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Opportunities for African indigenous vegetables (AIVs): regulations in the vegetable seed sector in sub Saharan Africa

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Abstract
African indigenous vegetables (AIVSs) play crucial roles in promoting a healthy diet and providing commercial opportunities for smallholder farmers. Despite their nutrient-rich nature, their consumption is limited, highlighting the need to develop and promote them, as they are well adapted to climate change. To address this issue, a comprehensive study combining desk research and a survey was conducted in Malawi, Zambia, and Zimbabwe (Southern Africa), as well as Kenya and Tanzania (East Africa). This study aimed to assess progress and regulations on AIV germplasm management, crop improvement, seed production and seed trade and to propose seed regulations that could unlock opportunities for AIVs. The World Vegetable Centre has played a crucial role in vegetable seed sector development working with public and private partners. Kenya and Tanzania officially released several AIVs, namely, spider plant (Cleome gynandra), amaranth (Amaranthus spp.), okra (Abelmoschus esculentus), pumpkin (Cucurbita spp.) and African nightshade (Solanum spp.). These efforts represent important steps toward promoting and enhancing the cultivation and utilization of AIVs. The trade of AIV seeds has primarily been observed between Kenya and Tanzania, while such trade is not well documented in other Southern African countries. Regulations regarding the release of vegetable varieties vary across regions. In Kenya and Tanzania, formal release of vegetables is required, whereas is not mandatory in Malawi, Zambia and Zimbabwe. The need for testing for distinctness, uniformity and stability (DUS) and value for cultivation and use (VCU) need to be assessed to provide flexibility, whereas seed certification should allow for the certification and quality declared seeds (QDS), offering options that promote the growth of the AIV seed sector. The AIV sector has several strengths, including the presence of key stakeholders, abundant genetic resources and an untapped market. Opportunities include the recognition of different seed classes, free trade areas, and the integration of seed systems, allowing farmer and small seed companies to enter the seed business. Owing to climate uncertainty and nutrient deficiencies, there is an urgent need to develop seed regulations for AIVs to ensure that the vegetable sector can fully develop and contribute to food system resilience.

Keywords African indigenous vegetables, East Africa, Southern Africa, Variety release, Seed certification

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Introduction

Agriculture serves as the primary livelihood activity for the majority of economies in Sub-Saharan Africa (SSA), accounting for 60% of employment and contributing 15% of the gross domestic product (FAO 2016). Fruits and vegetables are gaining increasing attention in international research and development efforts, driven by the focus on nutrition, climate adaptation, biodiversity preservation and livelihood improvement (FAO 2020, 2021; Bokelmann et al. 2022). The African vegetable seed industry holds significant potential for growth and advancement, driven by factors such as population growth, urbanization, rising incomes, and favourable output prices (Schreinemachers et al. 2021).

The African continent faces severe challenges, including climate change, micronutrient deficiency, and low agricultural productivity (WHO 2017; FAO 2018). The vegetable sector comprises exotic vegetables, fruits and African Indigenous Vegetables (AIVs). Promoting the incorporation of AIVs into diets is a sustainable approach for ensuring a wide array of nutrients, addressing micronutrient deficiencies, and mitigating associated health problems for all households. AIVs have been an integral part of diets in Eastern and Southern African regions for centuries. In terms of nutritional quality, AIVs such as amaranths *(Amaranthus spp.*) surpass their exotic counterparts, such as cabbage (*Brassica oleracea*), containing 57 times more vitamin A precursors, 13 times more iron and eight times more calcium (Yang and Keding 2012). Among the significant AIVs on the African continent are African eggplant (*Solanum spp.*), leaf amaranth, spider plant (*Cleome gynandra*), okra (*Abelmoschus esculentus*), various species of nightshade (*Solanum spp.*) and pumpkins (*Cucurbita spp.*). In addition to their nutritional value, AIVs are deeply ingrained in local culinary traditions and cultural customs. They play dual roles as both a dietary staple and a medicinal resource, effectively addressing a spectrum of health concerns, such as cancer, snake bites, food poisoning, malaria, anaemia, and diabetes, and supporting childbirth and postnatal care (Azevedo-Meleiro and Rodriguez-Amaya 2007; Auya et al. 2016; Thovhogi et al. 2021; Erakoze et al. 2021; Ramulondi et al. 2021; Houdgegbe et al. 2022; Mashamaite et al. 2022).

The seed sector varies according to objectives, agro ecology, actors/stakeholders, crops, agricultural development, and opportunities and contributes to food and nutritional security and socioeconomic change. Two seed systems coexist namely, formal and informal and have enabled farmers to adapt to climate change and accomplish their social, cultural, and livelihood needs (Louwaars and Manicad 2022). Both systems demonstrate high permeability, as seeds developed in formal systems often originate from informal systems, and informal systems allow for the inflow of seeds from formal systems (Bellon et al. 2006; Westengen et al. 2014). In most of SSA, the deployment of seeds in the formal sector is governed by seed laws, which regulate the introduction of new cultivars through official testing. These tests evaluate the performance of cultivars (Value for Cultivation and Use; VCU) and describe their Distinctiveness, Uniformity, and Stability (DUS) (Setimela et al. 2009; Gisselquist et al. 2013). However, African governments have recognized the need to facilitate easier, faster and more affordable seed trade by establishing harmonized trade rules through regional economic communities such as the Southern Africa Development Community (SADC), the Common Market for Eastern and Southern Africa (COMESA) and the Eastern African Community (EAC) (Nzuma et al. 2011; Wafula and Waithaka 2016; SADC 2008; COMESA/ACTESA 2016). These initiatives aim to address the challenges associated with low agricultural production and promote regional cooperation. By streamlining seed trade regulations and fostering regional collaboration, these initiatives contribute to overcoming barriers and enhancing agricultural productivity in SSA.

In recent decades, several achievements have been made in the AIV seed sector, leading to a surge in demand for these crops in both urban and rural markets (Afari–Sefa et al. 2012). This increased demand has resulted in improved incomes for smallholder and peri-urban farmers (Weinberger and Msuya 2004; Ngugi et al. 2006; Afande et al. 2015). Furthermore, the impact of climate change and the promotion of biofortified crops have placed AIVs at the forefront of efforts to increase food and nutritional security. Despite the increasing importance of AIVs, comprehensive information regarding the regulation of AIV seed systems is lacking. Therefore, this study aimed to assess the value chain of the vegetable seed system in selected countries and propose interventions. Considering that seed systems play a crucial role in ensuring food security and improving livelihoods, implementing the identified interventions embraces the great potential for enhancing quality of life for women and youth farmers in Africa. These farmers are valuable resources for agricultural productivity (FAO, CTA and IFAD 2014; Afande et al. 2015; FAO 2016).

