oxalis latifolia Kunth	perennial herb	tropical America (America, Europe)	leaves	*quelite*, cooked as vegetable, pickled			contains oxalic acid	(Bown & Herb Society of America. 1995; Duke 2001; Vieyra-Odilon & Vibrans 2001; van den Eynden et al. 2003; Madamombe-Manduna et al. 2009; Maroyi 2011, 2013; Marandi & Britto 2015)
Piperaceae								
Piper auritum Kunth	perennial herb	tropical America (Americas)	leaves	*quelite*, cooked as vegetable, used as seasoning		high blood pressure, rheumatism, cramps	contains safrole	(Williams et al. 1985; Díaz-Betancourt et al. 1999; Mateos-Maces et al. 2020; Pascual-Mendoza et al. 2021)
Plantaginaceae								
Plantago lanceolata L.	perennial herb	Eurasia (cosmopolitan)	young leaves, rhizomes	cooked as vegetable, raw		antioxidant, bleeding, damaged tissue		(Chevallier 1996; Díaz-Betancourt et al. 1999; Turner et al. 2011)
Poaceae								
Eleusine coracana (L.) Gaertn.	annual herb	Africa (Africa, Asia)	seeds	ground into flour; eaten as porridge				(Madamombe-Manduna et al. 2009; Hunter et al. 2019; Ulian et al. 2020)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Eleusine indica (L.) Gaertn.	annual herb	Africa, Asia, (cosmopolitan)	seeds, seedlings	seeds ground into flour, seedlings cooked as vegetable		diuretic, laxative, liver disease, influenza, hypertension, retention of urine		(Madamombe-Manduna et al. 2009; Ediriweera 2010; Saikia & Kumar 2020)
Polygonaceae								
Polygonum aviculare L.	annual herb	Europe (cosmopolitan)	leaves, young shoots	*quelite*; cooked as vegetable	rich in Zn, Mn	kidney stones, stomach problems	high in nitrates, contains saponin	(Vieyra-Odilon & Vibrans 2001; Mateos-Maces et al. 2020)
Persicaria glabra (Willd.) M.Gómez	annual herb	north America (pantropical)	leaves	cooked as vegetable; raw		antioxidant, wounds, rheumatism, colic pain		(Sinha & Lakra 2007; Marandi & Britto 2015; Muddathir et al. 2017)
Rumex spp.	annual / biennial / perennial herbs	Eurasia (cosmopolitan)	young leaves	cooked as vegetable	source of minerals	anti-inflammatory, allergy treatment, urinary issues	contains oxalates	(Díaz-Betancourt et al. 1999; Duke 2001; Vieyra-Odilon & Vibrans 2001; Sinha & Lakra 2007; Turner et al. 2011; Marandi & Britto 2015; Saikia & Kumar 2020; Mateos-Maces et al. 2020; Abbas et al. 2020; Ulian et al. 2020; Borelli et al. 2020; García-Herrera et al. 2020; Gumisiriza et al. 2021)
Portulacaceae								
Portulaca oleracea L.	annual succulent	Asia (cosmopolitan)	leaves, young shoots, flowers, pods, seeds	*quelite*, raw, cooked as vegetable	rich in unsaturated fatty acids, vitamin E	antioxidant, mouth ulcer, sore nipples, scurvy, disease of kidney, liver, spleen bladder, cardio-vascular system, pyorrhea, insulin secretion, blood purifier, fever, sun stroke, dental problems, blood purification		(Díaz-Betancourt et al. 1999; Duke 2001; Kumari & Kumar 2001; Vieyra-Odilon & Vibrans 2001; van den Eynden et al. 2003; Sinha & Lakra 2007; Madamombe-Manduna et al. 2009; Maroyi 2011; Satapathy et al. 2012; Lal et al. 2012; Marandi & Britto 2015; Turreira-García et al. 2015; Durgawale et al. 2018; Bedigian 2019; Aryal et al. 2019a; Hunter et al. 2019; Medeiros Jacob et al. 2020; Mateos-Maces et al. 2020; Pascual-Mendoza et al. 2021; Daum et al. 2021; Kissanga et al. 2021)

Table 1 Continued

Family and species	Plant life form	Origin (distribution)	Part used	Mode of consumption	Nutritional benefits	Traditional medicinal use	Antinutritional properties	References
Portulaca quadrifida L.	annual herb	(Africa, Asia)	leaves, young shoots	cooked as a vegetable, raw	rich in unsaturated fatty acids	antioxidant, rheumatism, sedative, analgesic, fever, urinary issues, worm diseases, dysentery, ulcers, eczema, dermatitis	high in nitrates, contains oxalates	(Ogoye-Ndegwa & Aagaard-Hansen 2003; Balemie & Kebebew 2006; Sinha & Lakra 2007; Marandi & Britto 2015; Durgawale et al. 2018)
Solanaceae								
Physalis angulata L.	annual herb	tropical America (pantropical)	fruits	cooked; raw	source of minerals, high in protein	antibacterial		(Ogoye-Ndegwa & Aagaard-Hansen 2003; Maroyi 2011, 2013; Ong & Kim 2017; Cruz-Garcia 2017; Hunter et al. 2019; Pawera et al. 2020; Ralte et al. 2021)
Solanum nigrum L.	annual herb	Eurasia (cosmopolitan)	leaves, fruits	leaves as *quelite* and cooked as vegetable; fruit eaten raw		antioxidant, fever treatment	contains alkaloids	(Djah Francois & Danho Fursy Rodelec n.d.; Ogoye-Ndegwa & Aagaard-Hansen 2003; Balemie & Kebebew 2006; Maroyi 2011, 2013; Turner et al. 2011; Marandi & Britto 2015; Sujarwo et al. 2016; Aryal et al. 2019a; Mateos-Maces et al. 2020; Daum et al. 2021; Nguyen et al. 2021; Kissanga et al. 2021)
Verbenaceae								
Lantana camara L.	perennial shrub	tropical America (America, India, Italy)	leaves, fruits	leaves as *quelite*; fruits eaten raw		antibacterial, anticancer, antihyperglycemic, antioxidant, intestinal worms	unripe fruits, seeds toxic (lantadene)	(Lévi-Strauss 1952; Madamombe-Manduna et al. 2009; Termote et al. 2010; Maroyi 2011; Ojelel et al. 2019; Saikia & Kumar 2020; Medeiros Jacob et al. 2020)

