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REVIEW **Open Access**

Optimization of African indigenous vegetables production in sub Saharan Africa: a review

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Abstract

The numerous types of African Indigenous Vegetables (AIVs) in sub-Saharan Africa are not extensively cultivated, even after the realization of their superior nutritional, health benefits, and higher resistance to climate change. The recent increase in demand for AIVs brings about the need to match cultivation with consumption to prevent the extinction of these nutritious vegetables through overexploitation. This review aims to assess the most common AIVs and the associated agronomic practices in their production by smallholder farmers in Zimbabwe and SSA in general for potential commercialization. *Amaranthus*, *Cleome gynandra*, *Bidens pilosa*, *Abelmoschus esculentus*, *Vigna unguiculata*, *Cucurbita* spp. and *Corchorus molitorius* are some of the most consumed AIVs in sub-Saharan Africa. Plant density should balance between leaf quality and leaf and seed yield per unit area. Transplanting and sowing AIVs in lines as pure stand can optimize production when compared to broadcasting. Nutrient application whether organic or inorganic is crucial together with harvesting leaves in 1 to 2 weeks interval and removing flowers to increase budding for optimized AIVs production. There is vast information on the indigenous vegetables found and preferred in SSA but scarce information on their performance under different plant nutrition management regimes and different agroecological regions. Research is required to increase production and to improve the nutrient content of AIVs.

Keywords Deflowering, Density, Fertilizer, Harvesting, Nutrients, Planting, Production

Background

Sub Saharan Africa (SSA) is home to hundreds of types of African Indigenous Vegetables (AIVs), however, these vegetables are not extensively cultivated and have not been adequately included in staple diets (Dinssa et al. 2016; Nyaruwata 2019). AIVs refer to vegetable species or varieties genuinely native to Africa or that have been integrated and incorporated into local food cultures and farming systems over a period of time (Engle 2002; Etèka et al. 2010) e.g. *Amaranthus cruentus* (red amaranth), *Corchorus olitorius* (nalta jute), *Cleome gynandra* (Spider plant), *Bidens pilosa* (black jack), *Vigna unguiculata* (cowpea) amongst others. African indigenous vegetables fall under the neglected and underutilized crops (Chivenge et al. 2015). The low level of utilization is because in the past AIVs were considered food for rural and poor households (Maseko et al. 2017) mainly confined to smallholder farming areas (Chivenge et al. 2015) and have been overlooked by agricultural research and investments. Owing to extended neglect, AIVs grow either in semi-cultivated, wild, mixed cropping systems

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or small-scale gardens by some farmers with no direct application of inputs (Houdegbe et al. 2018). Since most of these crops grow naturally in the wild, there is not much information on cultivation practices nor guidelines to optimize production in some regions.

There is a recent increase in demand of AIVs due to improved awareness of their numerous nutritional and medicinal benefits and their resilience to climate change (Houdegbe et al. 2018). As has been noted by many authors (Chipurura et al. 2013; Ebert 2014; Nyaruwata 2011; Laibuni et al. 2020), AIVs have high nutritional value, are high in fibre, have increased mineral and vitamins levels and are also high in micronutrients such as zinc (Dinssa et al. 2015; Moyo et al. 2020). Zinc is of essence as it is believed to help in combating COVID-19 which has severely affected livelihoods (Sharma et al. 2020; Derwand and Scholz 2020). They also have anti-inflammatory, antiviral, antioxidant, antibacterial and anti-mutagenic properties (Ebert 2014, Nyaruwata 2019, Moyo et al. 2020). As a result of these many benefits, AIVs can reduce malnutritional deficiencies faced in Zimbabwe and the world at large (UN-OCHA 2020) and can improve livelihoods when grown by more families and are commercialized. According to Onyango (2010), improved amaranth research and development can result in easy and cost-effective ways of eliminating malnutrition, and achieving household food security. These vegetables can also be used as an affordable, nutritious supplement for animal feed (Mshenga et al. 2016).

The increased awareness of AIVs is also linked to their environmental benefits as they are presumed to be resilient to climate change, reduce the carbon footprint, reduce greenhouse gas emissions and improve ecological biodiversity (MacFall et al. 2015; Rotz and Fraser 2015). AIVs have important advantages over exotic vegetable species such as *Capsicum annuum* (pepper), *Lactuca sativa* (lettuce), *Apium graveolens* (celery), among others because of their adaptability to marginal agricultural areas, which is a necessity in the face of climate change (Rahim et al. 2008). Mabhaudhi et al. (2018), postulates that AIVs are less susceptible to diseases and pests and do not require high levels of fertilizers.