Methods

The data collection process involved conducting desktop studies on various aspects of genetic resource management, variety development and release, seed production, certification, marketing and seed regulation. The focus of the study was East African countries such as Tanzania and Kenya, as well as Southern Africa, including Zimbabwe, Zambia, and Malawi (Table 1, Fig. 1).

Table 1 A comprehensive review of the literature across different aspects of the vegetable seed sector value chain

Area	Literature search
Vegetable germplasm collection, variety development and release	Setimela et al. 2009; De Boef et al. 2010; Afari-Sefa et al. 2012; Dinssa et al. 2013; Dinssa et al. 2015; Dinnsa et al. 2016; Schreinemachers et al. 2017; World Vegetable Centre 2019; Ochieng et al. 2019; EMEA Agri 2020; Akinbo et al. 2021; Schreinemachers et al. 2021
Seed certification, Phytosanitary, Acts for East and Southern African countries	Nzuma et al. 2011, SADC 2008; FAO 2006; Setimela et al. 2009; Dube and Mujaju 2013; GURT 2015; Kuhlmann and Zhou 2015; ISSD Africa 2017; ARIPO; OECD; ISTA; Tanzania, Kenya, Malawi, Zambia and Zimbabwe Seed, Export, Import and Phytosanitary Acts
Seed systems and harmoniation	Almekinders and Louwaars 2002; ARIPO; OECD; ISTA, EAC, COMESA and SADC harmonization; De Boef et al. 2010; COMESA/ACTESA 2016; ISSD Africa 2017; Kuhlmann and Zhou 2015; Louwaars and de Boef 2012; Nzuma et al. 2011; Wafula and Waithaka 2016

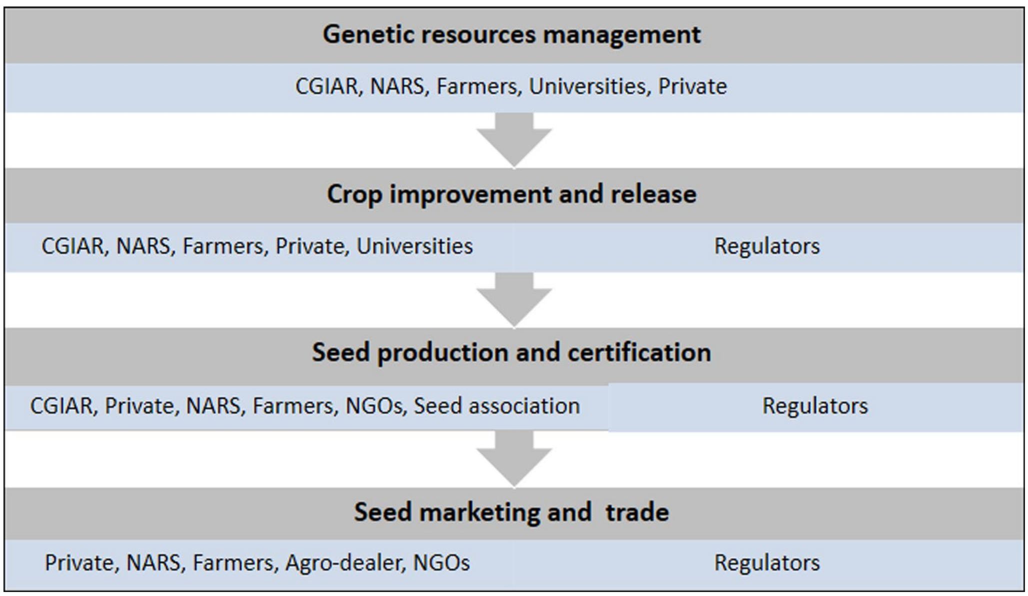

Fig. 1 Conceptual framework of AIV the seed value chain. *CGIAR* consultative group on international agricultural research, *NARS* National agricultural research system, *NGOs* nongovernmental organizations

A structured questionnaire was distributed to national seed authorities in Kenya, Tanzania, Malawi, Zambia, and Zimbabwe to gather data. Key informants (KIs) from these agencies responded to the questionnaire, with four (4) individuals representing each country. This survey aimed to collect information on vegetable seed genetic resources and regulations, specifically focusing on *Brassicas* spp. and AIVs with respect to their VCU and their DUS, variety release and seed certification as well as the number of cultivars released, seed imports and exports, and rights to both exotic plants and AIVs from 2000 to 2020. Additionally, the survey sought to gather information on the harmonization of variety release, seed certification, and phytosanitary standards. By examining the Strengths, Weaknesses, Opportunities and Threats (SWOT) of AIV seed sector regulations, this study aimed to assess and forecast the future trajectory of this sector.

Results and discussion

Genetic resources

The farming landscapes of Sub-Saharan Africa are rich in genetic diversity, particularly in the plant genetic resources of African indigenous vegetables (Maundu et al. 2009; Kwarteng et al. 2018). The assembly, characterization, and management of these plant genetic resources are governed by various national and international policies, such as Plant Genetic Resources for Food and Agriculture (PGRFA), which serve as the foundation of crop improvement programs. The World Vegetable Centre (WVC), in collaboration with its partners, has played a crucial role in collecting, characterizing, conserving, and disseminating AIV genetic resources (AVRDC 2008; Dinssa et al. 2015). Biodiversity International has also made significant contributions to AIV research and development, particularly in the case of amaranth and nightshade (Gotor and Irungu 2010). The Alliance for Green Revolution in Africa (AGRA) and the African Orphan Crops Consortium (AOCC) have actively supported the breeding of these neglected and underutilized species (Sogbohossou et al. 2018).

The germplasm collection at the World Vegetable Center, Eastern and Southern Africa hub, serves as a short-term storage facility and contains 1758 accessions representing 13 genera and 44 species (Dinssa et al. 2013, Table 2). These accessions can be shared with partners in the region, as reported by Dinssa et al. (2013) and Ochieng et al. (2019). The Kenyan gene bank holds 45 spider plant accessions, whereas Tanzania and South Africa share 184 duplicate accessions of spider plant (Kemei et al. 1995; Jansen van Rensburg et al. 2007). The Zimbabwe Genetic Resources Institute has a larger collection of accessions under its custody (O Chipfunde personal communications 2024, Table 2). Additional AIV accessions were obtained from the University of Zimbabwe, the African Indigenous Vegetable Institute (AIVI—MUAST), other universities, the Horticultural Research Institute, private companies and community gene banks (Kutsukutsa et al. 2014; Wenyika et al. 2015). Malawi and Zambia have AIV germplasm collections, with the SADC Plant Genetic Resources Centre (SPGRC) maintaining a larger regional combined germplasm collection on behalf of the member countries (Mnzava and Chigumira 2004, Table 2). These germplasm collections are kept ex situ, and there is a need for expansion to include plant materials from wild, purified lines and farmer landraces.

