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Genetic diversity and use of African indigenous vegetables especially slender leaf

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ABSTRACT
African indigenous (AIVs), and traditional, vegetables play a role in food security. This review examines distribution, use, diversity, and techniques used to study AIVs with special interest on *Crotalaria* species. Google scholar, PubMed, and the open web were searched for published articles between 1990 and 2020. The AIVs are distributed in almost all African countries but are mostly consumed in East and West Africa. The distribution and genetic diversity of some common AIVs has been documented. There is a need to create awareness on the use and conservation of AIVs because of their role in food security and livelihoods.

KEYWORDS
Crotalaria spp; traditional vegetables; rattle pods

Diversity in plant genetic resources (PGR) requires continuous study since the human population and urbanization are increasing and cultivable land is decreasing contributing to food insecurity (Govindaraj et al., 2015). Availability of diverse plant genetic resources facilitates the development of new, or improved, cultivars, with desirable characteristics using breeding. Undomesticated relatives of today's crops, and landraces, are often adapted to marginal environments. This potential can be tapped and introgressed into domesticated varieties to improve their potential to grow in harsh environments. Conservation genetics aims to maintain genetic diversity at many levels, providing a tool for population monitoring and assessment (Narain, 2000). The reduction in population in natural populations, referred to as genetic bottlenecks, contributes to reduced genetic diversity, which may lead to increased susceptibility of plants to pests and diseases.

Existing literature on vulnerability, food security, and ecosystems has focused on cultivated crops. However, there exists evidence that wild foods are an important part of the global food basket. Wild foods have provided small holder farmers with a 'hidden harvest,' as they often use co-evolved plant species, and other wild biodiversity in, and around, their farms to supplement food and earnings. Although the exact economic value, or volume, involved is

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difficult to estimate, trade-in, and use of, wild foods provides an important supplement to household income and is especially critical during economic hardship (Bharucha and Pretty, 2010). At the regional, and national, level food balances guide policies on trade, aid and declaration of food crises. Notably absent from these balances is the contribution made by wild edible species. Routine underestimation of wild foods may lead to neglect of their roles in the ecosystem and supportive local knowledge systems that sustain them (Bharucha and Pretty, 2010). This study reviewed distribution, use, genetic diversity, and study techniques of African indigenous vegetables with special interest in *Crotalaria* species. This is because the Fabaceae family has the highest number of indigenous vascular plants in Kenya; 576 species of which 93 belong to the genus *Crotalaria*, making it the third richest genus of indigenous plant species in Kenya. The species are distributed in almost all agro-ecological zones of the country (Zhou et al., 2017).

African indigenous vegetables are edible, native, vegetable species whose natural habitat can be traced to Africa, or have been in Africa long enough to have been indigenized (Gido et al., 2016). Other terms used to describe these vegetables have been detailed, with a shift from use of the term traditional vegetables to African indigenous or African leafy vegetables (Towns and Shackleton, 2018). About 64% of the African continent is either hyper-arid, arid, or semi-arid, with approximately 50% of the population living in these lands (Kigomo, 2003). Increasing population in agricultural potential regions has caused migration to areas with marginal rainfall. This means these lands cannot be fully exploited agriculturally unless there is intervention through irrigation, leaving inhabitants at the risk of starvation and malnutrition. The AIVs are often adapted to these regions and can withstand severe climatic conditions. The relative importance of these vegetables differs between communities (Table 2). Increasing aridity and unpredictable rainfall has forced many African governments to reconsider the role of AIVs in food security.

Crotalaria is the largest plant genus in tropical Africa with over 600 species, 500 of which are thought to have originated from Africa. Plant species in this genus are distributed in almost all agro-ecological zones of Africa; most are found in eastern and southern tropics of Africa. Some species in the genus are eaten as food especially in East-Africa (Pohill, 1982).

The distribution of AIVs has been extensively mapped (Chauvet, 2004; Schippers, 2000; Shmelzer and Gurib-Fakim, 2008). Domestication intensity can be calculated as a percent of the number of countries where the plant is domestica divided by the number of countries where it is found in its wild form (Table 1). This can be used to determine the domestication level and provide insight on diversity loss. Domestication intensity ranged from 11% to 85% in different species (Table 1). It is thought that most AIVs known today are a fraction of AIVs that previously existed (Adebooye and Opabode, 2004).

Table 1. Common African Indigenous Vegetables and their distribution in Africa, adapted from (Schippers 2000; Chauvet 2004; Shmelzer and Gurib-Fakim 2008).