The increase in demand for AIVs brings about the need for guidelines and or technologies for sustainable production/cultivation. Poor crop management by farmers is as a result of the common belief that AIVs are hardy and can grow under any environmental conditions thereby reducing yield and quality significantly (Orangi et al. 2020). The agronomic guidelines should balance economical vegetable production with environmental responsibility (Ebert 2014), maintaining the natural resource base and avoiding land degradation (Ghimire et al. 2018). Kuhnlein (2015) and Allen and Prosperi (2016) postulate that increasing production of AIVs improves their conservation, and species diversity which in turn improves resilience to shocks and threats, whether climatic or otherwise.

There is very limited agronomic information available for sustainable production of AIVs at either small-scale or commercial levels in Zimbabwe. There is vast potential to enhance crop management and improve the nutrient content of AIVs, since most are grown on a small scale without fertilizers or harvested from the wild (Aleni 2017). The current National Agricultural Policy Framework (2018–2030) in Zimbabwe supports the production of exotic vegetables e.g. rape (*Brassica napus*), cabbages (*Brassica oleracea* var. *capitata*), tomatoes (*Solanum lycopersicum*) but does not support the production of AIVs (Nyaruwata 2019) contributing to the low adoption by both large scale and smallholder farmers.

Promoting consumption of AIVs is important to increase and sustain production. Cooking/preparation methods and value addition techniques are some avenues that can be tapped into to promote consumption of the different types of AIVs. The lack of convenience in preparation reduces consumption as most preparation methods are lengthy and cumbersome and require knowledge and skills which results in them being abandoned for other faster cooking foods (Chopera et al. 2022). According to this study, other factors that influence consumption are affordability, and cultural or family influences. The need to adapt production systems to consumers' preferences is imperative because AIVs are extremely dependent on socio-cultural background (Achigan-Dako et al. 2010) e.g., others prefer *Cleome gynandra* for its bitter taste whilst others adapt their cooking techniques to do away with the bitterness. There is therefore need to either enhance the more desirable traits or reduce negative characteristics (Maundu et al. 2009).

The objective of this review is to assess the most common AIVs and the associated agronomic practices in their production by smallholder farmers in Zimbabwe and SSA in general and explore how they can be optimized to increase production. The specific objectives are to (1) Review the agronomic practices in the production of AIVs and (2) Review the challenges and opportunities associated with the production of AIVs. An understanding of the agronomy of AIVs, indigenous knowledge as well as embedded pros and cons in the cultivation and consumption of indigenous vegetables will significantly improve vegetable production in SSA.

Current status of production of AIVs

Most common AIVs cultivated

The most common AIVs are shown in Table 1. *Amaranthus species* (wild spinach, cockscomb), *Brassica* spp.

Table 1 Most cultivated African indigenous vegetables in sub–Saharan Africa

Region/country	African indigenous vegetable	Reference(s)
Zimbabwe	*Cleome gynandra*, *Vigna unguiculata*, *Abelmoschus esculentus* (L.), *Cucurbita maxima*, *Amaranthus* spp. and *Bidens pilosa* spp.	Wangolo et al. (2015), Alfred (2011), and Shava (2005)
Tanzania	*Amaranthus cruentus*, *Solanum villosum* and *Cleome gynandra*	Mamboleo et al. (2018)
South Africa	*Corchorus olitorius*, *Amaranthus cruentus*, *Citrullus lanatus*, *Vigna unguiculata*, *Cleome gynandra*, *Cucurbita* spp. and *Brassica rapa subsp. chinensis*	Maseko et al. (2017)
Botswana, Zambia, Malawi, Ghana, Cameroon, Namibia and Swaziland	*Cleome gynandra*	Wangolo et al. (2015)
Uganda	*Solanum aethiopicum* L., *Amaranthus blitum* L. and *Gynadropsis gynandra* L.	Semalulu et al. (2020)
Kenya	*Brassica carinata*, *Amaranthus* spp., *Corchorus olitorius*, *Solanum scabrum* spp., *Crotalaria* spp., *Cleome gynandra*, *Crotalaria brevidens*, *Vigna* sp.	Pincus et al. (2016) and Nambafu (2018)
	Corchorus olitorius and *Vigna unguiculata*	Ekesa et al. (2016)
Ethiopia	*Brassica carinata*	Dinssa et al. (2016)
Benin, Madagascar, and Mali	*Amaranth* spp., *S. aethiopicum* L., *Abelmoschus esculentus* and *Hibiscus sabdariffa*	Dinssa et al. (2016)