**quelite* = leafy vegetables locally consumed in Mexico

All plants investigated in our study belong to 26 botanical families, indicating high diversity among edible weedy species. This is further supported by the fact that each of the most important species according to the number of reports (*Portulaca oleracea* L., *Amaranthus hybridus* L., *Solanum nigrum* L., *Crotalaria* spp., and *Cleome gynandra* L.) belongs to different botanical family.

Although the species represented in this study may be diverse, a broader transnational context tells us that the overall biodiversity of weed species is on decline. Studies examining the functionality of agrobiodiversity in today's agriculture present concerning results (Benton et al. 2003). A functional agrobiodiversity is defined as a set of field biodiversity components providing ecosystem services that contribute to sustainable agricultural production and are beneficial to the overall regional and global environment (Bianchi et al. 2013). A significant decline in weed species diversity and overall species heterogeneity has been recorded in countries where intensive high input farming practices were put into practice (Benton et al. 2003). Marshall et al. (2003) concluded that this thread of biodiversity reduction may result in serious global changes, such as alterations in soil formation, circles of nutrients and trophic interactions of flora and fauna, microflora, and fungi (Marshall et al. 2003). Although there are case studies from Zambia and Mexico, reporting an increase in local implementation of pesticides (Vázquez-García et al. 2004; Daum et al. 2021), these conclusions of rapid biodiversity loss are, however, targeted rather at developed, industrialized countries. Regarding the study area of the tropics, the situation is likely to not be as alarming, considering that local agriculture, in many cases, still does not involve a high-input approach and techniques (Pingali 2012; Ameen & Raza 2018).

4.2. Distribution and invasivity

Almost half of the reported species are of cosmopolitan or pantropical distribution. Most of those species have been either intentionally or unintentionally introduced elsewhere from their locality of origin. *Bidens pilosa* L., weedy *Amaranthus* spp. are pantropically distributed weeds. However, their native territory is the area of tropical America (POWO 2022). Although being considered problematic, they have made their way into many cultures as edible weeds. For example, in eastern Africa, *B. pilosa* and weedy *Amaranthus* spp. are eaten together with Asian-introduced *Basella alba* L., and *Chenopodium* spp. from Eurasia. This green leafy mixture provides crucial nutrients to local rural population (Newmark 2002). A similar case of *B. pilosa* and *Amaranthus* spp. forming a staple part of local diet was documented in Zambia (Daum et al. 2021).

Weeds share certain properties, enabling them to be omnipresent representatives of the plant kingdom. One of those characteristics is the ability of fast spread and a high potential for invasivity. The topic of invasivity is discussed in many contexts. However, the term is mainly considered derogatory, and species with this label are mostly regarded to as somewhat harmful (Zimdahl 2007). The International Union for Conservation of Nature (IUCN) defines invasive species as following: "Invasive species is an alien species that becomes established in natural or seminatural ecosystems or habitats, is an agent of change, and threatens native biological diversity" (McNeely 2001). This definition succeeds at differentiating the term "invasive" from "alien", because then almost all the major food crops of the human era would be considered invasive in some geographical area. For example, corn, wheat, and rice were exotic crops introduced to the U.S.A. However, now, they are among the most productive crops in the US food system (Chafe 2005). A coherent summarisation of the matter of invasive species by Zimdahl (2007) further specifies invasive species as introduced species (i.e., brought from a distinct, ecologically separated environment) which, upon introduction, can form self-replacing populations. This makes the species "naturalised". Nevertheless, they only become "invasive" at a point when the offspring inhabit territories away from the parent population. This definition may not have definite boundaries, but it is as concrete as possible.

Weedy plants are frequently considered invasive, because of their fast and easy spread capability. Concerning the reasons for such ability, the properties of the seed should be taken into consideration. The seeds of most weedy species are of small size and are being produced in enormous quantities. For example, one plant of *Amaranthus hybridus* can produce up to 100.000 seeds, which can remain viable in the soil for years (CABI 2022). *Portulaca oleracea* produces over 52.000 seeds per plant (Zimdahl 2007), however, some sources report up to 240.000 seeds per plant (Cudney et al. 2007). Tiny seeds are also easily distributed by wind or water and dwell dormant in the soil for long periods of time. Weed seeds are also commonly morphologically adapted for other means of transportation, such as animal or human aided (Benvenuti 2007). Heavy agronomical machinery, such as combines, often preserve loads of weed seeds as the weed plants are harvested together with the food crop (Zimdahl 2007). Perennials also reproduce vegetatively by rhizomes or taproots. Weedy rhizomes are likely to remain intact, vigorous, and full of reserves as they are adapted to withstand environmental stress (Zimdahl 2007). Among other factors contributing to weeds' invasivity is their quick germination - *Cirsium arvense* L. produces mature seeds two weeks after flowering; *Amaranthus retroflexus* L., is able to produce seeds before their height has reached 20 cm (Baker 1965).