Common name	Botanical name	Countries/Regions cultivated	No. of countries found	Calculated domestication intensity (%)
Amaranth	*Amaranthus blitum* L./ *A. lividus* Linn./ *A. hypochondriacus* L. *and* *A. hybridus* L.	Uganda, Kenya, Cameroon	23	13
	Celosia argentea L.	Nigeria, Benin, Togo, Ghana, Cameroon	29	17
	Amaranthus cruentus L.	Ethiopia, Tanzania, Nigeria, D.R. Congo, Benin, Sierra Leone, Togo, Zimbabwe	23	35
	A. dubius Mart. ex Thell.	Kenya, Uganda Sierra Leone, Ghana, Benin, Nigeria, Cameroon, D.R Congo	20	45
	A. graecizans L.	Kenya, Uganda, Tanzania, Malawi, Malawi, Zimbabwe	31	19
Brassica	*Brassica carinata* A.Braun/ *B. integrifolia* L.H.Bailey	Ethiopia, Malawi, Tanzania, Zambia, Zimbabwe, Kenya, Uganda, Côte d'Ivoire	17	47
	Brassica juncea (L.) Czern.	Zimbabwe, Zambia, Nigeria, Malawi, Réunion, Mauritius	14	43
	Cleome monophylla L./ *C. gynandra* L.	Kenya, Tanzania, Zimbabwe, Zambia, Nigeria	43	12
Nightshade	*Solanum scabrum* Mill./ *S. nigrum* L.	Liberia, Ethiopia, Mozambique, South Africa, Côte d'Ivoire, Benin, Nigeria, Cameroon	18	44
	S. villosum Mill.	Ethiopia, Kenya, Uganda, Tanzania	17	24
	S. americanum Mill.	Sierra Leone, Ethiopia, Kenya, Uganda, Tanzania, Seychelles, Mauritius, Côte d'Ivoire, Cameroon, Zimbabwe, Mozambique	unknown	
Legumes	*Crotalaria brevidens* Benth.	Kenya, Uganda, Tanzania Sudan	12	33
	C. ochroleuca G.Don.	Kenya, Uganda, Tanzania, Congo, Cameroon, Nigeria	35	17
	Vigna unguiculata L.	West, Central, East, Southern Africa	46	85
	Cucumis metuliferus E.Mey.	Botswana, Zambia, Zimbabwe, Kenya	24	17
	Kedrostis pseudogijef Gilg.	Kenya, Ethiopia	Unknown	
	Lagenaria siceraria Molina.	Kenya, Tanzania, Cameroon, South Africa, Zimbabwe	Unknown	
	Momordica charantia L.	Kenya, Nigeria, Zimbabwe	27	11
Okra	*A. esculentus* L.	Ghana, Sudan, Cameroon, Cote d'Ivoire, Senegal, Congo, Uganda,	45	18
	Abelmoschus caillei A. Chev./ *A. manihot* L.	Nigeria, Ghana, Cameroon	13	23
Wild lettuce	*Launaea cornuta* (Hochst ex Oliv. & Hiern) C.Jeffrey/ *Vernonia cinerea* L.	Kenya, Tanzania	5	40
	Launaea taraxacifolia Willd.	Nigeria, Senegal, Benin	Unknown	

The AIVs in many communities were collected from the wild, or planted in home gardens among other staple food crops, for subsistence and household income (Abukutsa-Onyango et al., 2010). Based on origin, AIVs can be grouped into whether they originated from Africa or were introduced. Indigenous vegetables have Africa as their primary center of origin; traditional vegetables have Africa as their secondary center of origin (Abukutsa-Onyango et al., 2010; Godfrey et al., 2017). Vegetables common among African communities include: Amaranths (*Amaranthus* spp.), nightshade (*Solanum nigrum* L.), spider plant (*Cleome gynandra* L.), African kale (*Brassica carinata*

Table 2. Common African indigenous and traditional vegetables.