The conservation status of African Indigenous Vegetables (AIVs) indicates a deficiency in ex situ conservation compared with in situ preservation, necessitating efforts to fortify ex situ conservation practices (Allen et al. 2019; van Zonneveld et al. 2021). Collaboration among gene banks, botanical gardens, and other stakeholders is crucial. They should work in crafting integrated ex situ and in situ conservation strategies to bolster the safeguarding of AIVs amidst climate change challenges. This collaboration mirrors successful practices seen in cowpea conservation (Moray et al. 2014). Conservation recommendations and strategies should be formulated on the basis of identified gaps for cucurbits, okra, watermelon, and other food crops in the SADC region (Allen et al. 2019; Magos Brehm et al. 2022).

The current state of characterization of AIV germplasm shows much progress on conserved genetic resources (Omondi et al. 2017; Taher et al. 2017; Omondi et al. 2017; Sogbhossou et al. 2018/2019; Wu et al. 2018; Mkhabela et al. 2022), with the need to further focus on the underrepresented wild species. The combined utilization of agro-morphological, nutritional, and molecular characterization methods are crucial for the effective utilization and breeding of these genetic resources (Wenyika et al. 2015; Sogbohossou et al. 2018; Nyasulu et al. 2021; Houdegbe et al. 2022; Mkhabela et al. 2022). Molecular markers play crucial roles in assessing the relationships among genetic resources, crop varieties, and species, while genome sequences provide valuable information for crop improvement. The molecular markers most commonly utilized are Random Amplification of Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphisms (AFLPs), and Simple Sequence Repeats (SSR). The more recent technologies are the next–generation sequencing platforms utilizing chloroplast DNA (cDNA), Single Nucleotide Polymorphism (SNP) and Diversity Array Technology Sequencing (DArTseq) markers (Jaccoud et al. 2001; Mujaju et al. 2011; Tanaka et al. 2013; Tamboli et al. 2016). It is essential to enhance and strengthen the coordination of AIV germplasm collection, management and characterization among national, regional and international partners (Schreinemachers et al. 2017; Sogbohossou et al. 2018). Recently, there has been increased collaboration between

Table 2 The genetic resources of African indigenous vegetables are stored at various institutions

Species		Zambia	Zimbabwe	Malawi	Tanzania	SADC	World veg
Abelmoschus spp.	Okra	138	18	23	2	122	–
Amaranthus spp.	Amaranth	118	27	49	8	110	796
Cleome spp.	Spider plant	70	17	–	184	35	580
Corchorus spp.	Bush okra	47	–	–	–	22	–
Solanum	African eggplant	19	2	4	5	–	110
Hibicus spp	Roselle	43	2	–	–	14	–
Bidens polosa	black Jack	2	–	–	–	–	–
Solanum	African nightshade	–	13	–	4	13	290
Cucurbit/(*Cucumis spp*)	Pumpkin and (melon)	700 (193)	279 (54)	181	10	531 (6)	–

— missing data points, SADC additional information can be collected through https://www.genesys-pgr.org, http://www.spgrc.org/

the World Vegetable Centre and Seed Companies under the African Seed Trader Association (AFSTA) through the Africa Vegetable Breeding Consortium (AVBC). This consortium facilitates annual workshops and field days, promotes the exchange of experiences, addresses challenges, and shares germplasms for the development of the African vegetable sector, including AIVs (Ochieng et al. 2019). To ensure future global food and nutritional security, the World Vegetable Centre actively engages with National Research and Extension Systems (NARESs), private seed companies, universities, nongovernmental organizations and individual stakeholders. This active engagement facilitates the exchange of genetic resources and information for sustainable agricultural practices (Schreinemachers et al. 2017). This contribution has been significant, as all available amaranth seed varieties contain World Vegetable Centre germplasm (Ochieng et al. 2019). A coordinated approach on germplasm collection, conservation, and characterisation of AIV germplasm would greatly be required on all AIV crop species.

Crop improvement and variety release

The World Vegetable Centre effectively utilizes conventional and Participatory Plant Breeding (PPB) methods to capture the preferences of all stakeholders, raise awareness, and empower communities (World Vegetable Centre 2019). The consistent engagement of farmers, seed growers, retailers and consumers play a crucial role in the development of varieties (Ceccerelli and Grando 2007; Dinssa et al. 2015). Stakeholders' active involvement in PPB for AIVs has led to significant benefits, utilizing indigenous knowledge systems across various stages such as parental selection, trait development and cultivar enhancement, varietal evaluation, palatability considerations, and marketing strategies (Dinssa et al. 2015). The participation of women, youth and men in PPB approaches has yielded positive results in the development of product profiles of African eggplant, African nightshade, amaranth, and spider plant varieties (Adeniji and Aloyce 2013; Dinssa et al. 2015; Ndinya et al. 2020). Various AIV varieties developed through PPB have been well adopted (Ceccerelli and Grando 2007; Dinssa et al. 2015). For amaranth crop improvement, the objectives focus on traits such as rapid growth rate, nutritional quality, dual-use varieties, resistance to leaf diseases, and tolerance to heat and drought (Schafleitner et al. 2022). Eggplant improvement objectives include earliness, high yield, high antioxidant activity, and pest and disease tolerance (Taher et al. 2017). Spider plant improvement objectives include high leaf yield, phytonutrient content, resistance to abiotic and biotic stress, and improved germination (Sogbohossou et al. 2018; Kwarteng et al. 2018; Blalogoe et al. 2020; Ndinya et al. 2020; Achigan-Dako et al. 2021). The World Vegetable Centre breeding programs produce four types of breeding products, namely, open pollinated varieties, inbred lines, hybrids and agronomic traits, catering to the diverse needs of seed sector development worldwide. These products cater to the diverse needs of different countries (World Vegetable Centre 2019). Future breeding programs should emphasize research in these specific areas to meet evolving agricultural needs effectively.