(wild mustard), *Abelmoschus esculentus* (okra), *Bidens* spp. (beggar ticks, burr marigolds, blackjack, stickseeds, Spanish needles), *Cleome* spp. (spider plant), *Cucurbita* spp. (squashes, pumpkins, gourds), *Corchorus molitorius* (jute plant), *Mormodica* spp. (bitter melon; bitter-cucumber), *Vigna unguiculata* (cowpea leaves) are some of the most widely consumed indigenous vegetables in SSA (Moyo et al. 2020; Nambafu 2018; Chivenge et al. 2015; Alfred 2011). In southern Africa, okra and pumpkin leaves have since gained popularity amongst farmers more than spider plant, amaranthus and blackjack which are usually left to grow on their own and in the wild (Houdegbe et al. 2018). According to Nambafu (2018) in East Africa *Amaranthus* spp., *Cucurbita* spp., *Gynandropsis gynandra* (spider plant), *Corchorus molitorius*, *Crolataria brevidens* (slender leaf), *Vigna* spp., and *Solanum nigrum* (black nightshade) are the most popular vegetables. In Kisii, Kakamega, Nakuru and Kiambu counties of Kenya, these vegetables are majorly grown and consumed (Nambafu 2018). In Zimbabwe *Cleome gynandra*, *Vigna unguiculata*, *Abelmoschus esculentus* (L.), *Cucurbita maxima*, *Amaranthus* spp. and *Bidens pilosa* spp. are the most popular vegetables (Wangolo et al. 2015; Alfred 2011; Shava 2005) though *Bidens pilosa* is more common in Eastern Zimbabwe (Orchard and Ngwerume 2009). From Table 1 it can be noted that the most common AIVs in SSA region are *Amaranthus* spp., *Cleome gynandra*, *Corchorus* spp., *Vigna unguiculata*, *Cucurbita* spp., *Brassica* spp. and *Solanum* spp.

Agronomic management practices

In order to accelerate the domestication and production of AIVs and meet the recent increase in demand, it is crucial to improve our knowledge of their management e.g., the effects of planting density, nutrient requirements, transplanting time, harvesting methods on yield among others.

Plant population

Planting density is a vital yield determinant for the successful production (Aminifard et al. 2018) of AIVs. Yield per unit area tends to increase as plant population increases up to a certain point and then starts to decline (Aminifard et al. 2018). However, dense plant spacings may increase competition for resources resulting in low yields and limited vegetative growth (Maseko et al. 2015). Conversely, low plant densities may result in low yields because of the failure to maximize available space (Law-Ogbomo and Egharevba 2009).

A plant density of 66 666 plants ha^{-1} was recommended for *Amaranthus cruentus*, *Corchorus olitorius* and *Vigna unguiculata* under irrigation from a study by Maseko et al. (2015). This was because a higher plant density only increased yield but with poorer leaf attributes such as leaf area, chlorophyll content, and leaf number when compared with lower plant densities. Houdegbe et al. (2018) on the other hand, concluded that a plant density of 444 444 plants per ha^{-1} (spacing of 0.15 m × 0.15 m) gave the highest yield of *Cleome gynandra* under rainfed conditions, due to the increased plants per unit area. Various plant spacings have been endorsed for *Amaranthus cruentus*, *Vignia unguiculata* and *Corchorus olitorius* and these include 0.30–0.70 m between rows and 0.15–0.50 m within rows (Oluoch et al. 2009; Maseko et al. 2015). In South Africa, the recommended spacing for *Cleome gynandra* was 0.3 m inter-row and 0.1–0.15 m between plants whilst for amaranth the optimal spacing ranged from 0.2 m × 0.2 m to 0.5 m × 0.5 m, depending on the size of the plants with interrow spacing 1 m. The recommended spacing for cowpea is 0.5–0.75 m between rows and 0.5–0.75 m between plants for spreading varieties and 0.5 m between rows and 0.15–0.25 m for the erect and semi-erect varieties e.g., Cbc1-4 (Department of Agriculture, Forestry and Fisheries (DAFF) 2014). The Asian Vegetable Research and Development Centre (AVRDC) recommended a spacing of 0.20 m × 0.20 m for *Cleome gynandra* (Wangolo et al. 2015). However, other communities e.g., Adja in Southern Benin use broadcasting with no specific planting density (Matro et al. 2015).