Another factor playing a role in weed species competitiveness is the concept of allelopathy. Bais et al. (2006) define this phenomenon as suppressing plant's growth caused by chemical compounds produced by another plant. It is an effective mechanism by which weedy plants gain benefit over other plants in the competition for resources. These chemicals, called phytotoxins, can be released from dead decomposing plant tissue or as leafy volatiles or root exudates and can affect the vital functions of other plant's life cycles, such as photosynthesis, respiration, germination, and different metabolite functions (Mushtaq et al. 2020). Bais et al. (2006) have studied the concentrations of released phytotoxins in species of *Centaurea* spp. and *Sorghum* spp. and found remarkably high concentrations of toxins produced by invasive weedy species *Sorghum halepense* (L.) Pers. However, weeds and crops both have been found to contain compounds that can be considered allelopathic. The ability of food crops to emit phytotoxins has been utilised to design smart crop rotations suitable for natural weed management (Dukpa et al. 2020). However, thorough allelopathy research is limited because the realistic simulation of natural soil conditions remains a challenge (Bais et al. 2006).

4.3. Ethnobotany of weeds

Ethnobotany focuses on exploring the relationships between people and plants (Zimdahl 2007), shedding light upon neglected and underutilised plant species, and evaluating their potential for wider use. Weeds are one such group and, based on data research for this study, the ethnobotanical attention they have been receiving has been increasing gradually since the beginning of the 21^{st} century. Up to date, there have been quite a few reputable authors and studies in the field of weed use and potential research, discovering the variety of ways in which weeds are, or potentially could be, used. Documenting the uses of weedy plants by locals and studying them can lead to great discoveries in human nutrition or medicine fields (Zimdahl 2007; Cragg & Newman 2013). Areas in the tropics often still have a vivid culture of traditional plant use (Zimdahl 2007). This is perhaps influenced by most countries being classified as underdeveloped and low-income and therefore not having enough resources to rely on modern food sources or medicines. The core focus of this thesis is exploring the use of weeds as food for humans, yet other uses are also discussed, as to provide a broader context.

4.3.1. Food uses

The value of weeds as food sources is recognized by many societies worldwide (Cruz-Garcia & Price 2012). The reasons for weed collection and consumption are based on tradition, taste preferences and the awareness of necessary food supplementation (Daum et al. 2021).

As already discussed, wild plants have always provided food sources for humans, yet since the population growth has gained significant momentum during the twentieth century (Roser et al. 2013), the general focus of food provision has shifted towards a narrow scope of modern food crops (Pawera & Polesný 2015; Mateos-Maces et al. 2020). In the context of today, edible wild food consumption plays an important role mainly in the diets of people of underdeveloped, low-income countries, yet not so long ago, it was crucial even in those lands that are now among the most developed and financially and nutritionally secured. Dodgshon (2004) documents the approach towards wild plant food sources during frequent famines occurring among Scottish farming communities throughout the nineteenth century. Taking advantage of so-called "famine foods" was one sufficient coping method of how to handle periods of subsistence crises, induced mainly by climatic conditions. These alternative food sources were available regardless adverse weather or other circumstances that have ruined the main food crops. Having access to ecological diversity resulted crucial, as the communities required to find different species of plant or animal to satisfy their nutritional needs. Many farmland weeds were such sources of nutrition. Acknowledging the importance of weeds during famine periods implied that their appearance in crop fields was tolerated to some extent. The most resistant and obnoxious weeds resulted as a reliable food source, when all else failed.

A case study from rural parts of Zambia by Daum et al. (2021) documented how the relationship between weed consumption and food security is still relevant today. The study recording the intensity of edible weed intake per household revealed that most weeds were consumed between December and March, when stored food supplies from previous year's harvests have diminished and food scarcity have become a concern. This time period is also when the rainy season occurs, and the abundance of fresh weedy flora is high. Rainy season has been reported as main weed consumption period in other reports from Mexico (Vieyra-Odilon & Vibrans 2001) and India (Sinha & Lakra 2007). Outside the food scarcity period, weedy species are mainly eaten dried, however, their role in local diet is not so important as people depend on the main cultivated food crops as main sources of energy. Pawera and Polesný (2015) describe that general present days' attitude towards such plain, plant-based foods often consider them as "food for the poor". This perspective reflects the shift from traditional towards conventional modern agriculture, and the overall loss of interest and knowledge of wild edible species, particularly regarding middle-class citizens of developing countries (Ogoye-Ndegwa & Aagaard-Hansen 2003). A study from Kenya documented how local approaches can be lifted through active enthusiasm. Locally distributed development projects aimed at raising awareness of the positive aspects of wild edible flora helped spreading rural knowledge to urban communities. Subsequently, general approach was shifted toward wild food plant implementation with neglected and underutilized wild food plants reaching urban markets (Gotor & Irungu 2010). This course of action can be an inspiration for further efforts in spreading awareness about the recognized and undiscovered potential of edible weeds.

Regarding the information gathered from reviewed literature, there are several species that are recognized as popular food sources in countries across the whole tropical belt. Many of them are cosmopolitan, and they are found in temperate cuisines as well. One such species is *Portulaca oleracea*, searched literature revealed its consumption in 12 countries (Mexico, Guatemala, Ecuador, Brazil, Zambia, Sri Lanka, Ethiopia, Zimbabwe, Angola, Mozambique, India, and the Philippines). *P. oleracea* is an annual herb with fleshy leaves, and cosmopolitan distribution. Its use as a potherb (a cooked, culinary herb) has been documented also in non-tropical areas, such as the Mediterranean (Zhou et al. 2015). In parts of Mexico, young shoots of *P. oleracea* are boiled in salty water, fried with onion and chilli or cooked with pork in green chilli sauce (Vieyra-Odilon & Vibrans 2001). It can also be consumed fresh in salads. This species is regarded as a noxious weed in some countries, implying that there are legal requirements for its management (HEAR 2007). Bedigian (2019) reports its wide consumption in Africa, and classifies the plant as mucilaginous leafy vegetable, by its consistence after heat processing. In North-eastern India, *P. oleracea* is found mainly during rainy season (June to September) and it has been reported popular among all tribes (Sinha & Lakra 2007).