The regulation of vegetable variety release systems varies among countries and is influenced by factors such as the presence or absence of regulations, the number of tests conducted, the number of sittings for regulatory bodies, and the adoption of harmonization protocols (Table 3; Setimela et al. 2009; www.agrilinks.org). Countries such as Kenya, Malawi, Zambia, and Zimbabwe require VCU data for vegetable crops (Table 3), whereas other countries indirectly require VCU data. DUS test data for vegetable seeds are also needed for Tanzania, Kenya, Malawi, Zambia and Zimbabwe. However, in some cases, the requirements for VCU and DUS testing may not be fully met. Certain countries, such as the United States of America (USA) and the European Union (EU), have provisions for the voluntary declaration of seed quality and the possibility of farmer varieties that can be sold without VCU and DUS requirements, respectively (Louwaars and Burgaud 2016). The EU has specific regulations for crops such as cereals, fodder, cabbage and fruit trees (Batur et al. 2021). Asian countries have adopted variety registration for vegetables that do not require VCU testing (FAO 2020). It is necessary to explore potential options for AIV variety registrations, including conducting DUS tests only, considering farmer varieties or developing specific regulations for each AIV. The EU farmer varieties have further split the farmer varieties into 4 different pathways for registration without DUS testing: conservation, amateurs, organic varieties and cross composite populations (Batur et al. 2021). The recognition of farmer varieties could promote affordable food systems across Africa, and DUS testing could be utilized for varieties suitable for industrial use and export markets. The advantages of DUS testing alone and specific regulation of AIVs include the potential for export and industrial utilization. African countries could establish regulations tailored to each specific AIV, such as spider plant, which are distinct from other vegetables and hold societal and industrial significance, including their use in traditional medicine (Kwarteng et al. 2018). The development of regulations for various AIVs would benefit the AIV industry, which generates billions of USD in SSA, with retailers enjoying profit margins of 30–45% and households receiving 100% income (Weinberger

Table 3 Vegetable seed sector regulations in selected Eastern and Southern African countries

Regulation	Countries
VCU For Vegetable Crops	Kenya, Malawi, Zambia, Zimbabwe
DUS For Vegetable Crops	Tanzania, Kenya, Malawi, Zambia, Zimbabwe
Number Of Years For VCU	Kenya (2), Malawi (3), Zambia (2), Zimbabwe (2 Seasons)
Number Of Years For DUS	Tanzania (4), Kenya (2 Seasons), Malawi (2), Zambia (2), Zimbabwe (1 Season)
Who Conducts VCU	Tanzania (SC, NSA), Kenya (NSA), Malawi (SC), Zambia (NSA), Zimbabwe (SC)
Who Conducts DUS	Tanzania (NSA), Kenya (NSA), Zambia (NSA), Zimbabwe (NSA)
Number Of Sittings For variety release per Annum	Tanzania (2), Kenya (1), Malawi (2), Zambia (2) Zimbabwe (2)
Requirement Of Variety Release For Exotic Vegetables—Mandatory	Tanzania, Kenya, Malawi,
Requirement Of Variety Release For Exotic Vegetables—Optional	Zimbabwe, Zambia
Variety Release For AIV—Mandatory	Tanzania, Kenya
Variety Release For AIV—Optional	Zimbabwe, Malawi, Zambia
Have Online Variety Catalogue (VC) For Vegetables	Tanzania, Kenya
Frequency Of Updating Online VC	Tanzania (Once), Kenya(Twice), Malawi(Once)
Harmonization Of PVP	Kenya(UPOV), Zimbabwe
Harmonization of Variety release	Tanzania (EAC), Kenya (COMESA), Malawi (COMESA,SADC), Zambia (COMESA,SADC), Zimbabwe (COMESA, SADC)
Vegetable Seed Certification	Tanzania (Min Stds), Kenya (Act Cap326), Malawi(Min Stds), Zambia, Zimbabwe (Min Stds)
Use Of Vegetables Seed Certification	Tanzania, Kenya, Malawi, Zimbabwe
Harmonization Of Seed certification	Kenya (COMESA), Malawi, Zambia, Zimbabwe
Vegetable Phytosanitary Stds (PS)	Kenya, Tanzania, Malawi, Zambia, Zimbabwe
Harmonization of PS Standards	Kenya (COMESA), Malawi(SADC, COMESA), Zambia(SADC, COMESA), Zimbabwe(SADC,COMESA)

VCU value for cultivation and use, *SC* seed certification, *DUS* distinctness, uniformity and stability, *SC* seed company, *NSA* National seed authority, *VC* variety catalogue, *PVP* plant variety protection, *PS* phytosanitary standards, *COMESA* Common market for eastern and southern Africa, *SADC* Southern African development community. *EAC* eastern African community, *Min Stds* minimum standards. Appendix 1

et al. 2009; Onyango et al. 2013; Diouf and Ba 2014; Olabode et al. 2017).

In Tanzania and Kenya, a significant number of AIV varieties have been released following established regulations and procedures for vegetable release (Fig. 2, Table 3). However, these countries lack specific standards for releasing vegetables; therefore, the regulations are based on those developed for field crops (Afari-Sefa et al. 2012). In Tanzania, a total of fifteen nutrient-dense AIV varieties rich in zinc, iron, and magnesium were released from 2000–2020 (Fig. 2). The five varieties of amaranth were released, followed by the three varieties of eggplant.

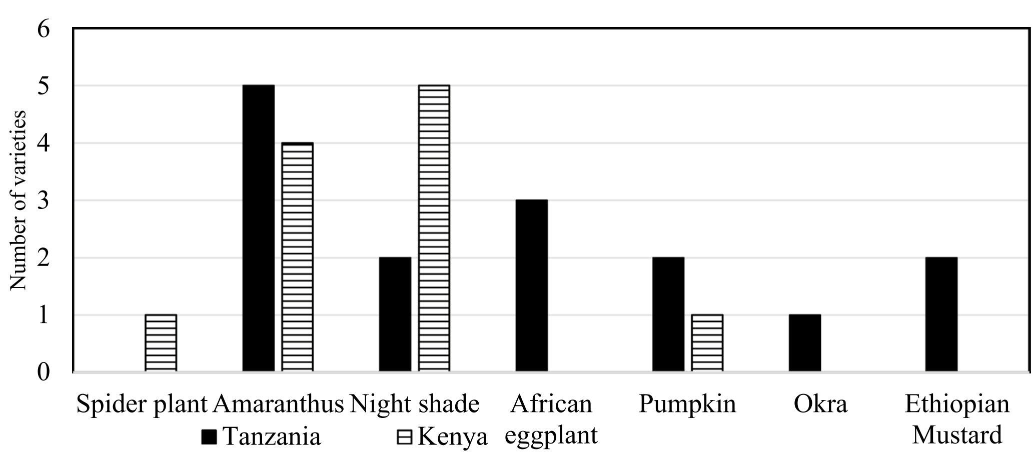

Fig. 2 Various releases of indigenous African vegetables from 2000–2020

One of the released is Madiira 1 (Ex-Zim), which was released in 2011.

This variety is popular among growers because of its long-lasting green leaves, preferred taste, and cooking quality (Dinssa et al. 2018). The released varieties exhibited greater nutritional qualities, including increased calcium, iron and fibre contents (Dinssa et al. 2018). Two African nightshade varieties, Ndutuma and Olevolosi, were released in 2011 on the basis of their yield and acceptability. Ndutuma is characterized by a sweet taste, high leaf and seed yield, and late flowering, whereas Olevolosi has a bitter taste, and these varieties are more resistant to fusarium wilt (Ojiewo et al. 2013). Mshumaa is one of the released eggplant varieties known for its sweetness (Taher et al. 2017). Additionally, a considerable number of exotic vegetables (22) have been released (Table 4; Supplementary Table 1; Tahar et al. 2017).