Scientific name	Common name	Selected local name	Parts used	Reference
Amaranthaceae Family				
Amaranthus. hybridus	green amaranth	Mchicha (Swahili), Terere (Luhya), Ododo (Luo)	Leaves	Muriuki et al., 2014; Ochieng et al., 2019
A. dubius	spleen amaranth	Terere (Kikuyu), Telele (Kamba), Mchicha (Swahili)	Leaves	Nyaura et al., 2014
A. spinosus L	spiny amaranth	Pespes (Turkana) Oringogwo (Pokot)	Leaves, Seed	Timberlake, 1994
A blitum L	purple amaranth	Lidodo (Luhya) Ododo (Luo)	Leaves	Abukutsa-Onyango et al., 2010
A. hypochondriacus	prince's-feather	Terere (Kikuyu) Mchicha (Swahili)	Leaves, Seed	Muriuki et al., 2014
A. cruentus	grain amaranth	Terere (Kikuyu)	Leaves, Seed	Gupta and Thimba, 1992; Nyaura et al., 2014
A. graecizans	Mediterranean amaranth	Ombok Alika (Luo)	Leaves	Orech et al., 2007a
Acanthaceae Family				
Asystasia mysorensis	-	Atipa (Luo)	Leaves	Geissler et al., 2002; Orech et al., 2007a
Asystasia gangetica	Chinese violet	Nyohonyoho (Luo) Kichwamangwo/Mtikini (Swahili)	Leaves	Grubben, 2004; Orech et al., 2007a
Asteraceae Family				
Launaea cornuta/ Vernonia cinerea	bitter lettuce	Uthunga (Kamba) Mchunga (Swahili)	Leaves/ stem	Ambajo and Matheka, 2016
Brassicaceae Family				
Brassica carinata	African kale	Kanzira (Luhya), Kadhira (Luo), Sukuma ya kiasili (Swahili)	Leaves	Abukutsa-Onyango, 2007a; Prain et al., 2010
Erucastrum arabicum	-	Kabich Samba (Luo)	Leaves	Orech et al., 2007a; Orech et al., 2007b
Cucurbitaceae Family				
Coccinia grandis	Ivy gourd	Nyamit Kuru (Luo), Minjilwo (Marakwet), ketpomukang (Pokot)	Fruits	Kipkore et al., 2014; Orech et al., 2007a
Lagenaria siceraria	Bottle gourd	Mongu (Kamba)	Fruits	Mumbi, 2004
Cucurbita moschata	Pumpkins	Nenge (Kamba), Lisebebe (Luhya), Malenge (Swahili), Budho (Luo), Omuongo (Kisii)	Fruits/	Leaves
Abukutsa-Onyango, 2007a; Mumbi, 2004				
Capparaceae Family				
Cleome gynandra/ Gynandropsis gynandra	Spider weed	Dek (Luo), Chinsaga (Kisii), Tsisaka (Luhya), Mgagani (Swahili), Mwianzo (Kamba)	Leaves	Onyango et al., 2013
Convolvulaceae Family				
Ipomoea spp.	Sweet potatoes	Viazi tamu (Swahili), Makwasi (Kamba), Mabuon/Rabuon (Luo) Mabuoni (Luhya), Ngwaci (kikuyu)	Leaves,	Tubers
Maundu, 1997				
Fabaceae Family				
Crotalaria intermedia/C. Ochloreuca	Slender leaf/ Rattle pod	Marejea (Swahili), Miro/mitoo (Luhya), Mitoo (Luo)	Leaves	Abukutsa-Onyango et al., 2010; Abukutsa-Onyango, 2007a
Vigna unguiculata	Cowpea	Boo (Luo), Kunde (Swahili), Egesare (Kisii), Likhubi (Luhya)	Leaves	Abukutsa-Onyango, 2007a; Orech et al., 2007a
Lablab purpureus	Hyacinth bean	Njahi (Kikuyu), Mbumbu (Kamba)	Seed	Grubben, 2004
Moringaceae family				

(*Continued*)

Table 2. (Continued).

Scientific name	Common name	Selected local name	Parts used	Reference
Moringa oleifera	Drumstick plant/ Horseradish tree	Mboga chungu/Mkimbo (Swahili)	Leaves, seed, Stem	Emongor, 2011
Solanaceae Family				
Solanum nigrum/ S. scabrum/ S. villosum	African nightshade	Mnavu (Swahili), Lisutsa (Luhya), Osuga (Luo)	Leaves	Onyango et al., 2016
Tiliaceae Family				
Corchorus olitorius	Jute mallow	Apoth (Luo), mlenda (Swahili), Omurere (Luhya), Omotere (Kisii)	Leaves	Abukutsa-Onyango, 2007a

A. Braun.), jute mallow (*Corchorus olitorius* L.) and okra [*Abelmoschus esculentus* (L.) Moench] (Table 1). Distribution of indigenous, and traditional, vegetables across the continent is uneven. Most North African, and some South African, countries have fewer AIVs compared to West and East African countries. Of the 15 most common AIVs in this review, Kenya, Uganda, Tanzania, Cameroon, Democratic Republic of Congo and Nigeria had 13 each. At least 12 AIVs have been reported in Zimbabwe.

Domestication of plants has led to intensification of agriculture contributing to population growth. A comparison of domesticates and their wild relatives indicates differences in morphology, physiology, and genetics, a phenomenon referred to as domestication syndrome (Doebley et al., 2006). They also have relatively reduced physical and chemical defenses and are more prone to pest and disease attack (Flint-Garcia, 2013). There are many wild relatives of domesticated AIVs which can serve as a gene pool for their improvement.