Food uses of *Amaranthus hybridus* has been reported in 8 countries (Mexico, Zimbabwe, Zambia, Côte d'Ivoire, Angola, Ecuador, Kenya, Indonesia) with other species of *Amaranthus* recorded in almost all reviewed literature. This taproot annual herb species is related to *Chenopodium* spp., a genus of useful weedy and semi-cultivated species. *C. berlandieri* and *C. album* were also among reported edible weed species. *Amaranthus* spp. and *Chenopodium* spp. are among top most popular edible weedy genera consumed in Mexico and are widely available at local markets (Vieyra-Odilon & Vibrans 2001). Locally, it is cooked with meat and chilli sauce, young shoots of *Chenopodium spp.* also fried and eaten with cheese and egg, or, in case of *C. ambroisioides*, it is used as a condiment for mushroom dishes or bean soups. *Chenopodium* spp. was documented in 5 countries (Mexico, Zimbabwe, India, Angola, Kenya), however its consumption is common worldwide (Ulian et al. 2020; Borelli et al. 2020).

Solanum nigrum was reported in 10 countries (Zambia, Zimbabwe, India, Sri Lanka, Indonesia, Côte d'Ivoire, Ethiopia, Mexico, Angola, Viet Nam). Although considered bitter-tasting by some respondents in Zimbabwe and Kenya (Ogoye-Ndegwa & Aagaard-Hansen 2003; Maroyi 2013), *S. nigrum* still forms a part of local diets. It is collected mainly for its fruit (Djah Francois & Danho Fursy Rodelec n.d.), however leaves are also edible (François Malan et al. 2020).

Crotalaria spp., a genus of weedy subshrubs, was reported to be used in Mexico, Guatemala, Zambia, Kenya, and Uganda. Similarly to *Solanum nigrum*, its taste is rather bitter (Ogoye-Ndegwa & Aagaard-Hansen 2003), however some find it pleasant.

Cleome gynandra is a cosmopolitan weedy species of high importance in Zimbabwean community (Maroyi 2013), along with *Amaranthus hybridus*, *Bidens pilosa*, *Galinsoga parviflora* Cav., *Commelina zambesica* C.B. Clarke., *Cucumis anguria* L. and *Corchorus tridens* L. Zimbabwean study documents that *C. gynandra* is one of scarce species (together with *Cucumis anguria*) available during dry season as well, providing households with accessible food source all throughout the year (Maroyi 2013). Leaves and young shoots of *C. gynandra* are cooked as leafy vegetable, or sundried and stored for later consumption (Maroyi 2013). Zimbabweans often add various other leafy species (*Amaranthus* spp, *Chenopodium* spp. or *Cleome monophylla* L.) whilst cooking *C. gynandra* to add volume to the mixture (Maroyi 2013).

To conclude general aspects of edible weed consumption, the most recorded plant parts used were leaves (51) and young shoots (30). These plants can therefore be classified as wild leafy vegetables. Some species were recorded to be eaten as "whole plants. Recorded definitions of different modes of consumption were mostly quite broad, or, on the other hand, rather specific. Most investigated species were consumed boiled, cooked, steamed, or stir-fried. To summarize the data, a common label "cooked as a vegetable" was assigned.

Twenty-three species in this study were classified as *quelites.* A study by Mateos-Maces (2020) lists 84 plant genera of edible plants frequently consumed in Mexico. These edible species are important in Mexican cuisine and are regionally classified as *quelites*. Their typical preparation mode is primarily boiled with salt, cooked with meat, fried with eggs or onion and chilli serrano, or raw in case of young tender plants (Vieyra-Odilon & Vibrans 2001). The style of consumption also varies depending on the maturity of the plant. For example, in the case of *Amaranthus* spp., young plants are consumed as part of *caldo* (vegetable broth), whereas mature parts of the plant are mostly consumed without the broth, accompanied by onion and chilli salsa (Mateos-Maces et al. 2020).

More than 250 plant species belong in the category of *quelites*, some of them cultivated or semi-cultivated. However, many of them classify as crop weeds (Mapes & Basurto 2016). Although the regional pattern of intensive agronomy occupies around 85% of the natural area (FAO 2018), the diverse group of *quelites* managed to remain inherent to local nutrition. Mateos-Maces (2020) reports that *quelites* provide a variety of nutrients, such as A, B, C, E vitamins, minerals, amino acids, and other bioactive compounds, such as flavonoids or carotenoids (Mateos-Maces et al. 2020).

Among the species labelled as a *quelite*, there were most of the above-mentioned species with the greatest numbers of reports - *Portulaca oleracea*, *Amaranthus hybridu*, *Solanum nigrum*, and *Crotalaria* spp. It is, however, quite likely that this correlation is influenced by the imbalance of available sources for this study (many sources used were focused on Mexico). *Quelites* represent supplementary foods, which regionally and seasonally turn into significant parts of the household's diet, accompanying maize tortillas, beans, and spicy condiments (Basurto-Peña et al. 2017). They are great ambassadors of edible weedy species and a perfect case to illustrate the nutritional potential of this group of plants. However, the future of *quelites* as major parts of rural Mexican diets is threatened. A case study by Vázquez-García et al. (2004), carried out in rural parts of Ixhuapan, Veracruz, concludes that an increasing number of field workers rely on pesticides rather than manual weeding, by which they obtain field *quelites*. Manual weeding is a demanding activity that used to be done with the participation of the whole family of the farmer. Nowadays, the farmers rather send their children to school than to the field and thus are forced to hire paid labour if wanting to remain loyal to manual weeding. Switching to a much cheaper chemical weed control often resembles an easy and pragmatic solution of the issue.

