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Adoption of improved amaranth varieties and good agricultural practices in East Africa

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ABSTRACT

This study quantifies the adoption of improved amaranth varieties in Kenya and Tanzania, and the extent to which these result from international vegetable breeding research conducted by the World Vegetable Center (WorldVeg) and partners. The study used expert elicitation and a questionnaire survey among vegetable seed producers. Nine expert panels were conducted involving 123 local experts. The results show that improved amaranth varieties were planted on 51% of the planted area in Kenya and 70% in Tanzania. Improved varieties were planted on 17,502 ha and reached 404 thousand smallholder farmers. WorldVeg is the main source of improved varieties, reaching 231 thousand farm households in Kenya and Tanzania. Seed companies sold 2.9 tons of amaranth seed in 2016 and 59% of this was WorldVeg-based germplasm. Opportunities exist to improve amaranth production through the development and promotion of better varieties (particularly resistance to white rust and leaf spot) and good agronomic practices (particularly the use of certified seed, mineral fertilizers, seed treatment and nurseries). Investment in amaranth research and development will contribute to better livelihoods and better nutrition in sub-Saharan Africa.

1. Introduction

The diets of many households in sub-Saharan Africa are unbalanced and generally short of micronutrient-dense food such as fruit and vegetables (Mason et al., 2001; Global Panel, 2016). Inadequate micronutrient supplies are expected to intensify in the coming decades (Nelson et al., 2018). The increased production and consumption of leafy vegetables in particular can make an important contribution to improved nutrition. Recently, traditional African vegetables such as amaranth, nightshade and Ethiopian mustard have received much attention as these are hardy, locally adapted, generally liked and dense in essential micronutrients currently lacking in the local diets (Abukutsa-Onyango, 2014). The promotion of these vegetables has led to a rise in demand, particularly in urban areas, which has created opportunities for local smallholder farmers to improve their income and family nutrition (Ojiewo et al., 2013; Ochieng et al., 2017a; Rajendran et al., 2016).

Yet, the surge in popularity of traditional vegetables has not been accompanied by increased investment in their genetic improvement (Afari-Sefa et al., 2012), as crop breeding research continues to be focused on a narrow range of food staples and other globally important crops (Lynam, 2011). For two decades, the World Vegetable Center (WorldVeg) in Tanzania has been one of few organizations collecting, characterizing and conserving the genetic diversity of traditional African vegetables and using this to supply better varieties to farmers. The Center's effort has focused on amaranth and African eggplant and this has stimulated seed companies in Tanzania and Kenya to include these crops in their portfolios. A previous study showed that two WorldVeg-developed varieties of African eggplant accounted for 98% of commercial seed sales in East and Southern Africa in 2014 (Schreinemachers et al., 2017b). However, there is no information about the extent that farmers in East Africa have adopted improved amaranth varieties.

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Therefore, the objective of this study is to quantify the adoption of improved amaranth varieties in Kenya and Tanzania, and the extent to which these varieties result from investment in international vegetable breeding conducted by the World Vegetable Center and its local partners. This information is important because nearly all previous adoption studies have focused on food staples such as maize, rice, peal millet, wheat, cassava and legumes (e.g. Walker and Alwang, 2015) while there is very little information about the effectiveness of international breeding of micronutrient-dense vegetables, and particularly traditional African vegetables.

Amaranth (*Amaranthus* spp.) originates from Central America and was introduced to Africa in the 20th century. There are over 60 species of amaranths globally (Sauer, 1967). About ten species are common in sub-Saharan Africa, with the most popular ones being *A. hypochondriacus*, *A. cruentus, A. caudatus*, and *A. dubius* (Glen, 2002; Dinssa et al., 2016a, 2016b). Farmers in sub-Saharan Africa cultivate amaranth either for its leaves or for its grain. The leaves are rich in vitamin C and pro-Vitamin A as well as in iron, zinc and calcium (Yang and Keding, 2009). The grains are rich in quality protein, lysine and calcium and is consumed directly or used to fortify maize flour (Petr et al., 2003; Macharia-Mutie et al., 2011). It is hardy and can be grown under diverse agro-ecological conditions.

Table 1 shows government statistics on amaranth production in Kenya and Tanzania in 2017. It shows that amaranth was planted on about 25,548 ha in 2017. Most of this was for leaf harvesting, but grain production was also common in Kenya. Tanzania has the largest area, but the average leaf yield is only 2.2 tons/ha as compared to 10.7 tons/ha for Kenya, which suggests variations in growing conditions and the use of technologies.