Methodology

Google scholar, PubMed, and the open web were searched for articles that reported any aspect of African Indigenous Vegetables between 1990 and 2020. The search domains used were African Indigenous Vegetables, Traditional African Vegetables, Crotalaria, Rattle pods, Slender leaf, genetic diversity and Africa. Eligible studies for inclusion were those which reported studies on AIVs, especially on the aspects of genetic diversity, nutrition, and medicinal importance.

Genetic diversity of AIVs

Genetic diversity is the quantitative measure of variability of a given population, a reflection of the equilibrium between mutation and loss of genetic variation (Carvalho et al., 2019). Biodiversity erosion directly, or indirectly, leads to the extinction of plant species. Loss of diversity denies breeders opportunities to develop new cultivars with desired characteristics. Techniques to assess genetic diversity within, and between, plant populations are: morphological, biochemical characterization (allozyme), and DNA (or molecular) marker analysis (Govindaraj et al., 2015). Diversity assessment by morphological markers is based on visual traits including shape/color, growth habit, flower color, and others, and does not need sophisticated technology although it requires large tracts of land for field experiments. Biochemical markers involve the identification of allelic variants of enzymes (isozymes) detected by electrophoresis or specific staining. The allozyme technique was common in the pre-genomic era and is rarely used today. A molecular marker is a genetic locus that can be tracked and quantified in a population and is associated with a certain gene or trait of interest (Hayward et al., 2015). These markers detect variations that arise from deletions, duplications, insertions, or inversions in chromosomes. They are usually located near, or are linked to, genes controlling trait(s) in question; the markers themselves do not affect the phenotype of the trait. Molecular markers used to study plant diversity include: Restriction Fragment Length Polymorphism (RFLP), Amplified Fragment Length Polymorphism (AFLP), Simple Sequence Repeats (SSR), Sequence-tagged Site (STS), Sequence Characterized Amplified Region (SCAR), Expressed Sequence Tag-Simple Sequence Repeat (EST-SSR), Single Nucleotide Polymorphism (SNP), Simple Primer Amplification Reaction (SPAR), Sequence-Related Amplified Polymorphism (SRAP) and Target Region Amplification Polymorphism (TRAP) markers (Jonah et al., 2011). Start codon targeted (SCoT) markers, which are based on short conserved regions flanking the start codon (ATG) in plant genes, have been used to study genetic diversity in plants (Satya et al., 2016).

A total of 27 studies that investigated the diversity of common AIVs were considered in this review (Table 3). Of the 27 studies, 7 used morphological characterization exclusively while 4 employed a combination of morphology and DNA markers. Two studies used allozyme and isozyme markers combined with DNA markers; 15 used DNA markers exclusively, or in combination with others. Only 1 was a sequence-based genetic diversity assessment study. Of the 27 studies, 23 were done in the post-genomic era yet only 1 involved genotyping by sequencing. Eighteen studies considered a sample size of 0–50 individuals; 6 had sample sizes of 51–100. Three studies used sample sizes of more than 100 plants. Based on parametric statistics, it was thought that using 30 individuals randomly from a population would be enough to accurately determine the actual mean of a parameter. Based on this, most plant population studies used sample sizes of 50 individuals as a standard sample size. However, that sample size underestimates the allelic richness of populations (Miyamoto et al., 2008).

Table 3. Techniques used to study genetic diversity in African Indigenous Vegetables.

Vegetable species	Diversity study technique used	Samples per study	Country(s) collected	Reference
Amaranthaceae				
Amaranthus spp	Morphology	32	USA, Tanzania, Botswana, South Africa, Germany	Gerrano et al., 2015
Amaranthus spp	RAPD	6, 33	Romania, USA	Popa et al., 2010; Transue et al., 1994
A. caudatus, A. cruentus, a	*A. hypochondriacus* Wu and Blair, 2017		Genotyping by Sequencing (GBS)	95
Amaranthus spp	Isozyme and RAPD markers	60	b	Chan and Sun, 1997
Amaranthus spp	AFLP and Double-Primer Fluorescent Inter-SSR markers	26	c	Xu and Sun, 2001
Amaranthus cruentus	RFLP markers	72	d	Park et al., 2015
Solanaceae				
Solanum spp	Morphology, SSR and AFLP markers	54	Kenya, Tanzania, Cameroon	Ronoh et al., 2018
Solanum spp	RAPD markers	28	India	Singh et al., 2006
S. scabrum and *S. nigrum*	AFLP markers	48	e	Manoko et al., 2008
Solanum L	Morphology	50	East, West and Southern Africa	Mwai et al., 2003
S. nigrum	Morphology	15	India	Suganthi et al., 2018
Cruciferae				
Brassica juncea	Morphology and SSR markers	44	India, Australia, Poland, China	Vinu et al., 2013
B. rapa	RFLP markers	15	f	Crouch et al., 1995
Leguminoceae				
Vigna unguiculata	Morphology and SSR markers	32, 20	Kenya	Mafakheri et al., 2017; Wamalwa et al., 2016
V. unguiculata	RAPD, Allozyme markers	56, 271	i	Ba et al., 2004; Pasquet, 2000
Crotalaria spp	Morphology	29	Kenya	Mwakha et al., 2020
Cucumis spp	Morphology and SSR markers	36	South Africa, Zimbabwe, Netherlands, Zambia, Burundi, USA, Russia	Weng, 2010
Cucumis spp	SNPs, InDel and SSR markers	66	j	Tanaka et al., 2013
Lagenaria siceraria	SSR markers	398	k	Gürcan et al., 2015; Mashilo et al., 2016
L. siceraria	Morphology	418	Turkey	Taş et al., 2019
Momordica charantia	Morphology	25	India	Singh et al., 2014
Malvaceae				
Abelmoschus esculentus	Morphology	20, 10	Nigeria	Alake, 2020; Bello and Aminu, 2017
A. esculentus	ISSR markers	24	China	Yuan et al., 2015