In Kenya, a total of twelve AIV varieties were released between 2000 and 2020. The released varieties were selected on the basis of criteria such as high iron content for spider plant; high protein content; drought tolerance for amaranth; high zinc, iron and magnesium contents; and high antioxidant activity for African nightshade (Table 4; Dinssa et al. 2015). One notable African nightshade variety in Kenya is the giant nightshade from the World Vegetable Centre. The amaranth varieties KAM001 and KAM 114, previously released as Madiira1 and 2 in Tanzania, were released in Kenya in 2017, along with two other amaranth varieties released in 2018, KAM201 and KATveg, which were well preferred by farmers (Ndinya et al. 2020). The World Vegetable Centre plays a crucial role in supporting local seed companies, as its germplasm is found in 84% and 44% of the varieties sold in Tanzania and Kenya, respectively (Ochieng et al. 2019). These AIV cultivar releases are accompanied by comprehensive release catalogues and up-to-date databases, providing farmers with essential educational information that impacts production and commercialization. The demand for traditional vegetables from communities and consumers has led private seed companies in East African countries such as Kenya, Tanzania, and Uganda to invest in research and the multiplication of traditional vegetable seeds (Dinssa et al. 2016; Ochieng et al. 2019). The breeding efforts for African eggplant have transitioned from Open Pollinated Varieties (OPVs) to hybrids, similar to exotic vegetables such as cabbage and rape (Palada et al. 2006; Dinssa et al. 2016; Table 4). This shift towards hybrids is driven by the benefits they offer to farmers and consumers, such as increased yield, tolerance to biotic and abiotic stress, early maturity, and desirable consumer traits. Hybrid seed production in the vegetable sector also provides employment opportunities, particularly for women. Countries such as India, witness more than 1 million people engaged in manual emasculation and crossing for hybrid seed production, showcasing the sector's employment potential (Koundinya and Kumar 2014). The initial stages of spider plant hybrid variety seed production can create employment opportunities, and later costs can be minimized through the development of a male sterility system (Sogbohossou et al. 2018). The implementation of Plant Variety Protection (PVP) regulations encourages the participation of both private and public enterprises in the seed industry, leading to increased investment and capacity (King et al.

Table 4 Characteristics of the cabbage and African indigenous vegetable varieties available on the market in selected countries

Crop	Green and white cabbage*		Red cabbage	Spider plant	Amaranth	African night shade	African eggplant
Variety type	**OPV**	**Hybrid**	**Hybrid**	**OPV**	**OPV**	**OPV**	**OPV-hybrid**
Age (years)	Above 20–100	–		< 10 years	< 10 years	< 10 years	< 10 years
Days to Maturity	80–115	80–100	45–60	28–35	60–115	35–56	60–90
Yield	1.7–5.1 kg	3.5–> 5 kg	0.8–3.5 kg	20–40 t/ha	1–7 t/ha	20–40 t/ha	25 t/ha
Pest and diseases	Non	F, BR, DBM,T					
Abiotic stress	Non	Frost, heat, cold		drought, heat, low soil nitrogen	drought, heat, low soil nitrogen		
Interior leaf color	Yellow, white, light green	Yellow, white, light green	Purple, Red, Yellow, white	purple, green	Green,		
Outstanding qualities	Widely adapted	Uniform heads, good shelf life, high yield, widely adapted		Multiple harvest, tall variety, High Iron, Zinc, Magnesium, Calcium	Drought tolerant, high mineral (Ca, Mg, Zinc, Protein, vitamin A)	Scabrum green and purple, bitter taste, High Mineral (Ca, Mg, Zn), antioxidant activity	Sweet

*Adopted from supplementary Table 1; characteristics of cabbage varieties, *BR* black rot, *F* Fusarium, *DBM* diamond black moth, *T* tuber moth

2012). PVPs are essential for innovators of new varieties because they provide protection for their crop variety products for a period of 20 years (FAO 2018).

Seed certification

The National Seed Authorities (NSA) in different countries oversee the certification of seeds. Each country has its own regulations governing both local and international seed trade to protect the rights of sellers and buyers (Table 3). These regulations prevent seed falsification, ensure good quality (especially for AIVs that may require preseed treatment), and prevent the spread of pests, diseases and weeds (Kamotho et al. 2014). NSAs require the registration of all seed crops for inspection, following established procedures primarily designed for field crops. Many NSAs participate in certification schemes, such as the Organization for Economic Cooperation and Development (OECD) and the International Seed Testing Association (ISTA). Seed exporters are typically required to obtain a seed passport, such as Orange International Certificates (OICs), through these schemes. Interest in AIV seed production is increasing in many countries, and efforts are needed to increase the seed production capacity of AIVs through small projects (EMEA 2020). Tanzania produces certified seeds of amaranth, nightshade, and African eggplant, with African eggplant seeds being exported to other countries. Notably, the seed legislation in Tanzania, Zambia, and Zimbabwe includes provisions that allow for informal seed production and the sale of Quality Declared Seed (QDS)/Standard Grade Seed (SGS) (FAO 2006; Mujaju 2010; ISSD Africa 2017). Flexible measures, such as true labelling, which are implemented in South Africa, India and the United States of America, can also be adopted in AIVs to ensure adherence to standards and provide quality data on seed labels (Batten et al. 2021; Kuhlmann and Dey 2021). The informal seed system of AIVs faces challenges related to seed quality, low germination rates, lack of purity, and a high incidence of pests and diseases (Keatinge et al. 2015). These challenges can be addressed by incorporating principles of the QDS system, providing training to farmers, developing AIV seed procedures and encouraging the registration of seed companies by national seed authorities (FAO 2006; Visser 2015). Kenya is involved in spider plant seed production, and its production increased from 2000 to 2020 (Table 5). However, the market for vegetable seeds is still dominated by exotic vegetables (Tables 5 and 6). The inclusion of AIV seeds in their portfolio, such as spider plant, African nightshade, and African eggplant, can offer seed companies profitable business opportunities in combination with hybrid pepper, tomato, and cucumber seed options.