2. Amaranth improvement and scaling in East Africa

The World Vegetable Center and its partners in East Africa have collaborated for over 15 years to collect, characterize and conserve the genetic diversity of traditional African vegetables including amaranths. The partnership includes Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya Agricultural & Livestock Research Organization (KALRO), Horticultural Research and Training Institute (Horti-Tengeru), Mikocheni Agricultural Research Institute, Sokoine University of Agriculture in Tanzania, University of Nairobi and University of Eldoret in Kenya, and Uganda Christian University in Uganda. WorldVeg in Tanzania holds about 796 amaranth accessions of 18 species from the Americas, Africa and Asia, which is the largest public collection of amaranth germplasm in Africa.

Amaranth accessions in the WorldVeg genebank were mainly collected under two projects funded by the Federal Republic of Germany between 2003 and 2009 (ProNIVA, 2006; ProNIVA, 2010). The United States Agency for International Development (2002–2007) and the United States and Israel Cooperative Development Research Project (2007–2010) also supported germplasm collection (Dinssa et al., 2016a, 2016b). Furthermore, the project “Vegetable Breeding and Seed systems for Poverty Reduction in sub-Saharan Africa (vBSS)” funded by Bill and Melinda Gates Foundation distributed and evaluated a large number of amaranth accessions across Africa from 2007 to 2010. From 1980–2013, WorldVeg in partnership with national agricultural research systems (NARS) released 7 amaranth varieties, of which 4 were released between 2011 and 2013 (Dinssa et al., 2015).

In Tanzania, Horti-Tengeru in 2011 released ‘Madiira 1′, a leaf amaranth that has become a popular variety among farmers for its leaves remain green over a long period and its preferred taste and cooking quality (Dinssa et al., 2018). WorldVeg has combined multiple favorable traits in cultivars and used polyploidization of amaranth lines to extend shelf life (Schafleitner et al., 2016). Nutritional qualities were also improved with ‘Madiira 1′ and ‘Madiira 2′ having significantly higher concentrations of iron, calcium and fiber than other varieties (Dinssa et al., 2018).

Table 1
Amaranth production data for Kenya and Tanzania, 2017.
Sources: Agriculture Fisheries and Food Authority (AFFA), 2014; Tanzania National Bureau of Statistics, 2018.

	Kenya			Tanzania	Total
	Leaf	Grain	Total	Leaf	
Area planted (ha)	1,586	389	1,975	23,573	25,548
Production (1000 tons)	17.0	2.1	19.1	51.6	70.7
Average yield (tons/ha)	10.7	5.3	9.6	2.2	2.8

In Kenya, WorldVeg and JKUAT collaborated to develop advanced amaranth lines of leaf, grain- and dual type that were evaluated and distributed to public institutions and private seed companies for further improvement or direct release. The variety ‘Madiira 1′ (also known as ‘Ex-Zim’ in Tanzania and ‘KK Mrambi’ in Kenya) and ‘Madiira 2′ (also known as ‘AM38′ in Tanzania and ‘KK Livokoyi’ in Kenya), were particularly promising. These varieties have not been officially released, but have been widely adopted by farmers as a result of seed kit distribution projects by WorldVeg and various other organizations. For instance, van Zonneveld et al. (2019) reported that WorldVeg distributed 31,989 packages of amaranth seed to farmers in Tanzania from 2013–2018.

3. Methods and data

3.1. Expert elicitation

Maredia and Reyes (2014) defined an improved variety as “a variety developed by breeders and released in the formal system”. However, variety release procedures are less well-defined for traditional African vegetables like amaranth than for major crops. We therefore find farmers using improved breeding lines that have not gone through formal variety evaluation and release. Hence, we adjust the definition of an improved variety as a variety or named breeding line developed by breeders in the formal system and distributed to farmers.

Tracking farmer adoption of improved varieties over time is important and there is a need for straightforward and inexpensive methods to do this. Several recent studies have used expert elicitation to quantify adoption rates. Expert elicitation is a systematic method which uses repetitive and independent questioning of a panel of expert informants and is based on the Delphi method (Dalkey and Helmer, 1963; Linstone and Turoff, 1975).

The project “Diffusion and Impact of Improved Varieties in Africa (DIIVA)” (2010–2013) made an important contribution to the methodology of expert elicitation (Walker and Alwang, 2015). The DIIVA project covered 20 food crops in 30 countries in sub-Saharan Africa.[1] The project generated data on the geographical spread and adoption of improved varieties of food staples (e.g maize, barley, wheat, rice, sorghum, pearl millet, sweet potato, potato) and grain legumes (e.g groundnut, chickpea, faba bean, pigeon pea) (Walker and Alwang, 2015). The results showed that the adoption of improved crop varieties is quite low in Africa with 14 of the 20 crops having adoption rates below 35% (Walker and Alwang, 2015).