A density of about 20 plants m^{-2} for repeated cuttings was recommended by Achigan-Dako et al. (2010) and this translates to 200,000 plants ha^{-1} whilst Mabotja (2019), endorsed 200,000 to 250,000 plants ha^{-1} for *Solanum retroflexum* Planting densities between 1,000,000 to 2,000,000 plants ha^{-1} for *Amaranthus* may be practiced for increased yield when using the uprooting method of harvesting (Mamadi et al. 2009).

Further research is required to be able to strike a balance between planting density and the leaf size and yield per unit area.

Planting methods

Farmers involved in the production of AIVs have adopted different planting methods or techniques. Some AIVs are left to grow on their own some are sown in lines, some are broadcasted whilst others are transplanted (Ochieng et al. 2019). Direct sowing involves the spreading of the seeds in rows, which are later thinned leaving the vigorously growing seedlings (Kuo 2002). According to Ochieng et al. (2019) 21% and 59% of AIVs farmers adopted the line sowing for amaranth method in Tanzania and Kenya, respectively. Line sowing amaranth had an advantage over broadcasting because broadcasting caused plant overcrowding and resulted in poor-quality grains (Ochieng et al. 2019).

During transplanting, the ability of seedlings to thrive is dependent on: the quantity of retained roots, their water absorption capacity, soil moisture and the rate of new root formation (Leskovar and Stoffella 1995). Transplanting allows selection of vigorous seedlings from a nursery and enables seedlings to get ahead of weeds. Transplanting from nurseries is becoming popular in the AIVs commercial production to avoid wastage of expensive seed (Ochieng et al. 2019). Transplanting shortens the crop duration in the field, and is preferred when seed is scarce, labour is abundant and during the wet season when heavy downpours may otherwise wash seeds away. Transplanting also enhances yield due to more vigorous plant growth (Ochieng et al. 2019). A study by Orchard and Ngwerume (2009) of *Cleome gynandra* revealed that transplanting increased leaf yield by 133.3% more than direct seeding, yet according to Mnzava and Chigumira (2004) transplanting is not common in *Gynandropsis gynandra* because of the long taproot system. The long tap root system of *Cleome gynandra* consists of a few secondary roots and is associated with slow production of new roots which makes transplanting a challenge (Houdegbe et al. 2018) and direct seeding more appropriate.

Broadcasting is usually done when AIVs are intercropped with other plants. Chauhan et al. (2006) reported that *Galium tricornutum* (rough corn bedstraw, rough fruit corn bedstraw, and corn cleavers) seeds showed no germination when broadcasted on the soil surface. Broadcasting wastes seed and is associated with low germination as most seeds are left exposed to direct sunlight on the surface. Most wild vegetables are negatively photosensitive because of inhibition of seed germination as a result of light (Sowunmi and Afolayan 2015) and reduced moisture availability. Whilst broadcasting has been criticized, sowing AIVs too deep in the soil is also not advisable. According to Sowunmi and Afolayan (2015) a sowing depth of 0.05 m had the highest germination followed by 0.1 m, with no germination recorded at 0.15–0.5 m deep for *Cleome gynandra*. Transplanting proved to be superior than broadcasting as broadcasting waste seed and has low germination rates.

Cropping methods

Growing AIVs is a way of increasing crop diversity within local systems to cushion the effects of climate change. The different types of cropping methods are monocropping, intercropping, strip cropping, crop rotations, fallow systems and cover cropping amongst others (Rusinamhodzi 2020). The main idea behind multiple cropping systems is to maximize efficiency of resources and to increase crop production. In Uganda farmers used the mixed method in the production of *Solanum aethiopicum*, *Amaranthus blitum* and *Gynadropsis gynandra* where seeds are broadcasted at the same time taking advantage of the different maturity levels of these vegetables (Pincus et al. 2016) to increase land productivity and reduce costs of production. Only selected indigenous vegetables, were cultivated as part of mixed cropping in home gardens and small plots whilst most of them were gathered from the wild (Maseko et al. 2017). According to Notsi (2012) indigenous farming methods are cost effective, sustainable and environmentally friendly as opposed to conventional farming methods for the cultivation of AIVs. According to a study by Semalulu et al. (2020) leafy *Amaranthus blitum* (purple amaranth) performed well in both mixed and pure stand cropping systems because it established faster and suppresses *Solanum aethiopicum* (bitter tomato, Ethiopian eggplant) and *Gynadropsis* *gynandra*. Semalulu et al. (2020) concluded that it is more profitable for farmers to grow AIVs as pure stand and in lines as compared to mixed cropping. Even though AIVs grown under mixed cropping system allows farmers to get a variety of crops from the same piece of land over a prolonged period, they also pose a risk of low crop production as a result of competition for water and space (Semalulu et al. 2020). The lack of recommendations on the cropping methods of AIVs calls for further studies on the different methods cropping, methods.