Marketing and importing/exporting seed requirements

The vegetable seeds imported are predominantly exotic vegetables, including cabbage, pepper (*Capsicum*

Table 5 Average seed volumes for sales, imports and production of AIVs in Kenya

AIVs crop and description	Average yearly seed volumes 2000–2005 (kg)	Average yearly seed volumes 2006–2010 (kg)	Average yearly seed volumes 2011–2015 (kg)	Average yearly seed volumes 2016–2020 (kg)
Spider plant sold	0	17,441.6	17,556.58	20,575.15
Amaranthus sold	50	26,132.8	22,911.66	36,243.93
Pumpkins sold	0	1296	2919.02	665.68
Spider plant imported	0	0	0	0
Amaranthus imported	7213.32	6429.8	602	1873.65
Pumpkins imported	7740.08	53,738.03	97,878.71	145,051.39
Spider plant production	0	17,441.6	17,556.58	20,575.15

Table 6 Tanzania and Kenya exotic seed volumes for sale

Country and crop description	Average yearly seed volumes 2000–2005 sold (t)	Average yearly seed volumes 2006–2010 sold (t)	Average yearly seed volumes 2011–2015 (t)	Average yearly seed volumes 2016–2020 (t)
Tanzania; Rape	–	–	–	1.5
Tanzania; Cabbage	–	–	–	48
Kenya; Rape	4.14	28.1	24.6	156.7
Kenya; Cabbage	366.5	910.4	844.2	1117.3

– no data available.

annuum), cucumber, onion (*Allium cepa*) and hybrid tomato (*Solanum lycopersicum*). In contrast, OPV tomato seeds are produced locally and traded regionally by seed companies. In Tanzania, the importation of exotic vegetable seeds from 2010–2020 revealed that the yearly imported seed for rape was approximately 1.5 tonnes, whereas for cabbage, it was approximately 48 tonnes (Table 6). The requirements for most countries are that the company should obtain an import permit, fumigation certificate, orange international certificate, biosafety (Genetically Modified Organism [GMO]) certificate, seed treatment certificate, and invoice (appendix 1). Currently, most of these systems have transitioned to fully digital processes, as seen in Kenya through the Kenya Plant Health Inspectorate Service (KEPHIS) website (www.kephis.org). Similarly, other countries are also adopting digital processes, as demonstrated by Zimbabwe's National Biotechnology Authority (NBA) website (www.nba.ac.zw). The export requirements are that the import permit from the importing country is needed and that fields for seed production should be registered with the Seed Authority, which will allow the issuing of the required documents (EMEA 2020). Some countries require pre-shipment inspections before the seed is imported into the country; hence, the seed is inspected in the country of production, and these processes are considered costly and burdensome (Kuhlmann et al. 2023).

Phytosanitary standards

Vegetable seeds are subject to phytosanitary standards to prevent the spread of pests and diseases of economic importance. Importing countries establish requirements for exporting countries regarding both exotic and indigenous vegetable seed varieties. The national plant protection authorities are responsible for implementing these standards by conducting various tests and inspections before seeds are exported and after importation for verification (appendix 1). Some countries require that the exporting country sends pre-shipment samples to the importing country before the seeds are expected to arrive, allowing for various types of examinations to be conducted.

Regional harmonization

The climate smart agenda, which encompasses a wide range of approaches to agricultural growth (FAO 2013), has two main components: (i) seed and seed systems and (ii) harmonization of seed standards and certification. These elements aim to simplify administrative procedures for seed trade and variety release, thereby increasing access to a broader range of crop varieties. The World Bank's interregional harmonization agenda is also a policy priority for the African Union and regional trade organizations, which include COMESA, EAC, and SADC. The agenda for climate-smart seed system development aims to establish a system that delivers seeds through formal private markets that are license to sell seeds. However, since 80% of the seeds used by farmers come from the informal seed market, such a change would undoubtedly have significant financial, societal, and political implications (Westengen et al. 2019). Compared with public and farmer organizations, the private sector is recognized as a more effective driver of agricultural growth (Easterly 2005; Erenstein and Kassie 2018). The harmonization of seed policy in East Africa has identified field crops and vegetable crops, including cabbage and tomato, for inclusion (Lenné et al. 2005). Tanzania and Kenya comply with the EAC, whereas Malawi, Zambia, and Zimbabwe are members of the SADC harmonization (appendix 1). The SADC seed system allows for the registration of landraces on the basis of farmer experience, whereas other regional systems, such as COMESA and the Economic Community of West African States (ECOWAS), do not recognize them. Other instruments recognizing farmers' rights in Africa include the Africa Union guidelines for harmonization, the seed regulatory framework in Africa, the Arusha Protocol on PVP of 2015, and the ECOWAS-UEMOA-CILSS seed regulatory framework (2014). However, these instruments do not provide a procedure for obtaining rights, and no vegetable landrace variety has been registered, highlighting the need to ensure that farmers receive benefits. In practice, African farmers commonly sell and exchange landrace seed varieties without violating rules and regulations, a practice also observed in European countries (Louwaars and Burgaud 2016). Harmonization for PVP is being implemented by ARIPO, which has initiated the process of acceding to the UPOV convention for the African continent. Zambia and Zimbabwe align with the PVP law of ARIPO. Some countries, including Tanzania and Kenya, have full membership in UPOV-91 (Westengen et al. 2019; EMEA 2020). These harmonization procedures, such as EAC, SADC, COMESA, and OECD, cover plant variety development, seed certification, and phytosanitary standards. All regional policies in Africa recognize the importance of the ISTA for seed testing. COMESA and SADC also aim to streamline phytosanitary control procedures by creating common pest lists for seed inspections. Harmonization efforts acknowledge the existence of national regulations for Genetically Modified Organisms (GMOs). Regional bodies need to develop regulations that recognize farmers' landraces, informal seed systems, and QDSs for AIVs.

Informal seed sector

Vegetable research and development have been relatively neglected in SSA, with farmers taking the lead in the conservation, improvement and utilization of AIVs (Afari-Sefa et al. 2012). Farmers will continue to play a key role in the seed value chain for indigenous vegetables in collaboration with any researcher collaborators, seed production, and marketing (Almekinders and Louwaars 2002; Minot 2008; Dinssa et al. 2015; Westengen et al. 2023). The role of farmers in seed production can be enhanced through Community Seed Production (CSP). Successful CSP have been documented with farmers and farmer groups establishing their own companies in countries such as Ethiopia, Zimbabwe, and Zambia (de Boef et al. 2010; Visser 2015). AIVs are potential candidates for combining both formal and informal seed systems, defined as Integrated Seed Sector Development (ISSD) (Louwaars and de Boef 2012). The ISSD approach allows countries to tailor their seed systems and policies to their specific circumstances, avoiding conflicts between those advocating for private investment (World Bank 2015), those promoting local-level investments, and those emphasizing agro-biodiversity for climate change adaptation. (Louwaars and de Boef 2012; de Boef et al. 2010). Unlike many harmonization policies, ISSDs promote biodiversity and adapt seed systems to local practices, policies, and economies. Currently, African countries and regions have an opportunity to develop their own AIV seed systems (Louwaars and de Boef 2012). Integrating informal and formal seed systems for AIVs will leverage the strengths of both systems in the development of the AIV seed value chain. A SWOT (Strengths, Weaknesses and Opportunities and Threats) analysis of the AIV seed sector regulations is summarized in Table 7.