For the current study we also chose expert elicitation as a suitable method because farmers themselves are unable to tell the name of the variety they planted while identification with DNA methods is too expensive to do at a country level on a regular basis. The method uses a panel of experts to estimate adoption rates in two or more rounds of meetings with results summarized after each meeting and the panel revising its answers based on the judgements of the other experts. Fig. 1 shows the flow chart of expert elicitation as applied in our study.

[1] For details, see https://www.asti.cgiar.org/diiva

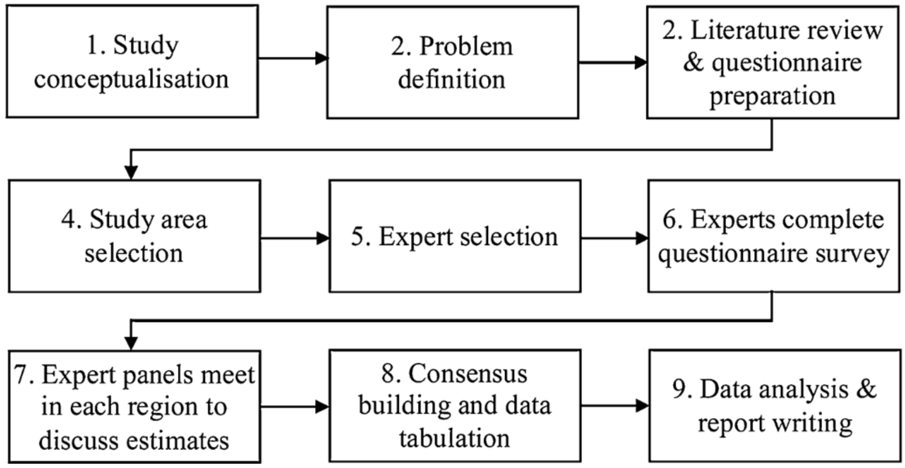

Fig. 1. Expert Elicitation process as used in this study.

Previous studies have shown that expert elicitation provides close estimates of the area planted to modern varieties with more accurate estimates obtained when expert panels are organized at the level of major agro-ecological or administrative regions. Studies have also shown that expert elicitation gives estimates that are consistent with farm survey data (Tsusaka et al., 2015; Walker and Alwang, 2015; Hassan et al., 2001).

3.2. Expert panels creation and meetings

Major amaranth growing regions of Tanzania and Kenya were selected based on government statistics and covering over 60% of the total amaranth production per country (Table 2). In Kenya it included Kakamega, Migori, Bungoma, Taita Taveta and Kilifi, and in Tanzania it included Arusha, Kilimanjaro, Morogoro, Zanzibar and Dar es Salaam.

Next, expert panels were created for each region. Each expert panel comprised of 11–18 experts of a diverse background in terms of knowledge and expertise (Table 2). These included agricultural researchers, extension officers, major seed dealers, NGOs staff, farmer representative and staff of seed companies and seed corporations. Key experts from KALRO and Horti-Tengeru were visited in person in preparation for the expert panel meetings. Each expert was sent an invitation and informed about the purpose and importance of the study. A first-round questionnaire was attached to the invitation letter and experts were asked to complete this in advance and bring it along to the meeting. Questions asked about the current amaranths area (planted or harvested in ha), production (tons), and average yield (kg/ha) for the region, list of varieties and their adoption, and a list of good agricultural practices and their adoption (e.g. timely weeding, nursery management, planting in lines, seedbed preparation, crop rotation and integrated pest management methods etc). The filled questionnaires were collected at the start of the meeting but not immediately analyzed.

The expert panels convened locally in each region. A workshop facilitator explained the study and the procedure to be used. Experts put their varietal adoption estimates on cards and pinned them on a board. Sometime the estimates were recorded on the board by the facilitator. After all experts had revealed their estimates then a facilitated discussion followed in which each expert was encouraged to revise his or her initial response to reach consensus. A final questionnaire was then filled out.

Through this process we collected data about the adoption of amaranth varieties as well as about the adoption of other technologies and practices since these tend to accompany that of improved crop varieties (Lukumay et al., 2018). In addition, we asked panel members to identify the constraints to amaranth production by writing them on cards and prioritizing them through discussion. These are important additions to the existing methodology. Workshops were held from September to December 2017. The data analysis quantified the adoption rate of each variety and each technology per region. Country averages were calculated using the amaranth area per region as weights while an overall average was calculated using the amaranth area per country as weights.