To maintain the supply of valuable edible weed species without the necessity of manual harvest from agricultural fields, in some cases, people make an extra effort of cultivating *quelite* species in the spaces of their gardens (Vázquez-García et al. 2004). This is how weeds become cultivated food crops. The present thesis reports seventeen weed species were recognised both as weeds as well as cultivated crops, mostly depending on geographical area (*Chenopodium album* L., *Celosia argentea* L., *Eryngium foetidum* L., *Raphanus raphanistrum* L., *Ipomoea aquatica* Forssk., *Cucumis anguria*, *Cyperus esculentus* L., *Cajanus cajan* (L.) Millsp., *Vicia sativa* L., *Hibiscus cannabinus* L., *Piper auritum* Kunth, *Eleusine coracana* (L.) Gaertn., *Portulaca oleracea*, *Corchorus olitorius* L., *Solanum nigrum*, *Amaranthus* spp. and *Crotalaria* spp.). This occurrence refers to the very definition of weeds as "undesired and threatening land features" and reveals this definition to be unambiguously conditioned by the circumstances.

Although these weedy species were recorded as cultivated in some areas, their production often serves for local consumption and only limited amounts enter international trade (except for *Corchorus olitorius*). Cruz-Garcia and Price (2012) reported *Cajanus cajan*, an edible weed species of Thai rice farms being widely cultivated in India, Malawi, Uganda, Kenya and Tanzania (PROTA 2022a). Reported as a crop weed in Mexico (Madamombe-Manduna et al. 2009), Zambia (Daum et al. 2021), Zimbabwe (Maroyi 2013) and India (Sinha & Lakra 2007; Marandi & Britto 2015), *Corchorus olitorius* is a multi-purpose plant cultivated mainly in India and Bangladesh (PROTA 2022b). Although being edible, the primary purpose of *C. olitorius* cultivation in these regions is jute fibre. There are reports of *C. olitorius* cultivation as a leafy vegetable in many countries in Africa (Côte d'Ivoire, Benin, Nigeria, Cameroon, Sudan, Kenya, Uganda, Zimbabwe), also in Brazil and the Caribbean (PROTA 2022b). *Ipomoea aquatica* Forssk., a crop weed of India (Marandi & Britto 2015) and Southeast Asia (Cruz-Garcia & Price 2012), is commercially produced in Japan, China, Africa, Thailand, and other Southeast Asian countries (Pinker et al. 2007; PROTA 2022c). *Eleusine coracana* is cultivated as a cereal crop in many eastern and southern African countries, India and Nepal (Borlaug et al. 1996). *Chenopodium album* is a popular cultivated food crop in India (NIIR Board of Consultants & Engineers 2017) and sub-Saharan Africa (Uusiku et al. 2010). Various species of *Amaranthus* are cultivated pantropically (Nic Phiarais & Arendt 2008). *Crotalaria* spp. and *Solanum nigrum* are cultivated in kitchen gardens of Kenya (Ogoye-Ndegwa & Aagaard-Hansen 2003).

4.3.2. Other uses

Besides supplementing human diets, the main purpose of collecting weeds is to provide fodder for domestic animals. Fifteen species were classified as animal fodder by Vieyra-Odilon and Vibrans (2001): *Amaranthus hybridus*, *Galinsoga parviflora*, *Sonchus oleraceus*, *Brassica rapa* L., *Raphanus raphanistrum* L., *Drymaria* spp., *Spergula arvensis* L., *Chenopodium berlandieri*, *Cyperus esculentus*, *Medicago polymorpha* L., *Vicia sativa*, *Oxalis latifolia* Kunth, *Polygonum aviculare* L., *Rumex* spp., *Portulaca oleracea* L. Among the main fodder crops there is *Amaranthus hybridus* L., *Galinsoga parviflora*, *Brassica rapa*, and *Medicago polymorpha*. The study further reveals that, unlike foraging weeds for human consumption, its usage as animal fodder is economically convenient, with a potential of raising the economic returns of a maize field by 50% or more. This calculation is, however, appliable mainly for maize fields, where the main crop is not affected by manual harvest of weeds (walking in a maize field does not damage the crop). Apart from already mentioned *Corchorus olitorius*, cultivated for jute fiber, another weedy plant with similar properties was reviewed in this study - *Hibiscus cannabinus*. In Zambia, this plant is collected from crop fields, cooked with oil and onion, and eaten as a garnish to local staple foods, such as maize porridge (Daum et al. 2021). However, in over 20 countries worldwide (top producers are China and Pakistan) it is cultivated for its fibrous stems called kenaf (Alexopoulou et al. 2013). Kenaf has mainly been used for rope manufacturing, whereas jute fibers are more suitable for making textiles and are among the most important plant fibers (Mohanty et al. 2005). Zimdahl (2007) also reports that weeds may be used as construction material, Vissoh et al. (2007) mentions the use of dried bundles of *Imperata cylindrica* (L.) Raeusch. (a non-edible weed of African and Mediterranean origin) as roofing for rural African households, implying that it is also a trade commodity.