Nutritional quality traits of AIVs

The diversification of diets with AIVs is a sustainable way to supply a range of nutrients to the body and combat nutrient deficiencies for all families (Bouis and Welch 2010). These neglected and underutilized vegetables have been incorporated into human diets for centuries in SSA and Asia. They possess superior nutritional qualities compared with their exotic counterparts, such as cabbage, lettuce, and spinach (Table 8). Amaranthus,

Table 7 SWOT analysis of AIV seed sector regulation

Strengths	Weaknesses
- Abundance of genetic resources - Existing regulations for germplasm management, research and development, seed production and marketing, phytosanitary and biosafety measures are in place - Available variety catalogues - National public and private and international actors are available - Significant untapped vegetable market in-country, region and internationally	- Insufficient research on genetic resources - Limited development of improved varieties - Seed regulations need to be updated to make them more adaptable for vegetable seeds - Lack of agricultural data on production, cultivated areas, commercialization and consumption - Seed quality challenges (purity, poor germination) - Need for updated online Variety Catalogues
Opportunities	**Threats**
- Updating regional policy documents: There is an opportunity to update seed policy regulations to accommodate different seed classes including farmer's varieties, quality declared seed, and internationally recognized certified seed scheme - Regional and continental trade: Taking advantage of regional and continental free trade areas, there is potential to facilitate trade by allowing certain quantities of AIV seed from the informal sector to be traded in the formal sector through the implantation of appropriate phytosanitary tests - Registration of seed companies: Creating regulations that enable farmer's and small seed companies to enter into seed business will promote increased participation and competition in the market - Development of a diversified or integrated seed systems: Training of and capacity building initiatives can be implemented to enhance the knowledge and skills of actors involved in informal seed systems, leading to the development of more diverse and integrated seed system - Diversification and promotion of value added products: Raising awareness about the potential value added products and benefits from developed seed products can stimulate interest and demand, promoting diversification and added value to the AIV seed sector - Harmonization of AIV seed regulations. There is an opportunity to harmonize seed regulations specific to AIVs across different regions, enabling smother trade and collaboration while ensuring consistent quality and standards	- Inadequate seed regulations for vegetable and AIVs: The existing seed regulations have primarily been derived from field crops, overlooking the unique attributes of vegetable and AIV seeds - Insufficient integration of formal and informal seed systems: lack of effective integration in policy development hinders the potential for a more holistic and inclusive approach - Recognition of Farmer's rights. The rights of farmers, especially in terms of seed saving, exchange, and use may not be adequately recognized and protected within the existing regulatory framework - Limited or low participation of farmers in seed policy development: this result in policies that may not fully address their needs and interests - Limited capacity of National Seed Authorities - Incomplete adoption of UPOV guidelines: Not all countries have ceded to the international union, which creates disparities in intellectual property rights and seed regulations among different countries - Climate change, new pest and diseases: The impacts of climate change, as well as the emergence of new pest, and diseases, pose threats to the productivity, necessitating adaptation and resilience –building measures

Table 8 Nutritional quality attributes of AIVs and exotic vegetable crops (mg/100 g)

Crop	PR	FE	ZN	K	PP	CU	MAG	CA	VIT A	VIT C
Spider Plant	2.6–6.8	8.4–15.9	12.8	410	18.0	2.0–8.0	86	2209.8	6.7–18.9	–
Amarathus	3.2–5.3	3.0–12.2	2.4	201	18	10.84	93	480–900	1.7–10.7	3.86
Black jack	5.2	–	–	653	534	5.9	609	618	–	–
Okra	4.5–5.64	7.7–9.44	6.4	436	746	2.69	386	360–497	6.4	14.6
Kale	2.5	32	–	–	–	–	–	187	7.3	
Cabbage	1.4–1.8	0.47–0.8	0.18	170	26	–	12	44	1.2	36.6
Spinach	1.8–2.3	32	–	–	–	–	–	93	5.1	–
Lettuce	1.36	0.86	0.18	194	29	0.029	13	36	–	9.2
Cauliflower	1.92	0.42	0.27	299	–	0.039	15	22	–	48.2

Pr protein, *Fe* iron, *Zn* zinc, *K* potassium, *Pp* phosphorus, *Cu* copper, *Mag* magnesium, *Ca* calcium, *Vit A* vitamin A, Muchuwetu et al. 2009, Mpala et al. 2013, Abukutsa Onyango 2003, Nyadanu and Lowor 2014, Yang and Keding 2012

okra, and spider plant have excellent nutrient profiles, such as vitamin A, and C, iron, calcium, and magnesium contents (Ndlovu and Afolayan 2008; Yang and Keding 2012; Omondi et al. 2017; Achigan-Dako et al. 2021). Spider plants and eggplants are also rich in flavonoids and phenolic compounds, respectively (Taher et al. 2017; Omondi et al. 2017). Phenolic acids in eggplant include chlorogenic acid in the fruit flesh and anthocyanins in the fruit skin (Mennella et al. 2012; Stommel et al. 2015). Spider plants, on the other hand, are rich in beneficial phenolic compounds, namely, terpenoids, ketones, and glucosinolates, which possess therapeutic properties, including anticancer, antiparasitic, antimicrobial and anti-inflammatory properties (Thovhogi et al. 2021). Spider plants possess moderate levels of vitamin A, carotenoids, ascorbic acid, and minerals and high levels of ascorbic acid (Gowele et al. 2019). The seeds of spider plants are characterized by elevated levels of oleic acid and linoleic and hexadecanoic acids (Aparadh and Karadge 2010; Mnzava 1990).

Amarathus grains, known for their use in food blending, contain significantly higher levels of calcium, magnesium, iron, and zinc (5.2-fold, 2.9-fold, 2.8-fold and 1.3-fold, respectively) than wheat grains do (Singh and Punia 2020; Baraniak and Kania-Dobrowolska 2022). These AIVs generally contain nutraceutical/health-promoting compounds, and consumer awareness is needed to develop a biobased economy around them. The variation observed in the nutrient contents of AIVs could be due to several factors, including genotype, sample preparation, management practices, drying methods, harvesting techniques, maturity stages, geographical origins, and growing conditions (Achigan-Dako et al. 2021; Sogbohossou et al. 2019; Managa and Nemadodzi 2023). To advance this sector, forthcoming studies need to target these knowledge gaps in AIVs, enhancing our understanding of these crucial factors for improved development and utilizations. Addressing these research gaps will contribute significantly to enhancement of AIV cultivation practices and nutritional outcomes.