Table 2
Number of experts consulted in Kenya and Tanzania, 2017.

Country and region	Research-ers*	Extension officers	NGO staff	Seed company staff	Farmers	Total
Kenya:	26	31	6	2	10	75
- Kakamega	7	2	3	1	2	15
- Bungoma	7	1	2	1	3	14
- Taita Taveta	4	8	1	0	1	14
- Kilifi	4	12	0	0	2	18
- Migori	4	8	0	0	2	14
Tanzania:	10	14	6	4	14	48
- Arusha/ Kilimanjaro	5	2	2	3	1	13
- Morogoro	2	4	1	1	3	11
- Dar es Salaam	1	6	1	0	3	11
- Zanzibar	2	2	2	0	7	13

* Vegetable breeders, seed specialists, agronomists, etc.

3.3. Data from seed producers

We furthermore collected seed production data from seed producers to compare to the expert elicitation data. We created a list of 27 private seed companies and 9 public sector organizations in Kenya and Tanzania involved in vegetable seed production (see Annex Table 1A). Each was approached to find out if they produced amaranth seed, which led to the identification of 8 seed producers (3 in Kenya and 5 in Tanzania).

Each seed company was approached with a request for data about the quantity of amaranth seed sold in the most recent year for which records were available. We used a structured questionnaire and the method is similar to that employed by previous studies (e.g. Thiele et al., 2006; Schreinemachers et al., 2017a). All companies complied with our request as they had benefitted from the germplasm received from WorldVeg and had contacts to other WorldVeg staff. The data were collected from October 2017 to January 2018.

Table 3
Use of improved amaranth varieties in Kenya and Tanzania and the role of the World Vegetable Center, 2017.

	Kenya	Tanzania	Total
Farm households producing amaranth [a]	286,048	369,816	655,864
All improved varieties:			
- Number of varieties	12	7	19
- Planted area (ha)	1,001	16,501	17,502
- % of total planted area	50.7	70.0	68.5
- Farm households using	145,026	258,871	403,898
WorldVeg-related varieties			
- Number of varieties	6	6	12
- Planted area (ha)	393	11,105	11,498
- % of total planted area	20.0	47.1	45.6
- Farm households using	56,850	174,221	231,071

Notes: [a] Refers to the number of farmers growing both local and improved amaranth varieties. The number of farmers was estimated by combing data about the number of smallholder farmers per country (FAO, 2018) with data from TNBS (2012; 2018) in Tanzania and a rural household survey conducted by Egerton University in 2006 in Kenya. These data show that 6.2% of smallholders in Tanzania and 6.4% in Kenya produce amaranth.

4. Results

4.1. Variety adoption

We estimate that amaranth is produced by about 656,000 smallholder farm households in Kenya and Tanzania (Table 3). Improved varieties were cultivated by 403,898 farm households in Kenya and Tanzania, or 62% of all amaranth growers. The adoption rate of improved varieties was higher in Tanzania (70%) than in Kenya (51%). However, the variation between regions was substantial (see Annex 1). For example, for Kenya, the adoption rate was 35% for Bungoma and 30% for Kakamega, but 65% for Kilifi. Similarly, the adoption of improved varieties was 35% for Zanzibar but 74–81% for mainland Tanzania (Arusha, Morogoro, and Dar es Salaam).

Most households produce amaranth on small plots of land—92 m^2 on average, and much of the harvest is used for home consumption rather than selling. Our data show that 17,502 ha of land was planted to improved amaranth varieties. The number of farmers using improved amaranth varieties was 258,871 in Tanzania and 145,036 in Kenya.

The expert elicitation method recorded 19 varieties used by farmers, of which 12 are found in Kenya and 7 in Tanzania. The top-four varieties include 'Dubius', 'Hybridus', 'Blitum' and 'Cruentus' (see Annex Table 1B). These variety names may be confusing because they actually refer to the names of species; however, seed companies in Kenya and Tanzania have used these to name their varieties. It is, however, possible that more than one variety is known by the same name. 'Dubius'—for leaf harvesting, and 'Hybridus'—for grain harvesting are the most important varieties in Kenya. The Kenya Seed Company (KSC) Ltd (with its vegetable seed production wing known as Simlaw Seeds Ltd) produced seed of both varieties. In Kenya, KSC is the main supplier of amaranth seed in the formal seed system with JKUAT, KALRO and East Africa Seed Company also producing amaranth, but in smaller quantities. The popularity of 'Dubius' shows that farmers produce amaranth for leaves rather than grains. 'Dubius' produces large leaves, is liked for its taste, and is more drought-tolerant than other varieties.