a. Mexico, Peru, India, USA, Guatemala, Bolivia, Zambia, Ecuador, Afghanistan, Argentina, Benin, China, Maldives, Nigeria, Pakistan, Russia, Rwanda, Sudan, Uganda, and Zimbabwe.
b. Germany, Canada, USA, Bolivia, Ecuador, India, Czechoslovakia, Guatemala, Mexico, Zimbabwe, France, Jamaica, Seychelles, Argentina, Nepal, Pakistan, Senegal, Russia, Rwanda, Peru, Indonesia, Taiwan, Zambia, Hong Kong, Bangladesh, China, Maldives, Philippines.
c. Argentina, Bolivia, India, USA, Guatemala, Zaire, Mexico, Nepal, Pakistan, France, Germany, Russia, Rwanda, Ecuador, Peru, China.
d. Guatemala, USA, Mexico, Peru, India, Nigeria, Ghana, Zaire, Zambia, Argentina, Bhutan, Bolivia, Pakistan, Peru, Nepal, Puerto Rico, Brazil, Chile, China, Uganda, Sri Lanka, Afghanistan, Bhutan.
e. Uganda, Indonesia, Cameroon, Ghana, Tanzania, Argentina, South Africa, Kenya, Italy, Germany, Netherlands, Belgium, Zimbabwe, El Salvador, Romania, Australia.

f. Netherlands, Germany, Canada, Turkey, Argentina, Sicily, Algeria, California, Greece, France.
g. India, Afghanistan, America, Brazil, Columbia, Turkey, Nigeria, Paraguay, Belgium, Iran.
h. Angola, Brazil, Cameroon, China, Colombia, Algeria, Egypt, Eritrea, Ethiopia, Guyana, Burkina Faso, Indonesia, India, Iraq, Italia, Laos, Madagascar, New-Caledonia, Pakistan, Philippines, Somalia, Georgia, Thailand, Togo, Uganda, Yemen, South-Africa, Zaire.
i. USA, England, France, Spain, China, India, Japan, Sudan, Cameroon, Senegal, Ghana, Korea, Egypt, Morocco, Ethiopia, Chad, Mali, Sierra-Leone, Zambia, Zimbabwe, Turkey, Syria, Iraq, Iran, Afghanistan, Maldives.
j. USA, Serbia, Greece, Mexico, Argentina, Turkey, Zimbabwe, Nigeria, Zambia, Russia, India, Italy, Syria, Ethiopia.

Microsatellite-based diversity studies should use sample sizes of not less than 56 individuals, and where possible 200 to 300 individuals (Miyamoto et al., 2008).

Genetic diversity of *Crotalaria* species

The global genetic diversity of the genus *Crotalaria* remains largely unknown. Although there are some species of economic importance within the genus, few studies have been done as DNA markers and known functional genes in *Crotalaria* are few (Mosjidis and Wang, 2011). Most species in the genus are not major crops, there has been little effort to sequence them. Searching the PopSet database in the National Center for Biotechnology Information (NCBI) for *Crotalaria* yielded 225 entries, compared to 2,141 and 843 for *Solanum* and *Brassica* species, respectively. Of the 225 entries, half of the sequences are related to ribosomal and chloroplast nucleic acids. In East Africa, a single diversity study based on morphological characterization has been done (Mwakha et al., 2020). Elsewhere, diversity studies have been done on some undomesticated species within the genus (Table 4). The EST-SSR markers were used to study diversity between the species *C. juncea* L., *C. pallida* Aiton., *C. retusa* L., and *C. spectablis* Roth. (Wang et al., 2006). These markers were designed from *Medicago* and soybean [*Glycine max* (L.) Merr.] and most likely cannot yield results for intra-specific polymorphism in *Crotalaria*. The SCoT markers were used to study genetic diversity of *C. juncea, C. pallida, C. spectabillis, C. verrucosa* L., *C. nana* Burm.f.,