Plant nutrition management

The management of plant nutrition greatly improves crop productivity per unit area owing to the essential role the nutrients have in plant growth and metabolism. According to Nambafu (2018) nitrogen and phosphorus are key nutrients in the production of leafy vegetables as they both promote cell expansion and cell division in leaves and root development. The full potential of improved seed varieties and technologies of AIVs can only be realized if essential nutrients are applied on time timeously and in the right quantities (Ogbodo 2013). Nutrient application in AIVs accelerates plant height, increases fresh and dry aboveground biomass, protein content, leaf quality, leaf number, canopy size, seed weight, number of branches amongst other vegetable traits (Nambafu 2018; Koile 2018; Seeiso and Materechera 2013).

According to Seeiso and Materechera (2013), *Amaranthus hybridus* and *Cleome gynandra* increased leaf biomass (366.13 and 470.86 g/plot respectively) when fertilized with either manure or any nitrogenous fertilizer during active growth stages. Increased nutrient levels (300 kg NPK ha^{-1}) in *Amaranthus* was reported to delay the onset of flowering thereby increasing the length of the vegetative stage by 3 weeks (Mutua et al. 2015). Fertilization therefore stimulates vegetative growth and boosts yield considerably, however, there is a dearth of information on the performance of *Bidens pilosa* under different essential nutrients and their performance under nutrient deficiency (Nambafu 2018). Table 2 shows the different rates of fertilizers and the corresponding leaf yields of selected AIVs in SSA. As shown in Table 2, organic fertilizers are producing yields that are comparable to inorganic fertilizers. For *Cleome gynandra* poultry manure produced 24.38 t ha^{-1} of fresh leaf yield whereas 100N:20P:150K kg ha^{-1} produced 20 t ha^{-1} (Table 2). Farm yard manure applied at 10 t ha^{-1} produced 3.6 t ha^{-1} of *Vignia Unguiculata* whilst 200 kg ha^{-1} of DAP produced 4.9 t ha^{-1}.

The integration of organic and inorganic fertilizers combines the advantages of both fertilizers in ameliorating the soil nutrient condition and increasing crop yield (Ebert 2014). According to Timsina (2018) the use of organic sources of nutrients is a sustainable strategy for producing safe, healthy and cheaper food whilst restoring soil fertility and mitigating climate change. However, it was observed that farmers producing amaranth for commercial purposes preferred mineral/chemical fertilizers whilst those producing for own consumption preferred organic manure (Ochieng et al. 2019). This is probably because chemical fertilizers are expensive for the resource poor farmers who often consume the AIVs whilst organic manures are bulky for commercial production. According to a review by Kebede and Bokelmann (2017), 30% of AIVs farmers in Kenya used organic fertilizers whilst 49% used inorganic fertilizers with 21%

Table 2 Fertilizer rates and leaf yield of selected common indigenous vegetables grown in sub-Saharan Africa