Of the 19 amaranth varieties recorded in the study, 12 were developed from germplasm developed by WorldVeg (see Annex Tables 1B and 1C). The two most popular varieties, 'Dubius' and 'Hybridus', originated from WorldVeg. Overall, 39% of the total amaranth area in Kenya and 67% in Tanzania is planted to varieties containing WorldVeg germplasm (Table 3) and this is planted on 393 ha in Kenya (20% of the total amaranth area) and 11,105 ha in Tanzania (47% of the amaranth area). An estimated 56,580 farmers in Kenya and 174, 221 in Tanzania benefit from WorldVeg amaranth lines.

Table 4
Adoption of agronomic practices in amaranth production in Kenya and Tanzania, in % of farmers adopting, 2017.

Agronomic practice	Kenya	Tanzania	Total
Farmer seed practice:			
- Seed rate (kg/ha)	2.3	3.4	3.3
- Use of certified seed (% of seed sown)	36.9	10.2	12.3
- Seed replacement rate (cropping cycles)	4.0	3.5	3.5
Seed treatment with:			
- Insecticides	0.5	1.8	1.7
- Fungicides	0.5	0.0	0.1
Line sowing	59.3	20.9	23.9
Nursery practices and transplanting	36.2	26.4	27.2
Seed bed preparation	87.8	84.8	85.0
Mineral fertilizers, basal dressings	47.7	8.9	11.9
Mineral fertilizers, top dressing	34.4	45.6	44.7
Mineral fertilizers, foliar application	31.7	5.2	7.2
Chemical insecticides/fungicides/ biopesticides	34.5	16.3	17.7
Irrigation	46.0	95.6	91.8
Production and application of compost	48.1	45.1	45.3
Use of IPM practices	16.1	5.8	6.6
Practices in stored grain/seed:			
- Use of insecticide/fungicide	0.3	0.5	0.5
- Use of hermetic storage bags	4.6	1.0	1.3

4.2. Adoption of agricultural practices

Our data show that 12% (37% in Kenya; 10% in Tanzania) of farmers used certified amaranth seed (Table 4). This includes Quality Declared Seed, but we did not separate this in the questionnaire. The average amaranth seed rate was about 3.0 kg/ha (2.3 kg/ha in Kenya; 3.4 kg/ha in Tanzania) and the farmer seed replacement rate was once in every four seasons (about two years). The most widely adopted agricultural practice in amaranth production is seed bed preparation with an adoption rate of 88% in Kenya and 85% in Tanzania. This practice is important because amaranth seed is very small in size and the soil needs to be loose to provide good contact with the seed and to allow sowing at the right depth. Farmers clear and burn bushes to produce ash and pulverize clods of earth to create a fine layer of loose soil.

A related practice is the use of line sowing, but the adoption rate was much lower at 21% of farmers in Tanzania and 59% in Kenya. Line sowing was particularly common in grain amaranth as broadcasting leads to overcrowding and poor-quality grains. Line sowing is also better for vegetable amaranth (Lukumay et al., 2018).

Amaranth is a relatively heavy feeder, which makes it important to use mineral fertilizer or organic manure to enhance yields. About half of the farmers applied compost or used basal fertilizer dressings with 45% applying top dressing and 7% foliar application. Despite the plant's need for nitrogen and other nutrients (Schippers, 2000), less than 40% of the farmers used mineral fertilizer. Nevertheless, it was observed that farmers producing amaranth for own consumption preferred organic manure while commercial producers preferred chemical fertilizers. There is an increasing number of farmers adopting irrigation to enhance yields or for multiple harvesting. Simple irrigation techniques such as watering cans were used by 46% of the farmers in Kenya and 96% in Tanzania.

Nursery practices and transplanting were used by 26% of farmers in Tanzania and 36% in Kenya, although experts said that these practices are increasing. Commercial farmers, especially those using certified seed, do this to avoid wastage of expensive seed. Transplanting is preferred when seed is scarce, labor is abundant and during wet season when heavy downpours may otherwise wash seeds away. Transplanting also shortens the crop duration in the field, secures a better and more uniform stand, and enhances yield due to more vigorous plant growth. Some farmers have started nurseries, and some sell seedlings to other farmers.