Table 4. Studies on genetic diversity of *Crotalaria.*

Study technique	Sample size	No. of species	Country collected from	Clades observed	Reference
Morphology	29	2	Kenya	7	Mwakha et al., 2020
Morphology	40	1	India	10	Nareshkumar et al., 2018
PCR amplification of ITS and *matK* regions	180	37	India	8	Rather et al., 2018
SCoT markers	94	7	India	9	Satya et al., 2016
EST-SSR markers	26	4	Nigeria, USA, Russia, Brazil, India, Pakistan, Senegal, Cameroon, Myanmar, Sir Lanka, Guadeloupe, South Africa, Australia.	4	Wang et al., 2006

C. retusa L. and *C. laburnifolia* L. (Satya et al., 2016). Although the SCoT marker system was found to be a reliable system for the genetic assessment of *Crotalaria* species, the markers were not suitable for diversity assessment of certain species such as *Crotalaria retusa* L. Genetic diversity of 37 wild *Crotalaria* species was through amplification and sequencing of the Internal Transcribed Spacer (ITS) region and *matK* regions, leading to discovery of 2 new species (Rather et al., 2018). These regions would be more reliable for detecting inter- and intra-specific polymorphism in any plant species. However, diversity generated from these markers is based on the chloroplast, other genomic regions were not considered. There is a need for more genetic diversity studies, especially using molecular methods in the genus, since genetic diversity of most species remains undescribed.

Nutritional and medicinal importance of AIVs

Malnutrition is the main cause of death and disease in the world, with over 462 million underweight people in the world with about 52 million children suffering from wasting (Anonymous, 2018a). Consequently, 56% of deaths in Africa in 2015 occurred as a result of nutritional conditions (Anonymous, 2018b). Numerous studies report the nutritional superiority of AIVs to common exotic vegetables. A detailed comparison of the nutritional value of various AIVs for β-carotene, folic acid, vitamin C, calcium, iron, and proteins has been done (Aworh, 2018). Iron, calcium, and zinc content in 54 species of AIVs were higher than reported levels of the exotic vegetable spinach (*Spinacia oleracea* L.) (Orech et al., 2007b). Levels of proteins, fats, crude fiber, ash and carbohydrates, and concentrations of calcium, zinc, and iron have been studied in amaranth species and are high, and adequate, for proper nutrition (Muriuki et al., 2014). An important component in these AIVs is zinc, a mineral whose deficiency in humans is shown to cause growth retardation and impaired development but whose over ingestion can be detrimental. Most staple crops of sub-Saharan African communities lack the ability to absorb zinc as growing plants (Laker, 2005). The AIVs are mixed with the staple diets or supplied as accompaniments to provide zinc.

Many AIVs are characterized by higher nutritional content compared to the global vegetables and therefore offer healthy, affordable, and accessible nutrient-dense alternatives. These vegetables also have potential to produce bioactive compounds, which contribute to antioxidant activities in the body, and therefore protect the body against diseases through nutraceutical effects (Mbhenyane et al., 2010). The nutritional superiority of AIVS is an important aspect of fighting infectious diseases such as the COVID-19 pandemic as well as providing protection against malnutrition and non-communicable diseases. Further, some AIVs are accessible all year round, hence can be found even in times of acute food or nutritional scarcity (Feyssa et al., 2012).

There are many medicinal drugs of plant origin, and more plants are under investigation to ascertain their therapeutic efficacy. Even with the advent of modern medicine, traditional medicine based on herbal extracts remains a component of health-care systems in African communities. The greatest hindrance to tapping this traditional knowledge on herbal remedies is that most ethnobotanical information remains undocumented and is passed on by word of mouth only to close relatives as a trade secret (Kipkore et al., 2014). The Green amaranth (A. hybridus L.), a common AIV, is used to manage diabetes and fertility problems and to treat mouth infections (Geissler et al., 2002; Ishiekwene et al., 2019). Vernonia amygdalina Delile. is used to manage diabetes and in treatment of diarrhea and stomach ailments. Ocimum gratissimum L. has been used in treatment of stomach ailments, diarrhea, colds, coughs, and in managing asthma, an aspect that could be attributed to the menthol and mint essential oils contained within the plant (Geissler et al., 2002; Ishiekwene et al., 2019). Early teething complications in children have been treated with Asystasia mysorensis (Roth) T.Anderson, Moringa oleifera Lam. has been used by Nigerian communities to treat high cholesterol, hypertension, liver problems, and wounds. The traditional vegetables: Gynandropsis gynandra (L.), Leptadenia hastate (Pers) Decne., Lippia javanica (Burm.f.) Spreng, Portulaca quadrifida L, Vangueria apiculate K.Schum., and V. madagascariensis J.F.Gmel. have been used as medicine (Kipkore et al., 2014).