4.3.3. Food-medicine continuum

Plants produce secondary metabolites, compounds that act as defence against external intrusion and environmental changes (Zimdahl 2007). Their consumption can result in positive impact on human health. These chemicals are abundant and mostly unknown or lacking deeper expert analysis. Ethnopharmacological surveys often prove that local people who gather various wild growing plants for food are also aware of the health benefits of those species (Sansanelli et al. 2017). Traditional tribal healers collect this unique wisdom of medicinal plant uses verified by generations of experience and they use this knowledge in practising traditional medicine. A study from North-eastern India described that local tribal communities inhabiting lands far from civilisation and thus rely almost entirely on the frequent use of available weedy medicinal plant sources, have not registered cases of hypertension, diabetes, and cholesterol related problems (Marandi & Britto 2015). In contrast, several such cases appear among tribal groups that adapted urban lifestyle and commercial foods. Although there are various factors responsible for this outcome, it points to the fact that, to some extent, good health can be maintained with the sole help of wild natural resources. Traditional herbal medicines have always been sources for research and development of new pharmaceuticals (Zimdahl 2007; Cragg & Newman 2013; Balick & Cox 2020). A ground-breaking example of healing potential among weeds is *Catharanthus roseus* (L.) G.Don., a common weed of Madagascar, used to treat diabetes by local folk. Scientific analyses discovered its great potential in cancer treatment (Cragg & Newman 2013), and it has revolutionised the treatment of leukaemia towards possible complete recovery (Zimdahl 2007). As modern medicine is costly and unavailable for most people, they still depend on traditional herbal medicine (Zimdahl 2007). These documented healing properties of many plants should be considered and adequately studied, as the discoveries could affect the course of treatment research for various illnesses. Most species in this study reported traditional medicinal uses. The data show significant variability, as this topic is extensive and inconsistent among different sources.

A high number of recorded weedy plants (30) are used in Ayurveda, a traditional Indian medicine system, according to Ayurvedic Medicinal Plants of Sri Lanka Compendium (2022). These species have been used for the treatment of multiple unrelated health issues. The scope of medicinal use per each plant is very broad, making it difficult to provide a comprehensive review. Most plants recorded to be used in traditional medicine were associated with the treatment of gastric issues (28 species), and urinary tract issues (18 species). Fifteen species treated skin-related issues, such as wounds and blisters. Nine species addressed cardiac troubles. Twenty-five species reported antioxidant properties. Mateos-Maces et al. (2020) revealed that *Chenopodium album*, *Portulaca oleracea*, *Crotalaria* spp. and *Amaranthus* spp. perform higher antioxidant activity than commercial leafy vegetables, such as spinach and lettuce. Plants with naturally occurring antioxidants often display other biological effects, such as anti-inflammatory, anti-cancer, anti-obesity, and anti-ageing properties (Randhawa et al. 2015; Xu et al. 2017).

4.4. Nutritional properties of edible weeds

Various tropical countries experience insufficient supply of nutrient-rich foods, with a diet based on one staple carbohydrate crop, often being maize and wheat, as regards to Mexico, South America, and Africa (Samtiya et al. 2020; Daum et al. 2021), or rice in the case of Asia, as was reported in many case studies (Pawera & Polesný 2015). Many low-income countries in the tropics are faced with insufficient consumption of fruits and vegetables among its citizens, resulting in widespread malnutrition (Keatinge et al. 2011). Additionally, modern selective breeding of vegetables focuses rather on features such as size and shape uniformity, aesthetics, or pest resistance, at the expense of nutrient density (Pawera & Polesný 2015). With nutritional values of modern vegetables being on decrease, more focus should be oriented on alternative sources of nutrients. Many authors in the field of wild edible plant research suggest addressing the issue of malnutrition and micronutrient deficiencies by implementing diverse wild edible flora into rural diets (Ogoye-Ndegwa & Aagaard-Hansen 2003; Jansen Van Rensburg et al. 2004; Penafiel et al. 2011; Mavengahama et al. 2013; Pawera & Polesný 2015; Mateos-Maces et al. 2020).

50 out of 69 recorded weedy species were reported to possess high concentrations of inorganic elements, macro and micronutrients essential in human diet (Cruz-Garcia & Price 2012; Maroyi 2013). Mateos-Maces et al. (2020) studied the medicinal potential of Mexican leafy vegetables, concluding that all studied plants provide essential amino acids including histidine, which is crucial for children and pregnant women. They also contain considerable amounts of micro and macroelements, vitamins A, B, C, E and niacin.

Mapes and Basurto (2016) revealed unique protein contents of some weedy species; the protein content of *Brassica rapa* and *Piper auritum* accounts for 32% to 40% of dry weight, respectively. Kissanga et al. (2021) reported protein contents of *Amaranthus hybridus*, *Bidens pilosa* and *Galinsoga parviflora* ranging from 20% to 30% of dry weight.

In the case of Mexican *quelites*, Mateos-Maces et al. (2020) have concluded that only a small part (15%) of the approximate number of 250 *quelite* species has been subjected to an analysis of chemical composition. This is likely to be the case for many other edible weedy plants, as the collected data on nutritional properties of selected edible weed species were often scattered and inconsistent. However, some general data can be obtained through available literature and verified databases. Green leafy plants as such are an easily accessible source of essential amino acids, minerals, vitamins, and fibre (Randhawa et al. 2015). Their antioxidant properties help manage oxidative stress. Leaf parts, engaged in photosynthesis, have higher amounts of vitamin K present in the tissue, than other plant parts (Randhawa et al. 2015). Vitamin K is essential for the proper forming of blood clots (Fakhree et al. 2021).

4.4.1. Antinutritional properties of edible weeds

The edibility of many plant species is limited by antinutritive secondary metabolites either produced by the plant or captured and cumulated within the plant's tissue (Ziarati & Mohammad-Makki 2015; Samtiya et al. 2020). These components may present health risks when consumed under certain conditions, i.e., in excess or without sufficient processing.

Portulaca quadrifida L., *Rumex* spp., *Oxalis latifolia*, and *Chenopodium album* contain oxalic acid and its derivates, whose excess consumption can lead to kidney related issues (Franceschi & Nakata 2005; Crivelli et al. 2020), ingestion by grazing animals is also linked to renal failure (Franceschi & Nakata 2005). *Piper auritum* contains safrole, an organic compound found mildly carcinogenic in rats (Liu et al. 1999). Excess consumption of glucosinolates found in *Brassica rapa* can harm the thyroid gland activity (Cornell University 2015). *Pteridium aquilinum* (L.) Kuhn showed the presence of thiaminase, an enzyme causing cerebrocortical necrosis in ruminants (Evans 1975). Pyrrolizidine alkaloids, secondary metabolites produced as defense against insect pests, found in *Crotalaria* spp. and lantadene, found in unripe seeds and fruits of *Lantana camara* L. both show hepatoxicity in humans (Sharma et al. 2007; Wiedenfeld & Edgar 2010). Saponin, found in *Polygonum aviculare*, is a foam-producing antinutritive compound that inhibits digestive enzymes' proper functioning (Samtiya et al. 2020).