Vegetable	Fertilizer/manure application rate	Leaf yield	References
Amaranthus spp.	10 t ha^{-1} sheep manure	2.6 t ha^{-1}	Mhlontlo et al. (2007)
	150 kg ha^{-1} NPK	3.4 t ha^{-1}	Mhlontlo et al. (2007)
	100N:20P:150K kg ha^{-1}	17.5 t ha^{-1}	Modisane et al. (2009)
	100N:20P:0K kg ha^{-1}	19 t ha^{-1}	Modisane et al. (2009)
Bidens pilosa	84 kg ha^{-1} NPK + 0.2 t ha^{-1} compost	0.74 t ha^{-1} (DW)	Zobolo and Staden (1999)
Cleome gynandra	80 kg ha^{-1} CAN	1.6 t ha^{-1}	Mauyo et al. (2008)
	100N:20P:150K kg ha^{-1}	20 t ha^{-1}	Modisane et al. (2009)
	No fertilizer	1.19 t ha^{-1}	Mavengahama (2013)
	300 kg ha^{-1} LAN	2.12 t ha^{-1}	Mavengahama (2013)
	30 t ha^{-1} poultry manure	24.38 t ha^{-1}	Houdegbe et al. (2018)
	200 kg ha^{-1} DAP	1.7 t ha^{-1}	Koile (2018)
Vigna unguiculata	200 kg ha^{-1} DAP	4.9 t ha^{-1}	Koile (2018)
	100 kg ha^{-1} DAP + 5 t ha^{-1} farm yard manure	4 t ha^{-1}	Koile (2018)
	10 t ha^{-1} farm yard manure	3.6 t ha^{-1}	Koile (2018)

CAN calcium ammonium nitrate, *LAN* limestone ammonium nitrate, *DAP* diammonium phosphate, *DW* dry weight with the rest being fresh weight using both and this was attributed to income levels/wealth status of farmers. Integrating organic and inorganic fertilizers may be a worthwhile solution to farmers who rear livestock (cattle, chickens, goat amongst others) but have limited cash for inorganic fertilizer. Integrated fertilizer management has chemical fertilizers for a quick release of nutrients and inorganic fertilizer, which slowly release the nutrients allowing for continuous nutrient supply throughout the growing season and ameliorates soil physical properties (Nyamangara et al. 2011).

The disadvantage of the existing nutrient management recommendations for most crops in most developing countries is that, for vast areas of production there is often only one predetermined rate of nutrients (Nyamangara et al. 2011). Such recommendations assume that crop nutrient needs are constant over time and space, yet that is not the case. There is need for crop specific nutrient rates in the different agro-ecological regions. According to Timsina (2018) the nutrient requirements for any crop can vary greatly amongst seasons, fields and agro-ecological regions, due to differences in crop-growing conditions, water, climate, nutrient and soil management resulting in large spatial and temporal variability in soil nutrient supply. Henceforth, nutrient management for commercial crops requires an approach that enables adjustments in nutrient application to accommodate the site- or soil-specific needs of the crop and the blanket recommendation of fertilizer application cannot be an effective approach. Types and amounts of fertilizers applied should be determined based on soil analysis to avoid excess or diminutive applications.

Deflowering

During the flowering stage, most of the plant nutrients or resources are re-allocated to the reproductive structures, drawing resources away from vegetative growth (Wangolo et al. 2015) demonstrating the significance of flowers as resource sinks. Removing these resource sinks (flowers), implies that energy and resources will continue to be directed to supply leaves and shoots, prolonging vegetative growth and delaying senescence (Oluoch et al. 2009; Kriedemann et al. 2010). Removing apical buds reduces apical dominance thus allowing for lateral budding translating into increased vegetable yields (Wangolo et al. 2015).

The early onset of flowering significantly reduces leaf yield (Mbwambo et al. 2015) because crops flower before producing significant economic leaf yields and also shortens the production season resulting in vegetable shortages (Mavengahama 2013) and economic losses to farmers. Early flowering in vegetables is induced by extreme temperatures, moisture stress, and photo period and in some instances genetic factors (Mutua et al. 2015). Early flowering (bolting) is most common in *Cleome gynandra* as flowering may start from as early as 2 weeks after emergence (Mutua et al. 2015) and this may hamper the current efforts to promote its production amongst farmers as this leads to production losses as crops flower before they have produced an economic yield (Mavengahama 2013).

Deflowering of *Cleome gynandra* increased shoots and leaves per plant and subsequently leaf yield, plant height and fresh and dry leaf weight in South Africa (Mavengahama 2013) and in Kenya (Wangolo et al. 2015). According to a study by Zobolo and van Staden (1999), deflowering *Bidens pilosa* (blackjack) resulted in taller plants with a higher plant weight than similar non deflowered plants. According to a review by Oluoch et al. (2009), the removal of flowers increased leaf yield of *Amaranthus* spp. and *Cleome gynandra* in comparison to where flowers were not removed.