Nutritional and medicinal importance of *Crotalaria* species

In East Africa, the edible species of *Crotalaria* are *C. ochroleuca* G.Don and *C. brevidens* Benth. *Crotalaria ochroleuca* has a mild taste when cooked, is taller (avg. 250 cm) than *C. brevidens* (avg. 210 cm) and has broader and bigger pods. *Crotalaria brevidens* has a bitter taste when cooked and has bluish green leaves and slender pods compared to *C. ochroleuca* (Abukutsa-Onyango, 2007b). These species are rich in vitamin A, iron, calcium, phosphorus, and proteins (Sahou et al., 2014). They also have relatively higher contents of Vitamin A, calcium, and phosphorous than other vegetables though they have low amounts of vitamin C (Table 5).

Other edible species outside East Africa include *C. lachnophora* A.Rich. whose seed are boiled then eaten in the Democratic Republic of Congo; *C. quinquefolia* L. whose flowers can be steamed and eaten, and *C. retusa* L., whose leaves are eaten as vegetables. Young shoots of *C. longirostrata* Hook. & Arn. are eaten cooked. Seed of *C. pallida* Aiton. are used to make a fermented food called "dage" and the flowers used as a vegetable. *Crotalaria cajanifolia* Kunth. leaves and young shoots are used as a potherb or vegetable. Young leaves of *C. macrocalyx* Benth. are eaten cooked as vegetables or stews when

Table 5. Nutrient and mineral composition of *C. brevidens* and *C. ochroleuca*[a] compared to other vegetables.

Nutrient/mineral content	*Crotalaria brevidens*	*Crotalaria ochroleuca*	*Amaranthus* spp.[b]	Nightshade.[c]	Cowpea leaves [d]	Cabbage [e]
Protein (%)	33.47	25.66	13.56	24.90	34.17	1.94
Vitamin C (mg/100 g)	0.53	0.68	4.20	35.18	36.0	56.37
Beta carotene (ug·g^{-1})	600.75	529.53	373	466	712	714
Dietary fiber (%)	17.45	23.46	6.70	6.81	21.79	3.77
Iron (%)	7.18	5.02	7.61	13.01	7.50	2.15
Calcium (mg/100 g)	437.99	442.42	159	17.33	25.1	28.9
Phosphorus (mg/100 g)	253.18	242.54	557	75.22	9.0	26.92

[a]Akubugwo et al. (2007)
[b]Soriano-García and Isabel (2019)
[c]Acipa et al. (2013)
[d]Owade et al. (2020)
[e]Ogbede et al. (2015)

mixed with *Vigna unguiculata* (L.) Walp. *Crotalaria natalitia* Meisn. leaves are cooked and mixed with groundnuts or coconut milk. *Crotalaria spectabilis* Roth. flowers are eaten cooked as a vegetable, or pickled after boiling (Fern et al., 2016). Flowers, buds, fruit, and seed of *C. juncea*, and *C. tetragona* Roxb. ex Andrews. are eaten cooked as vegetables, as are leaves of *C. retusa* and flowers of *C. micans* Link. (Pandey et al., 2010).

Crotalaria can be used in traditional medicine and may be potential drugs (Table 6). The *C. brevidens* leaves have been reported to treat stomach-ache, swellings and malaria (Abukutsa-Onyango, 2004). The *C. ochroleuca* is used to treat yellow fever and sore feet; *C. spectabilis* Roth. is used to treat scabies, impetigo and lower blood pressure. *Crotalaria juncea, C. vitelline* Ker-Gawl., *C. retusa* and *C. pumila* Ortega are used in traditional medicine to treat uterine hemorrhages, dysentery and inflamed wounds. This could be attributed to types of pyrrolizidine alkaloids present (Tamariz et al., 2018).

Other uses of AIVs

These vegetables generate income for communities (Schippers, 2000). The *A. spinosus* L. leaf extracts inhibit germination of tomato (*Solanum lycopersicum* L.), onion (*Allium cepa* L.) and carrot (*Daucus sativus* (Hoffm) Rupr.) seed (Alegbejo, 2014). Leaf extracts of nightshade (*S. americanum* Mill., *S. nigrum* L. and *S. opacum* A.Braun) may control *Bulinus* and *Biomphalaria* snail species which host *Schistosoma* parasites that cause bilharzia. Leaf and fruit extracts of *S. nigrum* and S. *villosum* are used to control mosquito larvae and in control of malaria and dengue fever. Most AIVs in the Fabaceae family are legumes and contribute to soil improvement. Lablab beans [*Lablab purpureus* (L.) Sweet] are used as green manure, cover crops, and forage and

Table 6. Traditional medicinal uses of different *Crotalaria* species (Fern et al., 2016).