Besides naturally occurring antinutritive compounds, different levels of environmental pollution also pose risks to the consumption of edible weeds. While it is rather common sense not to collect plants that emerge in close proximity to areas of traffic, landfills, sewage treatment plants etc., many people may not be aware of the spatially extensive effects of air and soil pollution. A study from Moradabad district, India revealed risky volumes of accumulated heavy metals in edible plants collected in agricultural fields near Moradabad city, known for its brass industry (Punetha et al. 2015). The study confirmed that plants are heavily susceptible to accumulating toxic elements from the soil treated with sewage sludge as fertiliser. Some reported species were found to contain high levels of nitrates. This occurrence is caused by the plants' excess accumulation of nitrates from soils treated with nitrogen fertiliser (Umar & Iqbal 2007). When nitrogen input exceeds demand by plants, the residues accumulate in the soil (Nosengo 2003), affecting groundwater supplies as well (Wang et al. 2015). Umar & Iqbal (2007) explain various health risks imposed by excessive nitrate consumption (CNS damage, cancer and dementia development, respiratory tract infections and more). Other sources however report health promoting effects of nitrates, such as lowering blood pressure (Jonvik et al. 2016; Kerley et al. 2018). It is therefore difficult to determine an accurate conclusion of the health impacts of nitrates. The potential of high nitrate content generally applies to plants collected from agricultural land, as extensive nitrogen fertiliser treatment has become universally implemented (Wang et al. 2015). In addition, most reported species in this study are leafy vegetables, which are usually prone to accumulate nitrates heavily (Wang et al. 2002).

4.4.1.1. Processing to eliminate antinutritional properties

Many indigenous communities have managed to preserve traditional knowledge in selecting and using wild edible plants, including those with antinutritional properties (Mapes & Basurto 2016; Mateos-Maces et al. 2020). Apart from careful selection of edible parts or the growth stage of least concentrations of toxins, simple methods of processing have been adapted in order to increase the edibility of the plants.

There are various ways to reduce antinutritive or toxic properties of plants to bearable volumes. Among traditional methods, there is fermentation, cooking, soaking, and puffing (Samtiya et al. 2020). These techniques also increase protein digestibility and improve the biological value of the ingested plant. A useful finding is that compounds cumulate more in some parts of the plant than in other (Umar & Iqbal 2007). The concentration depends on the particular growth phase, local climate and current season (Randhawa et al. 2015). Sensitive evaluation of these variables leads to a better understanding and selection of consumable plant individuals and plant parts.

Heat processing is a method used widely with many plants unsuitable for raw consumption. Preparation mode "cooked as a vegetable", has been reported as a primary preparation mode of almost all studied edible weed species. Boiling in water proved to be more effective in reducing oxalates than baking (Savage & Mårtensson 2010). Before boiling, many nuts and grains are also soaked in water for multiple days, causing seeds to initiate germination. Germination activates enzymes, such as phytase, which breaks apart phytic acid (Samtiya et al. 2020). The solubility of minerals and overall grain digestibility is increased (Ertaş & Türker 2014). Another form of grain preparation is fermentation, which is efficient in reducing bacterial contamination, improving the absorption of minerals, and lowering the content of phytic acid, tannins, and polyphenols (Samtiya et al. 2020). It is widely used in Africa (Samtiya et al. 2020). Milling, common in conventional grain industry, is a mechanic method used to separate grains from the bran layer, eliminating the anti-nutrients present in the bran (Samtiya et al. 2020).

Due to the increasingly concerning issue of nitrate accumulation in field plants, research on practical and economic nitrate removal has been carried out. Ziarati and Mohammad-Makki (2015) reported that adding lemon juice has been proved efficient in reducing nitrate levels in tomato derived products. Ekart et al. (2013) studied the impact of different methods of vegetable processing on nitrate content, revealing that boiling is an effective method of nitrate reduction in spinach, reducing its nitrate content by 53%. Other efficient methods were blanching (reduction by 36%) and washing (reduction by 27%). Considering that spinach is a leafy vegetable, these findings are likely to apply to leafy weedy species as well.

4.5. Agroecological value of weeds

In the context of conventional agriculture, competition for space, light, water, and nutrients represents one of the main concerns related to the presence of weedy plants in agroecosystems (Bastiaans et al. 2000). Crop management practices has always focused on intensifying the possible competitive advantages of the crop, for example by designing elaborate cropping systems or protecting vulnerable seedlings (Bastiaans et al. 2000). The introduction of herbicides has completely changed the game of weed management, bringing an easy and available method of complete weed destruction. As weed control has become so simple and yields have become greater, less thought has been given towards exercising other, more gentle weed management measures such as designing effective crop rotations. Concerning questions like the extent of herbicide impact on ecosystem functions and overall environment have been put aside (Bastiaans et al. 2000). However, over time, many weedy plants have shown great environmental adaptability and have developed resistance towards selected herbicides (Huang et al. 2005). This occurrence has posed a great thread to the herbicide-dependent cropping systems, as the possibility of weeds developing herbicide resistance would be detrimental to the yield (Bastiaans et al. 2000). With the loss of confidence in herbicides, concerns about the future of herbicide use and its impacts on nature arise, leading to a ban on agronomical use of selected products in some countries and general notions towards less usage of herbicides (Matteson 1995). Alternative approaches to current farming have emerged, adapting different strategies than conventional systems, where weeds are only perceived as detrimental factors to yield potential (Litterick & Watson 2016). Tactics of clever weed implementation are based on exploiting the natural functions of wild plants in agricultural ecosystems towards a more sustainable crop production.