Adoption of chemical insecticides, fungicide and biopesticides was estimated at 18% (16% in Tanzania and 35% in Kenya). Amaranth is susceptible to weeds, insect pest such as weevils, leaf webber and stink bugs, and diseases such as damping-off, choanephora blight and leaf spot. Insect pest and diseases are particularly problematic for farmers producing seed or grain as the crop is longer in the field. Vegetable amaranth, especially for uproot harvesting, is much less affected by pests and diseases. No herbicides were used and farmers managed weeds through mechanical weeding.

The most widespread cultural practices in the management of pests and diseases included uprooting and destroying the infested plants, use of disease-free seeds, avoidance of excessive watering and reduced planting density. Small areas of amaranth per farmer also contribute to the lower use of chemical pesticides as insects and weeds can be managed by hand. The usage of IPM practices was low with only 7% of farmers adopting any such (e.g. repellant crops, insect traps, and use of biopesticides).

4.3. Formal seed production and trait development

We found eight amaranth seed producers in the formal seed sector of Kenya and Tanzania. Total amaranth seed sales were 4.9 tons in 2016 – potentially enough to plant 2144 ha of amaranth. Our data in Table 5 show that private seed companies handled 96% of formal seed production of amaranth.

All seed producers used WorldVeg germplasm. Moreover, all five amaranth varieties commercially available in Tanzania and four out of five in Kenya were developed from the Center's germplasm. This shows that international vegetable breeding makes an important contribution to local seed companies. In 2016, seed companies sold 1.4 tons of WorldVeg amaranth varieties in Kenya (44% of the total seed company's sales) and 1.3 tons in Tanzania (84% of total sales there) (Table 6).

WorldVeg was also the most important source of germplasm to public sector institutions with all the public sector amaranth seed containing its germplasm (Table 5). These improved lines were developed by WorldVeg and then evaluated and released by NARS (Horti-Tengeru in Tanzania and KALRO in Kenya). KALRO also developed own amaranth varieties, which may include WorldVeg germplasm, but the extent is not known. For example, KALRO developed and released A. *hypochondriacus* varieties ('Terere Smart' (KAM 001) and 'Katumani Gold' (KAM 114)) at their Katumani research station, which are adopted by farmers on a small scale. KALROs' two advanced lines KAM 201 (grain type) and KATveg (vegetable type) lines are currently undergoing distinctiveness, uniformity and stability (DUS) testing by the Kenya Plant Health Inspectorate Service (KEPHIS) before being released. In Tanzania, Horti-Tengeru does not have an amaranth breeding program but collaborates with WorldVeg to release varieties.

Table 5
Seed sales of commercial amaranth varieties produced by eight seed producers in Kenya and Tanzania in 2016 and the contribution of WorldVeg germplasm.

	Kenya		Tanzania		Total
	Private	Public[1]	Private	Public[1]	
Total number of varieties sold	3	2	4	1	10
Of which:					
-With WorldVeg material	2	2	4	1	9
-Without WorldVeg material	1	0	0	0	1
Total seed sales for 2016 (kg) [2]	3,136	4	1,617	176	4,933
Seed sales with WorldVeg material (kg)	1,391	4	1,354	176	2,925
% of sales with WorldVeg material	44		85		59
Seed companies (n)	2	1	4	1	8

Note: [1]Public: KALRO in Kenya and ASA in Tanzania. [2] Data refer to the 2016 financial year.

Seed companies disclosed that WorldVeg's germplasm is used to select for certain traits. The most important traits were marketability, dark green leaf color, and creamy-white grain color. Respondents from seed companies informed that they would like the WorldVeg to focus its breeding on developing resistance to white rust (*Albugo bliti*) (89%), dark green leaf color (78%), and large grain size (1000-grain weight) (67%), resistance to leaf spot (*Alternaria amaranthi*; *Cercospora* sp.) (56%), high micronutrient content (e.g. iron, pro-vitamin A) and ensuring marketability of the vegetables and grain.

5. Discussion

5.1. Key findings

The results show widespread use of improved amaranth varieties in Kenya and Tanzania at 61% of the planted area. The total area under improved amaranth may appears small at 17,502 ha, but a large number of 403,898 farm households have adopted them as the average area per household is small. These high adoption rates for improved amaranth compare favorable to that of other crops in sub-Saharan Africa, despite the fact that amaranth is a considered a minor crop and a neglected crop. Part of this success can be attributed to the promotion by various organizations as part of vegetable seed kit distributions. The relative success of amaranth may also be explained by the fact that the crop is very hardy and grows well under a wide range of agro ecological conditions.

Our study also showed the importance of international vegetable breeding as done by the World Vegetable Center. The ready availability of improved lines from the Center allowed seed companies to include amaranth in their product portfolios, which they would otherwise not have done. All seed companies used WorldVeg germplasm and eight out of nine commercial varieties were based on the research of the Center. Varieties derived from WorldVeg germplasm were planted on 46% of the amaranth area in Kenya and Tanzania and benefitted about 231 thousand farm households.