Crotalaria species	Ailment treated/medicinal use	Possible medicinal drugs
ferruginea Graham ex Benth.	fevers	Antipyretics, Analgesics
quinquefolia L	snake and millipede bites, fevers, scabies, impetigo and lung afflictions	Analgesics, antibiotics, Antitoxins, Antivenins, Antihistamine
cunninghamii R. Br.	Swellings, eye infections	anti-inflammatory drugs, Antihistamines, antibiotics
lachnophora A. Rich.	otitis	anti-inflammatory drugs, antibiotics
retusa L.	coughing, dyspepsia, fever, cardiac disorders, stomatitis, diarrhea, scabies, impetigo, skin infections, lung diseases, cold and scorpion sting,	Expectorants, antacids, Analgesics, Anticoagulants, Anesthetics, antidiarrheals, antibiotics, Antivenins, Toxoids, decongestants
longirostrata Hook. & Arn.	Used as a purgative	
brevidens Benth.	stomach-ache, swellings, malaria, sore throat and mouth thrush	Antiemetics, anti-inflammatory drugs, Anti-fungal
ochroleuca G. Don.	yellow fever, sore feet	Antivirals, anti-inflammatory drugs
calycina Schrank.	pain, convulsions, wounds, venereal sores, syphilis	Analgesics, anticonvulsants, antibiotics, Antiseptics
pallida Aiton.	urinary problems, fever, skin infections, thrush, swollen joints and wounds	Antibiotics, Analgesic, Antiseptics
berteroana DC.	scabies and white atrophy	Ointments
pilosa Mill	gonorrhea, baths and poultices, wounds and sores	Antibiotics, Antiseptics
tanety Du Puy, Labat & H.E. Ireland.	dysentery	Antibiotics
uncinella Lam	dysentery	Antibiotics
prostrata Rottler ex Willd.	derangements of the stomach, infantile diarrhea, gout, cuts and wounds	Antidiarrheals, xanthine oxidase inhibitory drugs, Antiseptics
sessiliflora L	Headaches, detoxifier of toxins including DDT, arsenic and poisonous mushrooms	Analgesics, Antidotes
goodiiformis Vatke	stomachache and hookworms	Analgesics, Anthelminthics
aculeate De Wild	Malaria	Antimicrobials
juncea L	Blood purification, impetigo and psoriasis	Antitoxins, Antibiotics, Psoralens
albida	Indigestion, feet warts, bed wetting	Antacids, salicylates
medicaginea Lam	expel bile and phlegm, scabies and impetigo.	Ointments, Antibiotics
assamica Benth	bladder stones	Antihyperuricemic agents
verrucosa L.	Fever, stomach pains, blood purifier, emmenagogue, skin diseases,	Antipyretics, Analgesics, Ointments, Antitoxins,
incana L	Abortifacient, gonorrhea, for baths and as poultices, wounds and sores	Antibiotics, Antiseptics
alata Buch	malarial fever, bed wetting	Antimicrobials
laburnifolia L	sore throats, mouth inflammations, skin diseases, emmenagogue	Anesthetics, Antibiotics, progestins
natalitia Meisn	boils	Antibiotics
spectabilis Roth	scabies and impetigo, lowering blood pressure	Antibiotics, antihypertensives

fodder. *Crotalaria* species are used in control of *Striga hermonthica* (Delile) Benth., as green manure and to control nematodes in farming systems (Fern et al., 2016).

Importance of the review on AIVs

African indigenous vegetables and African traditional vegetables are an integral part of many societies and provide food, medicine, and livelihood. The present study mapped the use, distribution, and domestication of these vegetables. The different techniques that have been used to assess genetic diversity in AIVs populations including morphological characterization, DNA markers, allozyme, and isozyme markers as well as sequencing techniques have been highlighted. This study established that AIVs are nutritious and play an important role in diet with over 25 species in genus *Crotalaria* being of medicinal importance. This review examined the role of sample size in AIVs diversity assessment and recommends that future studies consider larger sample sizes, as small sample sizes underestimate the allelic richness of populations. Further, research on AIVs needs to be enhanced to be at par with other crops with a focus toward making them more adaptable to changing environments. More concerted efforts of conserving these species and their wild relatives are required to preserve the existing diversity which could be crucial in genetic improvement.

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