One of such strategies, called “push-pull” relies on chemical interactions between plants and pests. It involves surrounding the main crop by an intercrop which releases pest-repellent exudates. The pest is driven away from the food crop, and towards another plant placed further away, which releases attractant exudates (Frank et al. 2008). *Desmodium incanum* DC. is a weedy species (Ricketts & Marble 2020) which proved to be an effective repellent plant for parasitic plant *Striga hermonthica* (Delile) Benth., accountable for massive yield losses of *Sorghum bicolor* (L.) in Kenya (Frank et al. 2008). The root exudates of *Desmodium incanum* inhibit seed germination and growth of *S. hermonthica*, resulting in significant decline in infestation (Frank et al. 2008). Some weedy grasses, such as *Cenchrus purpureus* (Schumach.) Morrone, *Urochloa brizantha* (A.Rich.) R.D.Webster and *Sorghum bicolor* are utilized as attractant plants. *C. purpureus* releases green leaf volatiles attracting gravid stemborer moths (Chamberlain et al. 2006), whose larvae are then killed by sticky mucus released by the attractant plant (Khan et al. 2011). “Push-pull” strategy is a useful tool for integrated weed management programs which aim to shift sustainable principles of organic farming towards a higher yield potential while maintaining a low level of intervention into the landscape (Bàrberi 2002).

Another function of weedy species is their use as ground cover during fallow periods, preventing soil erosion, or their employment in the practice of green manuring (Zimdahl 2007). Cover crops are plants grown on agricultural sites for the purpose of soil coverage, they also increase organic matter content and improve nutrient cycling and physical properties of the soil (Pinto et al. 2017). Green manure is a method of controlled incorporation of green plants into agricultural soils (Pieters 1927) with an intention of increasing organic matter and improving nutrient availability for succeeding crop. It is adopted in some agricultural systems, mostly, but not exclusively, in organic farming (Larkin et al. 2011). Generally, it is done with Fabaceae species, which are associated with unique nitrogen-fixing bacteria presence in rood nodules, providing accessible form of nitrogen for succeeding field crop (Zahran 1999). Common weedy species of *Trifolium* spp. and *Vicia* spp. are used as green manure (Sullivan & Diver 2001).

Apart from intentional implementation of weedy species, their natural existence in crop fields provide a range of services, important to maintaining the fragile ecosystem suppressed by agronomical cultivation. Its role is complex due to a range of interactions with other organisms. Weeds provide primary production, making them the main food sources for many animals, such as pollinators of rare plants, earthworms, and other invertebrates, but herbivorous mammals as well (Petit et al. 2011). Many food crops depend on insects as pollination vectors (Steffan-Dewenter et al. 2005). Insect pollination is facing serious threads as modern agricultural practices change the natural environment, causing such occurrences as loss and fragmentation of natural land, decrease of biodiversity and species abundance and soil alteration caused by chemical inputs. Domesticated honeybees are regarded of the most merit regarding crop pollination, however most species of pollinators come from the wild (Winfree et al. 2008). Different plants attract different pollinators (Winfree et al. 2008), therefore with decreasing diversity of plants there is decreasing diversity of pollinators. Loss of pollinator feeding weedy species is directly proportional to the decrease in pollinator incidence in agroecosystems (Steffan-Dewenter et al. 2005). Wild plants' role as food sources relates not only to pollinators, but also different parasitoid species, which provide biological pest control. These invertebrates feed on pollen and nectar, therefore their lives are dependent on flower bloom period. Because the cultivated crops bloom synchronically, the periods in between blooms represent times of vast food scarcity for these animals. If a variety of weeds is available at the site, they can easily provide resources, thanks to their continuous bloom (Trefil 2016). The increase of cropland and subsequent crop isolation from pollinators has led to the development of a strategy based on pollinator-attractive flowers. Carvalheiro et al (2012) have revealed that planting patches of wildflowers within large crop fields could be effective in increasing the yield of pollinator-dependent plants. Even a small amount of flower patches has proved to increase the abundance and diversity of insect pollinators.

5. Conclusions

This review has documented the attitudes towards the utilisation of weed species across the tropics and has found that such plants are important components of the lives of many people. The findings indicate that weeds are important sources of nutrition in areas where high quality, healthy food sources are scarce. Leafy weedy species represent an easily accessible source of protein, minerals, vitamins, fibre and antioxidants, and their dietary implementation leads to increased nutrition security of people living in underdeveloped countries. Available literature documents that weedy plants have always been used as famine foods, and that many rural communities have preserved the perception of edible weed species as important components of food security. In areas of historical use of weeds as food sources, some species of edible weeds have become semi-cultivated. Aside addressing nutrition deficiencies, weedy plants are also greatly involved in the practices of traditional medicine and are commonly used for treatment of various illnesses, not only in communities outside the reach of modern medicine. The traditional medicinal use of plants has been a source of inspiration for research and development of new pharmaceuticals. Due to their invasive potential and unique adaptability, many weedy species are cosmopolitan, making them a universally available resource, not only of nutrition and medicine, but also of animal fodder, textile fiber, or construction material. The conservation of traditional knowledge of useful weedy plants, however, confronts a challenge in the face of conventional agricultural approaches aimed at mass production of modern food crops.

Thus far, the research regarding alternative food sources have mostly been focused on plant species found in the wild, as opposed to uncultivated flora growing in anthologically alternated areas, such as agricultural or urban zones. Articles documenting the use of weedy plants as food sources are scarce and mostly of a narrow geographical scope. Today's context of increasing global population and loss of high-quality nutrient rich foods due to agricultural intensification should, however, motivate further research and encourage the implementation of such available sources of nutrition.

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