Amaranth has become an important crop with market demand increasing in peri-urban and urban areas of Tanzania (Ochieng et al., 2017a) and Kenya (Chelang'a et al., 2013). The study identified various opportunities to seize the currently favorable market conditions for amaranth:

First, the study showed much variation in the adoption of improved varieties and agricultural practices between regions. Future projects may want to target these regions with low adoption rates as they have most to gain from the adoption of improved technologies.

Second, only 12% of the farmers used certified amaranth seed. Experts mentioned that effective demand for certified seed is hampered by lack of information and seed market constraints. These results are similar to those reported by Omar et al. (2019) and USAID (2016). Seed companies sold 2.9 tons of amaranth seeds in 2016 and 59% of this are WorldVeg-based germplasm.

Third, seed companies suggested that a closer collaboration with WorldVeg, including in breeding, would be beneficial. In response, the Center established the Africa Vegetable Breeding Consortium (AVBC) under the umbrella of the African Seed Trade Association (AFSTA) in 2018. This consortium promotes regular information exchange and stimulates the use of breeding lines by seed companies. AVBC will not only provide breeding resources to the members but also organize annual workshops to learn about ongoing WorldVeg research and to review selected field trials of improved breeding material; share their breeding experiences and challenges; and access to WorldVeg subsidized training opportunities. This is expected to stimulate innovation as it is currently observed that companies have produced the same amaranth varieties for over 15 years. Together with the strong growth in urban demand for amaranth and availability of improved germplasm will trigger the interest of seed companies to give amaranth priority in their crop portfolios.

Table 6
Amaranth plant traits developed from WorldVeg germplasm, incorporated, used and prioritized in variety development by the private and public sector in Kenya and Tanzania, in % of seed producers, n = 8, 2017.

WorldVeg-developed traits being used	Incorporated in a current variety (%)	Used in varietal development (%)	Priority for WorldVeg (%)
White rust (*Albugo bliti*) resistance	10.0	14.3	88.9
Stem weevil resistance/tolerance	0	0	55.6
Shattering resistance	10.0	28.6	55.6
Lodging resistance	10.0	0	33.3
Wet rot (*Choanephora cucurbitarum*) resistance	0	0	22.2
Heat tolerance	0	0	33.3
Leaf webber resistance/tolerance	0	0	33.3
High marketable vegetable yield	50.0	28.6	88.9
Seed size (high 1000-grain weight)	0	0	66.7
Leaf spot (*Alternaria amaranthi*; *Cercospora* sp.)	10.0	0	55.6
Taste	0	28.6	55.6
High micronutrient contents (e.g. iron, pro-vitamin A)	0	0	55.6
Long period for continuous harvesting	20.0	0	55.6
Early growth vigor for uprooting (clear harvesting)	0	28.6	22.2
Keeping quality (long shelf-life)	20.0	28.6	55.6
Synchronized flowering	10.0	0	44.4
Leaf webber resistance/tolerance	0	0	33.3
Compact panicle	10.0	28.6	22.2
Creamy-white grain color	20.0	57.1	22.2
Dark green leaf color	30.0	28.6	77.8
Yellow grain color	10.0	28.6	0

Fourth, the adoption of IPM practices was found to be generally low. Similar findings were reported for Babati District in Tanzania for other traditional African vegetables where only 21% used of farmers used IPM practices (Ochieng et al., 2017b). This would require a greater effort in capacity building.

5.2. Reflection on the methods used

The total cost of data collection, data analysis and writing was about US$ 40,000, which may serve as guidance for future studies in this area. Apart from relatively low cost, a further advantage of expert elicitation is that the involvement of local agricultural experts gives them ownership of the findings and increases the likelihood of these findings being used by the relevant public and private organizations, particularly seed companies and NARS.

Nevertheless, it is important to recognize that the data collected through expert elicitation relied on qualitative estimates of experts and have an unknown degree of error. Similarly, the data collected from seed companies relied on the knowledge of breeders about the pedigree of lines used in companies breeding programs. Some may not know where a particular trait came from and it is likely that some traits have been developed through international agricultural research. As also mentioned by Schreinemachers et al. (2017a), there could be some degree of positive response bias for instance companies using public germplasm are more likely to give accurate data than those that do not.