On the contrary, delayed flowering increases the exposure of vegetables to late coming stresses that affect grain yield and leaf quality (Achigan-Dako et al. 2014). Deflowering *Solanum nigrum* did not significantly affect plant height, plant canopy spread and number of branches per plant and that it significantly increased leaf ascorbic acid content (Mutua 2015). Again, deflowering seems unsuitable for vegetables grown for their seed e.g., grain amaranths where removing flowers reduces the fruit parts which produce seeds. Deflowering may only be convenient or suitable for small scale vegetable production as the process is quite tedious and may not be suitable for large scale production unless engineering technology for deflowering is developed. However, undertaking a cost benefit analysis would also be recommended for large scale production and consider spraying hormones that reduce flowering.

Harvesting methods

The harvesting methods employed are an important aspect in AIVs production though little is known about the specific guidelines (Seeiso and Materechera 2013). According to Rahman et al. (2008), leaf harvesting procedures and practices can potentially promote or reduce the yield of important components of the vegetables. Saidi et al. (2010) and Baloyi et al. (2013) have shown that biomass yield and nutritional quality of the crop are functions of the frequency, extent or intensity and timing of foliage removal from leafy vegetables. African indigenous leafy vegetables can be harvested by either cutting the top plant part, cutting from ground level, uprooting the whole plants or picking individual leaves or leafy branches at different intervals allowing the crop to produce grain and seed (Mamadi et al. 2009; Oluoch et al. 2009; Maseko et al. 2015).

Harvesting or picking leaves at different intervals over the course of the season enables farmers to market their produce over extended periods, it lessens supply gluts and associated price fluctuation risks and reduces problems associated with postharvest vegetable management (Oluoch et al. 2009) e.g. keeping vegetables fresh and lack of storage facilities. According to Mamadi et al. (2009) harvesting of side branches and leaves of amaranthus in intervals of 1-week or 2-weeks from about 3 to 4 weeks after planting produces profuse leaves after every harvest. In the production of *Gynandropsis gynandra*, leaves can be harvested by cutting every 2 weeks (Chivinge et al. 1998) and or once every week (Seeiso and Materechera 2013).

From a study of *Brassica carinata*, *Amaranthus* spp. and *Cleome gynandra* by Nambafu (2018), cutting and uprooting harvesting techniques mined more nutrients from the soil compared with picking leaves. Thus, harvest related nutrient losses can be considerably reduced by harvesting only edible organs (picking) instead of pulling the whole plant. Some studies on *Cleome gynandra* (Keller 2004) and *Amaranthus* spp. (Adeniji and Aloyce 2013) in Tanzania reported a prolonged production cycle (3 weeks) for repeat harvesting and early maturity for once off first harvest. However, according to Achigan-Dako et al. (2010), extended period of repeated harvests may not work for areas with low moisture conditions in rainfed production systems as harvesting can occur 4–5 weeks after sowing and that moisture stress induces early senescence. In regions infested by borers (*Melittia cucurbitae*), harvesting by uprooting is preferred according to Schippers (2004) as it removes larvae that has penetrated the roots, making the soil more suitable for a next crop. Frequent picking of *Cleome gynandra* may delay flowering and prolong the harvesting period (Community Technology Development Trust 2012).

The different harvesting methods have their pros and cons (Table 3) hence there is need to strike a balance between number of harvests, vegetable supply and nutrient mining amongst other environmental benefits.

Yield

According to Achigan-Dako et al. (2010) for the various AIVs *Solanum macrocarpon*, *Amaranthus cruentus*, *Amaranthus spinosus*, *Bidens pilosa*, *Cleome gynandra* and *Vigna unguiculata* only the young new leaves are harvested as the older ones are hairy or bitter. Number of leaves per branch, plant height, leaf size, number of branches per plant and chlorophyll content have an effect on the quality and quantity of leaf yield and these can be used as yield determinants. Yields of leafy vegetables are greatly varied from as little as 5–82 t ha^{-1} of fresh weight of *Amaranthus* spp., with *Corchorus olitorius* having an average of 12 t ha^{-1} and *Cleome gynandra* with a fresh leaf yield of 16 t ha^{-1} (Pincus et al. 2016). AIVs have a potential to reach fresh leaf harvests of about 40 t ha^{-1} (Olouch et al. 2009), but these yields vary with species for example, the yield of 'callaloo' (*Amaranthus cruentus*) was almost 12 t ha^{-1} whereas for 'green leaf' (*Amaranthus tricolor*) it was merely 2.40 t ha^{-1} (Maseko et al. 2017). The production of African Nightshade (*Solanum* spp.) vegetable yield ranges from 1 to 3 t ha^{-1} in Juja, Kenya against a biological yield potential of 30 t ha^{-1} (Orangi et al. 2020). It therefore implies that some realized yields are not up to the full potential of these vegetables and a lot needs to be done to increase the yields.