Conclusion and way forward

The World Vegetable Centre has collected and maintained germplasm and developed improved germplasms for several AIVs that are available for breeding, seed multiplication, and production. However, only a limited number of these improved AIV varieties have reached farming communities due to a number of challenges related to regulatory policies, including issues with germplasm access, variety release, production, and certification. The way forward calls for stakeholders' collaborative efforts in situ and ex situ conservation and characterization of vast genetic resources, as well as a focus on breeding, variety release, and seed production. Farmers and farmer groups have cultivars of AIVs that they have developed through their own farm selections or a collaborative effort, such as participatory plant breeding, that are unique. Hence, they is need to facilitate registering of these farmers varieties for commercial production. This will empower farmers, especially women and youth, to venture into the seed business and commercial production of AIVs. To foster the development of the vegetable seed sector, regulatory agencies should promote the commercialization of AIV seed varieties by establishing more flexible seed certification standards that are more liberal as a way of developing the seed sector. The presence of documented AIVs, seed production, seed sales, and imports in Kenya and Tanzania highlights their potential for seed development in other countries. Owing to climate uncertainty, poor soil fertility, high input costs, and micronutrient deficiencies in SSA, there is an urgent need to review or develop regional seed regulations specifically tailored for AIVs and promote greater system resilience.

Appendix 1. List of seed legislation

National Policies, Plans and Programs

Republic of Kenya, Ministry of Agriculture, National Seed Policy, June 2010.

Ministry of Agriculture and Co-operatives, National Agricultural Policy, 2004–2015 (Zambia).

Ministry of Agriculture and Ministry of Fisheries and Livestock, Second National Agricultural Policy, February 2016 (Zambia).

National Seed Policy, 2018 (Malawi).

Kenya

The Seeds and Plant Varieties (Amendment) Bill, 2015.

Seed and Plant Varieties Act, 2012.

The Seeds and Plant Varieties (Amendment) Act, 2011.

The Seeds and Plant Varieties Act, 1975, Chapter 326.

The Seeds and Plant Varieties (Seeds) Regulations, 1991.

The Seeds and Plant Varieties (National Performance Trials) Regulations, 2009.

Plant Protection (Importation of Plants, Plant Products and Regulated Articles) Rules, 2009 Cap 324 [rev 2012].

The Seed and Plant Varieties (Plant Breeder's Rights) (Vegetables Scheme) Cap 326, 2001.

GoK. Seed and Variety Plants Act Cap 326. 2012.

Malawi

Draft Seed Act, 2013.

Seed Act, 1996 (Act No. 9 of 1996) Amended.

Plant Breeder's Right Act, 2018.

Seed Act, 2018.

Seed Regulations, 2018.

Plant Protection Act, 2018.

National Agricultural Investment Plan (NAIP), 2018.

Tanzania

The Seeds Act, 2003.

Seeds Regulations, 2006.

The Seeds Regulations, 1976.

Plant Breeder's Rights Act, 2012.

Amendment of the Seeds Act Cap 308, 2014.

The Seeds (Amendment) Regulations, 2017.

Zambia

National Seed Industry Policy of Zambia, 1999.

The Plant Variety and Seeds Act (as amended by Act No. 21 of 1995).

Agriculture (Seeds) Act, 1968.

Plant Variety and Seeds Regulations, 1997.

Plant Breeder Right Act No. 18 of 2007.

The Plant Variety and Seeds Regulations 2018.

Zimbabwe

The Seeds Act, 1971, Chapter 19:13.

Plant Breeders' Rights Act of 1979 (revised in 2001).

Plant Pests and Diseases Act (Chapter 19:08).

The Plant Pests and Diseases (Importation) Regulations;

Plant Pests and Diseases (Pest Control) (Amendment) Regulations 1973; and

Plant Pests and Diseases (Pests and Alternate Hosts) (Amendment) Order 1988.

National policies, plans and programs

Republic of Kenya, Ministry of Agriculture, National Seed Policy, June 2010.

Ministry of Agriculture and Co-operatives, National Agricultural Policy, 2004–2015 (Zambia).

Ministry of Agriculture and Ministry of Fisheries and Livestock, Second National Agricultural Policy, February 2016 (Zambia).

National Seed Policy, 2018 (Malawi).

Regional regulations and policies

Regulation C/REG.4/05/2008 on Harmonization of the Rules Governing Quality Control, Certification and Marketing of Plant Seeds and Seedlings in ECOWAS region: and Procedure Manual for Variety Registration in the National Catalogue for Crop Species and Varieties in West African Countries developed in 2008.

Union for Protection of New Varieties of Plants (UPOVs).

African Regional Intellectual Property Organization (ARIPO) Arusha Protocol for Protection of New Varieties of Plant, 2015.

SADC 2008. Technical Agreement on the Harmonization of Seed Regulations in the SADC Region.

EAC Seed and Plant Varieties draft Bill.

COMESA (2014). Seed Trade Harmonization Regulations.

SADC (2008);

Abbreviations

AFLPs	Amplified fragment length polymorphisms (AFLPs)
AFSTA	African Seed Trader Association
AGRA	Alliance on the Green Revolution in Africa
AIVI-MUAST	African Indigenous Vegetable Institute Marondera University of Agricultural Sciences and Technology
AOCC	African Orphan Crops Consortium
AVBC	Africa Vegetable Breeding Consortium
AVRDC	World Vegetable Centre
BR	Black rot
Ca	Calcium
Cdna	Chloroplast DNA (cDNA)
CGIAR	Consultative group on international agricultural research
COMESA	Common market for eastern and southern Africa
Cu	Copper
DArTseq	Diversity array technology sequencing
DBM	Diamond black moth
DUS	Distinctness, uniformity and stability
EAC	Eastern African community
ECOWAS	Economic community of West African states
F	Fusarium
Fe	Iron
GMO	Genetically modified organism
ISTA	International Seed Testing Association
K	Potassium
Mg	Magnesium
Min Stds	Minimum standards
NARS	National agricultural research system

NGOs	Nongovernmental organizations
NSA	National seed authority
OECD	Organization for Economic Cooperation and Development
PPB	Participatory plant breeding
Pp	Phosphorus
Pr	Protein
PS	Phytosanitary standards
PVP	Plant variety protection
QDS	Quality-Declared Seed
RAPD	Random amplification of polymorphic DNA (RAPD)
SADC	Southern African development community
SC	Seed company
SC	Seed certification
SGS	Standard-grade seed
SNP	Single nucleotide polymorphism (SNP)
SPGRC	SADC Plant Genetic Resources Center (SPGRC)
SSR	Simple sequence repeats (SSR)
SWOT	Strengths, weaknesses and opportunities and threats
T	Tuber moth
VC	Variety catalogue
VCU	Value for cultivation and use
Vit A	Vitamin A
Zn	Zinc

Supplementary Information

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Supplementary material 1.

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Data availability
The data is available on request**.**

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Not applicable.

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The authors have no competing interest to disclose.

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