There is limited information on amaranth and it was difficult to estimate the current number of farmers producing amaranth. This presents a challenge in getting reliable and published agricultural production statistics for the key indicators for traditional African vegetables including amaranth. Amaranth is largely produced for home consumption in home gardens while national agricultural statistics tend to ignore home garden production. In light of the need to shift focus from energy-rich crops to micronutrient-rich crops, it would be important for governments in East Africa to collect better data on the production of traditional African vegetables.

6. Conclusion

Smallholder farm households in Kenya and Tanzania have widely adopted improved amaranth varieties. This is in large part due to international vegetable breeding supported by international donors and led by the World Vegetable Center in Tanzania with the involvement of a large number of public and private sector partners. The ready availability of improved amaranth varieties together with increasing consumer demand for the crop, have given private seed companies the incentive to include amaranth in their seed catalogues. Seed companies in Kenya and Tanzania produced 2.9 tons of amaranth seeds in 2016 with 8 out of 9 varieties based on WorldVeg breeding research. Further efforts are needed to develop varieties with a higher nutrient contents, better grain and leaf characteristics, and better resistance against diseases such as white rust (*Albugo bliti*) and leaf spot (*Alternaria amaranthi; Cercospora sp.)*. The success of international vegetable breeding in amaranth can be repeated for many other traditional African vegetables for which currently no improved varieties exist.

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Appendix A

Table 1A
Use of improved amaranth varieties and the role of the World Vegetable Center.

Country / Sub-region	Local and improved varieties		Improved varieties (% area)	WorldVeg-related varieties	
	Area planted (ha)	Yield (tons/ha)		# varieties	% area
Kenya	1208	5.1	51	3	20
- Bungoma[2]	53	2.3	35	6	21
- Kakamega	319	3.1	30	4	22
- Kilifi	613	13.5	58	2	18
- Taita Taveta[1]	49	3.0	65	2	20
- Migori[2]	174	3.5	71	4	35
Tanzania	4,142	2.8	71	5	53
- Arusha	832	2.3	74	5	74
- Morogoro	457	1.9	79	6	71
- Dar es Salaam	603	5.6	81	5	74
- Zanzibar	798	1.6	35	3	4

[1] Refers to grain amaranths only (data on leaf amaranths not available).
[2] The statistics from Bungoma and Migori include various unpublished data sources from Ministry of Agriculture, Kenya, 2017. Averages are weighted by area planted in each region. Taita Taveta statistics are for 2013.

Table 1B
Improved amaranth varieties, in % of area planted, 2016–2017, Kenya.

	Variety name	Origin[1]	% area planted	Farmers growing	Area planted (ha)
1	Dubius	WorldVeg	28.9	82,668	571
2	Hybridus	WorldVeg	6.8	19,451	134
3	Tricolor	Rutgers University	2.6	7,437	51
4	Cruentus	Unknown	2.4	6,865	47
5	Blitum	Unknown	2.2	6,293	43
6	AM-UG-40 (line)	WorldVeg	1.7	4,863	34
7	Madiira 2	WorldVeg	1.5	4,291	30
8	Lividus	Unknown	< 1	2,002	14
9	Retroflexus	Unknown	< 1	1,430	10
10	Hypochondriacus	WorldVeg	< 1	572	4
11	Madiira 1/Ex-Zim	WorldVeg	< 1	286	2
12	Palmeris	Unknown	< 1	1,144	8
	Other improved	–	2.7	7,723	53
	Local varieties	–	49.3	141,021	974
	Total		100.0	286,048	1,975

Notes: In % of area planted for the surveyed regions. [1]Variety with WorldVeg-developed genetic material in its pedigree.

Table 1C
Improved amaranth varieties, in % of area planted, 2016–2017, Tanzania.

	Variety name	Origin[1]	% area planted	Farmers growing	Area planted
1	Grain amaranth (golden giant)/Hypochondricus	WorldVeg	26.0	96,152	6,129
2	Grain amaranth (white)/IPS (Mchicha Nafaka)	WorldVeg	12.5	46,227	2,947
3	Grain amaranth (black)	Unknown	10.0	36,982	2,357
4	Ex Zanzibar/Michicha mpana	Unknown	4.0	14,793	943
5	Amaranthus Hybridus	WorldVeg	< 1	1,849	118
6	Madiira1/Ex-Zim	WorldVeg	2.0	7,396	471
7	Madiira 2	WorldVeg	1.0	3,698	236
	Others improved	–	14.0	51,774	3,300
	Local varieties	–	30.0	110,945	7,072
	Total	–	100.0	369,816	23,573

Notes: In % of area planted for the surveyed regions. [1]Variety with WorldVeg-developed genetic material in its pedigree.

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