In Benin and Nigeria, the yield of *Amaranthus cruentus* reached about 30 t ha^{-1} whereas in Tanzania yields of about 40 t ha^{-1} have been recorded (Mbwambo et al. 2015) with a highest of 82.8 t ha^{-1} reported by AVRDC in a study conducted in different sub-Saharan countries (Olouch et al. 2009). For *Cleome gynandra* the highest economic leaf yield of 32 t ha^{-1} was recorded in a review by Olouch et al. (2009), 22.1 t ha^{-1} in Kenya (Wangolo 2015) and 20 t ha^{-1} in South Africa (Modisane et al. 2009). According to Chivinge et al. (1998) *Cleome*

Table 3 Methods of harvesting indigenous vegetables and the associated advantages and limitations

Harvesting method	Example of African indigenous vegetable	Advantage(s)	Limitation(s)	References
Picking leaves or leafy branches	*Amaranthus*, *Cleome gynandra*, *Vignia unguiculata*, *Bidens pilosa*	High leaf and grain yield Prolonged production life cycle Reduced soil nutrient losses	Perpetuates cycle of pests and diseases Not suitable for low moisture conditions in rainfed systems	Olouch et al. (2009); Achigan-Dako et al. (2010)
Uprooting the whole plant	*Amaranthus* spp., *Cleome gynandra*, *Brassica rapa subsp. chinensis*	Early maturity Breaks the cycle of diseases	Reduced production cycle Soil nutrient mining	Nambafu (2018); Keller (2004); Adenji and Aloyce (2013); Schippers (2004)
Cutting from ground level	*Brassica rapa subsp. chinensis*, *Bidens pilosa*, *Amaranthus*, *Cleome gynandra*	Breaks the cycle of pests and diseases	Reduced leaf and seed yield Soil nutrient mining Short production life cycle	Keller (2004); Adenji and Aloyce (2013); Schippers (2004)

gynandra yielded an average of 0.5 t ha^{-1} whilst *Corchorus tridens* yielded an average of 1.12 t ha^{-1} in Zimbabwe. This implies that yields of AIVs also vary with location or region and this is attributed to the diverse environmental and weather conditions.

Average grain yield of *Vigna unguiculata* was 720 kg ha^{-1}, *Amaranthus* spp. 920 kg ha^{-1}, *Solanum* spp. 724 kg ha^{-1}, *Corchorus olitorius* 636 kg ha^{-1}, *Cleome gynandra* 700 kg ha^{-1} and *Mesembryanthemum nodiflorum* 772 kg ha^{-1} (Abukutsa-Onyango et al. 2010). Yields of about 100 g seed/plant are possible for *Cleome gynandra* thought capsule shattering and seed loss is rampant on fruits that are left for too long on the plant and that overripe black capsules contained more dormant seeds than yellow or brown capsules (K'opondo et al. 2005). Preferably, yellow or brown capsules should be picked and left to dry and be shelled in a controlled way, allowing for effective seed recovery. Seeds should be dried to a 9% moisture content to retain their viability and reduce dormancy up until the next season (K'opondo et al. 2005). Further research is required to determine seed yield of these popular AIVs as most reviewed articles only have leaf yield and not seed yield.

Conclusions

The most common AIVs in SSA are *Amaranthus* spp., *Cleome gynandra*, *Corchorus* spp., *Vigna unguiculata*, *Cucurbita* spp., *Brassica* spp. and *Solanum* spp. Planting density should balance between leaf size and yield per unit area. Transplanting and sowing AIVs as pure stands in lines, deflowering and harvesting/picking leaves and tender shoots at intervals over the course of the season can optimize their production. Nutrients from either manure or chemical fertilizers are required to increase leaf and seed yields of AIVs though the types and amounts of fertilizers applied should be determined based on soil analysis to avoid excess or diminutive applications. There is a huge potential for conventional production of AIVs given their nutritional benefits and their resilience in the face of climate change.

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Author contributions

JJK: conceptualization, writing—original draft preparation. GM, ENM and JN: supervision, writing—reviewing and editing.

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Declarations

Ethics approval and consent to participate

Not applicable.

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Competing interests

The authors declare no competing interests.

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